QUATERNARY STRATIGRAPHIC NOMENCLATURE, RED RIVER VALLEY, NORTH DAKOTA AND MINNESOTA: AN UPDATE

Kenneth L. Harris, Lorraine A. Manz, and Barbara A. Lusardi*

MISCELLANEOUS SERIES NO. 95
NORTH DAKOTA GEOLOGICAL SURVEY
Edward C. Murphy, State Geologist
Lynn D. Helms, Director Dept. of Mineral Resources
2020

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Cover photo: An ice-rafted boulder embedded in varved sediments of the Sherack Formation (deltaic facies) near Mayville, North Dakota. From an original photo by Lee Clayton.

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SOME NOTES ON
CALCULATING AND REPORTING ISOTOPIC AGES

Age measurements included in this publication are reported according to the following conventions:

OSL DATES

Dates obtained by optically stimulated luminescence (OSL) are reported in calendar years, typically abbreviated to ka. In contexts where the meaning is unambiguous, some authors use the expression "ka cal" to denote the units of measurement but to avoid confusion with the use of "cal" to mean calibrated (see below) we have opted for the shortened version.

RADIOCARBON DATES

Radiocarbon dates are reported as "conventional" or "calibrated" or both.

Conventional radiocarbon ages (CRAs) are uncalibrated and are expressed in ^{14}C years BP (before present) where 0 BP is defined as AD 1950. CRAs are written as follows:

AA-34344: 10,040 ± 120 ^{14}C yr BP

In this example, AA-34344 is the laboratory code for the sample (omitted in running text), 10,040 is the radiocarbon age in ^{14}C years BP, and 120 is the estimated standard error at the 1σ level.

Calibrated radiocarbon ages are expressed as a range in terms of cal yr AD, cal yr BC, or cal yr BP along with the appropriate confidence level. (Note that "cal" in this context means <u>calibrated</u>, not calendar.) Calibrated radiocarbon ages in this report are expressed in cal yr BP and look like this:

11,201-12,259 cal yr BP

Except where noted, all age ranges correspond to 2σ statistics (95% probability).

Calibration of radiocarbon ages did not become routine until the 1980s. Most older dates are therefore typically uncalibrated. Unlike CRAs, which are invariable, calibrated radiocarbon ages change as the data sets used to construct the calibration curves become more refined. It is important, then, to know which calibration curve and software was used to convert the CRA into a calibrated age. This information is usually included in the published report.

URANIUM-THORIUM DISEQUILIBRIUM DATES

Uranium-thorium disequilibrium dates are reported in calendar years (ka).

ACKNOWLEDGEMENTS

Efforts to understand the Quaternary stratigraphy of Lake Agassiz, the Red River Valley, and adjacent parts of North Dakota and Minnesota were accelerated by geologists at the University of North Dakota Geology Department (UND Geology) and the North Dakota Geological Survey (NDGS) in the 1960s through the 1980s. Their efforts were concentrated in developing North Dakota County Bulletins (NDGS), various studies of Lake Agassiz and regional Quaternary geology (UND Geology), and the development of a systematic approach to studying regional glacial stratigraphy (NDGS and UND Geology). John Bluemle (NDGS), Lee Clayton (UND Geology) and Steve Moran (NDGS) mapped some eastern North Dakota Counties and developed an initial sense of the variability and complexity of Quaternary geology and stratigraphic units present.

The focus on developing a disciplined interpretation method for the study of Quaternary stratigraphy was initiated by Steve Moran (NDGS), Lee Clayton (UND Geology), and Walter Moore (UND Geology). Local rivers, particularly the Red Lake River in Minnesota, exposed superb outcrops that displayed complex glacial stratigraphy. Canoeing these rivers stimulated their efforts to identify the Quaternary units present and characteristics that would be useful to correlate them throughout the region. Field efforts by Clayton (UND Geology) and Moran (NDGS) developed interpretations of regional glacial history, the distribution of Quaternary sediment types, and eventually a map of North Dakota that illustrated key elements of North Dakota Quaternary geology.

Moran (NDGS) developed and maintained a Quaternary database (N-File) that contained the correlation parameters that were judged to be useful when working with glacial stratigraphy in our region. Clayton (UND Geology), Moran (NDGS), and Moore (UND Geology) stimulated an interest in their graduate students through regional field trips in the Red River Valley and adjacent parts of North Dakota and Minnesota. Their graduate students completed numerous Theses and Dissertations. Those studies focused on sample collection, data analysis, interpretations of the glacial history, Quaternary stratigraphy, and correlations of stratigraphic units between the various study areas. The existence of the collected samples, standardized laboratory analysis, and the data management efforts of Steve Moran (NDGS) provided the basic data necessary to proceed with regional correlations. Continued collection and analysis of stratigraphic samples, maintenance of the database, and advances in correlation techniques has resulted in our ability to combine these data and develop our interpretation of the regional Quaternary stratigraphy.

Similar efforts in Minnesota at the Minnesota Geological Survey (MGS) have assembled the sample data collected through decades of studies. The collected data has been assembled into a Quaternary database (QDI) that is managed and interpreted by the MGS. Interpretation of this data by MGS Quaternary geologists, principally Barbara A. Lusardi, has allowed the identification and correlation of Quaternary stratigraphic units as well as the construction of regional cross sections of the Quaternary stratigraphic units of Minnesota. The MGS work is summarized in "Quaternary Lithostratigraphic Units of Minnesota" (Johnson and others, 2016). The identification of stratigraphic units in Minnesota has helped us identify and correlate Quaternary stratigraphic units in our area that were deposited by glaciers that advanced into our area from an eastern and northeastern source area.

The collection of high-quality stratigraphic samples has improved remarkably with the widespread use of hydraulic soil probes and continuous coring available using rotary-sonic drilling techniques. Samples collected using these techniques, especially continuous coring, have increased our confidence in the identification and correlation of stratigraphic units. To the extent possible, we have tried to select Type and Reference Sections that include both rotary-sonic core and outcrops. The core selected is stored in managed storage facilities maintained by the NDGS and/or the MGS. Rotary-sonic drilling is now used by the MGS on all county and regional studies.

Disciplined data collection, standardized laboratory analysis, computer management of the data, and computer-assisted interpretation methods allow regional correlations that were not previously possible.

We thank numerous colleagues and friends, notably Fred Anderson and Ed Murphy of the North Dakota Geological Survey, for their invaluable advice and commentary during the composition of this report.

INTRODUCTION

This report is an update of the North Dakota Geological Survey Miscellaneous Series 52 (Harris and others, 1974). There have been a number of stratigraphic studies that have defined new units and refined old units in the Red River Valley of North Dakota and Minnesota (RRV) over the intervening 45 years. The original document, MS-52, was based on the study of cut banks along about 130 miles (208 kilometers) of the Red Lake River (Harris, 1973) and reconnaissance studies in the northern Red River Valley conducted by University of North Dakota and North Dakota Geological Survey geologists. Subsequently, a number of University of North Dakota theses and dissertations as well as North Dakota Geological Survey (NDGS) and the Minnesota Geological Survey (MGS) mapping projects have been completed in the RRV. They range from small-scale studies to state survey studies covering multiple counties. All of these studies involved new sample data collected from shallow test borings and in many cases deeper borings using rotary sonic techniques. Most included interpretations of Pleistocene stratigraphy.

The units defined in MS-52 have proven to be a useful framework for understanding the geology of the region. It is intended that this revision will increase the level of understanding and continue to provide a useful interpretive framework for future workers.

We start with a general discussion of the geology of the RRV to put the stratigraphic units in time and space. Existing stratigraphic units are accepted, redefined, revised, or rejected and new stratigraphic units defined. Supporting documentation for all of these units is presented and all units discussed are correlated. We are defining and correlating lithostratigraphic units based on stratigraphic position and lithology. These definitions and discussions are in accordance with the requirements of the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 2005).

Figure 1. Four recognized ice centers or domes in North America and the approximate extent of the Laurentide Ice Sheet at about 15,000 radiocarbon years ago. Blue arrows indicate possible ice lobe flow paths.

GEOLOGIC SETTING

The RRV was subjected to multiple glaciations during the Pleistocene – the last 2.5 million years. However, most of the glacial material present at the surface in our area was deposited during the Late Wisconsinan, or about the last 20,000 years. Glacial ice flowed from ice centers that received sufficient precipitation to accumulate ice to a thickness that allowed it to behave plastically (about160 feet or 50 meters thick) and flow radially away from the areas of accumulation. Four ice centers are recognized in North America: the Alaskan, Cordilleran, Keewatin, and Labradorean domes or ice centers (fig. 1). The RRV received glacial ice flowing from the Keewatin and Labradorean ice centers. The timing of precipitation, the rate of accumulation of snow and ice, and the volume of ice moving away from the ice centers varied with time. Consequently, the source area, timing of advances, and the volume of ice in ice streams entering the RRV also varied with time.

It is useful to have some knowledge of the bedrock underlying the RRV to understand lithologic differences in the glacial sediment that was deposited. The RRV is located along the western edge of the Canadian Shield – the core of the North American continent that consists of Precambrian igneous and metamorphic rocks (crystalline rocks). Shield rocks dip to the west. Younger, Paleozoic and Mesozoic, sedimentary rocks lap up on the older Canadian Shield (fig. 2). The Paleozoic rocks also dip to the west, into the Williston basin, and are composed mainly of limestone and dolostone but also contain evaporites, shale, and sandstone. Younger Mesozoic rocks, (Triassic, Jurassic, and Cretaceous rocks) unconformably overlie the Paleozoic section. Triassic and Jurassic age rocks consist mainly of interbedded sandstone, shale, and evaporites but also contain some carbonates. Basal Cretaceous fluvial and marine shoreline clastics are overlain by a thick sequence of marine shale. A generalized geologic map of the region (fig. 3) shows that the bedrock to the northeast and east is composed largely of Precambrian igneous and metamorphic rocks (crystalline rocks) whereas bedrock to the north, northwest, and west is composed of Paleozoic and Mesozoic sedimentary rocks. Glaciers approaching the RRV directly from the north typically transported sediment containing more Paleozoic limestone than Cretaceous shale or Precambrian igneous and metamorphic rock fragments. Glaciers approaching the RRV from the northeast typically transported sediment containing more Precambrian igneous and metamorphic rock fragments than Paleozoic limestone or Cretaceous shale fragments. Glaciers approaching the RRV from the west and northwest transported sediment containing significantly more Cretaceous shale than the sediments derived from northern and northeastern sources. These simple distinctions allow us to characterize the various tills present, identify their source area, and interpret their history.

The lithostratigraphic approach to stratigraphy uses differences in texture, lithology, and stratigraphic position to characterize stratigraphic units, in this case glacial sediment. The ice that deposited these sediments approached the RRV from different directions depending on its source (ice center), the surface topography, and possible interaction with other ice lobes. The lithology of the till deposited is characteristic of the path the ice lobe traveled. The distribution of lithostratigraphic units in the RRV suggests that there was an interaction between ice streams from the different ice centers, in other words, a competition for space.

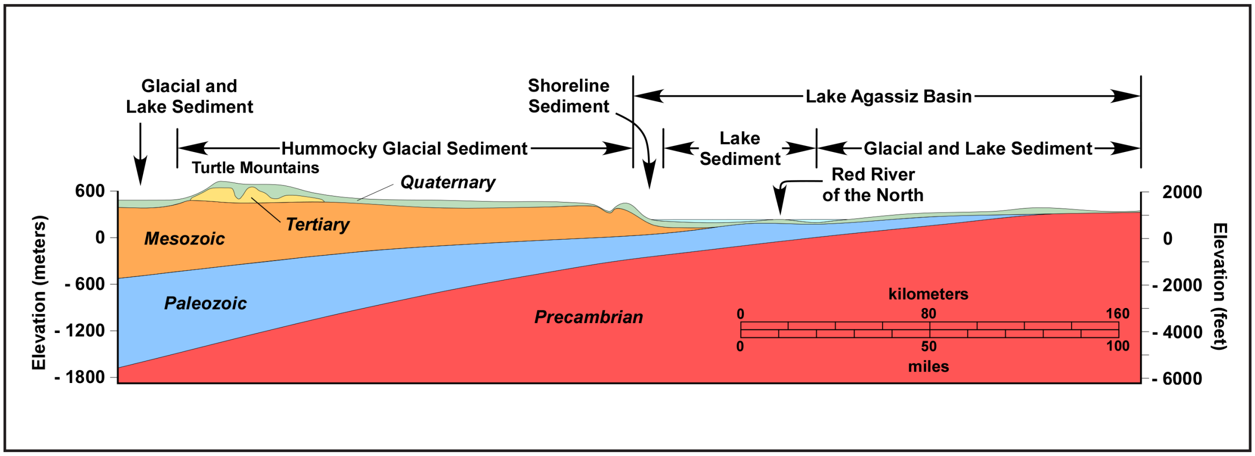


Figure 2. Cross section showing the orientation of bedrock units in northeastern North Dakota and northwestern Minnesota. Vertical exaggeration about 110. Modified from Bluemle (1983).

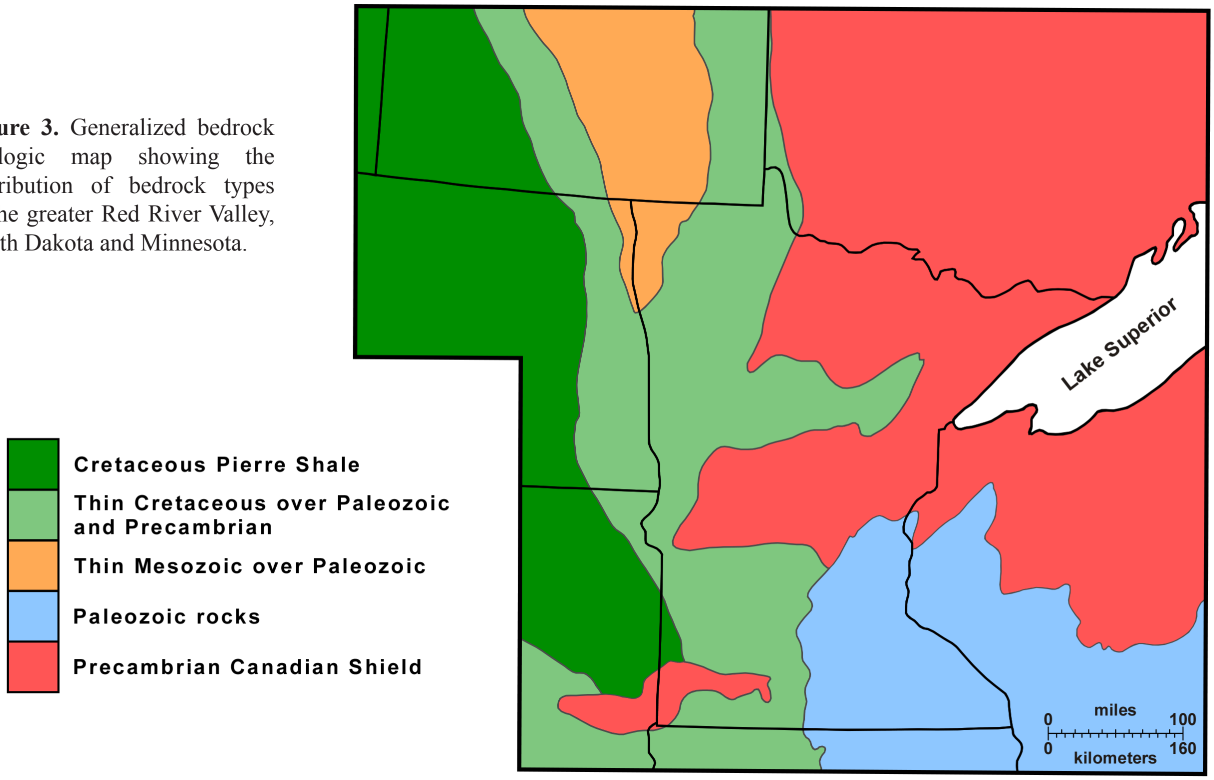


Figure 3. Generalized bedrock geologic map showing the distribution of bedrock types in the greater Red River Valley, North Dakota and Minnesota.

The location of the RRV relative to the bedrock types also resulted in the development of a north-south bedrock low that provided a path of least resistance for advancing glacial ice (fig. 4). The ancestral RRV was lower in elevation than the bedrock to the east or west and provided a natural pathway for ice streams that entered the area. Erosion of less resistant sedimentary rock along the western edge of the valley by glacial ice and by the action of spring sapping caused the ancestral RRV to migrate westward along the Precambrian surface (Teller and Bluemle, 1983).

Late Wisconsinan ice streams flowed through the RRV and advanced as far south as central Iowa – the Des Moines lobe (fig. 5). Advancing ice lobes eroded pre-existing sediment and built moraines at the maximum extent of their advance. As the ice lobes retreated they left behind a deposit of glacial sediment characteristic of their source area and flow path. Subsequent advances repeated the process. During the Wisconsinan, a series of advances and retreats left a "shingled" sequence of glacial sediment in the RRV (fig. 6). An east-west cross section constructed across the RRV in the Fargo, North Dakota area is shown in figure 7 and an east-west cross section from Red Lake Falls, Minnesota to Grand Forks, North Dakota is shown in figure 8. They show the orientation and distribution of stratigraphic units and geomorphic features typical of a glacial valley. The cross sections are constructed with a highly exaggerated vertical scale to clearly show the glacial units and glacial features. Figure 7 shows recessional, ice marginal drainage channels (the Maple River and Buffalo Creek) and Lake Agassiz sediment in the center of a broad "U" shaped valley. Deeply incised, vertically oriented sand bodies shown in figure 7 are longitudinal, basal drainage channels eroded beneath an active ice stream (tunnel valleys).

The weight of the glacial ice depressed the continental crust north of the RRV resulting in a reversal of drainage slope. Ponding of glacial melt water occurred along the southern margin of glacial ice streams entering the valley – a series of glacial lakes developed south of the ice front. Sediment deposited in these lakes was either eroded by advancing ice or buried and preserved in the geologic record by retreating ice streams. Some lake sediment deposited in the early lakes that occupied the RRV survives in the geologic record, but most was removed by erosion. Sediment from the last glacial lake, Lake Agassiz, blankets the central part of the RRV (figs. 6, 7, and 8).

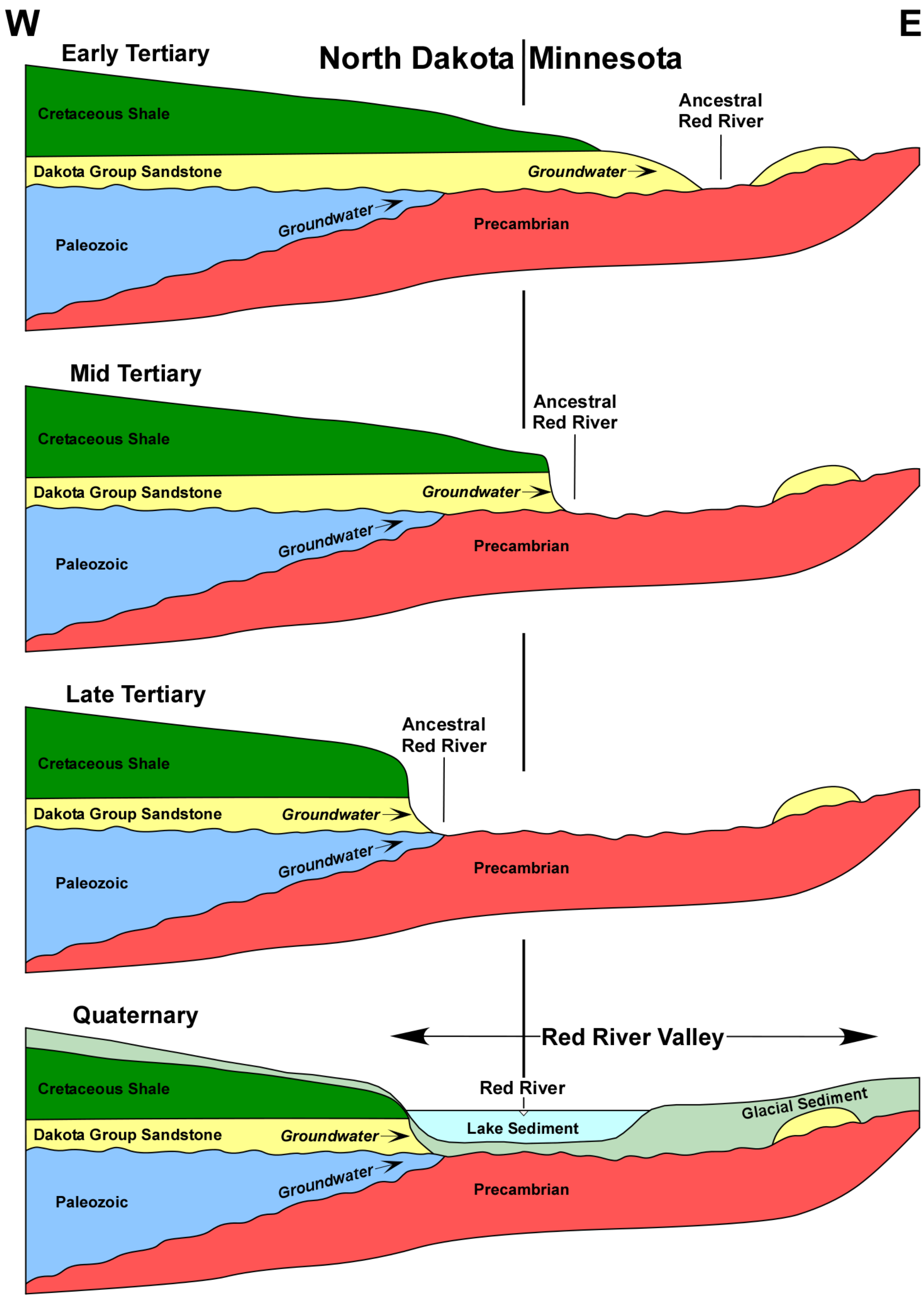
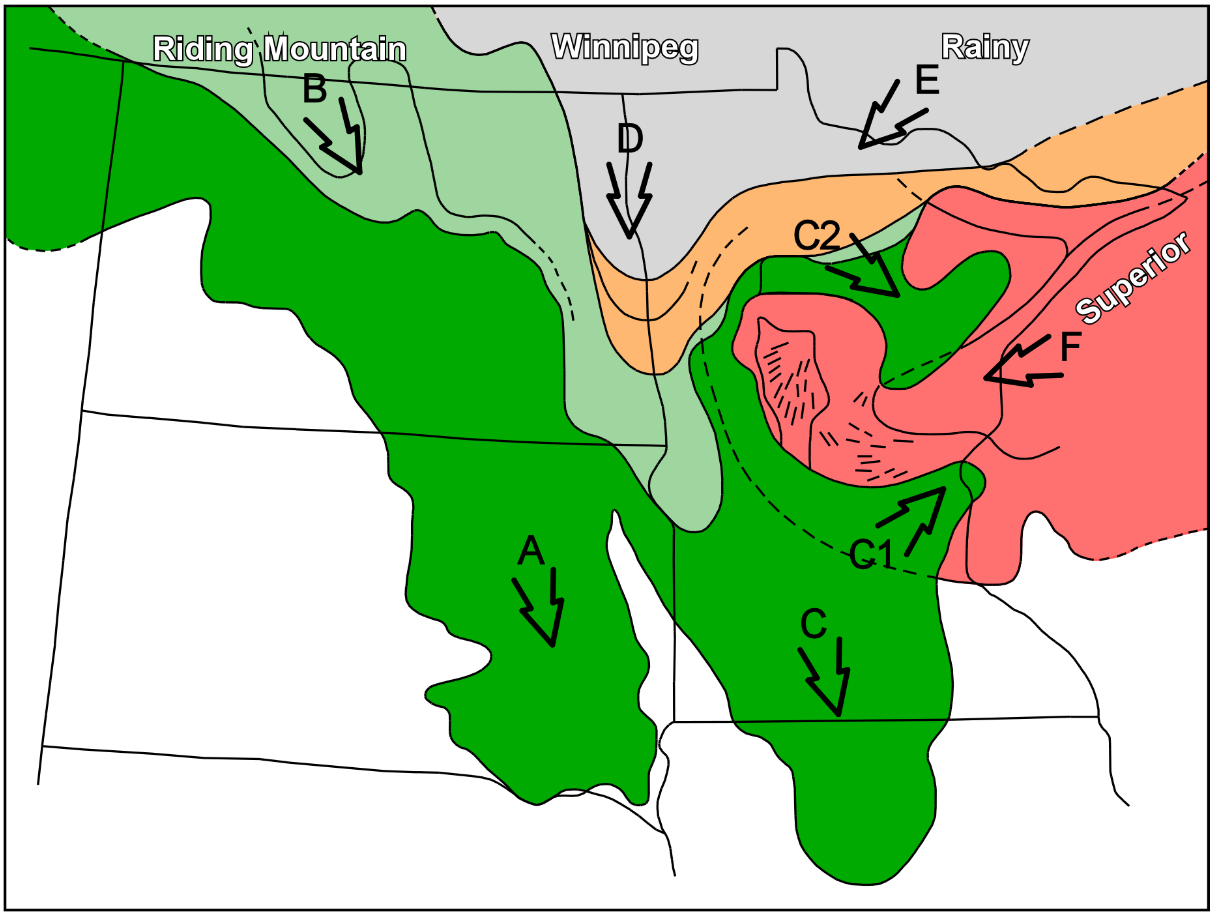


Figure 4. Cross section showing how the distribution of bedrock types and spring sapping affected the evolution of the Red River Valley of North Dakota and Minnesota. Modified from Bluemle (2000).



Major ice lobes of the midcontinent region of North America

	Ice lobe/sublobe	Source Area/Provenance
A	James lobe	Riding Mountain
B	Souris lobe	Riding Mountain
C	Des Moines lobe	Riding Mountain
C1	Grantsburg sublobe	Riding Mountain
C2	St. Louis sublobe	Riding Mountain
D	Red River lobe	Riding Mountain/Winnipeg
E	Rainy lobe	Rainy River
F	Superior lobe	Lake Superior

Figure 5. Map of the midcontinent region of North America showing the extent of major ice lobes, generalized direction of ice flow, and ice stream source areas or provenance. Modified from Clayton and Moran (1982).

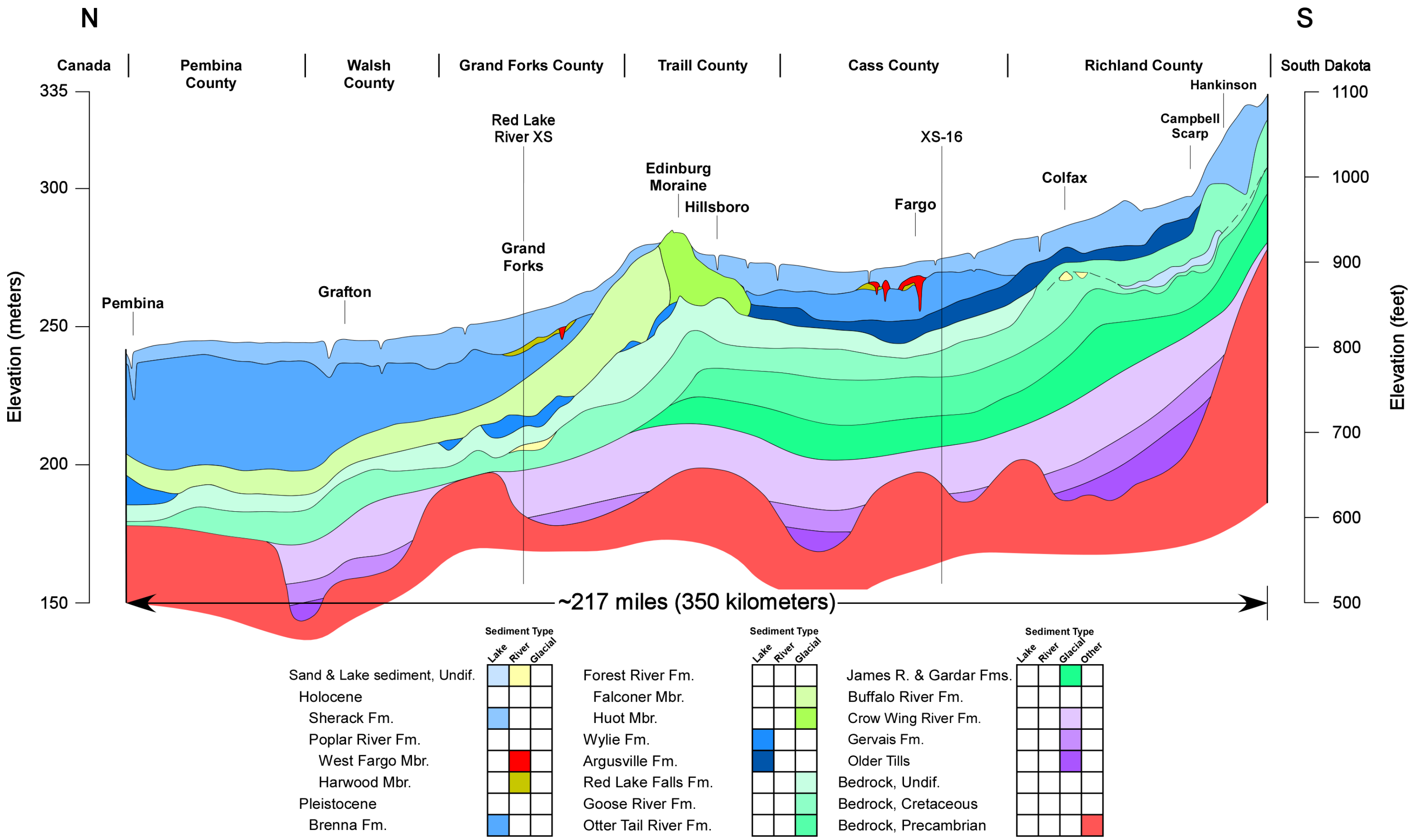


Figure 6. North-south cross section along Interstate 29 showing the orientation and distribution of Quaternary lithostratigraphic units and the bedrock surface. Elevation grid is labeled in feet (meters) above sea level. The vertical line labeled XS-16 marks the location of an east-west cross section near Fargo, North Dakota (fig. 7). The vertical line labeled Red Lake River XS marks the location of an east-west cross section at Grand Forks, North Dakota (fig. 8). The cross section is about 217 miles (349 kilometers) long. Vertical exaggeration is about 860.

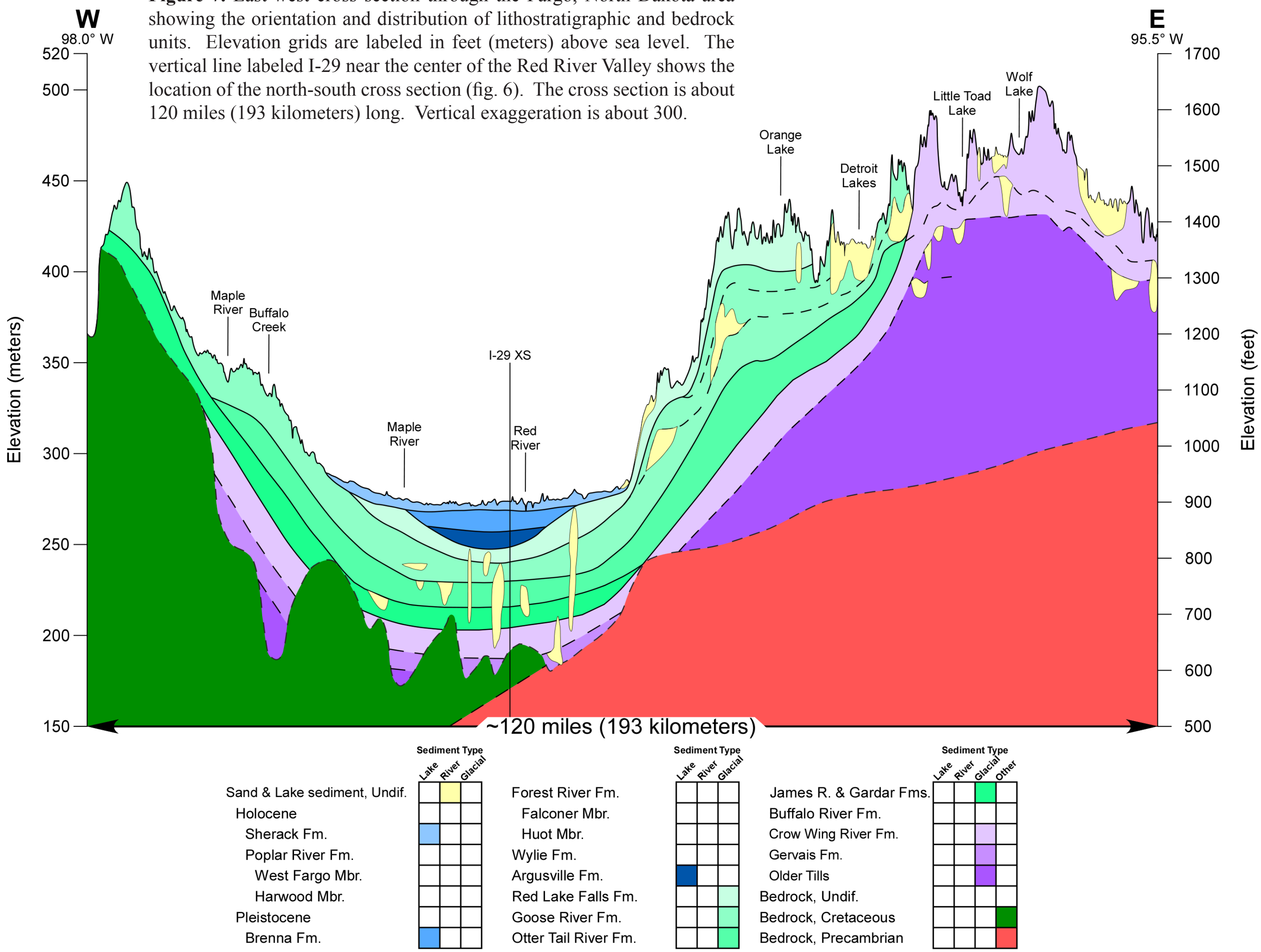


Figure 7. East-west cross section through the Fargo, North Dakota area showing the orientation and distribution of lithostratigraphic and bedrock units. Elevation grids are labeled in feet (meters) above sea level. The vertical line labeled I-29 near the center of the Red River Valley shows the location of the north-south cross section (fig. 6). The cross section is about 120 miles (193 kilometers) long. Vertical exaggeration is about 300.

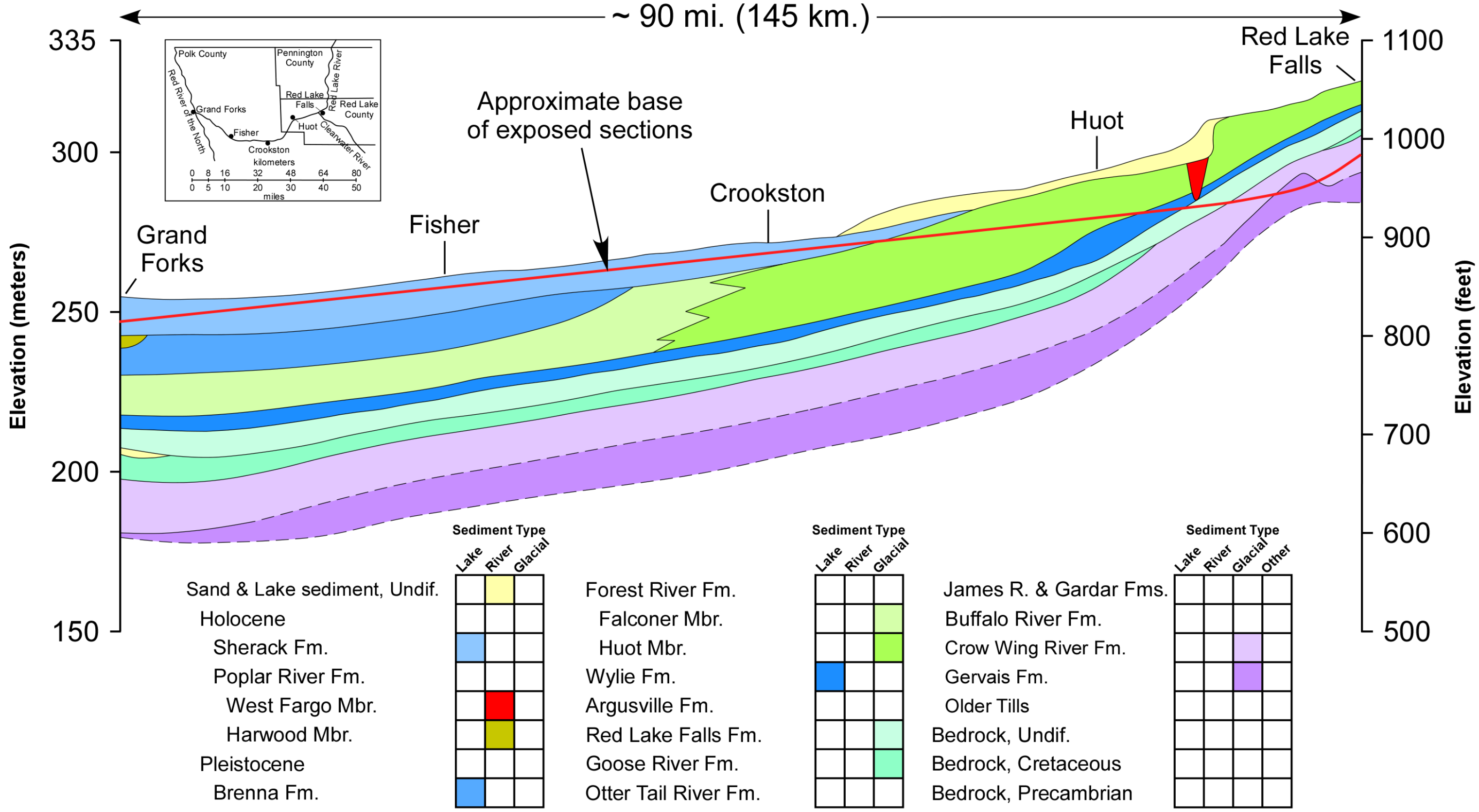


Figure 8. East-west cross section along the Red Lake River from Red Lake Falls, Minnesota to Grand Forks, North Dakota showing spatial relationship of the lithostratigraphic units on the eastern side of the Red River Valley. Elevation is shown in feet (meters) above sea level. Red line shows approximate base of exposed sections along the river. The cross section is about 90 miles (145 kilometers) long. Vertical exaggeration is about 380. Modified from Harris and others (1974).

LAKE AGASSIZ

Lake Agassiz formed as advancing glacial ice blocked the northerly drainage routes and glacial meltwater and surface drainage ponded south of the ice front. The lake formed sometime before 12,000 ^{14}C yr BP and finally drained about 8,000 ^{14}C yr BP (fig. 9; Clayton and Moran, 1982; Teller and Clayton, 1983; Lepper and others, 2013). With glacial ice to the north, Lake Agassiz received meltwater from a large area extending north and west to the Rocky Mountains. Water was delivered to the lake from the west through the Assiniboine, Pembina, and Sheyenne Rivers and from the east through the McIntosh channel (fig. 10). Water drained from the lake through the southern outlet into the River Warren and Mississippi drainage system, through the Prairie River and Mississippi drainage system, and through eastern outlets into Lake Nippigon and the Lake Superior drainage system (fig. 10). The position of advancing or retreating ice streams controlled which inlets and outlets were active and therefore the water level in the lake. As ice streams advanced into the RRV they advanced over previously deposited glacial and lake sediment and changed the shape and volume of the lake basin (fig 11).

Lake Agassiz "time" is divided into five phases (fig. 9; Clayton and Moran, 1982). The early phases, Cass and Lockhart, were periods when glacial ice advanced well into the southern RRV eroding older sediment and depositing the glacial sediment of the Goose River, RedLake Falls, and Forest River Formations (fig. 12). Lake sediments of the Argusville and Wylie Formations were deposited in the basin during this time. The ice that deposited the Forest River Formation was the last major advance into the RRV and the Brenna Formation was deposited in the basin following the retreat of that ice stream. The Moorhead Phase was a period of desiccation during which glacial ice retreated northward and the eastern outlets were opened, causing the lake level to drop. As it drained, Lake Agassiz receded almost as far as the international border. Streams and rivers flowed across the exposed lake bed to a north-flowing trunk stream depositing channel and overbank sediment of the Poplar River Formation. Glacial ice then moved south again and blocked the eastern outlets. The lake refilled and the sediment of the Sherack Formation was deposited during the Emerson and Morris Phases. Where the fluvial deposits of the Poplar River Formation are overlain by

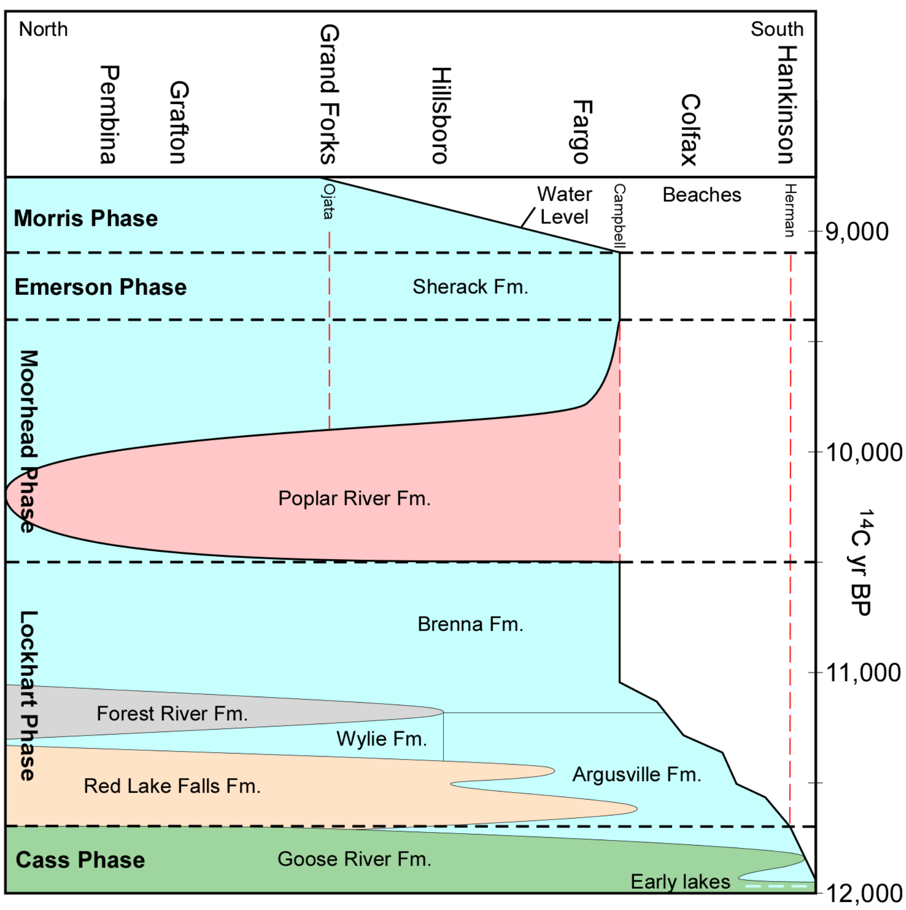


Figure 9. Time-distance diagram showing events and lithostratigraphic units in the southern Lake Agassiz basin. Beach elevations relative to lake level (solid, heavy black line) are indicated by red dashed lines. The horizontal axis shows location along I-29 from the South Dakota border to the Canadian border. The vertical axis shows approximate age of the illustrated events. Modified from Arndt (1977); updated to include revised estimates of phase durations by Fisher and Lowell (2006), Fisher and others (2008), and Lepper and others (2013) .

Figure 10. General geography of the Lake Agassiz area showing inlets, outlets, deltas, and maximum extent – the lake never covered all the indicated area at one time. Modified from Clayton and Moran (1982).

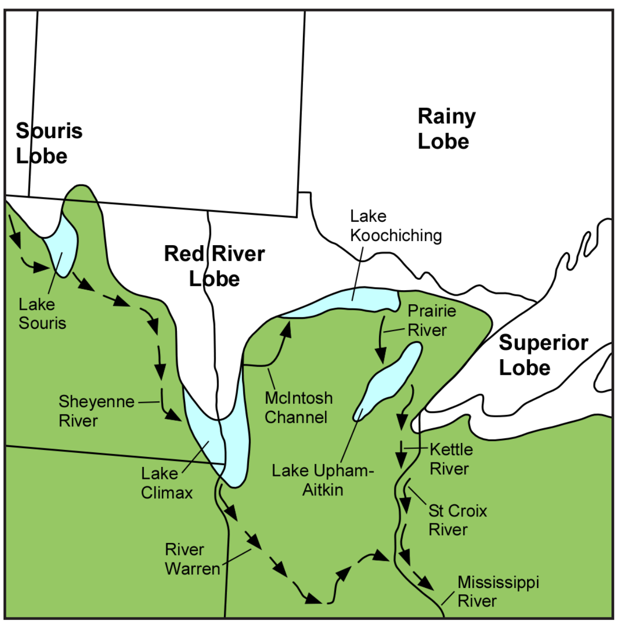


Figure 11. General geography of the Lake Agassiz area at about 11,500 ^{14}C yr BP. The ice that deposited the Forest River Formation is shown at the Comstock ice margin and two lakes occupy the lake basin – Lake Climax and Koochiching. Water is entering Lake Climax through the Sheyenne River. The River Warren (southern outlet) and Prairie River outlets are active. Water is flowing in the McIntosh Channel at this time. Modified from Clayton and Moran (1982),

offshore lake sediment of the Sherack Formation they can form compaction ridges due to the differential compaction between offshore sediment (silt and clay) and fluvial channel deposits (sand and gravel). These ridges (fig. 13) are best seen using aerial photographs, but some are pronounced enough to be clearly seen on the ground.

Stable water levels were established at the elevation of active lake inlets and outlets. Which inlets and outlets were blocked and which were open was controlled by the position of ice in the lake basin. Since the amount of ice in the basin varied with time, the active inlets and outlets also varied with time. As the lake level changed, wave action eroded the surface sediment and a thin layer of nearshore sediment was smeared across a wide area. During periods of stable water level, well-defined beaches were established. There are a number of these beaches in the lake basin; two of which, the Campbell and the Herman, are particularly well-defined. They are shown as vertical dashed lines in figure 9. As the glacial ice retreated out of the basin to the north the previously depressed continental crust began to rebound (isostatic rebound). All Lake Agassiz beaches were formed as rebound was occurring so they are now tilted – the elevation of the beach ridges increases to the north.

As the rapidly moving waters of the Sheyenne, Pembina and Assiniboine Rivers met the still waters of Lake Agassiz their sediment loads were deposited in the basin. Coarser sediment was deposited near the mouth of the rivers forming the Assiniboine, Pembina, Elk Valley, and Sheyenne deltas along the western side of the lake (figs. 10 and 12). Similarly, smaller deltas, the Fertile and Trail deltas formed on the eastern side of the lake. The silt and sand associated with these deposits is susceptible to wind erosion and forms large areas of dunes. The fine-grained sediment, silt and clay, delivered by the rivers was deposited as offshore sediment (Argusville, Wylie, Brenna, and Sherack Formations) throughout the lake basin during the Cass, Lockhart, Emerson, and Morris phases of Lake Agassiz.

The early stages of Lake Agassiz are poorly understood owing to the presence of active and stagnant ice in the RRV. Ice streams that deposited the Goose River, Red Lake Falls, and Forest River Formations were present in the valley during the Cass and early Lockhart Phases. All previous ice streams eroded most of the evidence of previous lakes in the basin and the shifting landscape associated with the melting of buried ice has obscured much of the lake's early history. The detailed history of Lake Agassiz has been the subject of many investigations and exhaustive discussions and is beyond the scope of this paper. The most thorough summaries are contained

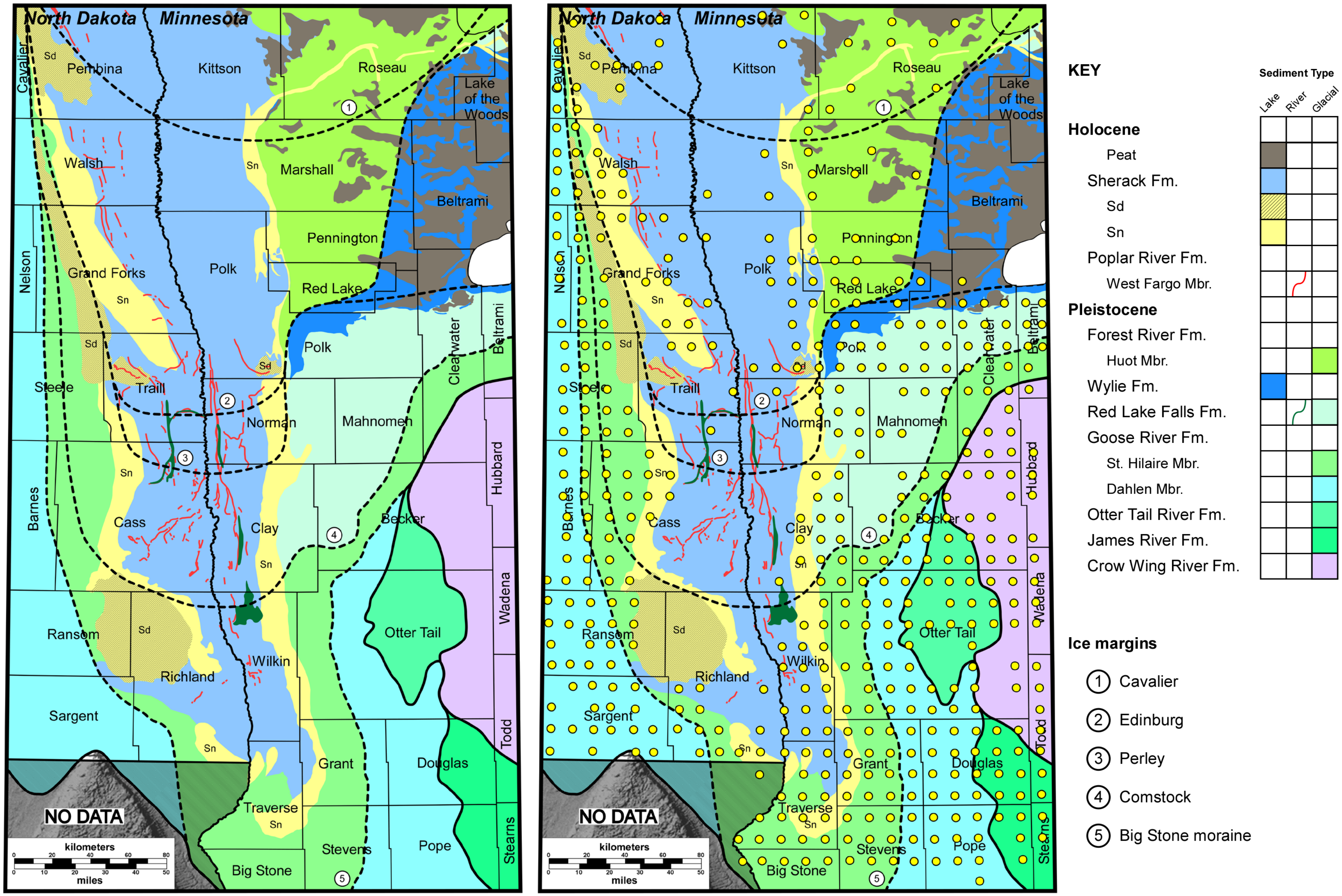


Figure 12. Map of the Red River Valley of North Dakota and Minnesota showing lithostratigraphic units defined in this report that are exposed at the surface. Sn and Sd indicate Sherack Formation nearshore and deltaic facies respectively. Also shown are the general outlines of ice-marginal positions, moraines (dashed lines), compaction ridges (red) and tunnel valleys (green). The map to the right shows townships with database control (yellow circles).

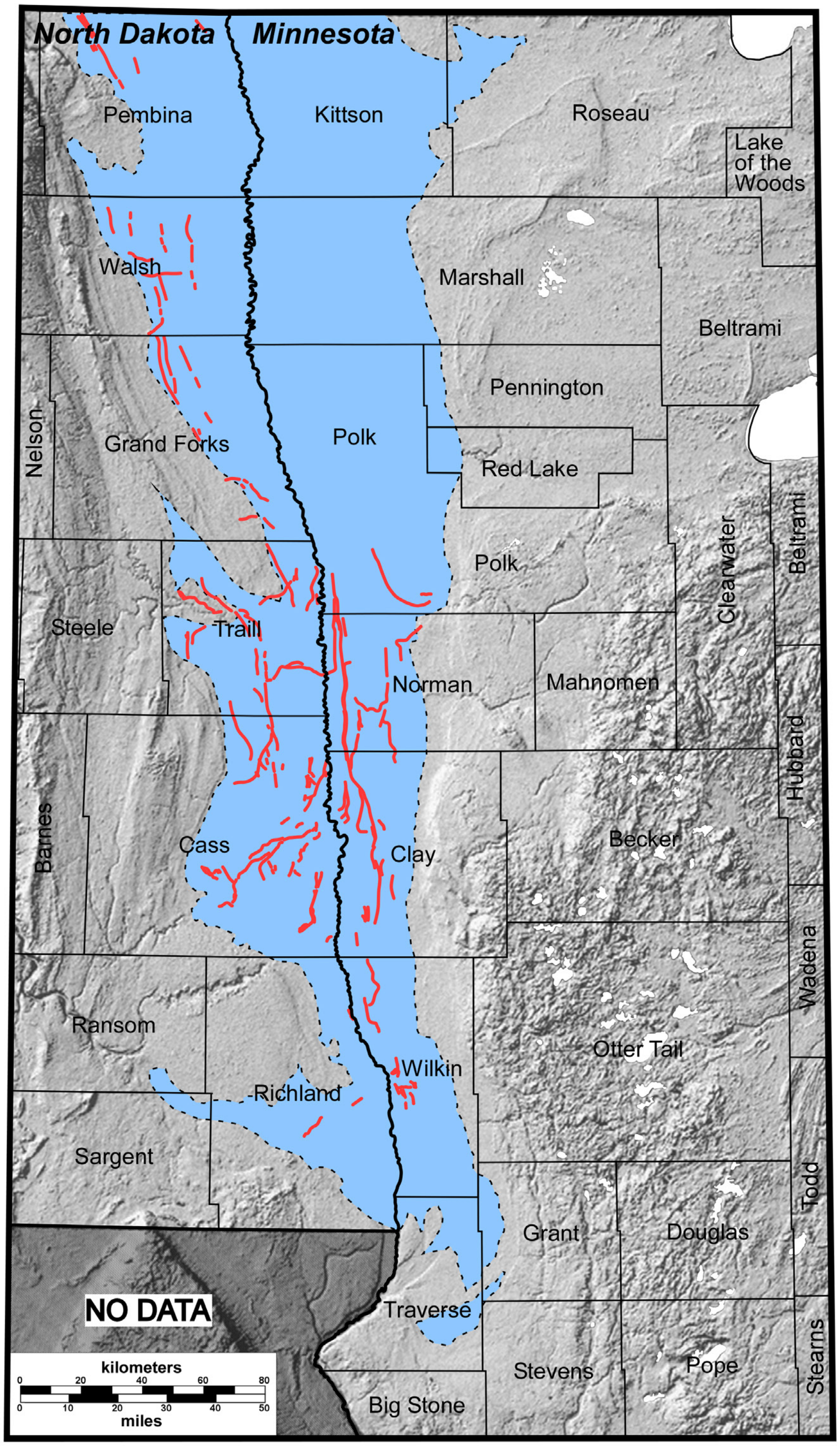


Figure 13. Map of the Red River Valley of North Dakota and Minnesota showing the mapped occurrence of compaction ridges. The blue shaded area indicates the extent of the Sherack Formation. Compaction ridges occur where the Poplar River Formation, West Fargo Member underlies the Sherack Formation. No compaction ridges are shown in northwestern Minnesota counties where the surface geology has not been mapped in detail.

in Geological Association of Canada Special Paper 26 (Teller and Clayton, 1983) and Mineralogical Association of Canada field trip Guidebook, "Sedimentology, Geomorphology, and History of the Central Lake Agassiz Basin", (Thorleifson, 1996). Recent Lake Agassiz investigations have focused on drainage history and geochronology (Fisher and Smith, 1994; Kehew and Teller, 1994; Fisher, 2003, 2005; Fisher and others, 2011; and Lepper and others, 2011, 2013).

PREVIOUS WORK

Studies that characterize RRV glacial sediment using lithostratigraphic methods started with Steve Moran, Lee Clayton, and Walter Moore in the early1970s. Steve Moran was a geologist with the North Dakota Geological Survey; Lee Clayton and Walter Moore were faculty members of the Geology Department at the University of North Dakota. They inspired a number of graduate students to pursue studies dealing with the glacial geology of the RRV. The following discussion addresses the studies by University of North Dakota, North Dakota Geological Survey, and also Minnesota Geological Survey geologists.

The history of formal Quaternary lithostratigraphic nomenclature in North Dakota starts with Bluemle defining the Coleharbor Group (Bluemle, 1971) to include all bouldery, cobbly, pebbly, sandy, silty clay, sand and gravel, and silt and clay deposited during the "ice age", that is, all glacial sediment deposited during the Quaternary Period, from about 2.58 million years ago to about 11,700 years ago. Bluemle (1973) defined the Walsh Formation as overlying the Coleharbor Group and containing a variety of clay, sand, silt, and gravel deposited as post-glacial sediment after about 11,700 years.

Harris (1973) conducted a stratigraphic study of tills exposed in 130 miles (208 kilometers) of cut banks along the Red Lake River in Pennington, Red Lake, and Polk Counties, Minnesota. Harris, Moran and Clayton (1974) formalized ten new formations (Gervais, Marcoux, St. Hilaire, Red Lake Falls, Wylie, Falconer, Huot, Brenna, Poplar River, and Sherack Formations) based on detailed studies in the Grand Forks, North Dakota and Red Lake Falls, Minnesota areas. Harris (1975) conducted thesis mapping in the northern part of the Grand Forks-Bemidji area of Minnesota that included the characterization of glacial sediment and interpretation of glacial stratigraphy. He recognized seven stratigraphic units (Unnamed unit 1, Unnamed unit 2, and the Marcoux, St. Hilaire, Red Lake Falls, Wylie, Huot, and Sherack Formations). Sackreiter (1975) conducted thesis mapping in the southern part of Grand Forks-Bemidji area of Minnesota that included the characterization of glacial sediment and interpretation of glacial stratigraphy. He recognized 10 stratigraphic units (Unit 1, Unit 2 and the Marcoux, St. Hilaire, Lower Red Lake Falls, Upper Red Lake Falls, Argusville, Huot, Poplar River, and Sherack Formations). Salomon (1975) characterized the glacial sediment in Cavalier and Pembina counties and formally named two units: the Gardar and Dahlen Formations. Hobbs (1975) characterized the glacial sediment in a large area of northeastern North Dakota including part or all of Pembina, Cavalier, Towner, Ramsey, Walsh, Nelson, and Grand Forks counties. He recognized ten stratigraphic units in his study (three unnamed units and the Cando, Tiber, Vang, Gardar, Dahlen, Hansboro, Falconer formations) and named four formations in his thesis (Hansboro, Vang, Tiber, and Cando formations).

Clayton, Moran and Bickley (1976) defined the Oahe Formation as a layer of silt found on gently sloping surfaces throughout much of North Dakota and adjacent areas, late Quaternary in age, and consisting largely of wind-blown sediment – material commonly referred to as loess. Clayton and Moran (1979) redefined the Oahe Formation by broadening the lithologic definition to include the complete range of grain sizes found in the material overlying the Coleharbor Group – clay, silt, sand, and gravel. Oahe replaced Walsh as the stratigraphic unit describing all post glacial (Holocene) sediment not included in the Coleharbor Group.

Anderson (1976) mapped the Comstock-Sebeka area in west-central Minnesota. He recognized five lithostratigraphic units in the area (Sherack, Barnesville, Dunvilla, New York Mills, and Sebeka Formations). All but the Sherack Formation were first recognized and named in his thesis. Perkins (1977) mapped the Moorhead-Park Rapids area in west-central Minnesota. He recognized eight stratigraphic units (Walsh, Sherack, Downer, Hawley, Barnesville, Dunvilla, New York Mills, and Sebeka Formations). Perkins formalized the Downer and Hawley Formations in his thesis. Arndt (1977) studied the offshore Lake Agassiz sediment using borings along Interstate Highway 29. He constructed cross sections showing the stratigraphy of the lake and recognized fourteen stratigraphic units (Unit A, Unit B, Unit C, and Unit D; Argusville, Wylie, Huot, Falconer, Brenna, and Poplar River Formations, Harwood and West Fargo Members of the Poplar River Formation, Sherack Formation, and Unit 10). Arndt (1977) formally named the West Fargo and Harwood Members of the Poplar River Formation and the Argusville Formation in North Dakota Geological Survey Report of Investigation Number 60. Camara (1977) recognized seven lithostratigraphic units in southeastern North Dakota (Units A, B, and C; the Gardar and Dahlen Formations; and Units D, and E).

The North Dakota Geological Survey completed mapping in all eastern North Dakota counties during the period 1967 to 1979. These county Bulletins addressed surficial, groundwater, and bedrock geology in the county; most of them also addressed some aspect of glacial stratigraphy. Map scales varied from map to map, but were generally about 1:100,000. North Dakota counties flanking the

RRV include Richland (Baker, 1967), Traill, (Bluemle, 1967), Barnes, (Kelly, and Block, 1967), Cass, (Klausing, 1968), Grand Forks, (Hansen and Kume, 1970), Nelson and Walsh, (Bluemle, 1973), Cavalier and Pembina (Arndt, 1975), Griggs and Steele (Bluemle, 1975), and Ransom and Sargent (Bluemle, 1979).

The North Dakota Geological Survey's Atlas Series mapped the area from the South Dakota border to Grand Forks and from the Red River to about Valley City at a scale of 1:250,000 (Harris, 1987; Harris and Luther, 1991). These were lithogenetic maps and did not address lithostratigraphy.

Recent surficial mapping by the North Dakota Geological Survey includes five 1:24,000 scale quadrangles in the Fargo (Anderson, 2005a, 2007), West Fargo (Anderson, 2008, 2009), and Grand Forks (Anderson, 2005b) areas that show subaerial exposure of lithostratigraphic units; and a suite of thirty-two1:24,000 scale surface geologic maps of an area of the RRV that extends north and west of the City of Grand Forks (Manz and Harris, 2015, 2016, 2017).

The Minnesota Geological Survey mapped the surficial geology and glacial stratigraphy in seven areas in the RRV during the period between 1995 and 2013. Areas mapped include the Southern RRV (RHA-3, Harris and others, 1995), Otter Tail area (RHA-5, Harris and Knaeble, 1999; Harris and others, 1999), Pope County Geologic Atlas (Harris and Knaeble, 2003; Harris and others, 2003); Fargo-Moorhead study area (Thorleifson and others, 2005), Fargo-Moorhead study surficial map (Lusardi and others, 2005), west central Minnesota (RHA-6; Harris and Knaeble, 2006; Harris and others, 2006), Crookston area (Harris, 2006), Fosston area (Harris, 2007) and a County Geological Atlas for Clay County (Gowan, 2014; Hobbs and Gowan, 2014).

All of the Minnesota Geological Survey studies developed surficial maps as well as characterizations and interpretations of the Quaternary stratigraphic units present. The southern RRV study (Harris and others, 1995) recognized 25 Quaternary stratigraphic units (6 non-glacial and 19 glacial): Walsh, Sherack, Poplar River, Brenna, Huot (RRV01), Falconer (RRV02), Argusville, Wylie, Upper Red Lake Falls (RRV03), Lower Red Lake Falls (RRV04), Barnesville (RRV06), St Hilaire (RRV07), Dahlen (RRV08), Heiberg (RRV09), Hawley (RRV10), New York Mills (RRV11), and Villard Formations (RRV12), James till (RRV05), Gardar (RRV13), Gardar II (RRV14), Buffalo River (RRV15), Sebeka (RRV16), Marcoux (RRV17), Sheyenne River (RRV18), and Gervais Formations (RRV19). Named units in the RRV study were those previously defined in MS-52 (Harris and others, 1974); numbered units were units first recognized and described in the southern RRV study. Subsequent studies in the RRV refined this list, added new units and developed a Quaternary stratigraphic column for the RRV.

QUATERNARY TIME

A brief discussion of Quaternary time nomenclature and our concept of Quaternary time seems useful. Measuring time in an absolute sense in the Quaternary is a problem. However, tying climatic change to glacial and interglacial ages is accomplished through marine isotope stages (MIS). Climatic cycles can be observed in the oxygen-16 and oxygen-18 ratios observed in calcite recovered in deep-sea core samples. Calcite is a main component of shells and hard body parts of many marine organisms. The ratio of oxygen-16 to oxygen-18 varies depending on the water temperature when the calcite forms; higher amounts of the heavier oxygen-18 isotope being associated with colder conditions. Plots of the oxygen isotope ratio have become the most commonly used time scale for the Quaternary Period and are referred to as marine isotope stages (fig. 14). Colder cycles are even-numbered peaks (left excursions) and warmer cycles are the odd-numbered peaks (right excursions). Fixing an absolute date to the MIS is still imprecise because of the time transgressive nature of glacial events and their uncertain relationship to deep sea temperature variations, but the beginning of cycle 1 is generally accepted as the beginning of the Holocene Epoch (11 ka). The beginning of cycle 4 is generally considered to be the start of the Wisconsinan glacial age (~ 71ka), the beginning of cycle 5e the start of the Sangamonian interglacial age (~ 130 ka) with less precision associated with older cycles. Figure 14 shows the MIS (1-9), Quaternary time nomenclature, and associated approximate absolute ages.

Absolute ages may be established by various dating methods. In the RRV, a number of radiocarbon (^{14}C) and optically stimulated luminescence (OSL) ages have been reported for some of the Late Wisconsinan units, but most have not been dated owing to a lack of dateable material or for other reasons. Units older than about 40 ka are beyond the range of radiocarbon dating and OSL is ordinarily not used to date material more than about 100,000 years old. Techniques for dating these older units include uranium-thorium dating and other cosmogenic radionuclide methods such as $^{10}Be/^{26}Al$ dating. Very few absolute ages have been reported for the pre-Wisconsinan units in the RRV.

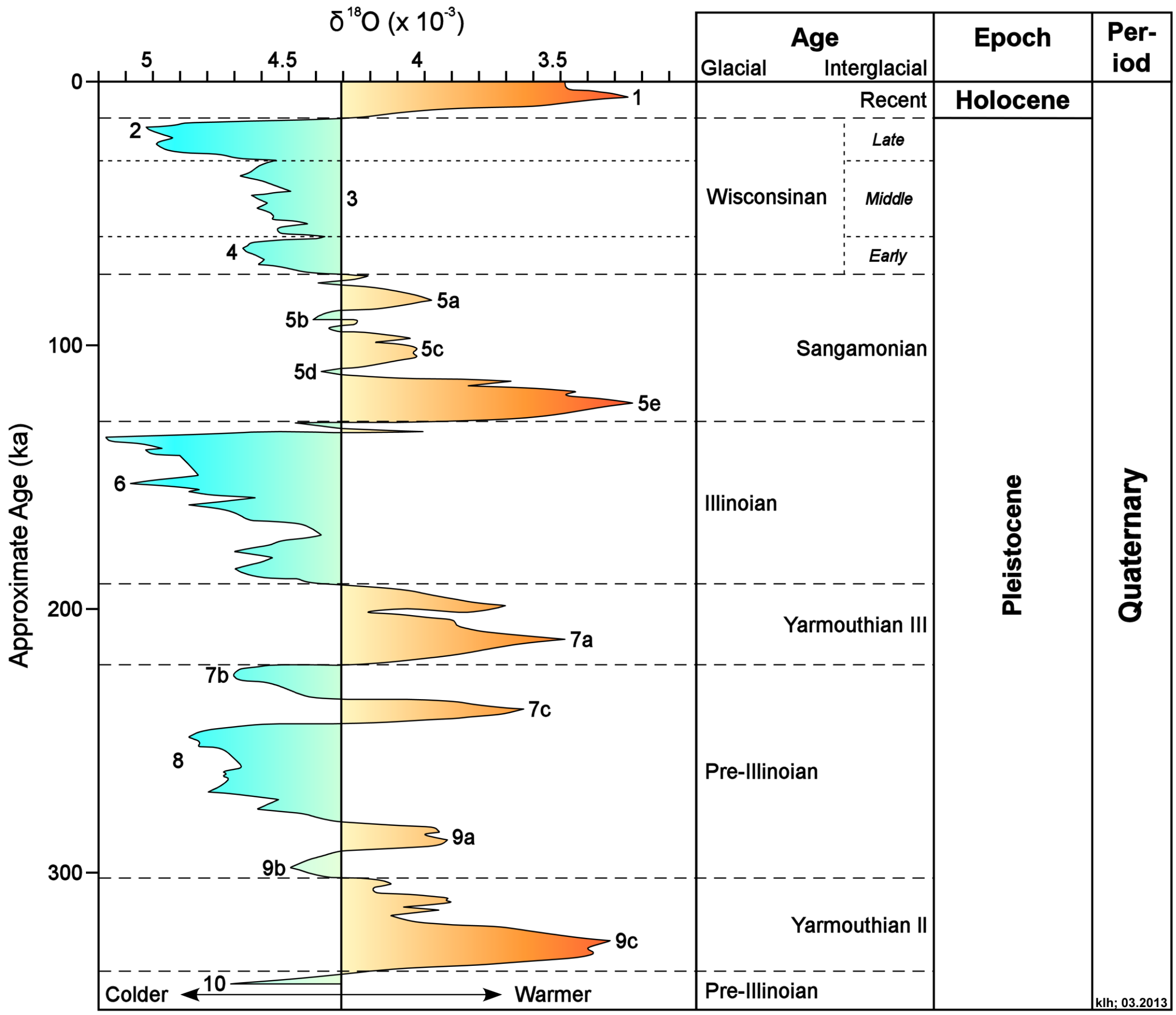


Figure 14. This figure shows the relationship between marine isotope stages (MIS), the Quaternary time nomenclature used in this report, and an approximate age scale. It is important to note that assigning ages to Quaternary units is imprecise owing to the time transgressive nature of the glacial events that deposited the lithostratigraphic units, the uncertain relationship between continental glacial events and variations in deep-sea temperature, and the scarcity and uncertainty associated with radiometric dates.

CORRELATION EFFORTS

During the period from 1971 to 2007 there were 22 Quaternary studies in the RRV that resulted in local stratigraphic interpretations and stratigraphic columns. There were four UND theses, three UND dissertations, seven North Dakota Geological Survey publications, six Minnesota Geological Survey publications, and two Minnesota Geological Survey miscellaneous studies. During that 36-year period, 223 names were used for the 37 stratigraphic units we describe in this document. Some studies used the same names for different units, some used different names for the same units, and some used the same names for the same units. In general, most of these studies made correlations within the area of the greater RRV.

Table 1 shows the units recognized in the various studies and our interpretation of how they correlate to the units defined in this report. The column at the right lists the formal and informal units recognized by this study. There is a column for each study in the RRV area arranged in chronological order, left to right. Columns show the first formal use (initial naming) of stratigraphic units, subsequent use of the terms, and other names used for the stratigraphic units. For example, the Walsh Formation was first named by Bluemle (1973). The term was used in Perkins (1977), Harris and others (1995), and Harris

Bluemle 1971	Bluemle 1973	Harris 1973	Harris, Moran, & Clayton 1974	Salomon 1975	Harris 1975	Sackreiter 1975	Hobbs 1975	Clayton, Moran, & Bickley 1976	Anderson 1976	Perkins 1977	Arndt 1977	Camara 1977	Harris 1995	Harris & others 1999	Harris & others 2003	Thorleifson & others 2005	Harris & Berg 2006	Harris 2006	Harris 2007	Harris unpub. 2007	Johnson & others 2016	Harris, Lusardi, Manz & Anderson This report 2019	Unit Status N	Unit Status A	Unit Status R	Unit Status M
								Oahe Fm.								X				X		Oahe Fm.		✓		
	Walsh Fm.									X	Unit 10		X			X		X	X						✓	
		Sherack fm.	**Sherack Fm.**		X	X			X	X	X		X			X		X		X	X	Sherack Fm.				✓
										Downer fm.															✓	
			Poplar River Fm.			X					X		X			X		X		X	X	Poplar River Fm.		✓		
											West Fargo Mbr.					X					X	West Fargo Mbr.		✓		
											Harwood Mbr.					X					X	Harwood Mbr.		✓		
			Brenna Fm.								X		X			X		X		X	X	Brenna Fm.		✓		
																Forest River gp.					Forest River fm.	**Forest River Fm.**	✓			
		Huot fm.	**Huot Fm.**		X	X					X		X			X		X		X	Huot mbr.	**Huot Mbr.**				✓
			Falconer Fm.				X				X		X			X		X		X	Falconer mbr.	**Falconer Mbr.**				✓
		Wylie fm.	**Wylie Fm.**		X						X		X			X		X	X	X	X	Wylie Fm.		✓		
						Argusville fm.					**Argusville Fm.**		X			X	X			X	X	Argusville Fm.		✓		
		Red Lake Falls fm.	**Red Lake Falls Fm.**		X											Red Lake River gp.					Red Lake Falls Fm.	Red Lake Falls Fm.		✓		
						U. Red Lake Falls fm.					MA-Unit A		RRV03			U. Red Lake Falls fm.		X	X	X	U. Red Lake Falls mbr.	**U. Red Lake Falls Mbr.**	✓			
						L. Red Lake Falls fm.							RRV04			L. Red Lake Falls fm.		X	X	X	L. Red Lake Falls mbr.	**L. Red Lake Falls Mbr.**	✓			
																Goose River gp.					Goose River fm.	**Goose River Fm.**	✓			
																U. Goose River gp.									✓	
									Barnesville fm.	X			RRV06	X		Barnesville till	X			X					✓	
		St. Hilaire fm.	**St. Hilaire Fm.**		X	X					MA-Unit B/MA-Unit C	MC-Unit C	RRV07	X	Goose	St. Hilaire Fm.	X	X	X	X	St. Hilaire mbr.	**St. Hilaire Mbr.**				✓
															River		Lake Benson I								✓	
																L. Goose River gp.									✓	
				Dahlen Fm.			X				MA-Unit D	MC-Unit B	RRV08	X	gp.,	Dahlen Fm.	X			X	Dahlen mbr.	**Dahlen Mbr.**				✓
																	Lake Benson II								✓	
									Dunvilla fm.	X		MC-Dahlen	RRV09	X	undif.	Heiberg fm.	X	X		X	**Heiberg Mbr.***	**Heiberg Mbr.**				✓
															Otter	Otter Tail River gp.					Otter Tail River fm.	**Otter Tail River Fm.**	✓			
										Hawley fm.			RRV10		Tail River	Hawley fm.	X			X	Hawley mbr.	**Hawley Mbr.**	✓			
									New York Mills fm.				RRV11	X	gp., undif.	New York Mills fm.	X			X	New York Mills mbr.	**New York Mills Mbr.**	✓			
													RRV12	X		Villard fm.	X								✓	
Coleharbor Gp.																James River gp.					James River fm.	**James River Fm.**	✓			
																				Villard fm.	**Villard Mbr.***	**Villard Mbr.**				✓
												MC-Unit A	RRV05	X	James River gp.	James River fm.	X			X		**L. James River Mbr.**	✓			
																Lake Tewaukon gp.									✓	
				Gardar Fm.			X					X	RRV13	X		Gardar Fm.	X			X	X	Gardar Fm.		✓		
													RRV14												✓	
																Buffalo River gp.									✓	
													RRV15			Buffalo River fm.	X			X	X	**Buffalo River Fm.**	✓			
									Sebeka fm.											Pierz fm.					✓	
															Crow Wing	Crow Wing River gp.					Crow Wing River fm.	**Crow Wing River Fm.**	✓			
										Sebeka fm.			RRV16	X	River gp.,	U. Marcoux fm.	X			X	Sebeka mbr.	**Sebeka Mbr.**	✓			
		Marcoux fm.	**Marcoux Fm.**		X	X				New York Mills fm.			RRV17	X	undif.	L. Marcoux fm.	X	Marcoux Fm.	X	X	Marcoux mbr.	**Marcoux Mbr.**				✓
																Sheyenne River gp.									✓	
												MC-Unit D	RRV18			Sheyenne River fm.	X			X	X	**Sheyenne River Fm.**	✓			
																Browerville gp.									✓	
															Browerville till	X	X			X	**Browerville Fm.**	Browerville Fm.		✓		
																Gervais gp.									✓	
		Gervais fm.	**Gervais Fm.**										RRV19	X	Gervais Fm.	X	X	X	X	X	X	Gervais Fm.		✓		
																						INFORMAL UNITS				
																Old Buffalo River gp.										
																Buffalo River II till	X			X		Old Buffalo River till				
																Old Otter Tail River gp.										
					kh-unit 1	ds-unit 1						MC-Unit E				New York Mills II till				X		Old New York Mills till				
					kh-unit 2	ds-unit 2							Sebeka till			Hawley II till	X			X		Old Hawley till				
																Old Crow Wing River gp.										
																U. Marcoux fm. II	X			X		Old Sebeka till				
																L. Marcoux fm. II	X			X		Old Marcoux till				
							Hansboro fm.																			
							Vang fm.															UNIT NOT INCLUDED				
							Tiber fm.															IN THIS STUDY				
							Cando fm.				AA1:L63															

* Formally named in Minnesota as a member of the New Ulm Formation.

Table 1. This table shows a correlation of Quaternary stratigraphic nomenclature that was developed by 22 studies in the Red River Valley of North Dakota and Minnesota. The studies (columns) are arranged chronologically from left to right to show the evolution of the nomenclature. Theses and dissertations are shown as white columns, state survey publications (maps and special reports) are shown as yellow columns, and formal naming publications are shown as green columns with the defined units in bold type. The "X" symbols indicate repeated use of the name to the left in that row. The headings in the four unit status columns at the extreme right denote the following: N = units formally named for the first time in this report, A = units formally defined elsewhere and already accepted by the NDGS, R = formal and informal units rejected by the NDGS because their usage is redundant or invalid, and M = existing formal units accepted by the NDGS that have either been redefined (required when modifications are made to the name or other descriptive terms of a stratigraphic unit) or revised (required when the unit rank or boundaries are changed).

(2006, 2007; unpub. data, 2007). Walsh Formation was probably correlative with Unit 10 of Arndt (1977). Redefinition of the Oahe Formation by Clayton and Moran (1979) resulted in the Oahe Formation replacing the Walsh Formation.

A lithostratigraphic unit is a body of sediment that is formally defined on the basis of lithologic characteristics and stratigraphic position. Lithostratigraphic units are formally defined in publications that follow guidelines outlined in the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 2005). Publications of state geological surveys are considered formal publications whereas theses and dissertations are not. Consequently, we will accept or modify nomenclature published formally, and redefine, rename, or reject units defined informally; i.e., in theses and dissertations.

Three notable attempts have been made to correlate RRV stratigraphic units on a more regional basis. In a monumental work, Moran and others (1976) correlated the results of regional theses and survey studies from the period 1965 to 1975 in eastern North Dakota, northwestern Minnesota, Iowa, and southeastern Manitoba. Harris and others (2007) presented a correlation of RRV stratigraphic units with recognized units in southeastern Manitoba (fig. 15). Interpretations were based on 23 rotary-sonic cores in southeastern Manitoba and three deep stratigraphic tests and a number of shallow borings in northwestern Minnesota. Lusardi and others (2011a) discuss ice stream dynamics and presented a correlation of Pleistocene units in southwestern and south central Minnesota with units in the southern RRV. Lusardi and others (2011b) presented a characterization and correlation of Quaternary stratigraphic units in Minnesota. Johnson and others (2016) present a formal lithostratigraphic definition and correlation of all recognized Quaternary units used in Minnesota.

Table 2 shows a correlation of the lithostratigraphic units recognized in this report with lithostratigraphic units defined by workers in adjacent areas of Minnesota and North Dakota. Figure 16 is a time-distance diagram for the RRV that shows the geographic variation and interpreted age of the RRV lithostratigraphic units as well as some nomenclature associated with Lake Agassiz.

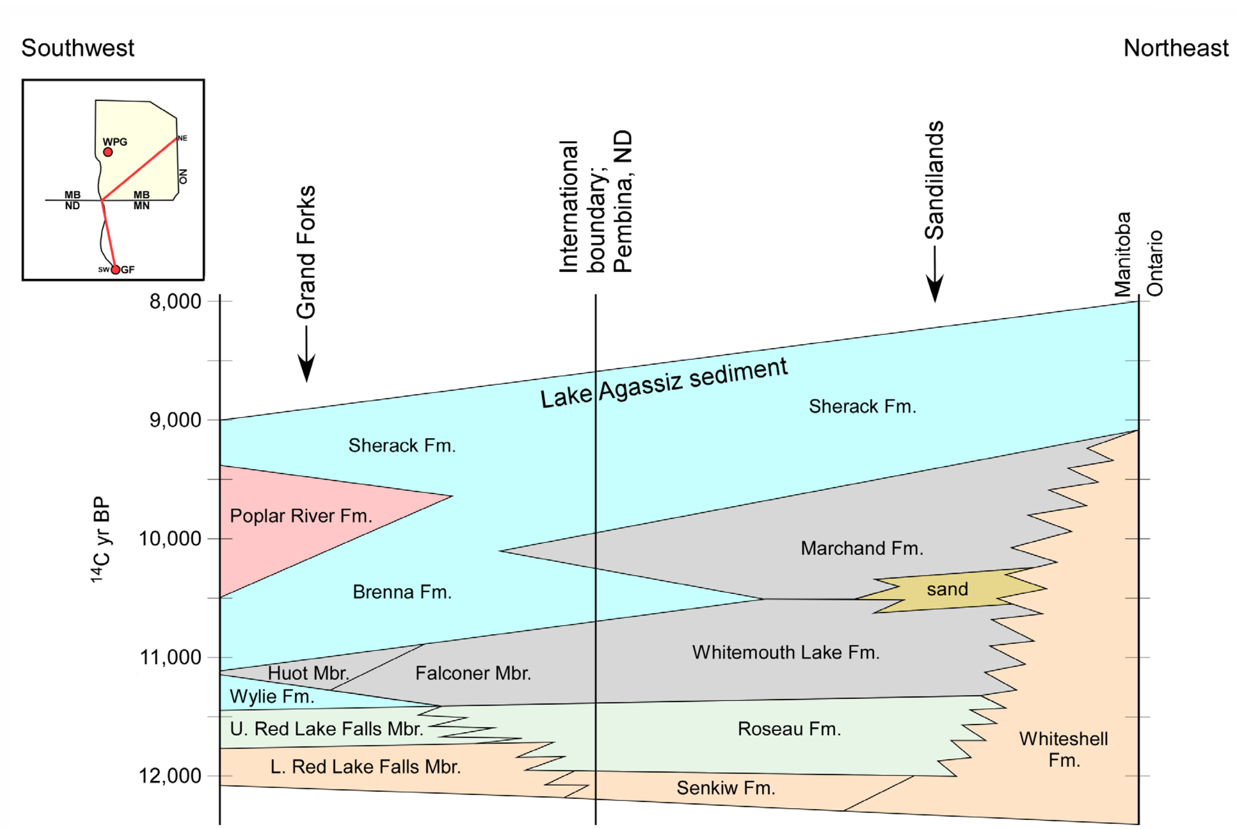


Figure 15. Generalized cross section showing the correlation of northern Red River Valley lithostratigraphic units with lithostratigraphic units in southeastern Manitoba. Modified from Teller and Fenton (1980).

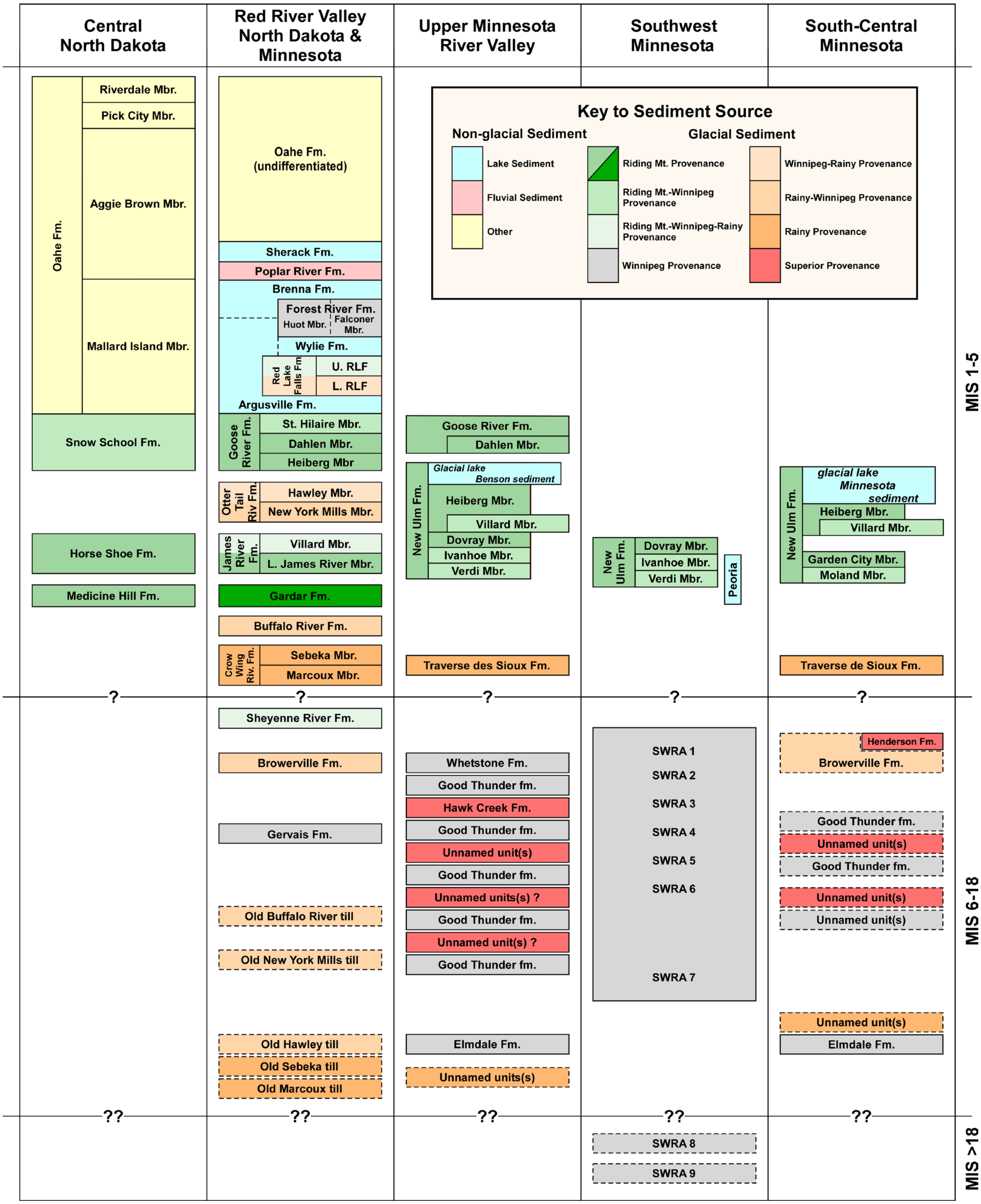


Table 2. This table correlates the lithostratigraphic units defined in this report with lithostratigraphic units defined in adjacent areas of North Dakota and Minnesota. Units are color coded to indicate the interpreted source area – a lithostratigraphic correlation. Little is known of units indicated as being older than MIS 5. Table modified from Johnson and others (2016).

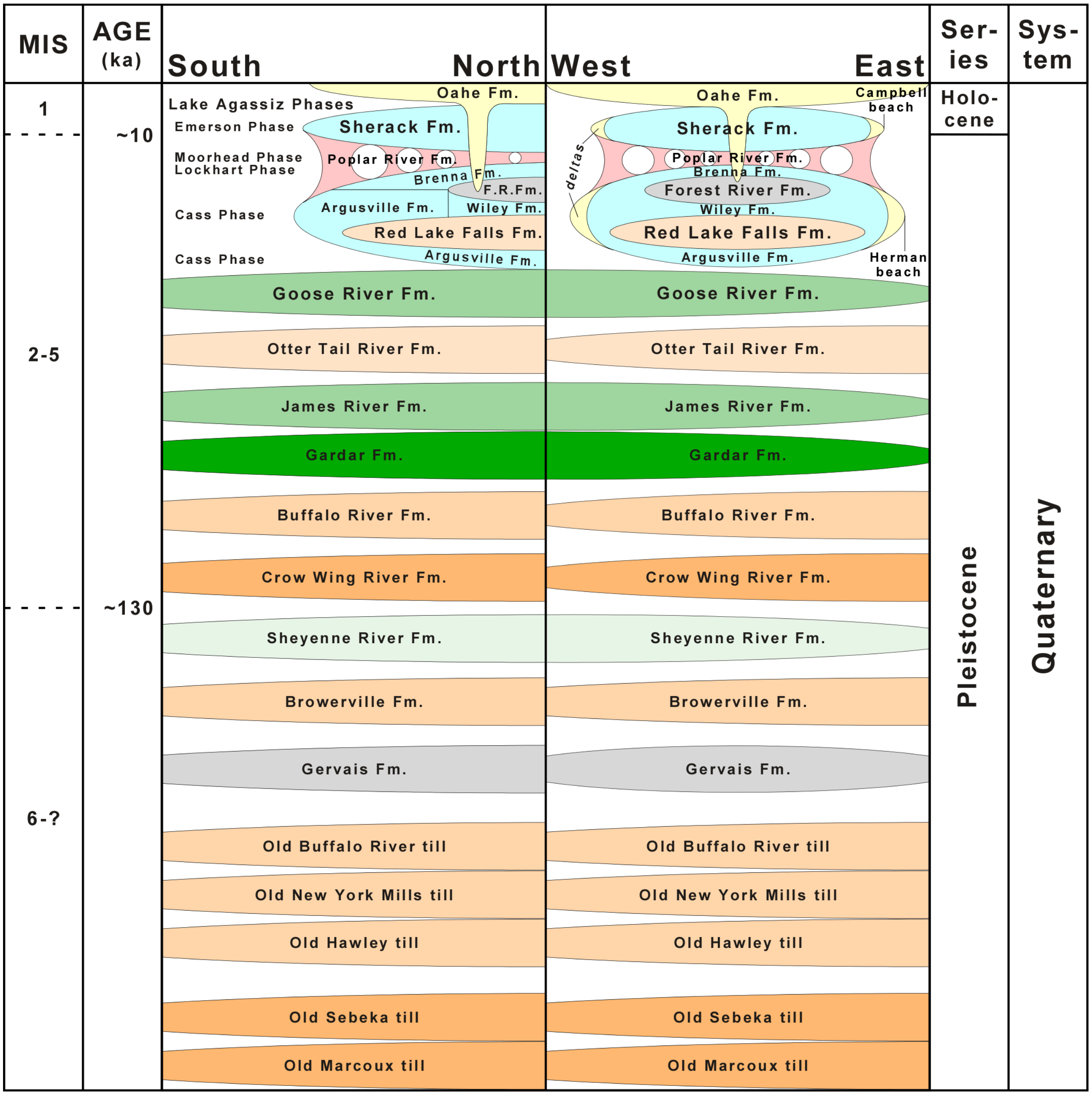


Figure 16. Time-distance diagram for the Red River Valley that shows geographical distribution and interpreted age of Red River Valley lithostratigraphic units and Lake Agassiz nomenclature.

METHODS

Most previous Quaternary stratigraphic studies in the RRV of North Dakota and Minnesota have been local in scope and have made correlations without the assistance of a large, quantitative database. Here we have used quantitative textural and compositional data as well as stratigraphic position to interpret and correlate tills in the RRV. The project database (QBASE) contained 5990 elements (fig. 12) from two sources. One source, N-File, consists of near-surface stratigraphic data generated by geologists with the University of North Dakota and the North Dakota Geological Survey. The second source, Minnesota Geological Survey's Quaternary Data Index (QDI), contains data generated by Minnesota geologists from mapping projects throughout the state. Information stored in QBASE includes sample site location, sample elevation, geologist's name, project name, sample texture and coarse-sand composition. QBASE allows the integration of data derived from different projects, geologists, and geologic settings (outcrops, hand-auger borings, soil-probe holes, power-auger holes, and rotary-sonic coring). The integration of data from these sources and settings facilitates the development of regional lithologic maps, and stratigraphic interpretations.

Computer-assisted lithostratigraphic techniques were used to identify natural tendencies in the data (clusters), interpret stratigraphic relations, and correlate lithostratigraphic units. Differentiation of glacial sedimentary units requires that the rate of compositional change within a stratigraphic unit is small compared to the absolute difference in the correlation parameters between units. The correlation parameters used with glacial sediments from the Red River Valley of Minnesota and North Dakota are derived from textural and lithologic data. Textural analysis provides the percentage composition of sand (SD), silt (SLT), and clay (CLY). Grain-count analysis of the lithology of the coarse-sand fraction (1-2 mm) provides the percentage composition of crystalline and metamorphic rock fragments (XT), limestone and dolostone rock fragments (CO_3), and shale fragments (SH). Finally, a sequential dataset is assembled; it consists of all sample data, arranged by location (township, range, section, and quarter section) and decreasing elevation at each sample site or borehole location. The sequential dataset provides a presentation of data that is useful for mapping and stratigraphic interpretation. For a detailed description of the methodology see Harris (1987, 1996, and 1998).

The software used with computer-assisted stratigraphy is designed to duplicate the procedures a geologist uses to evaluate textural and lithologic data, and develop interpretations and correlations (Harris, 1987). Two programs are used in the identification, verification, and correlation of tills in a dataset. They are a cluster-analysis program and a display-correlate program. The programs were originally written in FORTRAN but are now available in a version of QuickBASIC. These programs and other data-handling and graphic-display programs have been installed in a menu-driven environment designed for working with the till data (Harris, 2020).

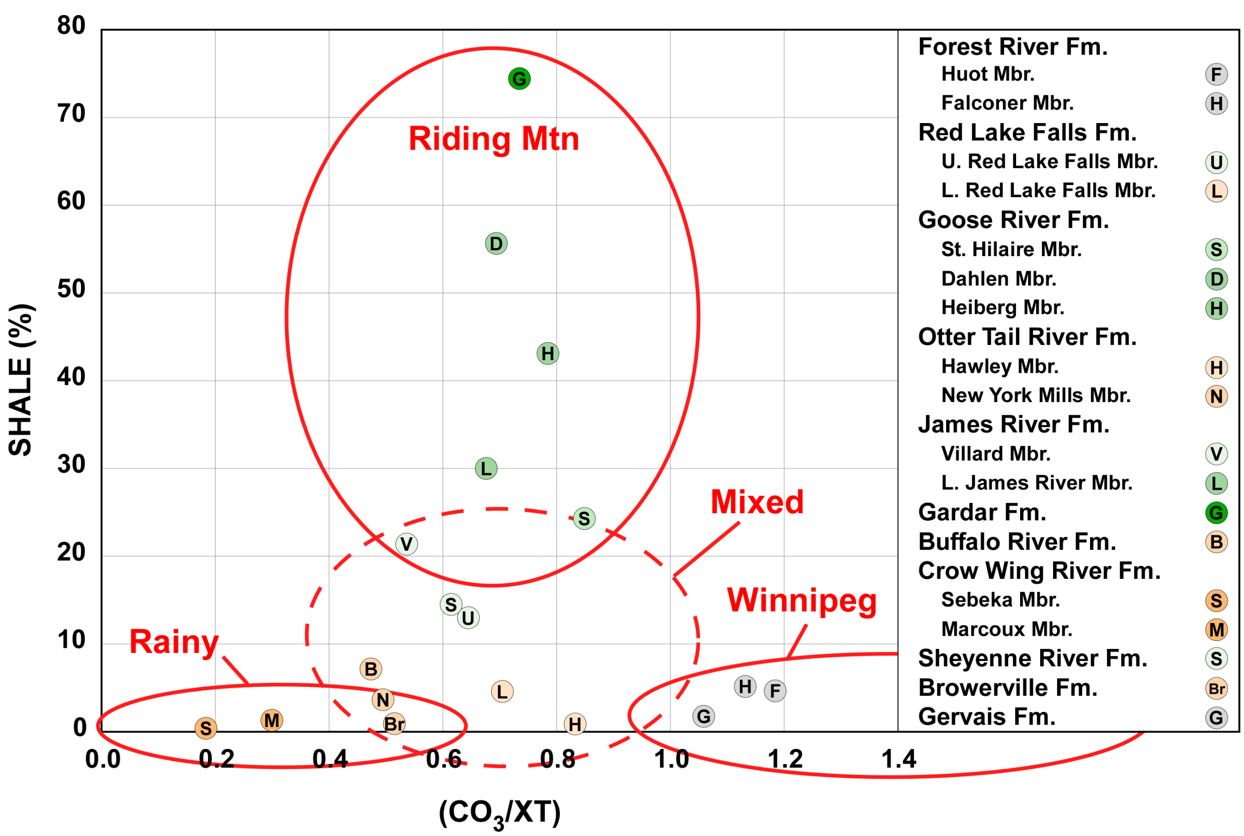


Figure 17. Glacial sediment deposited during each advance had a textural and detrital-grain composition that reflected its source area. This cross plot of the lithologic correlation parameters shows the provenance of the various units of glacial sediment deposited in the Red River Valley.

Formation Member / ***informal***	N	%	Texture			Lithology		
			SD	SLT	CLY	XT	CO_3	SH
Forest River Fm.								
Huot Mbr.	47	1.9	7	23	70	45	51	5
Falconer Mbr.	24	1.0	32	48	19	44	52	4
Red Lake Falls Fm.								
U. Red Lake Falls Mbr.	64	2.6	38	39	23	53	34	13
L. Red Lake Falls Mbr.	155	6.3	40	40	20	56	40	4
Goose River Fm.								
St. Hilaire Mbr.	174	7.0	28	43	29	41	35	24
Dahlen Mbr.	393	15.9	33	40	27	26	18	56
Heiberg Mbr.	319	12.9	34	39	27	32	25	43
Ottertail River Fm.								
Hawley Mbr.	20	0.8	41	39	21	54	45	1
New York Mills Mbr.	19	0.8	55	31	14	65	32	3
James River Fm.								
Villard Mbr.	113	4.6	43	36	21	51	27	22
L. James River Mbr.	155	6.3	40	36	23	42	28	30
Gardar Fm.	164	6.6	30	41	28	15	11	74
Buffalo River Fm.	74	3.0	34	36	30	64	30	7
Crow Wing River Fm.								
Sebeka Mbr.	233	9.4	58	27	14	85	15	0
Marcoux Mbr.	114	4.6	55	30	15	76	23	1
Sheyenne River Fm.	65	2.6	38	37	25	53	33	14
Browerville Fm.	90	3.6	45	36	19	65	34	1
Gervais Fm.	108	4.4	36	42	21	48	51	2
Old Buffalo River till	20	0.8	29	36	35	66	29	5
Old New York Mills till	4	0.2	25	48	28	62	37	1
Old Hawley till	8	0.3	37	36	28	58	40	2
Old Sebeka till	38	1.5	37	44	19	85	15	0
Old Marcoux till	70	2.8	39	40	21	73	25	1
N total =	2471	100.0						

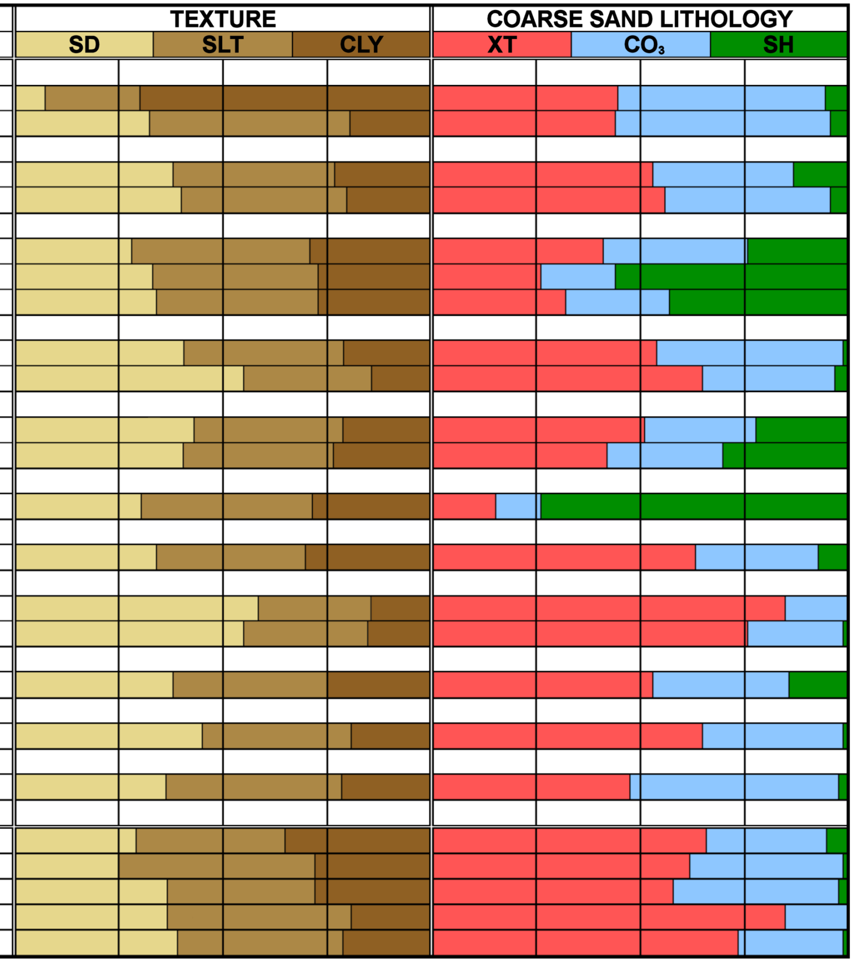


Table 3. Lithostratigraphic units were defined based on part of the correlated dataset, sequential presentation of the database, and field-based knowledge of regional geology. Eleven formations containing thirteen members and five informal units consisting of glacial sediment were recognized. This table shows general statistics, a numerical summary, and a graphic depiction of the correlation parameters. Also shown are the informal glacial units present in the Red River Valley.

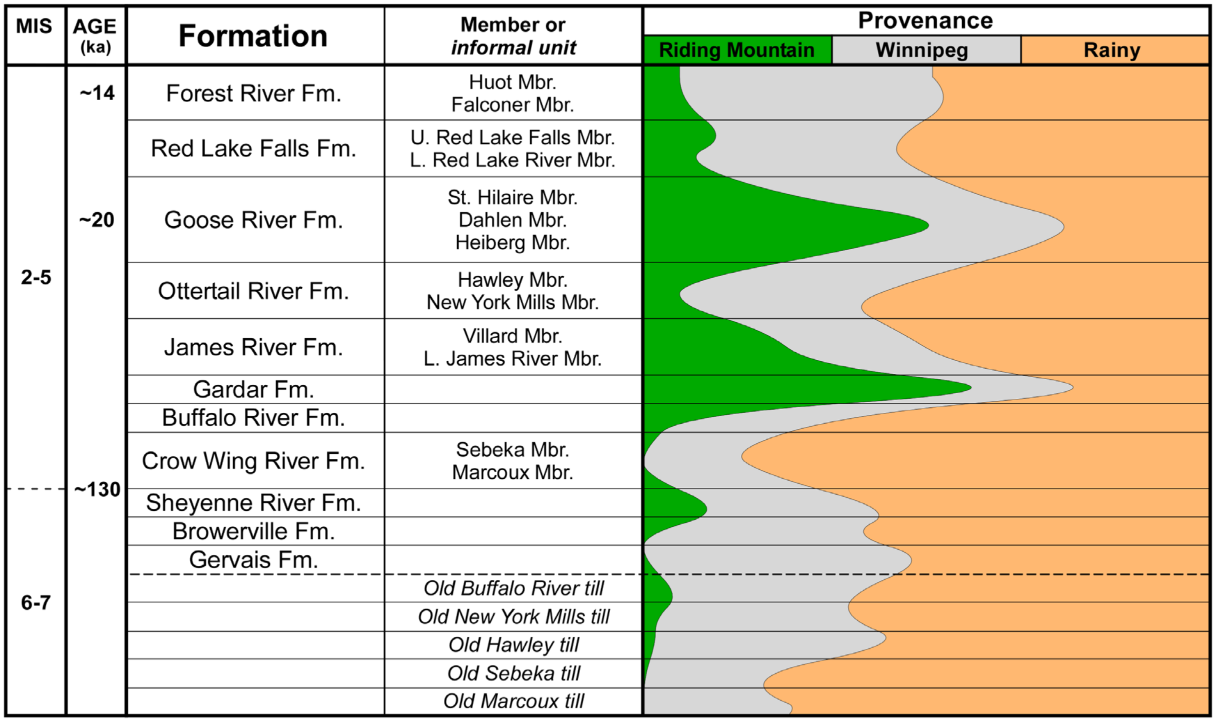


Figure 18. This figure shows the general variation of provenance versus time for lithostratigraphic units consisting of glacial sediment. The graph is based on the interpreted stratigraphic sequence, variations of the lithologic correlation parameters, and interpreted age of the lithostratigraphic units. The graphic presentation of the Rainy provenance is based on the lithologic content of crystalline and metamorphic rock fragments. Since sediment derived from all provenances contains crystalline and metamorphic rock fragments the graph exaggerates the dominance of the Rainy provenance, but the sequencing of source areas is accurate.

The cluster analysis program allows naturally occurring modal groups (clusters) in a dataset to be identified, isolated, and labeled. The initial definition of a modal group is refined interactively to isolate a cluster and label member samples. This procedure is repeated until all modal groups in the dataset have been identified, defined, and their member samples labeled. The result is a sequential file that contains all labeled and unlabeled samples. The results of the cluster analysis performed on the RRV dataset is shown in table 3. Lithostratigraphic units were defined based on part of the correlated dataset, sequential presentation of the database, and field-based knowledge of regional geology. Eleven formations containing thirteen members and five informal units were recognized. Table 3 shows the number of samples, percent of the total database, overall average value of the correlation parameters for each of the lithostratigraphic units, and a graphical representation of the correlation parameters.

The lithostratigraphic units identified formed the basis for the lithostratigraphic map of the RRV (fig. 12), which shows the area of surface exposure of stratigraphic units in the Red River Valley. Lithostratigraphic units present along the Glacial Lake Agassiz shoreline have been thinned or removed by shoreline erosion, in some cases exposing older units. Correlations between stratigraphic units defined here and lithostratigraphic units developed by other workers in the area are shown in table 1.

Glaciers advanced into the Red River Valley from the northwest (Riding Mountain or Keewatin provenance) and the north (Winnipeg provenance) as well as from the northeast and east (Rainy or Labrador provenance). Glacial sediment deposited during each advance has a textural and detrital-grain composition that reflects its source area. Cross plots of the correlation parameters show the characteristics of tills associated with each of the source areas (fig. 17). Figure 18 illustrates that ice streams from the different source areas were competing for space in the RRV and that the dominance of ice streams from different source areas varied with time.

APPENDIX I

DEFINITION OF UNITS

This section contains definitions, based on procedural guidelines described in the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 2005), of 36 of the 38 formal and informal lithostratigraphic units recognized in this report (see table 1). The Coleharbor Group (Bluemle, 1971) and Oahe Formation (Clayton, Moran, and Bickley, 1976; Clayton and Moran, 1979) are excluded because they do not pertain to this study and their formal definitions are unchanged. Readers are instead referred to the original naming publications.

Of the lithostratigraphic units described on the following pages, thirteen – the Sheyenne River Formation, the Crow Wing River Formation, the Sebeka Member of the Crow Wing River Formation, the Buffalo River Formation, the James River Formation, the Lower James River Member of the James River Formation, the Otter Tail River Formation, the New York Mills and Hawley Members of the Otter Tail River Formation, the Goose River Formation, the Upper and Lower Red Lake Falls Members of the Red Lake Falls Formation, and the Forest River Formation – are *new*, meaning they are formally named for the first time in this report. Ten units – the Gervais, Browerville, Gardar, Red Lake Falls, Argusville, Wylie, Brenna, and Poplar River Formations; and the Harwood and West Fargo Members of the Poplar River Formation – were formally named in earlier reports and are accepted without redefinition or revision. Three units – the Villard Member of the James River Formation, the Heiberg Member of the Goose River Formation, and the Sherack Formation – were formally named in earlier reports but are *redefined* here to incorporate descriptive revisions that involve no changes in the definition of the unit boundaries or rank. For example, the "Heiberg Member of the New Ulm Formation", defined in Minnesota by Lusardi and Harris (2016a) is redefined in North Dakota as the "Heiberg Member of the Goose River Formation". Five units – the Marcoux Member of the Crow Wing River Formation; the Dahlen, and St. Hilaire Members of the Goose River Formation, and the Falconer and Huot Members of the Forest River Formation, are formally *revised* owing to a change in rank (from Formation to Member).

Brief descriptions of five informal lithostratigraphic units are included in this section. These units are recognized but cannot be formally defined until more information becomes available.

For ease of reference to the tables and graphics in the preceding, introductory pages, we have elected to defy convention in this section by arranging the unit definitions in reverse stratigraphic order; that is, beginning with the youngest – the Sherack Formation – and proceeding downsection through progressively older Quaternary units to the underlying bedrock surface.

SHERACK FORMATION

(Redefined)

NAME AND RANK

The Sherack Formation, defined by Harris, Moran, and Clayton (1974), is here redefined to include a nearshore facies and deltaic facies. The source of the name is the village of Sherack in Polk County, Minnesota, located on the USGS 7.5-minute series Tabor, MN quadrangle.

TYPE AREA

The type area of the Sherack Formation, Offshore facies is the Grand Forks, Grand Forks County, North Dakota area and adjacent parts of northeastern North Dakota and northwestern Minnesota (USGS 7.5-minute series Grand Forks, MN – ND quadrangle; fig. A1.1).

TYPE SECTION

The type section of the Sherack Formation is U.S. Army Corps of Engineers, Boring 68-12M, Oslo Dike, at Oslo, Minnesota (T. 155 N., R. 50 W., sec. 31 dda; GPS: 48.198684, -97.130430; USGS 7.5-minute series Oslo, MN – ND quadrangle; fig. A1.2; and Appendix 2, p. 241).

REFERENCE SECTIONS

Offshore facies: Reference sections for the Sherack Formation, Offshore facies are:

Boring No. 3, Witmer Hall, University of North Dakota (T. 151 N., R. 50 W., sec. 5 dddb; GPS: 47.920182, -97.068709; USGS 7.5-minute series Grand Forks, MN – ND quadrangle; fig. A1.1; and Appendix 2, p. 230).

NDSWC Testhole 2430 (T. 152 N., R. 50 W., sec. 29 dda; GPS: 47.951190, -97.067115; USGS 7.5-minute series Grand Forks, MN – ND quadrangle; fig. A1.1; and Appendix 2, p. 235).

NDSWC Testhole 2431 (T.151 N., R. 50 W., sec. 22 bbb; GPS: 47.889183, -97.044831; USGS 7.5-minute series Grand Forks, MN – ND quadrangle; fig. A1.1; and Appendix 2, p. 233).

NDSWC Testhole 2433 (T. 151 N., R. 50 W., sec. 6 dad; GPS: 47.922602, -97.088630; USGS 7.5-minute series Grand Forks, MN – ND quadrangle; fig. A1.1; and Appendix 2, p. 231).

NDSWC Testhole 2609 (T. 152 N., R. 51 W., sec. 36 ddd; GPS: 47.933499, -97.110392; USGS 7.5-minute series Grand Forks, MN – ND quadrangle; fig. A1.1; and Appendix 2, p. 237).

Snake Curve North Section (N-1018, D-12) on the Red Lake River, Red Lake Falls Township, Red Lake County, Minnesota (T. 151 N., R. 44 W., sec. 18 cbaac; GPS: 47.897438, -96.349475; USGS 7.5-minute series Red Lake Falls, MN; fig. A1.3; and Appendix 2, p. 225).

Nearshore facies: The reference area of the Sherack Formation, Nearshore facies is the Melvin, Polk County, Minnesota area in northwestern Minnesota (western half of T. 148 N., R. 45 W.; GPS: 47.620938, -96.387759; USGS 7.5-minute series Harold and Melvin, MN quadrangles; fig. A1.4).

The reference section of the Sherack Formation, Nearshore facies is Snake Curve South section on the Red Lake River, Louisville Township, Red Lake County, Minnesota (T. 151N., R. 45 W., sec. 13 dadda; GPS: 47.895118, -96.352728; USGS 7.5-minute series Red Lake Falls, MN; USGS 7.5-minute series Red Lake Falls, MN quadrangle; fig. A1.3; and Appendix 2, p. 228).

Deltaic facies: A reference area of the Sherack Formation, Deltaic facies is the McLeod area in Ransom and Richland Counties of southeastern North Dakota (T. 132-137 N. and R. 48-54 W.; figs. A1.5, A1.6). McLeod is located at T. 134 N., R. 53 W., sec. 25 bcbad; GPS: 47.620938, -96.387759.

The Northwood area in east-central North Dakota (T. 145-159 N. and R. 52-58 W.; figs. A1.6, A1.7) is also designated a reference area for the deltaic facies of the Sherack Formation. Northwood is located at T. 149 N., R. 54 W., sec. 09 dbdd; GPS: 47.734212, -97.565701.

LITHOLOGIC DESCRIPTION

The Sherack Formation has been divided into three facies based on the environment of deposition and sediment texture: offshore facies (silt and clay), nearshore facies (lacustrine sand, silt and gravel), and deltaic facies (fluvial sand, silt, and gravel).

Offshore facies: The offshore facies of the Sherack Formation consists of laminated clay, clayey silt, silty clay, and silt, and minor amounts of sand. It is siltier toward its eastern and western margins and more clayey in the central part of the Red River Valley. Thin, sharply defined laminations are generally only a few millimeters thick, but some of the silty beds

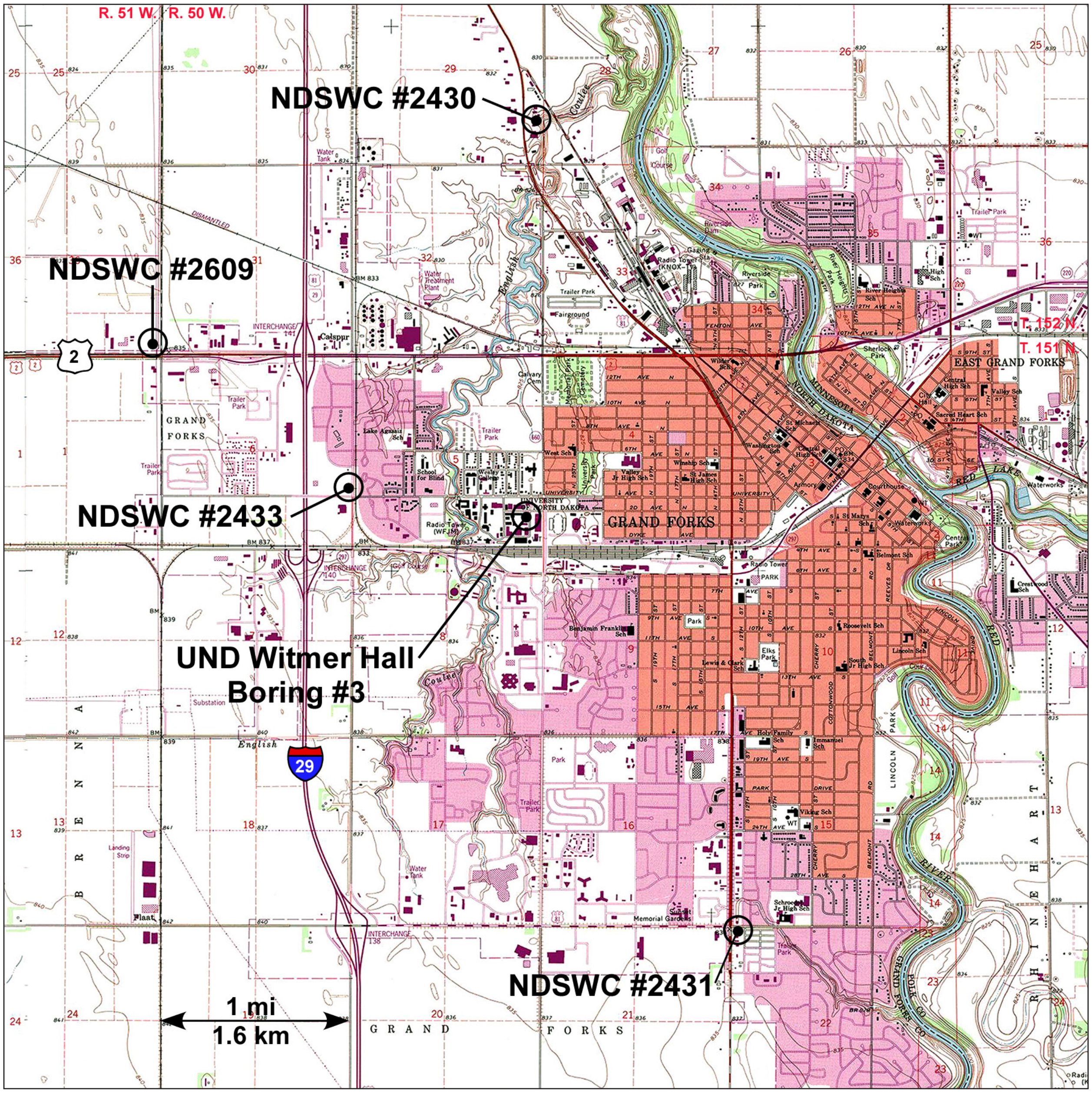
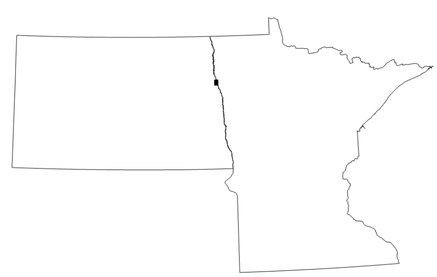


Figure A1.1. The type area of the Sherack Formation is the Grand Forks, Grand Forks County, North Dakota area. Shown are the locations of the University of North Dakota, Witmer Hall Boring Number 3 (T. 151 N., R. 50 W., Sec. 5 dddb; GPS: 47.920182, -97.068709; Appendix 2, p. 230) and North Dakota State Water Commission Testholes 2430 (T. 152 N., R. 50 W., sec. 29 dda; GPS: 47.951190, -97.067115; Appendix 2, p. 235), 2431 (T. 151 N., R. 50 W., sec. 22 bbb; GPS: 47.889183, -97.044831; Appendix 2, p. 233), 2433 (T. 151 N., R. 50 W., sec. 6 dad; GPS: 47.922602, -97.088630; Appendix 2, p. 231), and 2609 (T. 152 N., R. 51 W., sec. 36 ddd; GPS: 47.933499, -97.110392; Appendix 2, p. 237) that are reference sections for the offshore facies of the Sherack Formation. The topography of the map area is shown on the USGS 7.5-minute series Grand Forks, MN – ND quadrangle.



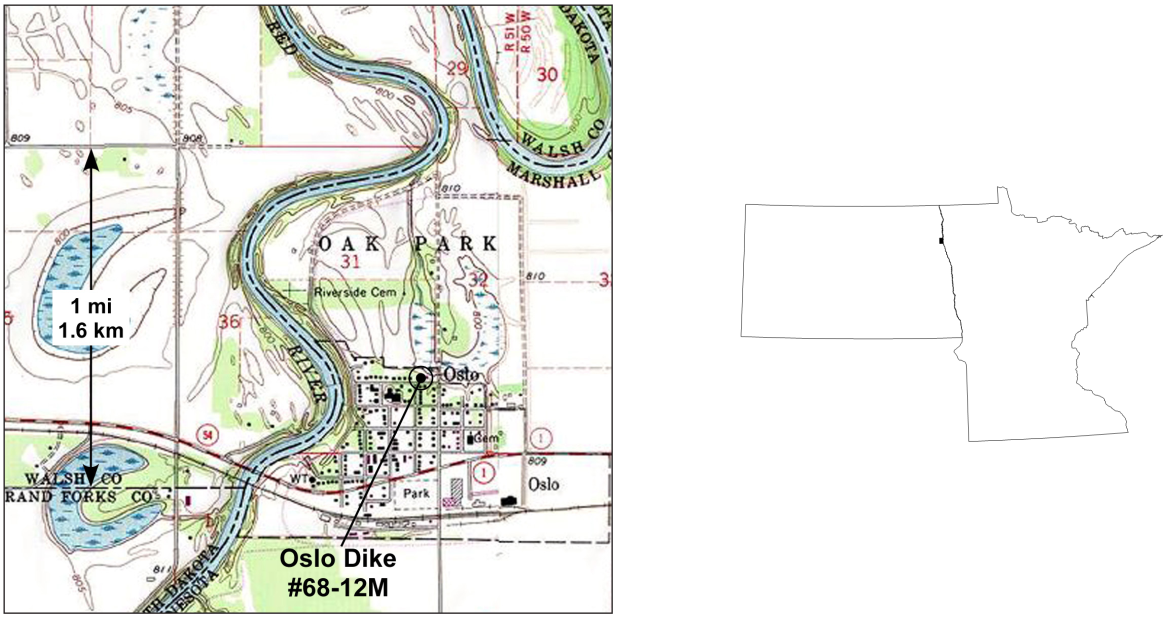


Figure A1.2. The United States Corps of Engineers Oslo Dike Boring 68-12M is the type section of the Sherack Formation (T. 155 N., R. 50 W., sec. 31 dda; GPS: 48.198684, -97.130430; Appendix 2, p. 241). The topography of the map area is shown on the USGS 7.5-minute series Oslo, MN – ND quadrangle.

are locally several centimeters thick. In some places the bedding has been deformed into folds a few feet high and several feet across. The Sherack Formation is light gray when unoxidized and yellowish gray to olive brown when oxidized. Pieces of abraded wood are commonly found in the lower few feet of the formation. Locally, the lower few feet of the formation contain considerable organic matter or beds of peat. Above the base, the formation contains little or no organic matter.

Nearshore facies: The nearshore facies of the Sherack Formation consists of low-angle flat-bedded to high-angle cross-bedded sand, silt, and gravel deposited in a lacustrine environment. Some organic-rich silt is sometimes present in the back beach environment. These sediments were deposited along the margin of Glacial Lake Agassiz in a band that ranges from a few miles to more than six miles wide. Gravel occurs in beach ridges that are flanked by low relief, lakeward sloping areas of sand and silt. Snail and small clam shells occur locally along the eastern and western edges of the unit. Nearshore facies of the Sherack Formation occur at elevations of about 1,000 feet (300 meters) or less.

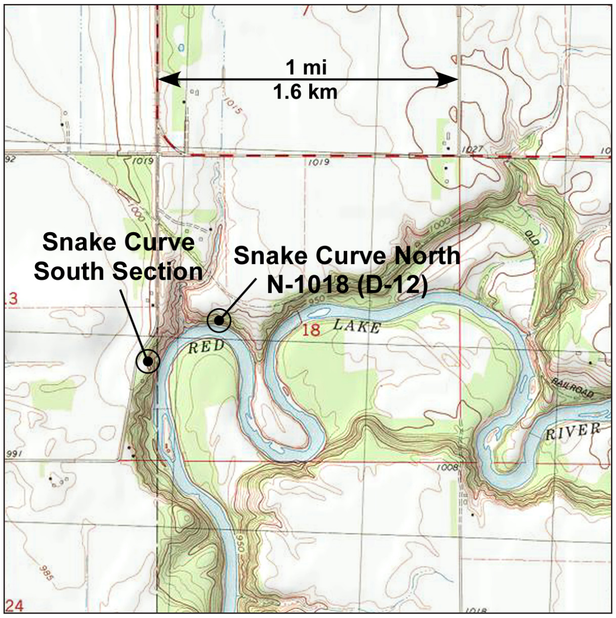
Deltaic facies: The deltaic facies of the Sherack Formation consists of low-angle flat-bedded to high-angle cross-bedded sand, silt, and gravel deposited in fluvial channels grading to turbidite and under-flow fan silt and clay deposited in the lake proximal to the mouth of the river. These sediments were deposited by rivers flowing into Lake Agassiz. Deltaic facies of the Sherack Formation occur at elevations of less than 1,000 feet (300 meters).

DESCRIPTION OF BOUNDARIES

The lower, unconformable contact of the offshore facies of the Sherack Formation is sharply marked by an abrupt change from light gray, laminated clay to the dark gray, obscurely laminated to unbedded clay of the Brenna Formation. Where the offshore facies of the Sherack Formation conformably overlies the Poplar River Formation, the contact is gradational by interbedding and the base of the Sherack Formation is placed where clay ceases to be the dominant lithology and sand beds make up most of the sequence. The transition zone is generally no more than a few feet thick.

The lower contact of the shoreline facies of the Sherack Formation is generally sharp and erosional and overlies older lacustrine and fluvial sediment or Pleistocene glacial sediment.

The lower contact of the deltaic facies of the Sherack Formation is generally sharp and erosional and overlies older lacustrine and fluvial sediment or Pleistocene glacial sediment.



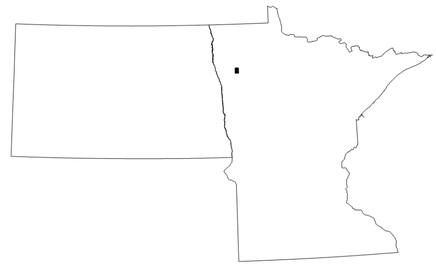
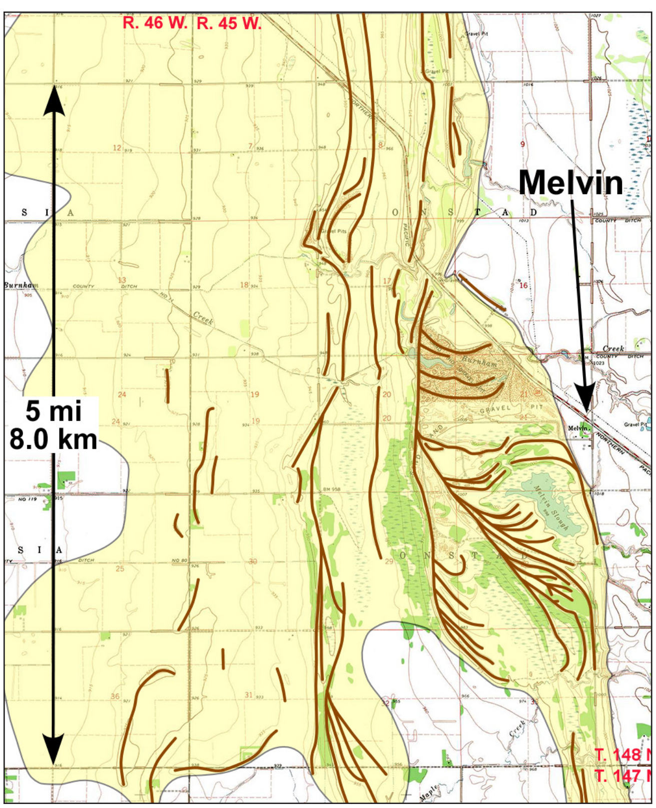


Figure A1.3. Snake Curve North Section (N-1018, D-12) on the Red Lake River, Red Lake Falls Township, Red Lake County, Minnesota (T. 151 N., R.44 W., sec.18 cbaac; GPS: 47.897438, -96.349475; USGS 7.5-minute series Red Lake Falls, MN quadrangle; Appendix 2, p. 225) is a designated reference section for the offshore facies of the Sherack Formation. Snake Curve South Section on the Red Lake River (T. 151 N., R. 45 W., sec. 13 dadda; GPS: 47.895118, -96.352728; Appendix 2, p. 228) is a designated reference section for the nearshore facies of the Sherack Formation. The topography of the map area is shown on the USGS 7.5-minute series Red Lake Falls, MN quadrangle.



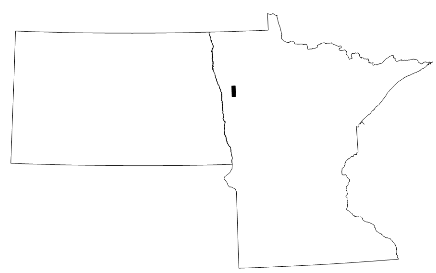


Figure A1.4. The western half of T. 148 N., R. 45 W. is designated a reference area for the nearshore facies of the Sherack Formation. The yellow field in the figure encloses the nearshore facies and the brown lines indicate the location of beach ridges and spits. The topography of the map area is shown on the USGS 7.5-minute series Harold and Melvin, MN quadrangles. Melvin, MN (T. 148 N., R. 45 W., sec. 21 daad; GPS: 47.620938, -96.387759) is located at the eastern edge of the area.

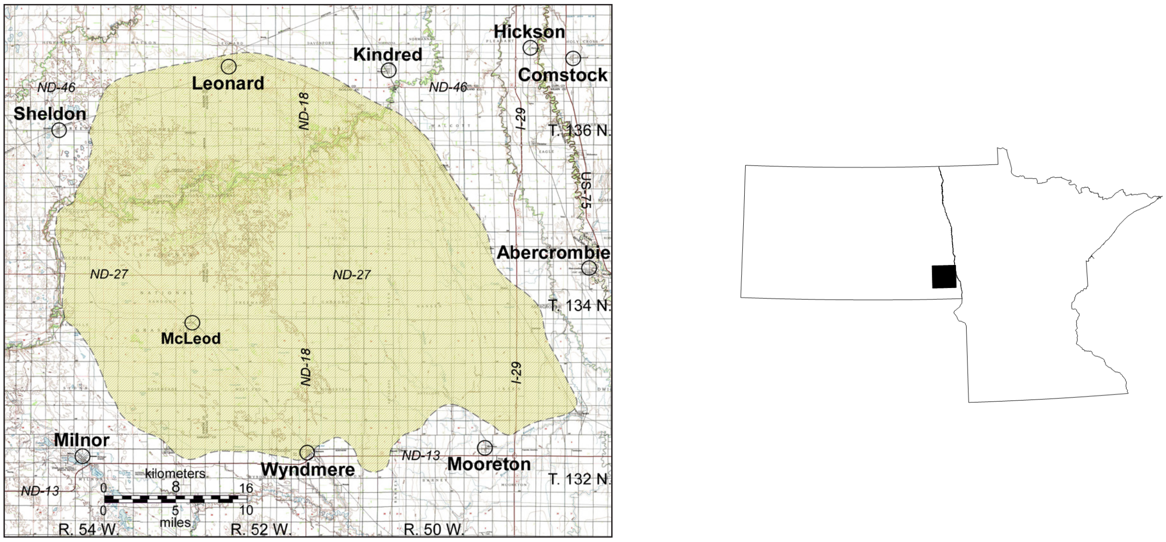


Figure A1.5. The Sheyenne Delta (hatched yellow area) is designated a reference area for the deltaic facies of the Sherack Formation. The topography of the map area is shown on the USGS 7.5-minute series quadrangles in North Dakota bounded by T. 132-137 N. and R. 48-54 W. McLeod, ND (T. 134 N., R. 53 W., sec. 25 bcbad; GPS: 47.620938, -96.387759) is located within the area.

The Sherack Formation either occurs at the surface or is overlain unconformably by the Oahe Formation (Clayton, Moran, and Bickley, 1976; Clayton and Moran, 1979). The contact between the Sherack Formation and the Oahe Formation is marked by a change from thinly laminated, inorganic clay to sediment of the Oahe Formation (peat, clay, sand and silt, or gravel facies).

HISTORICAL BACKGROUND

The offshore facies of the Sherack Formation was studied in borings in the Grand Forks area and outcrops along the Red Lake River (Harris, 1973) and later formally named by Harris, Moran, and Clayton (1974). Moran and others (1976) summarized the lithostratigraphy of the region. Arndt (1977) summarized the stratigraphy and engineering characteristics of subsurface materials penetrated by bridge borings along Interstate Highway 29 in North Dakota. He found the Sherack Formation to be present from the South Dakota border to the Canadian border with a significant thinning (or absence) in Traill County, North Dakota and Norman County, Minnesota where the Sherack overlies the Huot Formation. Regional lithostratigraphic units were characterized by Harris (1998).

REGIONAL EXTENT AND THICKNESS

The Sherack Formation extends throughout the central part of the Red River Valley in North Dakota and Minnesota (fig. A1.6). It extends at least as far north as Winnipeg, Manitoba. The formation is generally between 15 and 30 feet (4.6 and 9.1 meters) thick. The formation is thickest in Grand Forks County and thins northward.

DIFFERENTIATION FROM OTHER UNITS

The Sherack Formation can be differentiated from the Oahe Formation by the absence of disseminated organic matter, geologic setting, and stratigraphic position. Oahe Formation clay, silt, sand, and gravel are fluvial overbank and channel sediments overlying and incising the older Sherack Formation. Oahe Formation fine-grained silt and sand are eolian deposits that have modified and overlie the older Sherack Formation. The bedding in the Oahe Formation clay, silt, sand, and gravel facies is generally thicker and the boundaries between individual strata are much less distinct than in the Sherack Formation.

Differentiation of the Sherack offshore facies and Brenna Formations is generally not difficult because of the darker color, more obscure laminations, included white calcareous specks, and characteristic slickensided surfaces of the Brenna Formation. Where the Sherack Formation is thin enough that surface oxidation extends down into the Brenna Formation, their separation is more difficult.

In most of the Grand Forks area, the Sherack Formation is separated from the Wylie Formation by the Brenna and Falconer or Huot Members of the Forest River Formation, and there is no problem in their differentiation. Northeast of the Red Lake Falls area, laminated clay occurs at the

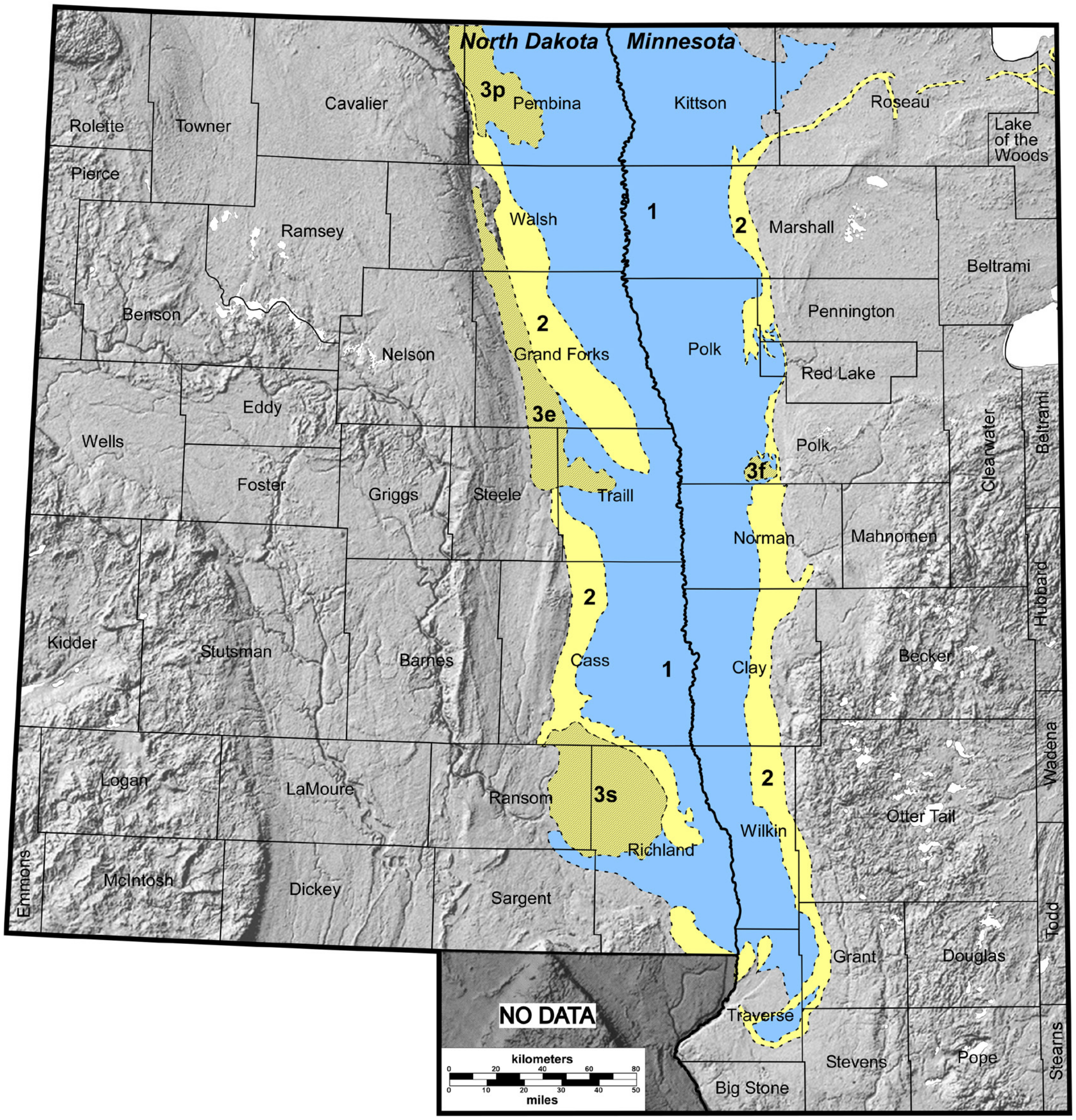
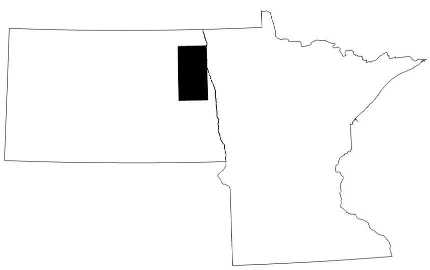


Figure A1.6. This figure shows the surface distribution of the Sherack Formation in the Red River Valley of North Dakota and Minnesota. The Sherack Formation is lake sediment deposited during the Emerson Phase of Glacial Lake Agassiz (figure 16) and consists of an offshore facies (1, the blue area), a nearshore facies (2, the yellow area), and a deltaic facies (the hatched yellow area; 3e the Elk Valley Delta, 3f the Fertile Delta, 3p the Pembina Delta, and 3s the Sheyenne Delta).

surface, beyond the limit of the Forest River Formation. In the absence of the intervening stratigraphic units it is not possible to tell from the characteristics of the clay whether it is part of the Sherack or Wylie Formation. This clay is included in the Wylie Formation because its lower contact is conformable with the Red Lake Falls Formation and it occurs at elevations greater than 1,000 feet (300 meters).

AGE

Deposition of the Sherack Formation began during the later part of the Moorhead Phase and continued throughout the Emerson and Morris Phases of Lake Agassiz. Two radiocarbon dates from the Snake Curve South section (fig. A1.3 and Appendix 2, p. xxx) of 9,530 ± 70 ^{14}C yr BP (about 10,900 cal yr BP) and 9,490 ± 70 ^{14}C yr BP (10,800 ± 200 cal yr BP) are from wood fragments sampled from the silty offshore unit near the



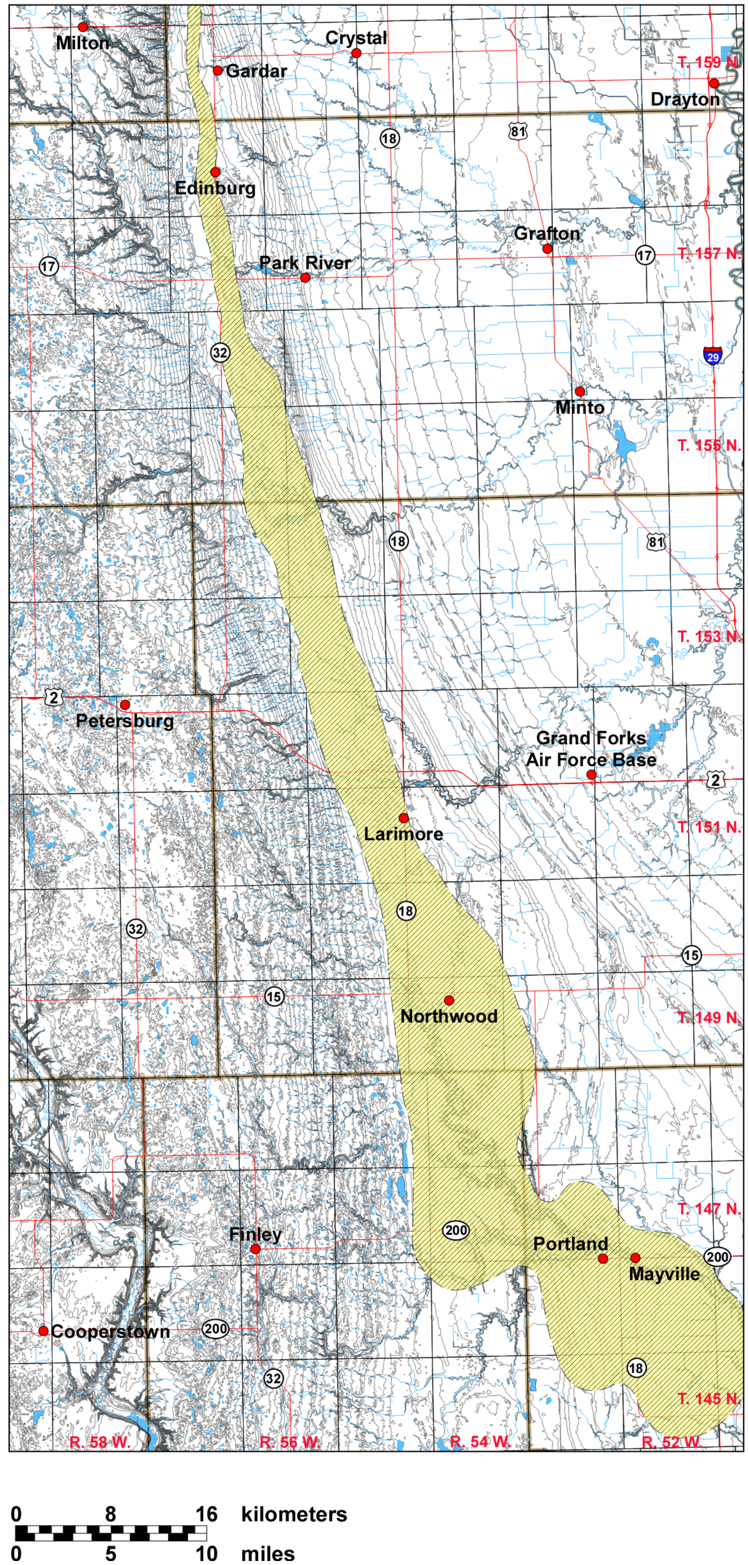


Figure A1.7. The Elk River Delta (hatched yellow field) is designated a reference area for the deltaic facies of the Sherack Formation. The topography of the map area is shown on the USGS 7.5-minute series quadrangles in North Dakota bounded approximately by (T. 145-159 N. and R. 52-58 W.). Northwood, North Dakota (T. 149 N., R. 54 W., sec. 09 dbdd; GPS: 47.734212, -97.565701) is located within the reference area.

top of the section (Fisher and others, 2008). These dates are consistent with OSL ages of 10.3 ± 0.2 and 10.7 ± 0.3 ka obtained from the Campbell beach at sites west and south of Fargo (Lepper and others, 2011, 2013).

CORRELATION

The Sherack Formation is the only Holocene Lake Agassiz sediment in the study area.

GENESIS

The Sherack Formation consists of offshore, nearshore, and deltaic sediment deposited during the Emerson Phase of Lake Agassiz. The organic silt and beds of peat that occur locally at the base of the unit were deposited in shallow water, in the back-swamp area of deltas, or along river flood plains.

POPLAR RIVER FORMATION

(Accepted)

NAME AND RANK

The Poplar River Formation is accepted as formally named by Harris, Moran, and Clayton, (1974) and modified by Arndt (1977). The source of the name is the Poplar River in Red Lake County, Minnesota, located on the USGS 7.5-minute series Brooks, MN quadrangle.

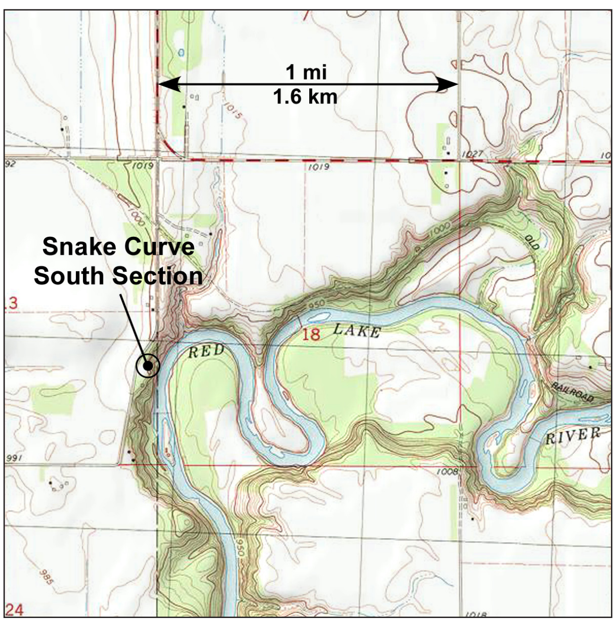
ORIGINAL TYPE AREA

The original type area of the Poplar River Formation is the Red Lake Falls area, Red Lake County, Minnesota, area (USGS 7.5-minute series Red Lake Falls, MN quadrangle).

ORIGINAL TYPE SECTION

The original type section of the Poplar River Formation is located very close to the north-south dividing line between two Public Land Survey System (PLSS) townships, and was originally considered to be in T. 151 N., R. 44 W., sec. 18 cdc. Recent GPS measurements, however, indicate a slightly more westerly position that places the site in the adjacent section. The corrected location is reported here.

The type section of the Poplar River Formation is the Snake Curve South Section on the Red Lake River, Louisville Township, Red Lake County, Minnesota. (T. 151N., R. 45 W., sec. 13 dadda; GPS: 47.895118, -96.352728; USGS 7.5-minute series Red Lake Falls, MN quadrangle; fig. A1.8; and Appendix 2, p. 228).



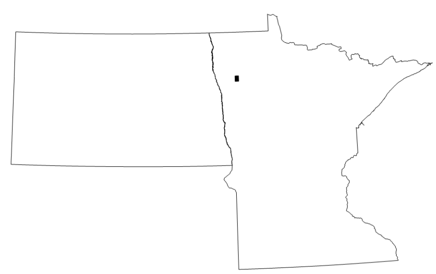


Figure A1.8. Snake Curve South Section on the Red Lake River is the original type section of the Poplar River Formation (Harris, Moran, and Clayton, 1974). It is the reference section for the West Fargo Member of the Poplar River Formation as defined by Arndt (1977). Twenty-five feet of the West Fargo Member are exposed underlying the Sherack Formation and overlying the Upper Red Lake Falls Member of the Red Lake Falls Formation at this location (T. 151 N., R. 45 W. sec. 13 dadda; GPS: 47.895118, -96.352728; USGS 7.5-minute series Red Lake Falls, MN quadrangle; Appendix 2, p. 228).

West Fargo Member of the Poplar River Formation

(Accepted)

NAME AND RANK

The West Fargo Member is accepted as formally named and defined by Arndt (1977) with minor modifications due to format changes and additional information. It is that part of the Poplar River Formation included in the original definition. It is named after the town of West Fargo, Cass County, North Dakota located on the USGS 7.5-minute series West Fargo North and West Fargo South, ND quadrangles.

TYPE AREA

Fargo, Cass County, North Dakota area located on the USGS 7.5-minute series Fargo North and Fargo South, MN – ND, and West Fargo North and West Fargo South, ND quadrangles (fig. A1.9).

TYPE SECTION

Composite of boring numbers 1, 2, and 3, F-2 Dormitory, Moorhead State College, Moorhead, Clay County, Minnesota, (T. 139 N., R. 48 W., sec. 8 dad; GPS: 46.865000, -96.755027; USGS 7.5-minute series Fargo South, MN – ND quadrangle; fig. A1.10; and Appendix 2, p. 209).

REFERENCE AREA

The reference area for the West Fargo Member of the Poplar River Formation is located between Fargo and Horace, Cass County, North Dakota (T. 138 N. and T. 139 N., R. 49 W.; USGS 7.5-minute series Fargo South, MN – ND, and West Fargo South, ND quadrangles; fig. A1.11). The surface expression of the West Fargo Member is a subtle ridge, a ‘compaction ridge’ that was formed by differential compaction of clayey lake sediment of the Sherack Formation and sandy channel sediment of the West Fargo Member of the Poplar River Formation (fig. A1.12).

REFERENCE SECTION

The reference section for West Fargo Member of the Poplar River Formation is Snake Curve South Section on the Red Lake River, Louisville Township, Red Lake County, Minnesota (T. 151N., R. 45 W., sec. 13 dadda; GPS: 47.895118, -96.352728; USGS 7.5-minute series Red Lake Falls, MN; USGS 7.5-minute series Red Lake Falls, MN quadrangle; fig. A1.8; and Appendix 2, p. 228).

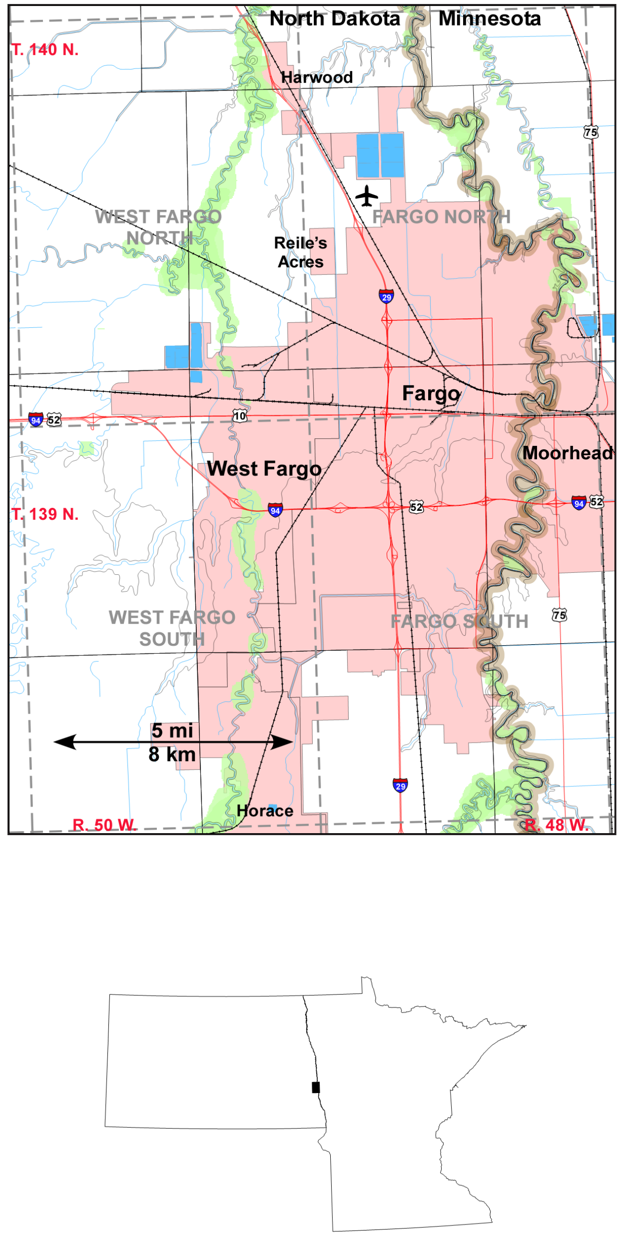
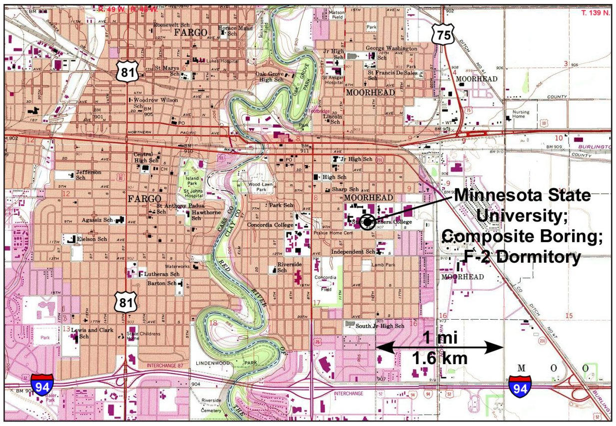


Figure A1.9. The Fargo, North Dakota area is the type area for the West Fargo Member of the Poplar River Formation (USGS 7.5-minute series Fargo North and Fargo South, MN – ND, and West Fargo North and West Fargo South, ND quadrangles; Fargo is located at GPS: 46.847568, -96.841060).



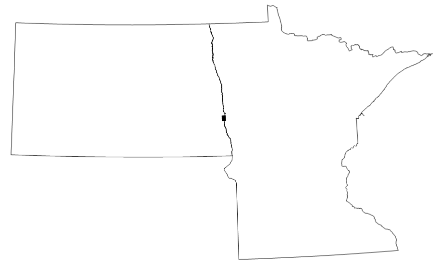


Figure A1.10. The type section for the West Fargo Member of the Poplar River Formation is a composite of borings number 1, 2, and 3; F-2 Dormitory, Minnesota State University Moorhead, Moorhead, Minnesota (T. 139 N., R. 48 W., sec. 8 dad; GPS: 46.865000, -96.755027; USGS 7.5-minute series Fargo South, MN – ND quadrangle; Appendix 2, p. 209).

LITHOLOGIC DESCRIPTION

The West Fargo Member of the Poplar River Formation consists largely of fine- to coarse-grained sand. Minor amounts of gravel occur near the base of the unit along the margins of the Red River Valley. Near Fargo, the West Fargo Member is predominantly composed of sand. Where it is present in Traill, Walsh, and Pembina Counties, it is composed mostly of silt and very fine sand. Testhole samples commonly show well-defined laminations. The sand and gravelly sand contain both large- and small-scale cross-bedding Harris and others, 1974). Mussel, small clam, and snail shells occur locally (Moran, Clayton, and Cvancara, 1971). Peat, wood, and other organic fragments are common in the West Fargo Member. Peat, up to 3 feet (1 meter) thick, was obtained from a testhole drilled in Traill County (T. 148 N., R. 49 W., sec. 33, cdd). In the silty parts of the unit, organic zones form conspicuous laminae that in places are as much as one inch (30 millimeters) thick.

DESCRIPTION OF BOUNDARIES

Except in Richland County, where it overlies the Argusville Formation, the West Fargo Member unconformably overlies the Brenna and Forest River Formations. The contact between it and these units is sharp and erosional. The West Fargo member conformably overlies the Harwood Member of the Poplar River Formation and has a distinct boundary with it. The West Fargo Member is conformably overlain by the Sherack Formation and the contact between the two is gradational. The boundary is placed where sand ceases to be a significant constituent and clay beds are abundant (Harris, Moran, and Clayton, 1974).

HISTORICAL BACKGROUND

The Poplar River Formation was named by Harris, Moran, and Clayton (1974) following detailed stratigraphic studies in the Red Lake River trench and Grand Forks, North Dakota area and a reconnaissance stratigraphic study in the northern Red River Valley. Arndt (1977) modified the definition of the Poplar River Formation to include two members (the West Fargo and Harwood Members) after extensive work that used data derived from bridge borings along the Interstate 29 corridor (central Red River Valley). He was able to refine the understanding of the lithology, stratigraphy, extent, and engineering characteristics of lithostratigraphic units in the southern part of the Lake Agassiz basin. Arndt's study area extended from the South Dakota border to the Canadian border. His units are presented here with minor modification.

REGIONAL EXTENT AND THICKNESS

The West Fargo Member of the Poplar River Formation occurs throughout the Red River Valley, but it is not laterally extensive. It occurs as narrow, trough-shaped, linear bodies, generally a few hundred feet wide that are inset into the top of the Brenna, Forest River, and Argusville Formations. The West Fargo Member is generally only a few feet to a few tens of feet thick.

The presence of the West Fargo Member in the subsurface is commonly indicated on the surface by the presence of a low ridge (compaction ridge) that can generally be traced along the subcrop of this unit (best seen on aerial photographs). Some compaction ridges that have been previously identified include the Sheyenne, West Fargo,

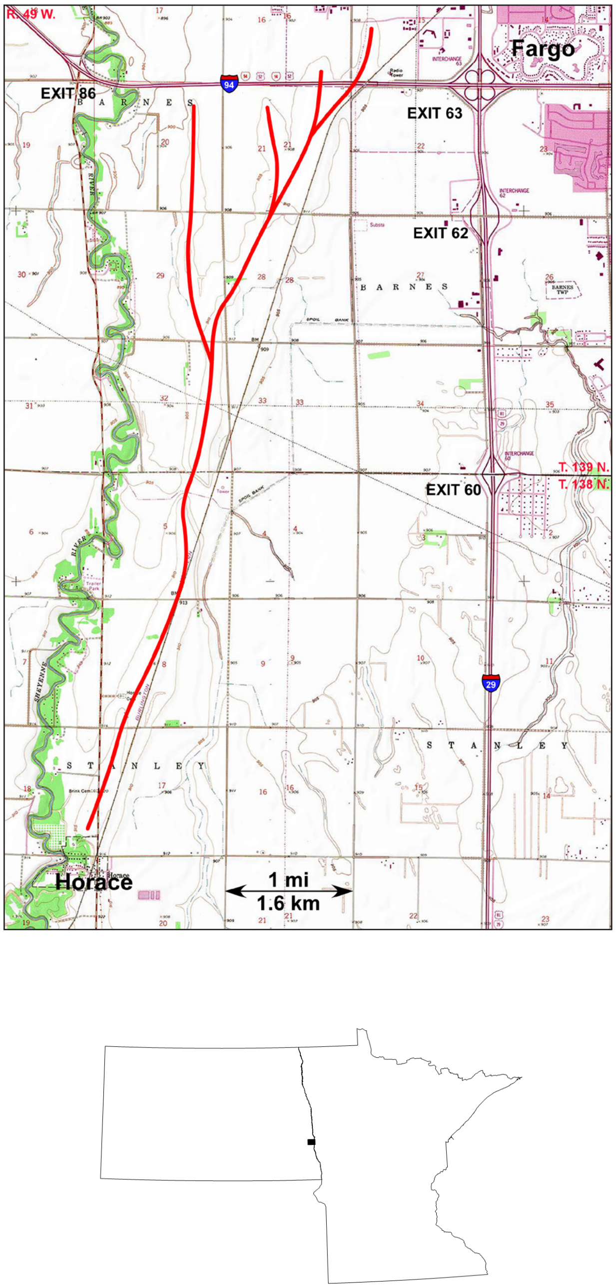


Figure A1.11. The reference area for the West Fargo Member of the Poplar River Formation is located between Fargo and Horace, North Dakota (T. 138 N. and T. 139 N., R. 49 W.; USGS 7.5-minute series Fargo South, MN – ND, and West Fargo South, ND quadrangles). The surface expression of the West Fargo Member is a subtle ridge shown by the red line. The ridge is a ‘compaction ridge’ that formed due to differential compaction of clayey lake sediment of the Sherack Formation and sandy channel sediment of the West Fargo Member of the Poplar River Formation. Horace, North Dakota is located at the south end of the compaction ridge (T. 138 N., R. 49 W., sec. 19 aaa; GPS: 46.760298, -96.90421; USGS 7.5-minute series West Fargo South, ND quadrangle).

Fargo, and Maple Ridges in Cass County (Klausing, 1968); Kelso Ridge in Traill County (Bluemle, 1967), and the Horgan Ridge in Pembina County.

Mapped occurrences of compaction ridges associated with the West Fargo Member of the Poplar River Formation are shown in figure A1.13. No detailed mapping has been done in Minnesota north of the northern part of Polk County. Consequently no compaction ridges are shown in that area.

DIFFERENTIATION FROM OTHER UNITS

The West Fargo Member is easily distinguished by its lithologic characteristics, presence of organic layers, and stratigraphic position.

The West Fargo Member may be confused with the sand and gravel of tunnel valley channels that are present at and near the surface in the Red River Valley. Tunnel valley deposits are generally wider, 0.5 to 1.0 mile (0.8 to 1.6 kilometers) wide; may form subtle ridges at the surface; and can be up to 300 feet (91 meters) thick (Harris and others, 1995, 1996, and 1998). Tunnel valley deposits tend to be linear, are associated with ice margins, and are generally oriented at right angles to the associated ice margins (fig. A1.14).

Sand and gravel deposits of the Buffalo Aquifer (Harris and others, 1996) extend downward more than 300 feet (91 meters) through the clay of the Wylie, Brenna, and Red Lake Falls Formations and into the underlying bedrock. Tunnel valley deposits can be important aquifers. The Buffalo aquifer and the Hillsboro aquifer are examples that produce water for the cities of Moorhead, MN and Hillsboro, ND. The exceptional thickness and coarse grain size of these deposits suggests that they were deposited by high-energy streams carrying considerably more water and sediment than those that deposited the West Fargo Member of the Poplar River Formation.

Tunnel valley deposits are older than the West Fargo Member of the Poplar River Formation and are associated with the ice marginal positions. In the central Red River Valley they are associated with ice that deposited the Red Lake Falls Formation, Forest River, and Gardar Formations in the Red River Valley. Tunnel valleys also occur along the lateral margins of ice sheets and have been mapped along the up-slope margins of ice streams that occupied the Red River Valley. It is beyond the scope of this document to discuss the various theories explaining the formation of these features (see: Winter, 1967; Wright, 1973; Patterson, 1994; Harris and others, 1995, 1996, and 1998; Quin, 1998).

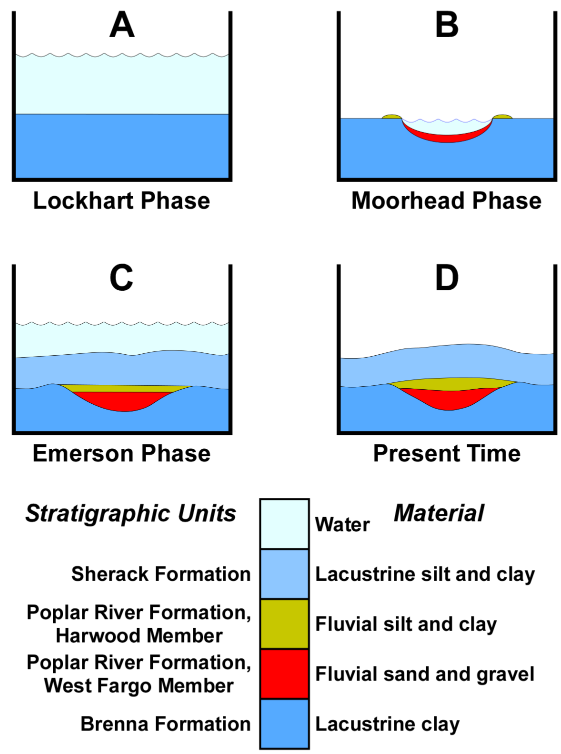


Figure A1.12. Steps involved in developing a compaction ridge in the Lake Agassiz basin: A – flooding of the lake and deposition of lake sediment during the Lockhart Phase; B – draining of the lake, establishing subaerial drainage across the lake plain, and deposition of channel and overbank sediment during the Moorhead Phase; C – flooding of the lake and deposition of lake sediment during the Emerson Phase; D – final draining of the lake, dewatering and compaction of the clay-rich lake sediment, and development of subtle ridges over the buried channel sediment (modified from Arndt, 1977).

AGE

Most of the Poplar River Formation was deposited on the unconformity at the upper surface of the Brenna, Forest River, and Argusville Formations. It is largely latest Wisconsinan in age and was deposited between about 10,600 and 9,400 ^{14}C yr BP (about 12,600 and 10,600 cal yr BP), during the low-water Moorhead Phase of Lake Agassiz (fig. 9). The upper part of the formation is locally very earliest Holocene. A conifer log collected near the base of the formation at the Snake Curve South section (fig. A1.8 and Appendix 2, p. xxx) was radiocarbon dated at 9,890 ± 150 ^{14}C yr BP (about 11,400 cal yr BP; Moran and others, 1971). Wood from peat overlain by lake sediment (Sherack Formation) yielded radiocarbon ages of 9,930 ± 280 ^{14}C yr BP (about 11,500 cal yr BP; Rubin and Alexander, 1958; McAndrews, 1967) and 9,900 ± 400 ^{14}C yr BP (11,450 cal yr BP; Brophy, 1967; McAndrews, 1967). Populus (poplar) wood and leaves from the base, middle and top of a rhythmite sequence in the lower part of the formation at the Trollwood Park site in Fargo yielded ages of 10,230 ± 80, 10,040 ± 120, and 9,920 ± 60 ^{14}C yr BP (11,975 ± 615, 11,730 ± 530, 11,410 ± 220 cal yr BP) respectively (Yansa and Ashworth, 2005). Radiocarbon ages ranging from 10,470 ± 75 to 10,000 ± 70 ^{14}C yr BP (12,400 ± 290 to 11,510 ± 260 cal yr BP) were obtained from wood and other organic material at the base of Moorhead Phase littoral deposits below the Ojata Beach in central Grand Forks County. The dates are consistent with an OSL age of 11.0 ± 0.3 ka from the overlying beach sand (Fisher and others, 2008).

CORRELATION

The West Fargo Member of the Poplar River Formation is correlative with sediment deposited in tributaries of the Red River Valley trunk stream at the beginning of the Holocene.

GENESIS

The West Fargo Member of the Poplar River Formation consists of fluvial channel sediment and some near-channel overbank sediment. The surface expression of the West Fargo Member as compaction ridges is due to differential compaction. As the clayey lake sediment of the Sherack Formation dries, the loss of moisture causes a significant reduction in pore space and it becomes denser (compact). A similar process takes place in the sandy channel deposits of the West Fargo Member of the Poplar River Formation but with little to no compaction (fig. A1.12). The result is a topographic inversion: the river channel becomes a ridge.

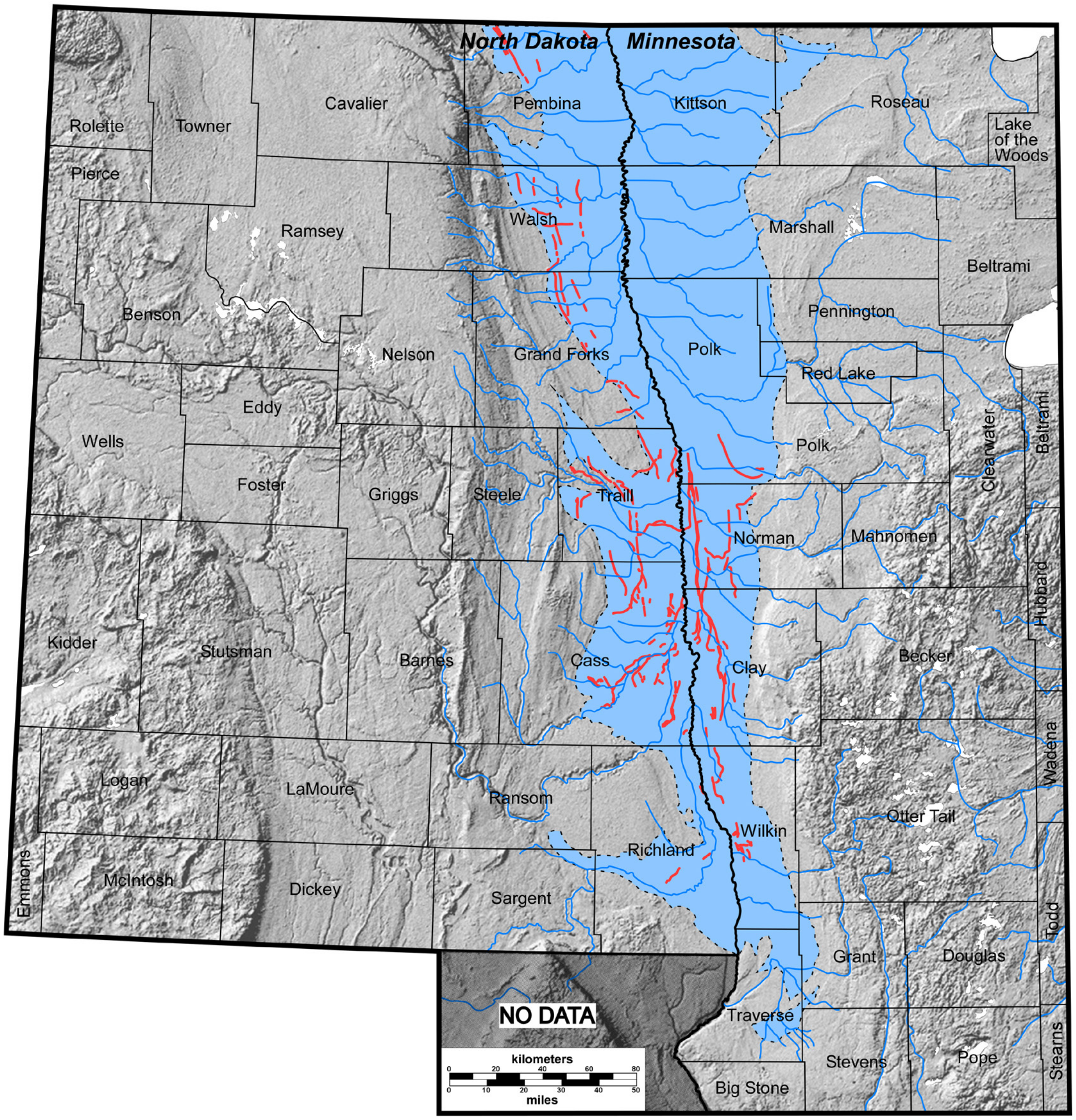


Figure A1.13. Mapped occurrences of compaction ridges associated with the West Fargo Member of the Poplar River Formation are shown as red lines. Compaction ridges only form where the West Fargo Member is overlain by the Sherack Formation (blue field). The path of compaction ridges tends to be subparallel to modern rivers (light blue lines). Compaction ridges are not shown in Minnesota north of southern Polk County because no recent Quaternary mapping has been done there.

Harwood Member of the Poplar River Formation

(Accepted)

NAME AND RANK

The Harwood Member of the Poplar River Formation is accepted as formally named and defined by Arndt (1977) with minor modifications due to format changes and additional information. It is named after the village of Harwood, Cass County, North Dakota, located on the USGS 7.5-minute series West Fargo North, ND quadrangle.

TYPE AREA

The type area Northern Cass County, North Dakota located on the USGS 1:100,000-scale county map series Cass County, ND map.

TYPE SECTION

North Dakota Geological Survey boring T-18 in Traill County, North Dakota (T. 147 N., R. 49 W., sec. 11 ccc; GPS: 47.555707, -96.876658; USGS 7.5-minute series Climax SW, ND quadrangle; figure A1.15; and Appendix 2, p. 221).

REFERENCE AREA

The Harwood Member of the Poplar River Formation is found extensively throughout Cass County, North Dakota, area but no reference sections are designated.

LITHOLOGIC DESCRIPTION

The Harwood Member of the Poplar River Formation is composed mostly of clay. It has a mealy structure (like cooked oatmeal mush) and color ranges from gray (5Y 5/1 and 4/1) to a mottled dark grayish brown (2.5Y 4/2). It is stiff and brittle and is difficult to break when fresh. It is noticeably more difficult to drill through this member than either the overlying or underlying units. Standard-penetration tests performed in conjunction with engineering-test boring range between 8 (2.4) and 18 (5.5) blows per foot (meter).

DESCRIPTION OF BOUNDARIES

Except in Richland County, where it overlies the Argusville Formation, the Harwood Member unconformably overlies the Brenna Formation. The contact between it and these two units is sharp and erosional. The Harwood Member is conformably overlain by the West Fargo Member of the Poplar River Formation and has a distinct boundary with it. The Harwood Member is unconformably overlain by the Sherack Formation.

HISTORICAL BACKGROUND

The Poplar River Formation was named by Harris, Moran, and Clayton (1974) following detailed stratigraphic studies in the Red Lake River trench and Grand Forks, North Dakota area and a reconnaissance stratigraphic study in the northern Red River Valley. Arndt (1977) modified the definition of the Poplar River Formation to include two members (the West Fargo and Harwood Members) after extensive work that used data derived from bridge borings along the Interstate 29 corridor (central Red River Valley). He was able to refine our understanding of the lithology, stratigraphy, extent, and engineering characteristics of lithostratigraphic units in the southern part of the Lake Agassiz basin. Arndt's study area extended from the South Dakota border to the Canadian border. His units are presented here with minor modification.

REGIONAL EXTENT AND THICKNESS

The Harwood Member of the Poplar River Formation occurs throughout the Red River Valley, but it is not laterally extensive. It occurs as relatively narrow, sub-linear bodies, generally a few hundred feet wide on top of the Brenna, Forest River, and Argusville Formations. The Harwood Member occurs in association with the West Fargo Member (fig. A1.12) and is usually not more than 6 feet (1.8 meters) thick.

DIFFERENTIATION FROM OTHER UNITS

The Harwood Member is easily recognized by its distinct mealy structure, stratigraphic position, and resistance to penetration.

AGE

Most of the Poplar River Formation was deposited on the unconformity at the upper surface of the Brenna, Forest River, and Argusville Formations. It is largely latest Wisconsinan in age and was deposited between 10,700 and 9,500 ^{14}C yr BP, during the low-water Moorhead Phase of Lake Agassiz. The upper part of the formation is locally very earliest Holocene. A conifer log collected near the base of the formation at the Snake Curve South section (fig. A1.8 and Appendix 2, p. 228) was radiocarbon dated at 9,890 ± 150 ^{14}C yr BP (Moran and others, 1971). Wood from peat overlain by lake sediment (Sherack Formation) yielded radiocarbon ages of 9,930 ± 280 ^{14}C yr BP (Rubin

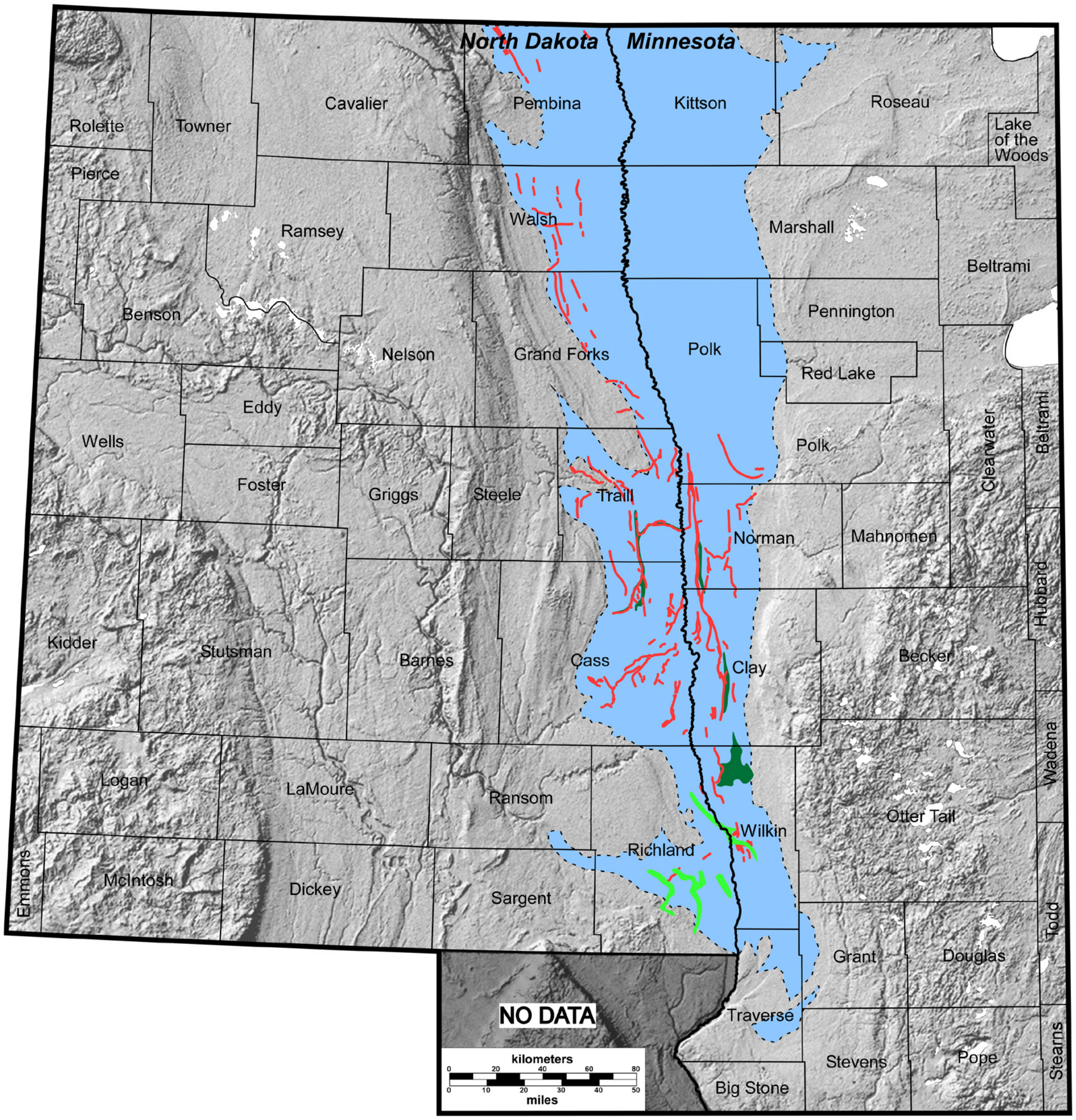


Figure A1.14. Mapped occurrences of compaction ridges associated with the West Fargo Member of the Poplar River Formation are shown as red lines. The extent of the overlying Sherack Formation is shown as the blue field. Tunnel valleys are shown in green. The dark green lines are tunnel valleys associated with the ice marginal positions (IMP) of the upper and lower Red Lake Falls Members of the Red Lake Falls Formation and the Forest River Formation. Light green lines depict older, deeper tunnel valleys associated with the Gardar Formation. Many of the tunnel valleys shown in dark green have surface expressions that may be confused with compaction ridges.

and Alexander, 1958; McAndrews, 1967) and 9,900 ± 400 ^{14}C yr BP (Brophy, 1967; McAndrews, 1967). Populus (poplar) wood and leaves from the base, middle and top of a rhythmite sequence in the lower part of the formation at the Trollwood Park site in Fargo yielded ages of 10,230 ± 80, 10,040 ± 120, and 9,920 ± 60 ^{14}C yr BP (11,975 ± 615, 11,730 ± 530, 11,410 ± 220 cal yr BP) respectively (Yansa and Ashworth, 2005). Radiocarbon ages ranging from 10,470 ± 75 to 10,000 ± 70 ^{14}C yr BP (12,400 ± 290 to 11,510 ± 260 cal yr BP) were obtained from wood and other organic material at the base of Moorhead Phase littoral deposits below the Ojata Beach in central Grand Forks County. The dates are consistent with an OSL age of 11.0 ± 0.3 ka from the overlying beach sand (Fisher and others, 2008).

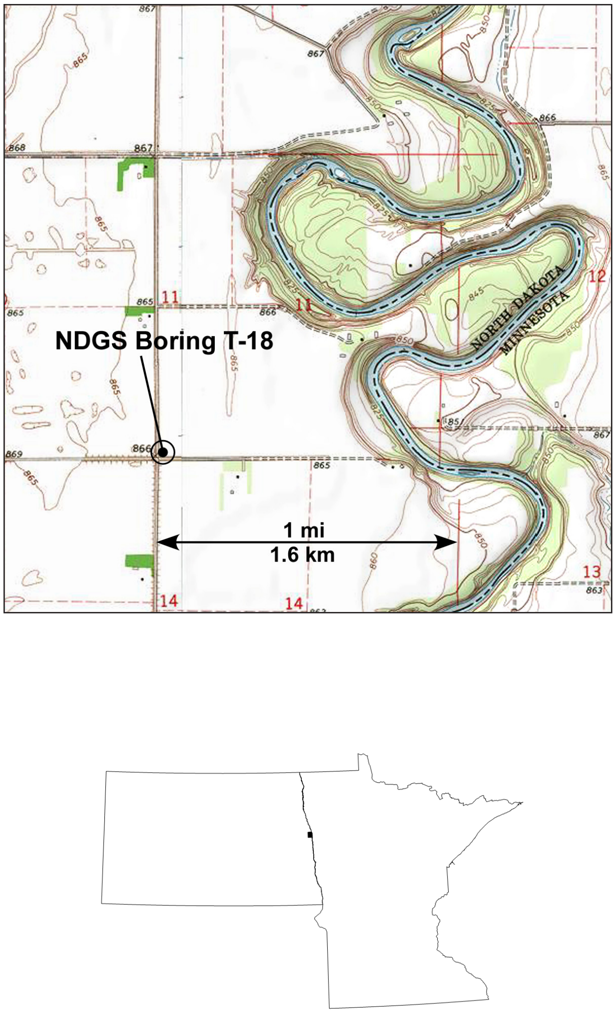


Figure A1.15. The type section for the Harwood Member of the Poplar River Formation is North Dakota Geological Survey boring T-18 (T. 147 N., R. 49 W., sec. 11 ccc; GPS: 47.555707, -96.876658; USGS 7.5-minute series Climax SW, ND quadrangle; Appendix 2, p. 221).

CORRELATION

The Harwood Member of the Poplar River Formation is correlative with sediment deposited in tributaries of the Red River Valley trunk stream at the beginning of the Holocene.

GENESIS

Last (1974) includes the Harwood Member in the upper part of his unit 2. Rominger and Rutledge (1952) include it in their unit 4. They interpreted this unit to be lacustrine sediment that was desiccated during a low-water phase of Lake Agassiz. Arndt (1977) concluded that the Harwood Member was fluvial-overbank sediment based on 1) its limited distribution and common occurrence with the West Fargo Member, 2) it is sediment associated with the fluvial-channel sediment of the West Fargo Member, and 3) its structure is similar to that of alluvium associated with present-day rivers in the Red River Valley. We agree with Arndt's interpretation.

BRENNA FORMATION

(Accepted)

NAME AND RANK

The Brenna Formation is accepted here as formally named by Harris, Clayton, and Moran (1974) with minor modifications due to format changes and additional information. The source of the name is Brenna Township, Grand Forks County, North Dakota.

TYPE AREA

The type area for the Brenna Formation is the Grand Forks, Grand Forks County, North Dakota area (fig. A1.16).

TYPE SECTION

The type section of the Brenna Formation is Boring No. 3, Witmer Hall, University of North Dakota, Grand Forks, Grand Forks County, North Dakota (T. 151 N., R. 50 W., sec. 5 dddb; GPS: 47.920182, -97.068709; USGS 7.5-minute series Grand Forks, MN – ND quadrangle; fig. A1.16; and Appendix 2, p. 230).

REFERENCE SECTIONS

There are five reference sections for the Brenna Formation:

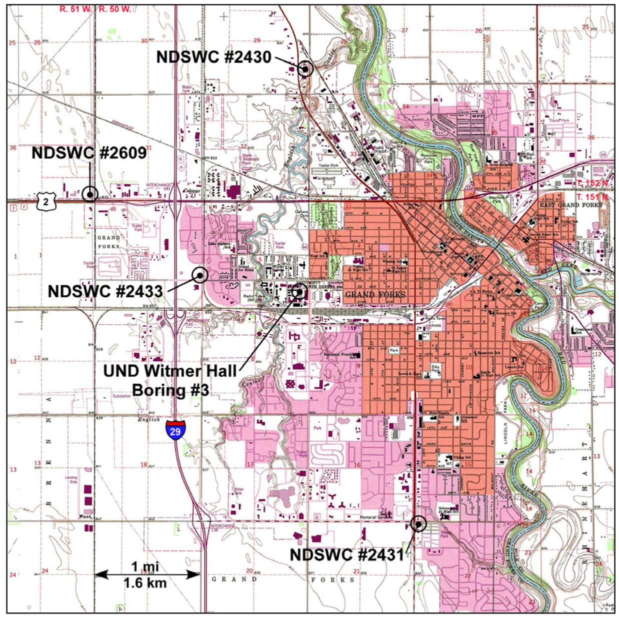
North Dakota State Water Commission (NDSWC) Testhole 2430 (T. 152 N., R. 50 W., sec. 29 dda; GPS: 47.951190, -97.067115; USGS 7.5-minute series Grand Forks, MN – ND quadrangle; fig. A1.16; and Appendix 2, p. 235).

NDSWC Testhole 2431 (T. 151 N., R. 50 W., sec. 22 bbb; GPS: 47.889183, -97.044831; USGS 7.5-minute series Grand Forks, MN – ND quadrangle; fig. A1.16; and Appendix 2, p. 233).

NDSWC Testhole 2433 (T. 151 N., R. 50 W., sec. 6 dad; GPS: 47.922602, -97.088630; USGS 7.5-minute series Grand Forks, MN – ND quadrangle; fig. A1.16; and Appendix 2, p. 231).

NDSWC Testhole 2609 (T. 152 N., R. 51 W., sec. 36 ddd; GPS: 47.933499, -97.110392; USGS 7.5-minute series Grand Forks, MN – ND quadrangle; fig. A1.16; and Appendix 2, p. 237).

U. S. Army Corps of Engineers Boring 68-12M Oslo Dike, at Oslo, Minnesota (T155 N, R. 50 W., sec. 31 dda; GPS: 48.198684, -97.130430; USGS 7.5-minute series Oslo, MN – ND quadrangle; fig. A1.17; and Appendix 2, p. 241).



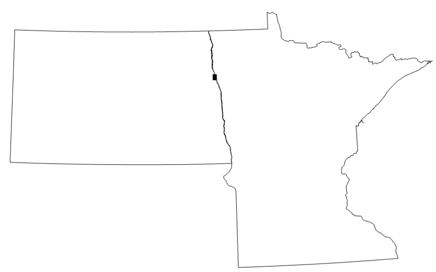
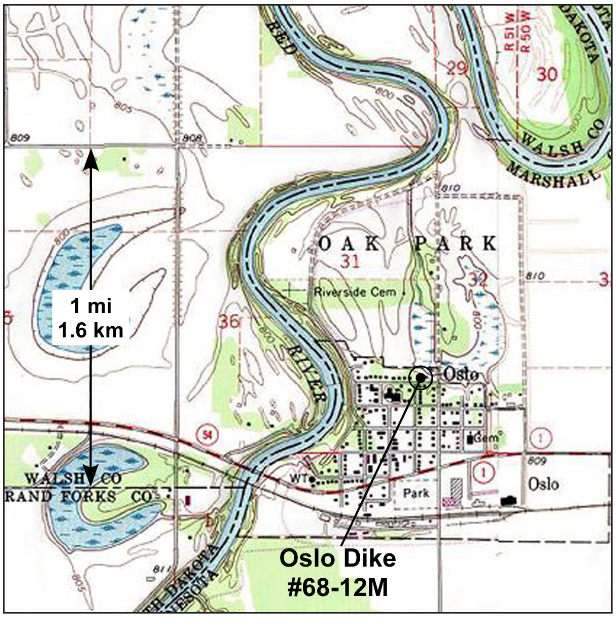


Figure A1.16. The type area for the Brenna Formation is the Grand Forks, Grand Forks County, North Dakota area. Shown are the locations of the Brenna Formation type section and four reference sections. All are located in Grand Forks, Grand Forks County, North Dakota and on the USGS 7.5-minute series Grand Forks, MN – ND quadrangle. The type section is Boring No. 3, Witmer Hall, University of North Dakota (T. 151 N., R. 50 W., sec. 5 dddb; GPS: 47.920182, -97.068709; Appendix 2, p. 230). The four reference sections are NDSWC Testhole 2430 (T. 152 N., R. 50 W., sec. 29 dda; GPS: 47.951190, -97.067115; Appendix 2, p. 235); NDSWC Testhole 2431 (T. 151 N., R. 50 W., sec. 22 bbb; GPS: 47.889183, -97.044831; Appendix 2, p. 233); NDSWC Testhole 2433 (T. 151 N., R. 50 W., sec. 6 dad; GPS: 47.922602, -97.088630; Appendix 2, p. 237); and NDSWC Testhole 2609 (T. 152 N., R. 51 W., sec. 36 ddd; GPS: 47.933499, -97.110392; Appendix 2, p. 237).



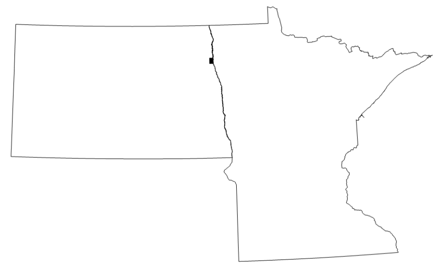


Figure A1.17. The United States Corps of Engineers Oslo Dike Boring 68-12M is a reference section of the Brenna Formation (T155 N, R. 50 W., sec. 31 dda; GPS: 48.198684, -97.130430; Appendix 2, p. 241). The topography of the map area is shown on the USGS 7.5-minute series Oslo, MN – ND quadrangle.

LITHOLOGIC DESCRIPTION

The Brenna Formation consists of clay that is dark gray to black (5Y 4/1 to 5Y 2/1) when wet. It is generally obscurely laminated to unbedded but locally contains more conspicuously laminated beds. It contains small, white, silty, calcareous fragments that range in size from 0.04 to 1.2 inches (1 to 30 millimeters). Pebbles of hard carbonate and crystalline rocks occur in places within the unit. The clay is highly plastic and has a characteristic slick appearance. It is nearly impossible to break a sample of this material without it shearing to produce a slickensided surface. The clay is very weak and generally has a shear strength of less than 500 psf (Moran, 1972). It has a high liquid limit and water content (Rominger and Rutledge, 1952; Moran, 1972). Except for the calcareous white flecks, the formation contains sand-sized material only near its base.

DESCRIPTION OF BOUNDARIES

North of the Edinburg moraine the Brenna Formation overlies the unbedded silty loam of the Falconer Member of the Forest River Formation (figs. 6 and 12). The contact of the Brenna Formation with the Falconer has not been observed, but it is believed to be conformable and gradational. Sand is present in the lower part of the Brenna Formation and decreases upward in abundance. Similarly, the clay content of the Falconer Member of the Forest River Formation increases upward toward the contact. South of the Edinburg moraine the Brenna overlies the clay of the Argusville Formation.

The Brenna is unconformably overlain by the light gray, thinly laminated clay of the Sherack Formation and by the Poplar River Formation, and conformably overlies the Falconer Member of the Forest River Formation and the Argusville Formation. Where the Brenna Formation overlies the Falconer Member of the Forest River Formation the contact is gradational and is commonly indicated by a transition zone marked by an increase in sand content and pebble-loam inclusions (Arndt, 1977). The upper 5 to 10 feet (1.5 to 3 meters) of the Brenna Formation is generally considerably harder, has greater shear strength, lower water content, and lower liquid limit than the remainder of the formation (Rominger and Rutledge, 1952; Moran, 1972). Rominger and Rutledge (1952) ascribed this change in the properties of the unit to desiccation during sub-aerial exposure.

HISTORICAL BACKGROUND

The Brenna Formation was defined from subsurface borings near Grand Forks (Harris and others, 1974). It was originally recognized as far south as northern Traill County, but Arndt (1977) extended the unit to just south of the Cass-Richland County line. Arndt's study used engineering criteria to differentiate between Lake Agassiz sediments and at this time his work remains a primary resource for defining Lake Agassiz stratigraphy.

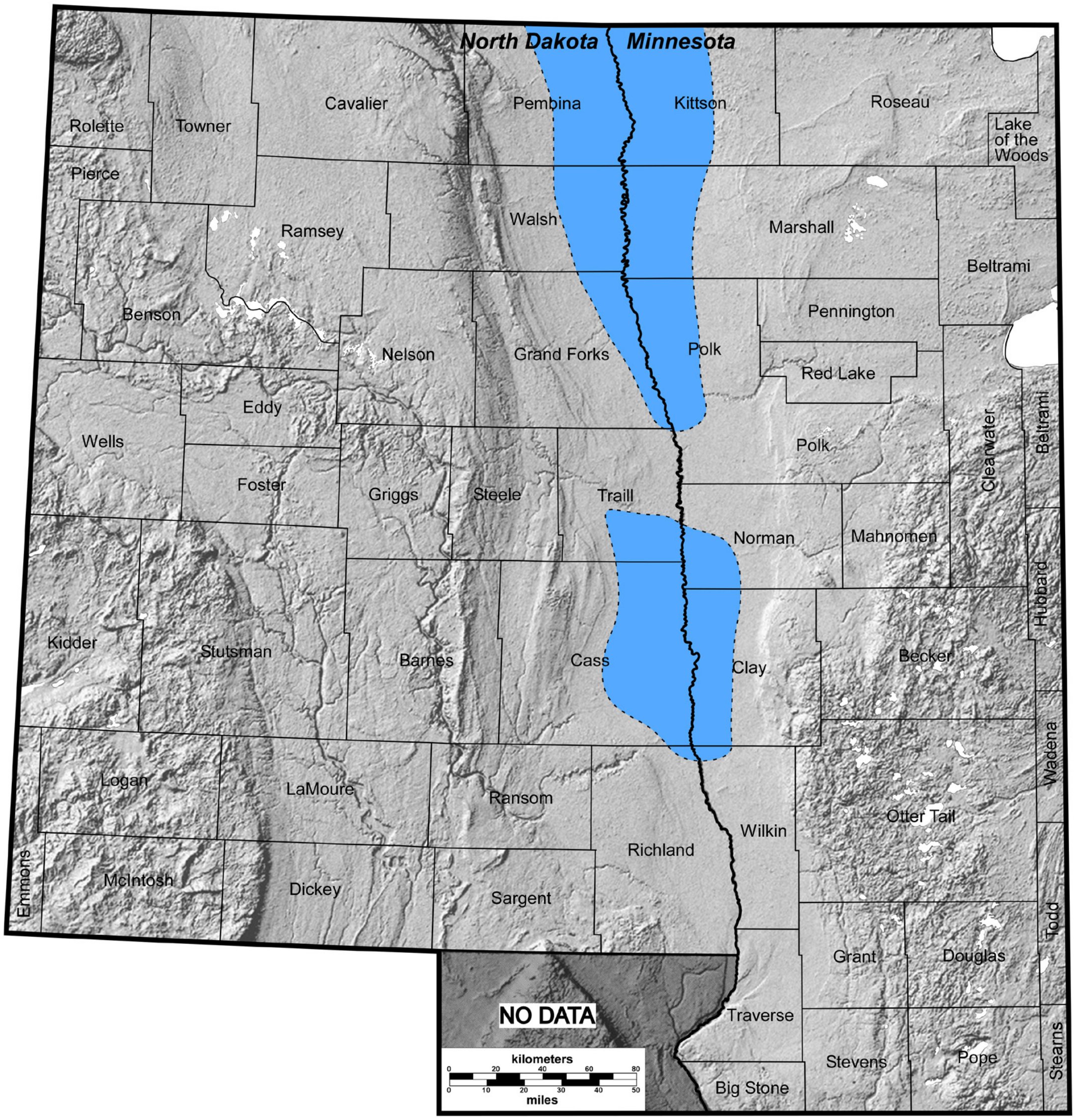


Figure A1.18. The blue shaded field shows the approximate subsurface occurrence of the Brenna Formation in the Red River Valley of North Dakota and Minnesota. The Brenna Formation is offshore lake sediment deposited during the Lockhart Phase of Glacial Lake Agassiz.

REGIONAL EXTENT AND THICKNESS

The Brenna Formation has been traced from its southern edge in northern Richland County and Wilkin County Minnesota (Arndt, 1977), as far north as the international boundary (fig. A1.18). It is absent in the Hillsboro area, Traill County, and Polk and Norman Counties, Minnesota near the Edinburg moraine, where the glacial sediment of the Forest River Formation is at the surface. It is believed to extend at least as far north as Winnipeg, Manitoba (fig. 15). The Brenna Formation occurs only in the central axis of the Red River Valley. It is overlain by the Sherack and Poplar River Formations and is exposed only in artificial excavations and a few river banks throughout the area. The Brenna Formation is as much as 150 feet (46 meters) thick in Pembina County.

DIFFERENTIATION FROM OTHER UNITS

The Brenna Formation looks very much like the Huot Member of the Forest River Formation, but may be differentiated from it by the greater sand and pebble content of the Huot and the presence of obscure laminations in the Brenna. The Brenna Formation is separated from the Wylie Formation by the pebble-loam of the Falconer Member of the Forest River Formation. The light gray color, the laminations, and the absence of the small white specks in the Sherack Formation differentiate it from the Brenna Formation. The Brenna Formation can be differentiated from the Falconer Member by the light gray color, complete lack of bedding, higher sand and pebble content, greater hardness, and greater strength of the latter. The Brenna Formation is difficult to differentiate from the Argusville Formation: they are both lacustrine sediment deposited in the Lake Agassiz basin. The Argusville is older, similar in color, composition, and structure; it was deposited south of the Edinburg moraine as the ice that deposited the Forest River Formation advanced into the Lake basin (fig. 6).

AGE

The Brenna Formation was deposited during the Lockhart Phase of Lake Agassiz, in latest Wisconsinan time. In the north-central part of the Red River Valley, deposition of the Brenna Formation continued throughout the early part of the Moorhead Phase (fig. 9). There are no radiocarbon dates directly associated with the Brenna Formation but OSL ages from the Herman Beach, which began forming early in the Lockhart Phase, yielded an average of 14.1 ± 0.3 ka. This age is consistent with existing chronologies for the deglacial history of the Lake Agassiz basin (Lepper and others, 2011, 2013).

CORRELATION

The Brenna Formation may correlate with unit 3 of Moran (1972) and units 1, 2, and 3 of Rominger and Rutledge (1952), and units 1 and 2 of Last (1974). The correlations made by Arndt (1977) are accepted here.

GENESIS

The Brenna Formation consists of clay that was deposited in deep water during the Lockhart Phase of Lake Agassiz. It is probable that some glacial mud-flow sediment is included in the lower few feet of the formation.

FOREST RIVER FORMATION

(New)

NAME AND RANK

The Forest River Formation is named here. It is named after the town of Forest River in Walsh County, North Dakota, located on the USGS 7.5-minute series, ND quadrangle.

This formation has two members: the Huot Member and the Falconer Member; they are lateral equivalents.

Huot Member of the Forest River Formation

(Revised)

NAME AND RANK

The Huot Member is modified in rank from formation to Huot Member of the Forest River Formation. The description of the unit, as described by Harris, Clayton, and Moran (1974), is accepted with minor modifications owing to format changes and additional information. The source of the name is the hamlet of Huot, Red Lake County, Minnesota, located on the USGS 7.5-minute series Gentilly, MN quadrangle.

TYPE SECTION

The type section of the Huot Member of the Forest River Formation is the Clearwater Section (N-113, CW-1) on the Clearwater River, Red Lake Falls Township, Red Lake County, Minnesota (T. 151 N., R. 44 W., sec. 22 aabda; GPS: 47.889269, -96.270801; USGS 7.5-minute series Red Lake Falls, MN quadrangle; fig. A1.19 and Appendix 2, p. 227).

REFERENCE SECTIONS

A reference section for the Huot Member of the Forest River Formation the Snake Curve North Section (N-1018, D-12) on the Red Lake River, Red Lake Falls Township, Red Lake County, Minnesota (T. 151 N., R. 44 W., sec. 18 cbaac; GPS: 47.897438, -96.349475; USGS 7.5-minute series Red Lake Falls, MN quadrangle; fig. A1.20 and Appendix 2, p. 225).

A second reference section is the Schist Cliff Section (E-6) on the Red Lake River, Louisville Township, Red Lake County, Minnesota (T. 151 N., R. 45 W., sec. 26 bbbac; GPS: 47.876108, -96.394678; USGS 7.5-minute series Dorothy, MN quadrangle; fig. A1.21 and Appendix 2, p. 229).

LITHOLOGIC DESCRIPTION

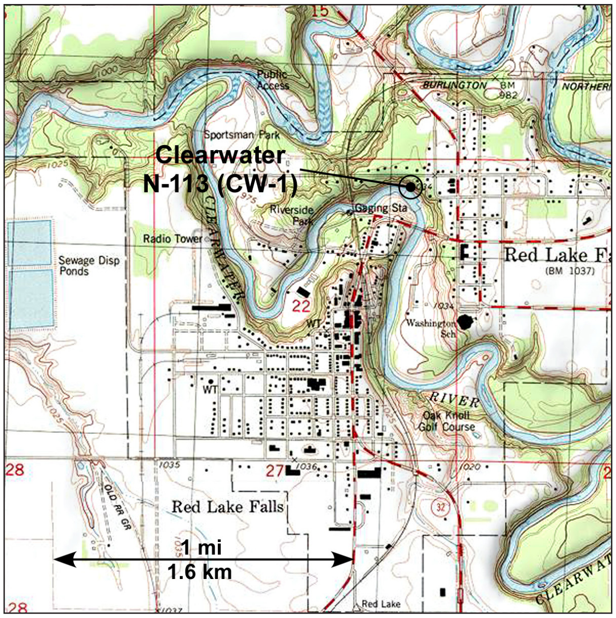
The Huot Member is unbedded slightly pebbly clay. It is gray (5Y 5/1) when dry and very dark grayish brown (2.5Y 3/2) when wet. The member is very hard and blocky when dry and very plastic when moist. The high clay content of the Huot Member causes it to slump in outcrop, so most exposures are poor. Slickensides typically occur on shear faces in the Huot Member.

The Huot Member contains limestone pebbles and cobbles and numerous tan, chalky inclusions that range in size from less than 2 mm to more than 1 cm. A few pebbles of igneous rock are also present. Locally, boulder-size inclusions of highly calcareous, pale-yellow glacial sediment are present.

One hundred samples of the Huot Member averaged 7 percent sand, 23 percent silt, and 70 percent clay (fig. A1.22A). The very coarse sand fraction (1-2 mm) contains 45 percent igneous and metamorphic rock types, 51 percent limestone, and dolostone, and 5 percent shale (fig. A1.22B).

DESCRIPTION OF BOUNDARIES

The lower contact of the Huot Member with the Wylie Formation is gradually interbedded to diffuse and locally is highly contorted. Boulder-size silt inclusions are associated with the areas of local disturbance. Where the Wylie is not present, the Falconer Member rests unconformably on older pebble-loam units (Arndt, 1977). The upper contact, where the Huot is unconformably overlain by the Poplar River or Sherack is sharp and erosional. The contact with the Brenna has not been seen but is believed to be gradational.



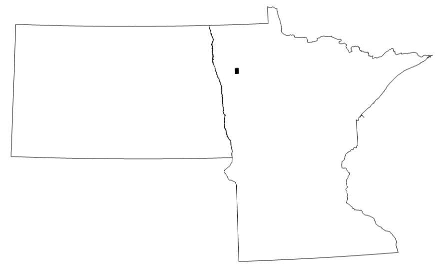
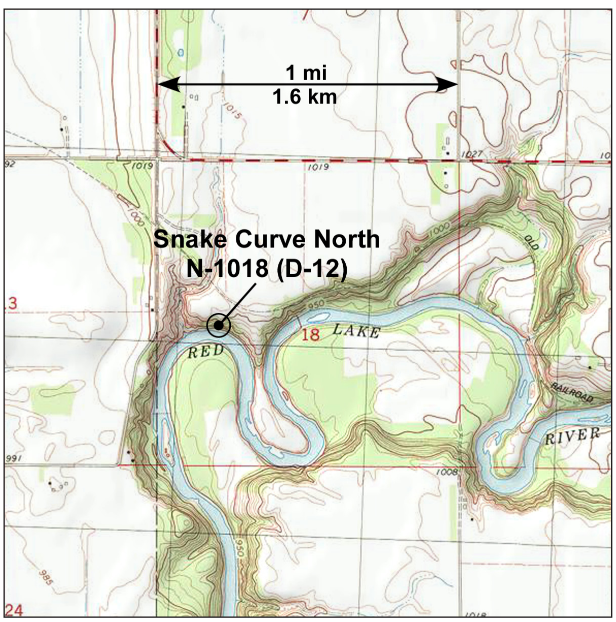


Figure A1.19. The Clearwater Section (N-113, CW-1) on the Clearwater River, Red Lake Falls Township, Red Lake County, Minnesota (T. 151 N., R. 44 W., sec. 22 aabda; GPS: 47.889269, -96.270801; USGS 7.5-minute series Red Lake Falls, MN quadrangle; Appendix 2, p. 227) is the type section of the Huot Member of the Forest River Formation.



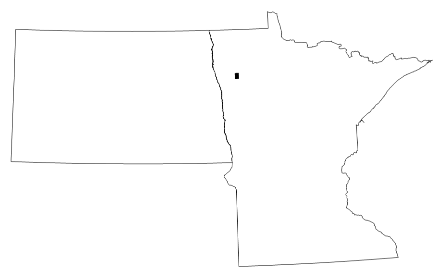


Figure A1.20. Snake Curve North Section (N-1018, D-12) on the Red Lake River, Red Lake Falls Township, Red Lake County, Minnesota (T. 151 N., R.44 W., sec.18 cbaac; GPS: 47.897438, -96.349475; USGS 7.5-minute series Red Lake Falls, MN quadrangle; Appendix 2, p. 225) is a reference section for the Huot Member of the Forest River Formation.

HISTORICAL BACKGROUND

The Huot Member was studied in outcrops along the Red Lake River (Harris, 1973) and later formally named by Harris, Clayton, and Moran (1974). Moran and others (1976) summarized the lithostratigraphy of the region and presented unit correlations. Arndt (1977) summarized the stratigraphy and engineering characteristics of subsurface materials penetrated by bridge borings along Interstate Highway 29 in North Dakota. He found the Huot Member to be present in the subsurface in Traill County, North Dakota. Surface exposures of the Huot Member, associated with the Edinburg moraine, were mapped in Norman, Pennington, Polk, and Red Lake Counties, Minnesota (Harris, 1975, 1987, 1996a and Harris and others, 1995) and in Grand Forks and Traill Counties, North Dakota (Harris and Luther, 1991). Regional lithostratigraphic units were characterized by Harris (1998).

REGIONAL EXTENT AND THICKNESS

The Huot Member is present in the Red River Valley north of Caledonia, Traill County, North Dakota and Shelly, Norman County, Minnesota (fig. A1.25). It is at the surface in the area north and west of Red Lake Falls, Red Lake County, Minnesota and in an arcuate belt a few miles wide extending north and west of the city of Grand Forks, Grand Forks County, North Dakota area. The Huot Member is generally prone to slumping. Consequently, its exposed thickness is variable in cut banks along the Red Lake River west of Red Lake Falls. Generally, from 3 to 15 feet (1 to 4.6 meters) of the member are exposed in most outcrops. However, as much as 70 feet (21.6 meters) of the Huot Member is exposed in the Schist Cliff Section (fig. A1.21 and Appendix 2, p. 229). As much as 100 feet (30.5 meters) of the Huot Member is present in the subsurface of the central part of the Red River Valley.

Figure 8 shows a cross section along the Red Lake River from Red Lake Falls, Minnesota to Grand Forks, North Dakota. The Huot Member extends as far east as the Red Lake Falls area and is at the surface from there west to the Gentilly, Polk County, Minnesota area. West of the Gentilly area the Huot Member is overlain by the Sherack Formation.

DIFFERENTIATION FROM OTHER UNITS

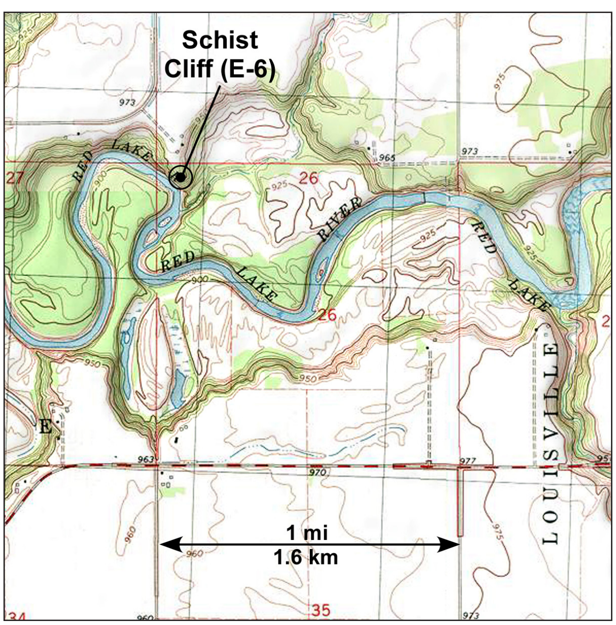
The Huot Member can be easily distinguished from other formations in the region by its texture, pebble content, unbedded, blocky structure, and color. The Brenna is the only formation resembling the Huot. They may be distinguished by the higher sand and pebble content of the Huot Member and the presence of obscure laminations in the Brenna Formation.

AGE

The Forest River Formation was deposited during latest Wisconsinan time. Richie and Lichti-Federovich (1968) reported a date of 12,800 ± 350 ^{14}C yr BP (about 15,200 cal yr BP) from the base of a pond near Brandon, Manitoba, located north of a moraine that may correlate with the Edinburg Moraine (Clayton, 1966). Clayton and Moran (1982) estimated an age of about 11.3 ^{14}C yr BP (about 13,200 cal yr BP) for the advance that deposited the Huot and Falconer Members (the Edinburg moraine, figs. 9, 15). Their estimate was based on a chronology of late Wisconsinan glacial fluctuations in middle North America derived from radiocarbon dates obtained solely from wood. Thorleifson (1996) estimated an age of about 11.2 ^{14}C yr BP (about 13,050 cal yr BP) based on a review of Lake Agassiz research and drainage history. The geographic extent and recent OSL dating of strandlines along the western margin of the southern Lake Agassiz basin suggest that the glacier that deposited the Forest River Formation reached its maximum extent between about 14.2 and 13.7 ka (Fisher and Lowell, 2012).

CORRELATION

The Huot Member is laterally and chronologically equivalent to the Falconer Member in the central and western part of the Red River Valley.



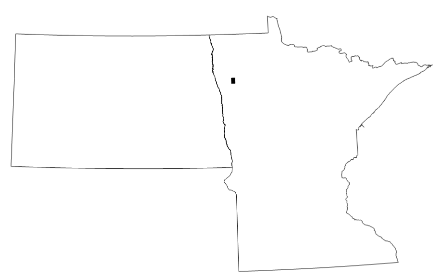


Figure A1.21. Schist Cliff Section (E-6) on the Red Lake River, Louisville Township, Red Lake County, Minnesota (T. 151 N., R. 45 W., sec.26 bbbac; GPS: 47.876108, -96.394678; USGS 7.5-minute series Dorothy, MN quadrangle; Appendix 2; p. 229) is a reference section for the Huot Member of the Forest River Formation.

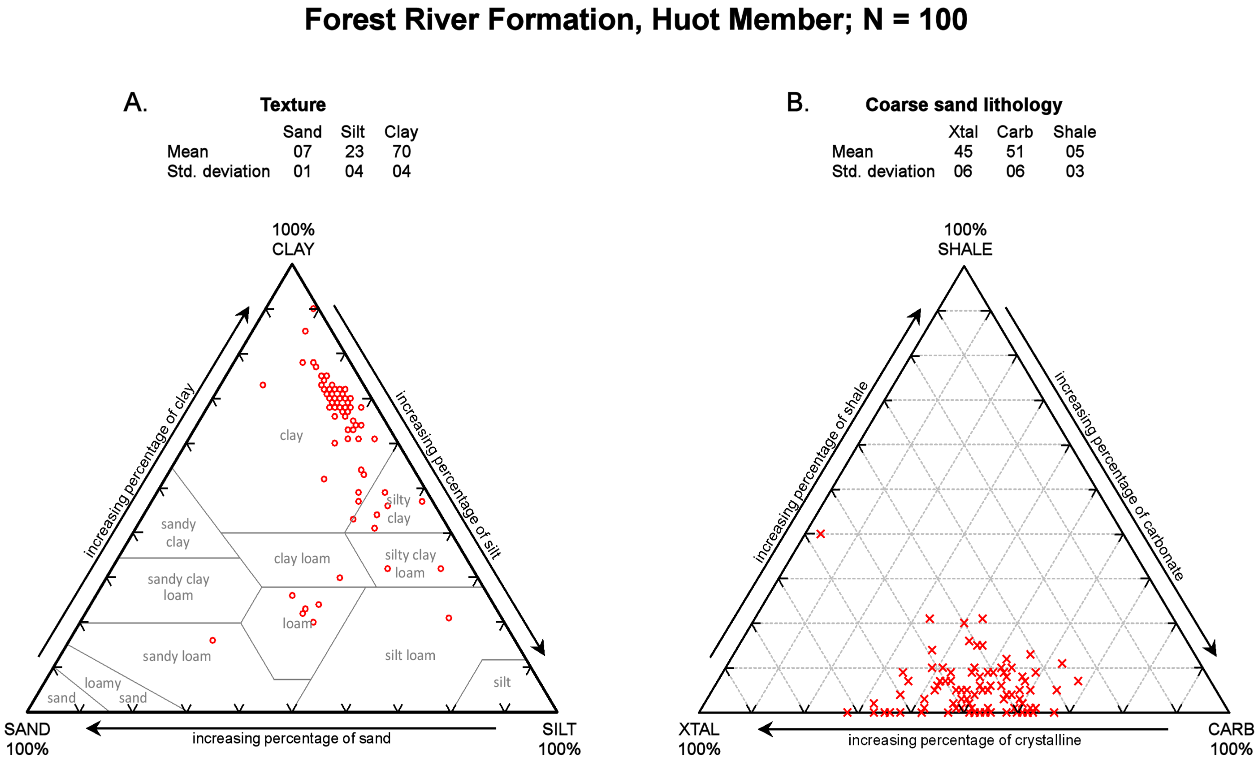


Figure A1.22. Ternary diagrams showing the results of the analysis of 100 samples that show typical textural and coarse-sand lithologic characteristics of the Huot Member of the Forest River Formation. The texture (A) of the Huot Member is clay to silty clay and the very coarse sand lithology (B) indicates a Winnipeg (northern) source area.

GENESIS

The Huot Member is glacial sediment deposited along the southern margin of the Red River lobe during the last major advance of ice into the Red River Valley. The southern limit of this advance is marked by the Edinburg moraine (fig. A1.25).

Falconer Member of the Forest River Formation

(Revised)

NAME AND RANK

The Falconer Member is modified in rank from formation to a member of the Forest River Formation. The description of the unit, as described by Harris, Clayton, and Moran (1974) and Arndt (1977), is accepted with minor modifications owing to format changes and additional information. The source of the name is the Falconer Township, Grand Forks County, North Dakota.

TYPE AREA

The city of Grand Forks, Grand Forks County, North Dakota.

TYPE SECTION

The type section of the Falconer Member of the Forest River Formation is Boring No. 3, Witmer Hall, University of North Dakota, Grand Forks, Grand Forks County, North Dakota (T. 151 N., R. 50 W., sec. 5 dddb; GPS: 47.920182, -97.068709; USGS 7.5-minute series Grand Forks, ND quadrangle; fig. A1.23 and Appendix 2, p. 230).

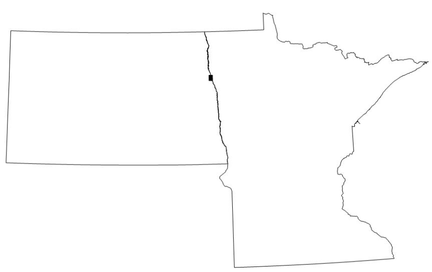
REFERENCE SECTIONS

The Falconer Member has four reference sections:

North Dakota State Water Commission (NDSWC) Testhole 2430, Grand Forks, Grand Forks County, North Dakota (T. 152 N., R. 50 W., sec. 29 dda; GPS: 47.951190, -97.067115; USGS 7.5-minute series Grand Forks, ND quadrangle; fig. A1.23, and Appendix 2, p. 235).

NDSWC Testhole 2431, Grand Forks, Grand Forks County, North Dakota (T. 151 N., R. 50 W., sec. 22 bbb; GPS: 47.889183, -97.044831; USGS 7.5-minute series Grand Forks, ND quadrangle; fig. A1.23, and Appendix 2, p. 233).

NDSWC Testhole 2433, Grand Forks, Grand Forks County, North Dakota (T. 151 N., R. 50 W., sec. 6 dad; GPS: 47.922602, -97.088630; USGS 7.5-minute series Grand Forks, ND quadrangle; fig. A1.23 and Appendix 2, p. 231).



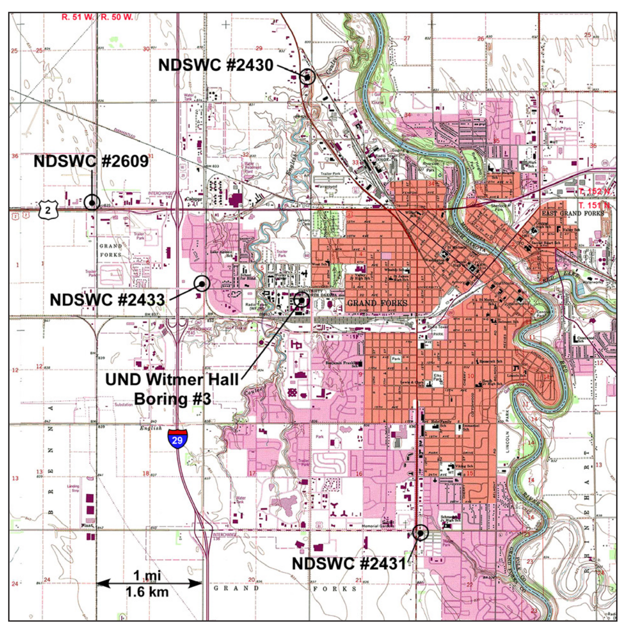


Figure A1.23. The type area for the Falconer Member of the Forest River Formation is the Grand Forks, Grand Forks County, North Dakota area. Shown are the locations of the Falconer Member type section and reference sections, all are located in Grand Forks, Grand Forks County, North Dakota and on the USGS 7.5-minute series Grand Forks, ND quadrangle. The type section is Boring No. 3, Witmer Hall, University of North Dakota (T. 151 N., R. 50 W., sec. 5 dddb; GPS: 47.920182, -97.068709 Appendix 2, p. 230). The four reference sections are NDSWC Testhole 2430 (T. 152 N., R. 50 W., sec. 29 dda; GPS: 47.951190, -97.067115; Appendix 2, p. 235); NDSWC Testhole 2431 (T. 151 N., R. 50 W., sec. 22 bbb; GPS: 47.889183, -97.044831; Appendix 2, p. 233); NDSWC Testhole 2433 (T. 151 N., R. 50 W., sec. 6 dad; GPS: 47.922602, -97.088630; Appendix 2, p. 231); and NDSWC Testhole 2609 (T. 152 N., R. 51 W., sec. 36 ddd; GPS: 47.933499, -97.110392; Appendix 2, p. 237).

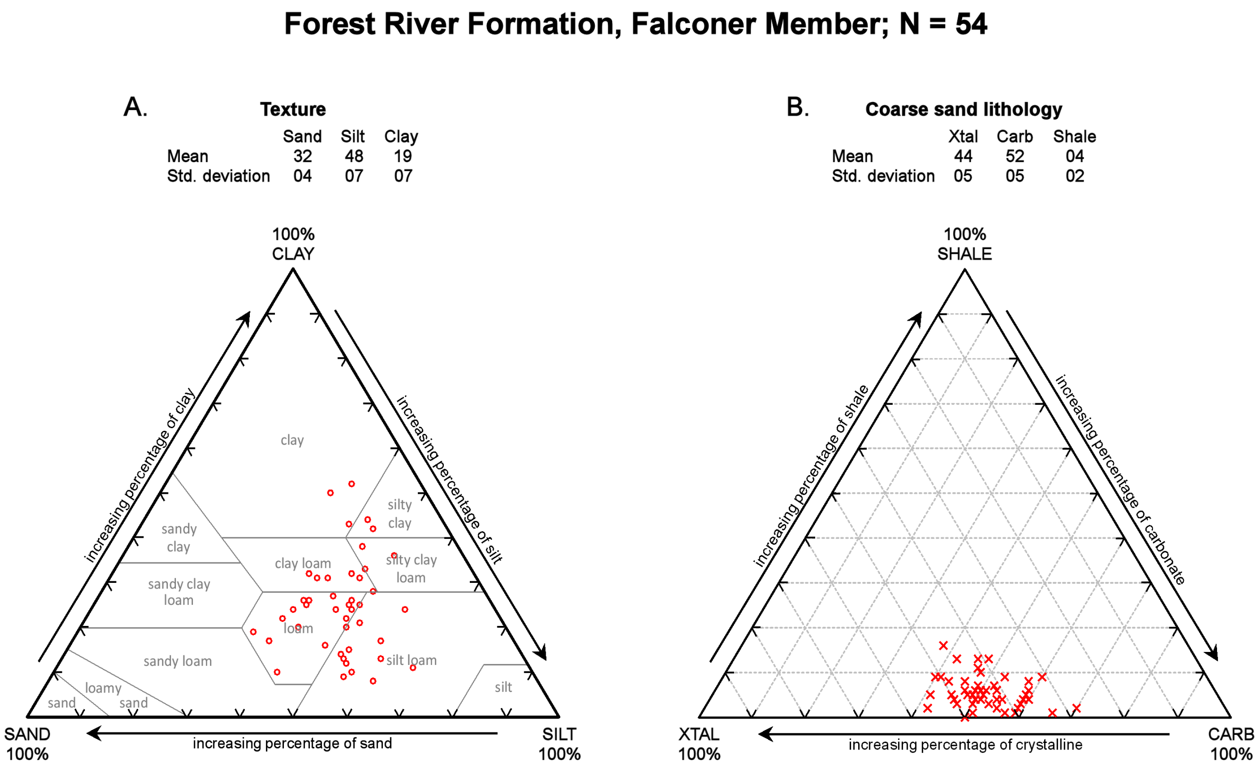


Figure A1.24. Ternary diagrams showing the results of the analysis of 54 samples that show typical textural and coarse-sand lithologic characteristics of the Falconer Member of the Forest River Formation. The texture (A) of the Falconer Member is loam to clay loam and the very coarse sand lithology (B) indicates a Winnipeg (northern) source area.

NDSWC Testhole 2609, Grand Forks, Grand Forks County, North Dakota (T. 152 N., R. 51 W., sec. 36 ddd; GPS: 47.933499, -97.110392; USGS 7.5-minute series; fig. A1.23 and Appendix 2, p. 237).

LITHOLOGIC DESCRIPTION

The Falconer Member consists of pebble-loam to clayey pebble-loam. It is light gray (5Y 6/1). Beds of sand or gravel occur locally, but they are nowhere a significant constituent of the member. Contorted beds of silt a few millimeters thick are locally abundant, especially in the upper part of the member. The average texture of the unit is 32 percent sand, 48 percent silt, and 19 percent clay (fig. A1.24A); the average lithology of the very coarse-sand fraction (1-2 mm) is 44 percent crystalline, 52 percent carbonate, and 4 percent shale rock fragments (fig. A1.24B).

DESCRIPTION OF BOUNDARIES

The Falconer Member is unconformably overlain by the Sherack Formation and conformably overlain by the Brenna Formation. It conformably overlies the Wylie Formation, and the contact between the two appears to be gradational. Where the Wylie is not present, the Falconer Member rests unconformably on older pebble-loam units (Arndt, 1977). The contact between the Huot Member, the clayey lateral equivalent of the Falconer Member, with the Wylie Formation is gradational by interbedding in many outcrops. Laterally the Falconer Member is completely gradational with the Huot Member in central Traill County, North Dakota, and in Red Lake, Polk, and Norman Counties, Minnesota (fig. A1.25). The two members are differentiated because of textural, compositional, and appearance differences.

HISTORICAL BACKGROUND

The Falconer was first defined by Harris and others (1974) as a lithostratigraphic unit of formation rank. It was modified by Arndt (1977) on the basis of additional data acquired from bridge borings along Interstate Highway 29 in North Dakota. In Minnesota the unit was informally referred to as the "Falconer Formation of the Forest River group" (Harris and others, 1995; Harris, 1998; Thorleifson, 2005).

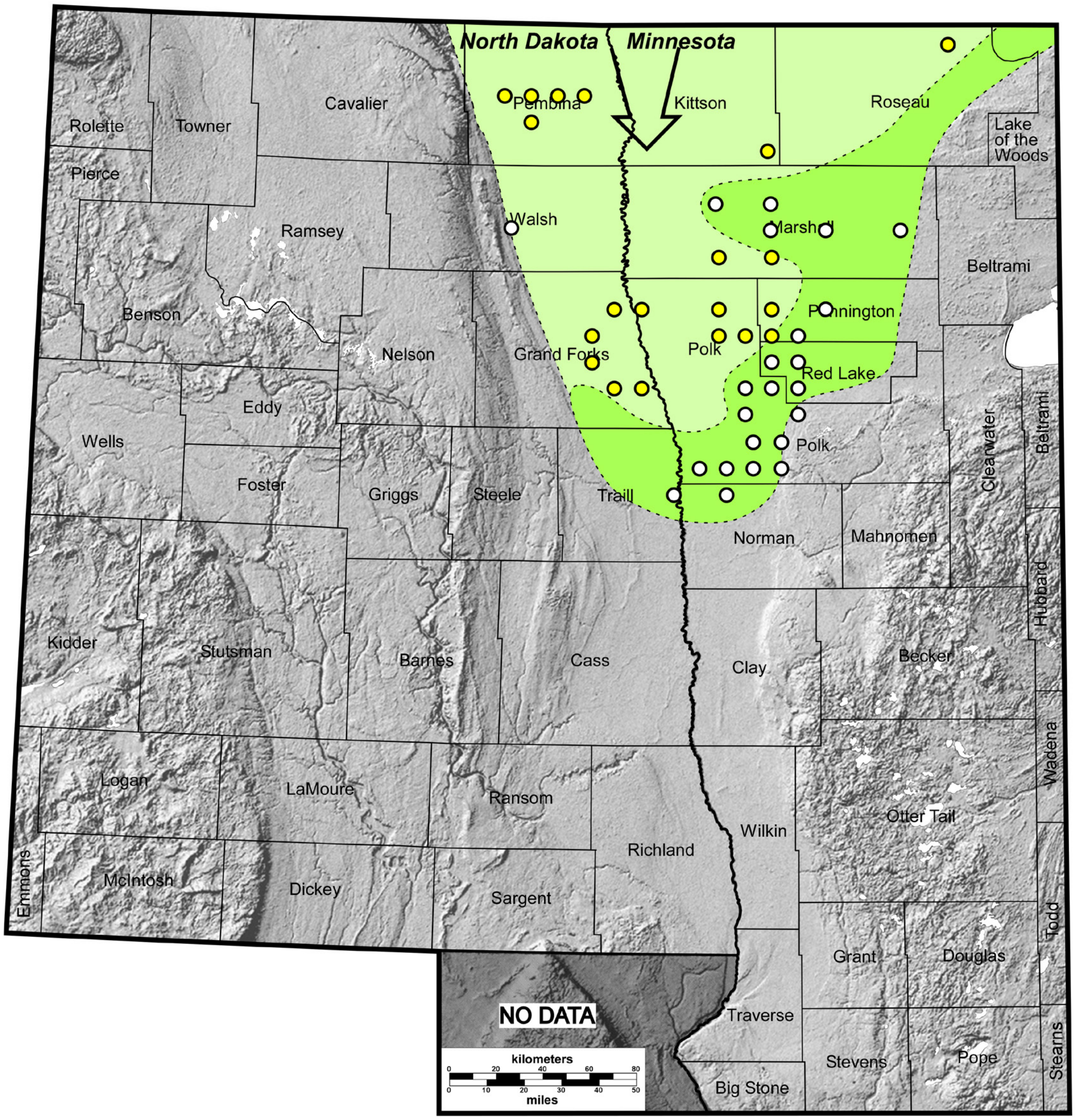


Figure A1.25. This map shows the surface occurrence of the Falconer Member (light green) and Huot Member (darker green) of the Forest River Formation in the Red River Valley of North Dakota and Minnesota. The Falconer Member is present up glacier of the Huot Member and is generally seen only in river cut banks or drill holes. Colored circles indicate townships where sample control is located; white circles indicate the Huot Member and yellow circles indicate the Falconer Member. The Edinburg moraine formed along the western and southern margins of the Forest River Formation. The arrow indicates the direction of ice flow.

REGIONAL EXTENT AND THICKNESS

The Falconer Member occurs throughout much of the northern half of the Red River Valley in North Dakota and Minnesota (fig. 8). It has been traced from its southern margin in central Traill County, North Dakota, as far north as the Canadian border. It is present as far north as southern Manitoba where it is correlative with the Whitemouth Lake Formation (Harris and others, 2007). The member is as much as 100 feet (30.5 meters) thick in northern Traill County, a few miles north of its southern limit.

DIFFERENTIATION FROM OTHER UNITS

The Falconer Member is lithologically distinct and is easily differentiated from both overlying and underlying units. It is less clayey than the Sherack, Brenna, or

Wylie Formations. Pebbles are common in this unit but are absent or rare in the underlying and overlying units. Where the Falconer Member grades into the Huot Member, the boundary is placed where sand content is 10 percent. The Falconer Member contains more than 10 percent sand and the Huot Member contains less than 10 percent sand (Arndt, 1977). The Falconer Member may be differentiated from both the Red Lake Falls Formation and Huot Member by its texture. The Falconer Member is less sandy and more clayey than the Red Lake Falls Formation, and considerably more sandy and less clayey than the Huot Member (table 3).

AGE

The Forest River Formation was deposited during latest Wisconsinan time. Richie and Lichti-Federovich (1968) reported a date of 12,800 ± 350 ^{14}C yr BP (about 15,200 cal yr BP) from the base of a pond near Brandon, Manitoba, located north of a moraine that may correlate with the Edinburg Moraine (Clayton, 1966). Clayton and Moran (1982) estimated an age of about 11.3 ^{14}C yr BP (about 13,200 cal yr BP) for the advance that deposited the Huot and Falconer Members (the Edinburg moraine, figs. 9, 15). Their estimate was based on a chronology of late Wisconsinan glacial fluctuations in middle North America derived from radiocarbon dates obtained solely from wood. Thorleifson (1996) estimated an age of about 11.2 ^{14}C yr BP (about 13,050 cal yr BP) based on a review of Lake Agassiz research and drainage history. The geographic extent and recent OSL dating of strandlines along the western margin of the southern Lake Agassiz basin suggest that the glacier that deposited the Forest River Formation reached its maximum extent between about 14.2 and 13.7 ka (Fisher and Lowell, 2012).

CORRELATION

The Falconer Member is laterally equivalent to the Huot Member and is thought to be correlative with the Whitemouth Formation in southeastern Manitoba (fig. 15; Harris and others, 2007). The Falconer Member may correlate with the upper diamicton of the Blackduck Formation of north-central Minnesota (Jennings and Gowan, 2016) and with part of the Whitemouth Formation in Canada (Teller and Fenton, 1980).

GENESIS

The Falconer Member is glacial sediment deposited by the Red River lobe during the final major readvance into the Red River Valley of the generally retreating Late Wisconsinan glacier. The gradational change in texture of the member is the result of the incorporation of clayey offshore sediment as the glacier advanced into Lake Agassiz. The Edinburg Moraine (fig. A1.25) in Traill, Grand Forks, and Walsh Counties, North Dakota, marks the limit of this glacial advance.

WYLIE FORMATION

(Accepted)

NAME AND RANK

The Wylie Formation is accepted as formally named by Harris, Clayton, and Moran (1974) with minor modifications due to format changes and additional information. The source of the name is the village of Wylie, Red Lake County, Minnesota, located on the USGS 7.5-minute series Red Lake Falls, MN quadrangle.

TYPE AREA

The Wylie area, Red Lake County, Minnesota.

TYPE SECTION

The type section of the Wylie Formation is Clearwater Section (N-113, CW-1) on the Clearwater River, Red Lake Falls Township, Red Lake County, Minnesota (T. 151 N., R. 44 W. sec. 22 aabda; GPS: 47.889269, -96.270801; USGS 7.5-minute series Red Lake Falls, MN quadrangle; fig. A1.26 and Appendix 2, p. 227).

REFERENCE SECTION

The reference section of the Wylie Formation is Old Dam Section (N-1025, D-3) on the Red Lake River, Red Lake Falls Township, Red Lake County, Minnesota (T. 151 N., R. 44 W, sec 14 bddba; GPS: 47.897152, -96.245396; USGS 7.5-minute series Red Lake Falls, MN quadrangle; fig. A1.27 and Appendix 2, p. 224).

LITHOLOGIC DESCRIPTION

The Wylie Formation contains clay and silt that are generally thinly laminated. The clay is olive gray (5Y 5/2) when dry and dark gray (5Y 4/1) when wet. The silt is light brownish gray (2.5Y 6/2) when dry and olive brown (2.5Y 4/4) when wet. In outcrop, the formation is friable when dry, and tough and plastic when moist. The silt laminae become thinner and the clay laminae become thicker upward. In most outcrops, the laminae range in thickness from a few millimeters to a centimeter.

DESCRIPTION OF BOUNDARIES

The lower contact of the Wylie Formation with the Red Lake Falls Formation is gradual and interbedded. This contact is locally highly contorted.

The upper contact with the overlying Huot Formation is gradually interbedded or diffuse. Locally the contact is

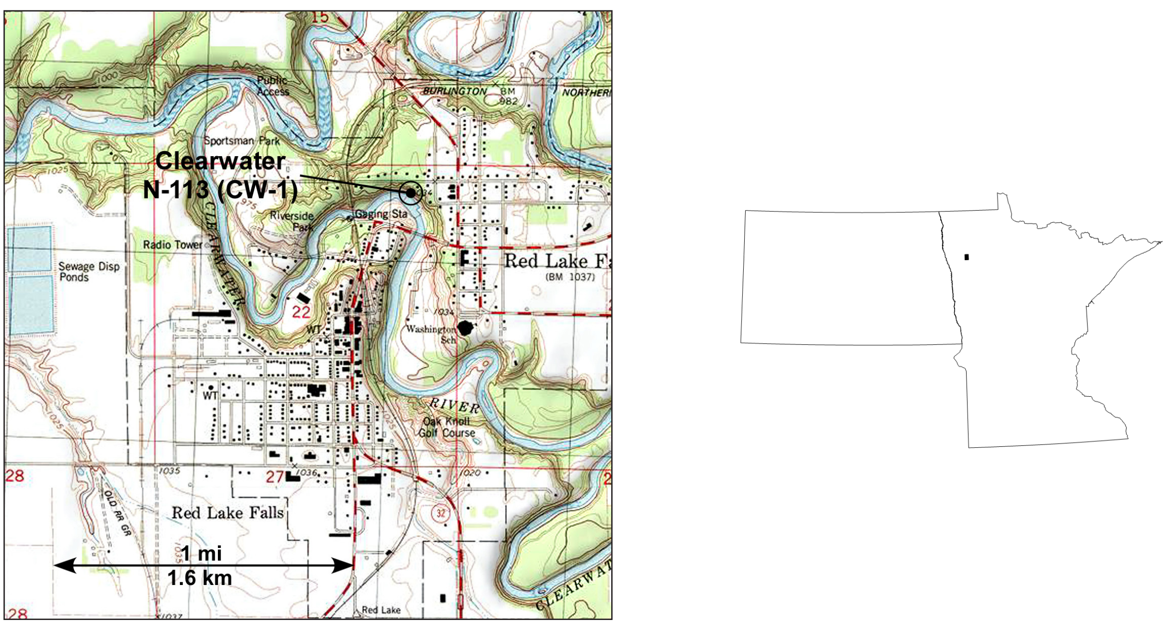
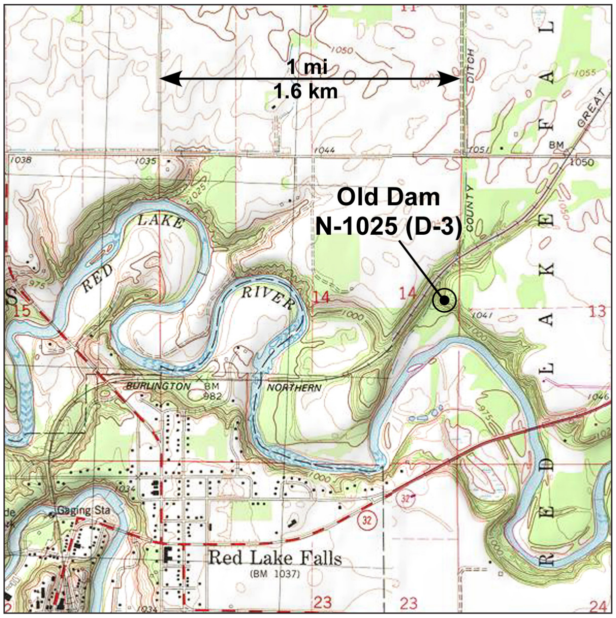


Figure A1.26. The Clearwater Section (N-113, CW-1) on the Clearwater River, Red Lake Falls Township, Red Lake County, Minnesota (T. 151 N., R. 44 W., sec. 22 aabda; GPS: 47.889269, -96.270801; USGS 7.5-minute series Red Lake Falls, MN quadrangle; Appendix 2, p. 227) is the type section of the Wylie Formation.



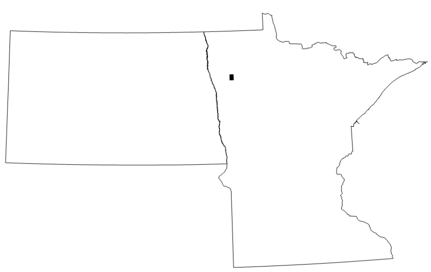


Figure A1.27. The Old Dam Section (N-1025, D-3) on the Red Lake River, Red Lake Falls Township, Red Lake County, Minnesota (T. 151 N., R. 44 W, sec. 14 bddba; GPS: 47.897152, -96.245396; USGS 7.5-minute series Red Lake Falls, MN quadrangle; Appendix 2, p. 224) is the reference section for the Wylie Formation.

highly contorted, and boulder-sized masses of glacial sediment are present.

The upper contact of the Wylie Formation with the Falconer Formation is diffuse and gradational.

HISTORICAL BACKGROUND

The Wylie Formation was named by Harris, Moran, and Clayton (1974) and modified by Arndt (1977). Harris, Moran, and Clayton defined the Wylie based on Red Lake River outcrops and drill hole data in the Grand Forks, North Dakota area. Arndt used engineering criteria from borings along Interstate 29 and other controls to refine the definition and correlate Lake Agassiz sediment from the South Dakota border to Canadian border.

REGIONAL EXTENT AND THICKNESS

On the Red Lake River the Wylie Formation is exposed from the Needles Eye Section (N-1008, C-7; T. 151 N., R. 13 W. sec. 18d dadbc) downstream to the area of the Schist Cliff Section (E-6; T. 151 N., R. 45 W., sec. 26 bbbac). It is exposed at the surface north of Red Lake Falls beyond the eastern limit of the Huot Formation (figs. 12, A1.28). The Wylie Formation is discontinuously present beneath the Forest River Formation throughout the central part of the Red River Valley in Grand Forks, Walsh, and southern Pembina Counties, North Dakota, and in Polk, Marshall, and Kittson Counties, Minnesota.

The Wylie Formation ranges in thickness from less than 2 feet (0.6 meters) to more than 27 feet (8.2 meters). The average thickness of exposures is about 5 feet (1.5 meters).

DIFFERENTIATION FROM OTHER UNITS

The Wylie Formation, by its distinct laminations, can be distinguished from all other named formations in the Grand Forks area except the Sherack Formation. The Sherack Formation is separated stratigraphically from the Wylie Formation by the Brenna and Forest River Formations. Where these formations are present the distinction can be readily made.

AGE

The Wylie Formation is Late Wisconsinan in age. It is offshore lake sediment deposited during the Lockhart Phase of Lake Agassiz prior to the advance of the ice that deposited the Forest River Formation (fig. 9).

CORRELATION

The Wylie Formation is stratigraphically equivalent to the Argusville Formation. It was subsequently overridden by the ice that deposited the Forest River Formation.

GENESIS

The Wylie Formation is lacustrine sediment. Deposition occurred in an ice-marginal lake during the retreat of the ice sheet that deposited the Red Lake Falls Formation and the advance of the ice sheet that deposited the Huot Formation and Falconer Formation.

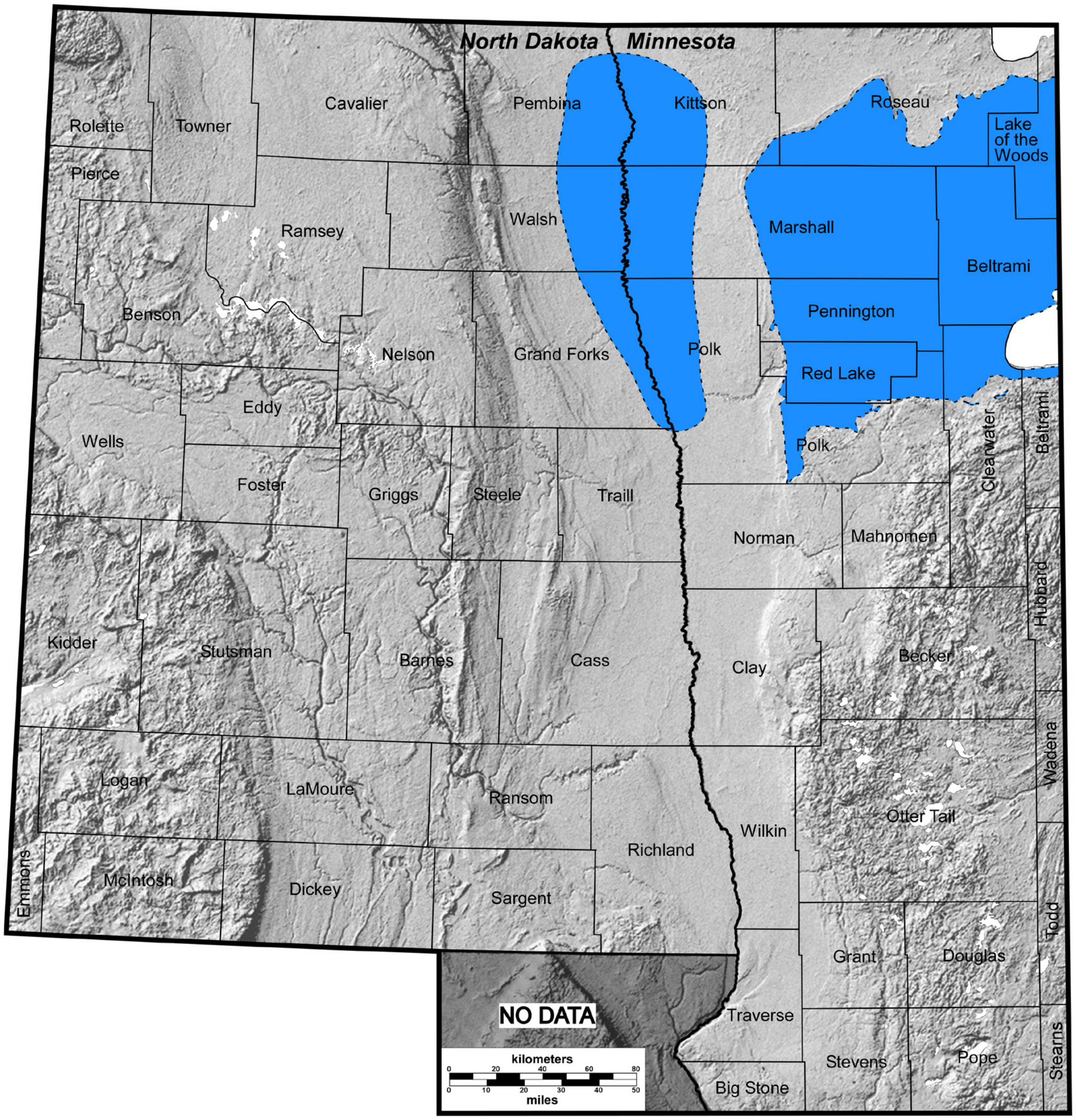


Figure A1.28. This figure shows the distribution of the Wylie Formation in the Red River Valley of North Dakota and Minnesota. The Wylie Formation is lake sediment deposited during the Lockhart Phase of Glacial Lake Agassiz (fig. 9) and consists of offshore sediment.

ARGUSVILLE FORMATION

(Accepted)

NAME AND RANK

The Argusville Formation is accepted as formally named by Arndt (1977) with minor modifications due to format changes and additional information. The source of the name is the village of Argusville, Cass County, North Dakota, located on the USGS 7.5-minute series Argusville, ND quadrangle.

TYPE AREA

Southern Traill County and northern Cass County, North Dakota.

TYPE SECTION

The type section of the Argusville Formation is boring number 2 of Interstate 29 structure 89, Rose Coulee Bridge, Cass County, North Dakota (T. 139 N., R. 49 W., sec. 26 ccc; GPS: 46.819838, -96.837254; USGS 7.5-minute series Fargo South, ND quadrangle; fig. A1.29 and Appendix 2, p. 211).

REFERENCE SECTIONS

The Argusville Formation has four reference sections:

Boring number 1 of Interstate 29 structure 89, Rose Coulee Bridge, Cass County, North Dakota (T. 139 N., R. 49 W., sec. 26 ccc; GPS: 46.819838, -96.837254; USGS 7.5-minute series Fargo South, ND quadrangle; fig. A1.29 and Appendix 2, p. 210).

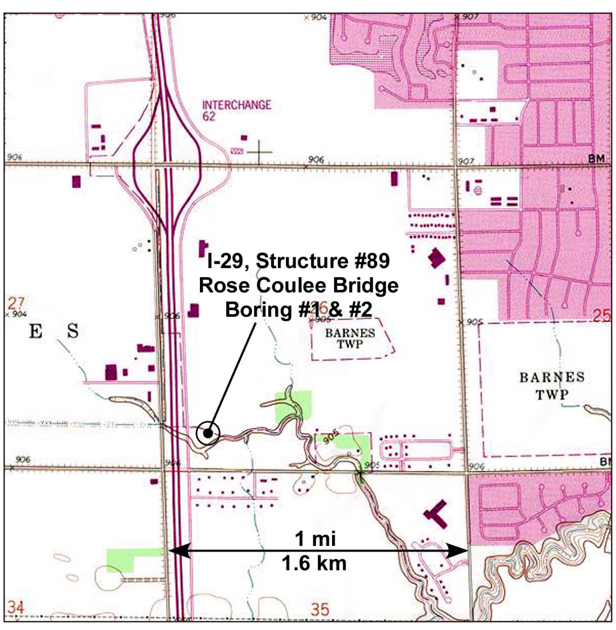
Boring numbers 1, 2, 3 of Interstate 29 structure 68, interchange south of Grandin, Cass County, North Dakota (T. 143 N., R. 50 W., sec. 15 dac; GPS: 47.199285, -96.988894; USGS 7.5-minute series Gardner, ND quadrangle; fig. A1.30 and Appendix 2, p. 214).

Boring number 1 of Interstate 29 structure 91, St. Benedict Interchange at St. Benedict, Cass County, North Dakota (T. 138 N., R. 49 W., sec. 35 ccd; GPS: 46.659664, -96.837382; USGS 7.5-minute series Hickson, ND quadrangle; fig. A1.31 and Appendix 2, p. 205).

Composite boring numbers 1, 2, 3 of Interstate 29 structure 105, Mooreton Interchange at Mooreton, Richland County, North Dakota (T. 132 N., R. 49 W., sec. 9 acc; GPS: 46.262340, -96.832475; USGS 7.5-minute series Mooreton East, ND quadrangle; fig. A1.32 and Appendix 2, p. 195).

LITHOLOGIC DESCRIPTION

The Argusville Formation is composed mostly of clay (fig. A1.33). Clay content ranges from 56 percent to 84 percent and sand content ranges from 2 percent to 6 percent. Its color ranges from gray (5Y 6/1) to dark gray (5Y 4/1). It is generally unbedded, but darker colored stringers



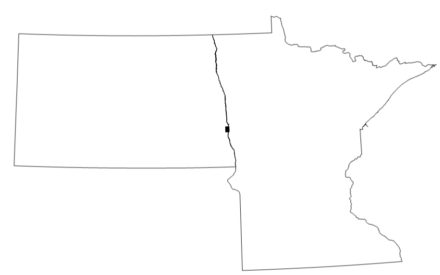
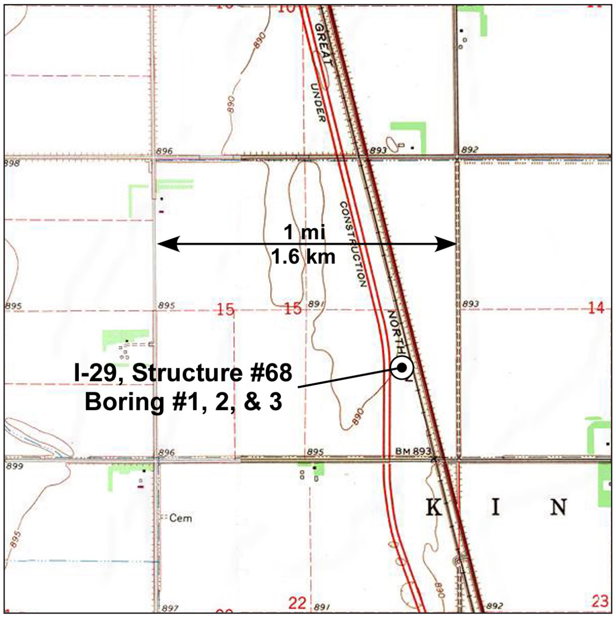


Figure A1.29. Boring number 2 of Interstate 29 structure 89, Rose Coulee Bridge, Cass County, North Dakota (T. 139 N., R. 49 W., sec. 26 ccc; GPS: 46.819838, -96.837254; USGS 7.5-minute series Fargo South, ND quadrangle; Appendix 2, p. 211) is the type section of the Argusville Formation. Boring number 1 (Appendix 2, p. 210) at this location is a reference section.



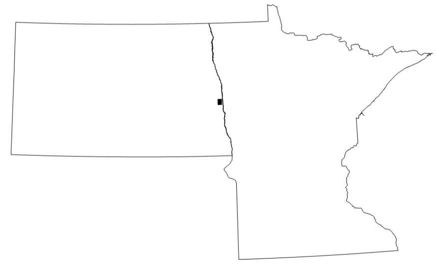
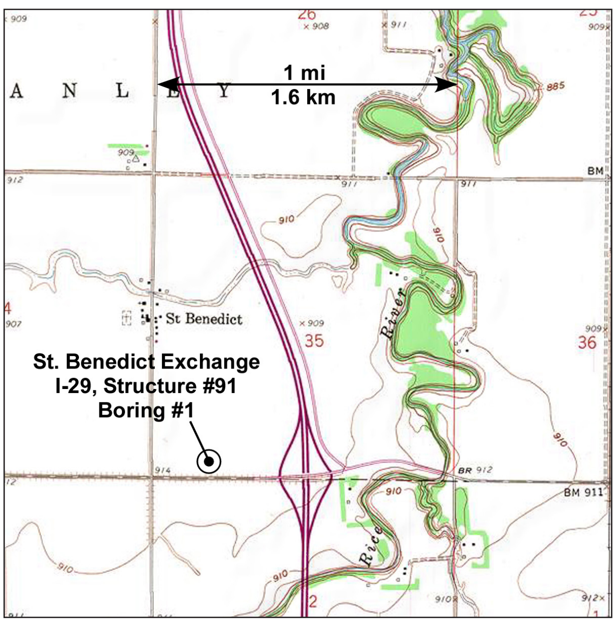


Figure A1.30. Boring numbers 1, 2, 3 of Interstate 29 structure 68, interchange south of Grandin, Cass County, North Dakota (T. 143 N., R. 50 W., sec. 15 dac; GPS: 47.199285, -96.988894; USGS 7.5-minute series Gardner, ND quadrangle; Appendix 2, p. 214) are reference sections for the Argusville Formation.



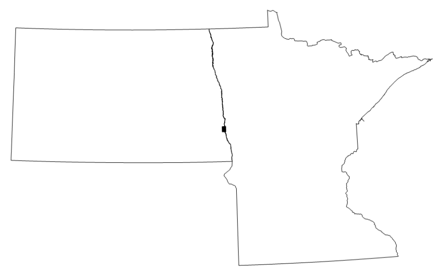
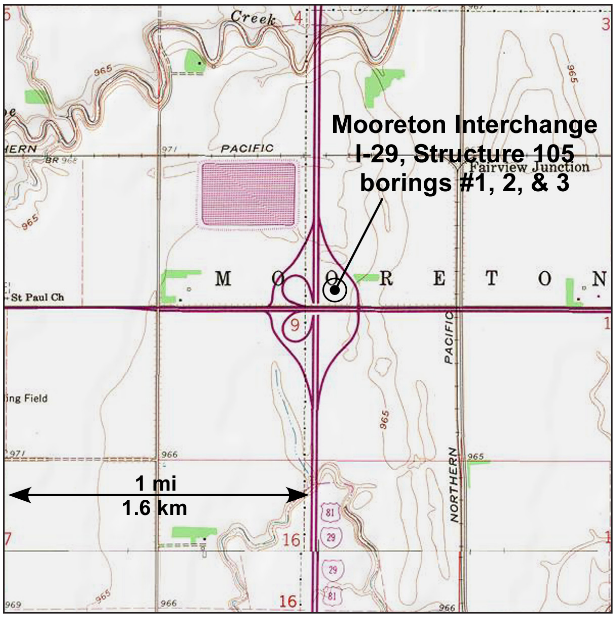


Figure A1.31. Boring number 1 of Interstate 29 structure 91, St. Benedict Interchange at St. Benedict, Cass County, North Dakota (T. 138 N., R. 49 W., sec. 35 ccd; GPS: 46.659664, -96.837382; USGS 7.5-minute series Hickson, ND quadrangle; Appendix 2, p. 205) is a reference section for the Argusville Formation.

are common, giving a marbled appearance that may be mistaken for laminations. Calcareous silt balls and pebble loam balls, generally less than 0.4 inches (10 millimeters) in diameter, are common throughout the unit.

DESCRIPTION OF BOUNDARIES

The Argusville Formation is overlain by the Brenna Formation except in Richland County where it is directly overlain by the Sherack Formation. It overlies the unnamed units A and B described by Arndt (1977), tentatively identified by K.L. Harris (unpub. data, 2013) as the Lower Red Lake Falls Member of the Red Lake Falls Formation and the St. Hilaire Member of the Goose River Formation respectively. At its northern extremity, the Argusville Formation is gradational with the Huot Member of the Forest River Formation. The boundary is placed where the sand content is 5 percent and 0.1 percent.



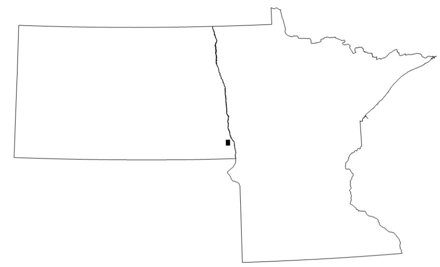


Figure A1.32. A composite of boring numbers 1, 2, 3 of Interstate 29 structure 105, Mooreton Interchange at Mooreton, Richland County, North Dakota (T. 132 N., R. 49 W., sec. 9 acc; GPS: 46.262340, -96.832475; USGS 7.5-minute series Mooreton East, ND quadrangle; Appendix 2, p. 195) is a reference section for the Argusville Formation.

HISTORICAL BACKGROUND

The Argusville Formation was first described by Sackreiter (1975) and formally defined by Arndt (1977) using data from subsurface borings along Interstate 29 near Fargo, North Dakota.

REGIONAL EXTENT AND THICKNESS

The Argusville Formation is only present in the southern part of the Red River Valley (fig. A1.34). It has no known surface exposures. The north-south extent of the formation is defined by a series of 46 borings along Interstate 29 between mile markers 13, approximately 1.5 miles (2.4 kilometers) south of where the highway crosses the Wild Rice River in Richland County and 105 on the distal side of the Edinburg moraine in central Traill County. The Argusville Formation has not been identified outside the Interstate 29 corridor. Its eastern and western limits are therefore unknown but are presumed to be similar to those of the Brenna Formation and the offshore facies of the Sherack. The Argusville Formation ranges in thickness from less than 10 feet (3 meters) at the Mooreton Interchange to more than 36 feet (11 meters) near Exit 67 off Interstate 29 in north Fargo. The average thickness is about 19 feet (5.8 meters).

DIFFERENTIATION FROM OTHER UNITS

Close similarities in color, composition, and structure of the Argusville Formation and the Brenna Formation south of the Edinburg moraine make these units hard to

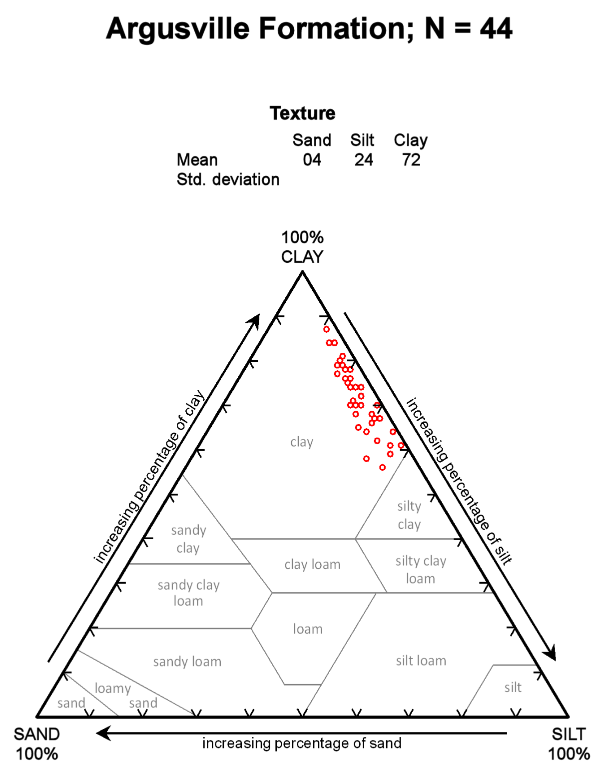


Figure A1.33. Ternary diagram showing the grain-size distribution of the Argusville Formation.

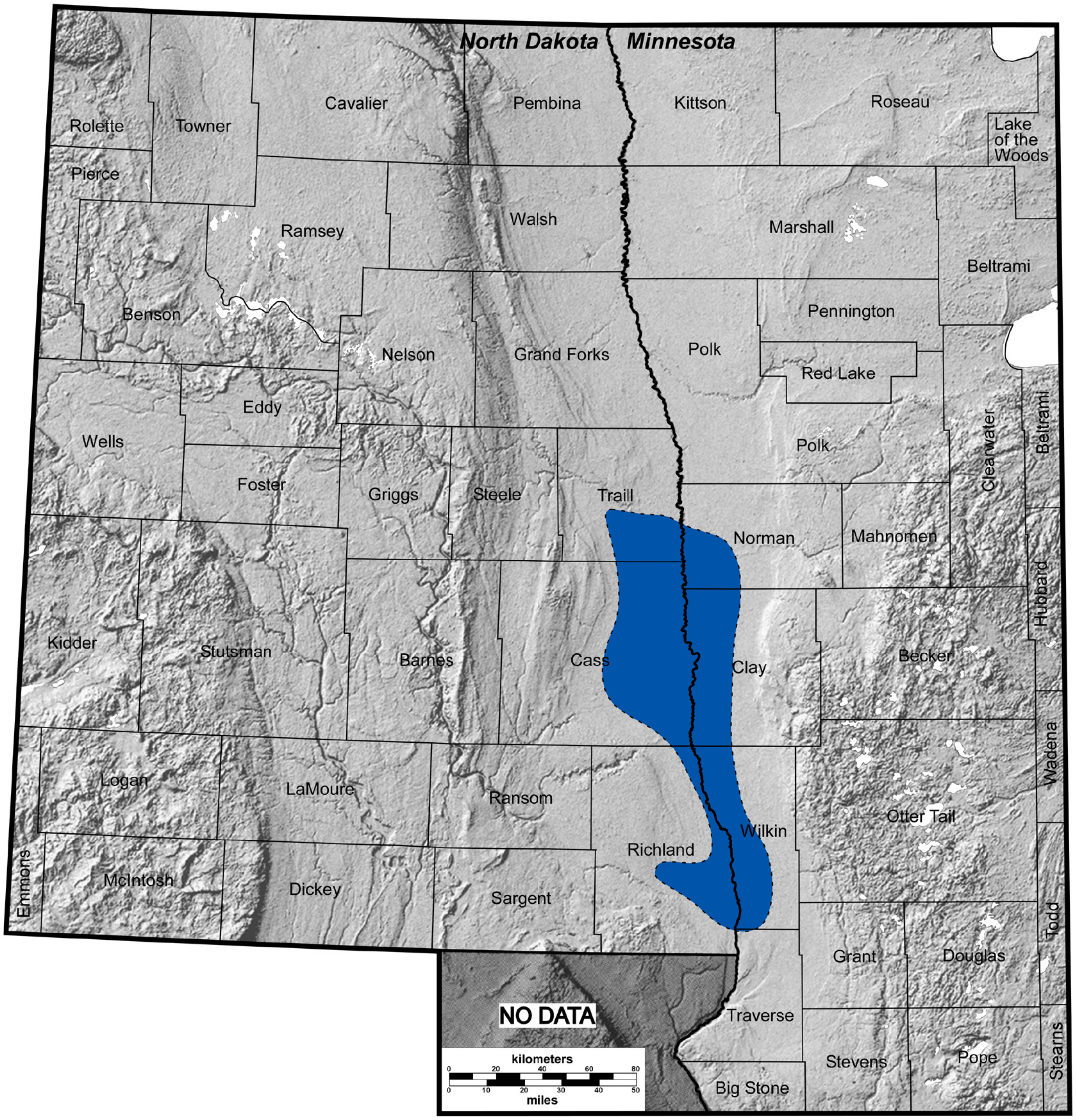


Figure A1.34. This figure shows the distribution of the Argusville Formation in the Red River Valley of North Dakota and Minnesota. The Argusville Formation is lake sediment deposited during the Cass and Lockhart Phases of Glacial Lake Agassiz (fig. 9) and consists of offshore sediment.

differentiate in the field. The Argusville Formation is older and does not extend north of the Edinburg moraine. The Argusville Formation may be differentiated from the offshore facies of the Sherack Formation by its darker color, high clay content, general lack of structure, and abundant calcareous inclusions. It is easily distinguished from the Huot Member of the Forest River Formation and the underlying till units on the basis of their lighter color, higher sand and pebble content, and lack of bedding.

AGE

The Argusville Formation was deposited during an interval in the Cass and early Lockhart Phases of Lake Agassiz when the Red River Valley south of the international border was ice-free for a time (fig. 9). It is older than the Brenna Formation but because the transitional boundary between these two units is not clearly defined, the timing of the end of one depositional event and the beginning of the other is difficult to determine. On the other hand, if it is assumed, arbitrarily, that the transition occurred as the glacier that deposited the Forest River Formation began to recede from its maximum extent, this would imply a minimum age for the Argusville Formation of between about 14.2 and 13.7 ka (Fisher and Lowell, 2012).

CORRELATION

The Argusville Formation is stratigraphically equivalent to the Wiley Formation.

GENESIS

The Argusville Formation is made up of offshore lacustrine sediment. It was deposited in the Agassiz basin as the Late Wisconsinan glacier retreated out of the area prior to, and during the readvances responsible for the deposition of the Red Lake Falls and Forest River Formations.

RED LAKE FALLS FORMATION

(Accepted)

NAME AND RANK

The Red Lake Falls Formation is accepted as formally named by Harris, Clayton, and Moran (1974) with minor modifications due to format changes and additional information. The source of the name is the city of Red Lake Falls, Red Lake County, Minnesota, located on the USGS 7.5-minute series Red Lake Falls, MN quadrangle.

The Red Lake Falls Formation contains two members: the Upper Red Lake Falls Member and the Lower Red Lake Falls Member.

Upper Red Lake Falls Member of the Red Lake Falls Formation

(New)

NAME AND RANK

The Upper Red Lake Falls Member of the Red Lake Falls Formation is formally named here. The source of the name is the city of Red Lake Falls, Red Lake County, Minnesota, located on the USGS 7.5-minute series Red Lake Falls, MN quadrangle.

TYPE AREA

Red Lake County, Minnesota.

TYPE SECTION

The type section of the Upper Red Lake Falls Member of the Red Lake Falls Formation is Clearwater Section (N-113, CW-1) on the Clearwater River, Red Lake Falls Township, Red Lake County, Minnesota (T. 151 N., R. 44 W., sec. 22 aabda; GPS: 47.889269, -96.270801; USGS 7.5-minute series Red Lake Falls, MN quadrangle; fig. A1.35 and Appendix 2, p. 227).

REFERENCE SECTIONS

Needles Eye Section (N-1008, C-7) on the Red Lake River, Gervais Township, Red Lake County, Minnesota (T. 151 N., R. 43 W., sec. 18 dadbc; GPS: 47.895068, -96.206373; USGS 7.5-minute series Plummer NW, MN quadrangle; fig. A1.36 and Appendix 2, p. 223) is a reference section for the Upper Red Lake Falls Member of the Red Lake Falls Formation.

A second reference section is the Powerline Section (N-226, C-2) on the Red Lake River, Gervais Township, Red Lake County, Minnesota (T. 151 N., R. 43 W., sec. 5 addd; GPS: 47.926786, -96.184546; USGS 7.5-minute series Plummer NW, MN quadrangle; fig. A1.37 and Appendix 2, p. 222).

LITHOLOGIC DESCRIPTION

The Upper Red Lake Falls Member of the Red Lake Falls Formation is unbedded pebble-loam. It is light gray (2.5Y 7/2) to light brownish gray (2.5Y 6/2) when dry and olive brown (2.5Y 4/4) when wet. Vertical joints result in a moderate to strong columnar structure in dry, weathered outcrops, and oxidation along the joints produces a reddish yellow (7.5YR 6/6) stain. The Upper Red Lake Falls Member is hard and resistant to erosion in dry outcrops and is friable when moist.

Sand and gravel inclusions are common; these include thin beds a few millimeters thick, channel fills, and contorted masses. Thin beds of laminated silt and clay as much as a few inches thick may be laterally persistent for tens of feet.

The Upper Red Lake Falls Member texture averages 38 percent sand, 39 percent silt, and 23 percent clay (fig. A1.38A); the very coarse-sand lithology (1-2 mm) averages 53 percent crystalline and metamorphic rock fragments, 34 percent carbonate rock fragments, and 13 percent shale fragments (fig. A1.38B). Pebbles, cobbles, and boulders are abundant and consist of about two-thirds limestone and dolomite; about one-third igneous and metamorphic rock types, and noticeable amounts of shale.

DESCRIPTION OF BOUNDARIES

The upper and lower contacts of the Upper Red Lake Falls Member are best observed in exposures along the Red Lake River in Red Lake and Pennington Counties, Minnesota. In this area the Upper Red Lake Falls Member overlies the Lower Red Lake Falls Member. The contact between these two units is gradational to sharp and in some

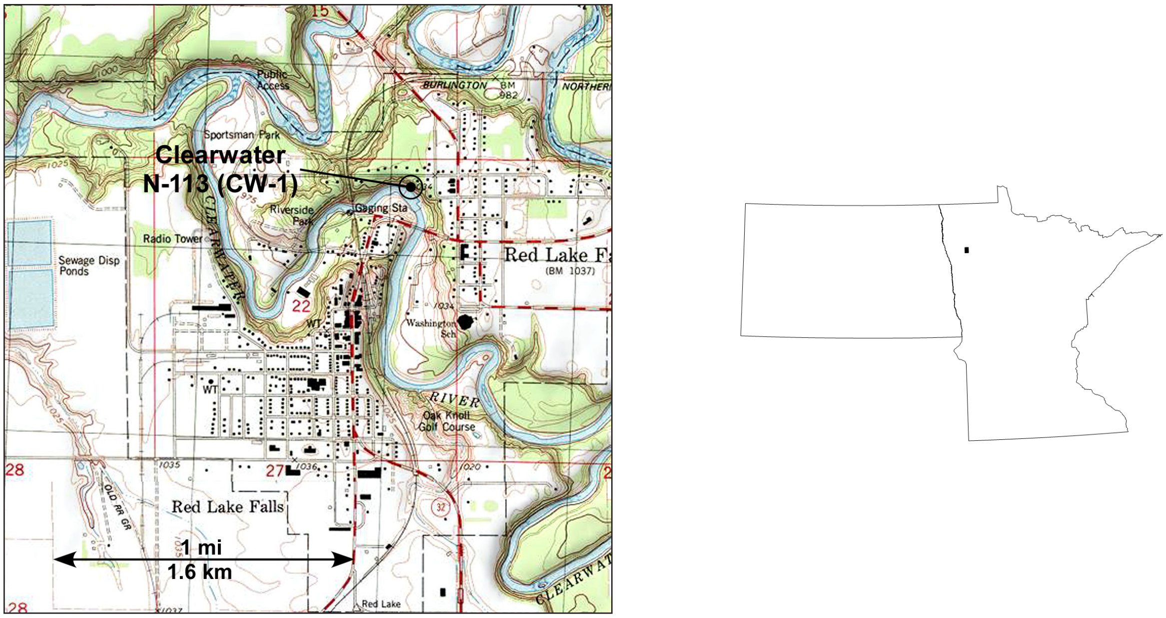


Figure A1.35. The Clearwater Section (N-113, CW-1) on the Clearwater River, Red Lake Falls Township, Red Lake County, Minnesota (T. 151 N., R. 44 W., sec. 22 aabda; GPS: 47.889269, -96.270801; USGS 7.5-minute series Red Lake Falls, MN quadrangleAppendix 2, p. 227) is the type section of the Upper Member of the Red Lake Falls Formation and a reference section for the Lower Member of the Red Lake Falls Formation.

places it is marked by a cobble concentration. The upper contact of the Upper Red Lake Falls Member is a gradual interbedding with the overlying Wylie Formation. The Upper Red Lake Falls Member commonly becomes less sandy and more clayey near its upper contact. Where the Wylie Formation is absent, there is a diffuse contact with a contorted silty, pebbly clay containing silt inclusions. This is probably a subaqueous mud flow deposit made up of material derived from the Upper Red Lake Falls Member and the Wylie Formation. At several exposures along the Red Lake River the upper contact is an erosional surface overlain by Holocene fluvial sediment.

HISTORICAL BACKGROUND

The Red Lake Falls Formation was first described by Harris (1973) following a detailed study of outcrops along the Red Lake River between Thief River Falls and Crookston, Minnesota. The unit was formally named by Harris and others (1974). Subtle lithologic differences between the upper and lower parts of the formation were further defined Sackreiter (1975) who referred to an "upper" and "lower unit of the Red Lake Falls Formation". These were the first of several informal terms associated with the Red Lake Falls Formation that fell in and out of use over a period of several decades. Others include RRV03 and RRV04, the upper and lower parts of the Red Lake Falls Formation (Harris and others, 1995); the "Red Lake River group" (Harris and others, 1995; Harris, 1998; Thorleifson and others, 2005), the "Upper Red Lake Falls formation", and the "Lower Red Lake Falls formation" (Thorleifson and others, 2005; Harris, 2006, 2007).

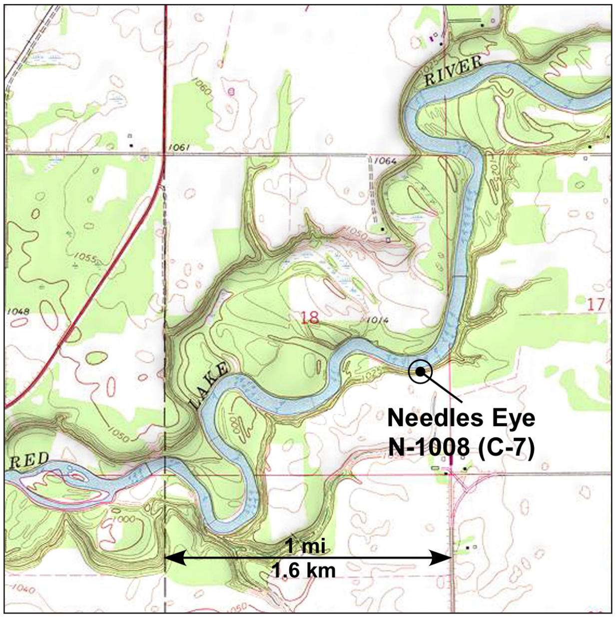
REGIONAL EXTENT AND THICKNESS

Figure A1.39 shows the regional extent of the Upper Red Lake Falls Member. The unit was deposited in the Red River Valley north and west of the Perley ice margin. It is exposed in outcrops along the Red Lake River trench from Thief River Falls, Minnesota to near Huot, Minnesota. It is present in surface exposures in northwestern Minnesota from the Canadian border to the Wild Rice River. It is present in the subsurface throughout the Red River Valley and is believed to extend westward into North Dakota.

The Upper Red Lake Falls Member ranges in thickness from 4 feet (1.2 meters) at the Red Lake River Cut Bank Section N-1020 (F-1) (T. 150 N., R. 45 W., sec. 17 cbccc) to at least 39 feet (11.9 meters) at the Old Dam Section (T. 151 N., R. 44 W., sec. 14 bddba). The normal range of thickness is from 7 to 23 feet (2.1 to 7 meters).

DIFFERENTIATION FROM OTHER UNITS

The Upper Red Lake Falls Member can be differentiated from similar units on the basis of texture, pebble lithology, and color. It is sandier than either the silty Gervais Formation or the Falconer and clayey Huot



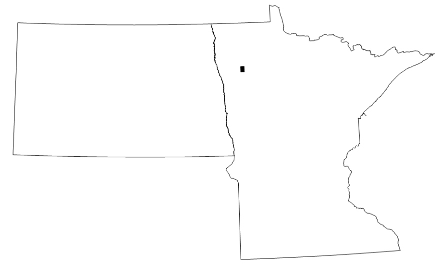
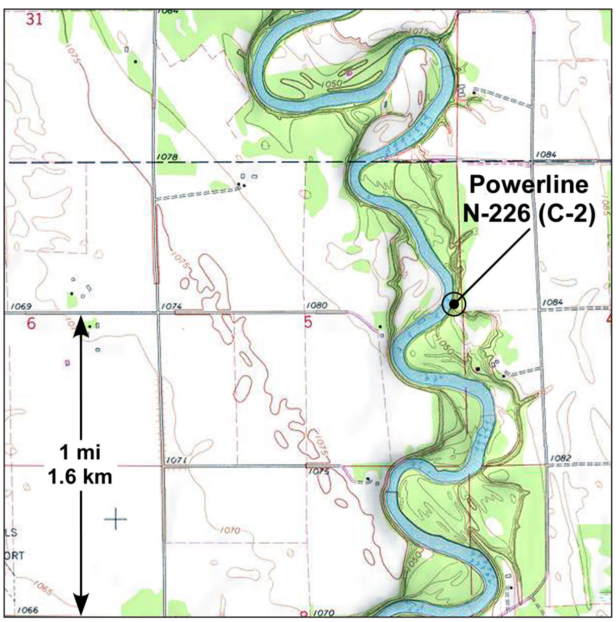


Figure A1.36. The Needles Eye Section (N-1008, C-7; T. 151 N., R. 43 W., sec. 18 dadbc; GPS: 47.895068, -96.206373; USGS 7.5-minute series Plummer NW, MN quadrangle; Appendix 2, p. 223) is a reference section for the Upper Member of the Red Lake Falls Formation.



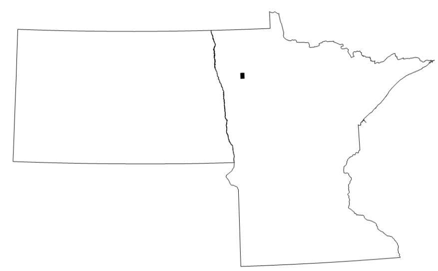


Figure A1.37. The Powerline Section (N-226, C-2; T. 151 N., R. 43 W., Sec. 5 addd; GPS: 47.926786, -96.184546; USGS 7.5-minute series Plummer NW, MN quadrangle; Appendix 2, p. 222) is a reference section for the Upper Member of the Red Lake Falls Formation and the type section of the Lower Member of the Red Lake Falls Formation.

Members of the Forest River Formation. It is lighter in color than both the Gervais Formation and the Huot Member of the Forest River Formation. Pebble lithology distinguishes the Upper Red Lake Falls Member from the Marcoux Member of the Crow Wing River Formation, and color distinguishes it from, the St. Hilaire Member of the Goose River Formation, which is much darker. The Upper Red Lake falls Member is distinguished from the Sheyenne River Formation by its stratigraphic position. The Upper Red Lake Falls Member is more conspicuously jointed and contains more shale than the Lower Red Lake Falls Member.

AGE

There are no absolute ages associated with the Upper Red Lake Falls Member. Based on its stratigraphic position it is Late Wisconsinan in age and was deposited when ice readvanced into the northern Red River Valley during the early Lockhart Phase of Lake Agassiz as deposition of the Argusville Formation continued in the southern part of the basin (fig. 9).

CORRELATION

The Upper Red River Falls Member does not appear to extend beyond the Red River Valley in North Dakota or Minnesota (B.A. Lusardi, written commun., 2018), although Harris and others (1974) noted stratigraphic similarities between the Upper Red Lake Falls Member and the "New Ulm Till" of Matsch (1971, 1972). Possible correlations of both units with part of the Blackduck Formation of north-central Minnesota have been suggested by Jennings and Gowan (2016) and Lusardi (2016). The Upper Red Lake Falls Member has no known correlative equivalent in North Dakota. The Upper Red Lake Falls Member may correlate with the Roseau Formation of southeastern Manitoba (fig. 15; Teller and Fenton, 1980; Harris and others, 2007). The correlation was based on data obtained from numerous rotary-sonic cores, shallow borings, and deep stratigraphic test wells.

GENESIS

The Upper Red Lake Falls Member is composed predominantly of glacial sediment. In the Red Lake Falls area, minor amounts of lake and stream sediment are included in the unit. In the central part of the Red River Valley, in eastern Grand Forks County, as much as 20 feet (6 meters) of laminated lacustrine clay lies between the Upper and Lower Red Lake Falls Members over an area of several tens of square miles. Several tens of feet of fluvial sand and gravel also occur in places.

The Upper Red Lake Falls Member of the Red Lake Falls Formation has a mixed Riding Mountain-Winnipeg-Rainy provenance. It was deposited as a result of a readvance of the generally retreating Late Wisconsinan glacier into the Red River Valley from a mainly north-northwesterly direction (fig. 17).

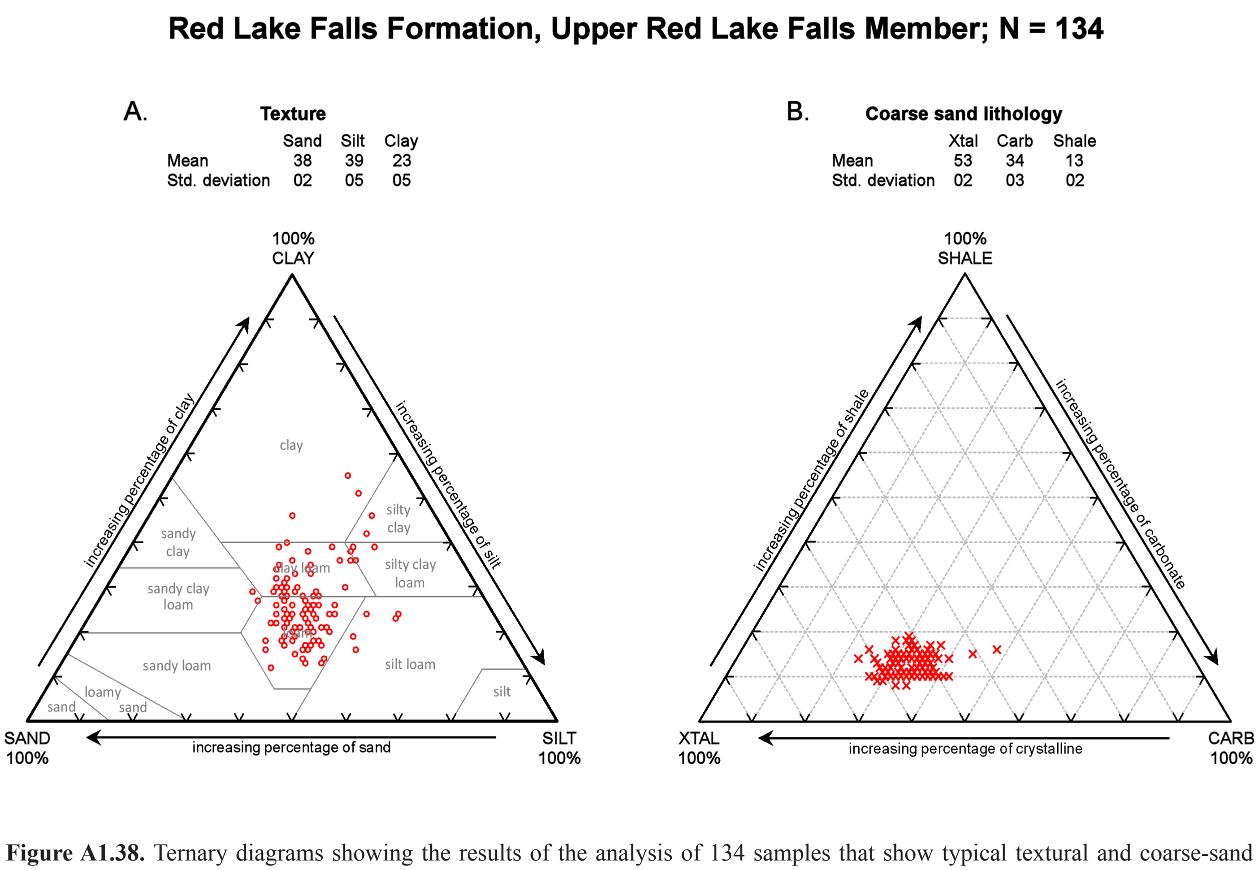


Figure A1.38. Ternary diagrams showing the results of the analysis of 134 samples that show typical textural and coarse-sand lithologic characteristics of the Upper Red Lake Falls Member of the Red Lake Falls Formation. The texture (A) of the Upper Red Lake Falls Member is loam to clay loam and the very coarse-sand lithology (B) indicates a mixed Riding Mountain-Winnipeg-Rainy provenance.

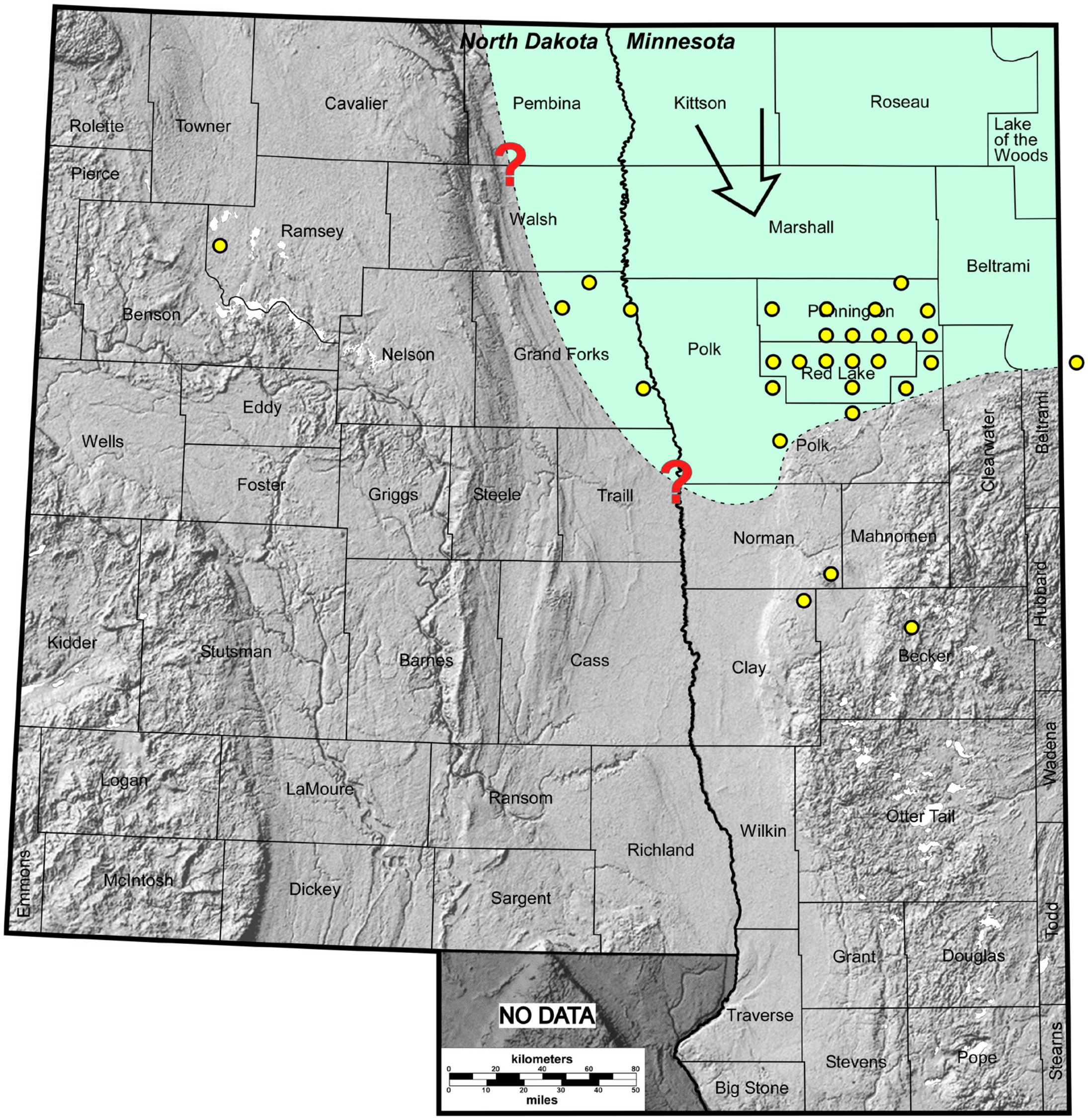


Figure A1.39. This figure shows the distribution of the Upper Red Lake Falls Member of the Red Lake Falls Formation in the Red River Valley of North Dakota and Minnesota. The Upper Red Lake Falls Member consists mainly of glacial sediment with a mixed Riding Mountain-Winnipeg-Rainy provenance. It is exposed at the surface along the Red Lake River and at several other locations throughout northwestern Minnesota but in North Dakota is only present in the subsurface. Yellow circles indicate townships where sample control is located. The arrow indicates the direction of ice flow.

Lower Red Lake Falls Member of the Red Lake Falls Formation

(New)

NAME AND RANK

The Lower Red Lake Falls Member of the Red Lake Falls Formation is formally named here. The source of the name is the city of Red Lake Falls, Red Lake County, Minnesota, located on the USGS 7.5-minute series Red Lake Falls, MN quadrangle.

TYPE AREA

Red Lake County, Minnesota.

TYPE SECTION

The type section of the Lower Red Lake Falls Member of the Red Lake Falls Formation is Powerline Section (N-226, C-2) on the Red Lake River, Gervais Township, Red Lake County, Minnesota (T. 151 N., R. 43 W., sec. 5 addd; GPS: 47.926786, -96.184546; USGS 7.5-minute series Plummer NW, MN quadrangle; fig. A1.37 and Appendix 2, p. 222).

REFERENCE SECTIONS

Three Creeks Section (N-1012, D-5) on the Red Lake River, Red Lake Falls Township, Red Lake County, Minnesota (T. 151 N., R. 44 W., sec. 21 babaa; GPS: 47.890372, -96.302541; USGS 7.5-minute series Red Lake Falls, MN quadrangle; fig. A1.40 and Appendix 2, p. 226) is a reference section for the Lower Red Lake Falls Member of the Red Lake Falls Formation.

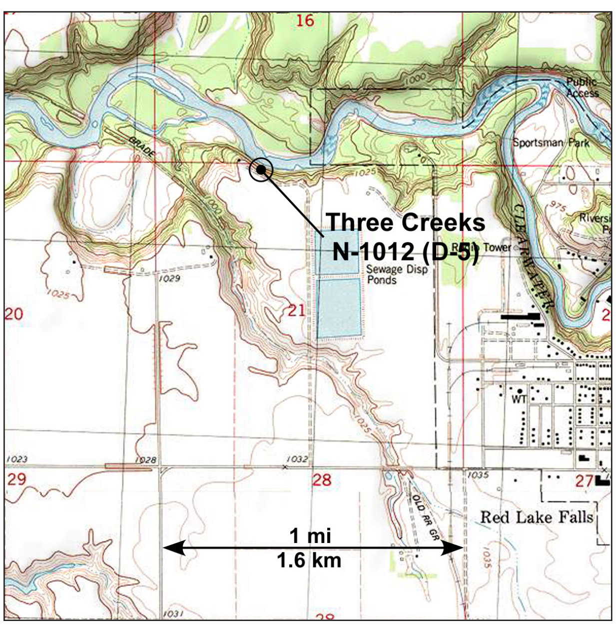
A second reference section is the Clearwater Section (N-113, CW-1) on the Clearwater River, Red Lake Falls Township, Red Lake County, Minnesota (T. 151 N., R. 44 W., sec. 22 aabda; GPS: 47.889269, -96.270801; USGS 7.5-minute series Red Lake Falls, MN quadrangle; fig. A1.35 and Appendix 2, p. 227).

LITHOLOGIC DESCRIPTION

The Lower Red Lake Falls Member is unbedded pebble-loam. It is light brownish gray (2.5Y 6/2) when dry and olive brown (2.5Y 4/4) when wet. The Lower Red Lake Falls Member is hard and resistant to erosion in dry outcrops and is friable when moist.

Sand and gravel inclusions are common; these include thin beds a few millimeters thick, channel fills, and contorted masses. Thin beds of laminated silt and clay as much as a few inches thick may be laterally persistent for tens of feet.

The Lower Red Lake Falls Member averages 40 percent sand, 40 percent silt, and 20 percent clay (fig. A1.41A); the very coarse-sand lithology (1-2 mm) averages 56 percent crystalline and metamorphic rock fragments, 40 percent carbonate rock fragments, and 4 percent shale



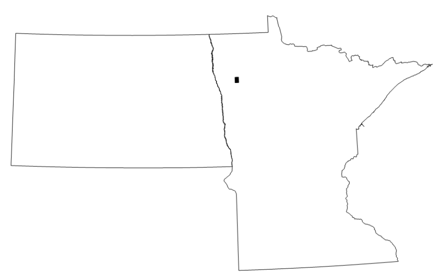


Figure A1.40. The Three Creeks Section (N-1012, D-5; T. 151 N., R. 44 W., sec. 21 babaa; GPS: 47.890372, -96.302541; USGS 7.5-minute series Red Lake Falls, MN quadrangle; Appendix 2, p. 226) is a reference section for the Lower Member of the Red Lake Falls Formation.

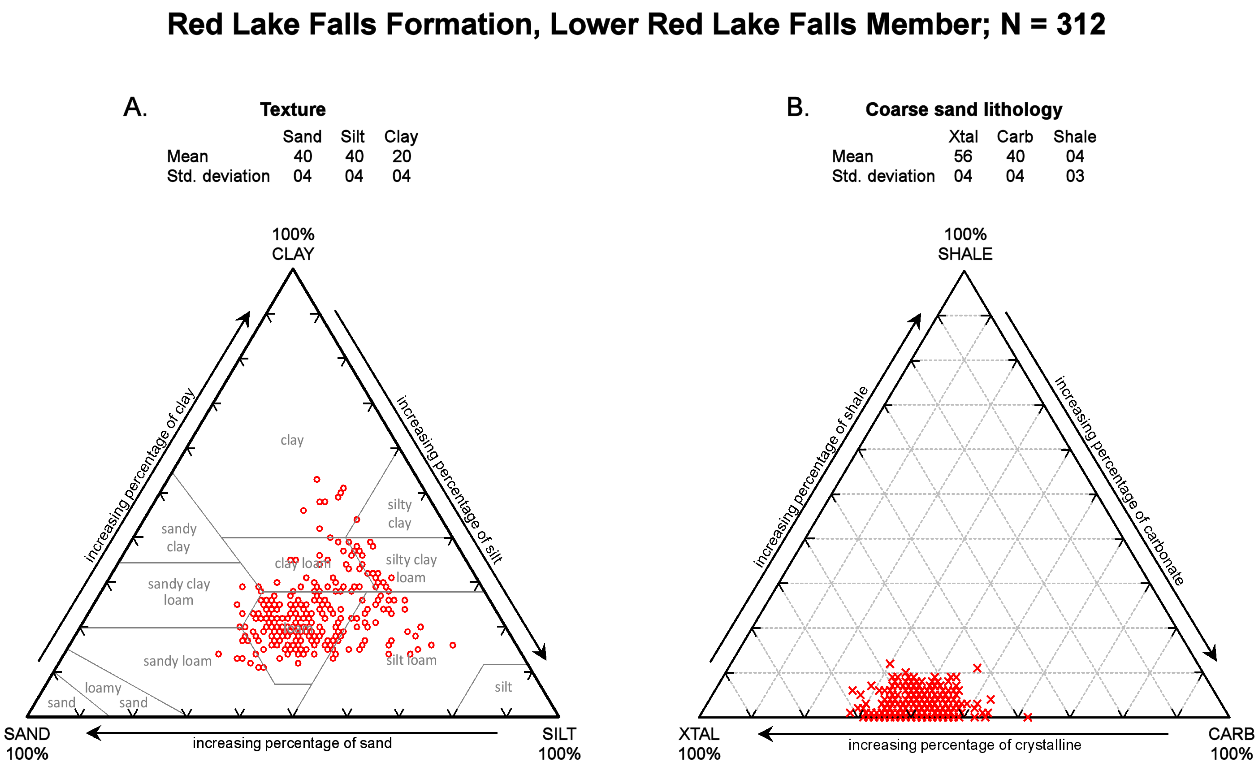


Figure A1.41. Ternary diagrams showing the results of the analysis of 312 samples that show typical textural and coarse-sand lithologic characteristics of the Lower Red Lake Falls Member of the Red Lake Falls Formation. The texture (A) of the Lower Red Lake Falls Member is loam to clay loam and the very coarse-sand lithology (B) indicates a mixed Winnipeg-Rainy (northern and northeastern) source area.

fragments (fig. A1.41B). Pebbles, cobbles, and boulders are abundant and consist of about two-thirds limestone and dolomite; about one-third igneous and metamorphic rock types, and noticeable amounts of shale.

DESCRIPTION OF BOUNDARIES

The upper and lower contacts of the Lower Red Lake Falls Member are best observed in exposures along the Red Lake River in Red Lake and Pennington Counties, Minnesota. In this area the Lower Red Lake Falls Member is overlain by the Upper Red Lake Falls Member. The contact between these two units is gradational to sharp and in some places it is marked by a cobble concentration. North of the Powerline Section (fig. A1.37), the Lower Red Lake Falls Member overlies the St. Hilaire Member of the Goose River Formation. The contact between these units is sharp to diffusely graded. The Marcoux Member of the Crow Wing River Formation underlies the Lower Red Lake Falls Member south of the Powerline Section. The contact between the two units is sharp, with sand and gravel commonly present. The sand and gravel ranges from a few inches to 17 feet (5.2 meters) thick. A boulder pavement is present at the contact in some outcrops.

HISTORICAL BACKGROUND

The Red Lake Falls Formation was first described by Harris (1973) following a detailed study of outcrops along the Red Lake River between Thief River Falls and Crookston, Minnesota. The unit was formally named by Harris and others (1974). Subtle lithologic differences between the upper and lower parts of the formation were further defined Sackreiter (1975) who referred to an “upper” and “lower unit of the Red Lake Falls Formation”. These were the first of several informal terms associated with the Red Lake Falls Formation that fell in and out of use over a period of several decades. Others include RRV03, RRV04, and the upper and lower parts of the Red Lake Falls Formation (Harris and others, 1995); the “Red Lake River group” (Harris and others, 1995; Harris, 1998; Thorleifson and others, 2005), the “Upper Red Lake Falls formation”, and the “Lower Red Lake Falls formation” (Thorleifson and others, 2005; Harris, 2006, 2007).

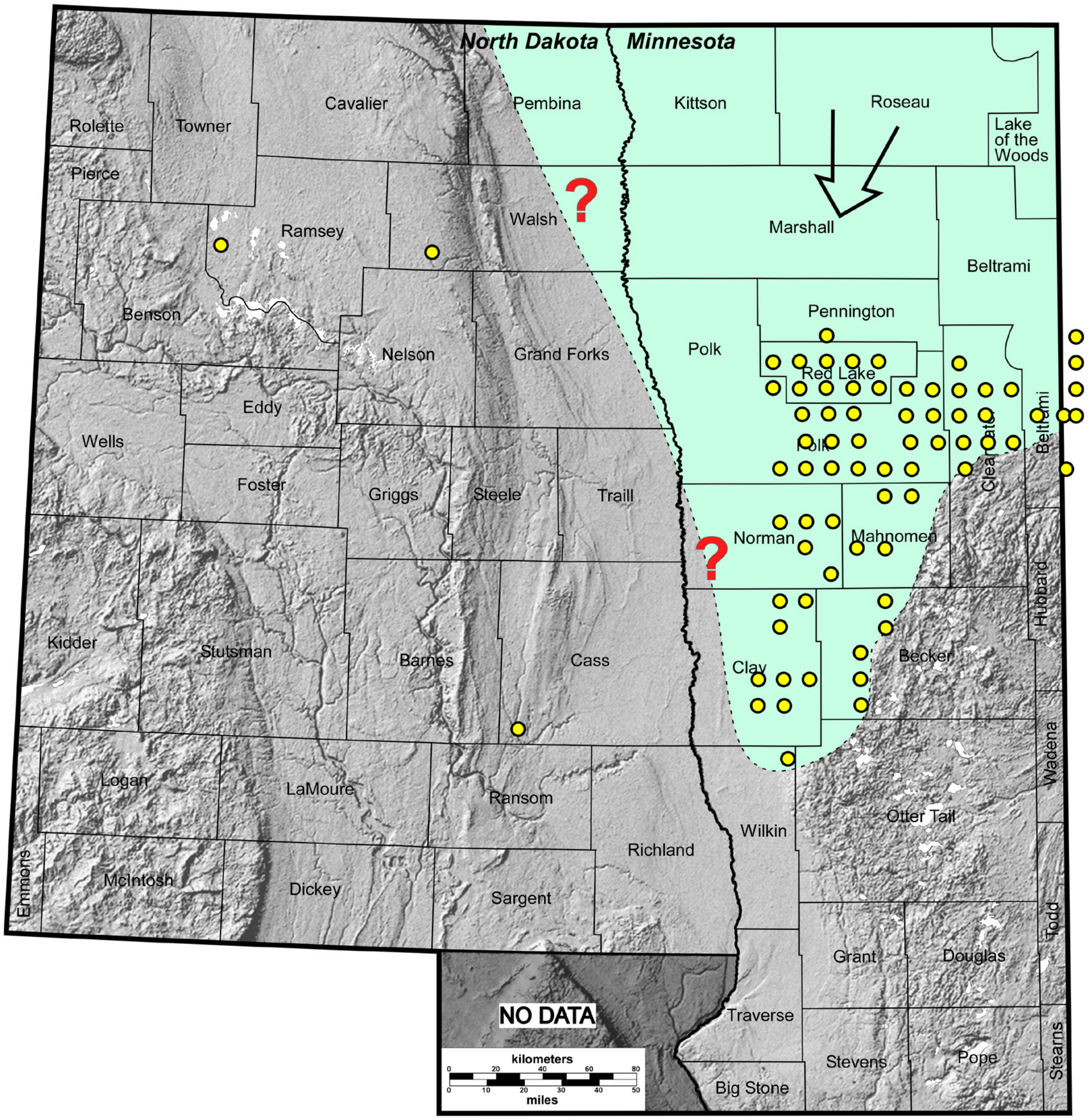


Figure A1.42. This figure shows the distribution of the Lower Red Lake Falls Member of the Red Lake Falls Formation in the Red River Valley of North Dakota and Minnesota. The Lower Red Lake Falls Member consists mainly of glacial sediment deposited by a glacier advancing from the north and northeast (mixed Winnipeg-Rainy provenance). It is exposed at the surface along the Red Lake River and at several other locations throughout northwestern Minnesota but in North Dakota is only present in the subsurface. Yellow circles indicate townships where sample control is located. The arrow indicates the direction of ice flow.

REGIONAL EXTENT AND THICKNESS

Figure A1.42 shows the regional extent of the Lower Red Lake Falls Member. The unit was deposited in the Red River Valley north of the Comstock ice margin. It is exposed in outcrops along the Red Lake River trench from Thief River Falls, Minnesota to near Huot, Minnesota. It is present in surface exposures in northwestern Minnesota from the Canadian border to the Wild Rice River. The western extent of the Lower Red Lake Falls Member is unclear but it is thought to be present in the subsurface of the Red River Valley in northeastern North Dakota.

The Lower Red Lake Falls Member ranges in thickness from 2 feet (0.6 meters) at Red Lake River Cut Bank Section N-1020 (F-1) (T. 150 N., R. 45 W., sec. 17 cbccc) to at least 100 feet (30.5 meters) in NDSWC Testhole 2430 (T. 151 N., R. 50 W., sec. 6 dad). The normal range of thickness is from 4 to 30 feet (1.2 to 9.1 meters).

DIFFERENTIATION FROM OTHER UNITS

The Lower Red Lake Falls Member can be distinguished from similar units on the basis of texture, pebble lithology, and color. It is sandier than either the silty Gervais Formation or the Falconer and clayey Huot Members of the Forest River Formation. It is lighter in color than both the Gervais Formation and the Huot Member of the Forest River Formation. Pebble lithology distinguishes the Lower Red Lake Falls Member from the Marcoux Member of the Crow Wing River Formation, and color distinguishes it from, the St. Hilaire Member of the Goose River Formation, which is much darker.

The Lower Red Lake Falls Member is not as conspicuously jointed and contains less shale than the Upper Red Lake Falls Member.

AGE

There are no absolute ages associated with the Lower Red Lake Falls Member. Based on its stratigraphic position it is Late Wisconsinan in age and was deposited when ice readvanced into the northern Red River Valley during the early Lockhart Phase of Lake Agassiz as deposition of the Argusville Formation continued in the southern part of the basin (fig. 9).

CORRELATION

Harris and others (1974) correlated the Lower Red Lake Falls Member with the "Granite Falls Till" of southwestern Minnesota (Matsch, 1971, 1972), a lithostratigraphic unit that the Minnesota Geological Survey has since abandoned (Johnson and others, 2016, p. 258).

The Lower Red River Falls Member does not appear to extend beyond the Red River Valley in North Dakota or Minnesota (B.A. Lusardi, written commun., 2018), although it has been suggested that it may be correlative with part of the Blackduck Formation of north-central Minnesota (Jennings and Gowan, 2016). The Lower Red Lake Falls Member may correlate with the lower part of the Roseau Formation and the Senkiw Formation in southern Manitoba (fig. 15; Harris and others, 2007). In North Dakota the Lower Red Lake Falls Member is stratigraphically and texturally similar to Arndt's "Unit A" (Arndt, 1977; K.L. Harris, unpub. data, 2013). A correlation between these two units would mean that the Lower Red Lake Falls Member extends much further west, at least as far as eastern Cass and Traill Counties, than figure A1.42 shows.

GENESIS

The Lower Red Lake Falls Member is composed predominantly of glacial sediment. In the Red Lake Falls area, minor amounts of lake and stream sediment are included in the unit. In the central part of the Red River Valley, in eastern Grand Forks County, as much as 20 feet (6.1 meters) of laminated lacustrine clay lies between the Upper and Lower Red Lake Falls Members over an area of several tens of square miles. Several tens of feet of fluvial sand and gravel also occur in places.

On the basis of pebble and sand-grain lithology we believe that the Lower Red Lake Falls Member of the Red Lake Falls Formation was deposited as a result of a readvance of the generally retreating Late Wisconsinan glacier into the Red River Valley from the north and northeast (mixed Winnipeg-Rainy provenance; fig. 17).

GOOSE RIVER FORMATION

(New)

NAME AND RANK

The Goose River Formation is named here. It is named after the Goose River in Traill County, North Dakota. The formation has three members: the St. Hilaire Member, the Dahlen Member and the Heiberg Member.

St. Hilaire Member of the Goose River Formation

(Revised)

NAME AND RANK

The St. Hilaire Member is modified in rank from formation to a member of the Goose River Formation. The description of the unit, as described by Harris, Clayton, and Moran (1974) is accepted with minor modifications owing to format changes and additional information. The source of the name is the village of St. Hilaire in Pennington County, Minnesota, located on the located on the USGS 7.5-minute series Thief River Falls, MN quadrangle.

TYPE AREA

Pennington County, Minnesota.

TYPE SECTION

The type section of the St. Hilaire Member of the Goose River Formation is Powerline Section (N-226, C-2) on the Red Lake River, Gervais Township, Red Lake County, Minnesota (T. 151 N., R. 43 W., sec. 5 addd; GPS: 47.926786, -96.184546; USGS 7.5-minute series Plummer NW, MN quadrangle; fig. A1.43 and Appendix 2, p. 222).

REFERENCE SECTIONS

A reference section for the St. Hilaire Member of the Goose River Formation is Minnesota Geological Survey rotary-sonic core OTT-3 (N-6603) in Grant County, Minnesota (T. 130 N., R. 42 W., sec. 17 dcdcb; GPS: 46.065364, -95.984458; USGS 7.5-minute series Fourmile Lake, MN quadrangle; fig. A1.44 and Appendix 2, p. 180).

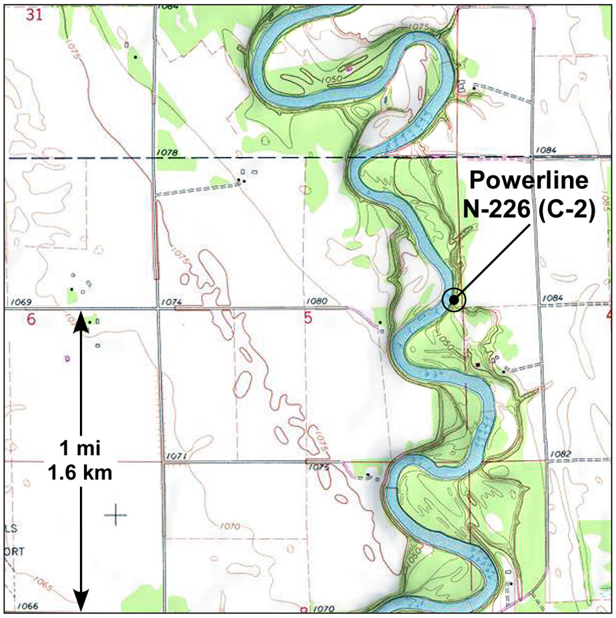
A second reference section is North Dakota Geological Survey power auger boring N-1917 in Mahnomen County, Minnesota (T. 144 N., R. 41 W., sec. 6 dccc; GPS: 47.311370, -95.921614; USGS 7.5-minute series Mahnomen, MN quadrangle; fig. A1.45 and Appendix 2, p. 215).

LITHOLOGIC DESCRIPTION

The St. Hilaire Member of the Goose River Formation is unbedded pebble-loam. It is gray (5Y 5/1) when dry and very dark gray (10Y 3/2) when wet. Weak vertical joints are common and result in a moderately columnar structure. The texture of the St. Hilaire Member averages 28 percent sand, 43 percent silt, and 29 percent clay (fig. A1.46A). Pebbles and cobbles are abundant. Two groups of pebbles, igneous and metamorphic rock types, and limestone and dolomite occur in equal numbers and constitute most of the pebbles. Shale pebbles, which are conspicuously present are about half as abundant as either of these groups. Lignite pebbles are commonly present in amounts as great as 5 percent of the total pebble fraction. The very coarse-sand lithology (1-2 mm) averages 41 percent crystalline and metamorphic fragments, 35 percent carbonate rock fragments, and 24 percent shale fragments (fig. A1.46B). Calcareous material makes up about 25 percent of the sediment finer than 200 mesh.

DESCRIPTION OF BOUNDARIES

The St. Hilaire Member overlies the Marcoux Member of the Crow Wing River Formation in the Red Lake Falls area. The contact between them is sharp and is typically marked by a cobble concentration or boulder pavement. In some places as much as 18 inches (0.5 meters) of fine sand is present at the contact. To the west and south the St. Hilaire Member overlies older members of the Goose River Formation. The upper contact with the lower member of the Red Lake Falls Formation is sharp to



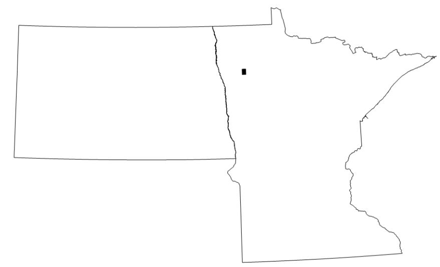
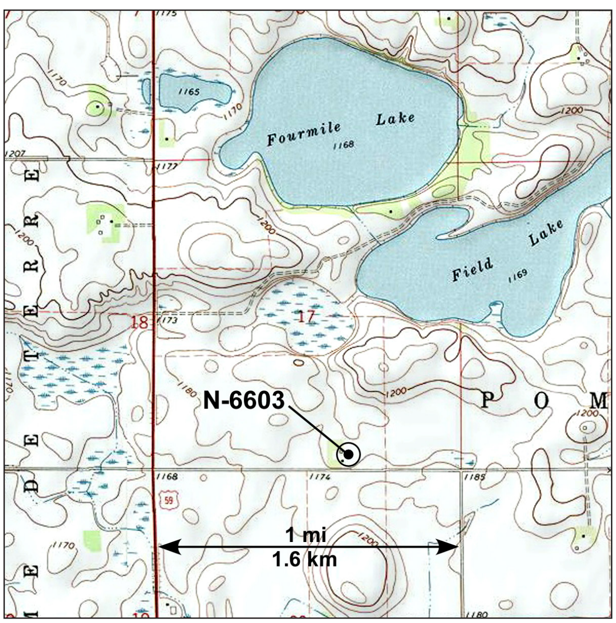


Figure A1.43. The Powerline Section (N-226, C-2) on the Red Lake River, Gervais Township, Red Lake County, Minnesota (T. 151 N., R. 43 W., sec. 5 addd; GPS: 47.926786, -96.184546; USGS 7.5-minute series Plummer NW, MN quadrangle; Appendix 2, p. 222) is the type section of the St. Hilaire Member of the Goose River Formation.



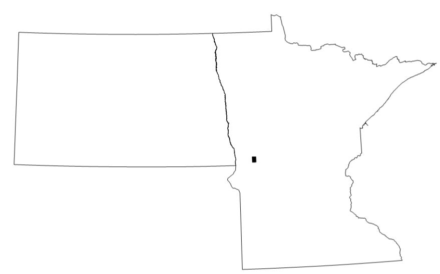
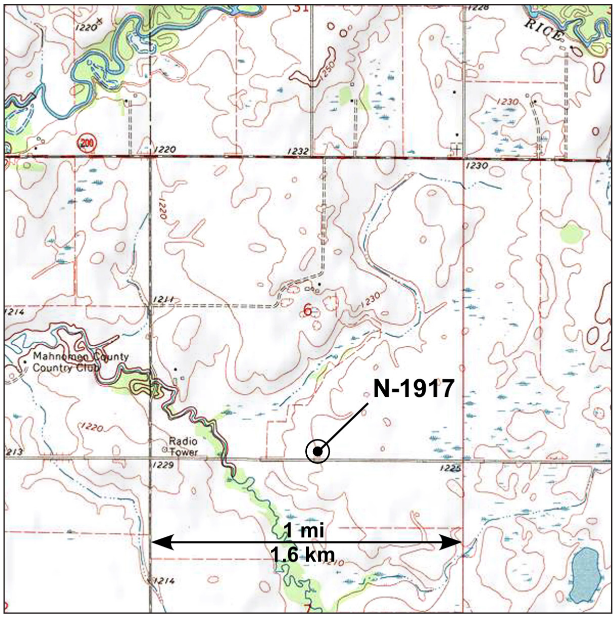


Figure A1.44. Minnesota Geological Survey rotary-sonic core OTT-3 (N-6603) in Grant County, Minnesota (T. 130 N., R. 42 W., sec. 17 dcdcb; GPS: 46.065364, -95.984458; USGS 7.5-minute series Fourmile Lake, MN quadrangle; Appendix 2, p. 180) is a reference section for the St Hilaire Member of the Goose River Formation.

gradational. Discontinuous and contorted sand beds are commonly present.

HISTORICAL BACKGROUND

The St. Hilaire Member was first described by Harris (1973) and formally named by Harris and others (1974) as a lithostratigraphic unit of formation rank. In the southern Red River Valley, the St. Hilaire Formation was correlated with unit RRV07 of the informal Goose River group (Harris and others, 1995; Harris, 1998). Later reports refer to this unit as the St. Hilaire Formation of the Upper Goose River group (Harris and others, 1999, 2003; Harris and Berg, 2006). The St. Hilaire Member also includes till of the Barnesville formation, an informal unit in west-central Minnesota described by Anderson (1976) and Perkins (1977), and correlated with unit RRV06 of Harris and others (1995).



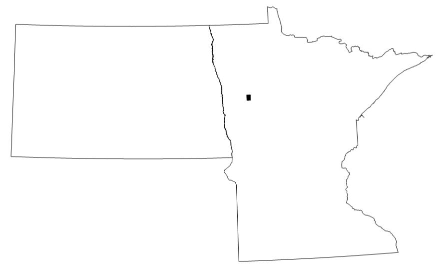


Figure A1.45. North Dakota Geological Survey power auger boring N-1917 in Mahnomen County, Minnesota (T. 144 N., R. 41 W., sec. 6 dccc; GPS: 47.311370, -95.921614; USGS 7.5-minute series Mahnomen, MN quadrangle; Appendix 2, p. 215) is a reference section for the St. Hilaire Member of the Goose River Formation.

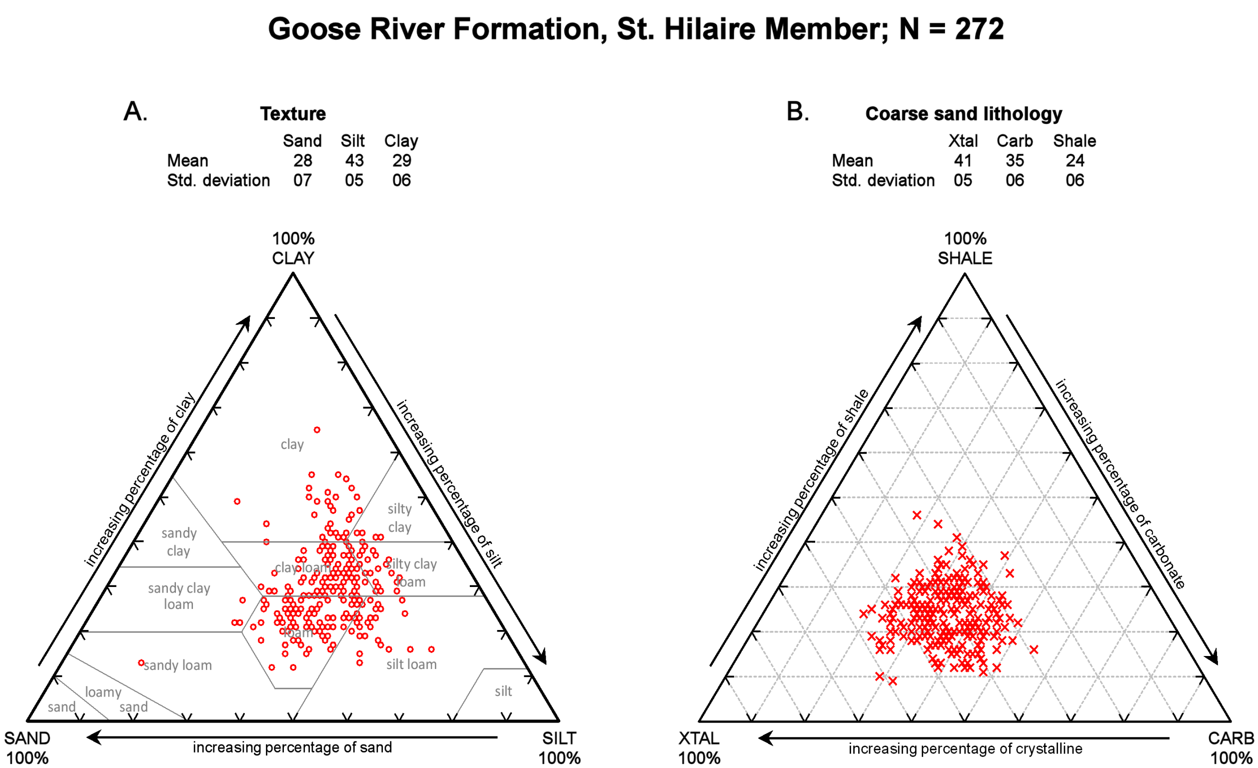


Figure A1.46. Ternary diagrams showing the results of the analysis of 272 samples that show typical textural and coarse-sand lithologic characteristics of the St. Hilaire Member of the Goose River Formation. The texture (A) of the St. Hilaire Member is loam to clay loam and the very coarse-sand lithology (B) indicates a mixed Riding Mountain-Winnipeg (northwestern and northern) source area.

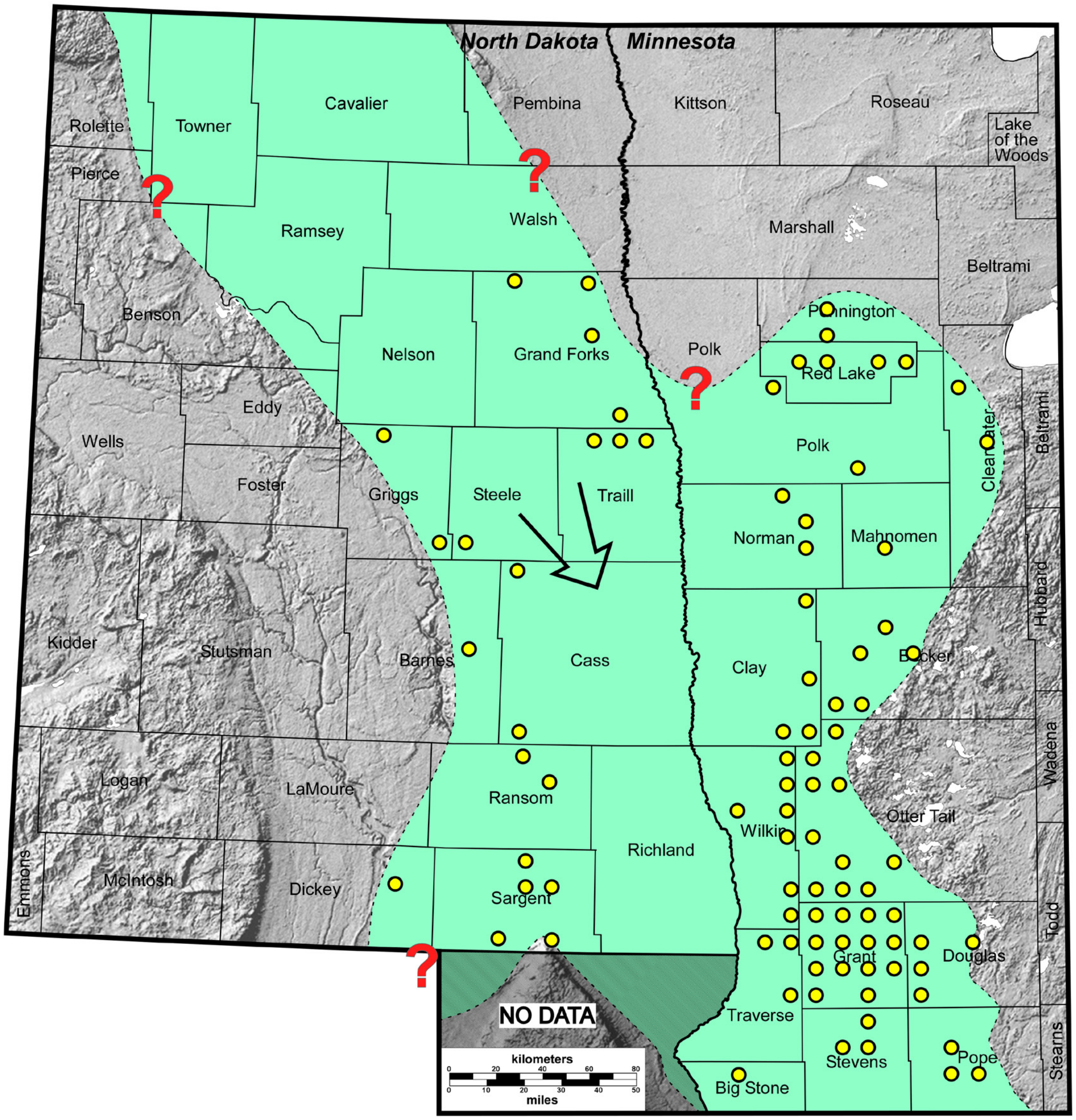


Figure A1.47. This figure shows the distribution of the St Hilaire Member of the Goose River Formation in the Red River Valley of North Dakota and Minnesota and eastern North Dakota. The St. Hilaire Member consists mainly of glacial sediment deposited during a minor readvance of the Des Moines lobe from the northwest and north (mixed Riding Mountain-Winnipeg provenance). It is exposed at the surface along the Red Lake River and at several other locations throughout northwestern Minnesota. It is the surface unit outside the Red River Valley in parts of eastern North Dakota but is only present in the subsurface within the Valley itself. Yellow circles indicate townships where sample control is located. The arrow indicates the direction of ice flow.

REGIONAL EXTENT AND THICKNESS

The St. Hilaire Member is present in the subsurface throughout the central and southern Red River Valley. It extends east and southeastward into Minnesota as far as the Alexandria and Itasca moraine complexes (fig. A1.47; Johnson and others, 2016, fig. 13). In North Dakota till identified as the St. Hilaire Member has been found in eastern and northwest Griggs County and in eastern Barnes and Dickey counties. Its western boundary is coincident with a series of end moraines associated with the Cooperstown ice margin (Clayton and Moran, 1982), which probably correlates with the Big Stone moraine at the southern end of the Red River Valley. The St. Hilaire Member was expected to continue northwestward across northeastern North Dakota and into parts of southern Manitoba, but the absence of the unit from exposures along the Forest River and Pembina Escarpment, suggests its partial or complete removal from the area, most likely by postglacial erosion. Where it is present, the St. Hilaire Member is commonly the surface unit in eastern North Dakota outside the Red River Valley.

In Minnesota the St. Hilaire Member is exposed along the Red Lake River valley between Thief River Falls, south to the Powerline Section. In this area the unit is between 1 and 4 feet (0.3 to 1.2 meters) thick. Its characteristic dark color makes it a useful stratigraphic marker.

The St. Hilaire Member thickens to the south and west. About 20 feet (6.1 meters) of the unit is exposed on the Wild Rice River near Heiberg, Minnesota. The maximum recorded thickness of the unit is 63 feet (19.2 meters) in North Dakota Geological Survey boring N-1914 in Clearwater County, Minnesota (T. 148 N., R. 37 W., sec. 18 bbc). The average thickness is about 23 feet (7 meters).

DIFFERENTIATION FROM OTHER UNITS

In its type area the St. Hilaire Member is easily distinguished from the Marcoux and Lower Red Lake Falls Members by pebble lithology and color. The Marcoux Member contains predominantly igneous and metamorphic pebbles and the Lower Red Lake Falls Member contains largely limestone and dolomite pebbles. Neither of these units contain appreciable shale or lignite, and both are lighter in color than the dark gray St. Hilaire Member. The Dahlen and Heiberg Members of the Goose River Formation contain significantly more shale than the St. Hilaire Member.

AGE

The stratigraphic position of the St Hilaire Member suggests that it is Late Wisconsinan in age and was deposited during the Cass Phase of Lake Agassiz between about 11.8 and 11.6 ^{14}C yr BP (fig. 9; Arndt, 1977; Clayton and Moran, 1982). This is consistent with radiocarbon and OSL dates from sites adjacent to the Big Stone moraine, which indicate a minimum age for the moraine of about 14.0 ka (Lepper and others, 2007).

CORRELATION

The St. Hilaire Member is stratigraphically and texturally similar to Arndt's "Unit B" (Arndt, 1977; K.L. Harris, unpub. data, 2013), "Unit C" of Camara (1977), and the informal Hansboro formation described by Hobbs (1975). The unit has no known correlative equivalent outside the Red River Valley and the adjacent areas.

GENESIS

The St. Hilaire Member is glacial sediment that was deposited during a brief readvance of the Des Moines lobe to the Cooperstown ice margin and the Big Stone moraine. The lithology of the pebble and coarse sand fractions suggests northwestern and northern source areas (mixed Riding Mountain-Winnipeg provenance; fig. 17).

Dahlen Member of the Goose River Formation

(Revised)

NAME AND RANK

The Dahlen Member is modified in rank from formation to a member of the Goose River Formation. The description of the unit, as described by Salomon (1975) is accepted with revisions owing to format changes and additional information. The source of the name is the village of Dahlen in Nelson County, North Dakota, located on the located on the USGS 7.5-minute series Dahlen, ND quadrangle.

TYPE AREA

Western Grand Forks County, North Dakota.

TYPE SECTION

The original type section defined by Salomon (1975) was a stream cut (Cut I, N-518) along the Forest River in Grand Forks County, North Dakota (T. 154 N., R. 55 W., sec. 10 ada; USGS 7.5-minute series Inkster, ND quadrangle; fig. A1.48 and Appendix 2, p. 239). Here, approximately 6 feet (1.8 meters) of the "Dahlen Formation" is exposed at the base of the section. It is overlain by 4 feet (1.2 meters) of lake sediment interpreted as the Wylie Formation, which is covered, in turn, by 40 feet (12.2 meters) of diamicton interpreted as the "Falconer Formation". The uppermost unit consists of 39 feet (11.9 meters) of silty and sandy lake sediment. This section was resampled by Harris and Luther in the late 1980s who determined that, in terms of its texture and coarse sand lithology, the unit identified as the "Falconer Formation" more closely resembles the older tills of the Goose River Formation. Further studies corroborated these findings, but a shortage of quantitative data has precluded attempts to reliably correlate this unit, determine its overall extent, or explain the stratigraphic anomaly. Notwithstanding, the unit was added to the Goose River Formation as the youngest and informally named "Inkster member" (K.L. Harris, unpub. data, 2014). These uncertainties imply that the original type section is no longer considered to be an adequate representation of the Dahlen Member. The redefined type section (N-5943, fig. A1.48 and Appendix 2, p. 240) is consequently supplemented by a principal reference section.

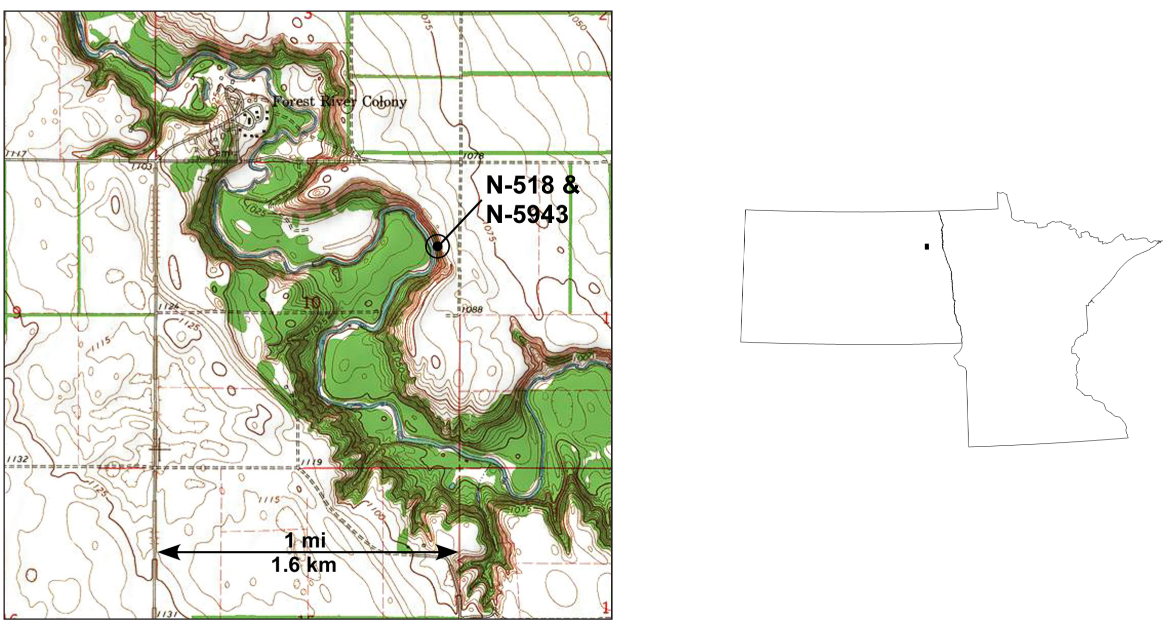
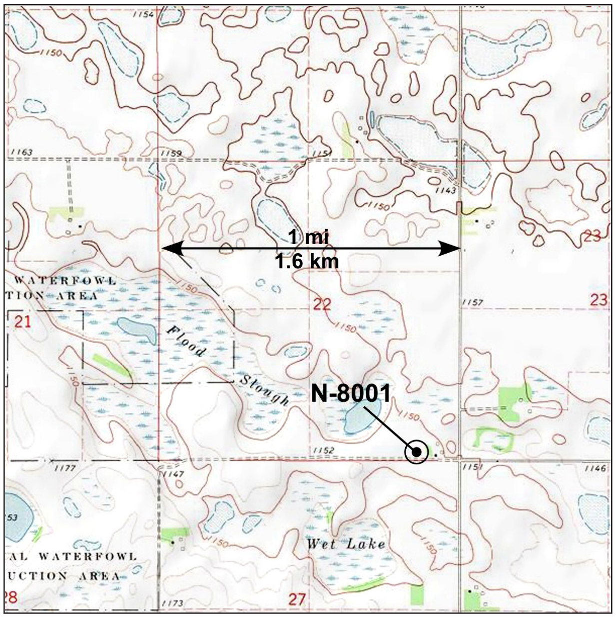


Figure A1.48. Forest River Cut I (N-518) on the Forest River, Inkster Township, Grand Forks County, North Dakota (T. 154 N., R. 55 W., sec. 10 ada; GPS: 48.176736, -97.689121; USGS 7.5-minute series Inkster, ND quadrangle; Appendix 2; p. 239) is the original type section of the Dahlen Member of the Goose River Formation. It was redefined as Forest River Cut I (N-5943) after further studies showed the section had been incorrectly described.



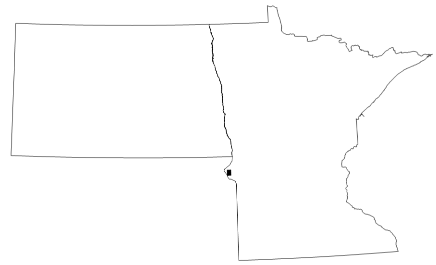
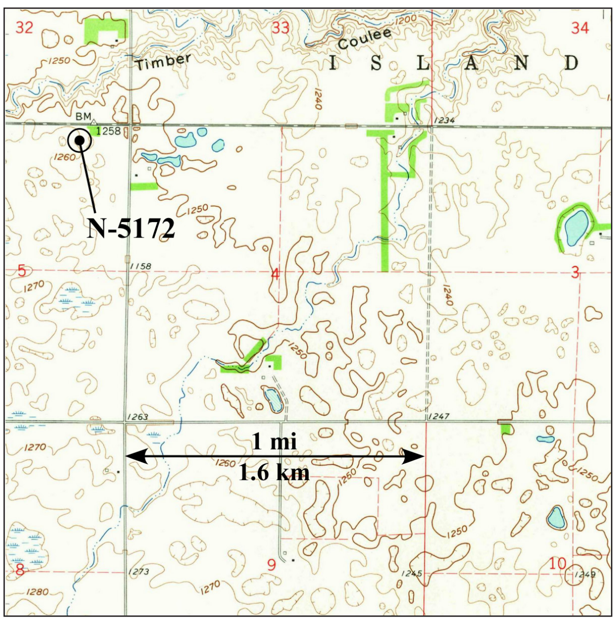


Figure A1.49. Minnesota Geological Survey rotary-sonic core TG-1 (N-8001) in Traverse County, Minnesota (T. 125 N., R. 48 W., sec. 22 ddcdda; GPS: 45.615106, -96.680721; USGS 7.5-minute series Beardsley, MN quadrangle; Appendix 2, p. 163) is the principal reference section of the Dahlen Member of the Goose River Formation.



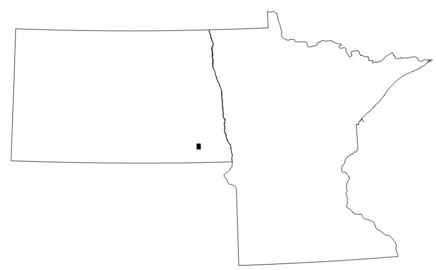


Figure A1.50. North Dakota Geological Survey power auger boring N-5172 in Ransom County, North Dakota (T. 133 N., R. 56 W., sec. 5 aab; GPS: 46.368457, -97.745185; USGS 7.5-minute series Lisbon SW, ND quadrangle; Appendix 2, p. 196) is a reference section of the Dahlen Member of the Goose River Formation.

REFERENCE SECTIONS

The principal reference section is Minnesota Geological Survey rotary-sonic core TG-1 (N-8001) in Traverse County, Minnesota (T. 125 N., R. 48 W., sec. 22 ddcdda; GPS: 45.615106, -96.680721; USGS 7.5-minute series Beardsley, MN quadrangle; fig. A1.49 and Appendix 2, p. 163).

A reference section for the Dahlen Member of the Goose River Formation is North Dakota Geological Survey power auger boring N-5172 in Ransom County, North Dakota (T. 133 N., R. 56 W., sec. 5 aab; GPS: 46.368457, -97.745185; USGS 7.5-minute series Lisbon SW, ND quadrangle; fig. A1.50 and Appendix 2, p. 196).

LITHOLOGIC DESCRIPTION

The Dahlen Member of the Goose River Formation consists of pebble-loam and a minor amount of weakly bedded lake sediment. The massive, friable pebble-loam contains abundant shale pebbles. The color of the Dahlen

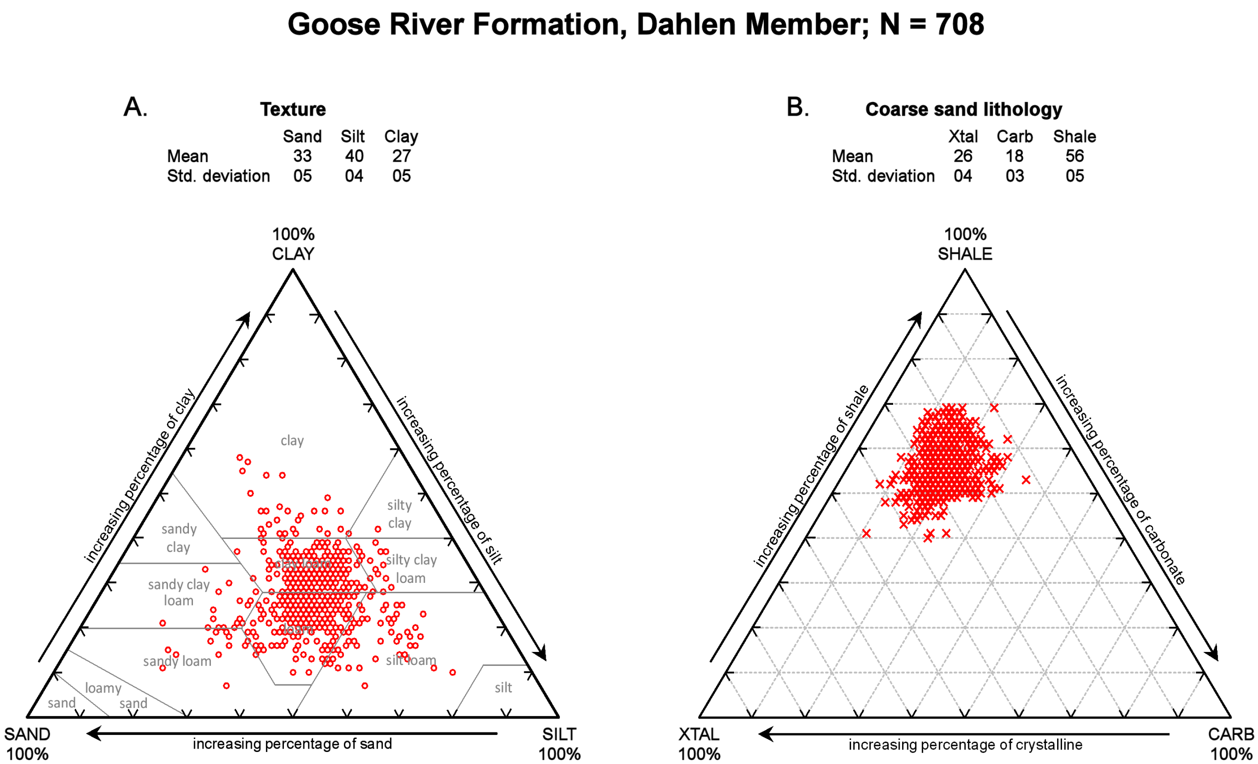


Figure A1.51. Ternary diagrams showing the results of the analysis of 708 samples that show typical textural and coarse-sand lithologic characteristics of the Dahlen Member of the Goose River Formation. The texture (A) of the Dahlen Member is mainly loam to clay loam and the very coarse-sand lithology (B) indicates a Riding Mountain (northwestern) source area.

Member varies but typically is light olive brown (2.5Y 5/4) to light brownish gray (2.5Y 6/2) when oxidized and grayish brown (2.5Y 5/2) to very dark gray (10YR 3/1) when unoxidized. The average shale content of the very coarse sand fraction (1-2 mm) is 56 percent, with 26 percent crystalline and metamorphic fragments, and 18 percent carbonate rock fragments. The texture of the sediment is clay loam, silty clay loam, silty loam, or loam with an average composition of 33 percent sand, 40 percent silt, and 27 percent clay (fig. A1.51).

DESCRIPTION OF BOUNDARIES

In southeastern North Dakota and near the Big Stone moraine, the Dahlen Member commonly overlies the Heiberg Member from which it is almost indistinguishable in the field. At the principal reference section (core TG-1) south of the moraine, the Dahlen Member overlies the Villard Member of the James River Formation. In boring N-5172, and at numerous other sites throughout eastern North Dakota, the Dahlen Member directly overlies the Gardar Formation or, more rarely, bedrock. In many outcrops, the pebble-loam of the Dahlen Member and pebble-loam of the Gardar Formation are separated by a soled boulder pavement. Striations on the boulder pavement indicate a northwest-southeast flow direction. In other outcrops, stratified sand and gravel of the Dahlen Member directly overlies pebble-loam of the Gardar Formation. In western Grand Forks County, the Dahlen Member commonly overlies Cretaceous bedrock. In this area, the base of the Dahlen Member typically consists of a boulder lag, but stratified sand and gravel and laminated, silty clay also occur at the base of the unit.

In parts of the northwestern Red River Valley and the adjacent uplands, the Dahlen Member is directly overlain by pebble loam of the St. Hilaire Member or the informal Inkster member of the Goose River Formation (K.L. Harris, unpub. data, 2014). Locally, the contact between the two units is marked by a layer of sand and gravel that ranges in thickness from about 10 to 50 feet (3 to15.2 meters). In outcrop, the contact between the Dahlen Member and the Inkster member is difficult to determine. Outside the Red River Valley in eastern North Dakota, where it is not at the surface, the Dahlen Member is commonly overlain by the St. Hilaire Member.

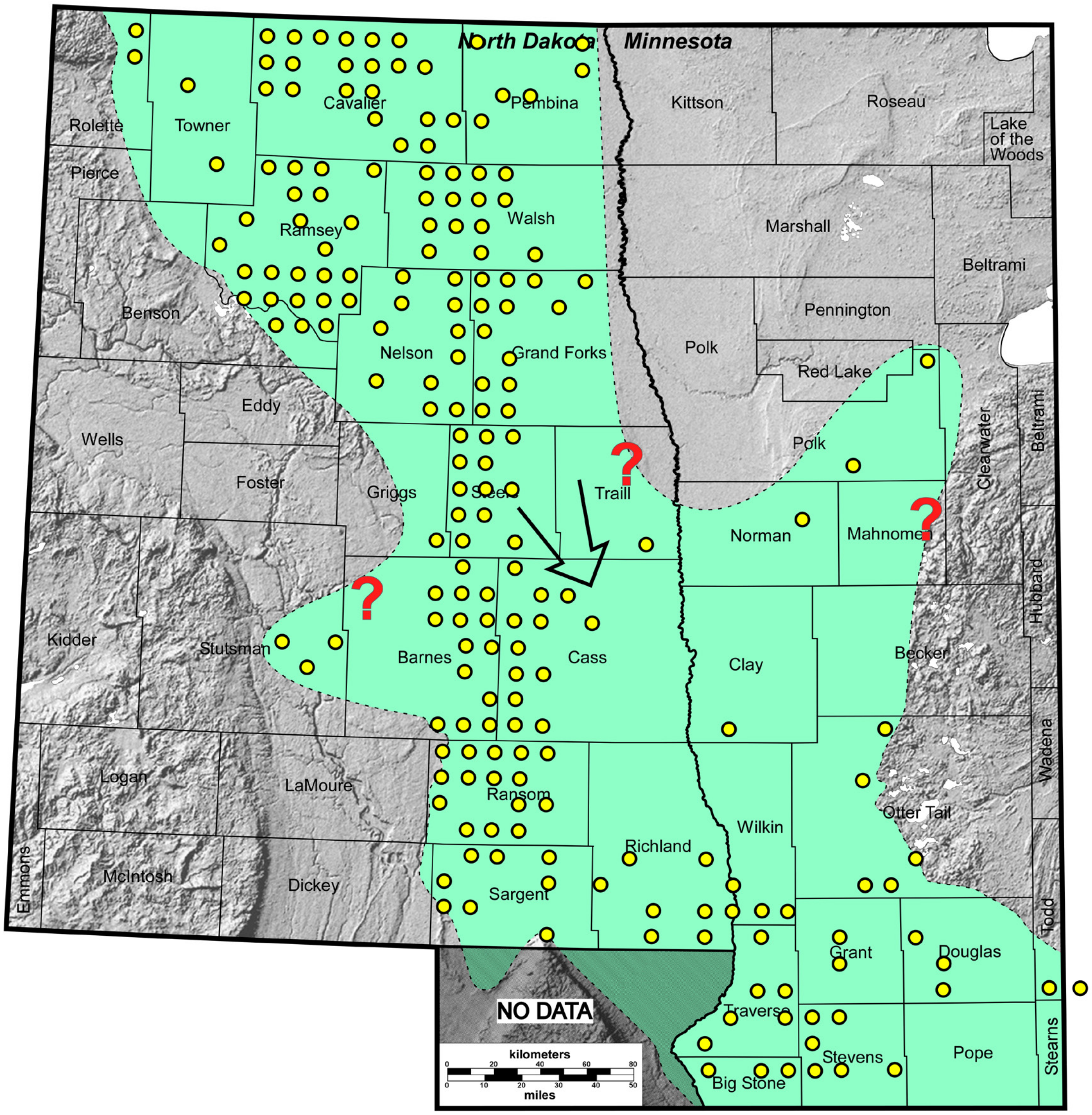


Figure A1.52. This figure shows the distribution of the Dahlen Member of the Goose River Formation in the Red River Valley of North Dakota and Minnesota, and eastern North Dakota. The Dahlen Member consists mainly of glacial sediment that was deposited either during a readvance of the Des Moines lobe from the northwest (Riding Mountain provenance) or as a recessional feature that records a pause in its retreat from the Algona moraine in northern Iowa. The Dahlen Member is the surface unit throughout most of eastern North Dakota and is exposed in the western Red River Valley along the steep banks of former meltwater channels now occupied by modern streams such as the Forest and Park River. Yellow circles indicate townships where sample control is located. The arrow indicates the direction of ice flow.

HISTORICAL BACKGROUND

The Dahlen Member was first described and formally named by Salomon (1975) as a lithostratigraphic unit of formation rank. In the southern Red River Valley, the Dahlen Formation was correlated with unit RRV08 of the informal Goose River group (Harris and others, 1995; Harris, 1998). Later reports refer to this unit as the Dahlen Formation of the Lower Goose River group (Harris and others, 1999; Thorleifson and others, 2005; Harris and Berg, 2006).

REGIONAL EXTENT AND THICKNESS

The Dahlen Member is present throughout eastern North Dakota and all but the northeastern quarter of the Red River Valley (fig. A1.52). It is spatially more continuous than the St. Hilaire Member but otherwise covers approximately the same area, and is mostly bounded by the same landforms, that is, the Alexandria and Itasca moraine complexes to the east and southeast in Minnesota (fig. A1.52; Johnson and others, 2016, fig. 13), the Big Stone moraine to the south, and the Cooperstown moraine in northeast-central North Dakota. In northern Barnes County, the Dahlen Member extends westward to the southern lobe of the Kensal end moraine (Kelly and Block, 1967; Clayton and Moran, 1982; Biek, 1994) then follows the Kensal-Oakes ice margin into northeastern South Dakota. The Dahlen Member continues northwestward into southern Manitoba at least as far as the community of Lena, about 15 miles (24 kilometers) north of Rolla, North Dakota (Salomon, 1975).

Exposures of the Dahlen Member are common in Cavalier, Pembina, Walsh, Grand Forks, and Steele Counties, particularly along the Pembina Escarpment and the deeply incised valleys of former meltwater channels now occupied by modern streams such as the Forest and Park Rivers. To the south, the Dahlen Member is exposed in outcrops along the Sheyenne River trench as far as Lisbon in Ransom County (Bluemle, 1979), and on the Big Stone moraine. It is the surface unit throughout a large part of eastern North Dakota.

The Dahlen Member ranges in thickness from 0 to 100 feet (0 to 30.5 meters) with an average thickness of 28 feet (8.5 meters). In areas where the unit tends to be thin, most notably along the Pembina Escarpment, the pebble-loam may be absent in places or so thin that it is obscured by the overlying soil horizon, leaving the only the basal boulder pavement intact. The Dahlen Member is thickest on the distal side of the Big Stone moraine.

DIFFERENTIATION FROM OTHER UNITS

The pebble-loam of the Dahlen Member contains more shale fragments than pebble-loam of the St. Hilaire and Heiberg Members, the Lower Red Lake Falls Member of the Red Lake Falls Formation, and the Falconer Member of the Forest River Formation. It is distinguished from the Gardar Formation by its lower shale content and shale pebble (4 to 64 mm) count. Pebble-loam of the Dahlen Member is visually very similar to the pebble-loam of the Inkster member, particularly in the vicinity of the Edinburg moraine. In most outcrops, pebble-loam of the Dahlen Member contains more shale pebbles than the overlying pebble-loam. In other outcrops, the units look alike, and the only way to differentiate between them in in the field is where they are separated by a sizeable interval of lake sediment or sand and gravel.

AGE

The stratigraphic position of the Dahlen Member suggests that it is Late Wisconsinan in age. It is slightly older than the St. Hilaire Member and was deposited sometime prior to 14.0 ka, shortly before the retreating ice margin moved north of the Big Stone moraine (Arndt, 1977; Lepper and others, 2007).

CORRELATION

The Dahlen Member is stratigraphically and texturally similar to Arndt's "Unit D" (Arndt, 1977; K.L. Harris, unpub. data, 2013), and "Unit B" of Camara (1977). The unit has no known correlative equivalent outside the Red River Valley and the adjacent areas.

GENESIS

The Dahlen Member is glacial sediment that may have been deposited during a readvance of the Des Moines lobe to the Kensal-Oakes ice margin and the Big Stone moraine (Clayton and Moran, 1982). Lepper and others (2007) suggest that the Big Stone moraine is a major recessional feature of the Des Moines lobe that records a pause in its retreat from the Algona moraine in northern Iowa. The lithology of the pebble and coarse sand fractions of the Dahlen Member suggests a northwestern (Riding Mountain) provenance (fig. 17).

Heiberg Member of the Goose River Formation

(Redefined)

NAME AND RANK

The Heiberg Member of the New Ulm Formation was formally named in Minnesota by Lusardi and Harris, 2016a. It is redefined here for use in North Dakota as the Heiberg Member of the Goose River Formation. The unit is named after the town of Heiberg, Minnesota located on the USGS 7.5-minute series Twin Valley, MN quadrangle.

TYPE SECTION

Wild Rice River cut bank (N-5945, Heiberg Section) near Heiberg, Minnesota is designated as the type section of the Heiberg Member of the Goose River Formation. The section is in Norman County at T. 144 N., R. 44 W., sec. 16 cccab (GPS: 47.283060, -96.277867; USGS 7.5-minute series Twin Valley, MN quadrangle; fig. A1.53 and Appendix 2, p. 216).

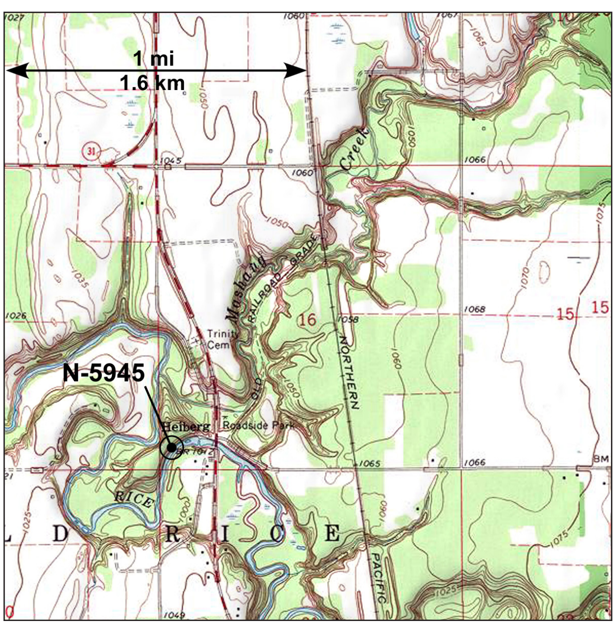
REFERENCE SECTIONS

Minnesota Geological Survey rotary-sonic core N-8002 (TG-2) is designated as a reference section for the Heiberg Member of the Goose River Formation. The core was drilled in Traverse County, Minnesota at T. 127 N., R. 45 W., sec. 2 bcccd GPS: 45.840177, -96.294181; USGS 7.5-minute series Wheaton SE, MN quadrangle; fig. A1.54 and Appendix 2, p. 170).

Minnesota Geological Survey rotary-sonic core N-8003 (TG-3) is also a reference section for the Heiberg Member of the Goose River Formation. This core was drilled in Stevens County, Minnesota at T. 124 N., R. 43 W., sec. 28 cddadb; GPS: 45.514182, -96.066534; USGS 7.5-minute series Alberta, MN quadrangle; fig. A1.55 and Appendix 2, p. 160).

LITHOLOGIC DESCRIPTION

The Heiberg Member is composed almost entirely of loamy diamicton, which is interpreted to be till. Till of the Heiberg Member of the Goose River Formation is a pebbly loam to clay loam that averages 34 percent sand, 39 percent silt, and 27 percent clay (fig. A1.56A). The till color varies but is typically light yellowish brown (10 YR 6/4) to light brownish gray (10 YR 6/2) when oxidized, and dark gray brown (10 YR 4/1) to gray (10 YR 5/1) when unoxidized. The composition of the very coarse sand fraction averages 32 percent crystalline, 25 percent carbonate, and 43 percent shale rock fragments (fig. A1.56B). In addition to the diamicton, the Heiberg Member includes associated sand and gravel that was deposited in meltwater streams, and silty lacustrine sediment.



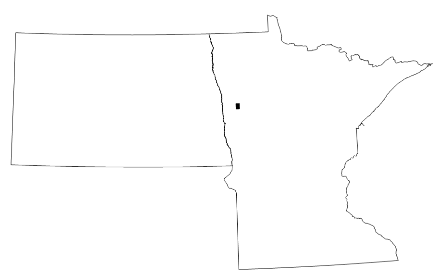
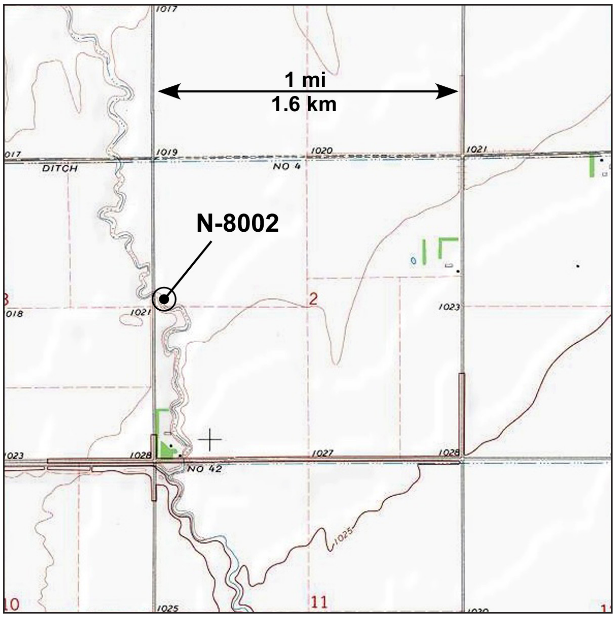


Figure A1.53. Wild Rice River cut bank (N-5945, Heiberg Section) near Heiberg, Minnesota is designated as the type section of the Heiberg Member of the Goose River Formation. The section is located in Norman County at T. 144 N., R. 44 W., sec. 16 cccab (GPS: 47.283060, -96.277867; USGS 7.5-minute series Twin Valley, MN quadrangle; Appendix 2, p. 216).



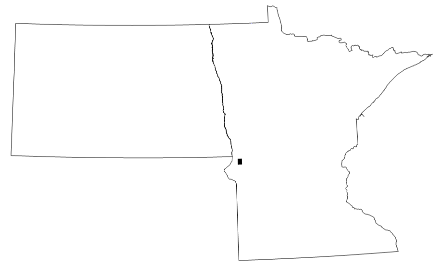
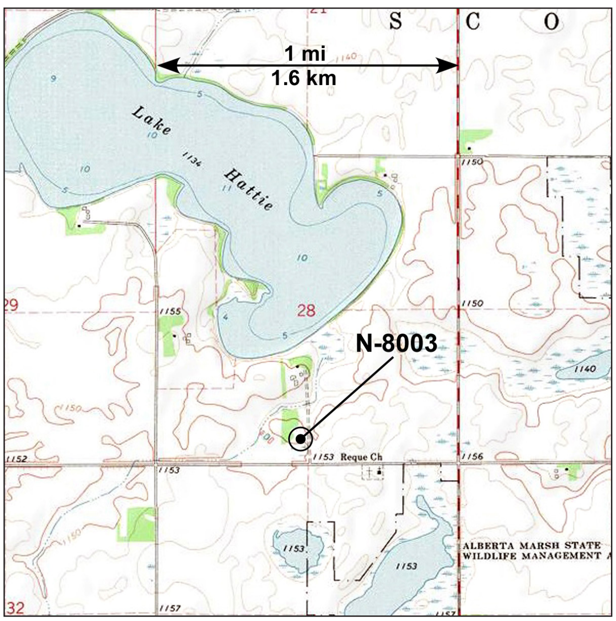


Figure A1.54. Minnesota Geological Survey rotary-sonic core N-8002 (TG-2) is designated as a reference section for the Heiberg Member of the Goose River Formation. The core was drilled in Traverse County, Minnesota at T. 127 N., R. 45 W., sec. 2 bcccd GPS: 45.840177, -96.294181; USGS 7.5-minute series Wheaton SE, MN quadrangle; Appendix 2, p. 170).



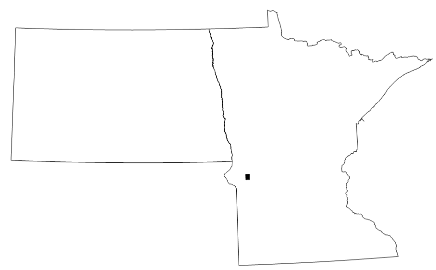


Figure A1.55. Minnesota Geological Survey rotary-sonic core N-8003 (TG-3) is also a reference section for the Heiberg Member of the Goose River Formation. This core was drilled in Stevens County, Minnesota at T. 124 N., R. 43 W., sec. 28 cddadb; GPS: 45.514182, -96.066534; USGS 7.5-minute series Alberta, MN quadrangle; Appendix 2, p. 160).

DESCRIPTION OF BOUNDARIES

The Heiberg Member is a common surface unit throughout much of eastern North Dakota and the western margin of the Red River Valley. It is otherwise typically overlain by younger tills of the Goose River Formation or by glaciolacustrine and modern lake sediment. In some places, in Norman County, Minnesota, it is overlain by the Lower Red Lake Falls Member of the Red Lake Falls Formation. The Heiberg Member is also at the surface across a large part of southern Minnesota, where it is included in the New Ulm Formation (Lusardi and Harris, 2016a).

The Heiberg Member overlies a number of older glacial units and bedrock. In parts of the central and southern Red River Valley and the adjacent uplands, and south of the Big Stone moraine, it overlies either the Villard or Lower James Member of the James River Formation. As a general rule, it is the Lower James Member to the north of the moraine and the Villard to the south. In two borings, N-6219 (T. 137 N., R. 47 W., sec. 10 ddddda; Appendix 2, p. 199) and N-6220 (T. 131 N., R. 47 W., sec. 35 aaaaab; Appendix 2, p. 187), the Heiberg Member overlies the Otter Tail Formation. Further to the west and northwest as far as the International Boundary and near the Big Stone moraine, the Heiberg Member overlies the Gardar Formation. At three sites, one each in Barnes, Griggs, and Steele Counties, it is underlain by undifferentiated Upper Cretaceous shale.

In the southernmost part of the Red River Valley and the adjacent uplands to the west, and near the Big Stone moraine in the vicinity of the reference section, the Heiberg Member overlies the Sheyenne River Formation. A similar stratigraphy is likely to be found in the northeastern part of the Red River Valley where the intervening units between the Heiberg and the Buffalo River Formation are absent.

HISTORICAL BACKGROUND

Till of the Heiberg Member was first described and defined in a cut bank along the Wild Rice River near Heiberg, Minnesota. This unit was designated as unit RRV09, or "Heiberg till," of the informal lower "Goose River group," by Harris and others (1995, 1999, 2003) and Harris and Berg (2006). Continued mapping showed that the Heiberg Member extends to the south and in Minnesota is included in the New Ulm Formation where it occurs south of the Big Stone moraine.

REGIONAL EXTENT AND THICKNESS

The Heiberg Member of the Goose River Formation is present throughout eastern North Dakota and all but the northeastern quarter of the Red River Valley. It is bounded by the Alexandria and Itasca moraine complexes to the east and southeast in Minnesota (fig. A1.57; Johnson and others, 2016, fig. 13), the Big Stone moraine to the south, and the Cooperstown moraine in northeast-central North

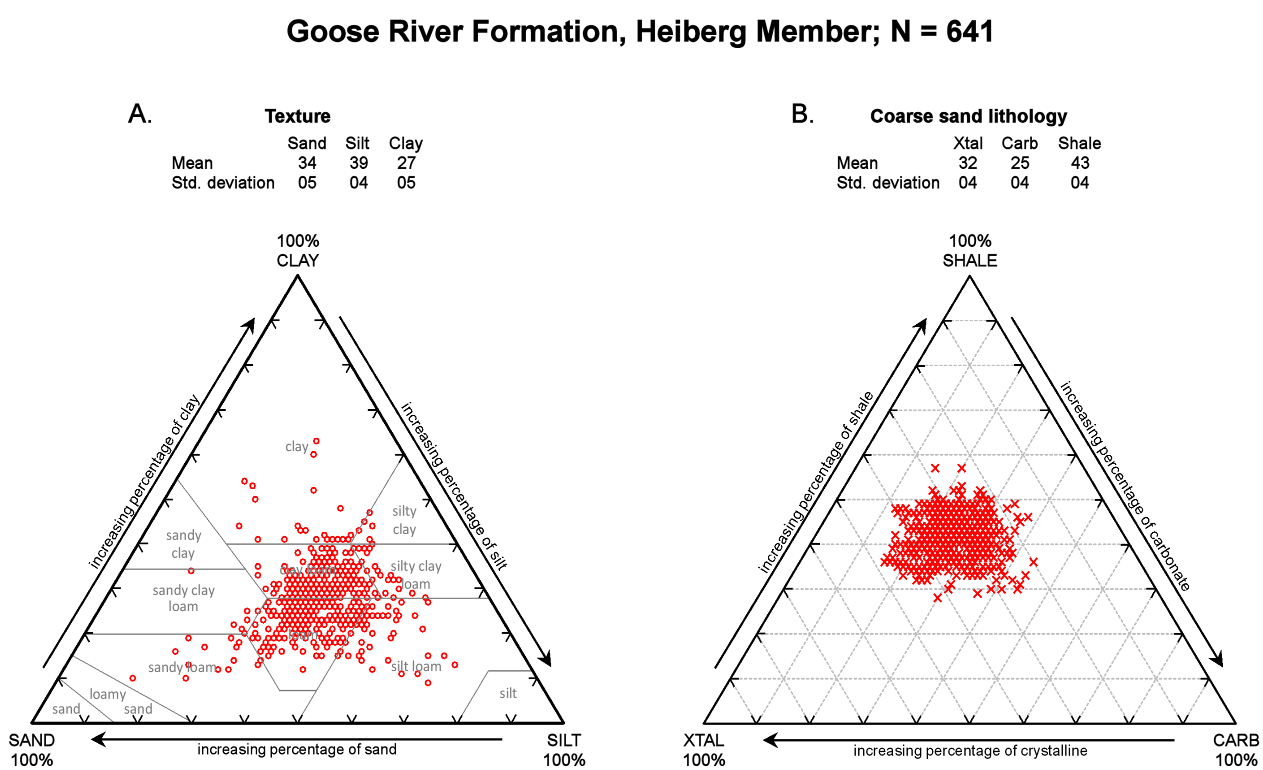


Figure A1.56. Ternary diagrams showing the results of the analysis of 641samples that show typical textural and coarse-sand lithologic characteristics of the Heiberg Member of the Goose River Formation. The texture (A) of the Heiberg Member is mainly loam to clay loam and the very coarse-sand lithology (B) indicates a Riding Mountain (northwestern) source area.

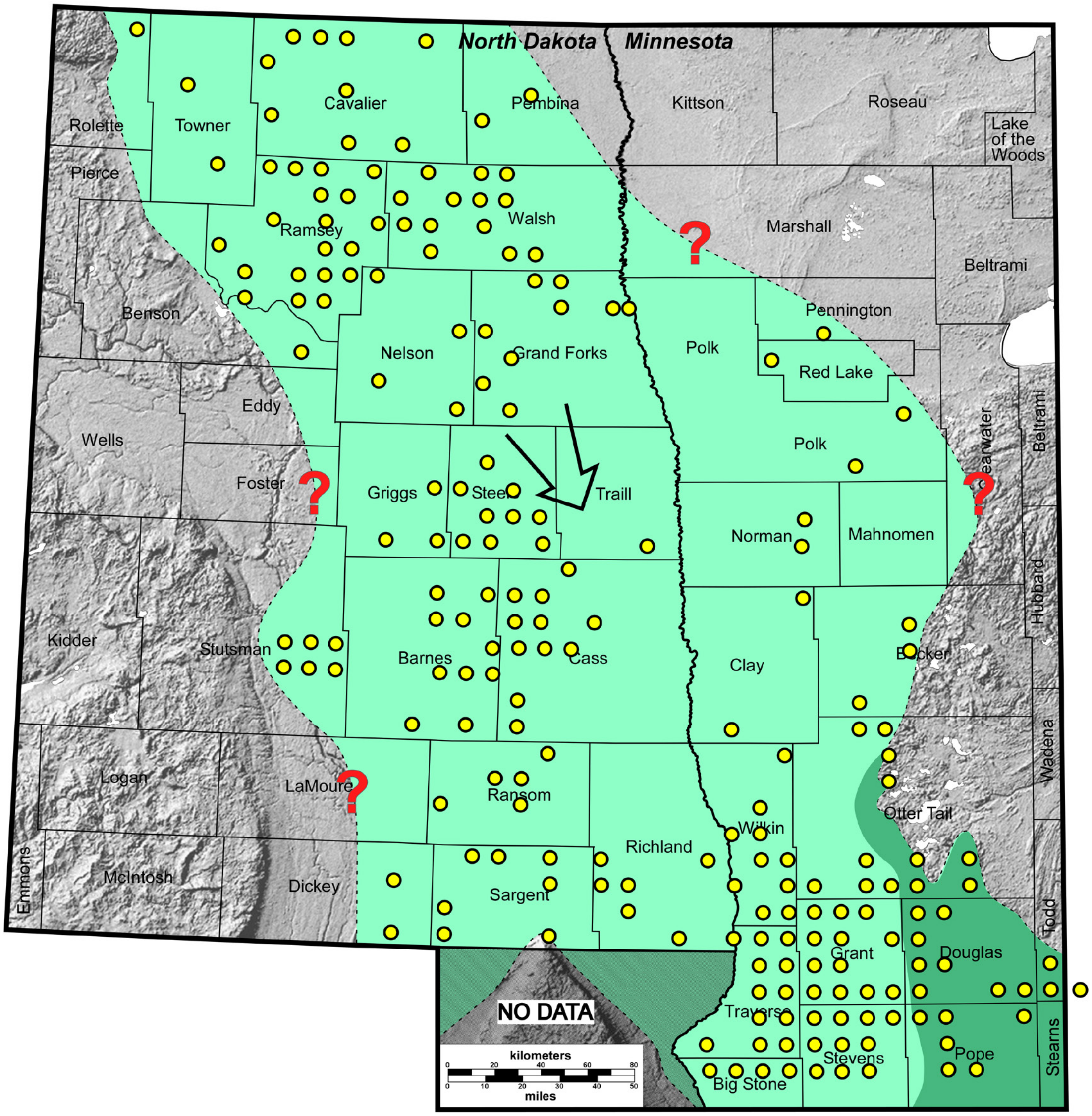


Figure A1.57. This figure shows the distribution of the Heiberg Member of the Goose River Formation in the Red River Valley of North Dakota and Minnesota, and eastern North Dakota. In Minnesota the Heiberg Member is included in the New Ulm Formation (darker green). The nomenclature break is the Big Stone moraine. The Heiberg Member consists mainly of glacial sediment that was deposited during a readvance of the Des Moines lobe from the northwest (Riding Mountain provenance). The Heiberg Member is a common surface unit throughout much of eastern North Dakota. Yellow circles indicate townships where sample control is located. The arrow indicates the direction of ice flow.

Dakota. In northern Barnes County, the Heiberg Member extends westward to the Kensal end moraine and follows the James River into northeastern South Dakota. The Heiberg Member extends to the International Boundary and is expected to continue into southern Manitoba. South of the Big Stone moraine, the Heiberg Member of the New Ulm Formation extends southeastwards almost to the Bemis moraine, a distance of approximately 160 miles (260 kilometers) (Lusardi and Harris, 2016a).

In the Red River Valley and eastern North Dakota till of the Heiberg Member is generally less than 30 feet (9 meters) thick, although it is considerably thicker in places, such as at the reference section where it is 67 feet (20.4 meters) thick. A borehole near Clear Lake in Sibley

County, Minnesota penetrated approximately 150 feet (45 meters) of diamicton interpreted to be the Heiberg Member (Lusardi and Harris, 2016a).

DIFFERENTIATION FROM OTHER UNITS

The Heiberg Member of the Goose River Formation is distinguished from other units primarily by its shale content. Pebble loam of the Heiberg Member contains appreciably more shale fragments (at least 40 percent) than pebble loams of the St. Hilaire Member, the Lower Red Lake Falls Member, The Otter Tail River Formation, and the Sheyenne River Formation. It is less sandy and has a higher shale content than the Villard and Lower James Members of the James River Formation. The Heiberg Member is markedly less shaly than the Gardar Formation and contains about 28 percent less shale than the Dahlen Member.

AGE

The Heiberg Member of the Goose River Formation is Late Wisconsinan in age. There are no dates associated with this unit in North Dakota but wood found at the contact of glacial Lake Minnesota sediment and the underlying Heiberg Member in south-central Minnesota suggests that the lake is no older than 12,260 ^{14}C years BP (14,376 ± 314 cal yr BP; Jennings and others, 2011). The ice that deposited the Heiberg Member must therefore have been in retreat by that time. It is chronologically equivalent to, and slightly younger than, the Villard Member of the James River Formation.

CORRELATION

The Heiberg Member of the Goose River Formation continues southeast of the Big Stone moraine, where it is included in the New Ulm Formation. The nomenclature break is at the Big Stone moraine, or about lat. 46º N., the approximate boundary between the Red River lobe and the Des Moines lobe nomenclature.

GENESIS

The Heiberg Member of the Goose River Formation was deposited by an ice stream of the Des Moines lobe that moved into North Dakota and the Red River Valley from the northwest (Riding Mountain provenance). It flowed into southern Minnesota where it was impeded by a second, dynamically independent Des Moines lobe ice stream that was advancing at the same time and which deposited the Villard Member of the James River/New Ulm Formation. The flow-parallel junction of the two streams is marked by a subtle, broad, linear highland that becomes less distinct in its southeastern extent. The highland ridge is dotted with small hills of sand and gravel, which are interpreted to represent the location of the shear-zone between the two ice masses (Lusardi and others, 2011a). There is evidence that a similar scenario may have played out in the northwestern Red River Valley between the Des Moines and Red River lobes in which the interlobate zone is marked by the prominent uplands on the western arm of the Edinburg moraine (Manz and Harris, 2016a, 2017a). If correct, this hypothesis could also explain the stratigraphic irregularities associated with the Inkster member of the Goose River Formation.

OTTER TAIL RIVER FORMATION

(New)

NAME AND RANK

The Otter Tail River Formation is named here. It is named after the Otter Tail River in east-central Minnesota. The formation has two members: the Hawley Member and the New York Mills Member.

TYPE AREA

The Detroit Lakes outwash plain in Becker, Otter Tail, and Douglas Counties, Minnesota.

Hawley Member of the Otter Tail River Formation

(New)

NAME AND RANK

The Hawley Member of the Otter Tail River Formation is formally named here. The source of the name is the village of Hawley in Clay County, Minnesota, located on the USGS 7.5-minute series Hawley, MN quadrangle.

TYPE SECTION

The type section for the Hawley Member is Minnesota Geological Survey rotary-sonic core RVR-3 (N-6220) on the Rabbit River in Wilkin County, Minnesota (T. 131 N., R. 47 W., sec. 35 aaaaab; GPS: 46.123325, -96.534345; USGS 7.5-minute series Fairmount, MN quadrangle; fig. A1.58 and Appendix 2, p. 187).

REFERENCE SECTION

The reference section for the Hawley Member of the Otter Tail River Formation is Minnesota Geological Survey soil boring N-5942 in Clay County, Minnesota (T. 140 N., R. 45 W., sec. 9 daa; GPS: 46.954440, -96.366743; USGS 7.5-minute series Hawley, MN quadrangle; fig. A1.59 and Appendix 2, p. 212).

LITHOLOGIC DESCRIPTION

The Hawley Member consists of massive, unsorted to weakly bedded pebble-loam interpreted to be till. Thin lenses of silty lake sediment, and fluvial sand and gravel are common throughout the unit. Pebbles, cobbles, and boulders are abundant and consist primarily of limestone

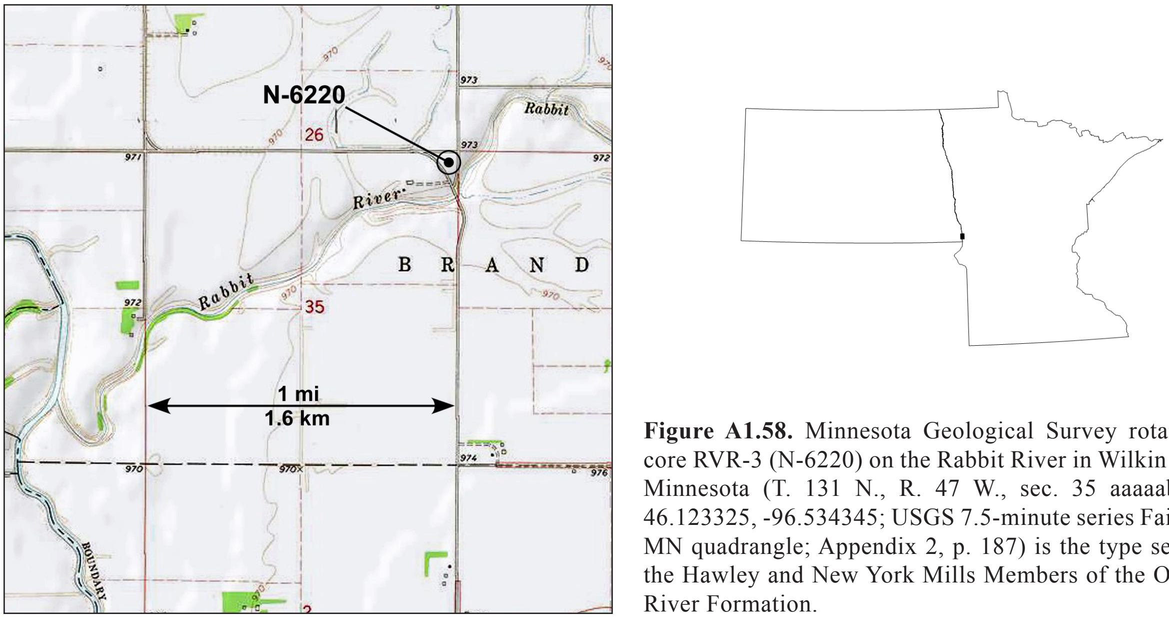
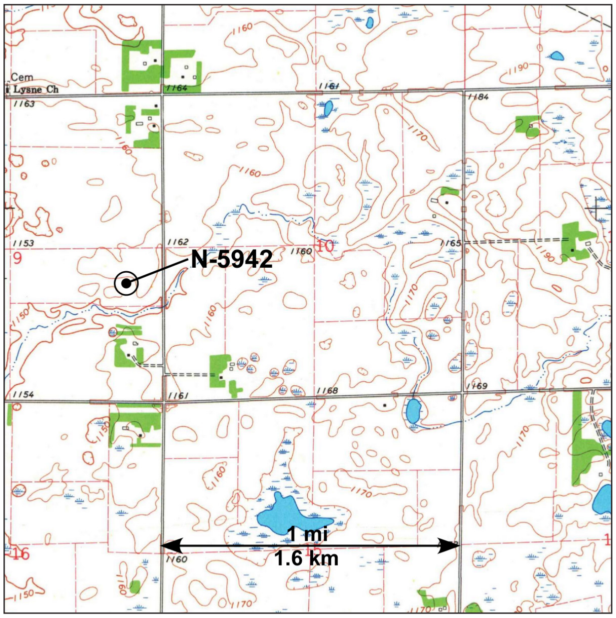


Figure A1.58. Minnesota Geological Survey rotary-sonic core RVR-3 (N-6220) on the Rabbit River in Wilkin County, Minnesota (T. 131 N., R. 47 W., sec. 35 aaaaab; GPS: 46.123325, -96.534345; USGS 7.5-minute series Fairmount, MN quadrangle; Appendix 2, p. 187) is the type section of the Hawley and New York Mills Members of the Otter Tail River Formation.



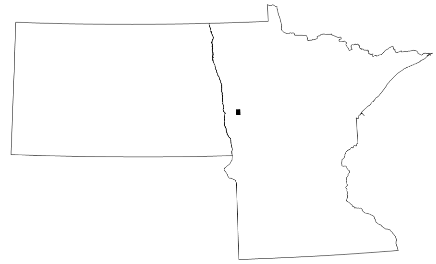


Figure A1.59. Minnesota Geological Survey soil boring N-5942 in Clay County, Minnesota (T. 140 N., R. 45 W., sec. 9 daa; GPS: 46.954440, -96.366743; USGS 7.5-minute series Hawley, MN quadrangle; Appendix 2, p. 212) is a reference section for the Hawley Member of the Otter Tail River Formation.

and igneous-metamorphic rock types with little to no shale, except for some localized concentrations. Lignite and small wood fragments are common in places. Till of the Hawley Member is light gray (5Y 7/1) when oxidized and dry, and olive gray (5Y 5/2) to dark olive gray (5Y 3/2) when unoxidized. It has a pebbly sandy loam to loam texture that averages 41 percent sand, 39 percent silt, and 21 percent clay (fig. A1.60A). The very coarse sand lithology (1-2 mm) averages 54 percent crystalline and metamorphic rock fragments, 45 percent carbonate rock fragments, and 1 percent shale fragments (fig. A1.60B).

DESCRIPTION OF BOUNDARIES

The Hawley Member is at the surface in parts of eastern Clay, Douglas, and Pope Counties, south-central Becker, and north-central Otter Tail Counties in west-central Minnesota. To the west it is overlain by poorly to well-sorted, flat-bedded to low-angle crossbedded, fluvial sand and gravel, or tills of the Goose River Formation. At its type section the Hawley Member is overlain by the Heiberg Member of the Goose River Formation. The lower contact with the underlying New York Mills Member of the Otter Tail Formation is marked in places by a boulder pavement at the base of the Hawley Member.

In most places, the Otter tail Formation overlies the Villard Member of the James River Formation (Harris and others, 1995, 2003; Harris and Berg, 2006).

HISTORICAL BACKGROUND

The Hawley Member was originally named and described as an informal lithostratigraphic unit of formation rank by Perkins (1977). It was identified as unit RRV10 and included as the "Hawley formation" of the informal Otter Tail River group by Harris and others (1995), Thorleifson and others (2005) and Harris and Berg (2006).

REGIONAL EXTENT AND THICKNESS

The regional extent of the Hawley Member is poorly defined because it is present mainly in the subsurface and has only been located in a few places in west-central Minnesota and southeasternmost North Dakota (fig. A1.61). Besides the surface exposures described earlier, till of the Hawley Member has been identified in the subsurface at two sites in the southern Red River Valley: one in Richland County about 4 miles (6.4 kilometers) southwest of Fairmount and the other at the type section in Wilkin County, Minnesota. From here, it extends north-northeastwards into central Clay County, and by inference, continues to the source area. The eastern extent of the Hawley Member is defined by the western margin of the Alexandria moraine where it meets the Wadena drumlin field. It is present in the subsurface at sites in Otter Tail and Stearns Counties where it forms part of a complex stratigraphy with several older tills, including those of the Crow Wing River and Browerville Formations. In western Minnesota, the Hawley Member has been traced in the subsurface as far south as central Traverse County (Harris and Berg, 2006). The Hawley Member is either sparsely distributed or completely absent throughout the area between the Alexandria moraine and the unit's western limit.

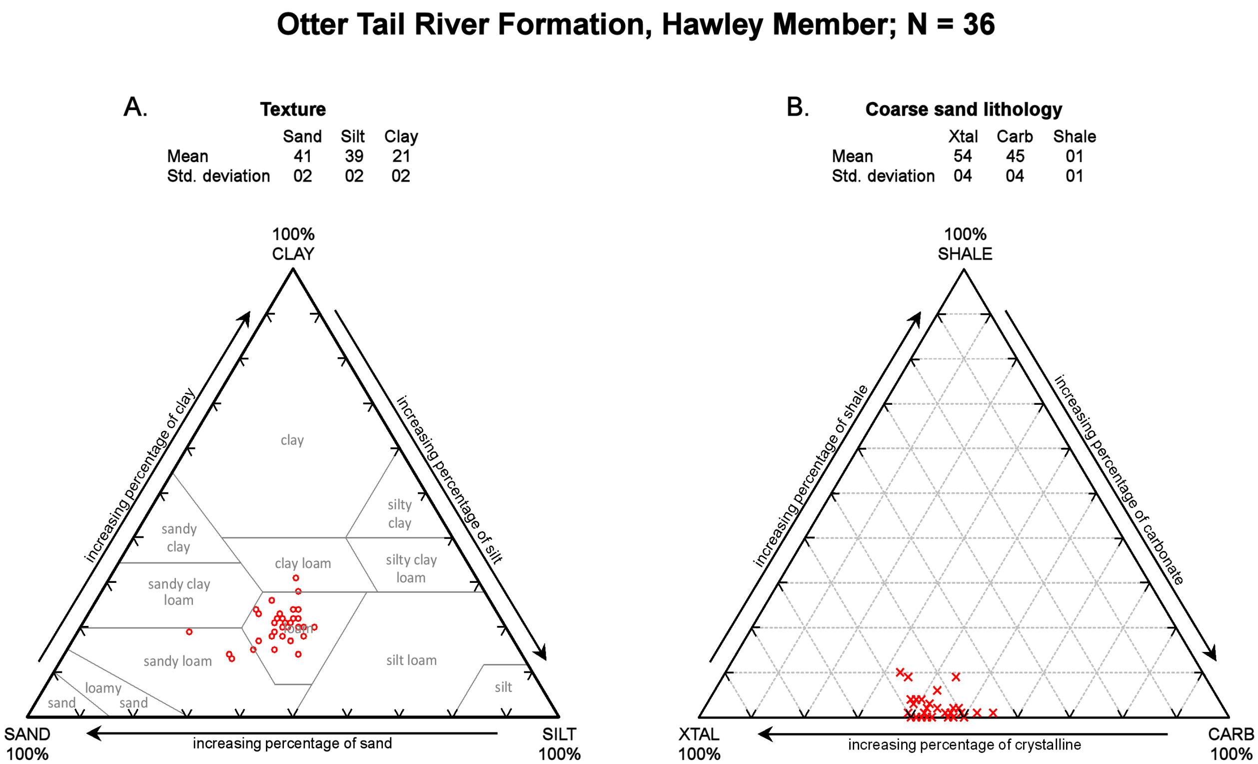


Figure A1.60. Ternary diagrams showing the results of the analysis of 36 samples that show typical textural and coarse-sand lithologic characteristics of the Hawley Member of the Otter Tail River Formation. The texture (A) of the Hawley Member is sandy loam to loam and the very coarse sand lithology (B) indicates a mixed Winnipeg-Rainy (northern and northeastern) source area.

The thickness of the Hawley Member ranges from 7 feet (2.1 meters) to a maximum of 47 feet (14.3 meters) at the type section. The average thickness of the unit is 27 feet (8.2 meters).

DIFFERENTIATION FROM OTHER UNITS

In the Red River Valley, the Hawley Member may be differentiated from other units by its limited geographic extent and stratigraphic position. It is easily distinguished from the overlying Goose River tills and older units of Riding Mountain or mixed Riding Mountain/Winnipeg provenance by its significantly lower shale content and lighter color in outcrop. The Hawley Member is finer-textured than the New York Mills Member and contains about 32 percent more carbonate and 17 percent fewer crystalline rock fragments in its very coarse sand fraction.

AGE

The stratigraphic position of the Hawley Member indicates that it is Late Wisconsinan in age and was deposited at or about the same time as the Heiberg Member and the Villard Member of the James River Formation. Radiocarbon dates indirectly associated with these two units suggest that deposition of the Hawley Member took place between about 12,300 and13,000 ^{14}C yr BP (Jennings and others, 2011, 2013).

CORRELATION

The Hawley Member may correlate chronologically with the Heiberg Member of the Goose River Formation and the Villard Member of the James River Formation, but its lithology indicates a different provenance.

GENESIS

The Hawley Member is glacial sediment that was deposited during a readvance of the Red River lobe from the north and northeast. The lithology of the pebble and very coarse sand fractions indicates source areas in eastern Manitoba and western Ontario (mixed Winnipeg-Rainy provenance; fig. 17).

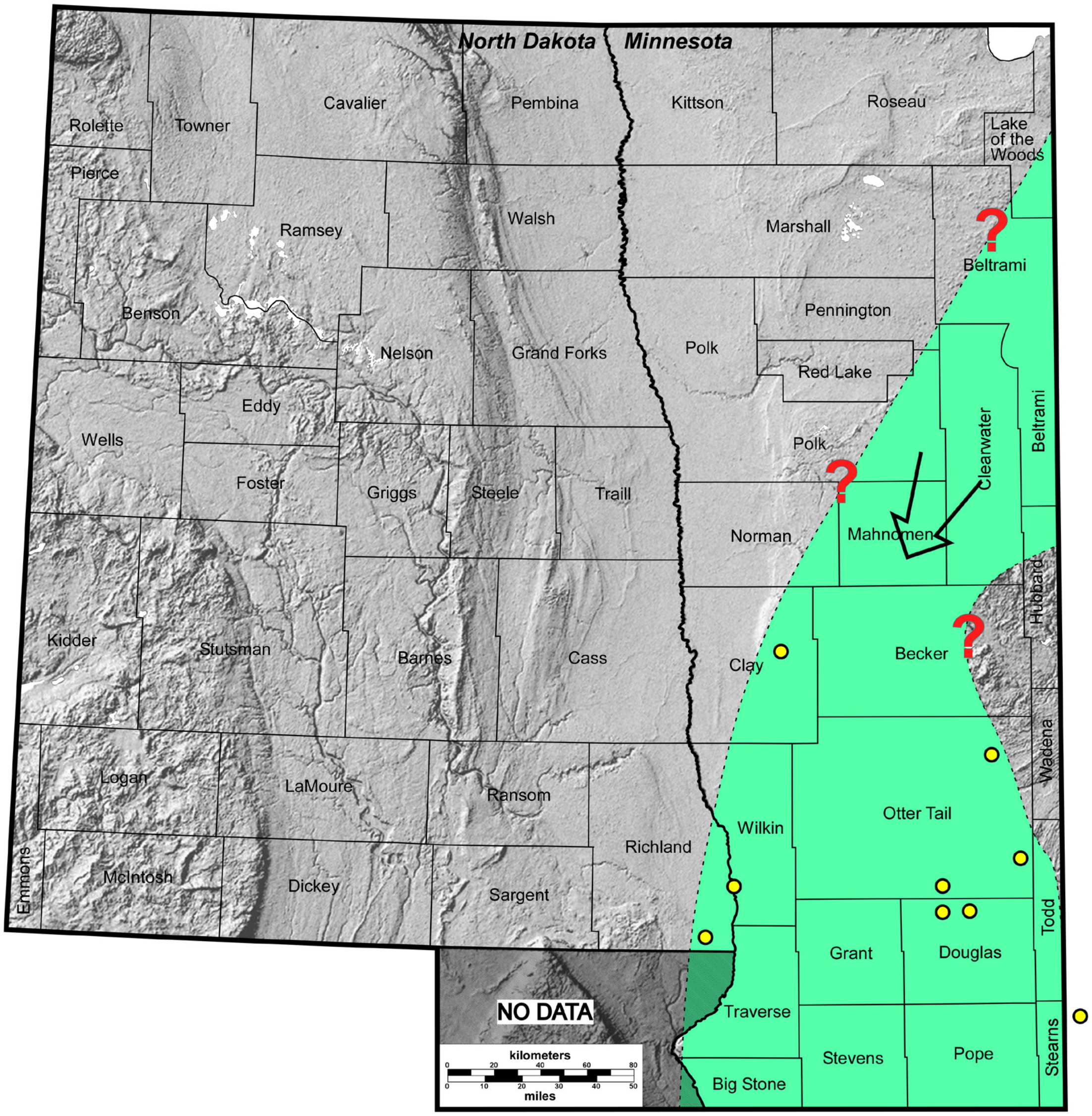


Figure A1.61. This figure shows the distribution of the Hawley Member of the Otter Tail River Formation in the Red River Valley of North Dakota and Minnesota. The Hawley Member consists mainly of glacial sediment deposited during a readvance of the Red River lobe from the north and northeast (mixed Winnipeg-Rainy provenance). It is exposed at the surface in parts of west-central Minnesota but is only present in the subsurface in the Red River Valley. Yellow circles indicate townships where sample control is located. The arrow indicates the direction of ice flow.

New York Mills Member of the Otter Tail River Formation

(New)

NAME AND RANK

The New York Mills Member of the Otter Tail River Formation is formally named here. The source of the name is the village of New York Mills in Otter Tail County, Minnesota, located on the located on the USGS 7.5-minute series New York Mills East and New York Mills West, MN quadrangles.

TYPE AREA

The New York Mills area in Otter Tail County, Minnesota.

TYPE SECTION

The type section for the New York Mills Member is Minnesota Geological Survey rotary-sonic core RVR-3 (N-6220) on the Rabbit River in Wilkin County, Minnesota (T. 131 N., R. 47 W., sec. 35 aaaaab; GPS: 46.123325, -96.534345; USGS 7.5-minute series Fairmount, MN quadrangle; fig. A1.58 and Appendix 2, p. 187).

REFERENCE SECTION

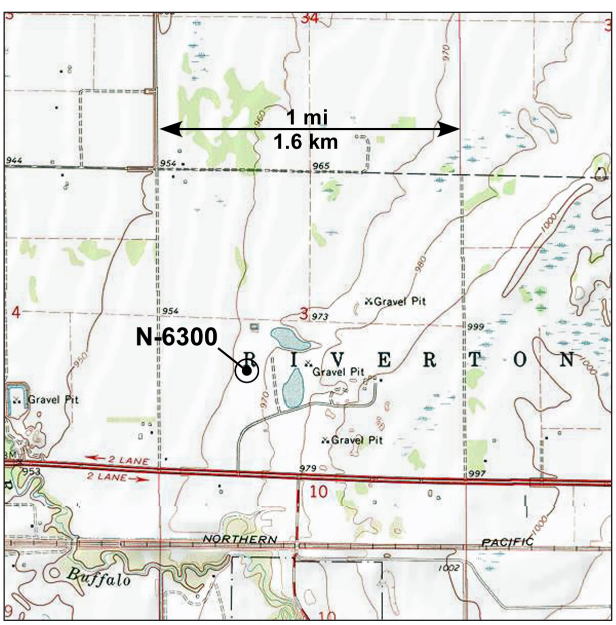
The reference section for the New York Mills Member is Minnesota Geological Survey rotary-sonic boring N-6300 in Clay County, Minnesota (T. 139 N., R. 46 W., sec. 3 cacbdb; GPS: 46.882270, -96.482723; USGS 7.5-minute series Hawley NW, MN quadrangle; fig. A1.62 and Appendix 2, p. 206).

LITHOLOGIC DESCRIPTION

The New York Mills Member of the Otter Tail River Formation consists of loamy diamicton, interpreted to be till, and silty to coarse-sandy fluvial sediment. The massive, friable, weakly jointed till is a pebbly sandy loam to loam that averages 55 percent sand, 31 percent silt, and 14 percent clay (fig. A1.63A). Lignite and small wood fragments are common in places. The till of the New York Mills Member is pale yellow (5Y 7/3) to olive (5Y 5/4) in color when oxidized, and variously described as dark grayish brown (2.5Y 4/2) to very dark grayish brown (2.5Y 3/2) and olive gray (5Y 4/2) to very dark gray (5Y 3/1) when unoxidized. The lithology of the very coarse sand fraction averages 65 percent crystalline, 32 percent carbonate, and 3 percent shale rock fragments (fig. A1.63B).

DESCRIPTION OF BOUNDARIES

The New York Mills Member is the primary surface unit in its type area and is exposed in other parts of west-central Minnesota including eastern Douglas and Pope Counties (Harris and others, 2003). To the west it is overlain by poorly to well-sorted, flat-bedded to low-angle crossbedded, fluvial sand and gravel, or tills of the Goose River Formation. In parts of Clay County and areas to the



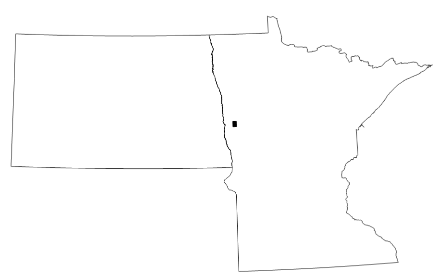


Figure A1.62. Minnesota Geological Survey rotary-sonic boring N-6300 in Clay County, Minnesota (T. 139 N., R. 46 W., sec. 3 cacbdb; GPS: 46.882270, -96.482723; USGS 7.5-minute series Hawley NW, MN quadrangle; Appendix 2, p. 206) is a reference section for the New York Mills Member of the Otter Tail River Formation.

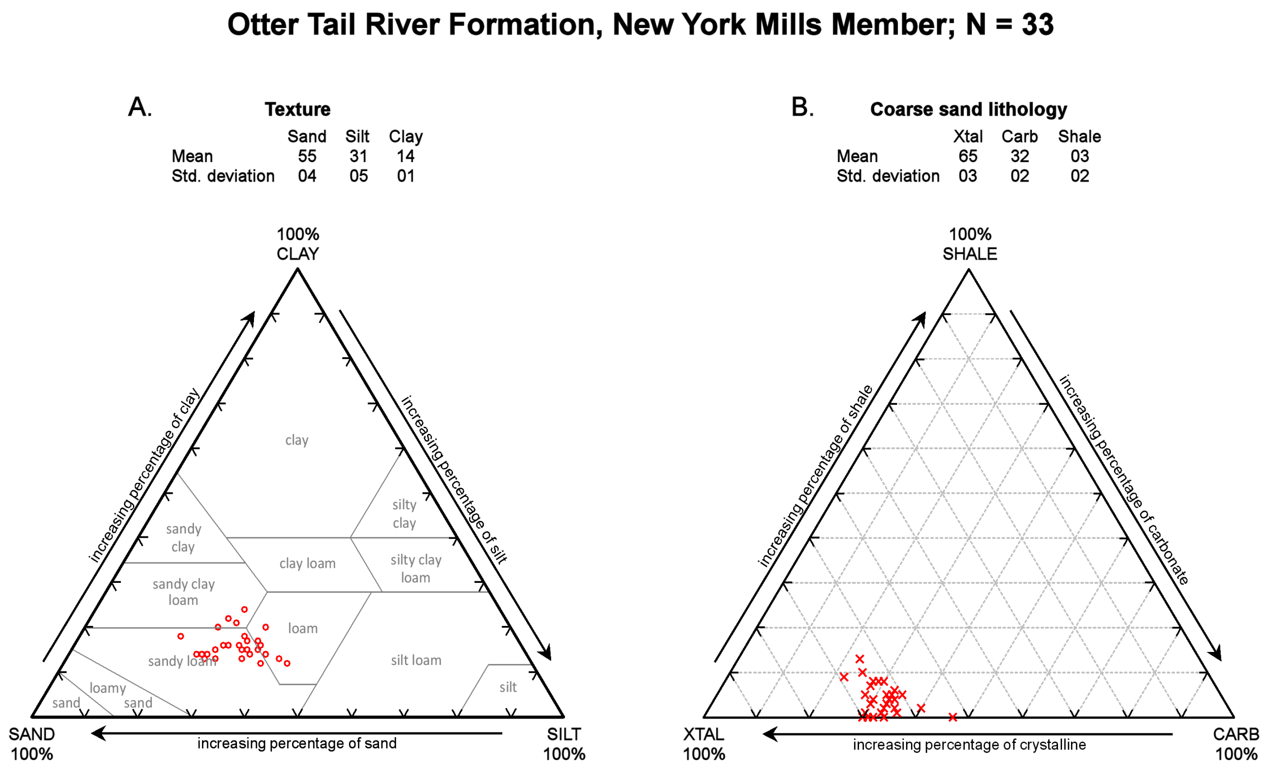


Figure A1.63. Ternary diagrams showing the results of the analysis of 33 samples that show typical textural and coarse-sand lithologic characteristics of the New York Mills Member of the Otter Tail River Formation. The texture (A) of the New York Mills Member is sandy loam to loam and the very coarse sand lithology (B) indicates a mixed Rainy-Winnipeg (northeastern and northern) source area.

northeast where the Goose River Formation is absent, the New York Mills Member is overlain by the Lower Red Lake Falls Member of the Red Lake Falls Formation. At its type section the New York Mills Member is overlain by the Hawley Member. The lower contact of the New York Mills Member has not been observed in outcrop but in boreholes throughout west-central Minnesota, it is with the Villard Member of the James River Formation, except in westernmost Wilkin County where the New York Mills Member directly overlies Cretaceous bedrock. In more northerly areas of its extent the New York Mills Member commonly overlies the Marcoux Member of the Crow Wing River Formation.

HISTORICAL BACKGROUND

The New York Mills Member was originally named and described as an informal lithostratigraphic unit of formation rank by Anderson (1976). It was identified as unit RRV11 and included as the “New York Mills formation” of the informal Otter Tail River group by Harris and others (1995, 1999, 2003), Thorleifson and others (2005) and Harris and Berg (2006).

REGIONAL EXTENT AND THICKNESS

Figure A1.64 shows the presumed extent of the New York Mills Member. Beyond its type area the unit is almost everywhere only present in the subsurface, so its regional extent uncertain. Till of the New York Mills Member has been identified in the subsurface at four sites in the eastern Red River Valley but to date has not been found in North Dakota. It has been traced northwards as far as Red Lake and central Beltrami Counties, but its northern boundary is unknown. The eastern extent of the New York Mills Member is defined by the western margin of the Alexandria moraine where it meets the Wadena drumlin field. It is present in the subsurface at sites in Otter Tail and southeast Douglas Counties as part of a complex stratigraphy with at least two much older, unnamed tills. In western Minnesota, the New York Mills Member has been traced in the subsurface as far south as central Traverse County (Harris and Berg, 2006). The New York Mills Member is either sparsely distributed or completely absent throughout the area between the Alexandria moraine and the unit’s western limit.

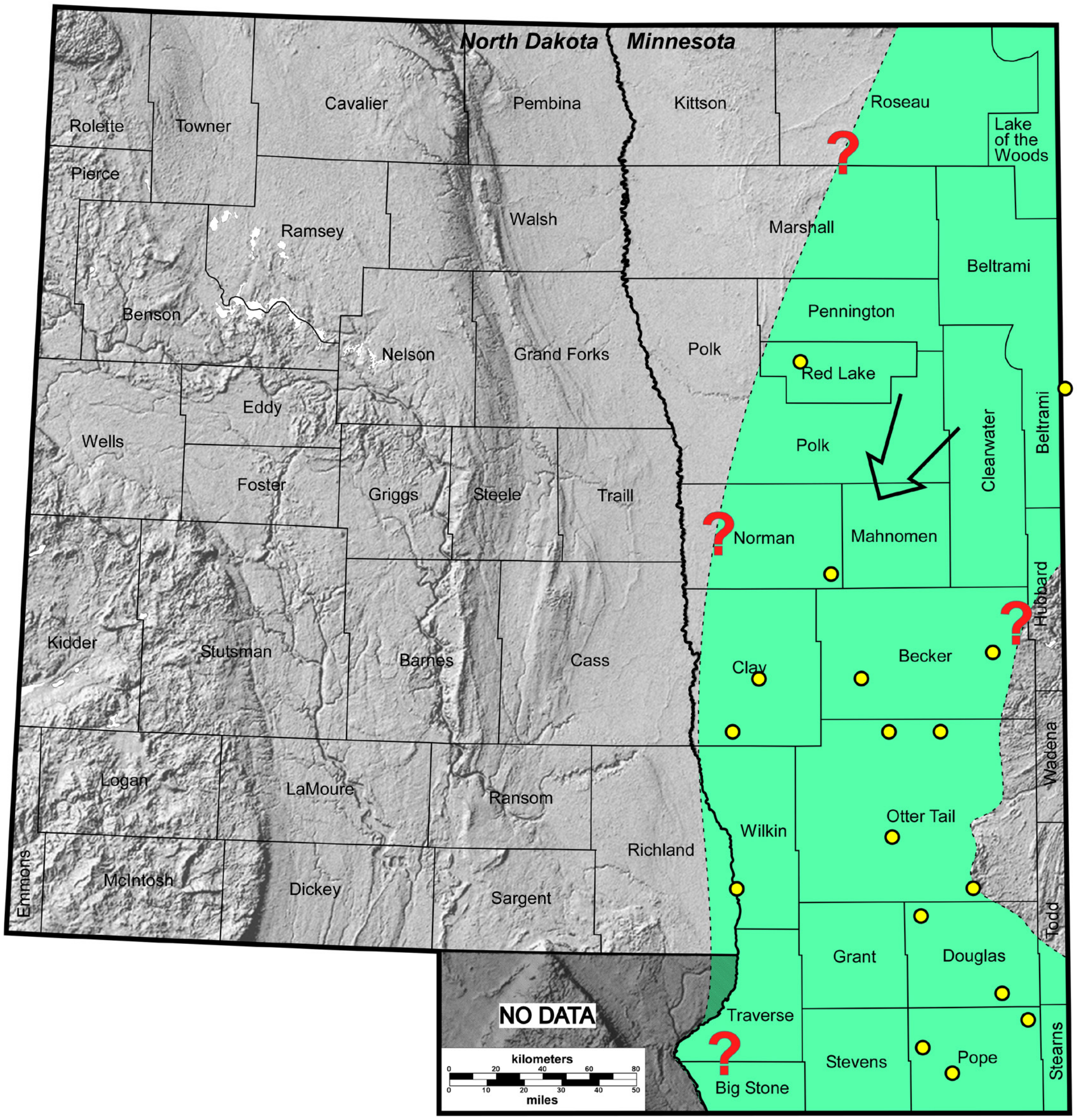


Figure A1.64. This figure shows the distribution of the New York Mills Member of the Otter Tail River Formation in the Red River Valley of North Dakota and Minnesota. The New York Mills Member consists mainly of glacial sediment deposited during a readvance of the Red River lobe from the northeast and north (mixed Rainy-Winnipeg provenance). It is exposed at the surface in parts of west-central Minnesota but is only present in the subsurface in the Red River Valley. Yellow circles indicate townships where sample control is located. The arrow indicates the direction of ice flow.

The thickness of the New York Mills Member ranges from about 7 feet (2.1 meters) to a maximum of 35 feet (10.7 meters) at the type section. The average thickness of the unit is 18 feet (5.5 meters).

DIFFERENTIATION FROM OTHER UNITS

In the Red River Valley, the New York Mills Member may be differentiated from other units by its limited geographic extent and stratigraphic position. It is easily distinguished from the overlying Goose River tills and older units of Riding Mountain or mixed Riding Mountain/Winnipeg provenance by its significantly lower shale content and lighter color in outcrop. It is sandier and generally lighter and more yellow in color than the Lower Red Lake Falls Member. The Marcoux Member contains about 16 percent more crystalline rock fragments in its very coarse sand fraction.

AGE

The stratigraphic position of the New York Mills Member indicates that it is Late Wisconsinan in age and was deposited at or about the same time as the Heiberg and the Villard Members. Radiocarbon dates indirectly associated with these two units suggest that deposition of the New York Mills Member took place between about 12,300 and13,000 ^{14}C yr BP (Jennings and others, 2011, 2013).

CORRELATION

The New York Mills Member may correlate chronologically with the Heiberg Member of the Goose River Formation and the Villard Member of the James River Formation, but its lithology indicates a different provenance.

GENESIS

The New York Mills Member is glacial sediment that was deposited during a readvance of the Red River lobe from the north and northeast. The lithology of the pebble and very coarse sand fractions indicates source areas in western Ontario and eastern Manitoba (mixed Rainy-Winnipeg provenance; fig. 17).

JAMES RIVER FORMATION

(New)

NAME AND RANK

The James River Formation is named here. It is named after the James River in eastern North Dakota. The formation has two members: the Villard Member and the Lower James River Member.

Villard Member of the James River Formation

(Redefined)

NAME AND RANK

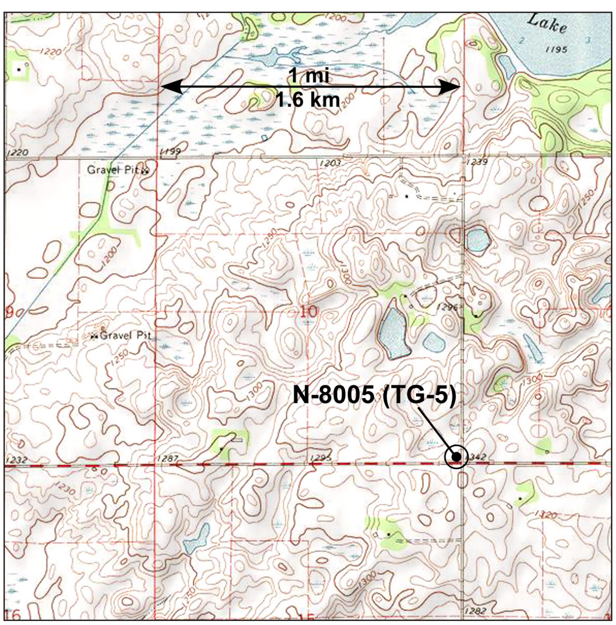
The Villard Member of the New Ulm Formation was formally named in Minnesota by Lusardi and Harris, (2016b). It is redefined here for use in North Dakota as the Villard Member of the James River Formation. The unit is named after the town of Villard in Pope County, Minnesota, located on the USGS 7.5-minute series Villard, MN quadrangle.

TYPE SECTION

The type section for the Villard Member of the James River Formation is Minnesota Geological Survey rotary-sonic core TG-5 (N-8005) in Pope County, Minnesota (T. 123 N., R. 38 W., sec. 10 dddd; GPS: 45.470267, -95.419036; USGS 7.5-minute series Swift Falls, MN quadrangle; fig. A1.65 and Appendix 2, p. 154). An original summary of this core appears in Harris and others (2003). Since then, however, the interpretation of named units has been revised.

REFERENCE SECTION

The reference section for the Villard Member of the James River Formation is Minnesota Geological Survey rotary-sonic core TG-6 (N-8006) in Pope County, Minnesota (T. 124 N., R. 36 W., sec. 9 cbbaba; GPS: 45.563694, -95.212103; USGS 7.5-minute series Sedan, MN quadrangle; fig. A1.66 and Appendix 2, p. 157).



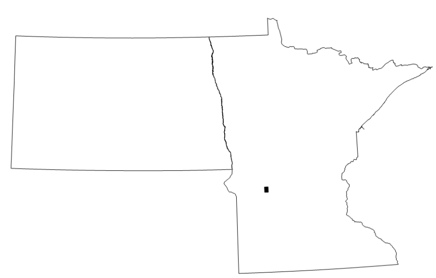
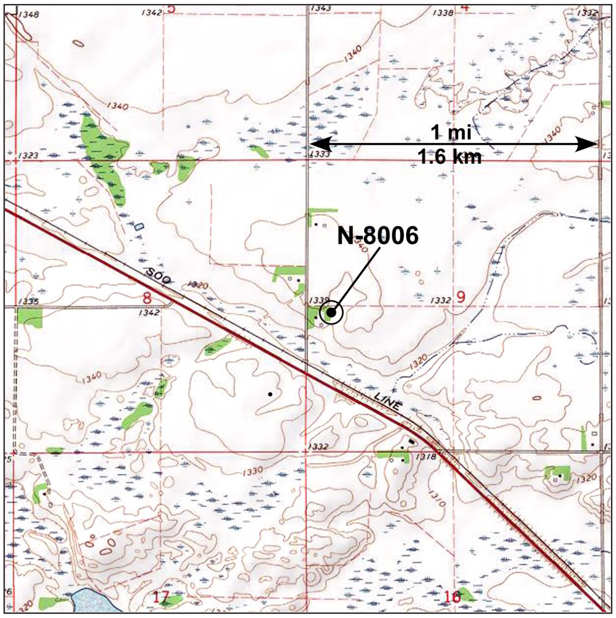


Figure A1.65. The type section for the Villard Member of the James River Formation is Minnesota Geological Survey rotary-sonic core TG-5 (N-8005) in Pope County, Minnesota (T. 123 N., R. 38 W., sec. 10 dddd; GPS: 45.470267, -95.419036; USGS 7.5-minute series Swift Falls, MN quadrangle; Appendix 2, p. 154).



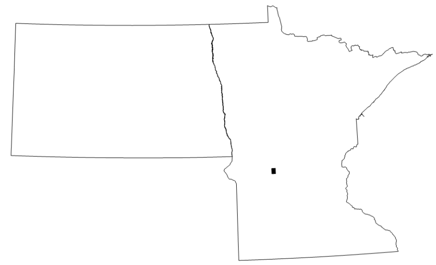


Figure A1.66. The reference section for the Villard Member of the James River Formation is Minnesota Geological Survey rotary-sonic core TG-6 (N-8006) in Pope County, Minnesota (T. 124 N., R. 36 W., sec. 9 cbbaba; GPS: 45.563694, -95.212103; USGS 7.5-minute series Sedan, MN quadrangle; Appendix 2, p. 157).

LITHOLOGIC DESCRIPTION

The Villard Member is composed almost entirely of diamicton, which is interpreted to be till. Till of the Villard Member of the James River Formation exhibits a pebbly sandy loam to clay loam texture, averaging 43 percent sand, 36 percent silt, and 21 percent clay (fig. A1.67A). Lignite and wood fragments are common in places. The till color is variable but is typically grayish brown (2.5Y 5/2) to light olive brown (2.5Y 5/4) when oxidized, and dark grayish brown (2.5Y 4/2) to very dark grayish brown (2.5Y 3/2) or very dark gray (10YR 3/1) when unoxidized. The composition of the very coarse sand fraction averages 51 percent crystalline rocks, 27 percent carbonate rocks, and 22 percent shale fragments (fig. A1.67B). In addition to the diamicton, the Villard Member includes associated sand and gravel that was deposited in meltwater streams, and silty lacustrine sediment.

DESCRIPTION OF BOUNDARIES

The Villard Member is exposed at the surface over large areas east and southeast of the Red River Valley in west-central Minnesota, and west of the valley in parts of Sargent and Stutsman Counties in North Dakota. Elsewhere, it is overlain primarily by glacial sediments of the Goose River Formation or, where it is present in the eastern Red River Valley and the adjacent uplands, the New York Mills Member of the Otter Tail River Formation. In some places, it is capped by a thin layer of lake sediment.

The Villard Member is underlain by the Lower James River Member or, in places, by older glacial units including the Gardar, Buffalo River, Crow Wing River and Browerville Formations.

HISTORICAL BACKGROUND

This unit was designated as unit RRV12, part of the informal “Otter Tail River group” by Harris and others (1995, 1999, 2003). Harris and Berg (2006) correlated their “Villard formation” of the Otter Tail River group with RRV12. The unit was reassigned to the informal “James River group” after additional lithologic data confirmed its shale content was more consistent with a mixed Riding Mountain-Winnipeg provenance rather than a Winnipeg-Rainy source area (K.L. Harris, unpub. data, 2007).

REGIONAL EXTENT AND THICKNESS

There are no clear geomorphic features that mark the boundaries of the Villard Member. It is present in the Red River Valley south of the Perley ice margin and extends westwards from the Pembina Escarpment across Barnes, Cass, Ransom, and Richland Counties, most of Sargent County and east-central Stutsman County, North Dakota. The Villard Member’s recognized northern extent in North Dakota is about 12 miles (19 kilometers) north of Valley City in Barnes County, but it may continue northwards, possibly as far as the International Boundary and beyond.

To the east, deposits of the Villard Member are exposed at surface in the Alexandria moraine and from there extend

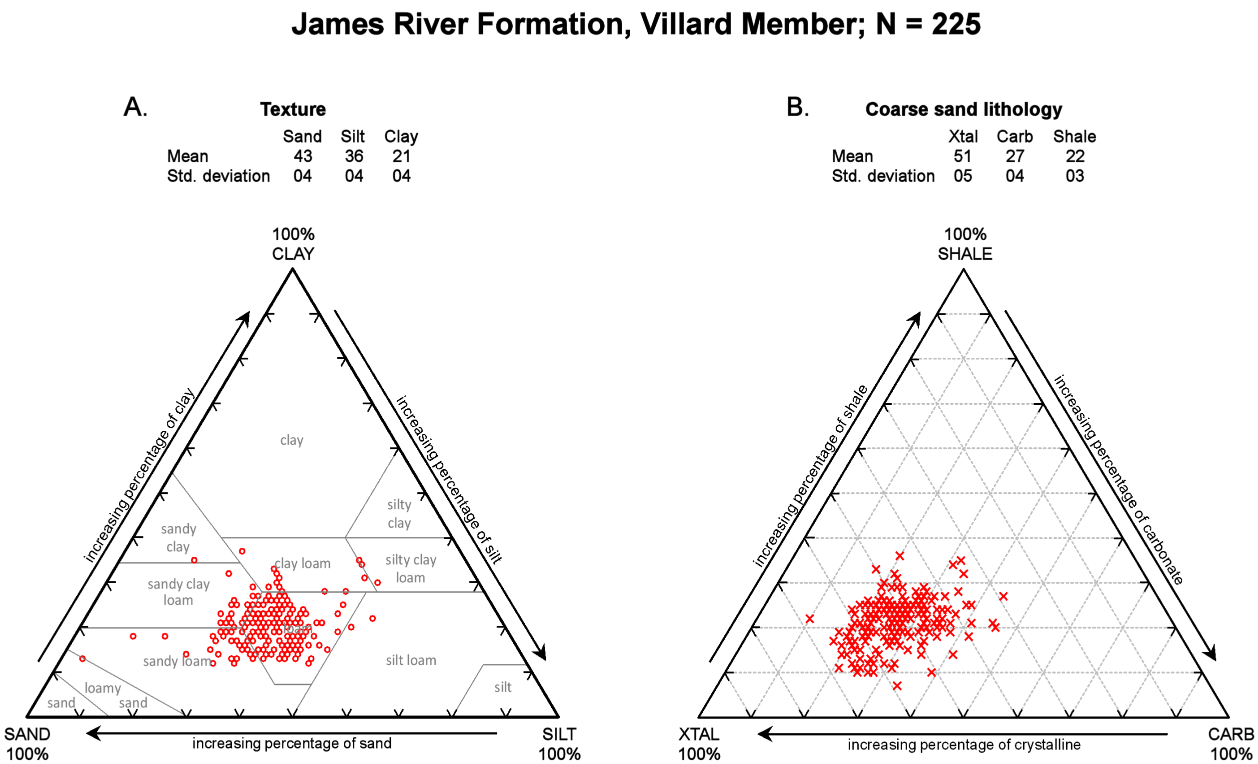


Figure A1.67. Ternary diagrams showing the results of the analysis of 225 samples that show typical textural and coarse-sand lithologic characteristics of the Villard Member of the James River Formation. The texture (A) of the Villard Member is sandy loam to clay loam and the very coarse-sand lithology (B) indicates a mixed Riding Mountain-Winnipeg-Rainy provenance.

southeastwards into parts of the Minneapolis-St. Paul metropolitan area and terminate at the Bemis moraine (fig. A1.69). Drilling indicates that the Villard Member extends below the Heiberg Member to the south, but not as far as the modern Minnesota River valley except at its southeasternmost extremity.

Within the area shown in figure A1.69, the Villard member ranges in thickness from 3 feet (1 meter) in some surface exposures on the Alexandria moraine, to about 65 feet (20 meters) at the type section. The average thickness is 27 feet (8.2 meters). Further to the southeast in McLeod County, about 74 feet of diamicton identified as the Villard Member was recorded at the surface in rotary-sonic core MCL-2 (MGS #257599), a reference section for the Villard Member where it is included in the New Ulm Formation (Lusardi and Harris, 2016b).

DIFFERENTIATION FROM OTHER UNITS

The Villard Member is less sandy and/or contains more gray shale fragments than the New York Mills Member and the various underlying, older tills from the north and northeast. It contains about 21 percent more crystalline rock fragments and 35 percent fewer shale fragments than the Lower James River Member. The Villard Member is sandier and contains at least 24 percent more crystalline rock fragments and approximately 13 percent fewer shale fragments than the St. Hilaire Member of the Goose River Formation. It is considerably less shaly than the Dahlen and Heiberg Members, and the Gardar Formation.

AGE

The Villard Member of the James River Formation is Late Wisconsinan in age. No dates are associated directly with the Villard Member, but it is the same age as the Pine City moraine in east-central Minnesota. The moraine was deposited during a readvance of the Grantsburg sublobe of the Des Moines lobe that is thought to have ended sometime before 12,300 ^{14}C yr BP. (More recent estimations suggest that construction of the Pine City moraine may have taken place as early as 13,000 ^{14}C yr BP; Jennings and others, 2013). The Villard Member is chronologically equivalent to, and slightly older than, the Heiberg Member of the Goose River Formation.

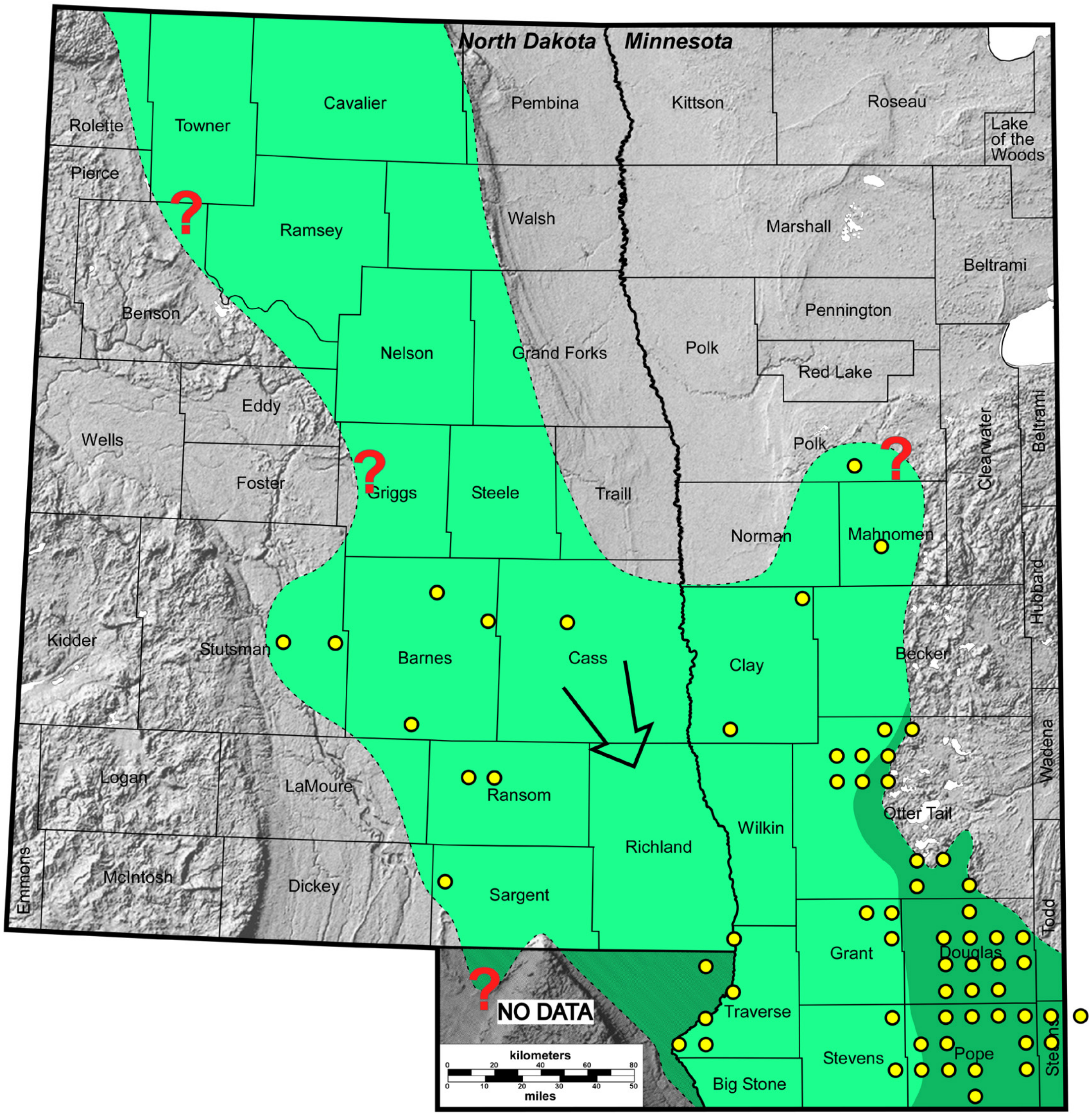


Figure A1.68. This figure shows the distribution of the Villard Member of the James River Formation in the Red River Valley of North Dakota and Minnesota, and eastern North Dakota. In Minnesota the Villard Member is included in the New Ulm Formation (darker green). The nomenclature break is the Big Stone moraine. The Villard Member consists mainly of glacial sediment that was deposited during a readvance of the Des Moines lobe from the northwest and north, although the crystalline content of till's very coarse sand fraction suggests a northeastern component as well (mixed Riding Mountain-Winnipeg-Rainy provenance). Yellow circles indicate townships where sample control is located. The arrow indicates the direction of ice flow.

CORRELATION

The Villard Member of the James River Formation continues southeast of the Big Stone moraine, where it is included in the New Ulm Formation. The nomenclature break is at the Big Stone moraine, or about lat. 46º N., the approximate boundary between the Red River lobe and the Des Moines lobe nomenclature. The Villard Member is the lateral equivalent of the Twin Cities Member of the New Ulm Formation. The Heiberg and Villard Members are coeval but are not lithologically equivalent. The Villard Member is also lithostratigraphically equivalent and correlative in age to the Trade River Formation in Wisconsin (Johnson and Hemstad, 2000).

GENESIS

The Villard Member was deposited by glacial ice that moved into North Dakota and Minnesota from the northwest and north (Riding Mountain and Winnipeg source areas). However, the crystalline content of the till suggests that ice from a more northeasterly (Rainy) source was also a component of the advancing glacier. The ice flowed through the Red River Valley, where the associated diamicton was later eroded from the northern half by glaciers during an early phase of Lake Agassiz, and into central and southern Minnesota. The ice that deposited the Villard Member likely did not extend as far south as the modern Minnesota River valley because its advance was impeded by a second Des Moines lobe ice stream that was advancing at the same time and lateral to it, and which deposited the Heiberg Member of the Goose River/New Ulm Formation. The flow-parallel junction of the till sheets is marked by a subtle, broad, linear highland that becomes less distinct in its southeastern extent. The highland ridge is dotted with small hills of sand and gravel, which are interpreted to represent the location of the shear-zone between the two ice masses (Lusardi and others, 2011a). The Heiberg Member overlaps the Villard Member along this junction, indicating that the two ice streams were dynamically independent; allowing the southern (Heiberg Member) ice stream to move into the area occupied by the northern (Villard Member) ice stream as the latter thinned, stagnated, or retreated.

Lower James River Member of the James River Formation

(New)

NAME AND RANK

The Lower James River Member of the James River Formation is formally named here as a lithostratigraphic unit of member rank. The source of the name is the James River in eastern North Dakota. South of the Big Stone moraine, in central and southern Minnesota, the Lower James River Member is the lithostratigraphic equivalent of the Dovray Member of the New Ulm Formation (Lusardi and Jennings, 2016).

TYPE SECTION

The type section for the Lower James River Member of the James River Formation is Minnesota Geological Survey rotary-sonic core OTT-3 (N-6603) in Grant County, Minnesota (T. 130 N., R. 42 W., sec. 17 dcdcb; GPS: 46.065364, -95.984458; USGS 7.5-minute series Fourmile Lake, MN quadrangle; fig. A1.69 and Appendix 2, p. 180).

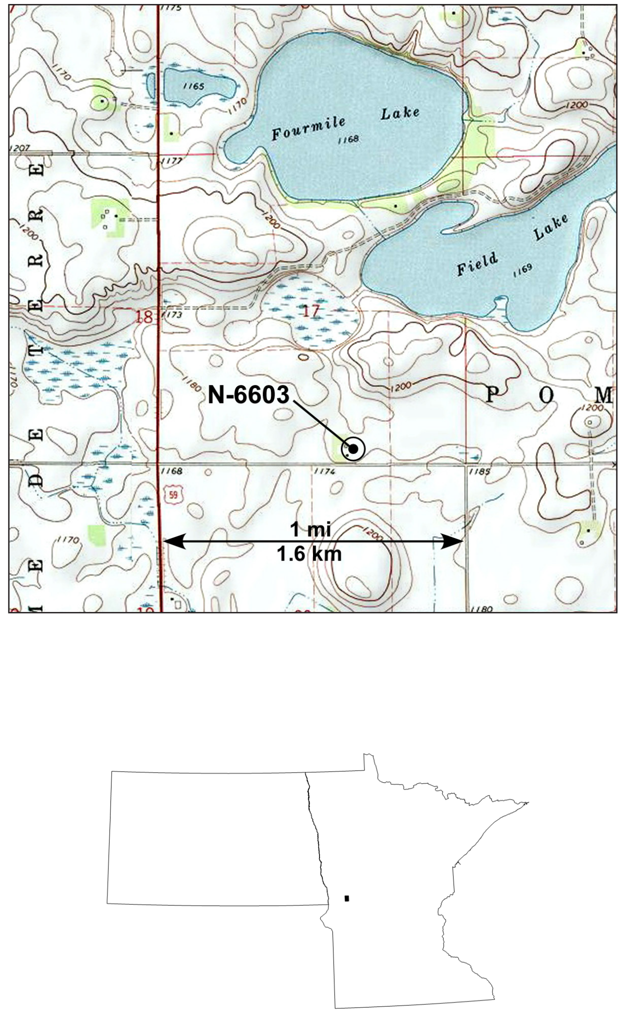


Figure A1.69. The type section for the Lower James River Member of the James River Formation is Minnesota Geological Survey rotary-sonic core OTT-3 (N-6603) in Grant County, Minnesota (T. 130 N., R. 42 W., sec. 17 dcdcb; GPS: 46.065364, -95.984458; USGS 7.5-minute series Fourmile Lake, MN quadrangle; Appendix 2, p. 180).

REFERENCE SECTION

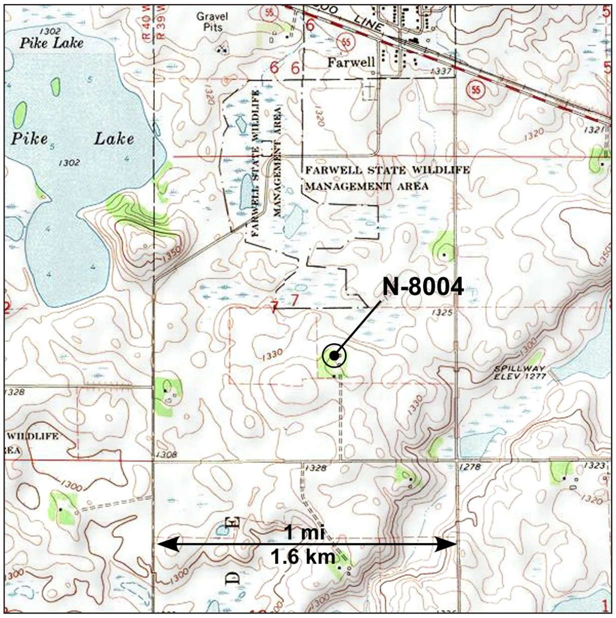
The reference section for the Lower James River Member of the James River Formation is Minnesota Geological Survey rotary-sonic core TG-4 (N-8004) in Pope County, Minnesota (T. 126 N., R. 39 W., sec. 7 dbcaac; GPS: 45.735507, -95.621822; USGS 7.5-minute series Lowry, MN quadrangle; fig. A1.70 and Appendix 2, p. 167).

LITHOLOGIC DESCRIPTION

The Lower James River Member consists mainly of calcareous diamicton that is interpreted to be till. The unoxidized till ranges in color from very dark grayish brown (2.5Y 3/2) and very dark gray (10YR 3/1) to black (10YR 2/1). It has a pebbly sandy loam to clay loam texture with an average composition of 40 percent sand, 37 percent silt, and 23 percent clay (fig. A1.71A). Lignite and wood fragments are common in places. The composition of the very coarse sand fraction averages 42 percent crystalline rocks, 28 percent carbonate rocks, and 30 percent shale fragments (fig. A1.71B). In addition to the diamicton, the Lower James River Member includes associated sand and gravel that was deposited in meltwater streams, and silty lacustrine sediment.

DESCRIPTION OF BOUNDARIES

The Lower James River Member is at the surface in several places along, and adjacent to, the Alexandria and Big Stone moraines. In North Dakota, it is exposed on the proximal side of the Oakes ice-margin in eastern LaMoure, and western Ransom and Sargent Counties; in eastern Barnes County near the communities of Fingal and Tower City; and locally in parts of Cass, Steele, Nelson, and Cavalier Counties. South and east of the Big Stone moraine, the Lower James River Member is overlain by the Villard Member or by younger sediments, mainly of



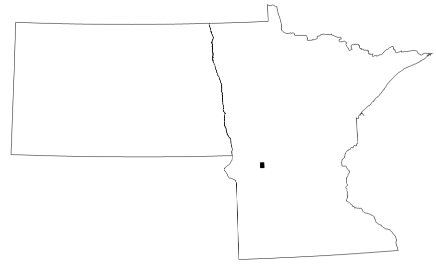


Figure A1.70. The reference section for the Lower James River Member of the James River Formation is Minnesota Geological Survey rotary-sonic core TG-4 (N-8004) in Pope County, Minnesota (T. 126 N., R. 39 W., sec. 7 dbcaac; GPS: 45.735507, -95.621822; USGS 7.5-minute series Lowry, MN quadrangle; Appendix 2, p. 167).

the Heiberg Member, of the Goose River Formation. A general northward increase in the predominance of the Goose River Formation as the overlying unit continues into the Red River Valley and eastern North Dakota where almost everywhere the Lower James River Member is overlain by the Heiberg or, less commonly, the Dahlen Member. In some places, it is capped by a thin layer of lake sediment.

The Lower James River Member overlies a variety of older glacial units including, in west-central Minnesota, the Buffalo River, Crow Wing River, Sheyenne River, and Gervais Formations. It overlies the Buffalo River Formation in the southern Red River Valley and the Gardar Formation to the north and west.

HISTORICAL BACKGROUND

This unit was designated as unit RRV05, or "James River till" of the informal "James River group" by Harris and others (1995, 1999, 2003). The unit was later referred to as the "James River formation" by Harris and Berg (2006).

REGIONAL EXTENT AND THICKNESS

Because it is mainly present in the subsurface in North Dakota, the western margin of the Lower James River Member is not well defined. Its presumed extent is shown in figure A1.72. The Lower James River Member is present in the Red River Valley south of the Perley ice margin and extends westwards from the Pembina Escarpment across Cavalier and Ramsey Counties in the northeastern part of the state. To the south, the Lower James River Member has been recognized in borings and at the surface as far west as the Kensal-Oakes moraine, although this does not necessarily mark the unit's western boundary. The Lower James River Member is expected to continue northwards into southern Manitoba, although a general thinning of the unit towards the north and west suggests that it may have been removed by erosion.

In Minnesota the Lower James River Member is bounded to the east and south by the Alexandria and Big Stone moraines. It continues beyond the Big Stone moraine into south-central Minnesota as the Dovray Member of the New Ulm Formation (Lusardi and Jennings, 2016).

The Lower James River Member is thickest at its reference section where 61 feet (18.5 meters) of the unit is at the surface. At the type section, 50 feet (15 meters) of the Lower James River Member is overlain by 111 feet (34 meters) of tills, and lake and river sediment of the Goose River Formation. In eastern North Dakota, and where it has been identified in the Red River Valley, the thickness of the Lower James River Member is typically about 10 to 20 feet (3 to 6 meters) and thins northward to 3 feet (1 meter) or less in Ramsey and Cavalier Counties.

DIFFERENTIATION FROM OTHER UNITS

The Lower James River Member may be distinguished from other till units by its shale content. It is texturally similar to but contains about 21 percent fewer crystalline rock fragments and 35 percent more shale fragments than the Villard Member. It is sandier than the St. Hilaire Member, and contains about 20 percent less carbonate and 20 percent more shale fragments in its very coarse sand fraction. The Dahlen and Heiberg Members of the Goose

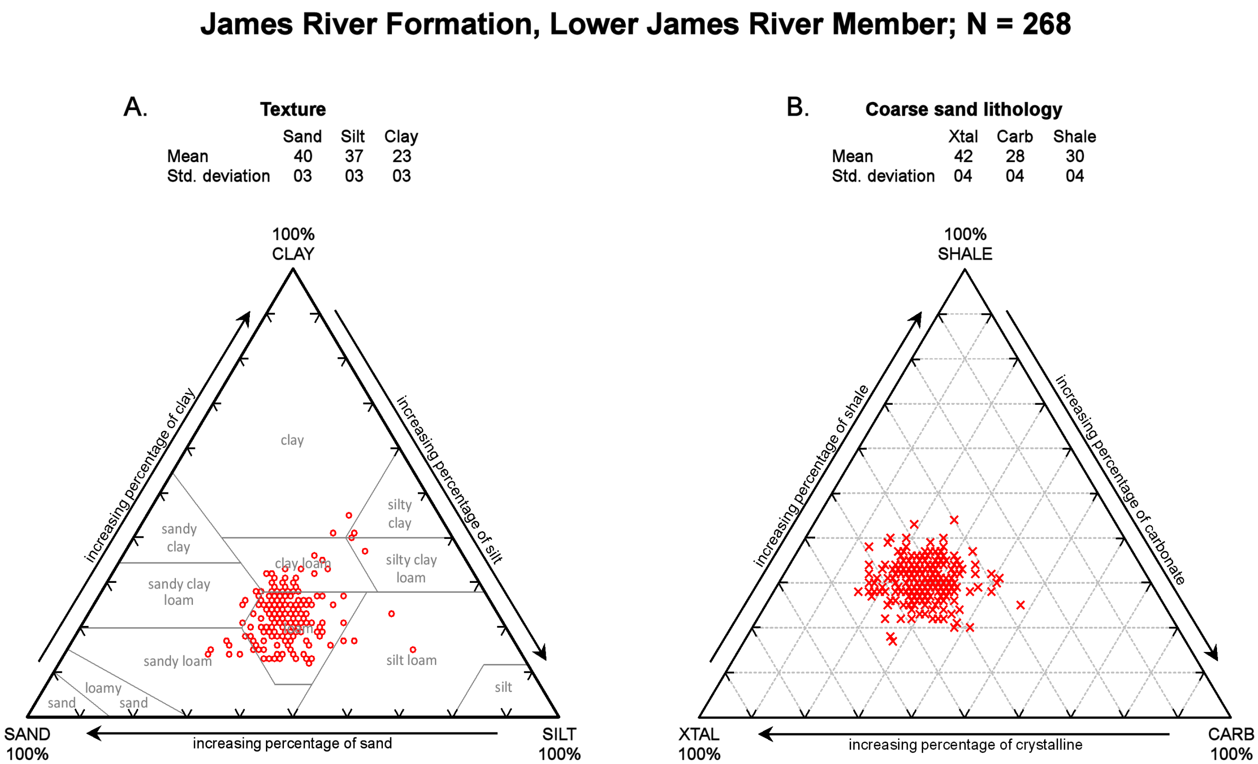


Figure A1.71. Ternary diagrams showing the results of the analysis of 268 samples that show typical textural and coarse-sand lithologic characteristics of the Lower James River Member of the James River Formation. The texture (A) of the Lower James River Member is sandy loam to clay loam and the very coarse-sand lithology (B) indicates a Riding Mountain (northwestern) provenance.

River Formation, and the Gardar Formation are all less sandy and contain considerably more shale fragments. The underlying, older tills from the north and northeast are generally shale-poor with correspondingly higher concentrations of crystalline or carbonate rock fragments or both.

AGE

The Lower James River Member of the James River Formation is slightly older than the Villard Member and is Late Wisconsinan in age. No dates are associated directly with the Lower James River Member, but an estimated age for Dovray Member of the New Ulm Formation, with which it is lithostratigraphically equivalent, suggests it was deposited around 13,000 ^{14}C yr BP (Lusardi and Jennings, 2016).

CORRELATION

The Lower James River Member of the James River Formation continues southeast of the Big Stone moraine, where it is included as the Dovray Member of the New Ulm Formation (Lusardi and Jennings, 2016). The nomenclature break is at the Big Stone moraine, or about lat. 46º N., the approximate boundary between the Red River lobe and the Des Moines lobe nomenclature. Its equivalence to the Dovray Member implies a possible correlation between the Lower James River Member and part of the Dows Formation in Iowa (Hallberg and Kemmis, 1986). The Lower James River Member also correlates with an unnamed till unit found in two boreholes near Sevenmile Coulee in eastern Stutsman County, North Dakota and described by Biek (1994).

GENESIS

The Lower James River Member was deposited by glacial ice that moved into North Dakota and Minnesota mainly from the northwest (Riding Mountain provenance). The ice flowed through the Red River Valley, where the associated diamicton was later eroded from the northern half by glaciers during an early phase of Lake Agassiz, and into central and southern Minnesota.

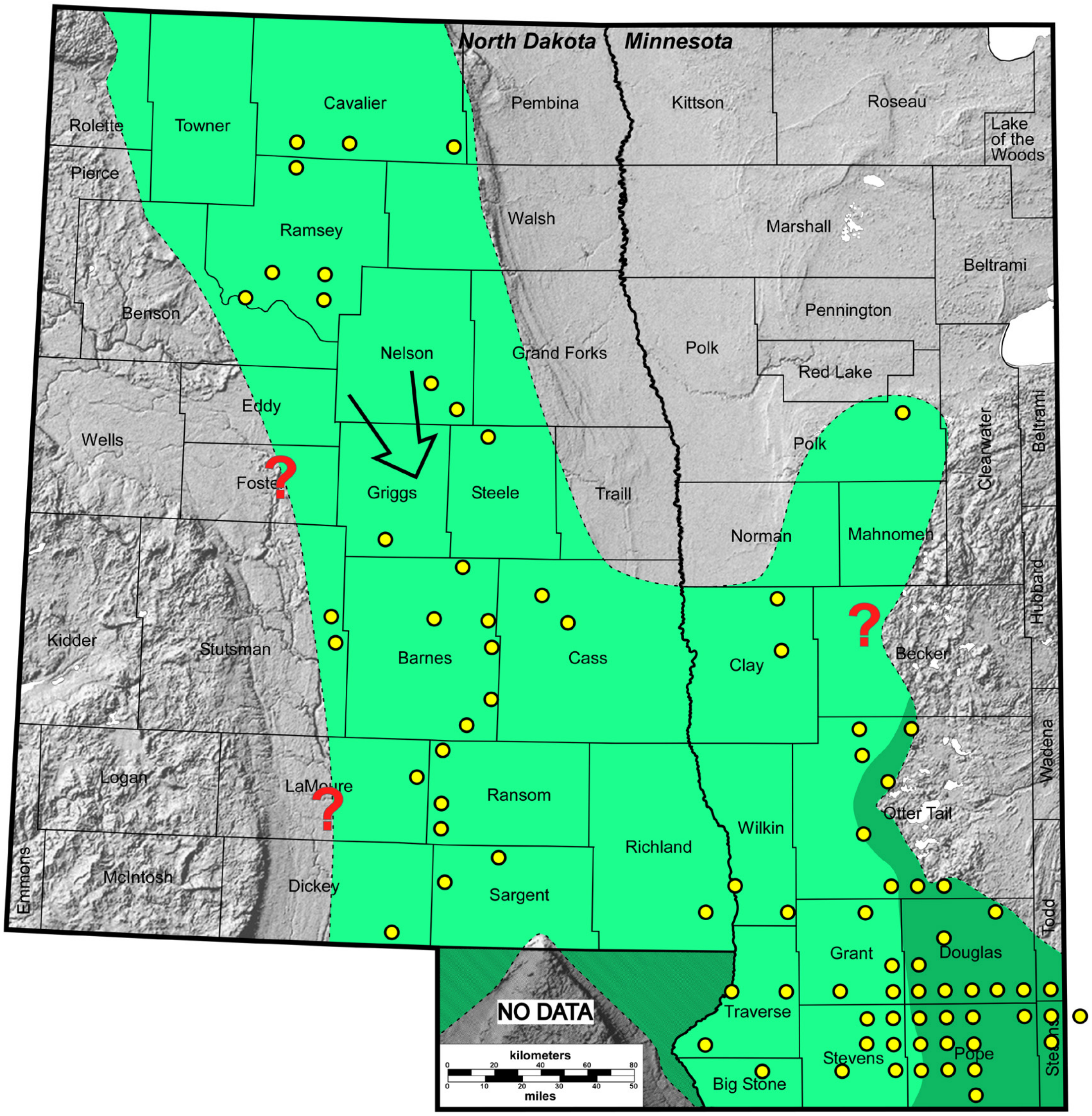


Figure A1.72. This figure shows the distribution of the Lower James River Member of the James River Formation in the Red River Valley of North Dakota and Minnesota, and eastern North Dakota. In Minnesota the Lower James River Member is included as the Dovray Member in the New Ulm Formation (shown in dark green). The nomenclature break is the Big Stone moraine. The Lower James River Member consists mainly of glacial sediment that was deposited during a readvance of the Des Moines lobe from the northwest (Riding Mountain provenance). Yellow circles indicate townships where sample control is located. The arrow indicates the direction of ice flow.

GARDAR FORMATION

(Accepted)

NAME AND RANK

The Gardar Formation is accepted as formally named by Salomon (1975) with minor modifications owing to format changes and additional information. The source of the name is the village of Gardar in Pembina County, North Dakota, located on the USGS 7.5-minute series Gardar, ND quadrangle.

TYPE AREA

Western Grand Forks County, North Dakota.

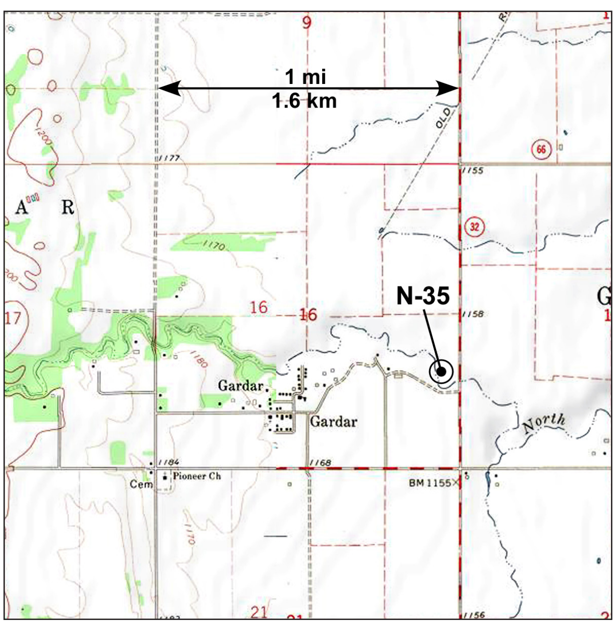
TYPE SECTION

The original type section defined by Salomon (1975) was a stream cut (N-35) on the south side of North Branch of the Park River in Pembina County, North Dakota (T. 159 N., R. 56 W., sec. 16 dad; USGS 7.5-minute series Gardar, ND quadrangle; fig. A1.73 and Appendix 2, p. 242). The diamicton at this site contains an excessively high amount of shale (90 percent) in its coarse sand fraction (Salomon, 1975; Hobbs, 1975) and is atypical of the Gardar Formation for which the mean is 74 percent (fig. A1.74). It is not a good representation of the unit and given the overabundance of shale, it may, in part at least, have been misinterpreted. The original type section is therefore supplemented by a principal reference section.

REFERENCE SECTIONS

The principal reference section for the Gardar Formation is Minnesota Geological Survey rotary-sonic core RVR-2 (N-6219) in Clay County, Minnesota (T. 137 N., R. 47 W., sec. 10 ddddda; GPS: 46.689069, -96.590021; USGS 7.5-minute series Baker, MN quadrangle; fig. A1.75 and Appendix 2, p. 199).

A reference section for the Gardar Formation is North Dakota Geological Survey power auger boring N-5164 in Sargent County, North Dakota (T. 131 N., R. 56 W., sec. 21 ccc; GPS: 46.140496, -97.713878; USGS 7.5-minute series Gwinner, ND quadrangle; fig. A1.76 and Appendix 2, p. 190).



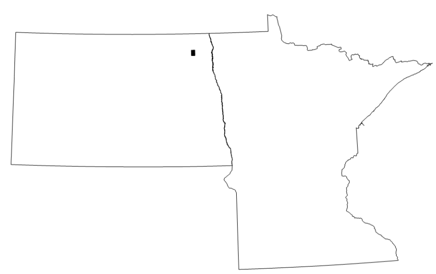


Figure A1.73. Stream cut (N-35) on the south side of North Branch of the Park River in Pembina County, North Dakota (T. 159 N., R. 56 W., sec. 16 dad; USGS 7.5-minute series Gardar, ND quadrangle; Appendix 2, p. 242) is the original type section of the Gardar Formation. The proportion of shale in the very coarse sand fraction of the diamicton at this site is atypical of the Gardar Formation and some aspects of the sedimentary sequence may have been misinterpreted. The original type section is therefore supplemented by a principal reference section.

Gardar Formation; N = 336

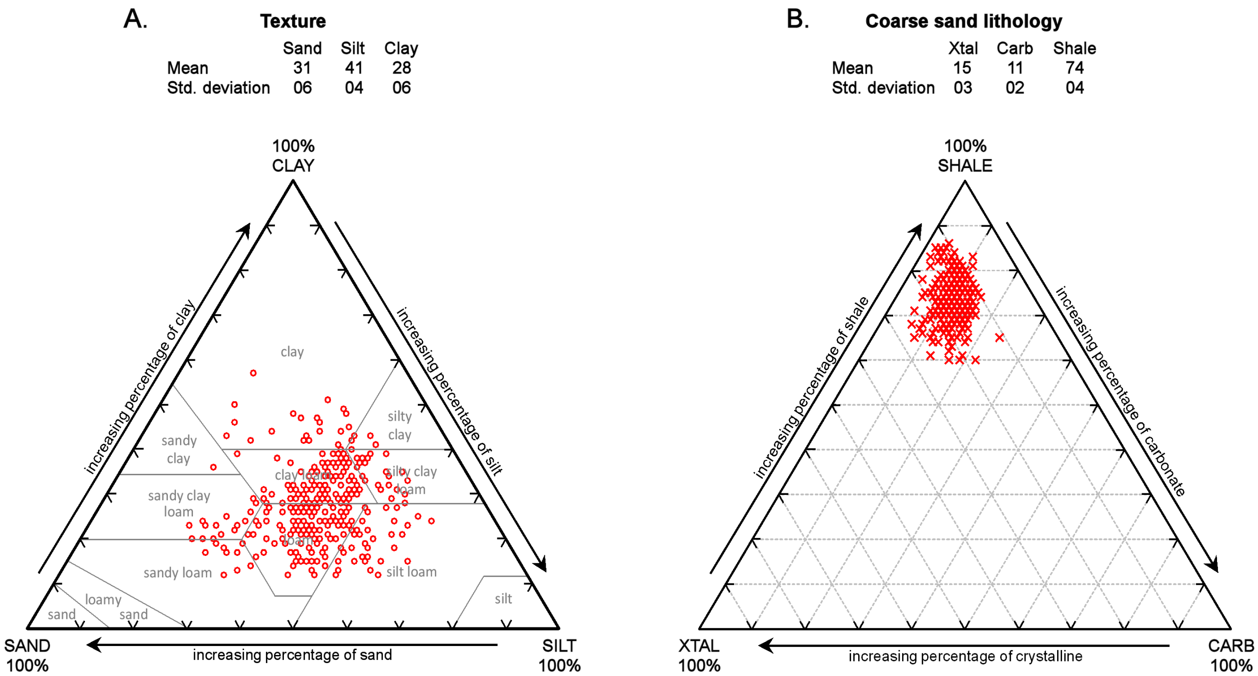
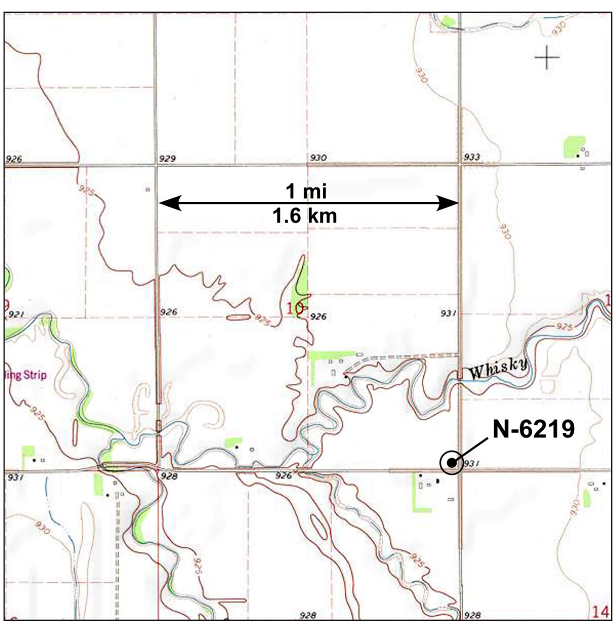


Figure A1.74. Ternary diagrams showing the results of the analysis of 336 samples that show typical textural and coarse-sand lithologic characteristics of the Gardar Formation. The texture (A) of the Gardar Formation is sandy loam to clay loam and the very coarse-sand lithology (B) indicates a Riding Mountain (northwest) provenance.



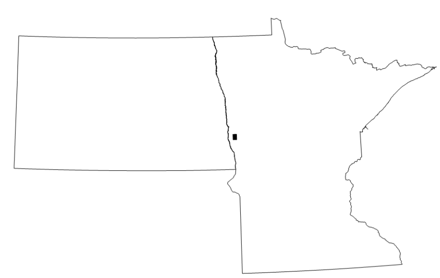
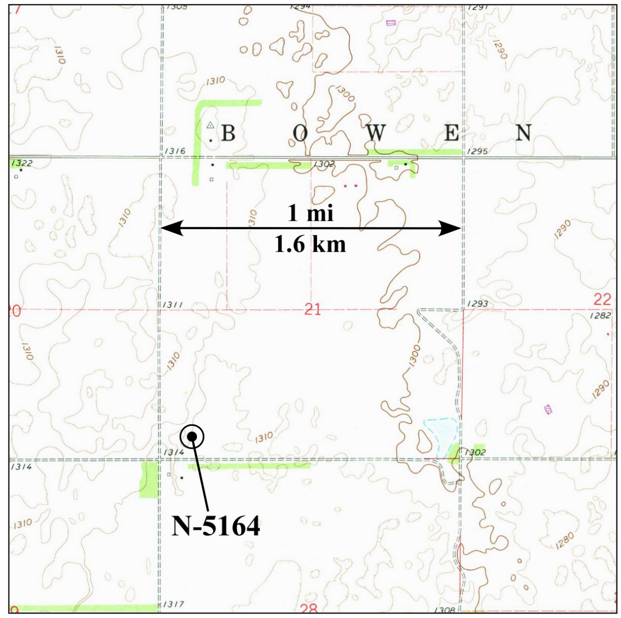


Figure A1.75. The principal reference section for the Gardar Formation is Minnesota Geological Survey rotary-sonic core RVR-2 (N-6219) in Clay County, Minnesota (T. 137 N., R. 47 W., sec. 10 ddddda; GPS: 46.689069, -96.590021; USGS 7.5-minute series Baker, MN quadrangle; Appendix 2, p. 199).



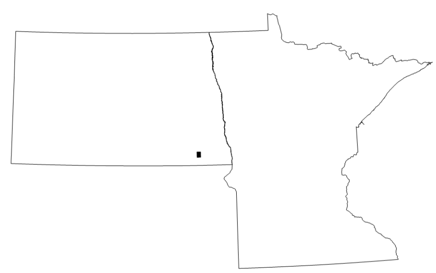


Figure A1.76. A reference section for the Gardar Formation is North Dakota Geological Survey power auger boring N-5164 in Sargent County, North Dakota (T. 131 N., R. 56 W., sec. 21 ccc; GPS: 46.140496, -97.713878; USGS 7.5-minute series Gwinner, ND quadrangle; Appendix 2, p. 190).

LITHOLOGIC DESCRIPTION

The Gardar Formation consists of pebble-loam diamicton interpreted to be till, and a minor amount of stratified sediment. It is variously colored when oxidized but typically is light yellowish brown (2.5Y 6/4) to light olive brown (2.5Y 5/4) or light brownish gray (2.5Y 6/2). Unoxidized, it is dark grayish brown (2.5Y 4/2 to very dark gray (5Y 3/1). The blocky, friable till is commonly iron-stained along joints and may contain ocher inclusions or localized concentrations of gypsum. Lignite and organic debris are common in places. Diamicton of the Gardar Formation has a texture that ranges from sandy loam to clay with an average composition of 31 percent sand, 41 percent silt, and 28 percent clay (fig. A1.74A). The average shale content of the very coarse sand fraction (1-2 mm) is 74 percent, with 15 percent crystalline and metamorphic fragments, and 11 percent carbonate rock fragments (fig. A1.74B).

DESCRIPTION OF BOUNDARIES

Except in the Red River Valley, the Gardar Formation is the surface unit in several outcrops and boreholes throughout eastern North Dakota, especially in Cavalier and Sargent Counties. It is otherwise overlain primarily by the Dahlen Member of the Goose River Formation or, in places, the Heiberg Member. A notable exception is at the type section, where it is overlain by the Villard Member of the James River Formation. The upper contact with the Dahlen Member is commonly marked by a soled, striated boulder pavement at the top of the Gardar Formation.

The Gardar Formation overlies a variety of older units including the Sheyenne River and Gervais Formations. In northeastern North Dakota, Hobbs (1975) and Hobbs and Bluemle (1987) described several units underlying the Gardar Formation. Three, the Cando, Camp Grafton, and Churchs Ferry Formations are formal lithostratigraphic units, but are of limited extent and none are well-represented in the Red River Valley, so are not part of this publication. Along the Pembina Escarpment and the adjacent uplands; in central Ramsey County, and at a few other sites further west of the Escarpment, the Gardar Formation overlies shale bedrock. In many places it is separated from the underlying glacial sediment or shale by a soled boulder pavement.

HISTORICAL BACKGROUND

The Gardar Formation was formally named and defined by Salomon (1975), and further described by Hobbs (1975). In the southern Red River Valley, it was correlated with unit RRV13 of the informal Lake Tewaukon group (Harris and others, 1995, 1999; Harris, 1998; Thorleifson and others, 2005; Harris and Berg, 2006). The underlying unit, referred to as RRV14, is similar to, but more sparsely distributed than, the Gardar Formation, and is thought to be a local variant (Harris, 1998; Johnson and others, 2016, p. 259).

REGIONAL EXTENT AND THICKNESS

The presumed extent of the Gardar Formation is shown in figure A1.77. It is widespread throughout eastern North Dakota and all except the northeastern quarter of

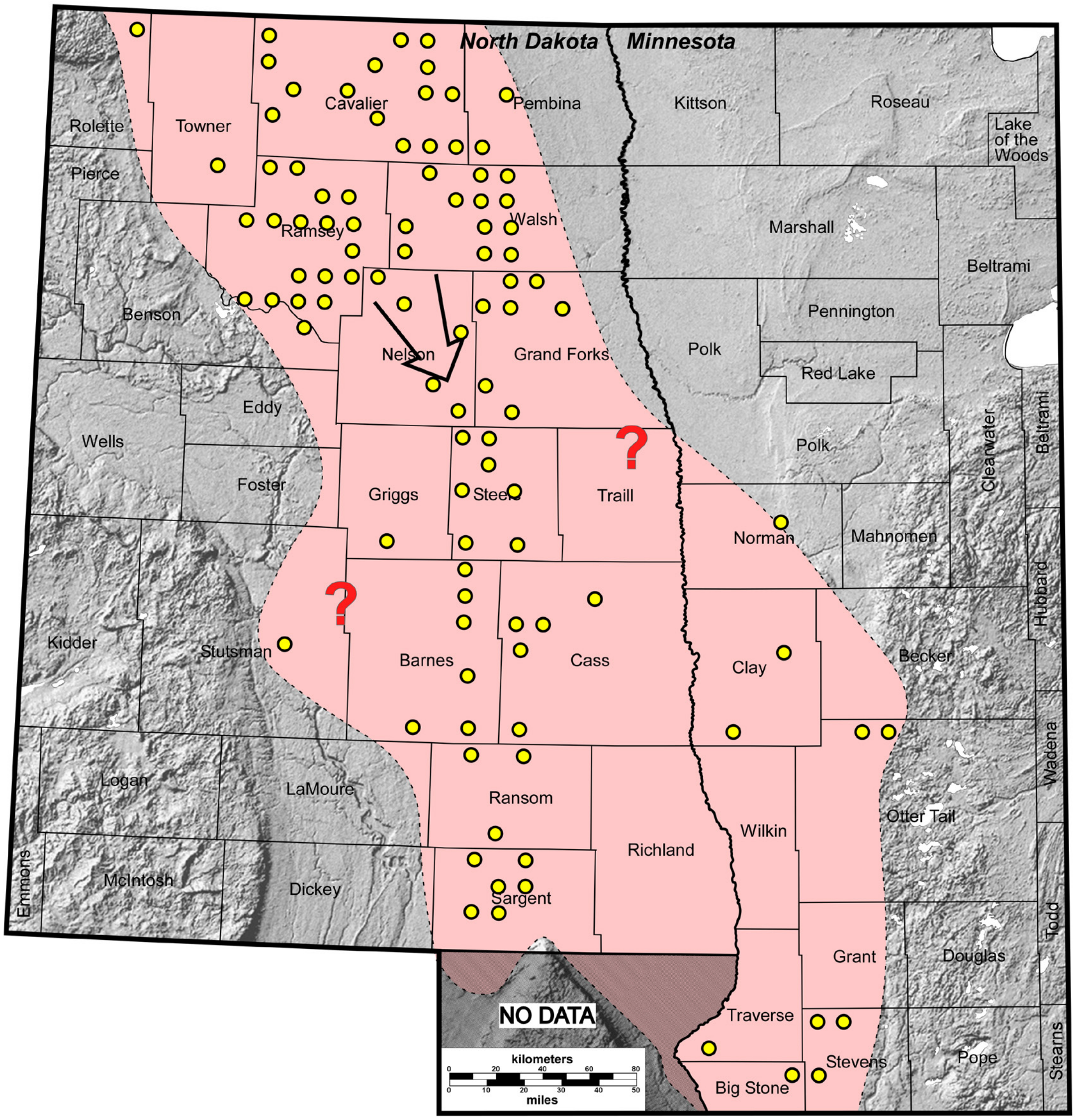


Figure A1.77. This figure shows the distribution of the Gardar Formation in the Red River Valley of North Dakota and Minnesota, and eastern North Dakota. The Gardar Formation consists mainly of glacial sediment that was deposited during a readvance of the Des Moines (Red River) lobe from the northwest (Riding Mountain provenance) during an early phase of the Late Wisconsinan glaciation. Yellow circles indicate townships where sample control is located. The arrow indicates the direction of ice flow.

the Red River Valley, but erosion has removed the unit completely from much of this area. East and south of the Red River Valley, the Gardar Formation has only been traced as far as the Big Stone moraine. From south-central Becker County in Minnesota, it extends northwestwards into North Dakota where it crosses the International Boundary just east of the Cavalier-Pembina County line and continues into southern Manitoba. Outcrops of the Gardar Formation near the community of Lena, about 15 miles (24 kilometers) north of Rolla, North Dakota, mark the unit's northernmost observed extent. To the west, the Gardar Formation has been identified at sites in eastern Rolette and central Stutsman Counties. The sites in Stutsman County are approximately midway between the Kensal and Woodhouse moraines, so it is possible that Gardar Formation is present beyond the western boundary shown in figure A1.77.

In eastern North Dakota, the Gardar Formation commonly occurs as valley fill with a maximum thickness of more than 200 feet (60 meters; Hobbs and Bluemle, 1987). It otherwise ranges in thickness from zero to an observed maximum of 135 feet (41 meters) at the foot of the Pembina Escarpment in northern Grand Forks County.

DIFFERENTIATION FROM OTHER UNITS

The Gardar Formation contains considerably more shale (at least 28% in its very coarse sand fraction) than any other till unit in the Red River Valley and the adjacent uplands in Minnesota and North Dakota.

AGE

The age of the Gardar Formation is unknown. Clayton and Moran (1982) suggested it was deposited during an early phase ("phase E") of the Late Wisconsinan that was followed by an ice-free period when the glacier retreated north of the International Boundary. The duration of this interval is unclear, but the eroded upper contact and sparse distribution of the Gardar Formation indicate its age likely predates the glacial advances that deposited the Goose River and James River Formations by at least a few thousand years. Clayton and Moran (1982) proposed a minimum age for phase E of about 15,000 ^{14}C yr BP (Hobbs, 2016).

CORRELATION

The Gardar Formation has no known lithostratigraphic equivalent in Minnesota or southern Manitoba.

GENESIS

The Gardar Formation is glacial sediment that was deposited during a readvance of the Des Moines (Red River) lobe into eastern North Dakota and the Red River Valley. The lithology of the pebble and coarse sand fractions of the Gardar Formation suggests a northwestern (Riding Mountain) provenance (fig. 17).

BUFFALO RIVER FORMATION

(New)

NAME AND RANK

The Buffalo River Formation is formally named here. It is named after the Buffalo River in Clay County, west-central Minnesota.

TYPE SECTION

The type section for the Buffalo River Formation is North Dakota Geological Survey power auger boring N-5157 in Sargent County, North Dakota (T. 130 N., R. 54 W., sec. 15 cdd; GPS: 46.065611, -97.436933; USGS 7.5-minute series Cayuga, ND quadrangle; fig. A1.78 and Appendix 2, p. 185).

REFERENCE SECTIONS

The Buffalo River Formation has three reference sections:

Minnesota Geological Survey rotary-sonic core TG-1 (N-8001) in Traverse County, Minnesota (T. 125 N., R. 48 W., sec. 22 ddcdda; GPS: 45.615106, -96.680721; USGS 7.5-minute series Beardsley, MN quadrangle; fig. A1.79 and Appendix 2, p. 163).

North Dakota Geological Survey power auger boring N-5158 in Sargent County, North Dakota (T. 130 N., R. 55 W., sec. 20 cdd; GPS: 46.051757, -97.602890; USGS 7.5-minute series Rutland, ND quadrangle; fig. A1.80 and Appendix 2, p. 186).

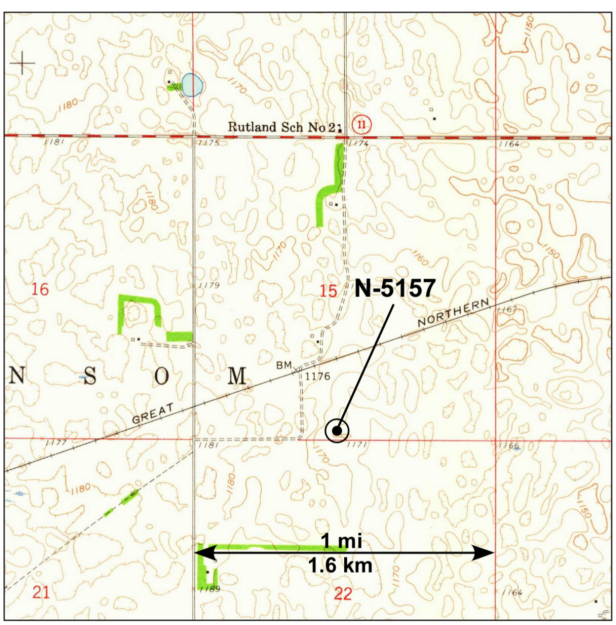
North Dakota Geological Survey power auger boring N-1918 in Clay County, Minnesota (T. 142 N., R. 44 W., sec. 36 bcbb; GPS: 47.074297, -96.215179; USGS 7.5-minute series Tilde Lake, MN quadrangle; fig. A1.81 and Appendix 2, p. 213).

LITHOLOGIC DESCRIPTION

The Buffalo River Formation consists almost entirely of massive, compact, unsorted, unbedded pebble-loam interpreted to be till. Fluvial and lake sediment is uncommon in this unit. The pebble-loam is olive brown (2.5Y 4/3 to 2.5Y 4/4) where oxidized and very dark gray (2.5Y 3/0) where unoxidized. It has a clay loam to sandy loam texture that averages 34 percent sand, 36 percent silt, and 30 percent clay (fig. A1.82A). The very coarse sand lithology (1-2 mm) of the pebble-loam averages 64 percent crystalline and metamorphic rock fragments, 30 percent carbonate rock fragments, and 7 percent shale fragments (fig. A1.82B). Pebbles are abundant and consist mainly of igneous and metamorphic rock types, with moderate amounts of carbonate and little to no shale.

DESCRIPTION OF BOUNDARIES

The Buffalo River Formation is at the surface at reference section N-5158 in Sargent County, North Dakota and in numerous other places throughout the uplands



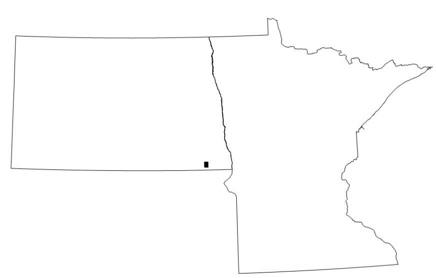
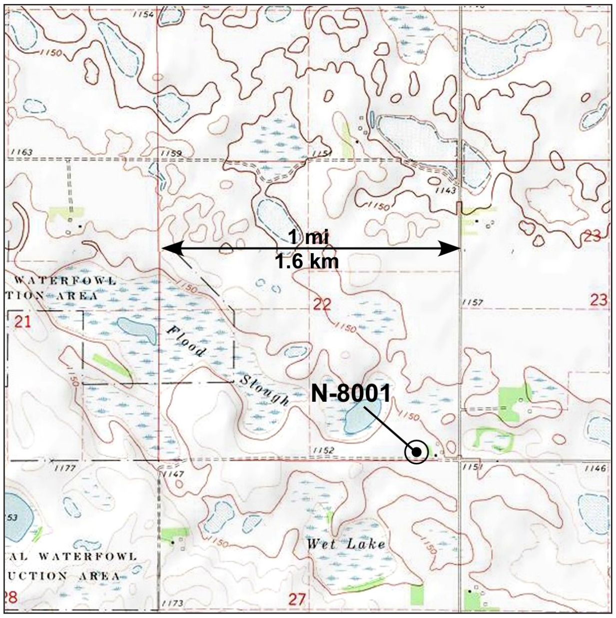


Figure A1.78. North Dakota Geological Survey power auger boring N-5157 in Sargent County, North Dakota (T. 130 N., R. 54 W., sec. 15 cdd; GPS: 46.065611, -97.436933; USGS 7.5-minute series Cayuga, ND quadrangle; Appendix 2, p. 185) is the type section for the Buffalo River Formation.



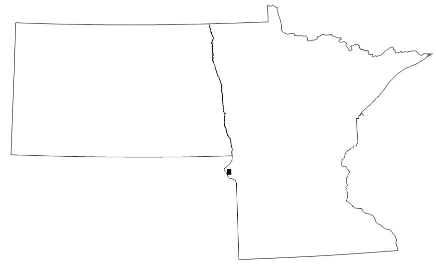
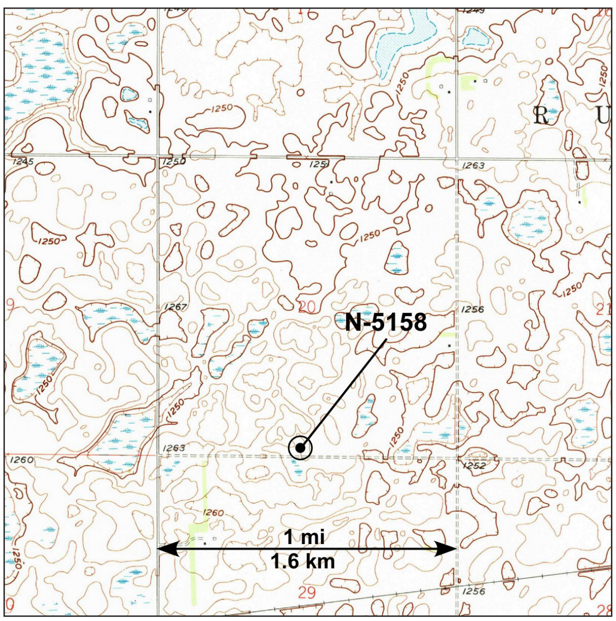


Figure A1.79. Minnesota Geological Survey rotary-sonic core TG-1 (N-8001) in Traverse County, Minnesota (T. 125 N., R. 48 W., sec. 22 ddcdda; GPS: 45.615106, -96.680721; USGS 7.5-minute series Beardsley, MN quadrangle; Appendix 2, p. 163) is a reference section for the Buffalo River Formation.



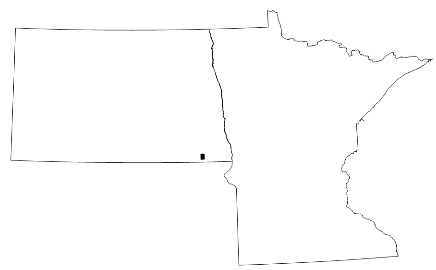
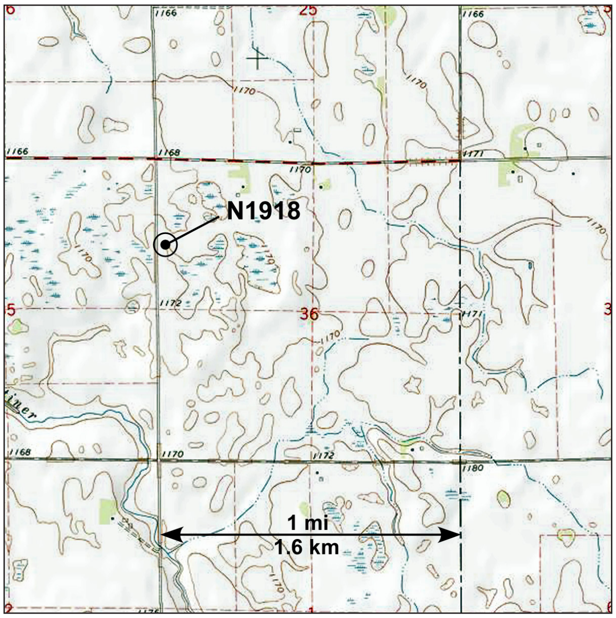


Figure A1.80. North Dakota Geological Survey power auger boring N-5158 in Sargent County, North Dakota (T. 130 N., R. 55 W., sec. 20 cdd; GPS: 46.051757, -97.602890; USGS 7.5-minute series Rutland, ND quadrangle; Appendix 2, p. 186) is a reference section for the Buffalo River Formation.

surrounding the Red River Valley. The unit is mostly present in the subsurface within the valley itself, where it is overlain by one or more members of the Goose River Formation; although it is also exposed in a few isolated areas east of the Red River in Polk and Wilkin Counties, Minnesota. At its type section, the Buffalo River Formation is overlain by about 10 feet (3 meters) of a weathered, shale-poor pebble loam, probably of rainy lobe origin. In places south and east of the Big Stone moraine where the Buffalo River Formation is in the subsurface, it is commonly overlain by, or may even be a component of, one or more out-of-sequence or repeated sequences of glacial sediments that are separated by low-angle faults interpreted to be the result of ice-thrusting. Besides the Buffalo River Formation, these sedimentary sequences typically include some or all of the members of the Goose River, James River, and Crow Wing River Formations, and possibly older units as well. Probable thrust faults are noted in the core descriptions for reference sections N-8001 (T. 125 N., R. 48 W., sec. 22 ddcdda;



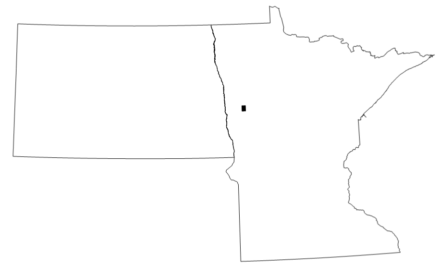


Figure A1.81. North Dakota Geological Survey power auger boring N-1918 in Clay County, Minnesota (T. 142 N., R. 44 W., sec. 36 bcbb; GPS: 47.074297, -96.215179; USGS 7.5-minute series Tilde Lake, MN quadrangle; Appendix 2, p. 213) is a reference section for the Buffalo River Formation.

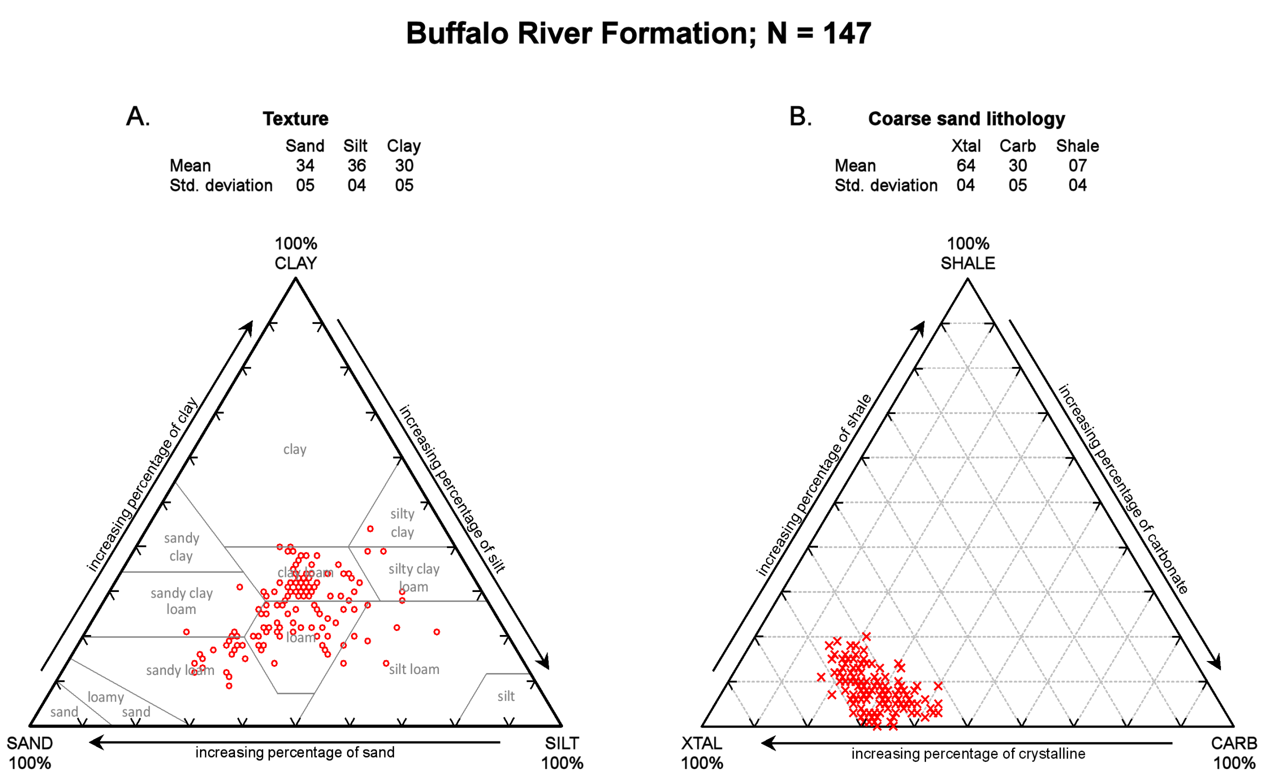


Figure A1.82. Ternary diagrams showing the results of the analysis of 147 samples that show typical textural and coarse-sand lithologic characteristics of the Buffalo River Formation. The texture (A) of the Buffalo River Formation is mainly sandy loam to clay loam and the very coarse-sand lithology (B) indicates a mixed Rainy-Winnipeg (northeastern and northern) source area.

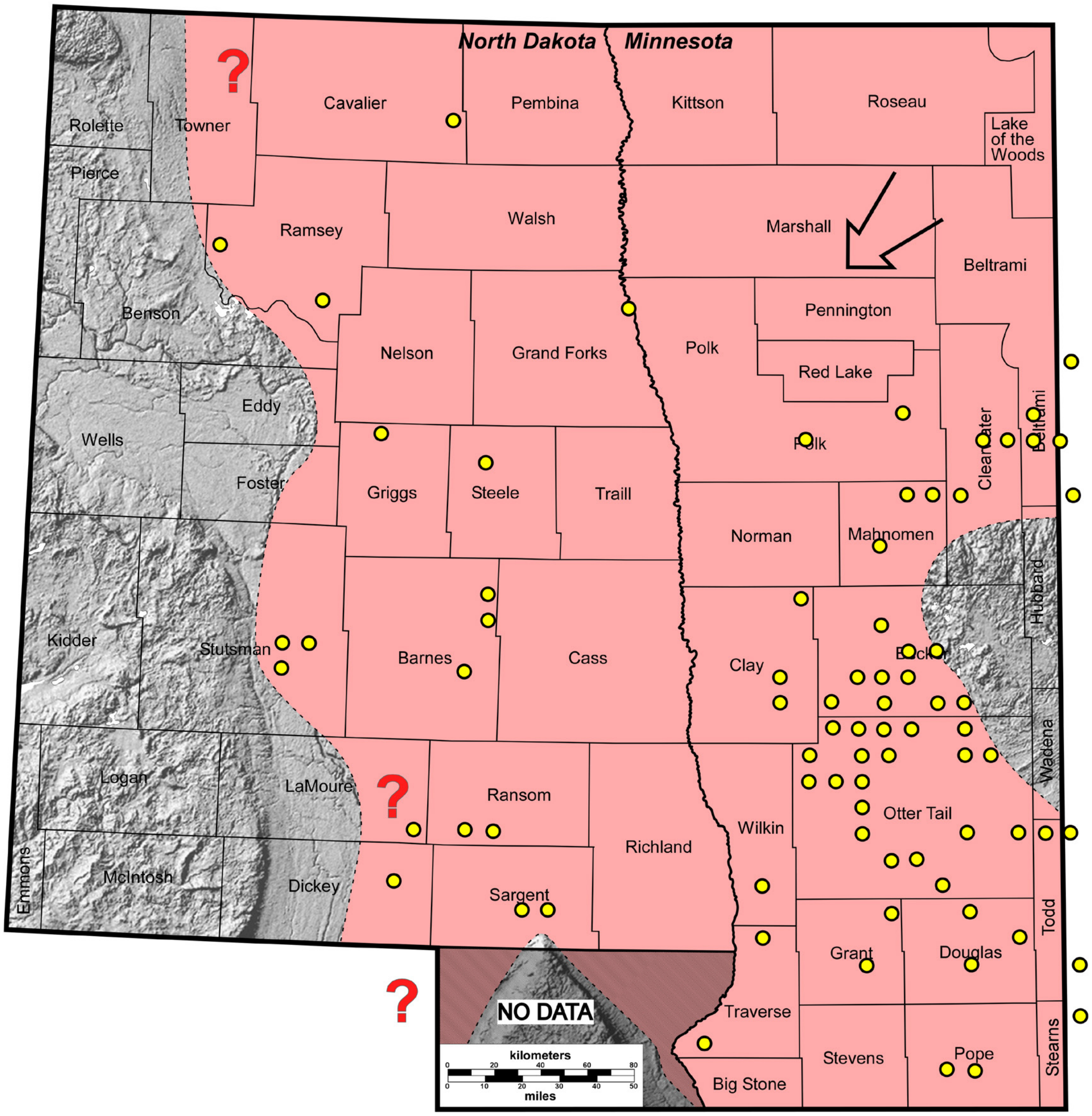


Figure A1.83. This figure shows the distribution of the Buffalo River Formation in the Red River Valley of North Dakota and Minnesota and the surrounding region. The Buffalo River Formation consists mainly of glacial sediment deposited by a glacier advancing from the northeast and north (mixed Rainy-Winnipeg provenance). It is exposed at the surface in several places throughout its extent but is only present in the subsurface in the Red River Valley. Yellow circles indicate townships where sample control is located. The arrow indicates the direction of ice flow.

Appendix 2, p. 163) and N-1918 (T. 142 N., R. 44 W., sec. 36 bcbb; Appendix 2, p. 213). There is also evidence of ice-thrusting in the glacial deposits west of the Red River Valley but because the borings here are generally shallower, the faulted sequences are not always observed. In most places, the unit directly overlying the Buffalo River Formation is one of the members of the Goose River Formation, or the Villard or Lower James River Member of the James River Formation. North and west of the Big Stone moraine, the overlying unit is primarily one of the members of the Goose River Formation, although here and there, it is the Gardar Formation. South and east of the Big Stone moraine, the Villard and Lower James River Members of the James River Formation tend to predominate. At one site in Clay County, Minnesota the Buffalo River Formation is overlain by the Lower Member of the Red Lake Falls Formation.

The Buffalo River Formation overlies a variety of older units. In a total of twelve boreholes in Dickey, Grand Forks, LaMoure and Ransom Counties, North Dakota, and Becker, Mahnomen, Otter Tail and Todd Counties, Minnesota, the Buffalo River Formation overlies the Sheyenne River Formation. In a further eleven boreholes in west-central Minnesota, it overlies the Crow Wing River Formation. At the type section the Buffalo River Formation overlies the Old Marcoux till. It overlies the Gervais Formation at reference section N-8001 (T. 125 N., R. 48 W., sec. 22 ddcdda; Appendix 2, p. 163) and at two sites east of the Big Stone moraine in Douglas and Otter Tail Counties. The Buffalo River Formation overlies shale bedrock in a single borehole in Cavalier County. In some places, the lower contact between the Buffalo River Formation and the underlying till unit is marked by about 3 feet (1 meter) of very dark gray, obscurely laminated silty and clayey lake sediment.

HISTORICAL BACKGROUND

The Buffalo River Formation was originally identified in the southern Red River Valley as RRV15 and included in the informal “Crow Wing River group” by Harris and others (1995). Thorleifson and others (2005) and Harris and Berg (2006) correlated their “Buffalo River formation” with RRV15 and reassigned the unit to the informal “Buffalo River group” as the product of a mixed north-northeastern (Winnipeg-Rainy) rather than an exclusively northeastern (Rainy) provenance.

REGIONAL EXTENT AND THICKNESS

The regional extent of the Buffalo River Formation is large but because it is primarily a subsurface unit, its boundaries are, for the most part, undefined. It is present throughout the Red River Valley and has been traced westward as far as western Ramsey and central Stutsman Counties in North Dakota. The northern and northeastern extent of the Buffalo River Formation is presumed to be its source areas, but evidence of this is lacking owing to the sparsity of subsurface data for the northern Red River Valley and northwestern Minnesota. The range of the Buffalo River Formation to the east and south is unknown except where it is bounded by the Wadena drumlin field in central Minnesota (fig. A1.83).

The Buffalo River Formation is more than 50 feet (15.2 meters) thick at reference section N-5158 in Sargent County, North Dakota, where it extends to an unknown depth below the base of the core. It measures 35 feet (10.7 meters) at the type section, approximately 8 miles (12.8 kilometers) to the east. Outside Sargent County, the Buffalo River Formation is comparatively thin, averaging only about 9 feet (2.7 meters) and not exceeding 20 feet (6.1 meters) in thickness.

DIFFERENTIATION FROM OTHER UNITS

The Buffalo River Formation is distinguished from similar units mainly by its pebble lithology. It contains more crystalline rock fragments and significantly less shale than sediments of the Des Moines lobe, and at least 50 percent more shale than most Winnipeg- and Rainy-provenance diamicton. The only exceptions are the Upper Member of the Red Lake Falls Formation and the Sheyenne River Formation, which both contain about 60 percent more shale, 13 to 14 percent more carbonate, and are correspondingly depleted in crystalline rock fragments. The Buffalo River Formation may also be differentiated from the Upper Member of the Red Lake Falls Formation by its stratigraphic position.

AGE

The age of the Buffalo River Formation is unknown, but it was probably deposited during an early phase of the Late Wisconsinan glaciation.

CORRELATION

The Buffalo River Formation may correlate with “Till unit 7”, one of several lithostratigraphic units identified by Patterson (1999) underlying the New Ulm Formation in the upper Minnesota River Valley (Harris and Berg, 2006, table 3).

GENESIS

The Buffalo River Formation is glacial sediment that was deposited during a readvance of the generally retreating Late Wisconsinan glacier into western Minnesota and eastern North Dakota including the entire Red River Valley. The lithology of the pebble and coarse sand fractions of the Buffalo River Formation indicates source areas to the northeast and north (mixed Rainy-Winnipeg provenance; fig. 17).

CROW WING RIVER FORMATION

(New)

NAME AND RANK

The Crow Wing River Formation is formally named here. It is named after the Crow Wing River in central Minnesota. The formation has two members: the Sebeka Member and the Marcoux Member. In Minnesota, sediment of the Crow Wing River Formation outside the Red River Valley is included in the Hewitt Formation (Knaeble, 2016).

Sebeka Member of the Crow Wing River Formation

(New)

NAME AND RANK

The Sebeka Member is formally named here. It is modified in rank from formation to a member of the Crow Wing River Formation. The unit is accepted as named by Anderson (1976) with minor modifications owing to format changes and additional information. The source of the name is the village of Sebeka in Wadena County, Minnesota, located on the USGS 7.5-minute series Sebeka, MN quadrangle.

TYPE AREA

Sebeka (northwest) area of the Wadena drumlin field, west-central Minnesota.

TYPE SECTION

The type section for the Sebeka Member of the Crow Wing River Formation is Minnesota Geological Survey rotary-sonic core TG-6 (N-8006) in Pope County, Minnesota (T. 124 N., R. 36 W., sec. 9 cbbaba; GPS: 45.563694, -95.212103; USGS 7.5-minute series Sedan, MN quadrangle; fig. A1.84 and Appendix 2, p. 157).

REFERENCE SECTION

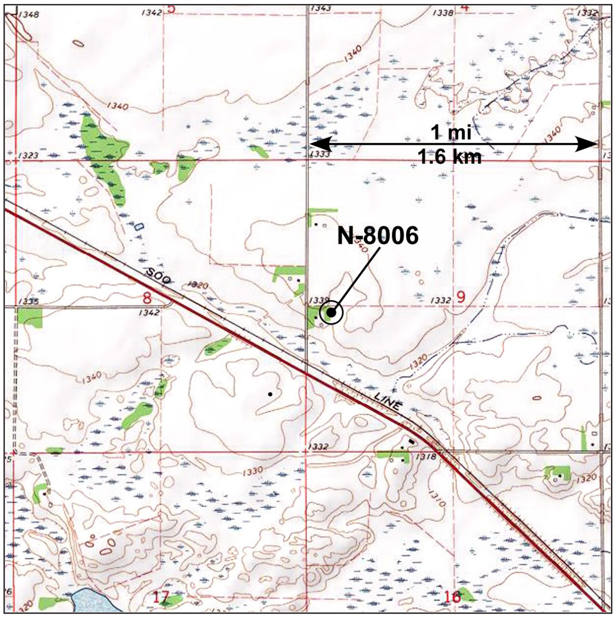
The reference section for the Sebeka Member of the Crow Wing River Formation is Minnesota Geological Survey rotary-sonic core OTT-1 (N-6601) in Becker County, Minnesota (T. 138 N., R. 37 W., sec. 35 abbccd; GPS: 46.729574, -95.318283; USGS 7.5-minute series Butler, MN quadrangle; fig. A1.85 and Appendix 2, p. 201).

LITHOLOGIC DESCRIPTION

The Sebeka Member is unbedded, very sandy pebble-loam interbedded with lesser amounts of glaciofluvial sand and gravel, and silty lake sediment. The oxidized pebble-loam has a pale yellow color (5Y 7/3) when dry and an olive (5Y 5/3) or light olive brown color (2.5Y 5/3) when wet. Unoxidized material ranges in color from dark grayish brown (2.5Y 4/2) to very dark grayish brown (2.5Y 3/2). The composition of the pebble-loam of the Sebeka Member averages 58 percent sand, 27 percent silt, and 15 percent clay (fig. A1.86A). Pebbles are abundant and consist of roughly two-thirds igneous and metamorphic rock types and one-third limestone and dolomite. Shale pebbles are extremely rare. The very coarse sand fraction (1-2 mm) averages 85 percent igneous and metamorphic rock types, 15 percent limestone and dolomite, and 0 percent shale (fig. A1.86B). The pebble-loam of the Sebeka Member forms near-vertical slopes in outcrops. It is weakly jointed and very friable.

DESCRIPTION OF BOUNDARIES

The Sebeka Member is at the surface throughout the uplands east of the Red River Valley, and south of the Big Stone moraine in Minnesota. In some places, including the type section, the Sebeka Member is overlain by oxidized sediment of the overlying Villard Member of the James River Formation. This zone of oxidation extends about 10 feet (3 meters) into the Sebeka Member, a total depth of 48 feet (14.6 meters), suggestive of a prolonged period of aerial exposure. The boundary has not been observed in outcrop. East of the Alexandria moraine, the Sebeka Member is overlain in places by the Buffalo River Formation or well-sorted, medium- to coarse-grained fluvial sand. In the eastern Red River Valley, the Sebeka Member is overlain by the St. Hilaire Member of the Goose River Formation. In the northeastern part of the valley, where the Goose River Formation is absent, it is overlain by one or both members of the Red Lake Falls Formation.



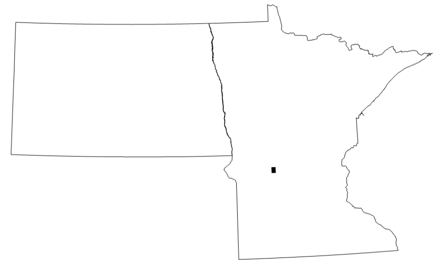
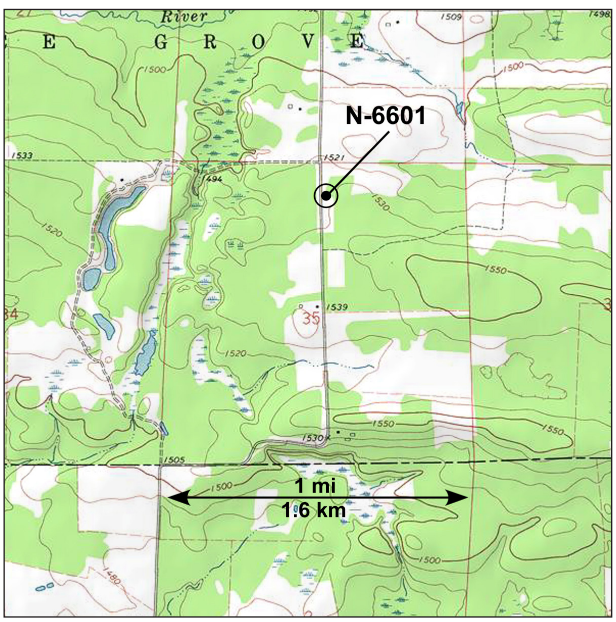


Figure A1.84. Minnesota Geological Survey rotary-sonic core TG-6 (N-8006) in Pope County, Minnesota (T. 124 N., R. 36 W., sec. 9 cbbaba; GPS: 45.563694, -95.212103; USGS 7.5-minute series Sedan, MN quadrangle; Appendix 2, p. 157) is the type section of the Sebeka Member of the Crow Wing River Formation.



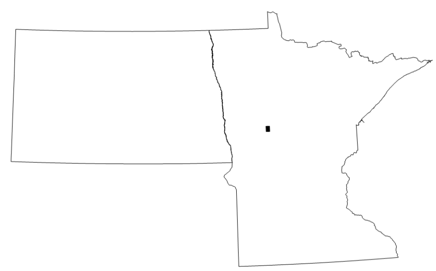


Figure A1.85. Minnesota Geological Survey rotary-sonic core OTT-1 (N-6601) in Becker County, Minnesota (T. 138 N., R. 37 W., sec. 35 abbccd; GPS: 46.729574, -95.318283; USGS 7.5-minute series Butler, MN quadrangle; Appendix 2, p. 201) is a reference section for the Sebeka Member of the Crow Wing River Formation.

The lower contact of the Sebeka Member has no known surface exposures and has only been identified in a few boreholes, where it overlies the Marcoux Member or older, pre-Late Wisconsinan sediments of the Browerville and Gervais Formations. At the reference section, the pebble-loam of the Sebeka Member is separated from the underlying Gervais Formation by a thick sequence of fluvial sand and gravel and lake sediment. The sharp, basal contact between the Sebeka Member and this sandy unit was also recognized by Anderson (1976) in gravel pits northwest of Sebeka. He assigned the unit to the Sebeka formation but did not consider it a distinguishing feature.

HISTORICAL BACKGROUND

The Sebeka Member was originally named and described as a lithostratigraphic unit of formation rank (Anderson, 1976; Perkins, 1977). In the southern Red River Valley, Harris (1996) and Harris and others (1995) identified a “Sebeka till” (RRV20) but did not assign the unit a

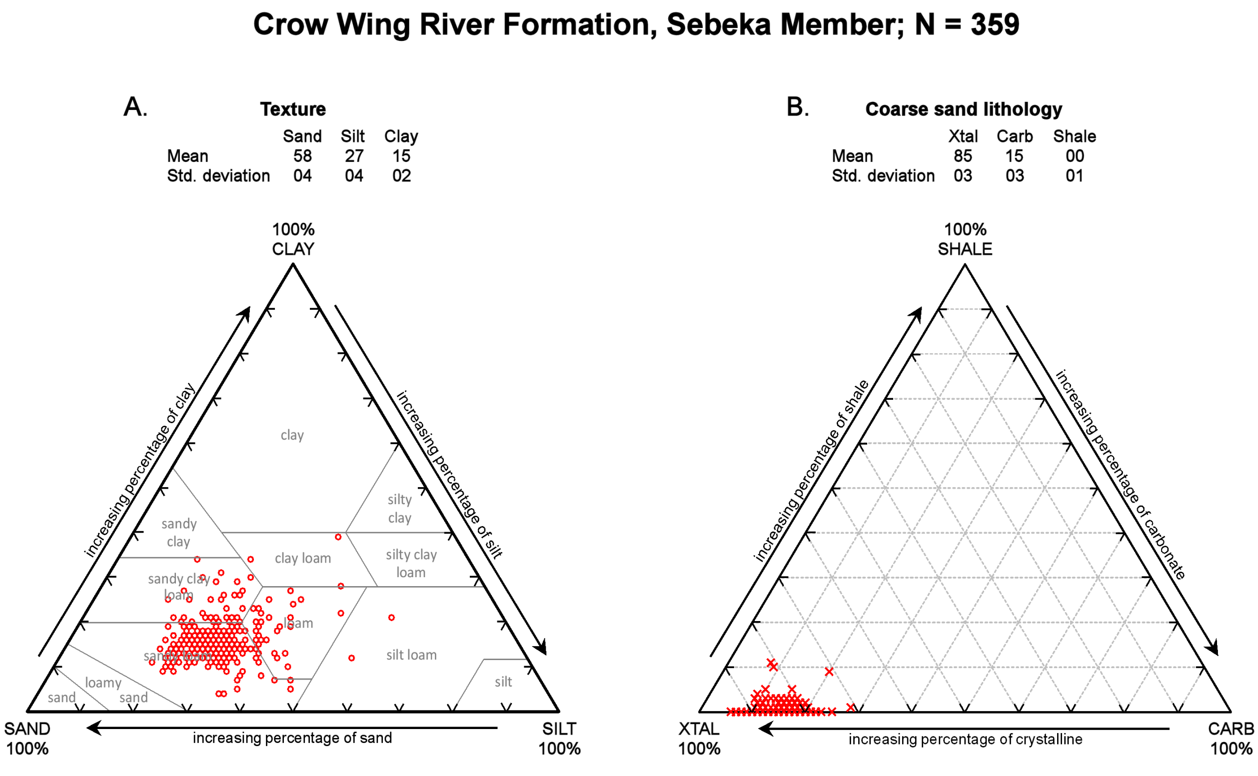


Figure A1.86. Ternary diagrams showing the results of the analysis of 359 samples that show typical textural and coarse-sand lithologic characteristics of the Sebeka Member of the Crow Wing River Formation. The texture (A) of the Sebeka Member is sandy loam and the very coarse sand lithology (B) indicates a Rainy (northeastern) source area.

stratigraphic position. The Sebeka formation was later correlated with unit RRV16 of the informal Crow River group by Harris and Berg (2006). Thorleifson and others (2005) referred to this unit as the "Upper Marcoux formation of the Crow Wing River group".

REGIONAL EXTENT AND THICKNESS

Figure A1.87 shows the presumed extent of the Sebeka Member. Exposures of the Sebeka Member are common in its type area; throughout, and adjacent to, the Wadena drumlin field; and in the Itasca moraine to the north. It is also at the surface in places along the Alexandria moraine. Further west and northwest, the Sebeka Member is mostly buried by younger, Des Moines lobe sediments. The distribution of the Sebeka Member beyond the Alexandria and Itasca moraines is patchy and limited to a few, widely spaced locations east of the Red River. It is present at five sites in, and on the margins of, the Red River lowland in Minnesota: one each in Clay, Kittson, Norman, Red Lake, and Traverse Counties. At the sites in Norman and Red Lake Counties, the Sebeka Member is overlain by the St. Hilaire Member of the Goose River Formation. The other three are surface exposures. It is unclear how close to the western boundary of the Sebeka Member these locations are. A single, isolated exposure tentatively identified as the Sebeka Member in Barnes County, North Dakota would, if correctly recognized, extend the unit's western limit by more than 60 miles (96 kilometers). The Sebeka Member is presumed to extend northeastward to the source area in central Ontario, but its limit north of the Itasca moraine is unknown.

In and around the Red River Valley, the pebble loam of the Sebeka Member ranges in thickness from 0 to 56 feet (17 meters), although with so few data points, the upper limit may be greater. It is 39 feet (12 meters) thick at the type section and 43 feet (13 meters) thick at the reference section. Including the underlying river and lake sediment, the total thickness of the Sebeka Member at the reference section is 188 feet (57 meters).

DIFFERENTIATION FROM OTHER UNITS

The most useful characteristic for distinguishing the Sebeka Member from other late Quaternary units is its texture. Apart from the Marcoux Member, and the New

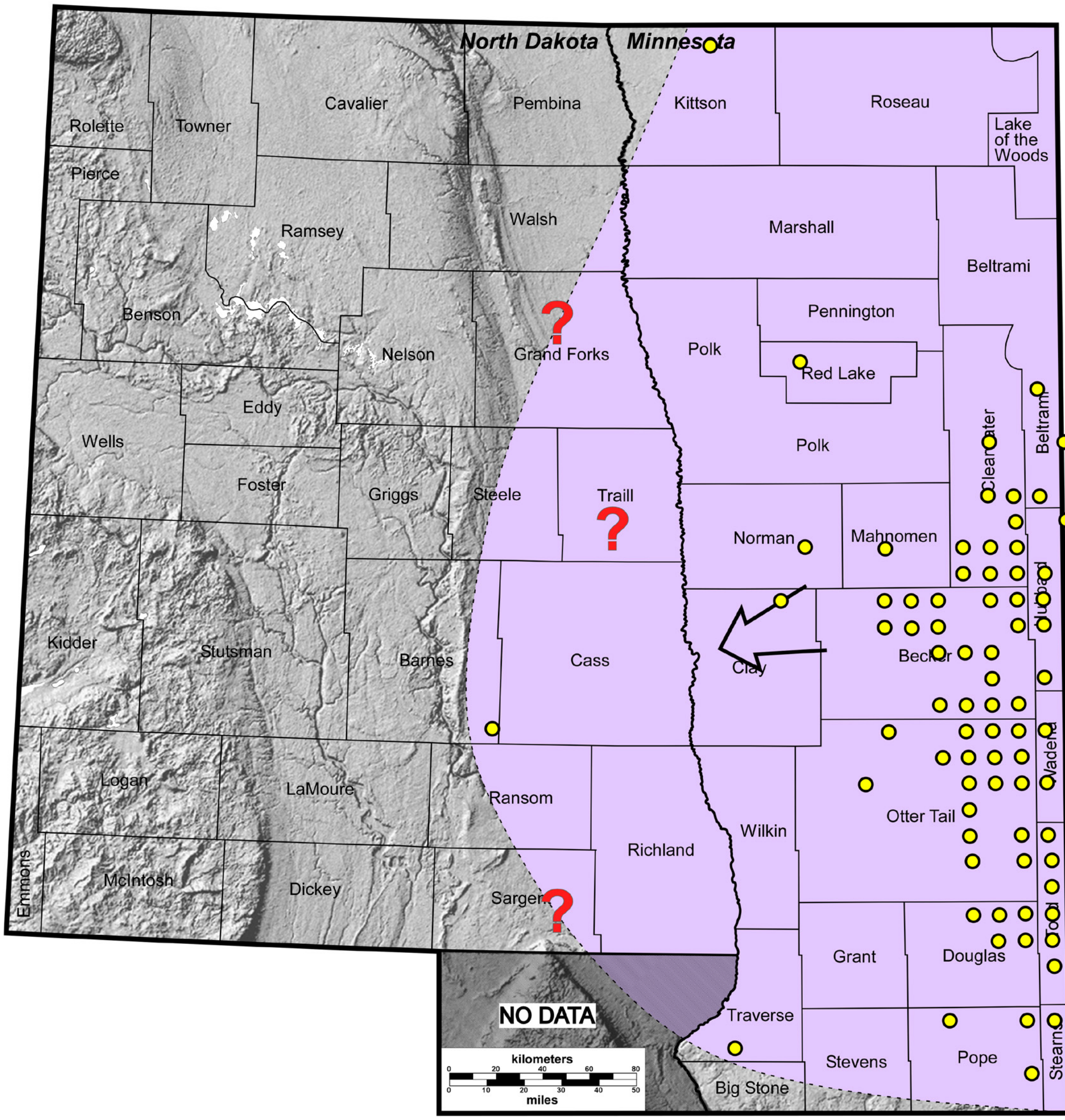


Figure A1.87. This figure shows the distribution of the Sebeka Member of the Crow Wing River Formation in the Red River Valley of North Dakota and Minnesota. The Sebeka Member consists mainly of glacial sediment deposited during a readvance of the Wadena lobe from the northeast (Rainy provenance). It is exposed at the surface throughout the Wadena drumlin field and the Itasca and Alexandria end moraines in central Minnesota and in a few places in the Red River Valley. The distribution of the Sebeka Member beyond the western margins of the Itasca and Alexandria moraines is patchy and limited to a few, widely spaced locations, mainly east of the Red River. Yellow circles indicate townships where sample control is located. The arrow indicates the direction of ice flow.

York Mills Member of the Ottertail River Formation, no other unit contains as much sand and as little clay as the Sebeka. The abundance of stones, predominance of igneous and metamorphic pebbles, and almost complete absence of shale rock fragments in the very coarse-sand fraction of the pebble loam distinguish the Sebeka Member from all other units except the Marcoux. The Sebeka and Marcoux Members are virtually indistinguishable in the field and are best differentiated by their very coarse sand lithology.

AGE

The age of the Sebeka Member is unknown. In areas where the stratigraphy is undisturbed, and both members of the

Crow wing River Formation are present, it is always the upper unit and therefore slightly younger than the Marcoux Member. Clayton and Moran (1982) suggested the Sebeka Member may have been deposited during the earliest phase ("phase D") of the Late Wisconsinan glaciation around 20,000 ^{14}C yr BP.

CORRELATION

Harris and Berg (2006) correlated the "Crow Wing River group" with the "Wadena till" of Meyer and Knaeble (1996), which was later included in the Hewitt Formation in central Minnesota (Knaeble, 2016). The Crow Wing River Formation may be lithostratigraphically equivalent to the Traverse des Sioux Formation in south-central Minnesota (Johnson and Knaeble, 2016), based on a strong correlation between the Traverse des Sioux and Hewitt Formations.

GENESIS

The Sebeka Member consists of glacial, glaciofluvial, and glaciolacustrine sediment that was deposited by a readvance of ice that moved across the Canadian Shield into Minnesota and the Red River Valley from the northeast. The lithology of the pebble and very coarse sand fractions indicates a Rainy provenance (fig. 17).

Marcoux Member of the Crow Wing River Formation

(Revised)

NAME AND RANK

The Marcoux Member is modified in rank from formation to a member of the Crow Wing River Formation. The unit, as described by Harris, Clayton, and Moran (1974) is accepted with minor modifications owing to format changes and additional information. The source of the name is Marcoux Corners in Red Lake County, Minnesota, located on the USGS 7.5-minute series Marcoux Corners, MN quadrangle.

TYPE AREA

Red Lake Falls area, Minnesota.

TYPE SECTION

The type section for the Marcoux Member of the Crow Wing River Formation is Clearwater Section (N-113, CW-1) on the Clearwater River, Red Lake Falls Township, Red Lake County, Minnesota (T. 151 N., R. 44 W., sec. 22 aabda; GPS: 47.889269, -96.270801; USGS 7.5-minute series Red Lake Falls, MN quadrangle; fig. A1.88 and Appendix 2, p. 227).

REFERENCE SECTIONS

A reference section for the Marcoux Member of the Crow Wing River Formation is Minnesota Geological Survey rotary-sonic core TG-5 (N-8005) in Pope County, Minnesota (T. 123 N., R. 38 W., sec. 10 dddd; GPS: 45.470267, -95.419036; USGS 7.5-minute series Swift Falls, MN quadrangle; fig. A1.89 and Appendix 2, p. 154). An original summary of this core appears in Harris and others (2003). Since then, however, the interpretation of named units has been revised.

A second reference section is Needles Eye Section (N-1008, C-7) on the Red Lake River, Gervais Township, Red Lake County, Minnesota (T. 151 N., R. 43 W., sec. 18 dadbc; GPS: 47.895068, -96.206373; USGS 7.5-minute series Plummer NW, MN quadrangle; fig. A1.90 and Appendix 2, p. 223).

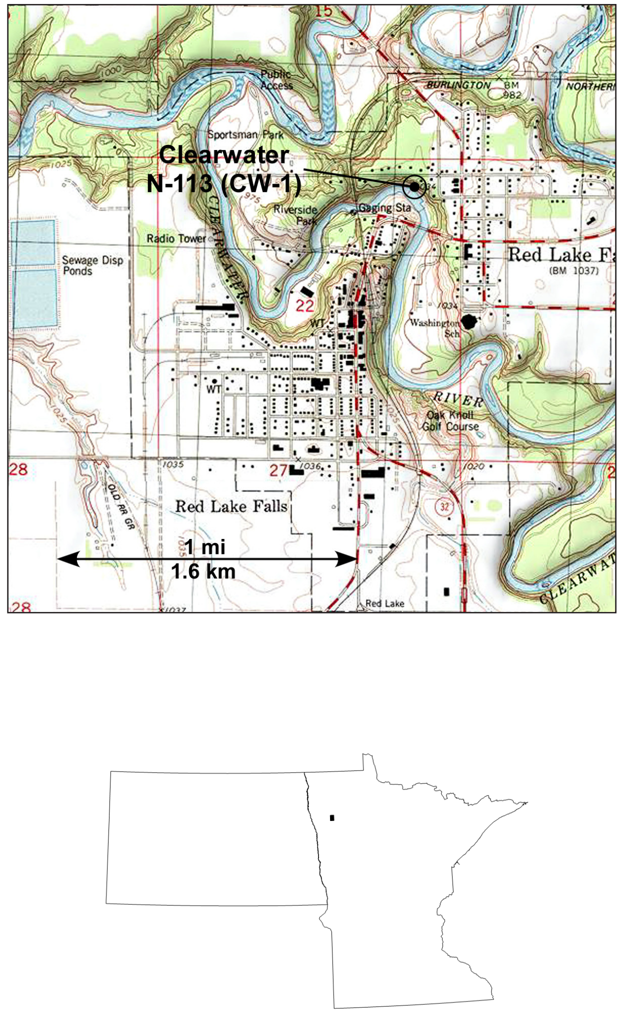
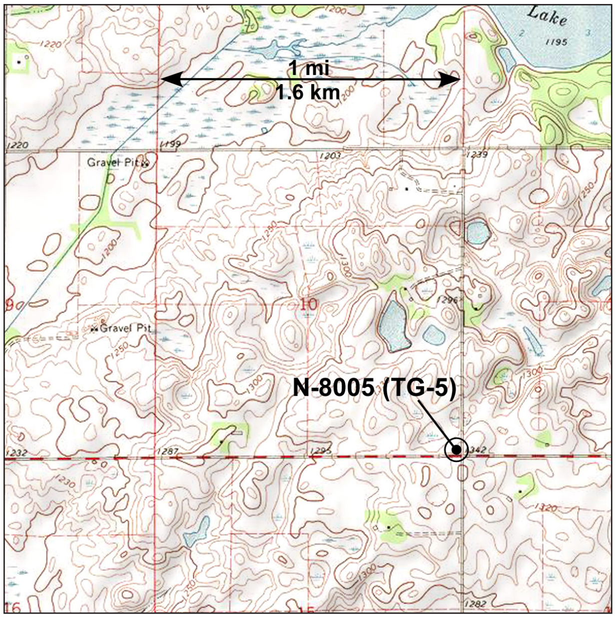


Figure A1.88. Clearwater Section (N-113, CW-1) on the Clearwater River, Red Lake Falls Township, Red Lake County, Minnesota (T. 151 N., R. 44 W., sec. 22 aabda; GPS: 47.889269, -96.270801; USGS 7.5-minute series Red Lake Falls, MN quadrangle; Appendix 2, p. 227) is the type section of the Marcoux Member of the Crow Wing River Formation.

LITHOLOGIC DESCRIPTION

The Marcoux Member is unbedded, very sandy pebble-loam. The unit is gray (5Y 6/1) when dry and grayish brown (2.5Y 5/2) when wet. In weathered outcrops it is extremely hard and stands in nearly vertical slopes. It is weakly jointed. Pebbles, cobbles, and boulders are abundant in this unit. Rapids along the Red Lake River are generally associated with outcrops of the Marcoux Member. The composition of the pebble loam of the Marcoux Member averages 55 percent sand, 30 percent silt, and 15 percent clay (fig. A1.91A). The abundant pebbles consist of roughly two-thirds igneous and metamorphic rock types and one-third limestone and dolomite. Shale pebbles are rare. The very coarse sand fraction (1-2 mm) averages 76 percent igneous



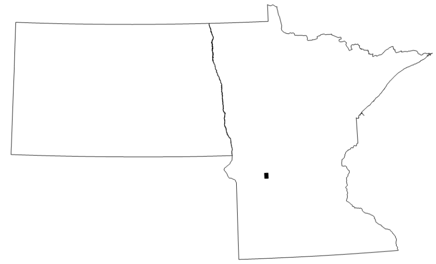
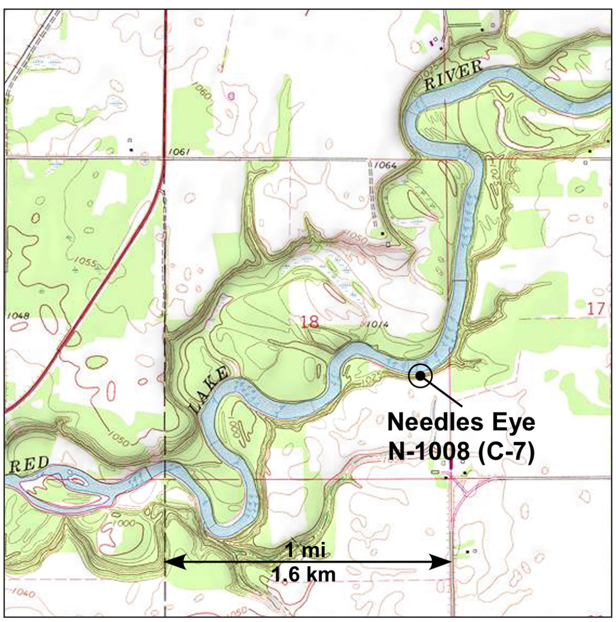


Figure A1.89. Minnesota Geological Survey rotary-sonic core TG-5 (N-8005) in Pope County, Minnesota (T. 123 N., R. 38 W., sec. 10 dddd; GPS: 45.470267, -95.419036; USGS 7.5-minute series Swift Falls, MN quadrangle; Appendix 2, p. 154) is a reference section for the Marcoux Member of the Crow Wing River Formation.



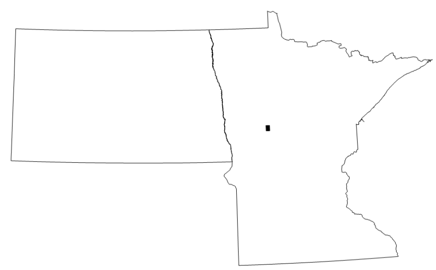


Figure A1.90. Minnesota Geological Survey rotary-sonic core OTT-1 (N-6601) in Becker County, Minnesota (T. 138 N., R. 37 W., sec. 35 abbccd; GPS: 46.729574, -95.318283; USGS 7.5-minute series Butler, MN quadrangle; Appendix 2, p. 223) is a reference section for the Marcoux Member of the Crow Wing River Formation.

and metamorphic rock types, 23 percent limestone and dolomite, and 1 percent shale and miscellaneous rock types (fig. A1.91B). Calcareous material makes up about 28 percent of the less than 200 mesh (0.074 mm) fraction of the sediment.

DESCRIPTION OF BOUNDARIES

At, and north of the Powerline Section (N-226, C-2; T. 151 N., R. 43 W., sec. 5 addd; fig. A1.43 and Appendix 2, p. 222) the Marcoux Member is overlain by the St. Hilaire Member of the Goose River Formation. The contact is sharp and generally marked by a boulder pavement. Where the boulder pavement is absent, a bed of sand up to 18 inches (0.5 meters) thick is commonly present. South and west of the Powerline Section, including at its type and Needles Eye reference section, the Marcoux Member is overlain by one or both members of the Red Lake Falls Formation. The contact between the units is sharp and marked by a bed of sand or sand and gravel ranging in thickness from a few inches to 17 feet (5.2 meters). A

Crow Wing River Formation, Marcoux Member; N = 243

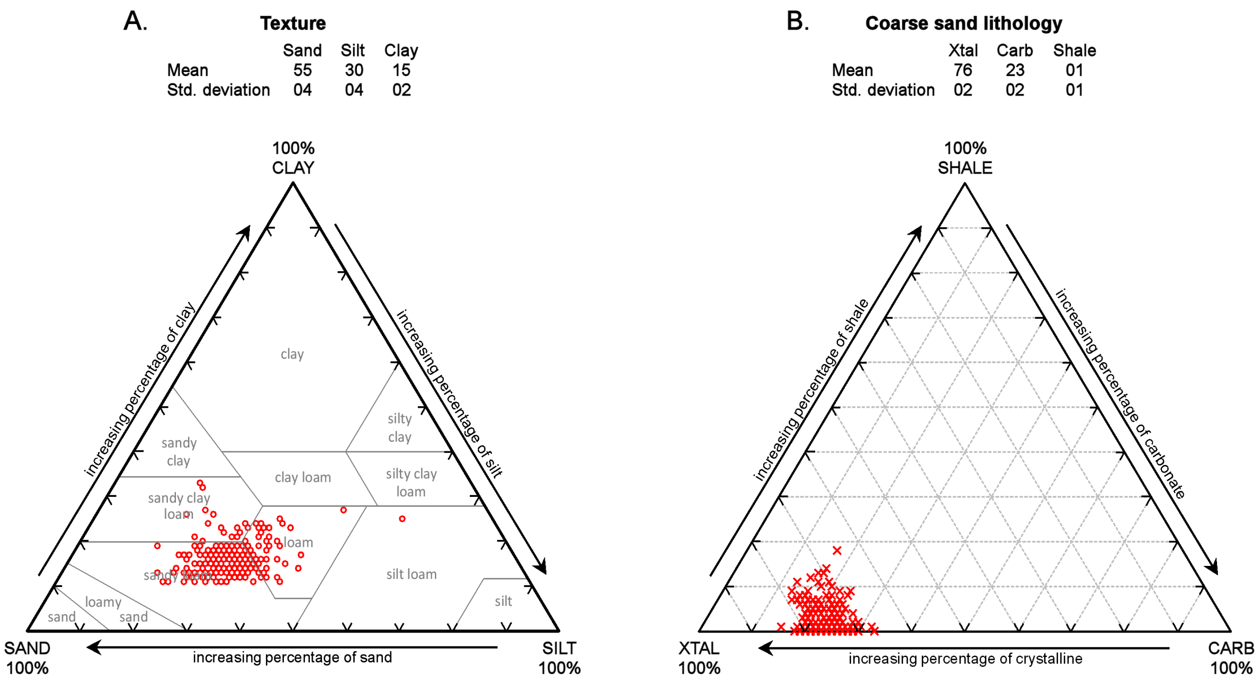


Figure A1.91. Ternary diagrams showing the results of the analysis of 243 samples that show typical textural and coarse-sand lithologic characteristics of the Marcoux Member of the Crow Wing River Formation. The texture (A) of the Marcoux Member is sandy loam and the very coarse sand lithology (B) indicates a Rainy (northeastern) source area.

boulder pavement is present in some outcrops but is not common. In several shallow boreholes east of the Red River Valley in Becker, Pope, Stearns, Todd, and Traverse Counties, Minnesota, the Marcoux Member is overlain by the Sebeka Member. In places where it is at the surface on, and east of, the Alexandria moraine in Otter Tail County, the Marcoux Member is overlain by the Buffalo River Formation.

There are no known exposures of the lower contact of the Marcoux Member with older units, but it has been recognized in several boreholes throughout west-central Minnesota where it overlies either the Sheyenne River, Browerville, or Gervais Formation. The Marcoux Member also overlies the Browerville Formation in two boreholes in the Red River Valley: one in northeastern Grand Forks County, North Dakota and one in south-central Polk County, Minnesota. In the four North Dakota State Water Commission testholes (2430, 2431, 2433, and 2609) shown in figure A1.1, the Marcoux Member lies directly on Ordovician bedrock of the Winnipeg Group. The basal contact between the Marcoux Member and the underlying unit is locally marked by a thick sequence of fluvial sand and gravel and lake sediment.

HISTORICAL BACKGROUND

The Marcoux Member was originally described by Harris (1973) and formally named by Harris and others (1974) as a lithostratigraphic unit of formation rank. In the southern Red River Valley, the Marcoux Formation was correlated with unit RRV17 of the informal Crow River group (Harris and others, 1995, 1999, 2003; Harris, 1998, 2006; Harris and Berg, 2006). Thorleifson and others (2005) referred to this unit as the "Lower Marcoux formation of the Crow Wing River group".

REGIONAL EXTENT AND THICKNESS

The Marcoux Member is exposed in the Red Lake River from south of Thief River Falls to west of Red Lake Falls. It has been observed in outcrop from Florian, in Marshall County, Minnesota, to Ulen, in Clay County, Minnesota, a distance of about 100 miles (160 kilometers). The Marcoux Member is thought to extend from north of the

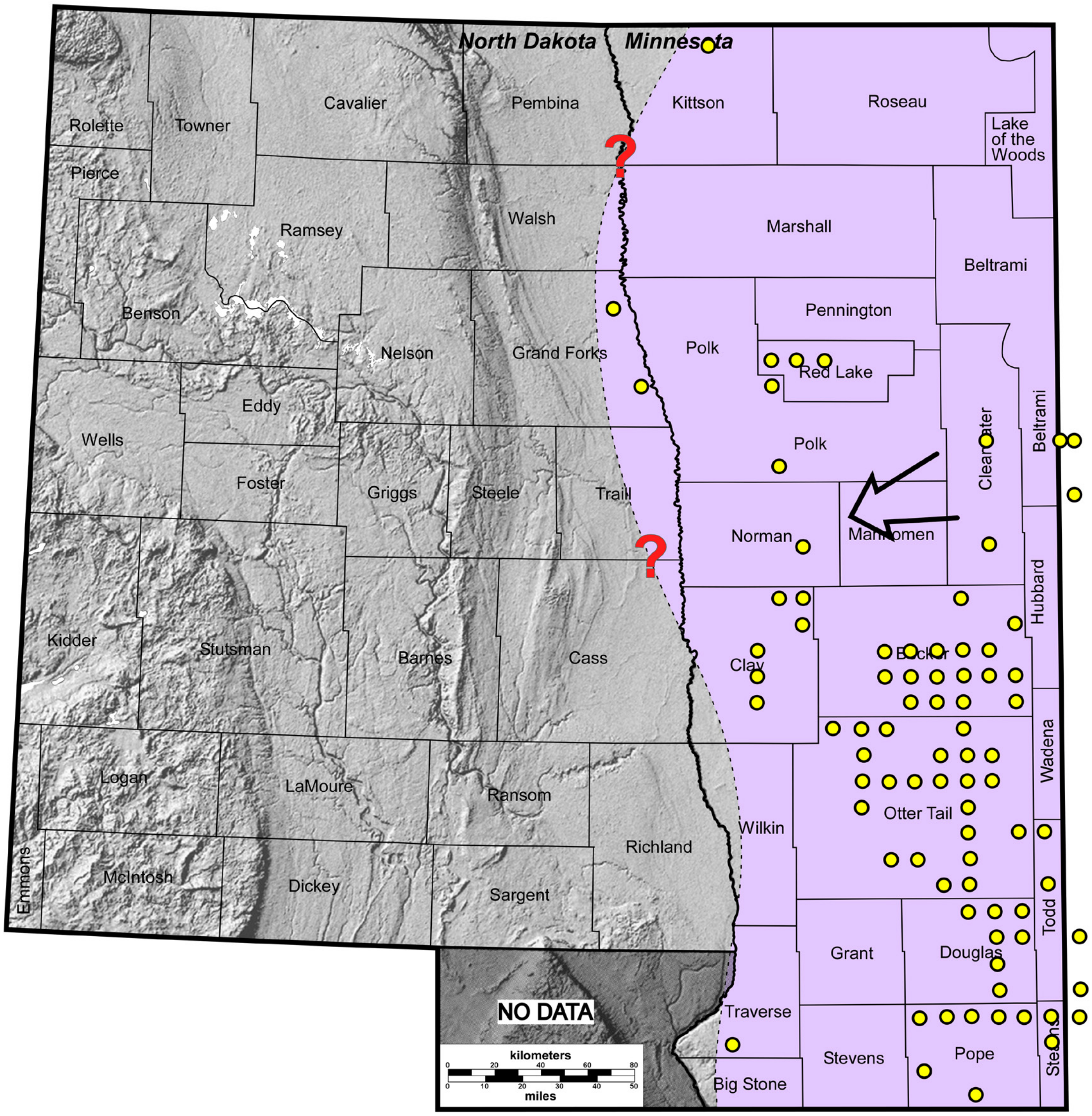


Figure A1.92. This figure shows the distribution of the Marcoux Member of the Crow Wing River Formation in the Red River Valley of North Dakota and Minnesota. The Marcoux Member consists mainly of glacial sediment deposited during an advance of the Wadena lobe from the northeast (Rainy provenance). It is exposed at the surface in several places in the eastern Red River Valley, but further west is only present in the subsurface. Yellow circles indicate townships where sample control is located. The arrow indicates the direction of ice flow.

Canadian border throughout northwestern Minnesota and eastern North Dakota although to date it has only been identified in boreholes at a few sites west of the Red River in Grand Forks County (fig. A1.92; K.L. Harris, unpub. data, 2013).

Exposed thicknesses of the Marcoux Member range from 6 inches (0.15 meters) to 27 feet (8.2 meters). Attempts to penetrate the Marcoux with a truck-mounted power auger proved difficult owing to the large number of boulders and extreme hardness of the unit. NDSWC Testhole 2430 (T. 152 N., R. 50 W., sec. 29 dda; fig. A1.1 and Appendix 2, p. 235) penetrated about 70 feet (21.3 meters) of the Marcoux Member in eastern Grand Forks County. The maximum recorded thickness of the Marcoux Member is 130 feet (40 meters) in boring N-8005 at the reference section in Pope County, Minnesota.

DIFFERENTIATION FROM OTHER UNITS

The most useful characteristic for distinguishing the Marcoux Member from other late Quaternary units is its texture. Apart from the Sebeka Member, and the New York Mills Member of the Ottertail River Formation, no other unit contains as much sand and as little clay as the Marcoux. The abundance of stones, predominance of igneous and metamorphic pebbles, hardness, and weak jointing distinguish the Marcoux Member from all other units except the Sebeka. The Marcoux and Sebeka Members are virtually indistinguishable in the field and are best differentiated by their very coarse sand lithology.

AGE

The age of the Marcoux Member is unknown. In areas where the stratigraphy is undisturbed, and both members of the Crow wing River Formation are present, it is always the lower unit and therefore slightly older than the Sebeka Member. Clayton and Moran (1982) suggested the Marcoux Member may have been deposited during the earliest phase ("phase D") of the Late Wisconsinan glaciation around 20,000 ^{14}C yr BP. It is thought to be the oldest Late Wisconsinan glacial sediment in the Red River Valley.

CORRELATION

Harris and Berg (2006) correlated the "Crow Wing River group" with the "Wadena till" of Meyer and Knaeble (1996), which was later included in the Hewitt Formation in central Minnesota (Knaeble, 2016). The Crow Wing River Formation may be lithostratigraphically equivalent to the Traverse des Sioux Formation in south-central Minnesota (Johnson and Knaeble, 2016), based on a strong correlation between the Traverse des Sioux and Hewitt Formations.

GENESIS

The Marcoux Member consists of glacial, glaciofluvial, and glaciolacustrine sediment that was deposited by ice that moved across the Canadian Shield into Minnesota and the Red River Valley from the northeast. The lithology of the pebble and very coarse sand fractions indicates a Rainy provenance (fig. 17).

SHEYENNE RIVER FORMATION

(New)

NAME AND RANK

The Sheyenne River Formation is formally named here. It is named after the Sheyenne River in central and southeastern North Dakota.

TYPE SECTION

The type section for the Sheyenne River Formation is Minnesota Geological Survey rotary-sonic core OTT-3 (N-6603) in Grant County, Minnesota (T. 130 N., R. 42 W., sec. 17 dcdcb; GPS: 46.065364, -95.984458; USGS 7.5-minute series Fourmile Lake, MN quadrangle; fig. A1.93 and Appendix 2, p. 180).

REFERENCE SECTION

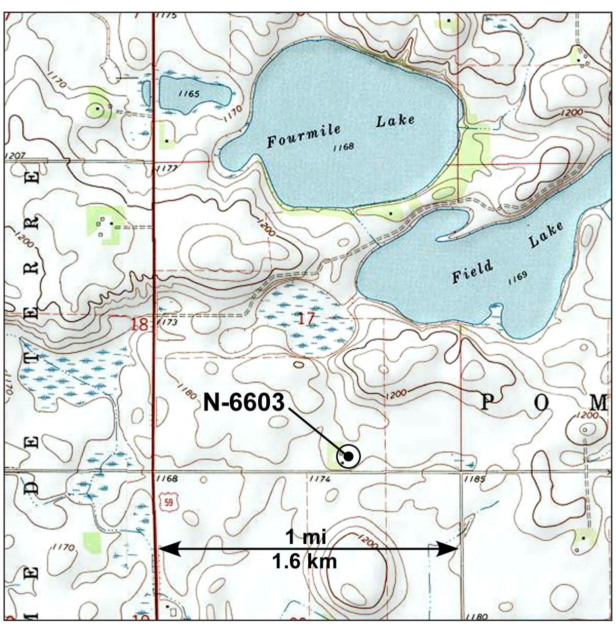
Minnesota Geological Survey rotary-sonic core TG-2 (N-8002) is designated as a reference section for the Sheyenne River Formation. The core was drilled in Traverse County, Minnesota at T. 127 N., R. 45 W., sec. 2 bcccd GPS: 45.840177, -96.294181; USGS 7.5-minute series Wheaton SE, MN quadrangle; fig. A1.94 and Appendix 2, p. 170).

LITHOLOGIC DESCRIPTION

The Sheyenne River Formation is unsorted, unbedded to massive pebble loam, interbedded with lesser amounts of fine- to medium-grained glaciofluvial sand, and silty lake sediment. Surfaces may be iron-stained. The pebble-loam is olive brown (2.5Y 4/4) where oxidized and very dark gray (10YR 3/1) or very dark grayish brown (2.5Y 3/2) where unoxidized. The texture of the pebble loam averages 38 percent sand, 37 percent silt, and 25 percent clay (fig. A1.95A); the very coarse-sand lithology (1-2 mm) averages 53 percent crystalline and metamorphic rock fragments, 33 percent carbonate rock fragments, and 14 percent shale fragments (fig. A1.95B). Red rock and lignite fragments are common in places. Pebbles are abundant and consist mainly of igneous and metamorphic rock types, with moderate amounts of carbonate and few shale fragments.

DESCRIPTION OF BOUNDARIES

The Sheyenne River Formation is a subsurface unit except in places on and near the Alexandria moraine in west-central Minnesota and in scattered patches throughout the uplands west of the Red River Valley in southeastern North Dakota, where it has been exposed by erosion of the overlying material. It is overlain by a variety of younger glacial units, the most common and widespread of which are the Goose River and Buffalo River Formations. As a general rule, the Goose River Formation tends to predominate in the northern Red



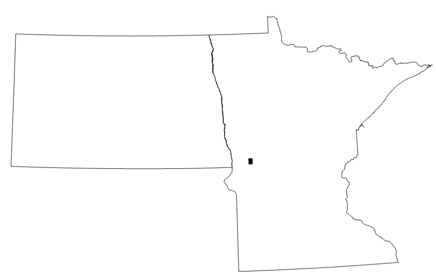
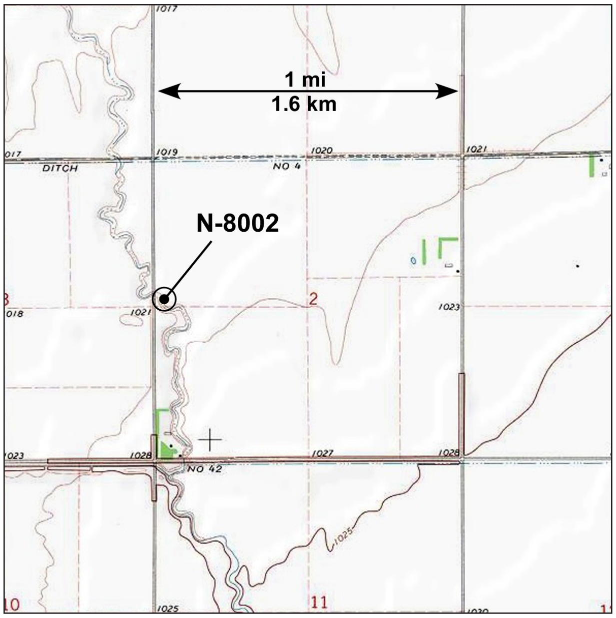


Figure A1.93. Minnesota Geological Survey rotary-sonic core OTT-3 (N-6603) in Grant County, Minnesota (T. 130 N., R. 42 W., sec. 17 dcdcb; GPS: 46.065364, -95.984458; USGS 7.5-minute series Fourmile Lake, MN quadrangle; Appendix 2, p. 180) is the type section for the Sheyenne River Formation.



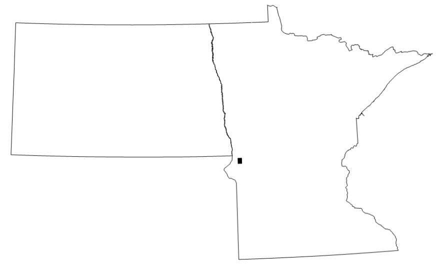


Figure A1.94. Minnesota Geological Survey rotary-sonic core N-8002 (TG-2) in Traverse County, Minnesota (T. 127 N., R. 45 W., sec. 2 bcccd GPS: 45.840177, -96.294181; USGS 7.5-minute series Wheaton SE, MN quadrangle; Appendix 2, p. 170) is a reference section for the Sheyenne River Formation.

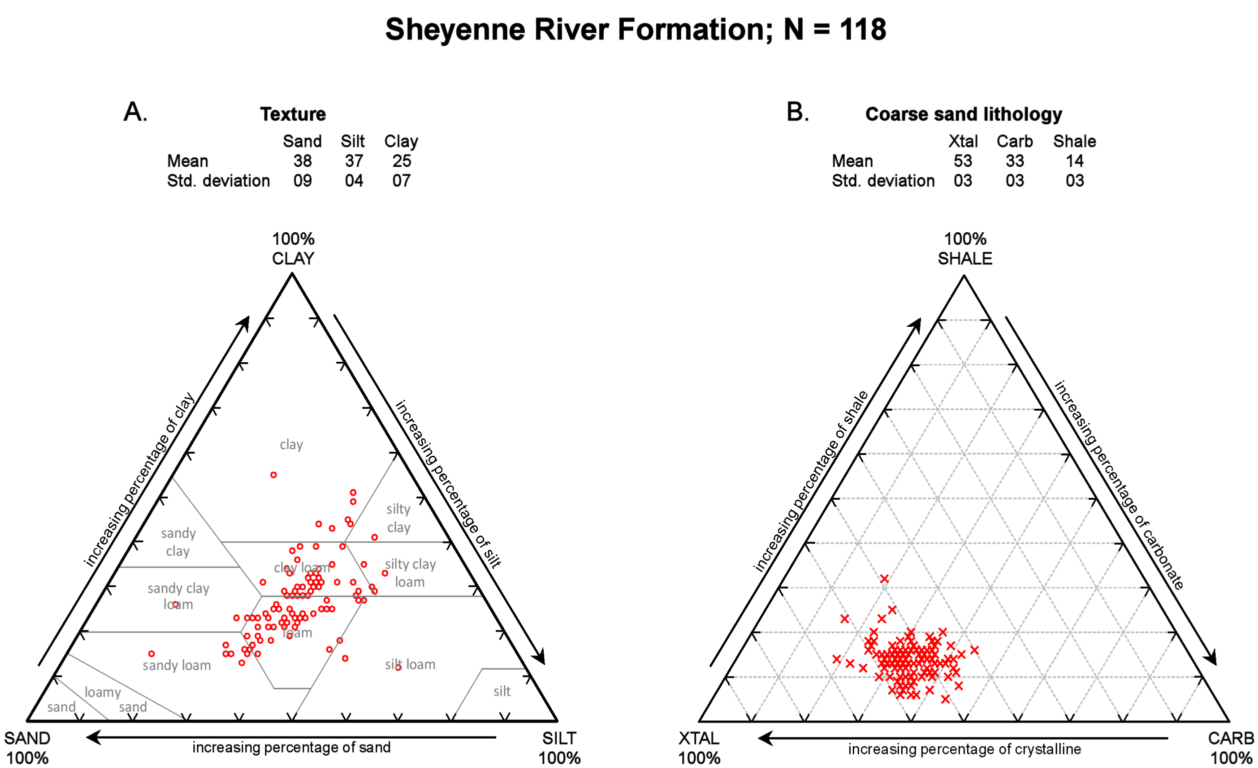


Figure A1.95. Ternary diagrams showing the results of the analysis of 118 samples that show typical textural and coarse-sand lithologic characteristics of the Sheyenne River Formation. The texture (A) of the Sheyenne River Formation is mainly loam to clay loam and the very coarse-sand lithology (B) indicates a mixed Riding Mountain-Winnipeg-Rainy provenance.

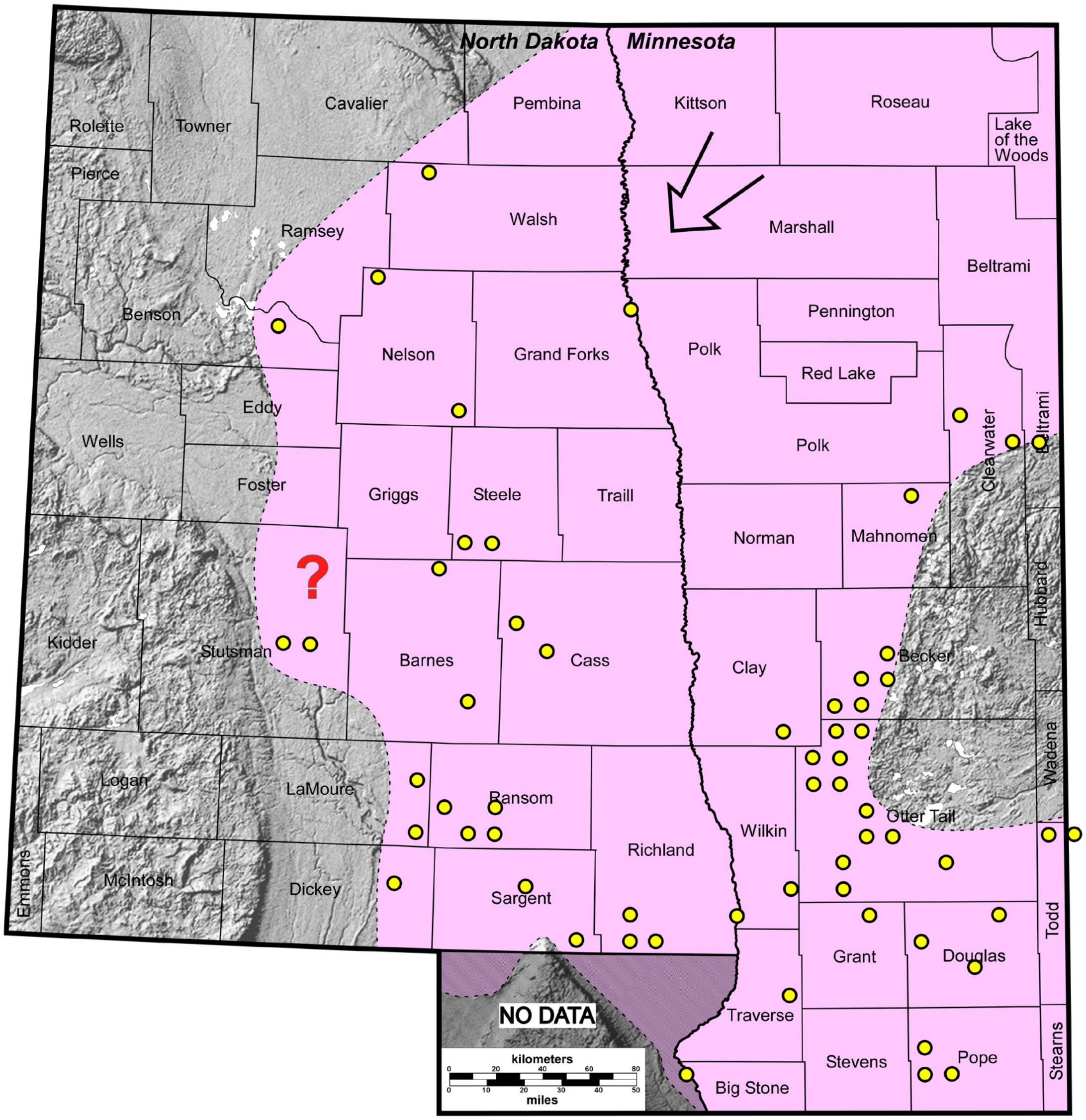


Figure A1.96. This figure shows the distribution of the Sheyenne River Formation in the Red River Valley of North Dakota and Minnesota. The Sheyenne River Formation consists of glacial sediment with a mixed Riding Mountain-Winnipeg-Rainy provenance. It is exposed at the surface in places on and near the Alexandria moraine in west-central Minnesota and in scattered patches throughout the uplands west of the Red River Valley in southeastern North Dakota but is otherwise a subsurface unit. Yellow circles indicate townships where sample control is located. The arrow indicates the direction of ice flow.

River Valley and northeastern North Dakota, whereas to the south and east it is the Buffalo River Formation, although there is considerable overlap between the two. Along the western margin of the Alexandria moraine, including at the type section and in parts of Otter Tail and Pope Counties, The Sheyenne River Formation is overlain by the James River Formation. In places on the eastern side of the moraine, it is overlain by the Marcoux Member of the Crow Wing River Formation.

The lower contact of the Sheyenne River Formation with older sediment has only been penetrated in a few boreholes. The underlying unit at four sites is either the Browerville or the Gervais Formation. At the reference section, the Sheyenne River Formation overlies pebble loam of the "Old Sebeka till" and at least two more, unnamed, Quaternary units that are stratigraphically below the Gervais Formation (table 2). At one site in Nelson County, North Dakota, the Sheyenne River

Formation lies directly over Upper Cretaceous shale bedrock. The lower boundary of the Sheyenne River Formation at its type section is interpreted to be an ice-thrust fault on the basis of the out-of-sequence position of the underlying Lower James River Member.

HISTORICAL BACKGROUND

The Sheyenne River Formation was originally identified in the southern Red River Valley as RRV18 and included in the informal "Crow Wing River group" by Harris and others (1995). Thorleifson and others (2005) and Harris and Berg (2006) correlated their "Sheyenne River formation" with RRV18 and reassigned the unit to the informal "Sheyenne River group" as the product of a mixed (Riding Mountain-Winnipeg-Rainy) provenance.

REGIONAL EXTENT AND THICKNESS

The regional extent of the Sheyenne River Formation is large but because it is primarily a subsurface unit, its boundaries are, for the most part, undefined. It is present throughout the Red River Valley and has been traced westward as far as eastern Benson and central Stutsman Counties in North Dakota. The northern and northwestern extent of the Sheyenne River Formation is presumed to be its source areas, but evidence of this is lacking owing to the sparsity of subsurface data for northeastern North Dakota and northwestern Minnesota. The range of the Sheyenne River Formation to the east and south is unknown except where it is bounded by the Wadena drumlin field in central Minnesota (fig. A1.96).

The observed thickness of the Sheyenne River Formation ranges from 70 feet (21.3 meters) in central Sargent County, North Dakota, to about 3 feet (1 meter) in parts of west-central Minnesota (K.L. Harris, unpub. data, 2014). The average thickness is about 24 feet (7.3 meters).

DIFFERENTIATION FROM OTHER UNITS

The Sheyenne River Formation may be differentiated from similar units on the basis of texture, pebble lithology, and stratigraphic position. It is not as sandy as the Crow Wing River and Browerville Formations, and contains more shale fragments than these, and other, predominantly Winnipeg- and Rainy-provenance diamicton. The Sheyenne River Formation contains about 40 percent fewer shale fragments than the Villard Member of the James River Formation, and at least 40 percent less shale and 25 percent more crystalline rock fragments than sediments of the Des Moines lobe. The Sheyenne River Formation is almost texturally and lithologically identical to the Upper Red Lake Falls Member of the Red Lake Falls Formation. They are most easily differentiated by their stratigraphic position.

AGE

The age of the Sheyenne River Formation is unknown and poorly constrained stratigraphically. It may be early Late Wisconsinan but the underlying Browerville Formation is pre-Illinoian in age (Knaeble and Meyer, 2007), which suggests it may be considerably older.

CORRELATION

The Sheyenne River Formation has no known lithostratigraphic equivalent in Minnesota or southern Manitoba.

GENESIS

Till of the Sheyenne River Formation has a mixed Riding Mountain-Winnipeg-Rainy provenance. It is thought to have been deposited by a glacier that advanced into western Minnesota and eastern North Dakota from a mainly north-northeasterly direction. As it flowed southwestward across the region, the ice incorporated shaly sediment of Riding Mountain provenance, most likely derived from local bedrock rather than any of the older glacial deposits, which all have Winnipeg, Rainy, and Superior source areas and contain little to no shale (< 5 percent in the very coarse sand fraction).

BROWERVILLE FORMATION

(Accepted)

NAME AND RANK

The Browerville Formation is accepted as formally named in Minnesota by Meyer and Knaeble (2016) as a lithostratigraphic unit of formation rank. It is named after the town of Browerville in Todd County, Minnesota, located on the USGS 7.5-minute series Browerville, MN quadrangle. This description pertains primarily to the part of the Browerville Formation that extends into the Red River Valley and the adjacent counties in west-central Minnesota.

TYPE SECTION

The type section defined by Meyer and Knaeble (2016) is a pit exposure (Transfer Station site, Minnesota Geological Survey Quaternary unique number 00Q0022789) in Todd County, Minnesota (T. 130 N., R. 33 W., sec. 17 cbabdc; USGS 7.5-minute series Browerville, MN quadrangle; fig. A1.97 and Appendix 2, p. 179). This site is some 60 miles (97 kilometers) east of the Red River Valley and outside the map limits of this report. We have therefore elected to supplement the type section with a principal reference section that is within the bounds of our area of interest (delineated in figures 12 and 13) and better represents the character of the Browerville Formation in the Red River Valley region.

REFERENCE SECTIONS

The principal reference section for the Browerville Formation in, and around the Red River Valley of Minnesota and North Dakota is Minnesota Geological Survey rotary-sonic core OTT-2 (N-6602) in western Todd County, Minnesota (T. 132 N., R. 35 W., sec. 22 bbdabb GPS: 46.235447, -95.079132; USGS 7.5-minute series Eagle Bend, MN quadrangle; fig. A1.98 and Appendix 2, p. 191).

A reference section for the Browerville Formation is Minnesota Geological Survey rotary-sonic borings TG-7 (N-8007) in Douglas County, Minnesota (T. 129 N., R. 36 W., sec. 29 addbdc; GPS: 45.952417, -95.231030; USGS 7.5-minute series Lake Osakis West, MN quadrangle; fig. A1.99 and Appendix 2, p. 174).

A second reference section is RVR-1 (N-6218) in Norman County, Minnesota (T. 144 N., R. 44 W., sec. 23 cdddda;

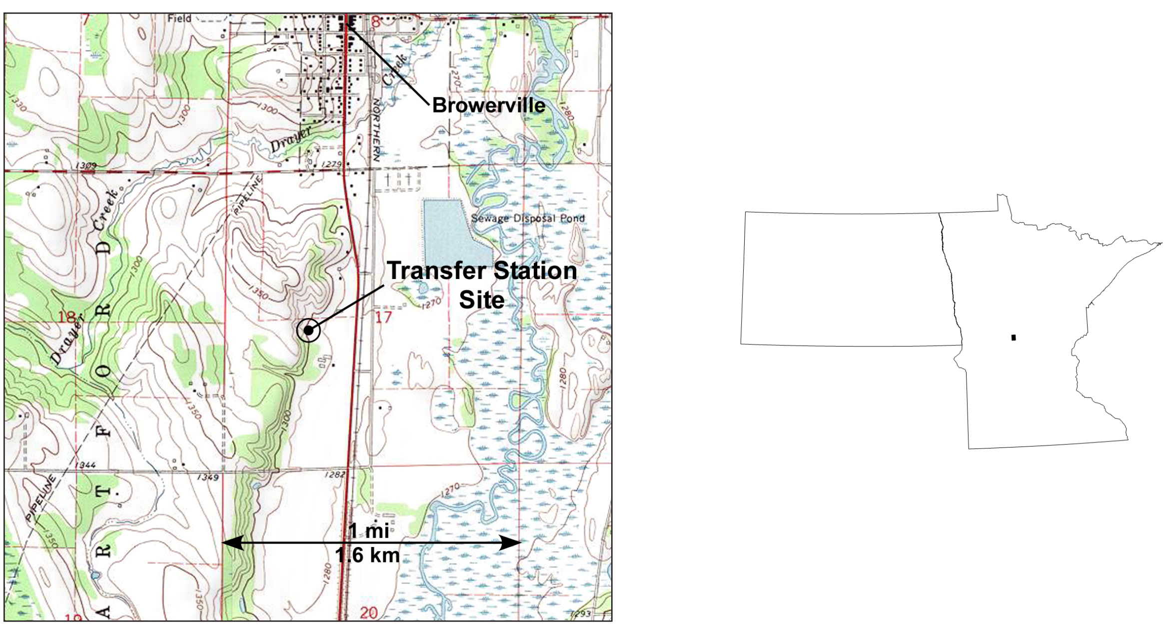
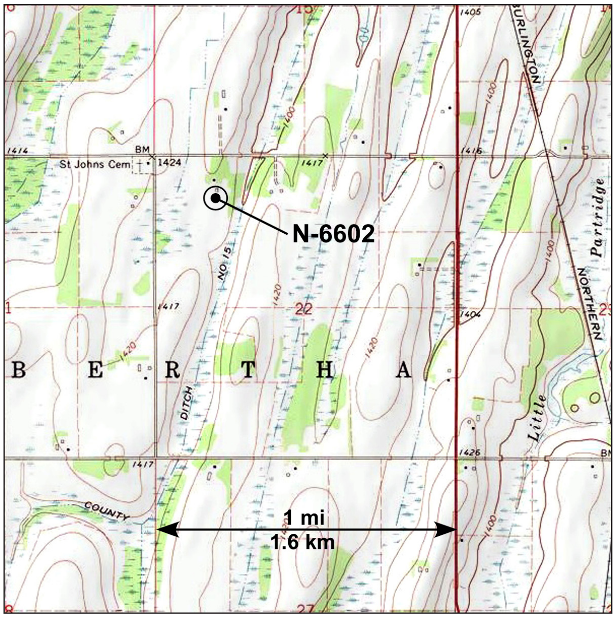


Figure A1.97. The Transfer Station site (Minnesota Geological Survey Quaternary unique number 00Q0022789) in Todd County, Minnesota (T. 130 N., R. 33 W., sec. 17 cbabdc; USGS 7.5-minute series Browerville, MN quadrangle; Appendix 2, p. 179) is the original type section for the Browerville Formation. The site is outside the map limits of this report and is therefore supplemented with a principal reference section that is within the map area.



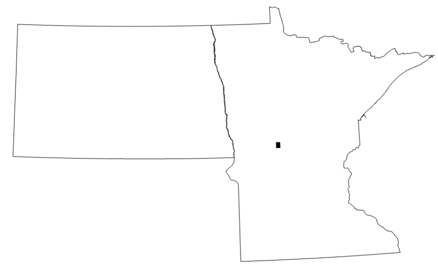


Figure A1.98. Minnesota Geological Survey rotary-sonic boring OTT-2 (N-6602) in western Todd County, Minnesota (T. 132 N., R. 35 W., sec. 22 bbdabb GPS: 46.235447, -95.079132; USGS 7.5-minute series Eagle Bend, MN quadrangle; Appendix 2, p. 191) is the principal reference section for the Browerville Formation.

GPS: 47.267344, -96.226940; USGS 7.5-minute series Waukon, MN quadrangle; fig. A1.100 and Appendix 2, p. 217).

LITHOLOGIC DESCRIPTION

The Browerville Formation includes diamicton and sorted sediment. The diamicton facies commonly has a loam texture, with an average composition of 45 percent sand, 36 percent silt and 19 percent clay (fig. A1.101A). The oxidized moist color may be light yellowish brown (10YR 6/4), light olive brown (2.5Y 5/4), olive brown (2.5Y 4/6), or dark olive brown (2.5Y 3/3). The unoxidized color is generally dark to very dark gray (10YR to 5Y 4-3/1). The very coarse sand fraction (1-2 mm) averages 65 percent Precambrian (crystalline and metamorphic) rock fragments, 34 percent carbonate rock fragments, and 1 percent shale (fig. A1.101B).

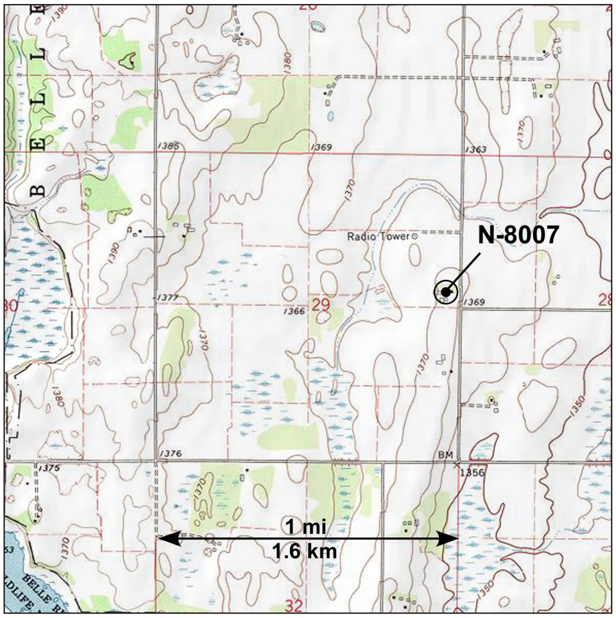
DESCRIPTION OF BOUNDARIES

The Browerville Formation is only present in the subsurface of the Red River Valley, where it is overlain by Late Wisconsinan sediment, primarily of the Crow Wing River Formation. In Minnesota Geological Survey rotary-sonic boring TG-6 (N-8006; T. 124 N., R. 36 W., sec. 9 cbbaba; fig. A1.84 and Appendix 2, p. 157) the Browerville Formation is oxidized to a depth of about 13 feet (4 meters) and overlain by about 27 feet (8.2 meters) of unoxidized sediment of the Sebeka Member of the Crow Wing River Formation. Similar buried oxidation zones, and evidence of soil formation, indicative of prolonged aerial exposure of the Browerville Formation prior to subsequent glaciations, were observed in central Minnesota (Meyer, 1986). At two sites, one in northwestern Otter Tail County and another in eastern Grand Forks County, the Browerville Formation is overlain by the Sheyenne River Formation.

At least six units older than the Browerville Formation have been identified in the Red River Valley. The youngest of these is the Gervais Formation, which underlies the Browerville Formation throughout much of west-central Minnesota and the Red River Valley. The contact is exposed at the Three Creeks Section (N-1018, T. 151 N., R. 44 W., sec. 21 babaa; fig.A1.34 and Appendix 2, p. 226), where it is sharp and marked by a concentration of cobble-sized rock fragments. Where the Gervais Formation is absent, the Browerville Formation is underlain by the informally named Old Marcoux till.

HISTORICAL BACKGROUND

Diamicton of the Browerville Formation was first recognized by Meyer (1986) at the base of a gravel pit exposure near Browerville, Minnesota and informally named the “Browerville till”. The term “Browerville Till” was used by Goldstein (1998) for a unit in a report on the Wadena drumlin region. Meyer and Knaeble (1998) defined the informal “Browerville formation” to include till and associated sorted sediment and paleosols. The Browerville Formation was included in the informal “Browerville group” by Thorleifson and others (2005).



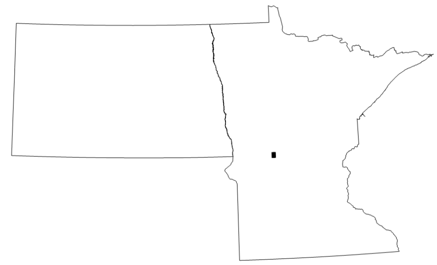
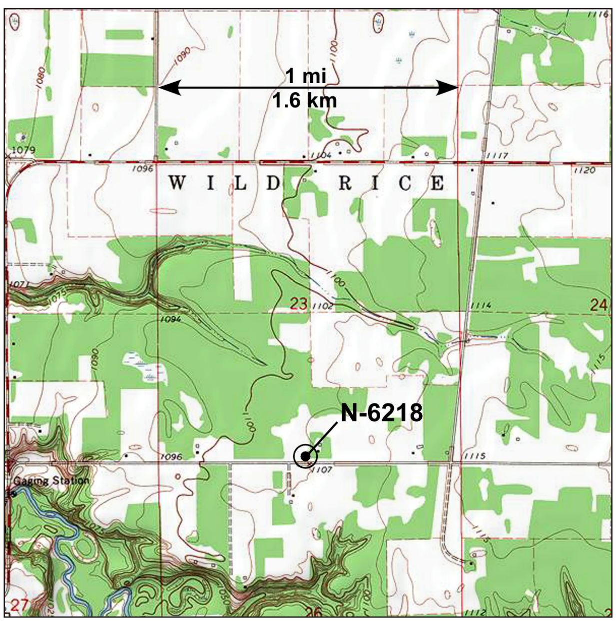


Figure A1.99. Minnesota Geological Survey rotary-sonic boring TG-7 (N-8007) in Douglas County, Minnesota (T. 129 N., R. 36 W., sec. 29 addbdc; GPS: 45.952417, -95.231030; USGS 7.5-minute series Lake Osakis West, MN quadrangle; Appendix 2, p. 174) is a reference section for the Browerville Formation.



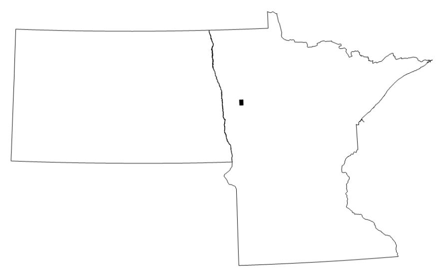


Figure A1.100. Minnesota Geological Survey rotary-sonic boring RVR-1 (N6218) in Norman County, Minnesota (T. 144 N., R. 44 W., sec. 23 cdddda; GPS: 47.267344, -96.226940; USGS 7.5-minute series Waukon, MN quadrangle; Appendix 2, p. 217) is a reference section for the Browerville Formation.

REGIONAL EXTENT AND THICKNESS

Figure A1.102 shows the presumed extent of the Browerville Formation in the Red River Valley and the adjacent uplands in west-central Minnesota. The Browerville Formation extends westward from central Minnesota to the Red River and a few miles into North Dakota. Meyer (1997) identified the Browerville Formation in the subsurface at three sites in western Lake of the Woods County in north-central Minnesota, which mark the unit's northernmost observed extent. To the south, the Browerville Formation has been recognized in Traverse County and possibly beyond at sites in southwestern Minnesota (Meyer and Knaeble, 2016).

The Browerville Formation is thickest at the principal reference section in northwestern Todd County, Minnesota where it exceeds 150 feet (46 meters). It is generally thinner, and is absent over large areas, to the west and northwest of Todd County, where its thickness

Browerville Formation; N = 153

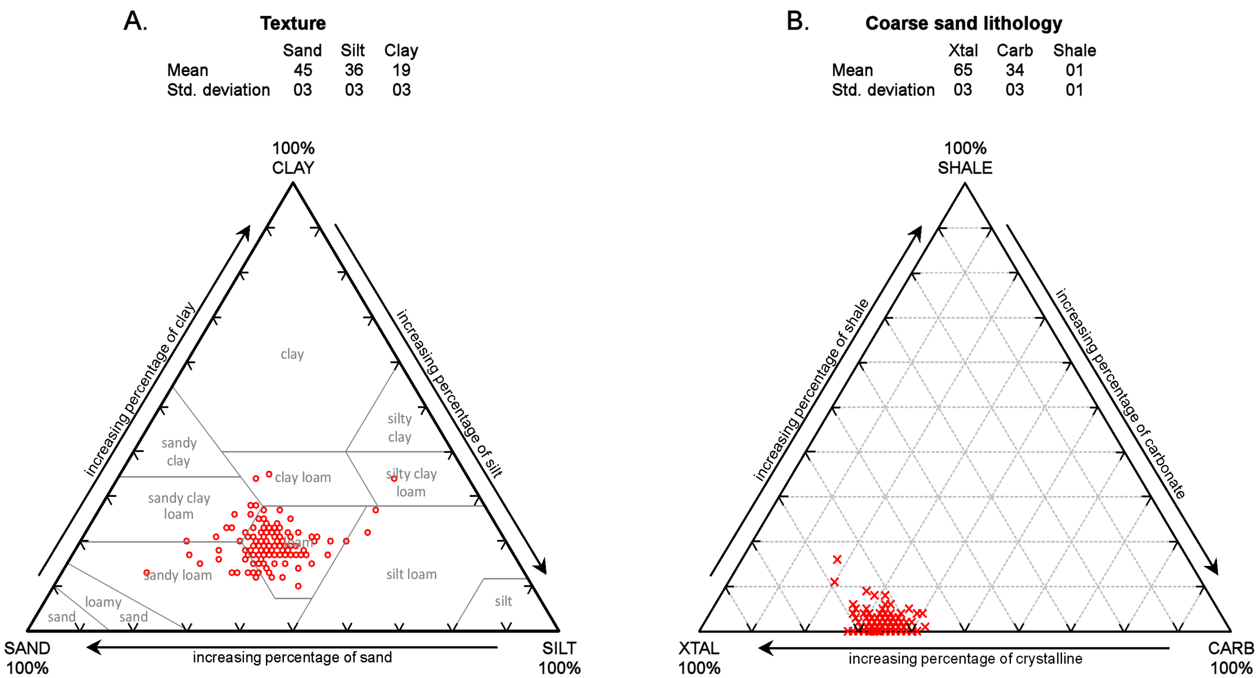


Figure A1.101. Ternary diagrams showing the results of the analysis of 153 samples that show typical textural and coarse-sand lithologic characteristics of the Browerville Formation. The texture (A) of the Browerville Formation is mainly loam and the very coarse sand lithology (B) indicates a mixed Rainy-Winnipeg (northeastern and northern) source area.

ranges from less than 1 foot (0.3 meters) to about 32 feet (9.8 meters), and averages about 18 feet (5.5 meters).

DIFFERENTIATION FROM OTHER UNITS

Diamicton of the Browerville Formation in the Red River Valley and west-central Minnesota contains more carbonate rock fragments and is finer-textured than the Sebeka and Marcoux Members of the Crow Wing River Formation and the older tills of Rainy provenance. It is considerably less shaly than the tills of the Goose River, James River, and Sheyenne River Formations. The Browerville Formation is generally sandier and contains about 40% fewer carbonate rock fragments than the Gervais Formation.

AGE

The Browerville Formation is beyond the range of radiocarbon dating. Deep weathering profiles in the Browerville Formation that are overlain by unweathered, Late Wisconsinan sediments suggest it is probably pre-Sangamonian. In central Minnesota, two calcite samples from lake sediment between the Browerville Formation and the overlying Hewitt (Crow Wing River) Formation yielded a uranium/thorium disequilibrium minimum age of 200,000 yr BP, indicating that the Browerville Formation is pre-Illinoian (Knaeble and Meyer, 2007). The Browerville Formation's normal polarity remanent magnetism suggests it was deposited during the Middle Pleistocene, sometime after 780,000 yr BP (Jennings and others, 2006).

CORRELATION

The Browerville Formation may correlate with units similar in stratigraphic position and lithology in southwest Minnesota and southeast South Dakota (Patterson, 1997; Meyer and Knaeble, 2016).

GENESIS

The Browerville Formation in the Red River Valley and west-central Minnesota was deposited by glacial ice that advanced from the northeast and north. The lithology of the pebble and very coarse sand fractions indicates source areas in western Ontario and eastern Manitoba (mixed Rainy-Winnipeg provenance; fig. 17).

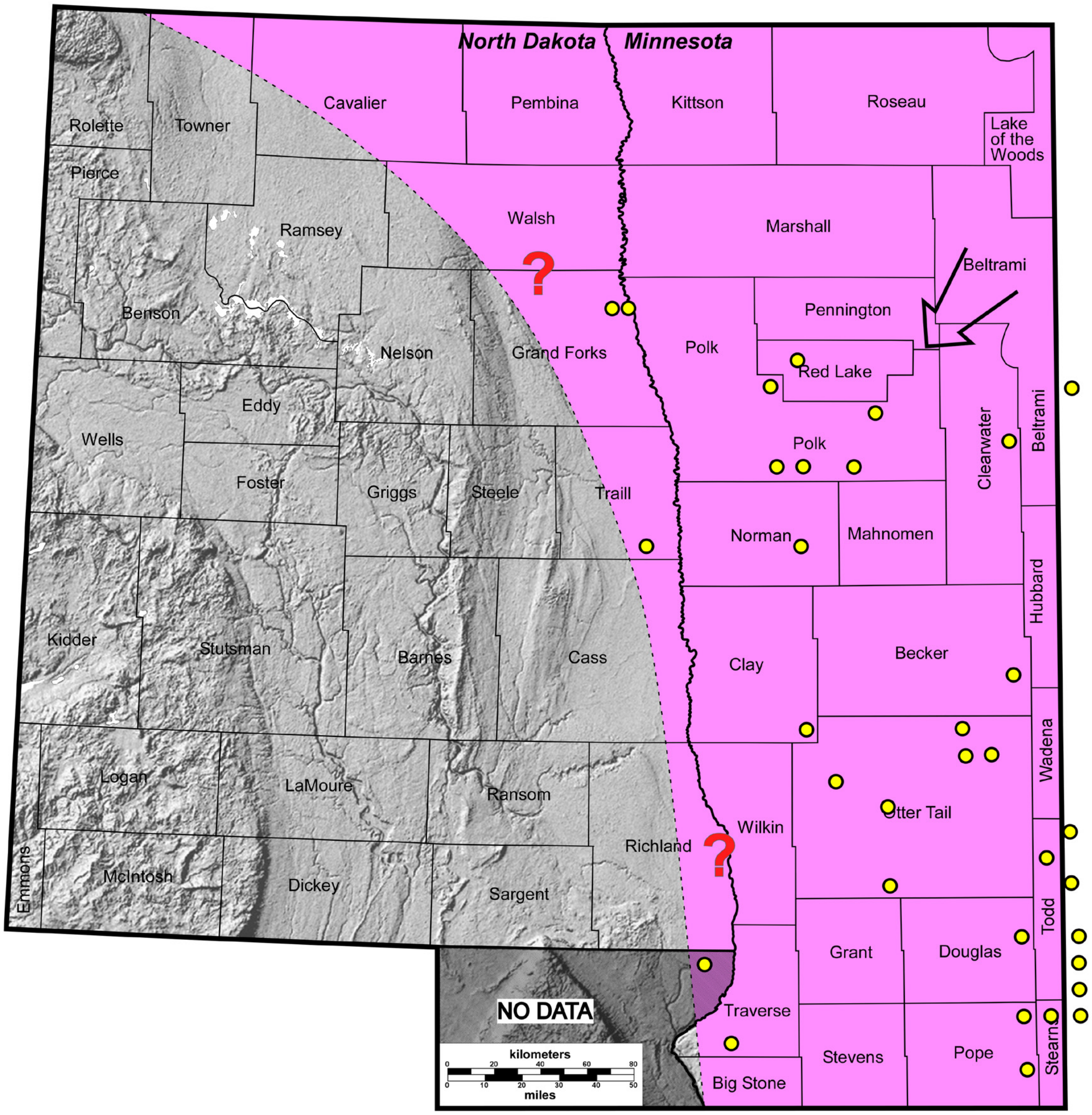


Figure A1.102. This figure shows the distribution of the Browerville Formation in the Red River Valley of North Dakota and Minnesota, and the adjacent uplands. The Browerville Formation consists mainly of glacial sediment deposited during a glacial advance from the northeast and north (mixed Rainy-Winnipeg provenance). It is exposed at the surface in parts of west-central Minnesota and the eastern Red River Valley but is otherwise overlain by younger, mainly Late Wisconsinan deposits. Yellow circles indicate townships where sample control is located. The arrow indicates the direction of ice flow.

GERVAIS FORMATION

(Accepted)

NAME AND RANK

The Gervais Formation is accepted as formally named by Harris, Clayton, and Moran (1974) with minor modifications owing to format changes and additional information. The source of the name is Gervais Township in Red Lake County, Minnesota, located on the USGS 7.5-minute series Plummer NW, MN quadrangle.

TYPE AREA

The Red Lake Falls area of Minnesota.

TYPE SECTION

The type section for the Gervais Formation is Three Creeks Section (N-1012, D-5) on the Red Lake River, Red Lake Falls Township, Red Lake County, Minnesota (T. 151 N., R. 44 W., sec. 21 babaa; GPS 47.890372, -96.302541; USGS 7.5-minute series Red Lake Falls, MN quadrangle; fig. A1.103 and Appendix 2, p. 226).

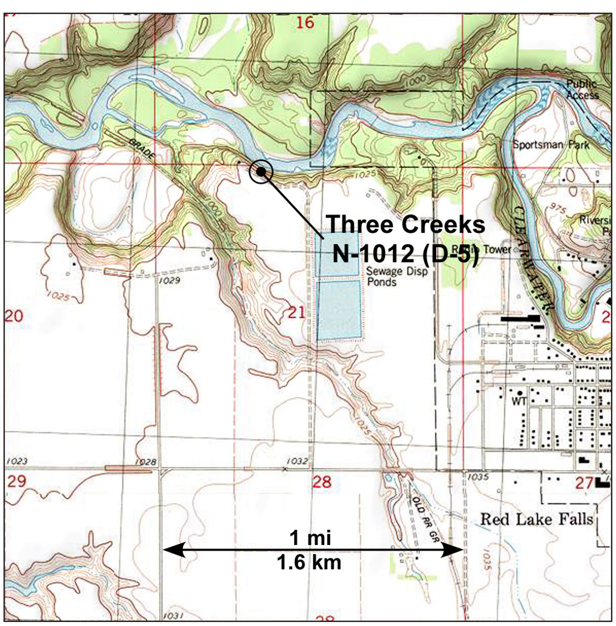
REFERENCE SECTIONS

A reference section for the Gervais Formation is Minnesota Geological Survey rotary-sonic core TG-6 (N-8006) in Pope County, Minnesota (T. 124 N., R. 36 W., sec. 9 cbbaba; GPS: 45.563694, -95.212103; USGS 7.5-minute series Sedan, MN quadrangle; fig. A1.104 and Appendix 2, p. 157).

A second reference section for the Gervais Formation is Minnesota Geological Survey rotary-sonic core RVR-1 (N-6218) in Norman County, Minnesota (T. 144 N., R. 44 W., sec. 23 cddddа; GPS: 47.267344, -96.226940; USGS 7.5-minute series Waukon, MN quadrangle; fig. A1.105 and Appendix 2, p. 217). The complex stratigraphy of this core is the result of probable ice-thrust faults at 132, 206.5, 231.5, and 250 feet (40, 63, 70.5, and 76 meters) below the surface.

LITHOLOGIC DESCRIPTION

The Gervais Formation is unbedded, silty, very slightly pebbly loam and clay loam, and associated fluvial and lacustrine sediment. The pebble-loam is light olive gray (5Y 6/2) when dry and dark gray (10YR 4/1) to very dark gray (5Y 3/1 or 10YR 3/1) or very dark grayish brown (2.5Y 3/2) when moist. In outcrop, it tends to part or flake along joints that are oxidized to dark brown (7.5YR 3/2), giving the outcrop a brownish cast. Organic material, including wood chips, twigs, and logs up to 6 inches (150 mm) in diameter, along with fragments of mollusk shells, insects, carbon flakes, and green moss, is increasingly abundant towards the base of the formation. Pebbles and sand lenses a few millimeters thick are found throughout the unit but their vertical distribution generally trends in the opposite direction (increases upwards). Igneous-



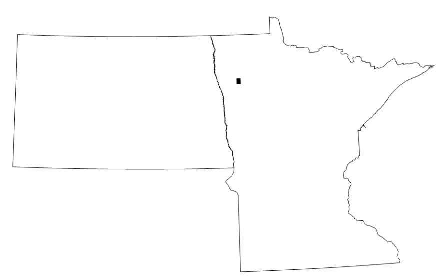
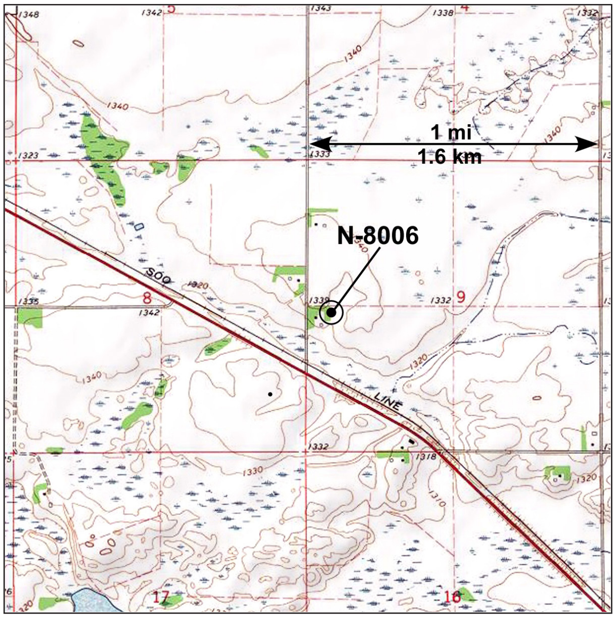


Figure A1.103. The Three Creeks Section (N-1012, D-5) on the Red Lake River, Red Lake Falls Township, Red Lake County, Minnesota (T. 151 N., R. 44 W., sec. 21 babaa; GPS 47.890372, -96.302541; USGS 7.5-minute series Red Lake Falls, MN quadrangle; Appendix 2, p. 226) is the type section of the Gervais Formation.



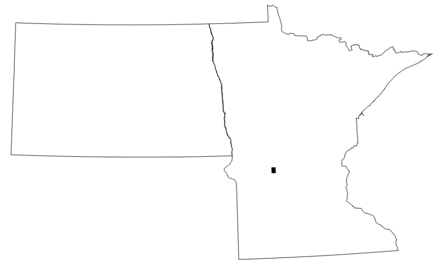


Figure A1.104. Minnesota Geological Survey rotary-sonic core TG-6 (N-8006) in Pope County, Minnesota (T. 124 N., R. 36 W., sec. 9 cbbaba; GPS: 45.563694, -95.212103; USGS 7.5-minute series Sedan, MN quadrangle; Appendix 2, p. 157) is a reference section for the Gervais Formation.

metamorphic and "butterscotch"-colored limestone pebbles are common. Local concentrations of cobbles mark the upper contact of the Gervais Formation in places.

The pebble-loam of the Gervais Formation has a texture that ranges mainly from loam to silty clay loam to clay with an average composition of 36 percent sand, 42 percent silt, and 21 percent clay (fig. A1.106A). The very coarse sand lithology (1-2 mm) averages 48 percent crystalline and metamorphic rock fragments, 51 percent carbonate rock fragments, and 2 percent shale fragments (fig. A1.106B).

DESCRIPTION OF BOUNDARIES

Although the Gervais Formation is at the surface in a few places in Barnes and Sargent Counties, North Dakota (K.L. Harris, unpub. data, 2014), it has only been observed as a subsurface unit in the Red River Valley. In Clearwater, Norman, Polk, and Red Lake Counties, Minnesota, it is commonly overlain by Late Wisconsinan sediment, primarily of the Red Lake Falls Formation. At the type section in Red Lake County, and in the counties southeast of the Red River Valley, it is overlain by the pre-Illinoian Browerville Formation. The contact with the Browerville Formation at the type section is sharp, and cobbles are concentrated along the contact.

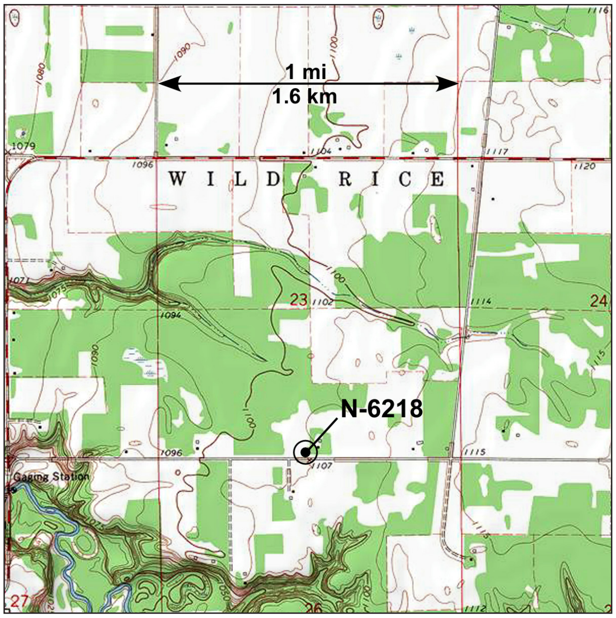
The lower contact of the Gervais Formation has only been observed in a few boreholes where it overlies older units of mixed Winnipeg-Rainy or Rainy provenance. At the reference section in Norman County, the base of the Gervais Formation is truncated by what is interpreted to be a thrust fault and overlies the younger, Browerville Formation.

HISTORICAL BACKGROUND

The Gervais Formation was first described by Harris (1973) following a detailed study of outcrops along the Red Lake River between Thief River Falls and Crookston, Minnesota. The unit was formally named by Harris and others (1974). In the southern Red River Valley, the Gervais Formation was correlated with unit RRV19 (Harris and others, 1995, 1999, 2003) and included by Thorleifson and others (2005) in the informal "Gervais group".

REGIONAL EXTENT AND THICKNESS

Figure A1.107 shows the presumed extent of the Gervais Formation in the Red River Valley and the adjacent uplands in Minnesota and North Dakota. It is distributed in patches, some quite large, throughout west-central Minnesota and the eastern Red River Valley and has been traced northwards as far as Red Lake and central Polk Counties. It likely continues to the International Border and into Manitoba but borings in northwestern Minnesota are sparse and generally terminate in younger, Late Wisconsinan sediment. In North Dakota, the Gervais Formation has only been identified at a few, widely scattered sites in Barnes, Dickey, Ransom, and Sargent Counties. At the site in Ransom County (N-5262; T. 135 N., R. 54 W., sec. 18 ccc; Appendix 2, p. 198), which



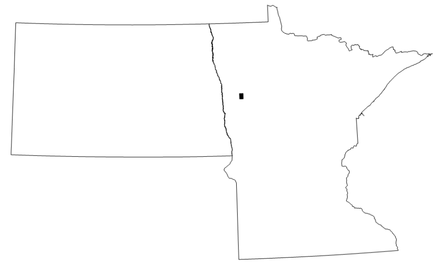


Figure A1.105. Minnesota Geological Survey rotary-sonic core RVR-1 (N-6218) in Norman County, Minnesota (T. 144 N., R. 44 W., sec. 23 cddddа; GPS: 47.267344, -96.226940; USGS 7.5-minute series Waukon, MN quadrangle; Appendix 2, p. 217) is a reference section for the Gervais Formation.

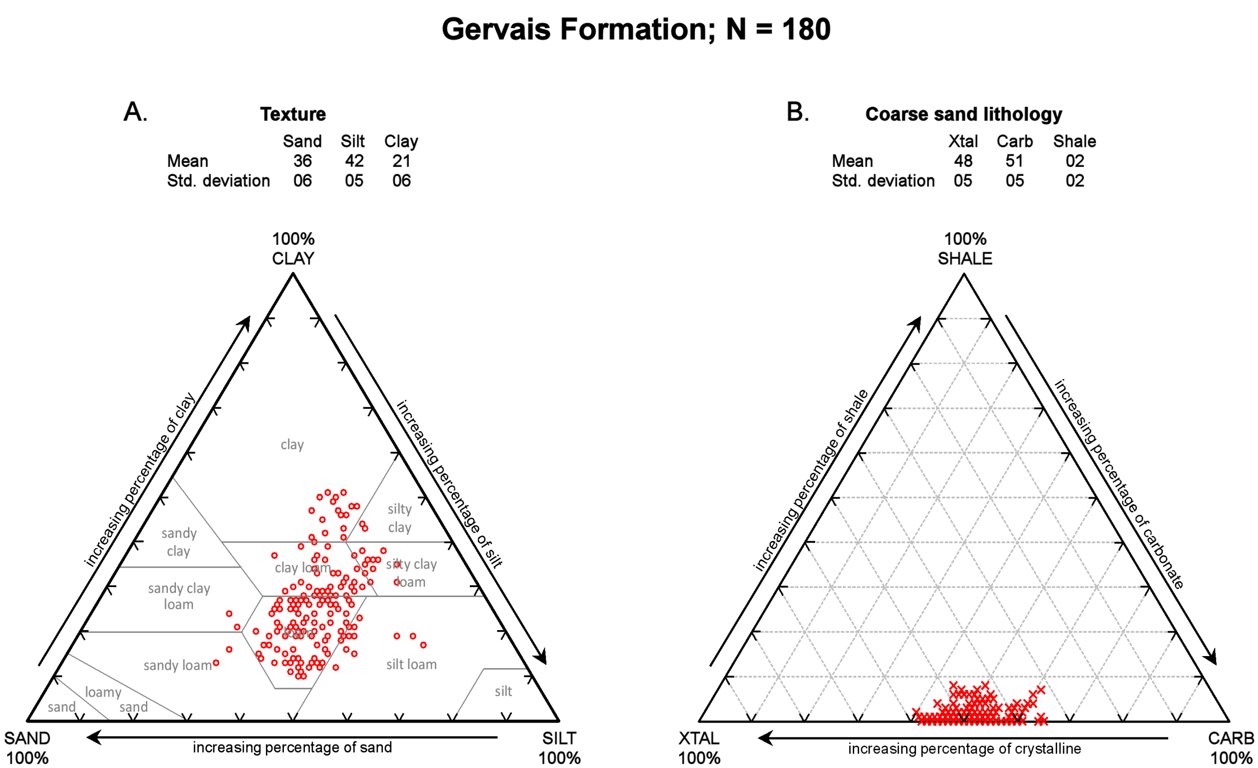


Figure A1.106. Ternary diagrams showing the results of the analysis of 180 samples that show typical textural and coarse-sand lithologic characteristics of the Gervais Formation. The texture (A) of the unit is mainly loam to clay loam and the very coarse-sand lithology (B) indicates a Winnipeg provenance.

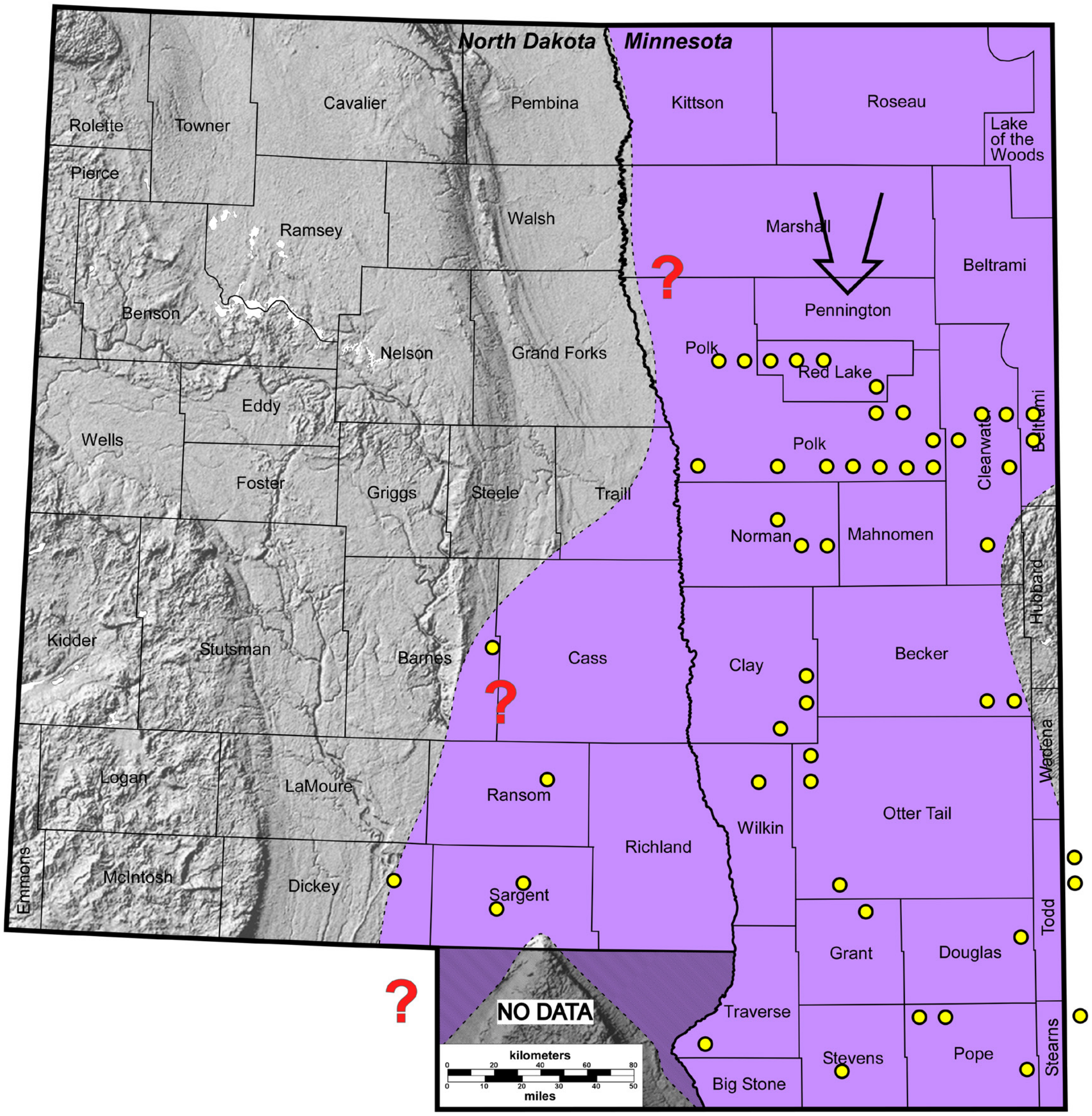


Figure A1.107. This figure shows the distribution of the Gervais Formation in the Red River Valley of North Dakota and Minnesota, and the adjacent uplands. The Gervais Formation consists of glacial sediment with a Winnipeg provenance. It is exposed at the surface in parts of west-central Minnesota, the northeastern Red River Valley, and in a few places in eastern North Dakota, but is otherwise overlain by younger, mainly Late Wisconsinan deposits. Yellow circles indicate townships where sample control is located. The arrow indicates the direction of ice flow.

is the only one on the Red River lowland, the Gervais Formation is within 7 feet (2.1 meters) of the surface below a veneer of the St. Hilaire Member of the Goose River Formation and a few feet of topsoil. It is overlain by the Sheyenne River Formation at the site in Dickey County and the more southerly of the two in Sargent County and is the surface unit at the remaining two (K.L. Harris, unpub. data, 2014).

The thickness of the Gervais Formation ranges from 1 foot (0.3 meters) to 106 feet (32 meters) at the type section with an average thickness of about 26 feet (8 meters).

DIFFERENTIATION FROM OTHER UNITS

The Gervais Formation may be differentiated from the Red Lake Falls and Browerville Formations on the basis of its finer texture, darker color, and the presence of organic debris. The Gervais Formation contains at least 15 percent more carbonate rock fragments that all other till units in the region except the Forest River Formation, from which it is distinguished by its stratigraphic position.

AGE

A radiocarbon date from a log near the base of the Gervais Formation at the type section was greater than 39,900 ^{14}C yr BP. Uranium/thorium disequilibrium dates for the overlying Browerville Formation indicate it is pre-Illinoian (Knaeble and Meyer, 2007). A possible correlation between the Gervais Formation and the Funkley Formation of north-central Minnesota suggests that the Gervais Formation is Middle Pleistocene in age, meaning it was deposited between about 780,000 and 190,000 yr BP (Jennings and others, 2006; Meyer, 2016a).

CORRELATION

The Gervais Formation may be correlative with a silt and sand unit found in well borings in the Lake Bronson area in northwestern Minnesota. Wood from organic debris found in borings ranging in depth from 90 to 140 feet (27.5 to 44 meters) yielded radiocarbon ages of > 19,000, > 36,000 (two samples), and > 38,000 ^{14}C yr BP (roughly 23,000 to 42,000 cal yr BP). The Gervais Formation may be correlative with other Winnipeg-provenance units including the Funkley Formation of north-central Minnesota (Meyer, 2016a), the Lake Henry Formation of central Minnesota (Meyer, 2016b), and the Whetstone Formation of west-central Minnesota and northeast South Dakota (Jennings, 2016) .

GENESIS

The Gervais Formation is glacial sediment that was deposited by ice that advanced into western Minnesota and southeastern North Dakota from the north (Winnipeg provenance; fig. 17).

OLDER UNITS

These are informal units that are poorly represented in the data. They are either very similar in texture and coarse-grained sand lithology to previously described units, but occur stratigraphically lower in the section, or are distinctly similar to previously described units in coarse-grained sand lithology, but have significantly different texture, and occur stratigraphically lower in the section. Stratigraphic positions are inferred from available drill data.

OLD BUFFALO RIVER TILL

(New, informal)

NAME AND RANK

The Old Buffalo River till is an informal stratigraphic unit that is similar in coarse-grained sand lithology to the Buffalo River Formation.

TYPE SECTION

Insufficient data precludes the designation of a representative section for the Old Buffalo River till at this time.

REFERENCE SECTION

Insufficient data precludes the designation of a representative section for the Old Buffalo River till at this time.

LITHOLOGIC DESCRIPTION

The Old Buffalo River till is unbedded, unsorted, massive pebble loam. The texture of the Old Buffalo River till averages 29 percent sand, 36 percent silt and 35 percent

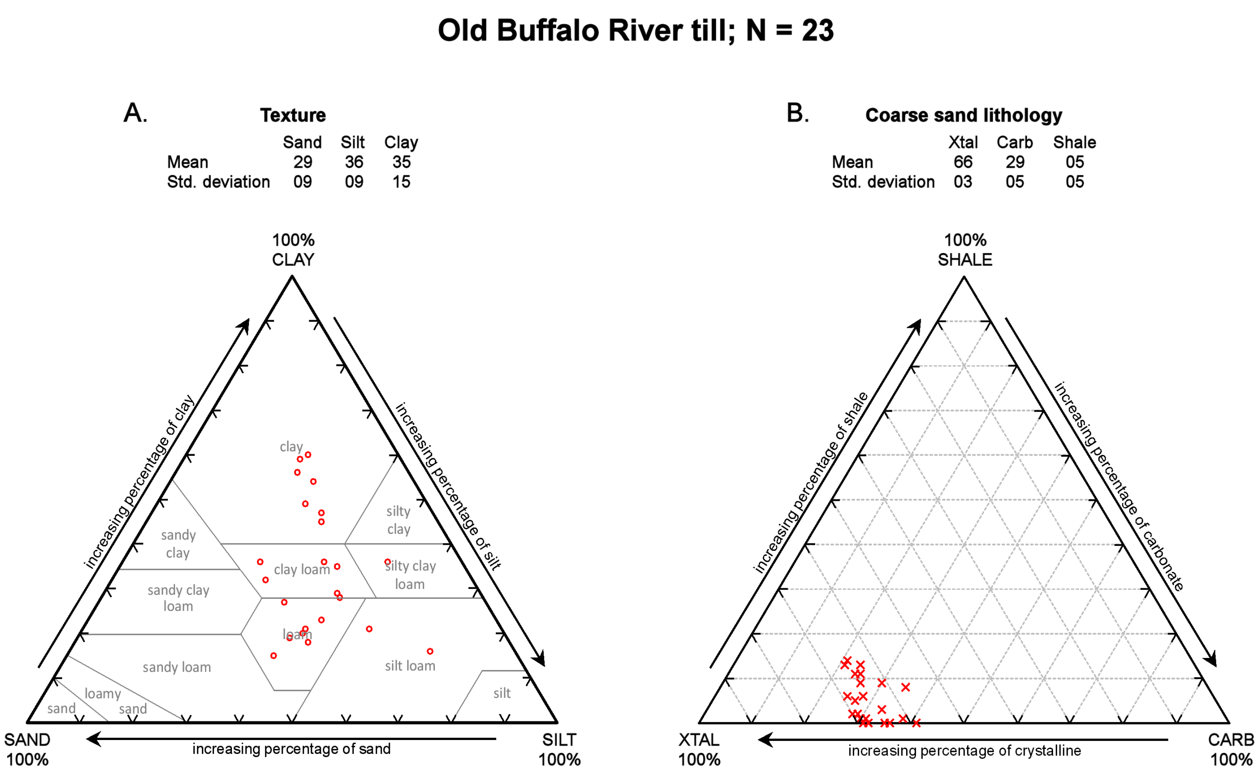


Figure A1.108. Ternary diagrams showing the results of the analysis of 23 samples that show typical textural and coarse-sand lithologic characteristics of the Old Buffalo River till. The texture (A) of the unit is mainly loam to clay loam to clay and the very coarse-sand lithology (B) indicates a mixed Rainy-Winnipeg provenance.

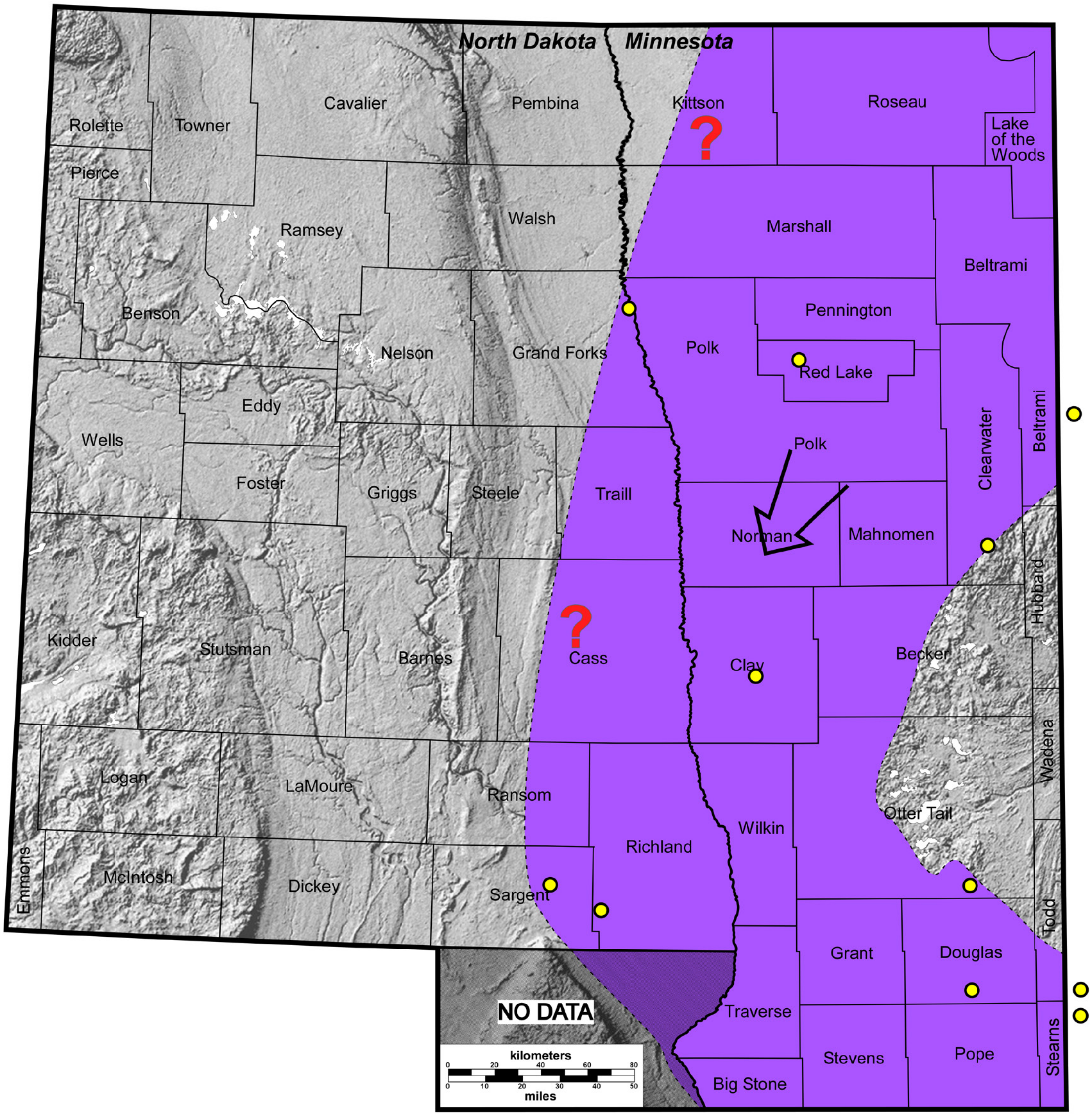


Figure A1.109. This figure shows the inferred distribution of the Old Buffalo River till in the Red River Valley of North Dakota and Minnesota, and the adjacent uplands. The Old Buffalo River till consists of glacial sediment with a mixed Rainy-Winnipeg provenance. Yellow circles indicate townships where sample control is located. The arrow indicates the direction of ice flow.

clay (fig. A1.108A). The very coarse sand lithology (1-2 mm) averages 66 percent crystalline and metamorphic rock fragments, 29 percent carbonate rock fragments, and 5 percent shale fragments (fig. A1.108B).

DESCRIPTION OF BOUNDARIES

The stratigraphic order of the till units below the Gervais Formation is unclear. Diamicton identified as the Old Buffalo River till is at the surface in southwest Richland County, North Dakota. In the few places where its upper or lower contacts have been observed, the Old Buffalo River till is overlain by various younger units including the Browerville and Sheyenne River Formations, and underlain by the Old Marcoux till.

HISTORICAL BACKGROUND

The Old Buffalo River till is one of five older till units recognized by Thorleifson and others (2005), and Harris and Berg (2006) stratigraphically below the Gervais Formation in the Fargo-Moorhead region of North Dakota and Minnesota. The unit was referred to as the “Buffalo River II till of the Old Buffalo River group”.

REGIONAL EXTENT AND THICKNESS

Insufficient data is available to meaningfully comment on the extent and thickness of the Old Buffalo River till. A rotary-sonic boring in southwestern Richland County, North Dakota (N-5156; T. 130 N., R. 52 W., sec. 30 baa; Appendix 2, p. 184) penetrated 25 feet (7.6 meters) of the unit below 8 feet (2.4 meters) of lake sediment without reaching the lower contact. An approximation of the extent of the Old Buffalo River till based on the handful of data points available is shown in figure A1.109.

DIFFERENTIATION FROM OTHER UNITS

The Old Buffalo River till contains more crystalline and metamorphic rock fragments than the Gervais and Sheyenne River Formations and appreciably fewer than the Crow Wing River Formation and the Old Marcoux till. The Browerville Formation has a much sandier texture than the Old Buffalo River till. It is distinguished from the Buffalo River Formation by its stratigraphic position.

AGE

The Old Buffalo River till is probably a pre-Illinoian glacial deposit.

CORRELATION

The stratigraphic position of the Old Buffalo River till relative to other units older than the Gervais Formation is uncertain. Any proposed correlative relationships are therefore tenuous at best. Harris and Berg (2006) suggested possible correlations between the Old Buffalo River till and the Meyer Lake Member of the Lake Henry Formation of central Minnesota, and Patterson's (1999) "Unit 10" of the upper Missouri River valley which, if correct, means it is younger than the Old Hawley till. The Old Buffalo River till may correlate with one of several till units in south-central Minnesota that are included in the informal Good Thunder formation (Johnson and others, 2016, fig. 11 and p. 261).

GENESIS

The lithology of the pebble and very coarse sand fractions suggest that the Old Buffalo River till was deposited by a glacier that advanced into Minnesota and eastern North Dakota from the northeast and north (mixed Rainy-Winnipeg provenance).

OLD NEW YORK MILLS TILL

(New, informal)

NAME AND RANK

The Old New York Mills till is an informal stratigraphic unit that is similar in coarse-grained sand lithology to the New York Mills Member of the Otter Tail River Formation.

TYPE SECTION

Insufficient data precludes the designation of a representative section for the Old New York Mills till at this time.

REFERENCE SECTION

Insufficient data precludes the designation of a representative section for the Old New York Mills till at this time.

LITHOLOGIC DESCRIPTION

The Old New York Mills till is unbedded; unsorted; massive pebble-loam. The texture of the Old New York Mills till averages 25 percent sand, 48 percent silt and 28 percent clay (fig. A1.110A). The very coarse sand lithology (1-2 mm) averages 62 percent crystalline and metamorphic rock fragments, 37 percent carbonate rock fragments, and 1 percent shale fragments (fig. A1.110B).

DESCRIPTION OF BOUNDARIES

The Old New York Mills till has only been recognized at four sites (fig. A1.111). In Ramsey County, North Dakota, it is overlain by sediments of the Goose River Formation. It is the surface unit at the site in Clearwater County, Minnesota. The lower contact of the Old New York Mills till has not been observed.

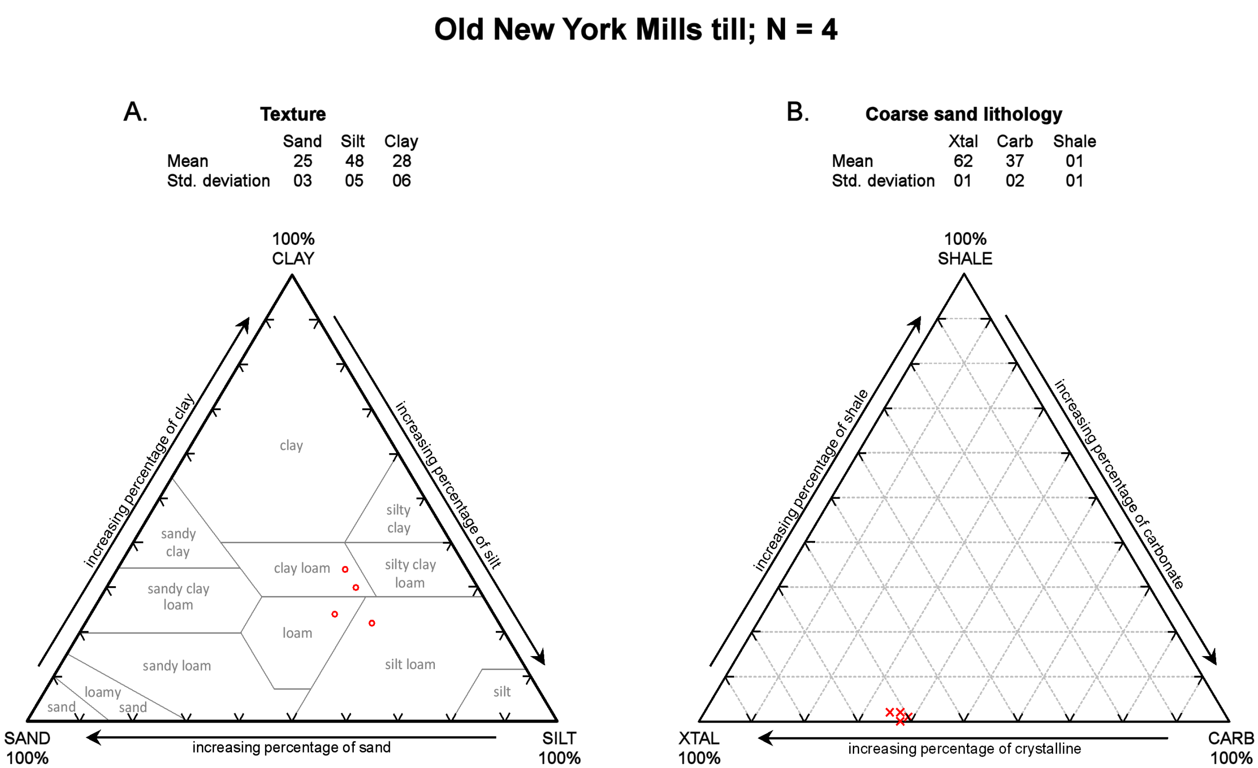


Figure A1.110. Ternary diagrams showing the results of the analysis of four samples that show typical textural and coarse-sand lithologic characteristics of the Old New York Mills till. The texture (A) of the unit is loam to silt and clay loam, and the very coarse-sand lithology (B) indicates a mixed Rainy-Winnipeg provenance.

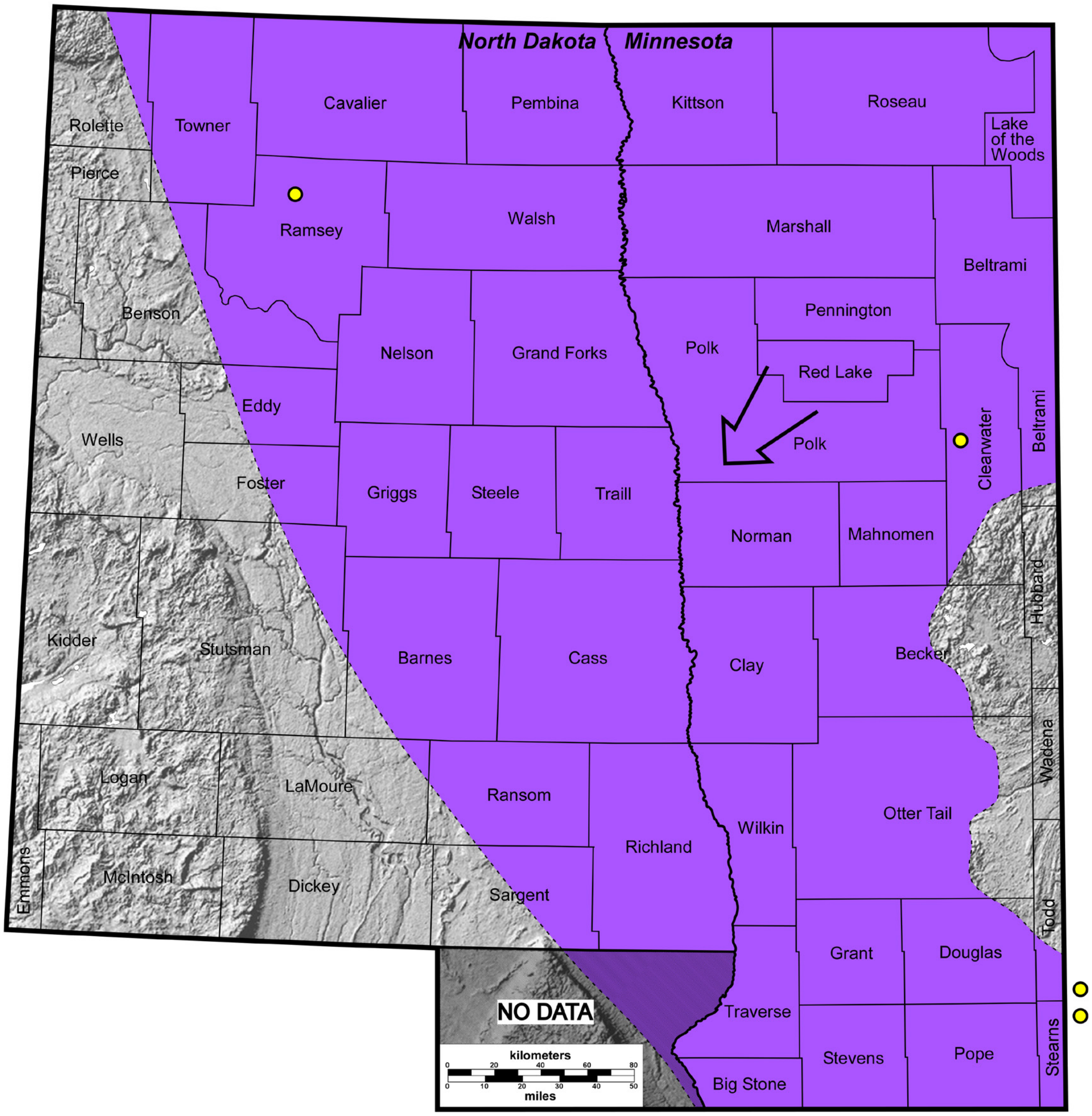


Figure A1.111. This figure shows the inferred distribution of the Old New York Mills till in the Red River Valley of North Dakota and Minnesota, and the adjacent uplands. The Old New York Mills till consists of glacial sediment with a mixed Rainy-Winnipeg provenance. Yellow circles indicate townships where sample control is located. The arrow indicates the direction of ice flow.

HISTORICAL BACKGROUND

The Old New York Mills till is one of five older till units recognized by Thorleifson and others (2005), and Harris and Berg (2006) stratigraphically below the Gervais Formation in the Fargo-Moorhead region of North Dakota and Minnesota. The unit was referred to as the "New York Mills II till of the Old Otter Tail River group".

REGIONAL EXTENT AND THICKNESS

Insufficient data is available to meaningfully comment on the extent and thickness of the Old Hawley till. An approximation of its extent based on the few data points available is shown in figure A1.111.

DIFFERENTIATION FROM OTHER UNITS

The Old New York Mills till contains considerably less shale in its very coarse sand fraction than the Goose River Formation. It contains about 25 percent more carbonate rock fragments than the Old Buffalo River till and may be distinguished from other lithologically similar units by its finer texture.

AGE

The Old New York Mills till is a pre-Illinoian glacial deposit.

CORRELATION

The stratigraphic position of the Old New York Mills till relative to other units older than the Gervais Formation is uncertain. Moreover, the shortage of data precludes any reasonable correlation with possible lithostratigraphic equivalents.

GENESIS

The lithology of the pebble and very coarse sand fractions suggest that the Old New York Mills till was deposited by a glacier that advanced into Minnesota and eastern North Dakota from the northeast and north (mixed Rainy-Winnipeg provenance).

OLD HAWLEY TILL

(New, informal)

NAME AND RANK

The Old Hawley till is an informal stratigraphic unit that is similar in coarse-grained sand lithology to the Hawley Member of the Otter Tail River Formation.

TYPE SECTION

Insufficient data precludes the designation of a representative section for the Old Hawley till at this time.

REFERENCE SECTION

Insufficient data precludes the designation of a representative section for the Old Hawley till at this time.

LITHOLOGIC DESCRIPTION

The Old Hawley till is unbedded, unsorted, massive, very compact pebbly loam to clay-loam. It contains abundant carbonate clasts and very few shale fragments. “Pebbles” of regolith are common locally. The texture of the Old Hawley till averages 37 percent sand, 36 percent silt and 28 percent clay (fig. A1.112A). The very coarse sand lithology (1-2 mm) averages 58 percent crystalline and metamorphic rock fragments, 40 percent carbonate rock fragments, and 2 percent shale fragments (fig. A1.112B).

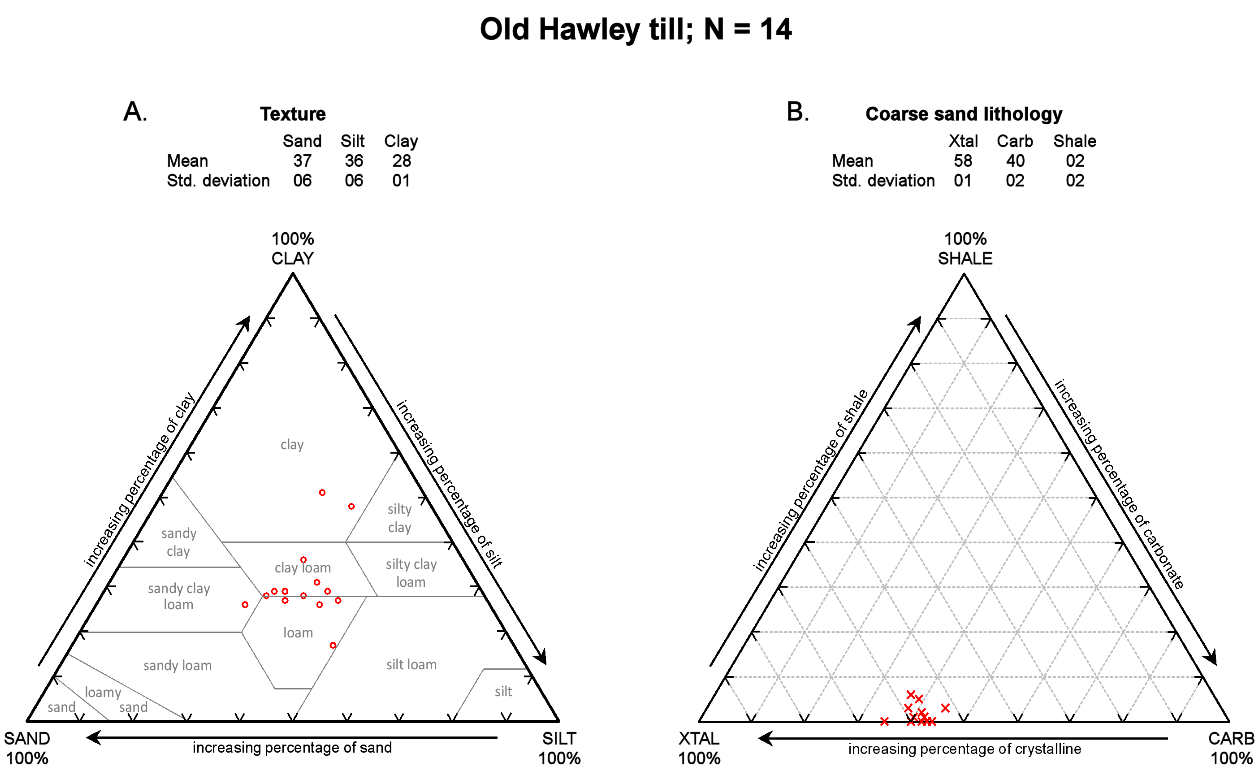


Figure A1.112. Ternary diagrams showing the results of the analysis of 14 samples that show typical textural and coarse-sand lithologic characteristics of the Old Hawley till. The texture (A) of the unit is mainly loam to clay loam and the very coarse-sand lithology (B) indicates a mixed Winnipeg-Rainy provenance.

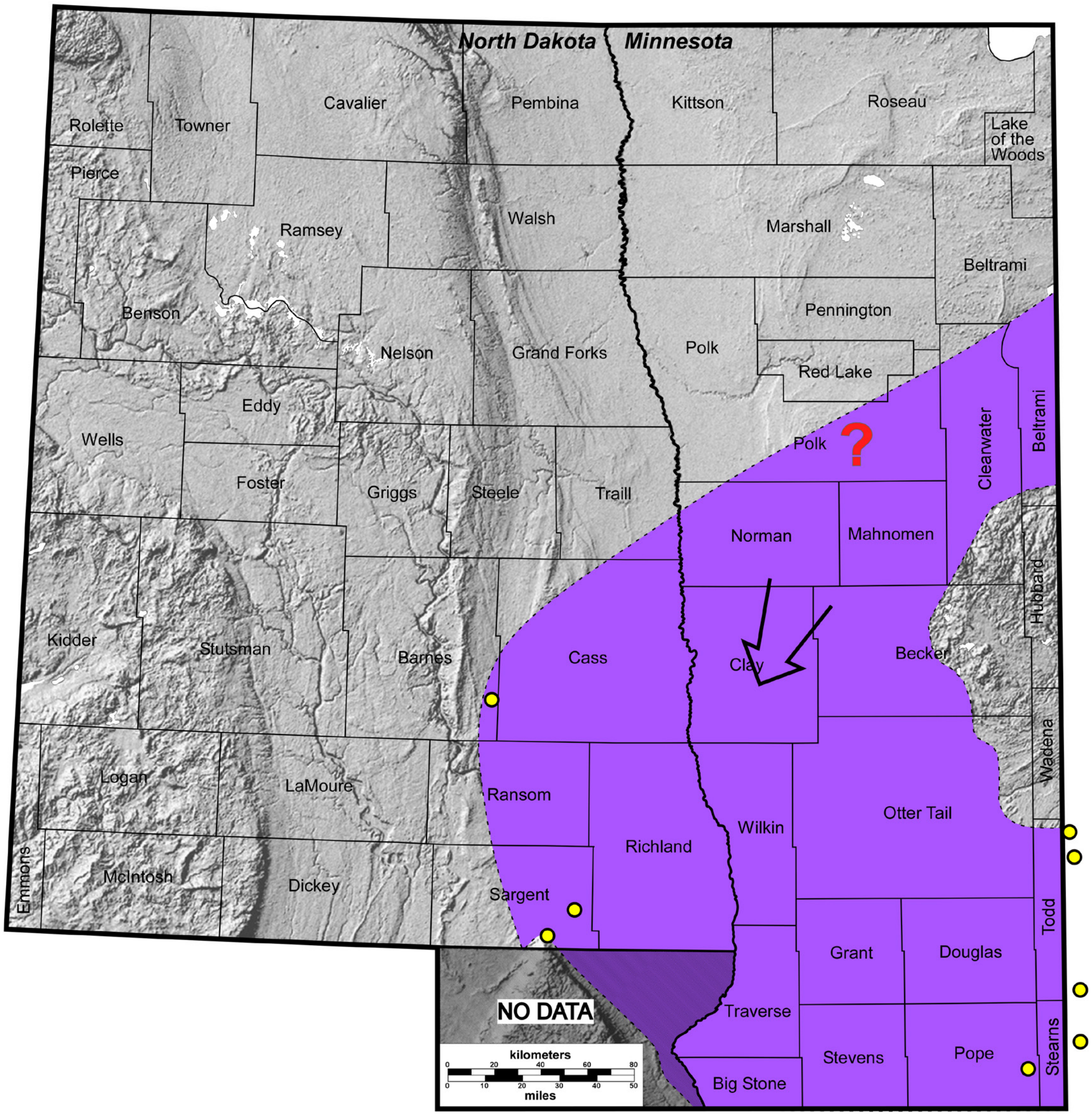


Figure A1.113. This figure shows the inferred distribution of the Old Hawley till in the Red River Valley of North Dakota and Minnesota, and the adjacent uplands. The Old Hawley till consists of glacial sediment with a mixed Winnipeg-Rainy provenance. It has no known surface exposures. Yellow circles indicate townships where sample control is located. The arrow indicates the direction of ice flow.

DESCRIPTION OF BOUNDARIES

The stratigraphy below the Gervais Formation is unclear. In the few places where its upper or lower contacts have been observed, the Old Hawley till is overlain by the Gervais Formation and underlain by the Old Marcoux till.

HISTORICAL BACKGROUND

The Old Hawley till is one of five older till units recognized by Thorleifson and others (2005), and Harris and Berg (2006) stratigraphically below the Gervais Formation in the Fargo-Moorhead region of North Dakota and Minnesota. The unit was referred to as the "Hawley II till of the Old Otter Tail River group".

REGIONAL EXTENT AND THICKNESS

Insufficient data is available to meaningfully comment on the extent and thickness of the Old Hawley till. An approximation of its extent based on the handful of data points available is shown in figure A1.113.

DIFFERENTIATION FROM OTHER UNITS

The Old Hawley till contains more crystalline and metamorphic rock fragments than the Gervais Formation and about twice as much carbonate in its coarse-sand fraction than the Old Marcoux till. It is distinguished from the Hawley Member by its stratigraphic position.

AGE

The Old Hawley till is a pre-Illinoian glacial deposit.

CORRELATION

The stratigraphic position of the Old Hawley till relative to other units older than the Gervais Formation is uncertain. Any proposed correlative relationships are therefore tenuous at best. Harris and Berg (2006) suggested possible correlations between the Old Hawley till and the Eagle Bend Formation of central and north-central Minnesota, and Patterson's (1999) "Unit 11" of the upper Missouri River valley. The Old Hawley till may correlate with one of several till units in south-central Minnesota that are included in the informal Good Thunder formation (Johnson and others, 2016, fig. 11 and p. 261).

GENESIS

The lithology of the pebble and very coarse sand fractions suggest that the Old Hawley till was deposited by a glacier that advanced into Minnesota and eastern North Dakota from the north and northeast (mixed Winnipeg-Rainy provenance).

OLD SEBEKA TILL

(New, informal)

NAME AND RANK

The Old Sebeka till is an informal stratigraphic unit that is similar in coarse-grained sand lithology to the Sebeka Member of the Crow Wing River Formation.

TYPE SECTION

Insufficient data precludes the designation of a representative section for the Old Sebeka till at this time.

REFERENCE SECTION

Insufficient data precludes the designation of a representative section for the Old Sebeka till at this time.

The general characteristics of the Old Sebeka till are illustrated here with a reference well.

The reference well for the Old Sebeka till is Minnesota Geological Survey rotary-sonic boring TG-7 (N-8007) in Douglas County, Minnesota (T. 129 N., R. 36 W., sec. 29 addbdc; GPS: 45.952417, -95.231030; USGS 7.5-minute series Lake Osakis West, MN quadrangle; fig. A1.99 and Appendix 2, p. 174).

LITHOLOGIC DESCRIPTION

The Old Sebeka till is unbedded, unsorted, massive, compact, calcareous pebble-loam and associated lake sediment. The color of the unoxidized pebble-loam is dark grayish brown (2.5Y 4/2) to very dark grayish brown (2.5Y 3/2). Pebbles are abundant and consist mostly of igneous and metamorphic rock types with lesser amounts of limestone and dolomite. Shale pebbles

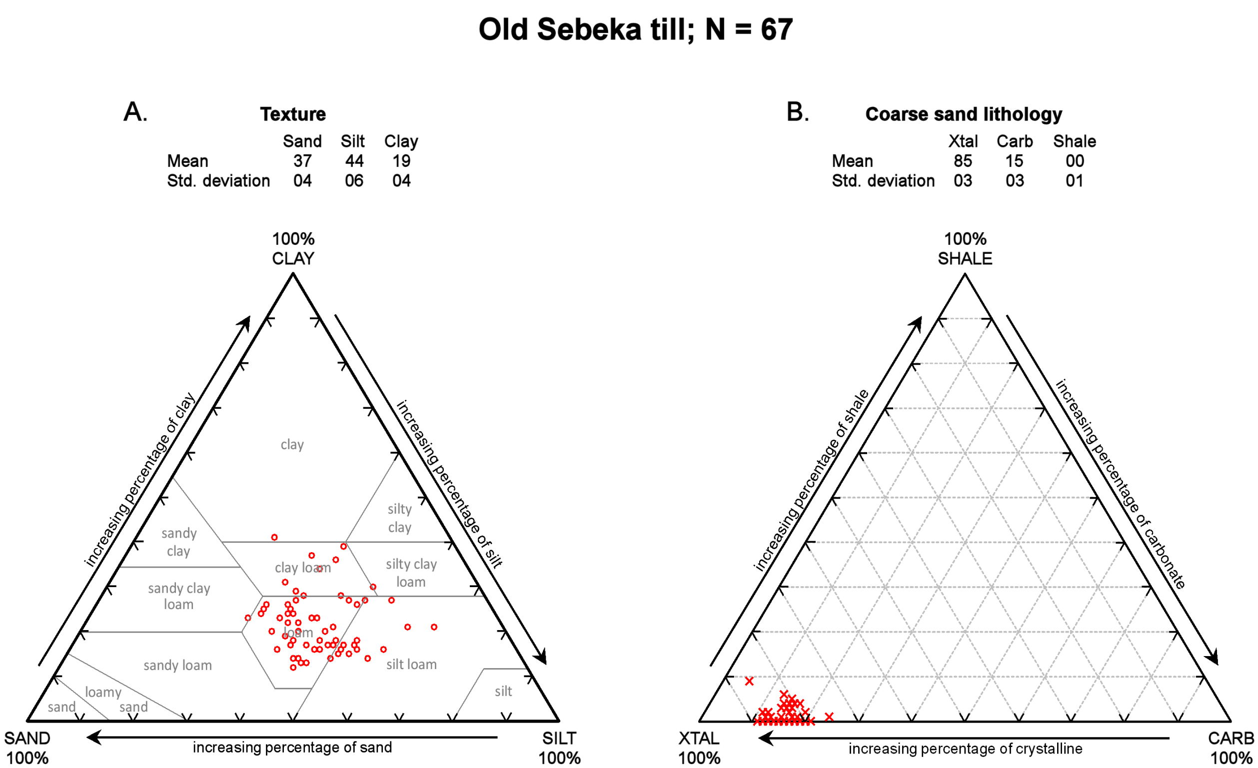


Figure A1.114. Ternary diagrams showing the results of the analysis of 67 samples that show typical textural and coarse-sand lithologic characteristics of the Old Sebeka till. The texture (A) of the unit is silt loam to loam to clay loam and the very coarse-sand lithology (B) indicates a Rainy (northeastern) provenance.

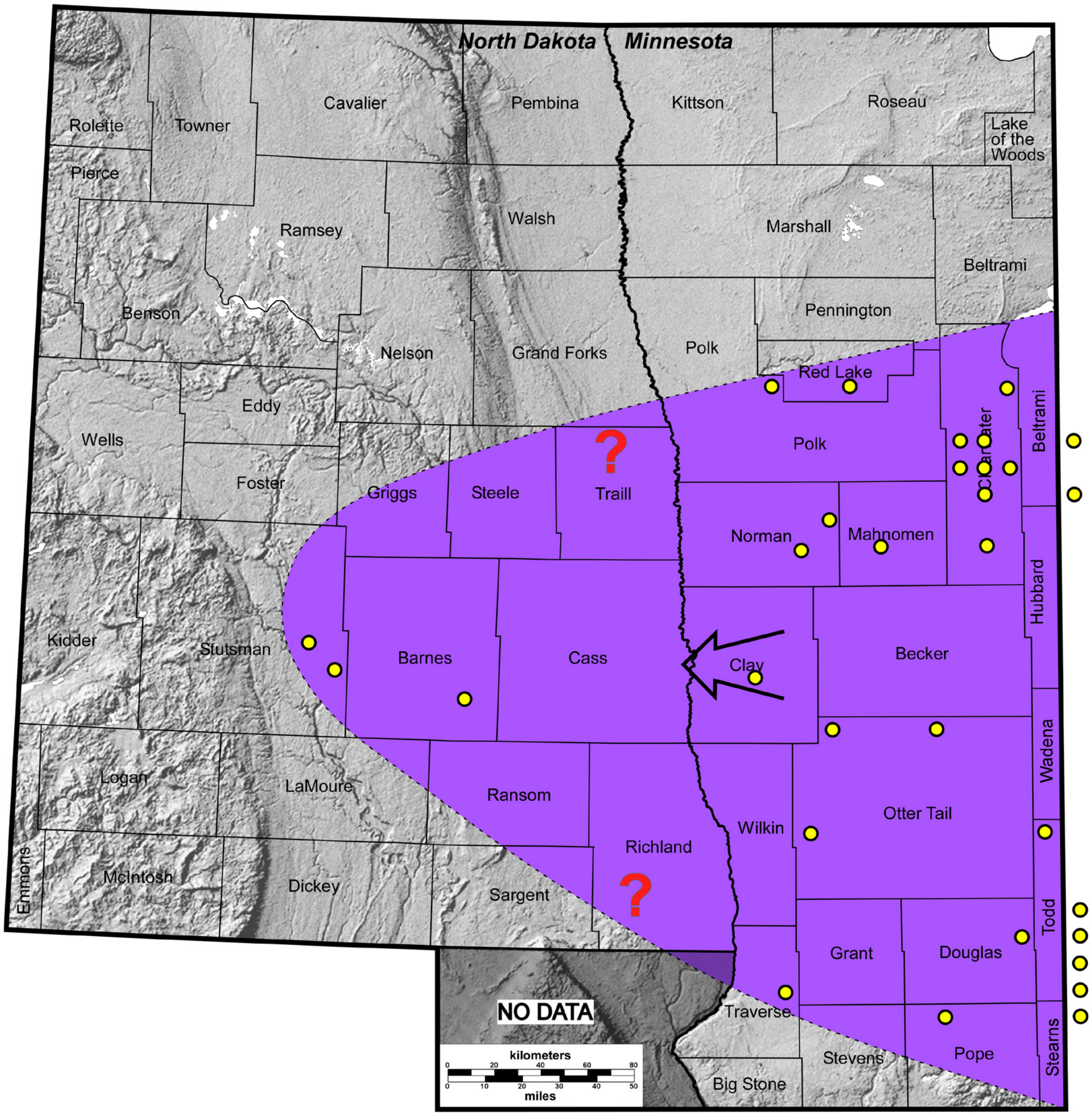


Figure A1.115. This figure shows the inferred distribution of the Old Sebeka till in the Red River Valley of North Dakota and Minnesota, and the adjacent uplands. The Old Sebeka till consists of glacial sediment with a Rainy provenance. Yellow circles indicate townships where sample control is located. The arrow indicates the direction of ice flow.

are very rare. A cobble zone is at the base of the unit in places. Wood fragments are common locally. The texture of the Old Sebeka till is silt-loam to clay loam that averages 37 percent sand, 44 percent silt and 19 percent clay (fig. A1.114A). The very coarse sand lithology (1-2 mm) averages 85 percent crystalline and metamorphic rock fragments, 15 percent carbonate rock fragments, and 0 percent shale fragments (fig. A1.114B).

DESCRIPTION OF BOUNDARIES

The stratigraphic order of the till units below the Gervais Formation is unclear. Diamicton interpreted to be the Old Sebeka till is the surface unit at sites in Barnes and Stutsman Counties, North Dakota, and also in places in Beltrami, Clearwater, and Todd Counties in central Minnesota (K.L. Harris, unpub. data, 2014). In the few places where its upper or lower contacts have been observed, the Old Sebeka till is overlain by various younger units, most commonly the Buffalo River and Sheyenne River Formations, and underlain by the Old Marcoux till or older, unnamed till units. In the reference boring, the stratigraphic order of the Old Sebeka and Old Marcoux tills is reversed. The lower contact of the Old Sebeka till was not reached in this borehole.

HISTORICAL BACKGROUND

The Old Sebeka till is one of five older till units recognized by Thorleifson and others (2005), and Harris and Berg (2006) stratigraphically below the Gervais Formation in the Fargo-Moorhead region of North Dakota and Minnesota. The unit was referred to as the "Upper Marcoux formation II of the Old Crow Wing River group".

REGIONAL EXTENT AND THICKNESS

Figure A1.115 shows the presumed extent of the Old Sebeka till. It has been recognized in the subsurface at a few widely scattered sites throughout west-central Minnesota and the eastern Red River Valley as far north as Red Lake County. The Old Sebeka till has not been found in the central or western part of the Red River Valley, but the distribution of the data points suggests it may be present further west, at least in patches.

The thickness of the Old Sebeka till is generally less than 7 feet (2.1 meters), although it is thicker in parts of central Minnesota where between 50 and 70 feet (15 and 21 meters) of the unit was recorded in borings in Clearwater, Mahnomen, and Todd Counties. The average thickness of the Old Sebeka till at 15 sites where it was measurable is 18 feet (5.5 meters).

DIFFERENTIATION FROM OTHER UNITS

The Old Sebeka till is distinguished from both members of the Crow Wing River Formation by its silty texture. The abundance of stones, predominance of igneous and metamorphic pebbles, and almost complete absence of shale rock fragments in the very coarse-sand fraction of the pebble loam distinguish the Old Sebeka till from all other units except the Old Marcoux till. The Old Sebeka and Old Marcoux tills are virtually indistinguishable in the field and are best differentiated by their very coarse sand lithology.

AGE

The Old Sebeka till is thought to be a pre-Illinoian glacial deposit.

CORRELATION

The stratigraphic position of the Old Sebeka till relative to other units older than the Gervais Formation is uncertain. Any proposed correlative relationships are therefore tenuous at best. Pre-Illinoian sediments of Rainy provenance that may correlate with the Old Sebeka till have been identified in central, south-central, and northeastern Minnesota (Johnson and others, 2016, fig. 11).

GENESIS

The lithology of the pebble and very coarse sand fractions suggest that the Old Sebeka till was deposited by a glacier that advanced across the Canadian Shield into Minnesota and eastern North Dakota from the northeast (Rainy provenance).

OLD MARCOUX TILL

(New, informal)

NAME AND RANK

The Old Marcoux till is an informal stratigraphic unit that is similar in coarse-grained sand lithology to the Marcoux Member of the Crow Wing River Formation.

TYPE SECTION

Insufficient data precludes the designation of a representative section for the Old Marcoux till at this time.

REFERENCE SECTION

Insufficient data precludes the designation of a representative section for the Old Marcoux till at this time.

The general characteristics of the Old Marcoux till are illustrated here with a reference well.

The reference well for the Old Marcoux till is Minnesota Geological Survey rotary-sonic boring TG-7 (N-8007) in Douglas County, Minnesota (T. 129 N., R. 36 W., sec. 29 addbdc; GPS: 45.952417, -95.231030; USGS 7.5-minute series Lake Osakis West, MN quadrangle; fig. A1.99 and Appendix 2, p. 174).

LITHOLOGIC DESCRIPTION

The Old Marcoux till is unbedded, unsorted, massive, compact, calcareous pebble-loam and associated glaciofluvial sand and gravel. The unoxidized pebble-loam is dark grayish brown (2.5Y 4/2) to very dark grayish brown (2.5Y 3/2) or very dark gray (10YR 3/1) in

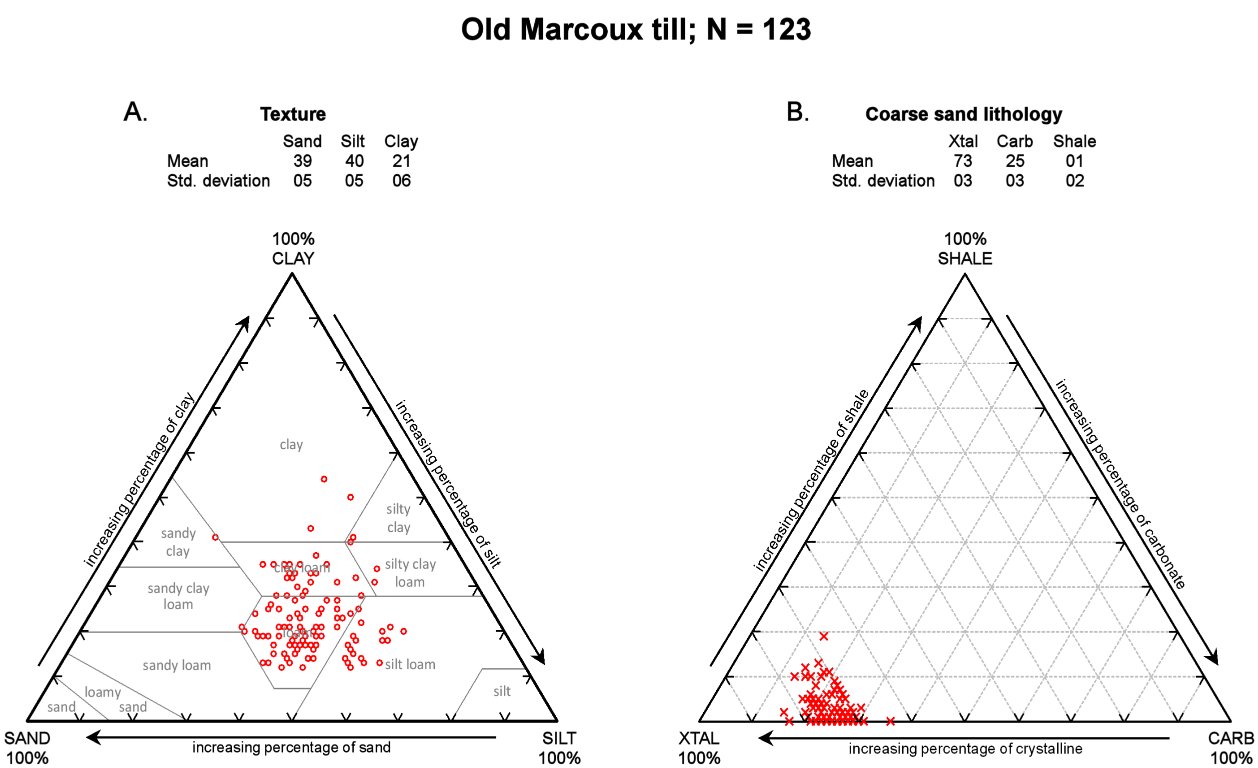


Figure A1.116. Ternary diagrams showing the results of the analysis of 123 samples that show typical textural and coarse-sand lithologic characteristics of the Old Marcoux till. The texture (A) of the unit is silt loam to loam to clay loam and the very coarse-sand lithology (B) indicates a Rainy (northeastern) provenance.

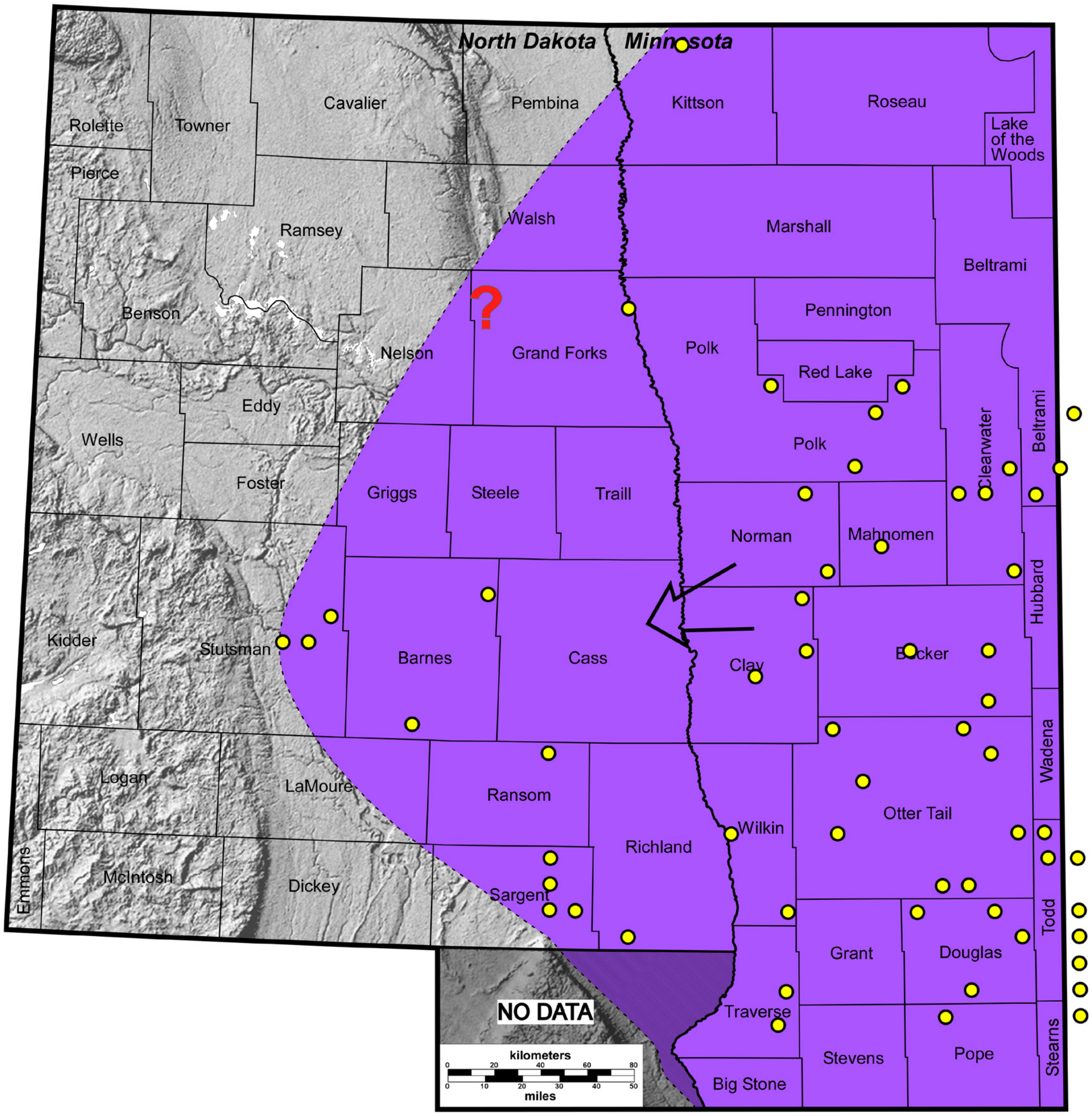


Figure A1.117. This figure shows the inferred distribution of the Old Marcoux till in the Red River Valley of North Dakota and Minnesota, and the adjacent uplands. The Old Marcoux till consists of glacial sediment with a Rainy provenance. Yellow circles indicate townships where sample control is located. The arrow indicates the direction of ice flow.

color. Pebbles are abundant and cobbles common locally, consisting mostly of igneous and metamorphic rock types with lesser amounts of limestone and dolomite. Shale pebbles are very rare. Wood fragments are common in places. The texture of the Old Sebeka till is silt-loam to clay loam that averages 39 percent sand, 40 percent silt and 21 percent clay (fig. A1.116A). The very coarse sand lithology (1-2 mm) averages 73 percent crystalline and metamorphic rock fragments, 25 percent carbonate rock fragments, and 1 percent shale fragments (fig. A1.116B).

DESCRIPTION OF BOUNDARIES

The stratigraphic order of the till units below the Gervais Formation is unclear. Diamicton interpreted to be the Old Marcoux till is the surface unit at sites in Barnes, Ransom, Sargent, and Stutsman Counties, North Dakota, and also in several places throughout west-central Minnesota, including sites in the eastern Red River Valley in Clay, Norman, Polk, and Wilkin Counties (K.L. Harris, unpub. data, 2014). It is otherwise overlain by younger pre-Illinoian units, primarily the Browerville Formation or by a variety of Late Wisconsinan sediments, mainly of northeastern (Rainy) or mixed north and northeastern (Winnipeg-Rainy) provenance. In the few places where its lower contact has been observed, the Old Marcoux till is underlain by the Old Sebeka till or older, unnamed units.

HISTORICAL BACKGROUND

The Old Marcoux till is one of five older till units recognized by Thorleifson and others (2005), and Harris and Berg (2006) stratigraphically below the Gervais Formation in the Fargo-Moorhead region of North Dakota and Minnesota. The unit was referred to as the "Lower Marcoux formation II of the Old Crow Wing River group".

REGIONAL EXTENT AND THICKNESS

Figure A1.117 shows the presumed extent of the Old Marcoux till. It has been recognized in the subsurface at several widely scattered sites throughout west-central Minnesota and the eastern half of the Red River Valley as far as the west bank of the Red River. The site in Ransom County is the only other place the Old Marcoux till has been found in the western part of the Red River Valley, but the distribution of the data points suggests it may be present in other areas, at least in patches.

The average thickness of the Old Marcoux till is about 24 feet (7.3 meters).

DIFFERENTIATION FROM OTHER UNITS

The Old Marcoux till is distinguished from both members of the Crow Wing River Formation by its silty texture. The abundance of stones, predominance of igneous and metamorphic pebbles, and almost complete absence of shale rock fragments in the very coarse-sand fraction of the pebble loam distinguish the Old Marcoux till from all other units except the Old Sebeka till. The Old Marcoux and Old Sebeka tills are virtually indistinguishable in the field and are best differentiated by their very coarse sand lithology.

AGE

The Old Marcoux till is a pre-Illinoian glacial deposit.

CORRELATION

The stratigraphic position of the Old Marcoux till relative to other units older than the Gervais Formation is uncertain. Any proposed correlative relationships are therefore tenuous at best. Pre-Illinoian sediments of Rainy provenance that may correlate with the Old Marcoux till have been identified in central, south-central, and northeastern Minnesota (Johnson and others, 2016, fig. 11).

GENESIS

The lithology of the pebble and very coarse sand fractions suggest that the Old Marcoux till was deposited by a glacier that advanced across the Canadian Shield into Minnesota and eastern North Dakota from the northeast (Rainy provenance).

APPENDIX II

TYPE AND REFERENCE SECTIONS

This section contains all the type and reference section descriptions for stratigraphic units discussed in this report. Section descriptions are organized in ascending numerical order by township, range, and section. All depths and elevations are measured in feet. Color notations are from the Munsell Soil Color Charts; all notations are for dry samples unless otherwise noted. Texture notation used is the USDA textural classification (% sand - % silt - % clay;); coarse-sand fraction lithology notation used is % igneous and metamorphic, % carbonate, and % shale. Thrust faults are interpreted where older stratigraphic units overlie younger stratigraphic units.

Abbreviations used include Minnesota Geological Survey (MGS), North Dakota Geological Survey (NDGS), University of North Dakota, College of Engineering and Mines (UND), and Minnesota Department of Natural Resources (MN DNR).

T. 123 N., R. 38 W., sec. 10 dddd
Type Section: James River Formation, Villard Member
Reference Section: Crow Wing River Formation, Marcoux Member
Minnesota Geological Survey Rotasonic Core (N-8005, MGS-255372, TG-5)
Pope County, Minnesota
Surface elevation = 1338 feet
Described by K. L. Harris (MGS) and A. Knaeble (MGS)

NOTE: This core is stored in 47 boxes at the MN DNR Core Library in Hibbing, MN

Depth	Elevation	Description
		HOLOCENE
Soil zone		
0.0-03.5	1338-1334.5	Loam, clayey; black (2.5Y 2/0); poorly to moderately consolidated; calcareous; massive; friable; pebbly; SOIL ZONE
		PLEISTOCENE
James River Formation, Villard Member		
03.5-04.5	1334.5-1333.5	Pebble loam; grayish brown (2.5Y 5/2); unsorted; massive; friable; calcareous; oxidized; iron stains; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, abundant shale rock fragments present; pebble-sized rocks; ocher inclusions; GLACIAL SEDIMENT
04.5-12.0	1333.5-1326	Pebble loam; grayish brown (2.5Y 5/4); unsorted; massive; friable; calcareous; oxidized; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and abundant shale rock fragments present; pebble-sized rocks; iron stains on joints; zones of obscurely bedded silt mixed in with the pebble loam; GLACIAL SEDIMENT
12.0-26.0	1326-1312	Pebble loam; sandy; grayish brown (2.5Y 5/4); unsorted; massive; friable; calcareous; oxidized; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and moderate shale rock fragments; pea- to cobble-sized stones; moderately stony; GLACIAL SEDIMENT
26.0-36.5	1312-1301.5	Pebble loam; sandy; very dark grayish brown (2.5Y 3/2); unsorted; massive; friable; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and moderate shale rock fragments; moderately stony; pea- to cobble-sized stones; Lignite fragments; GLACIAL SEDIMENT
36.5-46.0	1301.5-1292	Pebble loam; sandy; dark grayish brown (2.5Y 4/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and moderate shale rock fragments; moderately stony; pea- to cobble-sized stones; Lignite fragments; GLACIAL SEDIMENT
46.0-65.0	1292-1273	Pebble loam; sandy; dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; angular to rounded; abundant igneous and metamorphic, moderate carbonate, and moderate shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT

James River Formation, Lower James River Member

65.0-70.0	1273-1268	Pebble loam; dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and moderate shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
70.0-71.5	1268-1266.5	Sluff; dirty sand; loose desegregated pebble loam; medium- to coarse-grained
71.5-83.0	1266.5-1255	Pebble loam; dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and moderate shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
83.0-88.5	1255-1249.5	Pebble loam; dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and moderate shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
88.5-90.0	1249.5-1248	Sluff; pebbly sand; with some bedded silt; (2.5Y 4/2)

Crow Wing River Formation, Marcoux Member

90.0-95.5	1248-1242.5	Pebble loam; sandy; very dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; GLACIAL SEDIMENT
95.5-98.5	1242.5-1239.5	Sand, silty; poorly sorted; silt mixed with thin zone of pebble loam at 97.5 feet; RIVER SEDIMENT
98.5-106.0	1239.5-1232	Pebble loam; sandy; dark grayish brown (2.5Y 4/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; GLACIAL SEDIMENT
106.0-108.0	1232-1230	Sand and silt; fine- to medium-grained sand obscurely bedded with silt; mixed with pebble loam; LAKE OR RIVER SEDIMENT
108.0-117.0	1230-1221	Pebble loam; sandy; dark grayish brown (2.5Y 4/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; pebbles and cobbles present; lignite fragments present; thin medium-grained sand at 113.5 feet; GLACIAL SEDIMENT
117.0-119.0	1221-1219	Sand, silty; fine- to medium-grained; LAKE OR RIVER SEDIMENT
119.0-123.0	1219-1215	Pebble loam; sandy; very dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; pebbles and cobbles present; GLACIAL SEDIMENT
123.0-125.0	1215-1213	Sand; fine- to medium-grained; poorly sorted; mixed with zones of silt and pebble loam; LAKE OR RIVER SEDIMENT
125.0-127.0	1213-1211	Pebble loam; sandy; very dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; pebbles and cobbles present; GLACIAL SEDIMENT

127.0-129.0	1211-1209	Sand; fine- to medium-grained; poorly sorted; mixed with zones of silt and pebble loam; LAKE OR RIVER SEDIMENT
129.0-131.0	1209-1207	Pebble loam; sandy; very dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; pebbles and cobbles present; GLACIAL SEDIMENT
131.0-131.5	1207-1206.5	Sand; fine- to medium-grained; poorly sorted; mixed with zones of silt and pebble loam; LAKE OR RIVER SEDIMENT
131.5-132.5	1206.5-1205.5	Pebble loam; sandy; very dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; pebbles and cobbles present; GLACIAL SEDIMENT
132.5-141.5	1205.5-1196.5	Pebble loam; sandy; dark grayish brown (10YR 4/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale fragments; pebbly; GLACIAL SEDIMENT
141.5-151.5	1196.5-1186.5	Pebble loam; sandy; very dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; pebbly; GLACIAL SEDIMENT
151.5-154.0	1186.5-1184	Sluff; dirty sand and pea gravel; loose desegregated pebble loam; medium- to coarse-grained
154.0-156.5	1184-1181.5	Pebble loam; sandy; very dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; GLACIAL SEDIMENT
156.5-158.0	1181.5-1180	Sluff; dirty sand and pea gravel; loose desegregated pebble loam; medium- to coarse-grained
158.0-191.0	1180-1147	Pebble loam; sandy; very dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; GLACIAL SEDIMENT
191.0-209.0	1147-1129	Sand; medium-grained; poorly sorted; slightly pebbly; unbedded; LAKE OR RIVER SEDIMENT
209.0-218.0	1129-1120	Sand; coarse-grained; poorly sorted; contains pea-sized pebbles; iron oxide stains at 212 to 213 feet; LAKE OR RIVER SEDIMENT
218.0-220.0	1120-1118	Sand; medium- to coarse-grained; poorly sorted; pebbly; unbedded; LAKE OR RIVER SEDIMENT
220.0	1118	Total Depth

T. 124 N., R. 36 W., sec. 9 cbbaba
Type Section: Crow Wing River Formation, Sebeka Member
Reference Section: James River Formation, Villard Member
Reference Section: Gervais Formation
Minnesota Geological Survey, Rotasonic hole (MGS-255373, N-8006, TG-6)
Pope County, Minnesota
Surface elevation = 1338 feet
Described by K. L. Harris (MGS) and A. Knaeble (MGS)

NOTE: This core is stored at the MN DNR Core Library in Hibbing, MN

Depth	Elevation	Description
		HOLOCENE
Soil zone		
0-3	1338-1335	Loam, clayey; very dark brown (10YR 2/2); poorly to moderately consolidated; noncalcareous; massive; friable; SOIL ZONE
3-5	1335-1333	Sluff; dirty sand; loose desegregated pebble loam
5-8	1333-1330	Clay, sandy; dark gray (10YR 4/1); massive; no bedding seen; calcareous; LAKE SEDIMENT
		PLEISTOCENE
James River Formation, Villard Member		
8-10	1330-1328	Pebble loam; very dark grayish brown (2.5Y 3/2); unsorted; massive; friable; calcareous; oxidized; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and moderate shale rock fragments; pebble sized stones; Ocher pebbles present; GLACIAL SEDIMENT
10-14	1328-1324	Pebble loam; very dark grayish brown (2.5Y 3/2); unsorted; massive; friable; calcareous; oxidized; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and moderate shale rock fragments; pebble to cobble sized stones; moderately stony; Lignite pebbles present; GLACIAL SEDIMENT
14-24	1324-1314	Pebble loam; very dark gray (10YR 3/1); unsorted; massive; friable; calcareous; oxidized; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and moderate shale rock fragments; pebble to cobble sized stones; moderately stony; Lignite pebbles present; GLACIAL SEDIMENT
24-38	1314-1300	Pebble loam; very dark grayish brown (2.5Y 3/2); unsorted; massive; friable; calcareous; oxidized; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and moderate shale rock fragments; pebble sized stones; GLACIAL SEDIMENT
Crow Wing River Formation, Sebeka Member		
38-40	1300-1298	Pebble loam; sandy; dark grayish brown (2.5Y 4/2); unsorted; massive; friable; calcareous; oxidized; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; pebble sized stones; contact at 38 feet with overlying pebble loam, mixed with overlying pebble loam; GLACIAL SEDIMENT

40-41	1298-1297	Sand; silty; fine-grained with silt; grayish brown (2.5Y 5/2); unconsolidated; unbedded; calcareous; oxidized; *CLASTS:* igneous and metamorphic and carbonate rock fragments; LAKE OR RIVER SEDIMENT
41-48	1297-1290	Pebble loam; sandy; dark grayish brown (2.5Y 4/2); unsorted; massive; friable; calcareous; oxidized; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; pebble sized stones; GLACIAL SEDIMENT
48-49.5	1290-1288.5	Sand, silty; very fine-grained sand and silt; obscurely bedded; RIVER OR LAKE SEDIMENT
49.5-59.5	1288.5-1278.5	Pebble loam; sandy; dark grayish brown (2.5Y 4/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; pebble sized stones; mixed with silt at the upper contact; Lignite fragments present; GLACIAL SEDIMENT
59.5-60	1278.5-1278	Sand; fine-grained; no bedding seen; mostly washed away while coring; RIVER OR LAKE SEDIMENT
60-73	1278.5-1265	Pebble loam; sandy; very dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; pebble sized stones; GLACIAL SEDIMENT
73-77	1265-1261	Pebble loam; sandy; dark grayish brown (2.5Y 4/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; pebble sized stones; GLACIAL SEDIMENT

Browerville Formation

77-81.5	1261-1256.5	Pebble loam; sandy; light yellowish brown (2.5Y 6/4); mixed with dark grayish brown (2.5Y 4/2) from above; unsorted; massive; jointed; compact; calcareous; oxidized; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; pebble sized stones; iron stains on joint faces; GLACIAL SEDIMENT
81.5-83.5	1256.5-1254.5	Pebble loam; sandy; light olive brown (2.5Y 5/4); mixed with dark grayish brown (2.5Y 4/2); unsorted; massive; compact; calcareous; oxidized; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; pebble sized stones; GLACIAL SEDIMENT
83.5-90	1254.5-1248	Pebble loam; sandy; gradual color change from olive brown (2.5Y 4/4) to very dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; pebble sized stones; GLACIAL SEDIMENT
90-93	1248-1245	Sand; fine-grained; silty; mixed with silt and pebble loam (rod core from previous run) LAKE OR RIVER SEDIMENT
93-94	1245-1244	Pebble loam; sandy; very dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; pebble sized stones; GLACIAL SEDIMENT

Gervais Formation

94-129	1244-1209	Pebble loam; very dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, abundant carbonate, and very few shale rock fragments; pebble- to cobble-sized stones; GLACIAL SEDIMENT
129-130	1209-1208	Sand; medium-grained; poorly sorted; mixed with pebble loam above; LAKE OR RIVER SEDIMENT
130-168.5	1208-1169.5	Pebble loam; very dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, abundant carbonate, and very few shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
168.5-170	1169.5-1168	Pebble loam; very dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, abundant carbonate, and very few shale rock fragments; pebble-sized stones; butterscotch colored limestone pebbles are common; GLACIAL SEDIMENT
170-170.3	1167.5-1167.2	Silt, clayey; very dark grayish brown (2.5Y 3/2) to gray (2.5Y 5/0); organic rich, disseminated organics in matrix; no large pieces seen; LAKE OR RIVER SEDIMENT
170.3-171.8	1167.8-1166.3	Sand; fine grained to medium grained; light olive brown (2.5Y 5/4); calcareous; oxidized; LAKE OR RIVER SEDIMENT
171.8-177	1166.3-1161	Pebble loam; olive brown (2.5Y 4/4); unsorted; massive; compact; calcareous; oxidized; *CLASTS*: angular to rounded; abundant igneous and metamorphic, abundant carbonate, and very few shale rock fragments; pebble-sized stones; butterscotch colored limestone pebbles are common; GLACIAL SEDIMENT
177-200	1161-1138	Pebble loam; very dark grayish brown (2.5Y 3/2); unsorted; massive; very compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, abundant carbonate, and very few shale rock fragments; pebble-sized stones; butterscotch colored limestone pebbles are common; GLACIAL SEDIMENT
200.0	1138	Total Depth

T. 124 N., R. 43 W., sec. 28 cddadb
Reference Section: Goose River Formation, Heiberg Member
Minnesota Geological Survey Rotasonic Core (N-8003, MGS-255370, TG-3)
Stevens County, Minnesota
Surface elevation = 1154 feet
Core described by K. L. Harris (MGS) and A. Knaeble (MGS)

NOTE: This core is stored in the MN DNR Core Library in Hibbing, MN

Depth	Elevation	Description
		HOLOCENE
Soil zone		
00.0-02.5	1154-1151.5	Clay; silty; black; poorly to moderately consolidated; calcareous; massive; very stony; SOIL ZONE
		PLEISTOCENE
Goose River Formation, Heiberg Member		
02.5-05.0	1151.5-1149	Pebble loam; clayey; dark grayish brown (2.5Y 4/2) mottled with light gray; unsorted; massive; friable; calcareous; oxidized; iron oxide stains; *CLASTS*: angular to rounded; moderate igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; pebble-sized rocks; some rootlets; GLACIAL SEDIMENT
05.0-06.0	1149-1148	Sluff; drilling mud and till slurry.
06.0-14.0	1148-1140	Pebble loam; clayey; dark grayish brown (2.5Y 4/2) mottled with light gray to 10 feet; unsorted; massive; friable; calcareous; oxidized; iron stains on joints; *CLASTS*: angular to rounded; moderate igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; pebble-sized stones; ocher inclusions; GLACIAL SEDIMENT
14.0-19.0	1140-1135	Pebble loam; clayey; olive brown (2.5Y 4/4); unsorted; massive; friable; calcareous; oxidized; iron stains on joints; *CLASTS*: angular to rounded; moderate igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; pebble-sized stones; ocher inclusions; GLACIAL SEDIMENT
19.0-21.5	1135-1132.5	Pebble loam; clayey; very dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; oxidized; *CLASTS*: angular to rounded; moderate igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; pebble-sized stones; abundant lignite fragments; GLACIAL SEDIMENT
21.5-27.0	1132.5-1127	Pebble loam; clayey; very dark gray (10Y 3/1); unsorted; massive; compact; calcareous; oxidized; *CLASTS*: angular to rounded; moderate igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; pebble-sized stones; abundant gypsum; ocher inclusions; GLACIAL SEDIMENT
27.0-33.0	1127-1121	Pebble loam; clayey; dark grayish brown (2.5Y 4/2); unsorted; massive; compact; calcareous; oxidized; iron stains and secondary minerals on joints; *CLASTS*: angular to rounded; moderate igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; abundant pebbles; gypsum and ocher inclusions; GLACIAL SEDIMENT

33.0-43.0	1121-1111	Pebble loam; clayey; very dark gray (10YR 3/1) mottled with light brownish gray (2.5Y 6/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; moderate igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; abundant pebbles; GLACIAL SEDIMENT
43.0-48.5	1111-1105.5	Pebble loam; clayey; very dark gray (10YR 3/1); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; moderate igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
48.5-49.5	1105.5-1104.5	Clay; very dark gray (10YR 3/1) with zone of thinly bedded silt and fine sand (mm scale) light brownish gray (10YR6/2); compact; calcareous; LAKE SEDIMENT
49.5-53.0	1104.5-1101	Pebble loam; clayey; very dark gray (10YR 3/1); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; moderate igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; pebble-sized stones; gypsum present; GLACIAL SEDIMENT

Goose River Formation, Dahlen Member

53.0-56.0	1101-1098	Pebble loam; clayey; very dark gray (10YR 3/1); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; moderate igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
56.0-61.0	1098-1093	Sand; medium- to coarse-grained; poorly sorted; interbedded with till unconsolidated; calcareous; unbedded; LAKE OR RIVER SEDIMENT

James River Formation, undifferentiated

61.0-75.0	1093-1079	Pebble loam; very dark gray (10YR 3/1); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, abundant carbonate, and moderate shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
75.0-77.5	1079-1076.5	Pebble loam; very dark gray (10YR 3/1); unsorted; massive; friable; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, abundant carbonate, and moderate shale rock fragments; pebble-sized stones; mixed with pea gravel
77.5-95.0	1076.5-1059	Pebble loam to pebbly sandy clay loam; very dark gray (10YR 3/1); unsorted; massive; friable; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, abundant carbonate, and moderate shale rock fragments; pebble-sized stones; lignite fragments; GLACIAL SEDIMENT
95.0-100.0	1059-1054	Sand; fine-grained; gray; poorly sorted; unconsolidated; calcareous; unbedded; *CLASTS:* igneous and metamorphic, carbonate, and shale rock fragments; mixed with sandy pebble loam; LAKE OR RIVER SEDIMENT
100.0-106.0	1054-1048	Sand and gravel; medium-grained sand and pebbles; gray; poorly sorted; unconsolidated; calcareous; unbedded; *CLASTS:* igneous and metamorphic, carbonate, and shale rock fragments; mixed with sandy, silty pebble loam; RIVER SEDIMENT
106.0-110.0	1048-1044	Pebble loam; clayey; very dark grayish brown (10YR 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded;

		moderate igneous and metamorphic, moderate carbonate, and moderate shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
110.0-125.5	1044-1028.5	Silt; dark grayish brown (2.5Y 4/2); massive to obscurely bedded; a few thin laminae of very fine-grained sand, light brownish gray (2.5Y 6/2), and black clay; calcareous; *CLASTS*: pebble free; LAKE SEDIMENT
125.5-127.5	1028.5-1026.5	Silt; dark grayish brown (2.5Y 4/2); calcareous; with mm scale beds of black waxy clay; clay is non-calcareous; *CLASTS*: pebble free; LAKE SEDIMENT

Gervais Formation

127.5-129.0	1026.5-1025	Pebble loam; pinkish gray (7.5YR 6/2); unsorted; massive; compact; very slightly calcareous; oxidized; *CLASTS*: angular to rounded; abundant igneous and metamorphic, abundant carbonate, and very few shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT; Samples at 128 and 129 feet.

Thrust fault interpreted at 129.0 feet

Goose River Formation, Dahlen Member

129.0-136.5	1025-1017.5	Pebble loam; silty sandy; dark gray (10YR 4/1); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; moderate igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
136.5-140.0	1017.5-1014	Pebble loam; silty; very dark grayish brown (10YR 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; moderate igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
140.0-152.5	1014-1001.5	Silt; very dark grayish brown (2.5Y 3/2); massive to obscurely bedded; thin laminae of fine-grained sand and clay (mm scale); calcareous; *CLASTS*: pebble free; LAKE SEDIMENT

Older Unknown till (N-8003-2)

152.5-157.0	1001.5-997	Pebble loam; sandy, silty; dark grayish brown (2.5Y 4/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, very few shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
157.0-200.0	997-954	Silt; very dark grayish brown (2.5Y 3/2); massive to obscurely bedded; thin laminae of fine-grained sand and clay (mm scale); calcareous; *CLASTS*: scattered pebbles and cobbles; LAKE SEDIMENT
200.0	954	Total Depth

T. 125 N., R. 48 W., sec. 22 ddcdda
Principal Reference Section: Goose River Formation, Dahlen Member
Reference Section: Buffalo River Formation
Minnesota Geological Survey Rotasonic Core (N-8001, MGS-255368, TG-1)
Traverse County, Minnesota
Surface elevation = 1152 feet
Core described by K. L. Harris (MGS) and A. Knaeble (MGS)

NOTE: This core is stored in 47 boxes at the MN DNR Core Library in Hibbing, MN.

Depth	Elevation	Description
		HOLOCENE
Soil zone		
0.0-1.0	1152-1151	Pebble loam, silty, clayey; very dark grayish brown (2.5Y 3/2); unsorted; poorly to moderately consolidated; noncalcareous; massive; friable; oxidized; *CLASTS:* angular to rounded; igneous and metamorphic rock fragments; pebble-sized stones; SOIL ZONE
		PLEISTOCENE
Goose River Formation, Dahlen Member		
1.0-11.0	1151-1141	Pebble loam; light yellowish brown (2.5Y 6/4) mottled (2.5Y 6/2); unsorted; massive; friable; calcareous; oxidized; iron stains; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
11.0-20.0	1141-1132	Pebble loam; light olive brown (2.5Y 5/4); unsorted; massive; friable; calcareous; oxidized; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; pebble-sized stones; ocher inclusions; GLACIAL SEDIMENT
20.0-31.0	1132-1121	Pebble loam; clayey; light olive brown (2.5Y 5/4) to olive brown (2.5Y 4/4), mottled; unsorted; massive; friable; calcareous; oxidized; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
31.0-34.0	1121-1118	Pebble loam; clayey; light brownish gray (2.5Y 6/2); unsorted; massive; friable; calcareous; oxidized; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; pebble-sized stones; abundant gypsum; GLACIAL SEDIMENT
34.0-38.5	1118-1113.5	Pebble loam; clayey; light olive brown (2.5Y 5/4) to light brownish gray (2.5Y 6/2) mottled; unsorted; massive; friable; calcareous; oxidized; iron stains; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
38.5-40.0	1113.5-1112	Pebble loam; clayey; dark grayish brown (2.5Y 4/2); unsorted; massive; friable; calcareous; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT

40.0-42.0	1112-1110	Pebble loam; clayey; pale yellow (2.5Y 7/4); unsorted; massive; friable; calcareous; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; very pebbly; lignite fragments and organic debris; GLACIAL SEDIMENT
42.0-52.5	1110-1099.5	Pebble loam; clayey; grayish brown (2.5Y 5/2) to very dark gray (10YR 3/1) mottled; unsorted; massive; friable; calcareous; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; pebble-sized stones; lignite fragments; GLACIAL SEDIMENT
52.5-61.5	1099.5-1090.5	Pebble loam; clayey; very dark gray (10YR 3/1); unsorted; massive; friable; calcareous; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
61.5-69.0	1090.5-1083	Pebble loam; very dark gray (10YR 3/1); unsorted; massive; friable; calcareous; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
69.0-75.5	1083-1076.5	Silt; dark gray (10YR 4/1); weakly bedded to massive; thin laminae; friable; calcareous; *CLASTS*: pebble free; LAKE SEDIMENT
75.5-82.0	1076.5-1070	Pebble loam; clayey; very dark gray (10YR 3/1); unsorted; massive; friable; calcareous; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
82.0-85.0	1070-1067	Pebble loam; clayey; very dark gray (10YR 3/1); unsorted; massive; friable; calcareous; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
85.0-96.5	1067-1055.5	Pebble loam; clayey; very dark gray (10YR 3/1); unsorted; massive; friable; calcareous; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; pebble to cobble sized; GLACIAL SEDIMENT
96.5-100.0	1055.5-1052	Pebble loam; clayey; very dark gray (10YR 3/1); unsorted; massive; friable; calcareous; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT

James River Formation, Villard Member

100.0-105.5	1052-1046.5	Pebble loam; very dark grayish brown (2.5Y 3/2); unsorted; massive; friable; calcareous; oxidized; *CLASTS*: angular to rounded; abundant igneous and metamorphic, abundant carbonate, and moderate shale rock fragments; pebble-sized stones; lignite fragments; GLACIAL SEDIMENT
105.5-109.0	1046.5-1043	Pebble loam; very dark grayish brown (2.5Y 3/2); unsorted; massive; friable; calcareous; oxidized; *CLASTS*: angular to rounded; abundant igneous and metamorphic, abundant carbonate, and moderate shale rock fragments; pebble-sized stones; abundant gypsum; ocher inclusions; GLACIAL SEDIMENT
109.0-121.0	1043-1031	Pebble loam; very dark grayish brown (2.5Y 3/2); unsorted; massive; friable to compact; calcareous; oxidized; *CLASTS*: angular to rounded;

		abundant igneous and metamorphic, abundant carbonate, and moderate shale rock fragments; pebbly with a few cobbles sized; lignite fragments; GLACIAL SEDIMENT
121.0-133.5	1031-1018.5	Pebble loam; very dark grayish brown (2.5Y 3/2); unsorted; massive; friable to compact; calcareous; *CLASTS*: angular to rounded; abundant igneous and metamorphic, abundant carbonate, and moderate shale rock fragments; pebbly with a few cobbles; lignite fragments; GLACIAL SEDIMENT; Samples @ 124, 127, 130, and 133 feet.
133.5-141.0	1018.5-1011	Pebble loam; very dark grayish brown (2.5Y 3/2); unsorted; massive; friable to compact; calcareous; oxidized; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and moderate shale rock fragments; pebbly with a few cobbles; lignite fragments; GLACIAL SEDIMENT

Thrust fault interpreted at 141.0 feet

Goose River Formation, Heiberg Member

141.0-149.0	1011-1003	Pebble loam; silty; very dark grayish brown (2.5Y 3/2); unsorted; massive; friable to compact; calcareous; oxidized; *CLASTS*: angular to rounded; moderate igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; pebble-sized stones; lignite fragments common; GLACIAL SEDIMENT

Goose River Formation, Dahlen Member

149.0-162.0	1003-990	Pebble loam; silty; very dark grayish brown (2.5Y 3/2); unsorted; massive; friable to compact; calcareous; oxidized; *CLASTS*: angular to rounded; moderate igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; pebble-sized stones; lignite fragments common; GLACIAL SEDIMENT
162.0-164.0	990-988	Pebble loam; very dark grayish brown (2.5Y 3/2); unsorted; massive; friable to compact; calcareous; oxidized; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and few shale rock fragments; pebble-sized stones; lignite fragments common; GLACIAL SEDIMENT
164.0-171.5	988-980.5	Sand and gravel; coarse-grained sand with pebbles; light brownish gray (2.5Y 6/2); poorly sorted; unconsolidated to weakly cemented with drilling mud; unbedded; oxidized; *CLASTS:* angular to rounded; igneous and metamorphic, and carbonate rock fragments; RIVER SEDIMENT
171.5-180.0	980.5-972	Sand and gravel; medium- to coarse-grained sand pebbles; light brownish gray (2.5Y 6/2), mottled with red; poorly sorted; consolidated, cemented with silt; unbedded; oxidized; *CLASTS:* angular to rounded; igneous and metamorphic, and carbonate rock fragments; RIVER SEDIMENT
180.0-181.0	972-971	Sand and gravel; coarse-grained sand with pebbles; olive brown (2.5Y 4/4); poorly sorted; unconsolidated; unbedded; oxidized; *CLASTS:* angular to rounded; igneous and metamorphic, and carbonate rock fragments; RIVER SEDIMENT
181.0-183.0	971-969	Pebbly sand; medium- to coarse-grained; light olive brown (2.5Y 5/4); poorly sorted; unconsolidated with till clasts; unbedded; oxidized; *CLASTS:* abundant igneous and metamorphic, moderate carbonate, and few shale rock fragments; pea-sized pebbles; RIVER SEDIMENT

183.0-194.0	969-958	Sand and gravel; medium- to coarse-grained sand with pebbles; light olive brown (2.5Y 5/4); poorly sorted; unconsolidated; unbedded; oxidized; *CLASTS:* angular to rounded; igneous and metamorphic, and carbonate rock fragments; RIVER SEDIMENT

Buffalo River Formation

194.0-196.0	958-956	Pebble loam; silty; very dark gray (2.5Y 3/0); unsorted; massive; compact; calcareous; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and few shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
196.0-199.0	956-953	Clay and silt; silty clayey; very dark gray (2.5Y 3/0); obscurely laminated (80% clay / 20% silt); compact; noncalcareous; LAKE SEDIMENT

Gervais Formation

199.0-200.0	953-952	Pebble loam; silty; very dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, abundant carbonate, and very few shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
200.0	952	Total Depth

T. 126 N., R. 39 W., sec. 7 dbcaac
Reference Section: James River Formation, Lower James River Member
Minnesota Geological Survey Rotasonic Core (N-8004, MGS-255371, TG-4)
Pope County, Minnesota
Surface elevation = 1340 feet
Core described by K. L. Harris (MGS) and A. Knaeble (MGS)

NOTE: This core is stored in the MN DNR Core Library in Hibbing, MN

Depth	Elevation	Description
		HOLOCENE
Soil Zone		
0.0-1.0	1340-1339	Clay, silty; black (2.5Y 2/0); poorly to moderately consolidated; calcareous; massive; friable; SOIL ZONE
		PLEISTOCENE
James River Formation, Lower James River Member		
1.0-05.0	1339-1335	Pebble loam; dark grayish brown (2.5Y 4/2); mixed with soil; unsorted; massive; friable; calcareous; oxidized; iron stains; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; pebble-sized stones; abundant rootlets; calcic horizon at about 4 feet; GLACIAL SEDIMENT
05.0-10.0	1335-1330	Pebble loam; dark grayish brown (2.5Y 4/2); unsorted; massive; friable; calcareous; oxidized; highly jointed; abundant iron stains; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; pebble-sized stones; abundant ocher pebbles; lignite or carbon residue (powdery and sand-sized fragment) occurring in mm-scale lenses about 5 cm long GLACIAL SEDIMENT
10.0-24.0	1330-1316	Pebble loam; olive brown (2.5Y 4/4); unsorted; massive; friable; calcareous; oxidized; highly jointed; abundant iron stains and secondary minerals on joint faces; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; pebble-sized stones; Lignite fragments and abundant ocher pebbles; GLACIAL SEDIMENT
24.0-27.5	1316-1312.5	Pebble loam; olive brown (2.5Y 4/4); unsorted; massive; friable; calcareous; oxidized; jointed; abundant iron stains; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
27.5-28.5	1312.5-1311.5	Pebble loam; olive brown (2.5Y 4/4); unsorted; massive; friable; calcareous; oxidized; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and moderate shale rock fragments present; pebble-sized stones; GLACIAL SEDIMENT
28.5-44.5	1311.5-1295.5	Pebble loam; dark grayish brown (2.5Y 4/2); unsorted; massive; friable; calcareous; oxidized; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and moderate shale rock fragments present; pebble-sized stones; Lignite pebbles and secondary iron oxide present; GLACIAL SEDIMENT

44.5-54.0	1295.5-1286	Pebble loam; dark gray (10YR 4/1); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and moderate shale rock fragments present; pebble-sized stones; GLACIAL SEDIMENT
54.0-62.0	1286-1278	Pebble loam; very dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and moderate shale rock fragments present; GLACIAL SEDIMENT

Thrust fault interpreted at 62.0 feet

James River Formation, Villard Member

62.0-88.5	1278-1251.5	Pebble loam; very dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and moderate shale rock fragments present; sharp contact with underlying sand and gravel; GLACIAL SEDIMENT
88.5-91.0	1251.5-1249	Sand and gravel; coarse-grained sand and pea to cobble sized rocks; olive brown (2.5Y 4/4); poorly sorted; unbedded; oxidized; *CLASTS:* angular to rounded; abundant igneous and metamorphic, and abundant carbonate rock fragments; RIVER SEDIMENT
91.0-102	1249-1238	Pebble loam; very dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and moderate shale rock fragments; pebble-sized stones; sharp contact with overlying sand and gravel; very sandy and silty from 92.5 to 102 feet; GLACIAL SEDIMENT

Crow Wing River Formation, Marcoux Member

102-111.0	1238-1229	Pebble loam; sandy; very dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and few shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
111.0-114.5	1229-1225.5	Sand and gravel; coarse-grained sand with pebble-sized stones; grayish brown (2.5Y 5/2); poorly sorted; unconsolidated; reduced; *CLASTS:* angular to rounded; igneous and metamorphic, and carbonate rock fragments; RIVER SEDIMENT

Thrust fault interpreted at 114.5 feet

James River Formation, Lower James River Member

114.5-117.5	1225.5-1222.5	Pebble loam; sandy; very dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and few shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
117.5-126.0	1222.5-1214	Pebble loam; clayey; very dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; pebble-sized stones; Lignite fragments present; GLACIAL SEDIMENT
126.0-135.0	1214-1205	Sand; medium- to fine-grained; grayish brown (2.5Y 5/2); unbedded, poorly sorted; unconsolidated; calcareous; oxidized; *CLASTS:* mainly pea-sized Quartz and Feldspar stones; RIVER SEDIMENT

135.0-138.5	1205-1201.5	Sand and gravel; medium- to coarse-grained; grayish brown (2.5Y 5/2); unbedded, poorly sorted; unconsolidated; calcareous; oxidized; *CLASTS:* mainly pea- to pebble-sized Quartz and Feldspar stones; RIVER SEDIMENT

Crow Wing River Formation, Marcoux Member

138.5-139.5	1201.5-1200.5	Pebble loam; sandy; grayish brown (2.5Y 5/2); unsorted; massive; compact; calcareous; oxidized; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; pebble-sized stones; secondary iron oxide stains on joints faces; sharp contact with overlying sand and gravel; Lignite fragments present; GLACIAL SEDIMENT
139.5-159.5	1200.5-1180.5	Pebble loam; sandy; dark grayish brown (2.5Y 4/2); unsorted; massive; compact; calcareous; oxidized; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; pebbly to moderately stony; GLACIAL SEDIMENT
159.5-160.0	1180.5-1180	Sluff; dirty sand; loose desegregated pebble loam; medium- to coarse-grained
160.0-162.5	1180-1177.5	Pebble loam; sandy; dark grayish brown (10YR 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; pebbly to stony; disseminated wood chips and charcoal; GLACIAL SEDIMENT
162.5-167.0	1177.5-1173	Pebble loam; sandy; very dark gray (10YR 3/1); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; pebbly; black clayey inclusions; disseminated wood chips and charcoal; GLACIAL SEDIMENT
167.0-168.0	1173-1172	Sluff; dirty sand; loose desegregated pebble loam; medium- to coarse-grained
168.0-189.0	1172-1151	Pebble loam; sandy; dark grayish brown (2.5Y 4/2); unsorted; massive; very compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; GLACIAL SEDIMENT

Gervais Formation

189.0-200.0	1151-1140	Pebble loam; dark grayish brown (2.5Y 4/2); unsorted; massive; very compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, and abundant carbonate, very few shale rock fragments; regolith pebble at 199 feet (pastel green, friable); GLACIAL SEDIMENT
200.0	1140	Total Depth

T. 127 N., R. 45 W., sec. 2 bcccd
Reference Section: Goose River Formation, Heiberg Member
Reference Section: Sheyenne River Formation
Minnesota Geological Survey Rotasonic Core (N-8002, MGS-255369, TG-2)
Traverse County, Minnesota
Surface elevation = 1018 feet
Described by K. L. Harris (MGS) and A Knaeble (MGS)

NOTE: This core is stored the MN DNR Core Library in Hibbing, MN.

Depth	Elevation	Description
		HOLOCENE
Soil zone		
0.0-1.0	1018-1017	Clay, silty; black; poorly to moderately consolidated; calcareous; massive; friable; SOIL ZONE
		PLEISTOCENE
Goose River Formation, Heiberg Member		
1.0-3.0	1017-1015	Pebble loam; clayey; dark grayish brown (2.5Y 4/2) mixed with soil; unsorted; massive; friable; calcareous; oxidized; iron stains; *CLASTS*: angular to rounded; moderate igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
3.0-4.0	1015-1014	Pebble loam; clayey; dark grayish brown (2.5Y 4/2); unsorted; massive; friable; calcareous; oxidized; iron stains; *CLASTS*: angular to rounded; moderate igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
4.0-7.0	1014-1011	Pebble loam; clayey; olive brown (2.5Y 4/4); unsorted; massive; friable; calcareous; oxidized; CLASTS: angular to rounded; moderate igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
7.0-14.0	1011-1004	Pebble loam; olive brown (2.5Y 4/4); unsorted; massive; friable; calcareous; oxidized; CLASTS: angular to rounded; moderate igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
14.0-17.0	1004-1001	Pebble loam; clayey; very dark grayish brown (2.5Y 3/2); unsorted; massive; friable; calcareous; oxidized; *CLASTS*: angular to rounded; moderate igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; pebble-sized stones; abundant gypsum and iron oxide; GLACIAL SEDIMENT
17.0-35.0	1001-983	Pebble loam; clayey; very dark gray (10YR 3/1); unsorted; massive; friable; calcareous; reduced; *CLASTS*: angular to rounded; moderate igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; pebble-sized stones; 6 inches of silt laminated with till at 24.5 feet; GLACIAL SEDIMENT

Thrust fault interpreted at 35.0 feet

Goose River Formation, St Hilaire Member

35.0-45.5	983-972.5	Pebble loam; very dark grayish brown (10YR 3/2); unsorted; massive; friable; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, abundant carbonate, and moderate shale rock fragments; pebble-sized stones; lignite fragments; GLACIAL SEDIMENT
45.5-48.0	972.5-970	Pebble loam; very dark grayish brown (10YR 3/2); unsorted; massive; friable; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT

Goose River Formation, Heiberg Member

48.0-50.5	970-967.5	Sand, silty; fine- to medium-grained; dark grayish brown (2.5Y 4/2); unconsolidated; calcareous; reduced; obscurely bedded (cm scale cross beds); *CLASTS:* igneous and metamorphic and carbonate rock fragments; RIVER SEDIMENT
50.5-56.0	967.5-961	Pebble loam; very dark grayish brown (2.5Y 3/2); unsorted; massive; friable; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; pebble-sized stones; lignite fragments; GLACIAL SEDIMENT
56.0-56.5	961-961.5	Cobble zone; loose broken cobble fragments, mostly green; till matrix; calcareous
56.5-66.5	961.5-951.5	Pebble loam; very dark grayish brown (2.5Y 3/2); unsorted; massive; friable; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and abundant shale rock fragments; pebble-sized stones; lignite fragment; large limestone cobble at 58.5 feet; GLACIAL SEDIMENT
66.5-67.0	951.5-951	Sand, silty; fine-grained; dark grayish brown (2.5Y 4/2); well sorted; unconsolidated; calcareous; unbedded; *CLASTS:* igneous and metamorphic and carbonate rock fragments; LAKE OR RIVER SEDIMENT

Sheyenne River Formation

67.0-68.5	951-949.5	Pebble loam; very dark grayish brown (2.5Y 3/2); unsorted; massive; friable; calcareous; reduced; iron stains; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and few shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
68.5-69.0	949.5-949	Sand; silty; fine- to medium-grained; dark grayish brown (2.5Y 4/2); unconsolidated; calcareous; unbedded; *CLASTS:* igneous and metamorphic and carbonate rock fragments; LAKE OR RIVER SEDIMENT
69.0-84.0	949-934	Pebble loam; very dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and few shale rock fragments; pebble-sized stones; some clay pebbles in till matrix; GLACIAL SEDIMENT
84.0-88.0	934-930	Sand; fine- to medium-grained; dark grayish brown (2.5Y 4/2); unbedded, well sorted; unconsolidated; calcareous; oxidized; *CLASTS:*

		mainly Quartz and Feldspar grains; LAKE OR RIVER SEDIMENT
88.0-89.0	930-929	Sand; fine- to medium-grained; dark grayish brown (2.5Y 4/2) to dark gray (2.5Y 4/0); mm scale x-bedded, well sorted; unconsolidated; calcareous; oxidized to unoxidized; *CLASTS:* mainly Quartz and Feldspar grains; darker color due to dark minerals; LAKE OR RIVER SEDIMENT
89.0-102.0	929-916	Sand; fine- to medium-grained; dark grayish brown (2.5Y 4/2) to dark gray (2.5Y 4/0); unbedded, well sorted; unconsolidated; calcareous; oxidized; *CLASTS:* mainly Quartz and Feldspar grains; LAKE OR RIVER SEDIMENT
102.0-104.0	916-914	Pebble loam; olive brown (2.5Y 4/4); unsorted; massive; friable; calcareous; oxidized; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and few shale rock fragments; pebble-sized stones; mixed with obscurely bedded silt and sand; GLACIAL SEDIMENT
Older till, Old Sebeka till		
104.0-109.0	914-909	Pebble loam; silty; very dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, few carbonates, and very few shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
109.0-112.0	909-906	Silt and Clay; very dark grayish brown (2.5Y 3/2); thinly laminated; compact; calcareous; LAKE SEDIMENT
112.0-112.5	906-905.5	Cobble zone; loose cobbles
Older Unknown till (UNK8002a)		
112.5-116.0	905.5-902	Pebble loam; sandy; mixed with silty and clay from above; very dark grayish brown (2.5Y 3/2); unsorted; massive; very compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, very few carbonate, and abundant shale rock fragments; pebble-sized stones; contains greenstone and glauconite fragments; GLACIAL SEDIMENT
116.0-118.0	902-900	Pebble loam; sandy; very dark grayish brown (2.5Y 3/2); unsorted; massive; very compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, very few carbonate, and abundant shale rock fragments; pebble-sized stones; contains greenstone and glauconite fragments; GLACIAL SEDIMENT
Older Unknown till (UNK8002b)		
118.0-126.0	900-892	Pebble loam; clayey, silty; very dark grayish brown (2.5Y 3/2); unsorted; massive; very compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, very few carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
126.0-130.0	892-888	Pebble loam; clayey, silty; very dark grayish brown (2.5Y 3/2); unsorted; massive; very compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, very few carbonate, and abundant shale rock fragments; pebble-sized stones; contains regolith and shell fragments; GLACIAL SEDIMENT

CRETACEOUS

Pierre Formation

130.0-133.5	888-884.5	Shale; black; waxy; very firm and tough; bedded, thin (mm scale) partings; abundant shell fragments.

PRECAMBRIAN

Regolith

133.5-137.0	884.5-881	Granitic rock; highly weathered; greenish gray speckled with white powdery weathered clay; 3 inches round, flat ventifact at top contact; upper foot of regolith contains well rounded pebbles, shale and other lithologies.
137.0-150.0	881-868	Granitic and gneissic rock; highly weathered; greenish gray speckled with white powdery weathered clay; some mineral banding present; very clayey from 144.5 to 143.5 feet.
150.0	868	Total Depth

T. 129 N., R. 36 W., sec. 29 addbdc
Reference Section: Browerville Formation
Reference Well: Old Sebeka till and Old Marcoux till
Minnesota Geological Survey Rotasonic Core (N-8007, MGS-255374, TG-7)
Douglas County, Minnesota
Surface elevation = 1370 feet
Described by K. L. Harris (MGS)

NOTE: This core is stored in the MN DNR Core Library in Hibbing, MN.

Depth	Elevation	Description
		HOLOCENE
Soil zone		
0.0-0.5	1370-1369.5	Loam; silty, clayey; black (2.5Y 2/0); organic rich; poorly to moderately consolidated; calcareous; massive; friable; slightly pebbly; SOIL ZONE
		PLEISTOCENE
Otter Tail River Formation, Villard Member		
0.5-3.0	1369.5-1367	Pebble loam; yellowish brown (10YR 5/6); mottled with black from above; unsorted; massive; friable; calcareous; oxidized; iron stains; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and moderate shale rock fragments; pebble-sized stones; ocher inclusions; GLACIAL SEDIMENT
3.0-12.5	1367-1357.5	Pebble loam; olive brown (2.5Y 4/4); unsorted; massive; friable; calcareous; oxidized; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and moderate shale rock fragments; pebble-sized stones; iron stains on joints; ocher pebbles; GLACIAL SEDIMENT
Crow Wing River Formation, Marcoux Member		
12.5-21.0	1357.5-1349	Pebble loam; olive brown (2.5Y 4/4); unsorted; massive; jointed; friable; calcareous; oxidized; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; pebble-sized stones; iron stains on joint faces; ocher inclusions; GLACIAL SEDIMENT
21.0-21.5	1349-1348.5	Sluff; fine- to medium-grained sand; olive brown (2.5Y 4/4); poorly sorted; unconsolidated; calcareous; unbedded; oxidized; *CLASTS:* igneous and metamorphic and carbonate rock fragments; LAKE OR RIVER SEDIMENT
21.5-22.5	1348.5-1347.5	Pebble loam; dark grayish brown (2.5Y 4/2); unsorted; massive; jointed; friable; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; pebble-sized stones; iron stains on joint faces; ocher inclusions; GLACIAL SEDIMENT
22.5-23.0	1347.5-1347	Sluff; fine- to medium-grained sand; dark grayish brown (2.5Y 4/2); poorly sorted; unconsolidated; calcareous; unbedded; reduced; *CLASTS:* igneous and metamorphic and carbonate rock fragments; LAKE OR

		RIVER SEDIMENT
23.0-27.0	1347-1343	Pebble loam; dark grayish brown (2.5Y 4/2); unsorted; massive; jointed; friable; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; pebble-sized stones; iron stains on joint faces; ocher inclusions; GLACIAL SEDIMENT

Crow Wing River Formation, Lake and River Sediment

27.0-29.0	1343-1341	Silt; gray (2.5Y 5/0); mixed with pebble loam and medium-grained sand; cemented; calcareous; inclusions of blue gray silty clay; CLASTS: pebble free; LAKE SEDIMENT
29.0-35.0	1341-1335	Sand and gravel; silty with medium- to coarse-grained sand cm sized pebbles; light yellowish brown (2.5Y 6/4); loamy; poorly sorted; unbedded; oxidized; *CLASTS:* angular to rounded; igneous and metamorphic, and carbonate rock fragments; RIVER SEDIMENT
35.0-41.0	1335-1329	Pebble loam; light yellowish brown (2.5Y 6/4); unsorted; massive; friable; calcareous; oxidized; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; very stony; Lignite or charcoal fragments present; GLACIAL SEDIMENT
41.0-46.5	1329-1323.5	Sand and gravel; silty with medium- to coarse-grained sand cm sized pebbles; light yellowish brown (2.5Y 6/4); loamy; poorly sorted; unbedded; oxidized; *CLASTS:* angular to rounded; igneous and metamorphic, and carbonate rock fragments; RIVER SEDIMENT

Gervais Formation

46.5-50.0	1323.5-1320	Pebble loam; light olive brown (2.5Y 5/4); unsorted; massive; compact; calcareous; oxidized; *CLASTS*: angular to rounded; abundant igneous and metamorphic, abundant carbonate, and very few shale rock fragments; stony; GLACIAL SEDIMENT
50.0-51.5	1320-1318.5	Sand; medium-grained; light olive brown (2.5Y 5/4); well sorted; nconsolidated; calcareous; oxidized; unbedded; *CLASTS:* stone free; LAKE OR RIVER SEDIMENT
53.0-63.0	1318.5-1307	Sand and gravel; medium- to coarse-grained sand with cm-sized pebbles to fist sized cobbles; light yellowish brown (2.5Y 6/4); poorly sorted; unbedded; oxidized; *CLASTS:* angular to rounded; igneous and metamorphic, and carbonate rock fragments; RIVER SEDIMENT
63.0-69.0	1307-1301	Sand and gravel; medium- to coarse-grained sand with cm-sized pebbles; light yellowish brown (2.5Y 6/4); poorly sorted; unbedded; oxidized; *CLASTS:* angular to rounded; igneous and metamorphic, and carbonate rock fragments; few cobbles; black mineral debris present at 65.5 feet; very stony from 68 to 69 feet; RIVER SEDIMENT
69.0-73.0	1301-1297	Sand; medium-grained; light yellowish brown (2.5Y 6/4); well sorted; unconsolidated; calcareous; oxidized; unbedded; *CLASTS:* angular to rounded; igneous and metamorphic, and carbonate rock fragments; few cm-sized pebbles LAKE OR RIVER SEDIMENT
73.0-75.0	1297-1295	Sand and gravel; coarse-grained sand with cm-sized pebbles; light yellowish brown (2.5Y 6/4); poorly sorted; unbedded; oxidized; *CLASTS:* angular to rounded; igneous and metamorphic, and carbonate rock fragments; stony; iron oxide stains; RIVER SEDIMENT

75.0-78.0	1295-1292	Pebble loam; light yellowish brown (2.5Y 6/4); unsorted; massive; compact; calcareous; oxidized; *CLASTS*: angular to rounded; abundant igneous and metamorphic, abundant carbonate, and very few shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
78.0-90.0	1292-1280	Pebble loam; very dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, abundant carbonate, and very few shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT

Thrust fault interpreted at 90.0 feet

Crow Wing River Formation, Lake and River Sediment

90.0-93.5	1280-1276.5	Sand and gravel; medium- to coarse-grained sand with 2- to 3-cm pebbles; light yellowish brown (2.5Y 6/4); poorly sorted; unbedded; oxidized; *CLASTS:* angular to rounded; igneous and metamorphic, and carbonate rock fragments; RIVER SEDIMENT
93.5-95.0	1276.5-1275	Sand; fine- to medium-grained; light yellowish brown (2.5Y 6/4); well sorted; unconsolidated; calcareous; oxidized; unbedded; *CLASTS:* pebble free; LAKE OR RIVER SEDIMENT
95.0-97.5	1275-1272.5	Sand and gravel; medium- to coarse-grained sand with 2- to 3-cm pebbles; light yellowish brown (2.5Y 6/4); poorly sorted; unbedded; oxidized; *CLASTS:* angular to rounded; igneous and metamorphic, and carbonate rock fragments; RIVER SEDIMENT
97.5-98.0	1272.5-1272	Silt; gray (2.5Y 5/0); well sorted; bedded with thin laminae; friable; calcareous; *CLASTS*: pebble free; LAKE SEDIMENT
98.0-101.0	1272-1269	Sand; fine- to medium-grained; light yellowish brown (2.5Y 6/4); well sorted; unconsolidated; calcareous; oxidized; unbedded; *CLASTS:* pebble free; LAKE OR RIVER SEDIMENT
101.0-106.0	1269-1264	Sand; fine- to medium-grained; light yellowish brown (2.5Y 6/4); moderately well sorted; unconsolidated; calcareous; oxidized; unbedded; *CLASTS:* angular to rounded; igneous and metamorphic, and carbonate rock fragments; pea sized pebbles; LAKE OR RIVER SEDIMENT
106.0-108.0	1264-1262	Sand; medium-grained; light yellowish brown (2.5Y 6/4); well sorted; unconsolidated; calcareous; oxidized; unbedded; *CLASTS:* pebble free; LAKE OR RIVER SEDIMENT
108.0-110.0	1262-1260	Sand; medium-grained; light yellowish brown (2.5Y 6/4); moderately well sorted; unconsolidated; calcareous; oxidized; unbedded; *CLASTS:* angular to rounded; igneous and metamorphic, and carbonate rock fragments; pea sized pebbles; LAKE OR RIVER SEDIMENT
110.0-111.5	1260-1258.5	Sand; medium-grained; light yellowish brown (2.5Y 6/4); well sorted; unconsolidated; calcareous; oxidized; unbedded; *CLASTS:* pebble free; LAKE OR RIVER SEDIMENT
111.5-118.0	1258.5-1252	Sand; medium-grained; light yellowish brown (2.5Y 6/4); moderately well sorted; unconsolidated; calcareous; oxidized; unbedded; *CLASTS:* angular to rounded; igneous and metamorphic, and carbonate rock fragments; pea sized pebbles; LAKE OR RIVER SEDIMENT
118.0-119.5	1252-1250.5	Silt; with fine-grained sand; light yellowish brown (2.5Y 6/4); well sorted; flat bedded; friable; calcareous; *CLASTS*: pebble free; LAKE SEDIMENT
119.5-120.0	1250.5-1250	Sand; fine- to medium-grained; light yellowish brown (2.5Y 6/4); well

		sorted; unconsolidated; calcareous; oxidized; unbedded; CLASTS: stone free; LAKE OR RIVER SEDIMENT
120.0-122.0	1250-1248	Sand; medium- to coarse-grained; light yellowish brown (2.5Y 6/4); poorly sorted; unconsolidated; calcareous; oxidized; unbedded; *CLASTS:* angular to rounded; igneous and metamorphic, and carbonate rock fragments; pea sized pebbles; LAKE OR RIVER SEDIMENT
122.0-125.0	1248-1245	Sand and gravel; medium- to coarse-grained sand with pea-sized pebbles; light yellowish brown (2.5Y 6/4); poorly sorted; unbedded; oxidized; *CLASTS:* angular to rounded; igneous and metamorphic, and carbonate rock fragments; iron oxide stains; RIVER SEDIMENT

Crow Wing River Formation, Sebeka Member

125.0-125.5	1245-1244.5	Pebble loam; sandy; very dark grayish brown (2.5Y 3/2); unsorted; massive; compact calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, carbonate, and no shale rock fragments; pebble-sized stones; core was coated with red mud; GLACIAL SEDIMENT
125.5-126.5	1244.5-1243.5	Sand; fine-grained; light yellowish brown (2.5Y 6/4); well sorted; unconsolidated; calcareous; oxidized; unbedded; CLASTS: STONE free; LAKE OR RIVER SEDIMENT
126.5-127.0	1243.5-1243	Pebble loam; sandy; very dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, carbonate, and no shale rock fragments; pebble-sized stones; core was coated with red mud; GLACIAL SEDIMENT
127.0-132.0	1243-1238	Pebble loam; sandy; olive brown (2.5Y 4/4); mottled with yellowish red (5YR 4/6) pebble loam; unsorted; massive; compact; calcareous; oxidized; *CLASTS*: angular to rounded; abundant igneous and metamorphic, carbonate, and no shale rock fragments; pebble-sized stones; the red "streaks" are common from 127.5 to 129.5 feet, not present below 129.5 feet; core was coated with red mud; GLACIAL SEDIMENT

Browerville Formation

132.0-139.5	1238-1230.5	Pebble loam; olive gray (5Y 4/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, abundant carbonate, and very few shale rock fragments; "green till"; GLACIAL SEDIMENT
139.5-153.5	1230.5-1216.5	Pebble loam; olive gray (5Y 4/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, abundant carbonate, and very few shale rock fragments; "green till"; GLACIAL SEDIMENT
153.5-158.5	1216.5-1211.5	Sand; sandy silty to silty sandy; grayish brown (2.5Y 5/4); unconsolidated; calcareous; oxidized; unbedded; *CLASTS:* stone free; LAKE OR RIVER SEDIMENT
139.5-160.0	1211.5-1210	Pebble loam; olive gray (5Y 4/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, abundant carbonate, and very few shale rock fragments; "green till"; GLACIAL SEDIMENT

Older Till, Old Marcoux till

160.0-178.0	1210-1192	Pebble loam; olive gray (5Y 4/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, moderate carbonate, and very few shale rock fragments; wood fragments at 165 and 166 feet; "green till"; GLACIAL SEDIMENT

Older Till, Old Sebeka till

178.0-184.0	1192-1186	Pebble loam; silty; dark grayish brown (2.5Y 4/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, carbonate, and very few shale rock fragments; GLACIAL SEDIMENT
184.0-200.0	1186-1170	Pebble loam; silty; very dark grayish brown (2.5Y 3/2); unsorted; massive; compact; calcareous; reduced; *CLASTS*: angular to rounded; abundant igneous and metamorphic, carbonate, and very few shale rock fragments; wood fragments at 187 & 189 feet; inclusions of light gray (5Y 7/1) regolith at 200 feet; GLACIAL SEDIMENT
200.0	1170	Total Depth

T. 130 N., R. 33 W., sec. 17 cbabdc
Original Type Section: Browerville Formation
Transfer Station Exposure (MGS-00Q0022789)
Todd County, Minnesota
Surface elevation = 1330 feet
Section described by A. R. Knaeble and G. N. Meyer

Depth	Elevation	Description
		PLEISTOCENE
Hewitt Formation		
00-06	1330-1324	Diamicton, sandy loam-textured, light olive brown (2.5Y5/4)
Browerville Formation		
06-14	1324-1316	Diamicton, loam to clay loam-textured, dark grayish brown (10YR4/2)
14-20	1316-1310	Diamicton, loam to clay loam-textured, grades to a dark gray (10YR4/1), very coarse sand fraction (1-2 mm) of five samples ranges from 20 to 31% Paleozoic carbonate, and 2 to 11% Cretaceous clasts.
20	1310	Total Depth

T. 130 N., R. 42 W., sec. 17 dcdcb
Type Section: James River Formation, Lower James River Member
Type Section: Sheyenne River Formation
Reference Section: Goose River Formation, St. Hilaire Member
Minnesota Geological Survey Rotasonic Core (N-6603, MGS-251486, OTT-3)
Grant County, Minnesota
Surface elevation = 1183 feet
Described by K. L. Harris (MGS) and A. Knaeble (MGS)

NOTE: This Rotasonic core is stored in the MN DNR Core Library in Hibbing, MN.

Depth	Elevation	Description
		HOLOCENE
Soil Zone		
0.0-5.0	1183-1178	Loam; silty, clayey; slightly pebbly; black (2.5Y 2/0); unsorted; poorly to moderately consolidated; noncalcareous; massive; *CLASTS:* angular to rounded; igneous, metamorphic, and carbonate rock fragments; coarse-grained sand to pebble-sized stones; SOIL ZONE
		PLEISTOCENE
5.0-6.0	1178-1177	Loam; silty, clayey; slightly pebbly; light olive brown (2.5Y 5/4); unsorted; poorly to moderately consolidated; calcareous; massive; *CLASTS:* angular to rounded; igneous, metamorphic, and carbonate rock fragments; coarse-grained sand to pebble-sized stones; WEATHERED GLACIAL SEDIMENT
Goose River Formation, St. Hilaire Member		
6.0-14.0	1177-1169	Pebble loam; silty, clayey; light olive brown (2.5Y 5/3); unsorted; consolidated; calcareous; unbedded to massive but containing scattered zones of thin interbedded silt and sand; *CLASTS:* angular to rounded; igneous, metamorphic, carbonate, and shale rock fragments; coarse-grained sand to pebble-sized stones; some Lignite fragments; GLACIAL SEDIMENT
14.0-22.0	1169-1161	Pebble loam; silty; gray (10YR 6/2); unsorted; consolidated; calcareous; unbedded to massive but containing scattered zones of thin interbedded silt and sand; *CLASTS:* angular to rounded; igneous, metamorphic, carbonate, and shale rock fragments; coarse-grained sand to pebble-sized stones; some Lignite fragments; sharp lower contact; GLACIAL SEDIMENT
22.0-22.5	1161-1160.5	Sand; medium-grained; silty; olive brown (2.5Y 4/3); poorly to moderately sorted; unconsolidated; calcareous; flat bedded; iron oxide stains; *CLASTS:* angular to rounded; igneous, metamorphic and carbonate rock fragments; LAKE OR RIVER SEDIMENT
22.5-23.0	1160.5-1160	Pebble loam; olive brown (2.5Y 4/3); unsorted; consolidated; calcareous; unbedded to massive but containing zones of flat-bedded silt; *CLASTS:* angular to rounded; igneous, metamorphic, and carbonate rock fragments; coarse-grained sand to pebble-sized stones; GLACIAL SEDIMENT
23.0-29.0	1160-1154	Pebble loam; silty; grayish brown (2.5Y 5/2); unsorted; consolidated; calcareous; unbedded to massive; *CLASTS:* angular to rounded; igneous,

		metamorphic, and carbonate rock fragments; coarse-grained sand to pebble-sized stones; GLACIAL SEDIMENT
29.0-46.0	1154-1137	Pebble loam; silty; dark grayish brown (2.5Y 4/2); unsorted; consolidated; calcareous; unbedded to massive; *CLASTS:* angular to rounded; igneous, metamorphic, carbonate, and shale rock fragments some lignite fragments; coarse-grained sand to gravel sized clasts; GLACIAL SEDIMENT

Goose River Formation, Heiberg Member

46.0-47.5	1137-1135.5	Pebble loam; silty; very dark grayish brown (10YR 3/2); unsorted; consolidated; calcareous; unbedded to massive; *CLASTS:* angular to rounded; igneous, metamorphic, carbonate, and red rock fragments; coarse-grained sand to pebble-sized stones; GLACIAL SEDIMENT
47.5-55.0	1135.5-1128	NO RECOVERY
55.0-58.5	1128-1124.5	Pebble loam; silty, clayey; black (10YR 2/1); unsorted; consolidated; calcareous; unbedded to massive; *CLASTS:* angular to rounded; igneous, metamorphic, carbonate, and shale rock fragments; coarse-grained sand to pebble-sized stones; GLACIAL SEDIMENT

Goose River Formation, Lake and River Sediment

58.5-65.0	1124.5-1118	NO RECOVERY
65.0-68.0	1118-1115	SLUFF-Gravel; pea- to cobble-sized; very dirty; unsorted; unconsolidated; calcareous; unbedded; *CLASTS:* angular to rounded; igneous, metamorphic, and carbonate rock fragments; DRILLING DEBRIS AND RIVER SEDIMENT
68.0-69.0	1115-1114	SLUFF-Sand and gravel; coarse-grained to pea-sized; unsorted; unconsolidated; calcareous; unbedded; *CLASTS:* angular to rounded; igneous, metamorphic, and carbonate rock fragments; cobbles at 69 feet; DRILLING DEBRIS AND RIVER SEDIMENT
69.0-71.0	1114-1112	Sand and gravel; coarse-grained to pea-sized; unsorted; unconsolidated; calcareous; unbedded; *CLASTS:* angular to rounded; igneous, metamorphic, and carbonate rock fragments; RIVER SEDIMENT
71.0-73.5	1112-1109.5	SLUFF-Gravel; coarse-grained to cobble-sized; very dirty; unsorted; unconsolidated; calcareous; unbedded; *CLASTS:* angular to rounded; igneous, metamorphic, and carbonate rock fragments; DRILLING DEBRIS AND RIVER SEDIMENT
73.5-75.0	1109.5-1108	Pebble loam; silty, clayey to clayey; black (10YR 2/1); unsorted; consolidated; calcareous; unbedded to massive; *CLASTS:* angular to rounded; igneous, metamorphic, carbonate, and shale rock fragments; coarse-grained sand to gravel-sized clasts; GLACIAL SEDIMENT
75.0-78.0	1108-1105	SLUFF-Sand and gravel; coarse-grained to cobble-sized; very dirty; unconsolidated; calcareous; unbedded; *CLASTS:* angular to rounded; igneous, metamorphic, and carbonate rock fragments; DRILLING DEBRIS AND RIVER SEDIMENT
78.0-79.0	1105-1104	Sand; fine- to medium-grained; moderate- to well-sorted; unconsolidated; calcareous; silt beds; LAKE OR RIVER SEDIMENT.
79.0-85.0	1104-1098	Sand; fine to medium grained; moderate to poorly sorted; unconsolidated; calcareous; unbedded; *CLASTS:* angular to rounded; igneous, metamorphic, and carbonate rock fragments; LAKE OR RIVER SEDIMENT

85.0-92.0	1098-1091	Sand; fine-grained; silty; dark grayish brown (2.5Y 4/2); well sorted; unconsolidated; calcareous; obscurely bedded silt; LAKE OR RIVER SEDIMENT
92.0-105.0	1091-1078	Silt and sand; fine grained; dark gray (10YR 4/1); well sorted; moderately well consolidated; calcareous; obscurely to well bedded; LAKE OR RIVER SEDIMENT
105.0-106.5	1078-1076.5	Sand; fine grained; silty; dark grayish brown (2.5Y 4/2); moderately well sorted; unconsolidated; calcareous; unbedded; LAKE OR RIVER SEDIMENT Goose River Formation, Heiberg Member
106.5-107.5	1076.5-1075.5	Pebble loam; clayey; very dark gray (10YR 3/1); unsorted; consolidated; calcareous; unbedded to massive; *CLASTS:* angular to rounded; igneous, metamorphic, carbonate, and shale rock fragments; sand- to pebble-sized clasts; wood fragments; GLACIAL SEDIMENT
107.5-109.0	1075.5-1074	Sand; fine-grained; silty; dark grayish brown (2.5Y 4/2); moderately well to poorly sorted; unconsolidated; calcareous; unbedded; pebble- to cobble-sized till fragments; LAKE OR RIVER SEDIMENT
109.0-110.0	1074-1073	Pebble loam; light olive brown (2.5Y 5/3); unsorted; consolidated; calcareous; unbedded to massive; mixed with fine-grained sand; *CLASTS:* angular to rounded; igneous, metamorphic, carbonate, and shale rock fragments; sand- to pebble-sized clasts; GLACIAL SEDIMENT
110.0-110.5	1073-1072.5	Pebble loam; very dark grayish brown (2.5Y 3/2); unsorted; consolidated; calcareous; unbedded to massive; *CLASTS:* angular to rounded; igneous, metamorphic, carbonate, and shale rock fragments; Lignite fragments; coarse-grained sand to gravel-sized clasts; GLACIAL SEDIMENT

James River Formation, Lower James River Member

110.5-123.0	1072.5-1060	Pebble loam; black (10YR 2/1); unsorted; consolidated; calcareous; unbedded to massive; *CLASTS:* angular to rounded; igneous, metamorphic, carbonate, and shale rock fragments; Lignite fragments; coarse-sand- to pebble-sized clasts; GLACIAL SEDIMENT
123.0-133.5	1060-1049.5	Pebble loam; black (10YR 2/1); unsorted; consolidated; calcareous; unbedded to massive; *CLASTS:* angular to rounded; igneous, metamorphic, carbonate, and shale rock fragments; Lignite fragments; Wood fragment at 125 feet; coarse-sand- to gravel-sized clasts; GLACIAL SEDIMENT
133.5-135.0	1049.5-1048	Sand and gravel; coarse sand- to pebble-sized; unsorted; unconsolidated; calcareous; unbedded; *CLASTS:* angular to rounded; igneous, metamorphic, and carbonate rock fragments; till clasts; RIVER SEDIMENT
135.0-146.5	1048-1036.5	Sand; medium-grained; dark grayish brown (2.5Y 4/2); moderate- to well sorted; unconsolidated; calcareous; unbedded; *CLASTS:* Lignite at 135 feet; dirty at 140 to 141.5 feet; sharp lower contact; RIVER SEDIMENT
146.5-160.0	1036.5-1023	Pebble loam; very dark gray (10YR 3/1); unsorted; consolidated; calcareous; unbedded to massive; sand beds at 149 and 150 feet; *CLASTS:* angular to rounded; igneous, metamorphic, carbonate, and shale rock fragments; red rock fragments; Lignite fragments; coarse-sand- to gravel-sized clasts; GLACIAL SEDIMENT

Sheyenne River Formation

160.0-174.0	1023-1009	Pebble loam; very dark gray (10YR 3/1); unsorted; consolidated; calcareous; unbedded to massive; sand beds at 170-172.5 feet; *CLASTS:*

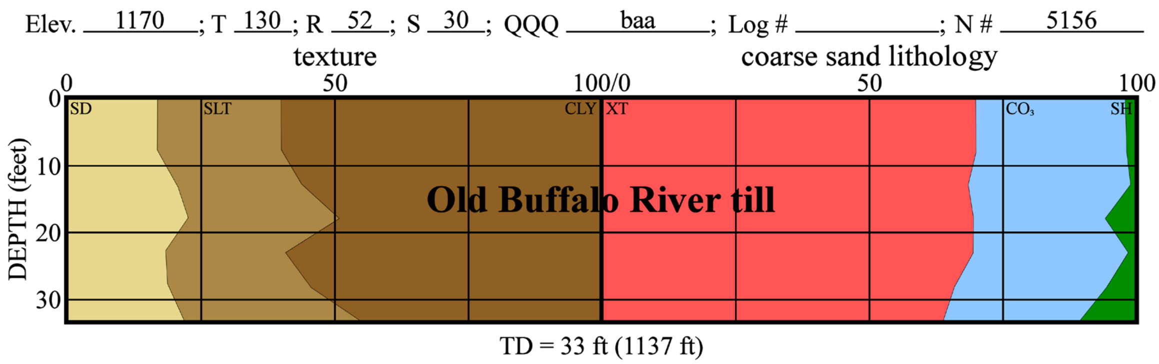
		angular to rounded; igneous, metamorphic, carbonate, and shale rock fragments; red rock fragments; Lignite fragments; coarse-sand- to gravel-sized clasts; GLACIAL SEDIMENT

Thrust fault interpreted at 174.0 feet

James River Formation, Lower James River Member

174.0-200.0	1009-983	Pebble loam; black (10YR 2/1); unsorted; consolidated; calcareous; unbedded to massive; silt beds at 175 feet; *CLASTS:* angular to rounded; igneous, metamorphic, carbonate, and shale rock fragments; red rock fragments; coarse-sand- to gravel-sized clasts; GLACIAL SEDIMENT
200.0	983	Total Depth

T. 130 N., R. 52 W., sec. 30 baa
Old Buffalo River till
North Dakota Geological Survey; Power Auger Boring (N-5156)
Richland County, North Dakota
Elevation 1170 feet
Section Description by K. L. Harris



Part (a)

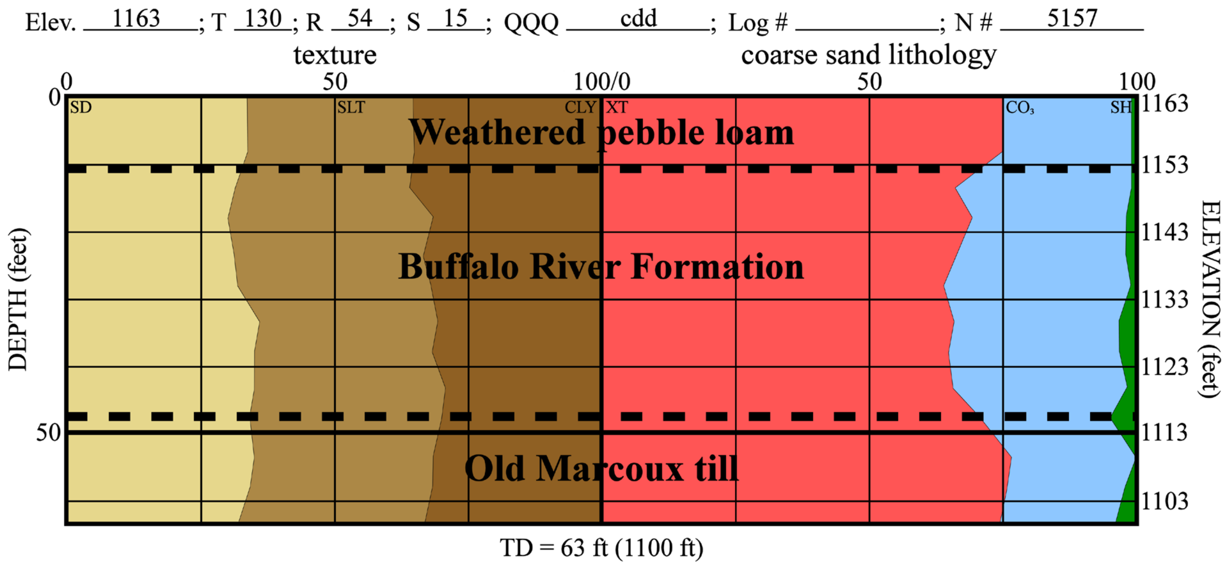
Surf = 1170 feet

QQQ	N	T	R	S	ELEV	DEPTH	SD	SLT	CLY	XT	CO_3	SH	WHO
baa	5156	130	52	30	1162	8	17	23	60	70	28	2	O' Buffalo
baa	5156	130	52	30	1157	13	21	23	56	68	31	1	O' Buffalo
baa	5156	130	52	30	1152	18	23	28	49	69	25	6	O' Buffalo
baa	5156	130	52	30	1147	23	19	22	59	69	29	2	O' Buffalo
baa	5156	130	52	30	1142	28	19	27	54	66	28	6	O' Buffalo
baa	5156	130	52	30	1137	33	22	33	45	64	25	11	O' Buffalo
QQQ	N	T	R	S	ELEV	DEPTH	SD	SLT	CLY	XT	CO_3	SH	WHO

Part (b)

Section description of NDGS borehole N-5156 showing (a) Graphical depiction of the borehole textural and coarse-sand data and interpreted stratigraphic units present; (b) the textural and coarse-sand data shown on part (a).

T. 130 N., R. 54 W., sec. 15 cdd
Type Section: Buffalo River Formation
North Dakota Geological Survey; Power Auger Boring (N-5157)
Sargent County, North Dakota
Elevation 1163 feet
Section Description by K. L. Harris



Part (a)

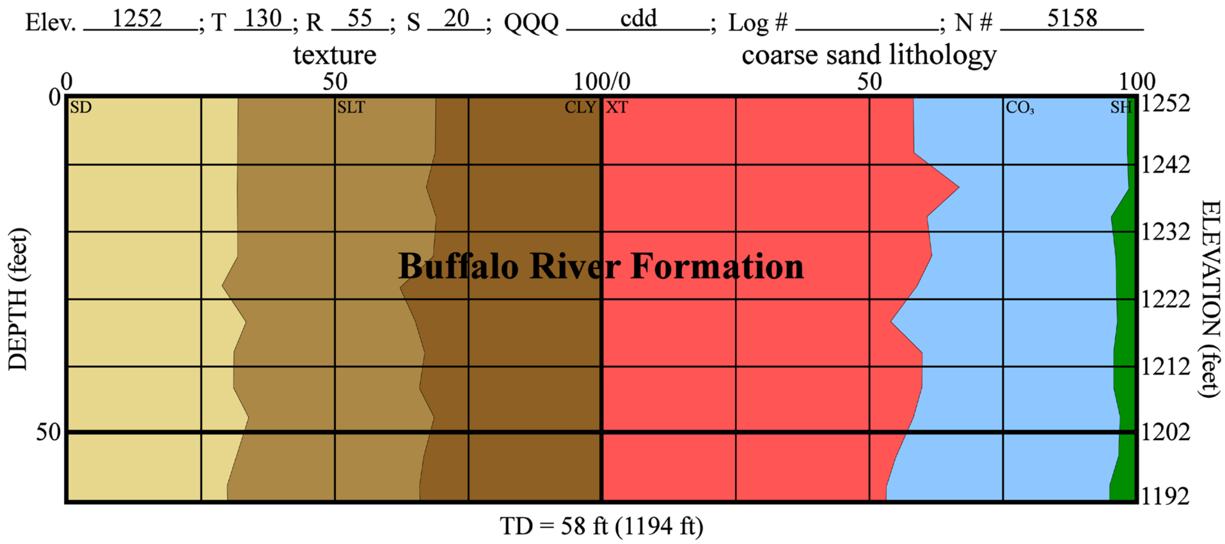
Surf = 1163 feet

QQQ	N	T	R	S	ELEV	DEPTH	SD	SLT	CLY	XT	CO_3	SH	WHO
cdd	5157	130	54	15	1155	8	34	31	35	75	24	1	Weathered
cdd	5157	130	54	15	1150	13	32	32	36	67	32	1	Buf Riv
cdd	5157	130	54	15	1145	18	30	38	32	69	29	2	Buf Riv
cdd	5157	130	54	15	1140	23	32	35	33	67	31	2	Buf Riv
cdd	5157	130	54	15	1135	28	33	35	32	64	35	1	Buf Riv
cdd	5157	130	54	15	1130	33	36	33	31	66	31	3	Buf Riv
cdd	5157	130	54	15	1125	38	35	33	32	65	32	3	Buf Riv
cdd	5157	130	54	15	1120	43	35	36	29	66	32	2	Buf Riv
cdd	5157	130	54	15	1115	48	34	36	30	71	24	5	O' Marcoux
cdd	5157	130	54	15	1110	53	35	33	32	77	23	0	O' Marcoux
cdd	5157	130	54	15	1105	58	34	34	32	76	22	2	O' Marcoux
cdd	5157	130	54	15	1100	63	33	34	33	74	22	4	O' Marcoux
QQQ	N	T	R	S	ELEV	DEPTH	SD	SLT	CLY	XT	CO_3	SH	WHO

Part (b)

Section description of NDGS borehole N-5157 showing (a) Graphical depiction of the borehole textural and coarse-sand data and interpreted stratigraphic units present; (b) the textural and coarse-sand data shown on part (a).

T. 130 N., R. 55 W., sec. 20 cdd
Reference Section: Buffalo River Formation
North Dakota Geological Survey; Power Auger Boring (N-5158)
Sargent County, North Dakota
Elevation 1252 feet
Section Description by K. L. Harris



Part (a)

Surf = 1252 feet

QQQ	N	T	R	S	ELEV	DEPTH	SD	SLT	CLY	XT	CO_3	SH	WHO
cdd	5158	130	55	20	1244	8	32	37	31	63	35	2	Weathered
cdd	5158	130	55	20	1239	13	32	35	33	67	31	2	Buf Riv
cdd	5158	130	55	20	1234	18	32	37	31	61	34	5	Buf Riv
cdd	5158	130	55	20	1229	23	32	36	32	62	35	3	Buf Riv
cdd	5158	130	55	20	1224	28	29	33	38	59	38	3	Buf Riv
cdd	5158	130	55	20	1219	33	33	32	35	54	43	3	Buf Riv
cdd	5158	130	55	20	1214	38	31	36	33	60	36	4	Buf Riv
cdd	5158	130	55	20	1209	43	31	35	34	60	36	4	Buf Riv
cdd	5158	130	55	20	1204	48	34	34	32	58	39	3	Buf Riv
cdd	5158	130	55	20	1199	53	32	35	33	55	42	3	Buf Riv
cdd	5158	130	55	20	1194	58	30	36	34	53	42	5	Buf Riv
QQQ	N	T	R	S	ELEV	DEPTH	SD	SLT	CLY	XT	CO_3	SH	WHO

Part (b)

Section description of NDGS borehole N-5158 showing (a) Graphical depiction of the borehole textural and coarse-sand data and interpreted stratigraphic units present; (b) the textural and coarse-sand data shown on part (a).

T. 131 N., R. 47 W., sec. 35 aaaaab
Type Section: Otter Tail Formation, Hawley Member
Type Section: Otter Tail Formation, New York Mills Member
Minnesota Geological Survey Rotasonic Core (N-6220, MGS-247580, RVR-3)
Wilkin County, Minnesota
Surface elevation = 972 feet
Described by K. L. Harris (MGS), Mark Luther (NDGS) and Robert Biek (NDGS)

NOTE: This core was split; splits are stored in the MN DNR Core Library at Hibbing, MN and in the NDGS Core and Sample Library at Grand Forks, ND.

Depth	Elevation	Description
		HOLOCENE
Road Fill		
0.0-3.5	972-968.5	Loam; silty-clayey; black; ROAD FILL
3.5-5.5	968.5-966.5	Loam; silty-clayey; mottled black and olive brown; ROAD FILL
		PLEISTOCENE
Goose River Formation, Dahlen Member		
5.5-9	966.5-963	Pebble-loam; clayey; mottled olive gray (5Y 3/2) and dark olive gray (5Y 3/2); limestone, igneous-metamorphic, and shale rocks present; calcareous; GLACIAL SEDIMENT
9-11	963-961	Pebble-loam; clayey; dark olive gray (5Y 3/2); limestone, igneous-metamorphic, and shale rocks present; very slightly pebbly; calcareous; GLACIAL SEDIMENT
11-25	961-947	NO RECOVERY
Goose River Formation, Heiberg Member		
25-29	947-943	Pebble-loam; dark olive gray (5Y 3/2); massive; slightly pebbly; GLACIAL SEDIMENT
29-45.5	943-926.5	Clay; very dark gray (5Y 3/1); massive; slightly pebbly zones; laminated zones; 39-40 feet, pebbly zone; LAKE SEDIMENT
45.5-61	926.5-911	Pebble-loam; very dark gray (5Y 3/1); massive; limestone and igneous-metamorphic rocks present; calcareous; GLACIAL SEDIMENT
Otter Tail River Formation, Hawley Member		
61-66.5	911-905.5	Pebble-loam; olive gray (5Y 4/2); massive; limestone and igneous-metamorphic rocks present; calcareous; GLACIAL SEDIMENT
66.5-67	905.5-905	Sand and Gravel; pea gravel; FLUVIAL SEDIMENT
67-69.5	905-902.5	Pebble-loam; dark olive gray (5Y 3/2); massive; limestone and igneous-metamorphic rocks present; calcareous; GLACIAL SEDIMENT
69.5-70.5	902.5-901.5	Pebble-loam; dark olive gray (5Y 3/2); mottled; weakly bedded; limestone and igneous-metamorphic rocks present; calcareous; GLACIAL SEDIMENT

70.5-71	901.5-901	Pebble-loam; dark olive gray (5Y 3/2); massive; limestone and igneous-metamorphic rocks present; calcareous; GLACIAL SEDIMENT
71-71.5	901-900.5	Sand; medium-grained; well sorted; weakly cemented at base; FLUVIAL SEDIMENT
71.5-84	900.5-888	Pebble-loam; dark olive gray (5Y 3/2); massive; limestone and igneous-metamorphic rocks present; calcareous; GLACIAL SEDIMENT
84-90	888-882	Pebbly-loam; dark olive gray (5Y 3/2); massive; limestone, igneous-metamorphic, and shale rocks present; abundant shale 89-90 feet; calcareous; GLACIAL SEDIMENT
90-91	882-881	Silt; clay laminae; grayish brown (2.5Y 5/2); LAKE SEDIMENT.
91-96	881-876	Pebble-loam; very dark gray (5Y 3/1); massive; limestone and igneous-metamorphic rocks present; calcareous; GLACIAL SEDIMENT
96-101	876-871	Pebble-loam; olive gray (5Y 4/2); massive; limestone and igneous-metamorphic rocks present; calcareous; GLACIAL SEDIMENT
101-106	871-866	Pebble-loam; olive gray (5Y 5/2); massive; limestone and igneous-metamorphic rocks present; calcareous; GLACIAL SEDIMENT
106-108	866-864	Sand; coarse-grained; poorly sorted; FLUVIAL SEDIMENT

Otter Tail River Formation, New York Mills Member

108-108.5	864-863.5	Pebble-loam; sandy; very dark gray (5Y 3/1); massive, limestone, igneous and metamorphic rocks present; calcareous; GLACIAL SEDIMENT
108.5-115	863.5-857	Pebble-loam; sandy; olive gray (5Y 4/2); limestone, igneous and metamorphic rocks present; thin sand at 110.5 feet; calcareous; GLACIAL SEDIMENT
115-115.5	857-856.5	Silt, sandy and sand silty; FLUVIAL SEDIMENT
115.5-118.5	856.5-853.5	Pebble-loam; sandy; very dark gray; massive; limestone, igneous and metamorphic rocks present; calcareous; GLACIAL SEDIMENT
118.5-121	853.5-851	Sand; fine- to medium-grained; well sorted; FLUVIAL SEDIMENT
121-122	851-850	Pebble-loam; very dark gray (5Y 3/1); massive; limestone, igneous and metamorphic rocks present; calcareous; GLACIAL SEDIMENT
122-125	850-847	Pebble-loam; sandy; very dark gray (5Y 3/1); massive; limestone, igneous and metamorphic rocks present; calcareous; GLACIAL SEDIMENT
125-136	847-836	Sand; medium- to coarse-grained; dark gray (5Y 4/1); FLUVIAL SEDIMENT
136-137	836-835	Pebble-loam; sandy; dark gray (5Y 4/1); limestone, igneous and metamorphic rocks present; calcareous; GLACIAL SEDIMENT
137-143	835-829	Sand; coarse-grained; light olive brown (2.5Y 5/3); FLUVIAL SEDIMENT

CRETACEOUS

Pierre Formation

143-201	829-771	Clay; laminated with thin, discontinuous silt beds; black (2.5Y 2/0); silt beds contain fossil fragments, fish scales, pyrite crystals and pebbles, mica flakes, and calcite needles; sulfur odor; fewer laminations with depth; CRETACEOUS SHALE

201-205	771-767	Clay; laminated with silt beds; black (2.5Y 2/0); silt beds are up to 1-foot thick and contain fossil fragments, fish scales, pyrite crystals and pebbles, mica flakes, and calcite needles; sulfur odor; CRETACEOUS SHALE
205-208	767-764	NO RECOVERY; thought to be Cretaceous sand.
208	764	Total Depth

T. 131 N., R. 56 W., sec. 21 ccc
Reference Section: Gardar Formation
North Dakota Geological Survey, Power Auger Boring (N-5164)
Sargent County, North Dakota
Surface elevation = 1312 Feet
Described by K. Harris (NDGS)

Depth	Elevation	Description
		PLEISTOCENE
Gardar Formation		
0-8	1312-1304	Pebble loam; light yellowish brown (2.5Y 6/4) mottled (2.5Y 6/2); unsorted; massive; friable; calcareous; oxidized; iron stains; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
8-18	1304-1294	Pebble loam; light olive brown (2.5Y 5/4); unsorted; massive; friable; calcareous; oxidized; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; pebble-sized stones; ocher inclusions; GLACIAL SEDIMENT
18-23	1294-1289	Pebble loam; clayey; light brownish gray (2.5Y 6/2); unsorted; massive; friable; calcareous; oxidized; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; pebble-sized stones; abundant gypsum; GLACIAL SEDIMENT
23-33	1289-1279	Pebble loam; clayey; light olive brown (2.5Y 5/4) to light brownish gray (2.5Y 6/2) mottled; unsorted; massive; friable; calcareous; oxidized; iron stains; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
33-38	1279-1274	Pebble loam; clayey; dark grayish brown (2.5Y 4/2); unsorted; massive; friable; calcareous; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
38-48	1274-1264	Pebble loam; clayey; pale yellow (2.5Y 7/4); unsorted; massive; friable; calcareous; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; very pebbly; lignite fragments and organic debris; GLACIAL SEDIMENT
48-53	1264-1259	Pebble loam; clayey; grayish brown (2.5Y 5/2) to very dark gray (10YR 3/1) mottled; unsorted; massive; friable; calcareous; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; pebble-sized stones; lignite fragments; GLACIAL SEDIMENT
53-58	1259-1254	Pebble loam; clayey; very dark gray (10YR 3/1); unsorted; massive; friable; calcareous; CLASTS: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
58	1254	Total Depth

T. 132 N., R. 35 W., sec. 22 bbdabb
Principal Reference Section: Browerville Formation
Minnesota Geological Survey Rotasonic Core (N-6602, MGS-251485, OTT-2)
Todd County, Minnesota
Surface elevation = 1416 feet
Described by K. L. Harris

NOTE: This core is stored in the MN DNR Core Library in Hibbing, MN

Depth	Elevation	Description
		HOLOCENE
Soil Zone		
0-1.5	1416-1414.5	Loam; silty; pebbly; very dark grayish brown (2.5Y 3/2); unsorted; poorly consolidated; noncalcareous; massive; *CLASTS:* angular to rounded; igneous, metamorphic and carbonate rock fragments; pebble to cobble sized; SOIL ZONE
		PLEISTOCENE
Crow Wing River Formation, Sebeka Member		
1.5-5.0	1414.5-1411	Pebble loam; silty, yellowish brown (10YR 5/6); unsorted; poorly consolidated; noncalcareous; massive; iron oxide stains; *CLASTS:* angular to rounded; igneous, metamorphic and carbonate rock fragments; pebble to cobble sized; WEATHERED GLACIAL SEDIMENT
5.0-14.0	1411-1402	Pebble loam; sandy, clayey; olive brown (2.5Y 4/4); unsorted; consolidated; calcareous; massive; *CLASTS:* angular to rounded; igneous, metamorphic and carbonate rock fragments; pebble to cobble sized; GLACIAL SEDIMENT
14-14.5	1402-1401.5	Sand; coarse-grained; poorly sorted; unconsolidated; calcareous; unbedded; *CLASTS:* igneous, metamorphic and carbonate rock fragments; RIVER SEDIMENT
Browerville Formation		
14.5-22	1401.5-1394	Pebble loam; dark olive brown (2.5Y 3/3); unsorted; consolidated; calcareous; massive; *CLASTS:* angular to rounded igneous, metamorphic and carbonate rock fragments; pea to pebble size; GLACIAL SEDIMENT
22-27	1394-1389	Pebble loam; dark olive brown (2.5Y 3/3); unsorted; consolidated; calcareous; massive; grungy; *CLASTS:* angular to rounded igneous, metamorphic and carbonate rock fragments; some red rock fragments; pea to pebble size; GLACIAL SEDIMENT
27-49.5	1389-1366.5	Sand; coarse-grained; poorly sorted; unconsolidated; calcareous; unbedded; *CLASTS:* igneous, metamorphic and carbonate rock fragments; RIVER SEDIMENT
49.5-53.5	1366.5-1362.5	NO RECOVERY
Older Till, Old Marcoux		
53.5-58	1362.5-1358	Pebble loam; very dark grayish brown (2.5Y 3/2); unsorted; consolidated; calcareous; massive; *CLASTS:* angular to rounded igneous, metamorphic and carbonate rock fragments; some red rock fragments; pea to gravel size; GLACIAL SEDIMENT

58-65	1358-1351	NO RECOVERY
65-68	1351-1348	Pebble loam; very dark grayish brown (2.5Y 3/2); unsorted; consolidated; calcareous; massive; *CLASTS:* angular to rounded igneous, metamorphic and carbonate rock fragments; some red rock fragments; pea to cobble size; GLACIAL SEDIMENT
68-75	1348-1341	NO RECOVERY
75-80.5	1341-1335.5	Pebble loam; very dark grayish brown (2.5Y 3/2) to very dark gray (10YR 3/1); unsorted; consolidated; calcareous; massive; *CLASTS:* angular to rounded igneous, metamorphic and carbonate rock fragments; some red rock fragments; pea to cobble size; GLACIAL SEDIMENT
80.5-80.8	1335.5-1335.3	Sand; fine- to medium-grained; dark grayish brown (2.5Y 4/2); well sorted; unconsolidated; calcareous; unbedded; *CLASTS:* igneous, metamorphic and carbonate rock fragments; RIVER SEDIMENT
80.8-81	1335.3-1335	Pebble loam; silty; very dark gray (10YR 3/1); unsorted; consolidated; calcareous; massive; *CLASTS:* angular to rounded igneous, metamorphic and carbonate rock fragments; some red rock fragments; pea to cobble size; GLACIAL SEDIMENT
81-81.3	1335-1334.8	Sand; fine- to medium-grained; dark grayish brown (2.5Y 4/2); well sorted; unconsolidated; calcareous; unbedded; *CLASTS:* igneous, metamorphic and carbonate rock fragments; RIVER SEDIMENT
81.3-82.3	1334.8-1333.7	Pebble loam; very dark gray (10YR 3/1); unsorted; consolidated; calcareous; massive; *CLASTS:* angular to rounded igneous, metamorphic and carbonate rock fragments; some red rock fragments; pea to cobble size; GLACIAL SEDIMENT
82.3-82.8	1333.7-1333.3	Sand; fine- to medium-grained; dark grayish brown (2.5Y 4/2); well sorted; unconsolidated; calcareous; unbedded; *CLASTS:* igneous, metamorphic and carbonate rock fragments; RIVER SEDIMENT
82.8-84	1333.3-1332	Pebble loam; very dark gray (10YR 3/1); unsorted; consolidated; calcareous; massive; *CLASTS:* angular to rounded igneous, metamorphic and carbonate rock fragments; some red rock fragments; pea to gravel size; GLACIAL SEDIMENT
84-84.5	1332-1331.5	Sand; fine- to medium-grained; dark grayish brown (2.5Y 4/2); well sorted; unconsolidated; calcareous; unbedded; *CLASTS:* igneous, metamorphic and carbonate rock fragments; RIVER SEDIMENT
84.5-85	1331.5-1331	Pebble loam; very dark gray (10YR 3/1); unsorted; consolidated; calcareous; massive; *CLASTS:* angular to rounded igneous, metamorphic and carbonate rock fragments; some red rock fragments; pea to gravel size; GLACIAL SEDIMENT
85-85.5	1331-1330.5	Sand; fine- to medium-grained; dark grayish brown (2.5Y 4/2); well sorted; unconsolidated; calcareous; unbedded; *CLASTS:* igneous, metamorphic and carbonate rock fragments; RIVER SEDIMENT
85.5-88	1330.5-1328	Pebble loam; very dark gray (10YR 3/1); unsorted; consolidated; calcareous; massive; *CLASTS:* angular to rounded igneous, metamorphic and carbonate rock fragments; some red rock fragments; pea to gravel size; GLACIAL SEDIMENT
88-88.5	1328-1327.5	Sand and gravel; medium-grained; dark grayish brown (2.5Y 4/2); unconsolidated; calcareous; unbedded; *CLASTS:* igneous, metamorphic and carbonate rock fragments; RIVER SEDIMENT

Thrust fault interpreted at 88.5 feet

Browerville Formation

88.5-89.5	1327.5-1326.5	Pebble loam; silty; very dark gray (10YR 3/1); unsorted; consolidated; calcareous; massive; *CLASTS:* angular to rounded igneous, metamorphic and carbonate rock fragments; some red rock fragments; pea to gravel size; GLACIAL SEDIMENT
89.5-115	1326.5-1301	Pebble loam; very dark gray (10YR 3/1); unsorted; consolidated; calcareous; massive; *CLASTS:* angular to rounded igneous, metamorphic and carbonate rock fragments; some red rock fragments; pea to gravel size; gravel zone at 95.5 feet; GLACIAL SEDIMENT
115-115.5	1301-1300.5	Sand; fine- to medium-grained; grayish brown (2.5Y 5/2); well sorted; unconsolidated; calcareous; unbedded; *CLASTS:* igneous, metamorphic and carbonate rock fragments; RIVER SEDIMENT
115.5-128	1300.5-1288	Pebble loam; very dark gray (10YR 3/1); unsorted; consolidated; calcareous; massive; *CLASTS:* angular to rounded igneous, metamorphic and carbonate rock fragments; some red rock fragments; shale fragment at 120; pea to gravel size; cobble zone at 128 feet; GLACIAL SEDIMENT
128-128.5	1288-1287.5	SLUFF; DRILLING DEBRIS
128.5-131.5	1287.5-1284.5	Pebble loam; very dark gray (10YR 3/1); unsorted; consolidated; calcareous; massive; *CLASTS:* angular to rounded; igneous, metamorphic and carbonate rock fragments; some red rock fragments; shale fragment at 131 feet; pea to gravel size; GLACIAL SEDIMENT
131.5-136.5	1284.5-1279.5	Pebble loam; very dark gray (10YR 3/1); unsorted; consolidated; calcareous; massive; *CLASTS:* angular to rounded; igneous, metamorphic and carbonate rock fragments; some red rock fragments; pea to gravel size; GLACIAL SEDIMENT
136.5-136.8	1279.5-1279.3	Silt; dark grayish brown (2.5Y 4/2); well sorted; unconsolidated; calcareous; weakly laminated; RIVER SEDIMENT
136.8-142	1279.3-1274	Pebble loam; very dark gray (10YR 3/1); unsorted; consolidated; calcareous; massive; iron oxide stains; *CLASTS:* angular to rounded; igneous, metamorphic and carbonate rock fragments; some red rock fragments; pea to gravel size; silt bed at 138 feet; WOOD at 139 feet; GLACIAL SEDIMENT
142-150.5	1274-1265.5	Pebble loam; very dark gray (10YR 3/1); unsorted; consolidated; calcareous; massive; *CLASTS:* angular to rounded; igneous, metamorphic and carbonate rock fragments; pea to gravel size; cobbles at 145 feet; GLACIAL SEDIMENT
150.5-156	1265.5-1260	Pebble loam; silty; very dark gray (10YR 3/1); unsorted; calcareous; friable; prismatic structure; *CLASTS:* angular to rounded; igneous, metamorphic and carbonate rock fragments; pea to gravel size; GLACIAL SEDIMENT
156-161	1260-1255	Pebble loam; very dark gray (10YR 3/1); unsorted; consolidated; calcareous; massive; *CLASTS:* angular to rounded; igneous, metamorphic and carbonate rock fragments; pea to gravel size; GLACIAL SEDIMENT
161-163	1255-1253	Sand; fine- to medium-grained; dark grayish brown (2.5Y 4/2); well sorted; unconsolidated; calcareous; unbedded; *CLASTS:* igneous, metamorphic and carbonate rock fragments; interbedded with pebble loam; very dark grayish brown (2.5 3/2) at 161.5 feet; RIVER SEDIMENT
163-165	1253-1251	Sand; medium- to coarse-grained; dark grayish brown (2.5Y 4/2); moderately to well sorted; unconsolidated; calcareous; unbedded; *CLASTS:* igneous, metamorphic and carbonate rock fragments; RIVER SEDIMENT

165-188	1251-1228	Pebble loam; very dark gray (10YR 3/1); unsorted; consolidated; calcareous; massive; *CLASTS:* angular to rounded; igneous, metamorphic and carbonate rock fragments; pea to gravel size; shale fragment at 186 feet; GLACIAL SEDIMENT
188-188.5	1228-1227.5	Sand; medium- to coarse-grained; most of it was washed out of the core; RIVER SEDIMENT
188.5-190	1227.5-1226	Pebble loam; very dark gray (10YR 3/1); unsorted; consolidated; calcareous; massive; *CLASTS:* angular to rounded; igneous, metamorphic and carbonate rock fragments; pea to gravel size; GLACIAL SEDIMENT
190-191	1226-1225	SLUFF; DRILLING DEBRIS.
191-194	1225-1222	Pebble loam; very dark gray (10YR 3/1); unsorted; consolidated; calcareous; massive; *CLASTS:* angular to rounded; igneous, metamorphic and carbonate rock fragments; pea to gravel size; GLACIAL SEDIMENT
194-194.3	1222-1221.8	Sand; medium-grained; grayish brown (2.5 5/2); very thin, most of it was washed out of the core; RIVER SEDIMENT
194.3-201	1221.8-1215	Pebble loam; very dark gray (10YR 3/1); unsorted; consolidated; calcareous; massive; *CLASTS:* angular to rounded; igneous, metamorphic and carbonate rock fragments; pea to gravel size; GLACIAL SEDIMENT
201	1215	Total Depth

T. 132 N., R. 49 W., sec. 9 acc
Reference Section: Argusville Formation
North Dakota State Highway Department
Interstate 29, Structure 105, Composite of Borings # 1, 2, 3, Mooreton Interchange
Mooreton, Richland County, North Dakota
Surface elevation = 966 feet
Described by B. Michael Arndt (NDGS)

Depth	Elevation	Description
		HOLOCENE
Sherack Formation, Offshore facies (Lake Agassiz, Emerson Phase)		
0-10	966-956	Silt, sand, clay; dark brown to black; dispersed organics; sand pebbles; oxidized; mottled; MODIFIED OFFSHORE SEDIMENT
Sherack Formation; Offshore facies (Lake Agassiz, Emerson Phase)		
10-45	956-921	Clay, silt; oxidized in upper parts; gray; laminated to unbedded; mostly lean clay; OFFSHORE SEDIMENT
		PLEISTOCENE
Argusville Formation (Lake Agassiz, Cass Phase)		
45-55	921-911	Silt, clay; unbedded; parallel clay stringers (marbled); gritty appearance; OFFSHORE SEDIMENT
Goose River Formation, Dahlen Member		
55-100	911-866	Pebble-loam; silty; clayey inclusions near base; GLACIAL SEDIMENT
Unit C; Lake Agassiz Sediment		
100-115	866-851	Clay; silty; laminated; clay stringers; silt balls; soft CO_3 nodules; LAKE SEDIMENT
James River Formation, Villard Member		
115-138	851-828	Pebble-loam; sandy; sand and gravel in part; silty in part; GLACIAL SEDIMENT
138	828	Total Depth

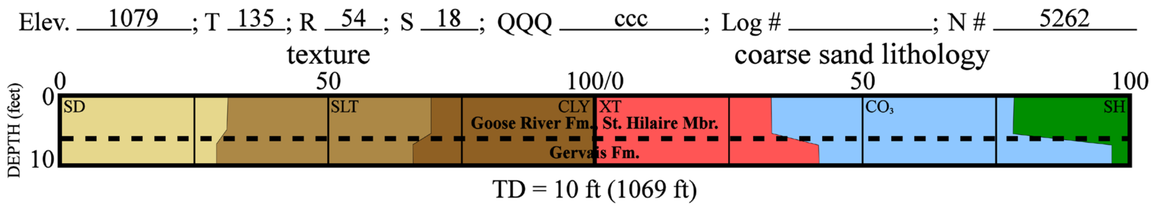
T. 133 N., R. 56 W., sec. 5 aab
Reference Section: Goose River Formation, Dahlen Member
North Dakota Geological Survey, Power Auger Boring (N-5172)
Ransom County, North Dakota
Surface elevation = 1260 Feet
Described by K. Harris

Depth	Elevation	Description
		PLEISTOCENE
Goose River Formation, Dahlen Member		
0-8	1260-1252	Pebble loam; light yellowish brown (2.5Y 6/4) mottled (2.5Y 6/2); unsorted; massive; friable; calcareous; oxidized; iron stains; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
8-18	1252-1242	Pebble loam; light olive brown (2.5Y 5/4); unsorted; massive; friable; calcareous; oxidized; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; pebble-sized stones; ocher inclusions; GLACIAL SEDIMENT
18-23	1242-1237	Pebble loam; clayey; light brownish gray (2.5Y 6/2); unsorted; massive; friable; calcareous; oxidized; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; pebble-sized stones; abundant gypsum; GLACIAL SEDIMENT
23-33	1237-1227	Pebble loam; clayey; light olive brown (2.5Y 5/4) to light brownish gray (2.5Y 6/2) mottled; unsorted; massive; friable; calcareous; oxidized; iron stains; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
33-38	1227-1222	Pebble loam; clayey; dark grayish brown (2.5Y 4/2); unsorted; massive; friable; calcareous; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
38-48	1222-1212	Pebble loam; clayey; pale yellow (2.5Y 7/4); unsorted; massive; friable; calcareous; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; very pebbly; lignite fragments and organic debris; GLACIAL SEDIMENT
48-53	1212-1207	Pebble loam; clayey; grayish brown (2.5Y 5/2) to very dark gray (10YR 3/1) mottled; unsorted; massive; friable; calcareous; *CLASTS*: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; pebble-sized stones; lignite fragments; GLACIAL SEDIMENT
53-58	1207-1202	Pebble loam; clayey; very dark gray (10YR 3/1); unsorted; massive; friable; calcareous; CLASTS: angular to rounded; moderate igneous and metamorphic, abundant carbonate, and abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT

Gardar Formation

58-63	1202-1197	Pebble loam; clayey; very dark gray (10YR 3/1); limestone and igneous-metamorphic rocks present; calcareous; abundant shale rock fragments; pebble-sized stones; GLACIAL SEDIMENT
63	1197	Total Depth

T. 135 N., R. 54 W., sec. 18 ccc
Gervais Formation
North Dakota Geological Survey, Power Auger Boring (N-5262)
Ransom County, North Dakota
Surface elevation = 1079 Feet
Described by K. Harris



Part (a)

Surf = 1079 feet

QQQ	N	T	R	S	ELEV	DEPTH	SD	SLT	CLY	XT	CO_3	SH	WHO
ccc	5262	135	54	18	1073	6	31	38	31	33	45	22	St Hilaire
ccc	5262	135	54	18	1069	10	29	37	34	42	55	3	Gervais
QQQ	N	T	R	S	ELEV	DEPTH	SD	SLT	CLY	XT	CO_3	SH	WHO

Part (b)

Section description of NDGS borehole N-5262 showing (a) Graphical depiction of the borehole textural and coarse-sand data and interpreted stratigraphic units present; (b) the textural and coarse-sand data shown on part (a).

T. 137 N., R. 47 W., sec. 10 ddddda
Principal Reference Section: Gardar Formation
Minnesota Geological Survey Rotasonic Core (N-6219, MGS-247579, RRV-2)
Clay County, Minnesota
Surface elevation = 929 feet
Described by K. L. Harris (MGS), Mark Luther (NDGS), and Robert Biek, (NDGS)

NOTE: This core is stored in the MN DNR Core Library at Hibbing, MN. A split of the core is stored in the NDGS Core and Sample Library at Grand Forks, ND.

Depth	Elevation	Description
		HOLOCENE
Soil Zone		
0-0.5	929-928.5	Loam; black; plow zone; Soil
Sherack Formation, Offshore facies (Lake Agassiz, Emerson Phase)		
0.5-11	928.5-918	Loam; clay; dark grayish brown (2.5Y 4/2); thin, obscure, silt laminae; bioturbated; OFFSHORE SEDIMENT
11-14.5	918-914	Clay; dark olive gray (5Y 3/2); thin silt laminae; slightly bioturbated; OFFSHORE SEDIMENT
		PLEISTOCENE
Brenna Formation (Lake Agassiz, Lockhart Phase)		
14.5-18	914-911	Clay; dark olive brown (5Y 3/2); massive to weakly laminated; plastic; OFFSHORE SEDIMENT
18-33	911-896	Clay; dark olive brown (5Y 3/2); massive; plastic; thin silt laminae in some zones; blocky failure to stress; pebble at 33 feet; OFFSHORE SEDIMENT
33-53.5	896-875	Clay; dark olive brown (5Y 3/2); massive, plastic; weakly bedded in zones; OFFSHORE SEDIMENT
53.5-65	875-864	Clay; dark olive brown (5Y 3/2); massive; plastic; weak laminae in zones; occasional small pebbles; OFFSHORE SEDIMENT
65-66.5	864-862.5	Clay; olive gray (wet - 5Y 4/2, dry - 5Y 5/2); contorted silt laminae; calcareous; OFFSHORE SEDIMENT
66.5-72	862.5-857	Clay; dark olive gray (5Y 3/2); massive; plastic; weak laminae in zones; occasional pebbles; OFFSHORE SEDIMENT
72-73.5	857-855.5	Clay and pebble-clay; dark olive gray (5Y 3/2); limestone and igneous-metamorphic rocks present; OFFSHORE SEDIMENT and MODIFIED GLACIAL SEDIMENT
73.5-75	855.5-854	Sand and Gravel; medium- to coarse-grained; charcoal flakes; thin beds of pebble-loam; dark olive gray (5Y 3/2); RIVER SEDIMENT
75-77	854-852	NO RECOVERY
Goose River Formation, Heiberg Member		
77-80	852-849	Pebble-loam; clayey; dark olive brown (5Y 3/2); limestone and igneous-metamorphic rocks present; very pebbly; GLACIAL SEDIMENT

80-86	849-843	Pebble-loam; clayey; dark olive brown (5Y 3/2); limestone and igneous-metamorphic rocks present; calcareous; cobbles; very stony; GLACIAL SEDIMENT
86-88	843-841	Silt; with clay laminae; dark olive brown (5Y 3/2); calcareous; OFFSHORE SEDIMENT
88-89	841-840	Pebble-loam; clayey; dark olive brown (5Y 3/2); calcareous; stony; GLACIAL SEDIMENT
89-90	840-839	Silt; sandy; poorly sorted; RIVER SEDIMENT
90-92	839-837	Sand; silty-clayey, poorly sorted; layers of charcoal at 90.5 feet and above pebble-loam at 92 feet; RIVER SEDIMENT
92-93	837-836	Silt; fine-grained sand laminae; dark olive brown (5Y 3/2); RIVER SEDIMENT
93-95	836-834	Pebble-loam; clayey; very dark gray (5Y 3/1); limestone and igneous-metamorphic rocks present; calcareous; very pebbly; GLACIAL SEDIMENT

Otter Tail River Formation, New York Mills Member

95-102	834-827	Pebble-loam; olive gray (5Y 5/2); igneous-metamorphic and limestone rocks present; calcareous; GLACIAL SEDIMENT

James River Formation, Villard Member

102-103.5	827-825.5	Pebble-loam; dark olive gray (5Y 3/2); limestone and igneous-metamorphic rocks present; calcareous; GLACIAL SEDIMENT
103.5-105.5	825.5-823.5	Pebble-loam; olive gray (5Y 4/2); limestone and igneous-metamorphic rocks present; calcareous; GLACIAL SEDIMENT
105.5-109	823.5-820	Pebble-loam; dark olive gray (5Y 3/2); limestone and igneous-metamorphic rocks present; calcareous; GLACIAL SEDIMENT
109-112	820-817	Sand; medium-grained; olive gray (5Y 4/2); well sorted; RIVER SEDIMENT
112-112.5	817-816.5	Pebble-loam; dark gray (5Y 4/1); limestone and igneous-metamorphic rocks present; calcareous; GLACIAL SEDIMENT

Gardar Formation

112.5-123.5	816.5-805.5	Pebble-loam; very dark gray (5Y 3/1); limestone and igneous-metamorphic rocks present; calcareous; GLACIAL SEDIMENT

PRECAMBRIAN

123.5-126	805.5-803	Metamorphosed basalt; epidote and quartz vein filling; green; UNDERBURDEN
126	803	Total Depth

T. 138 N., R. 37 W., sec. 35 abbccd
Reference Section: Crow Wing River Formation, Sebeka Member
Minnesota Geological Survey Rotasonic Core (N-6601, MGS-251484, OTT-1)
Becker County, Minnesota
Surface elevation = 1527 feet
Core described by K. L. Harris

NOTE: This Rotasonic core is stored in MN DNR Core Library in Hibbing, MN.

Depth	Elevation	Description
		HOLOCENE
Soil Zone		
0-3	1527-1524	Loam; sandy; pebbly; olive brown (2.5Y 4/3); unsorted; poorly to moderately consolidated; noncalcareous; massive; iron oxide stains; *CLASTS:* angular to rounded; igneous and metamorphic rock fragments; pebble size; SOIL ZONE
		PLEISTOCENE
Crow Wing River Formation, Sebeka Member		
3-6	1524-1521	Pebble loam; sandy; light olive brown (2.5Y 5/3); unsorted; moderately consolidated; calcareous; massive; *CLASTS:* angular to rounded; igneous, metamorphic and carbonate rock fragments; pebble size; GLACIAL SEDIMENT
6-38	1521-1489	Pebble loam; light olive brown (2.5Y 5/3); unsorted; consolidated; calcareous; massive; *CLASTS:* angular to rounded; igneous, metamorphic and carbonate rock fragments; pebble size; GLACIAL SEDIMENT
38-43.5	1489-1483.5	Pebble loam; light olive brown (2.5Y 5/3); unsorted; consolidated; calcareous; massive; iron oxide stains on joint at 40 feet; *CLASTS:* angular to rounded; igneous, metamorphic and carbonate rock fragments; pebble size; sharp contact with underlying sand; GLACIAL SEDIMENT
43.5-58	1483.5-1469	Sand; fine-grained; light olive brown (2.5Y 5/3); well sorted; unconsolidated; calcareous; unbedded; *CLASTS:* igneous, metamorphic and carbonate rock fragments; LAKE OR RIVER SEDIMENT
58-59	1469-1468	Sand; silty; fine-grained; light yellowish brown (2.5Y 6/3); well sorted; unconsolidated; calcareous; unbedded; *CLASTS:* igneous, metamorphic and carbonate rock fragments; LAKE OR RIVER SEDIMENT
59-60.5	1468-1466.5	Sand; fine-grained; light yellowish brown (2.5Y 6/3); well sorted; unconsolidated; calcareous; unbedded; *CLASTS:* igneous, metamorphic and carbonate rock fragments; LAKE OR RIVER SEDIMENT
60.5-63.5	1466.5-1463.5	Sand; medium-grained; light yellowish brown (2.5Y 6/3); well sorted; unconsolidated; calcareous; unbedded; *CLASTS:* igneous, metamorphic and carbonate rock fragments; some pea size; LAKE OR RIVER SEDIMENT
63.5-73.5	1463.5-1453.5	Silt and sand; fine-grained; light yellowish brown (2.5Y 6/3) to dark gray (10YR 4/1); well sorted; consolidated; calcareous; weakly laminated; clayey at 73 feet; gradational contact with underlying sand; LAKE OR RIVER SEDIMENT

73.5-76.5	1453.5-1450.5	Sand; medium- to fine-grained; dark gray (10YR 4/1); moderately to well sorted; unconsolidated; calcareous; unbedded; *CLASTS:* moderately to well rounded; igneous, metamorphic and carbonate rock fragments; pea to pebbles size; RIVER SEDIMENT
76.5-78	1450.5-1499	Sand; fine- to medium-grained; light olive brown (2.5Y 5/3); moderately to well sorted; unconsolidated; calcareous; unbedded; *CLASTS:* moderately to well rounded; igneous, metamorphic and carbonate rock fragments; pea to pebbles size; RIVER SEDIMENT
78-95	1499-1432	Sand; medium- to coarse-grained; light olive brown (2.5Y 5/4); moderately to poorly sorted; unconsolidated; calcareous; silt beds in zones; iron oxide stains at 91.5 feet; *CLASTS:* angular to well rounded; igneous, metamorphic and carbonate rock fragments; pea to gravel size; RIVER SEDIMENT
95-101.5	1432-1425.5	Sand; fine- to medium-grained; light yellowish brown (2.5Y 6/4); moderately to well sorted; unconsolidated; calcareous; unbedded; *CLASTS:* well rounded; fragments of bedded silt; pebble size; LAKE OR RIVER SEDIMENT
101.5-106	1425.5-1421	Sand; medium- to coarse-grained; light olive brown (2.5Y 5/4); moderately to well sorted; unconsolidated; calcareous; unbedded; *CLASTS:* angular to well rounded; igneous, metamorphic and carbonate rock fragments; pea to gravel size; RIVER SEDIMENT
106-111.5	1421-1415.5	Sand; fine- to medium-grained; light olive brown (2.5Y 5/4); moderately sorted; unconsolidated; calcareous; unbedded; *CLASTS:* well rounded; igneous, metamorphic, and carbonate rock fragments and silt fragments; pea to gravel size; RIVER SEDIMENT
111.5-113	1415.5-1414	Sand; medium- to coarse-grained; light olive brown (2.5Y 5/3); moderately to well sorted; unconsolidated; calcareous; unbedded; *CLASTS:* well rounded; igneous, metamorphic, and carbonate rock fragments and silt fragments; pea to gravel size; sharp contact with underlying silt; RIVER SEDIMENT
113-114	1414-1413	Silt; light yellowish brown (2.5Y 5/3); well sorted; moderately well consolidated; calcareous; weakly laminated; LAKE OR RIVER SEDIMENT
114-119	1413-1408	Sand; medium-grained; light olive brown (2.5Y 5/4); moderately to well sorted; unconsolidated; calcareous; unbedded; *CLASTS:* angular to well rounded; igneous, metamorphic, and carbonate rock fragments; RIVER SEDIMENT
119-131	1408-1396	Sand; fine- to medium-grained; light olive brown (2.5Y 5/4); moderately to well sorted; unconsolidated; calcareous; unbedded; *CLASTS:* angular to well rounded; igneous, metamorphic, and carbonate rock fragments; iron oxide stain at 123 feet, probable joint; RIVER SEDIMENT
131-132	1396-1395	Silt; sandy; light yellowish brown (2.5Y 6/3); moderate sorting; consolidated; calcareous; weakly laminated; LAKE OR RIVER SEDIMENT
132-132.5	1395-1394.5	Sand; medium- to coarse-grained; silty; light olive brown (2.5Y 5/4); moderately well sorted; unconsolidated; calcareous; unbedded; *CLASTS:* angular to well rounded; igneous, metamorphic, and carbonate rock fragments; iron oxide stains; possible joint at 132.5 feet; RIVER SEDIMENT

132.5-134	1394.5-1393	Sand; fine- to medium-grained; silty; dirty; light olive brown (2.5Y 5/3); poorly sorted; consolidated; calcareous; SLUFF
134-138	1393-1389	Sand; medium- to coarse-grained; light olive brown (2.5Y 5/4); poorly sorted; unconsolidated; calcareous; unbedded; *CLASTS:* angular to well rounded; igneous, metamorphic, and carbonate rock fragments; red rock fragments; RIVER SEDIMENT
138-141.5	1389-1385.5	Sand; coarse-grained; pebbly; light olive brown (2.5Y 5/4); poorly sorted; unconsolidated; calcareous; unbedded; *CLASTS:* angular to well rounded; igneous, metamorphic, and carbonate rock fragments; red rock fragments; pebble size; sharp contact with underlying silt; RIVER SEDIMENT
141.5-149	1385.5-1378	Silt; clayey; dark gray (10YR 4/1); well sorted; consolidated; calcareous; massive; some obscure beds due to coring; LAKE SEDIMENT
149-152	1378-1375	Sand; silty; pebbly; dirty; light yellowish brown (2.5Y 6/3); unsorted; unconsolidated; calcareous; unbedded; *CLASTS:* angular to well rounded; igneous, metamorphic, and carbonate rock fragments; red rock fragments; pebble size; SLUFF ?.
152-154.5	1375-1372.5	Sand; medium- to coarse-grained; pebbly; light olive brown (2.5Y 5/3); poorly sorted; unconsolidated; calcareous; unbedded; *CLASTS:* angular to well rounded; igneous, metamorphic, and carbonate rock fragments; red rock fragments; pea to pebble size; RIVER SEDIMENT
154.5-155	1372.5-1372	Sand; fine- to medium-grained; silty; pebbly; light olive brown (2.5Y 5/3); poorly sorted; consolidated; calcareous; weakly laminated; *CLASTS:* angular to well rounded; igneous, metamorphic, and carbonate rock fragments; red rock fragments; coarse-sand size; RIVER SEDIMENT
155-164	1372-1363	Sand; medium-grained; pebbly; light yellowish brown (2.5Y 6/3); poorly sorted; unconsolidated; calcareous; unbedded; *CLASTS:* angular to well rounded; igneous, metamorphic, and carbonate rock fragments; red rock fragments; pea size; RIVER SEDIMENT
164-166.5	1363-1360.5	Sand; coarse-grained; pebbly; light olive brown (2.5Y 5/3); poorly sorted; unconsolidated; calcareous; unbedded; *CLASTS:* angular to well rounded; igneous, metamorphic, and carbonate rock fragments; red rock fragments; pea to pebble size; RIVER SEDIMENT
166.5-168	1360.5-1359	Sand; fine- to medium-grained; light yellowish brown (2.5Y 6/4); well sorted; unconsolidated; calcareous; unbedded; *CLASTS:* angular to well rounded; igneous, metamorphic, and carbonate rock fragments; red rock fragments; sand size; RIVER SEDIMENT
168-170	1359-1357	Sand; fine- to medium-grained; silty; light olive brown (2.5Y 5/3); poorly sorted; consolidated with calcium-carbonate cement; calcareous; obscurely bedded; *CLASTS:* angular to well rounded; igneous, metamorphic, and carbonate rock fragments; red rock fragments; coarse-sands beds; sharp contact with underlying silt; RIVER SEDIMENT
170-180.5	1357-1346.5	Silt; dark gray (2.5Y 4/2); well sorted; consolidated; calcareous; massive to obscurely laminated with fine-grained sand; LAKE SEDIMENT
180.5-188.5	1346.5-1338.5	Sand; silty and silt, sandy; grayish brown (2.5Y 5/2); well sorted; consolidated; calcareous; obscurely bedded; *CLASTS:* angular to well rounded; igneous, metamorphic, and carbonate rock fragments; red rock fragments; fine- to coarse-sand size; sharp contact with underlying till; RIVER SEDIMENT

Gervais Formation

188.5-192	1338.5-1335	Pebble loam; silty; dark gray (10YR 4/1); unsorted; consolidated; calcareous; massive; *CLASTS:* angular to rounded; igneous, metamorphic and carbonate rock fragments; pea to pebble size; GLACIAL SEDIMENT
192-197	1335-1330	Sand; fine- to medium-grained; light olive brown (2.5Y 5/3); poorly sorted; unconsolidated; calcareous; unbedded; RIVER SEDIMENT
197-198	1330-1329	Silt; dark grayish brown (2.5Y 4/2); well sorted; consolidated; calcareous; massive; LAKE SEDIMENT

Older till, Old Marcoux till

198-215	1329-1312	Pebble loam; dark grayish brown (2.5Y 4/2); unsorted; consolidated; calcareous; massive; *CLASTS:* angular to rounded; igneous, metamorphic and carbonate rock fragments; pea to pebble size; cobbles at 202 feet; GLACIAL SEDIMENT
215	1312	Total Depth

T. 138 N., R. 49 W., sec. 35 ccd
Reference Section: Argusville Formation
North Dakota State Highway Department
Interstate 29, Structure 91, Boring # 1, St. Benedict Interchange
St. Benedict, Cass County, North Dakota
Surface elevation = 913 feet
Described by B. Michael Arndt (NDGS)

Depth	Elevation	Description
		HOLOCENE
Sherack Formation, Offshore facies (Lake Agassiz, Emerson Phase)		
0-6	913-907	Clay; silty; black to yellowish gray; oxidized; granular texture; unbedded; MODIFIED OFFSHORE SEDIMENT
6-14	907-899	Clay; gray; unbedded; lean clay; clay stringers (marbled); OFFSHORE SEDIMENT
		PLEISTOCENE
Brenna Formation (Lake Agassiz, Lockhart Phase)		
14-55	899-858	Clay; yellowish brown to gray; mostly lean; only thin clay stringers; silty toward base; OFFSHORE
Argusville Formation (Lake Agassiz, Cass Phase)		
55-75	858-838	Clay; gray; lean; clay nodules; sand pebbles; silt pebble inclusions; gritty appearance; OFFSHORE SEDIMENT
Red Lake Falls Formation, Lower Red Lake Falls Member		
75-97	838-816	Pebble-loam; silty; sandy; GLACIAL SEDIMENT
97	816	Total Depth

T. 139 N., R. 46 W., sec. 3 cacbdb
Reference Section: Otter Tail Formation, New York Mills Member
Minnesota Geological Survey Rotasonic Core (N-6300, MGS-537057, RVR-4)
Clay County, Minnesota
Surface elevation = 954 feet
Described by K. L. Harris (MGS), Mark Luther (NDGS),
and Omar Rood (JOR Engineering, Inc.)

NOTE: This core was split; splits are stored in the MN DNR Core Library at Hibbing, MN and in the NDGS Core and Sample Library at Grand Forks, ND.

Depth	Elevation	Description
		HOLOCENE
Soil Zone		
0-2.5	954-951.5	Loam; silty; black; organic rich; SOIL ZONE
Sherack Formation, Shoreline facies; Lake Agassiz Sediment (Emerson Phase)		
2.5-4.5	951.5-949.5	Sand; pebbly to cobbly; yellowish brown (10YR 5/6); SHORELINE SEDIMENT
		PLEISTOCENE
Red Lake Falls Formation, Lower Red Lake Falls Member		
4.5-7.5	949.5-946.5	Pebble-loam; silty; yellowish brown (10YR 5/4); predominantly igneous-metamorphic and carbonate rocks types; massive; calcareous; GLACIAL SEDIMENT
7.5-12	946.5-942	Pebble-loam; silty; dark brown (10YR 3/3); predominantly igneous-metamorphic and carbonate rocks types; massive; calcareous; GLACIAL SEDIMENT
12-28	942-926	Pebble-loam; silty; very dark grayish brown (2.5Y 3/2); predominantly igneous-metamorphic and carbonate rocks types; massive; calcareous; wood fragments at 15 and 24 feet; GLACIAL SEDIMENT
28-54	926-900	Pebble-loam; very dark grayish brown (2.5Y 3/2) to dark grayish brown (2.5Y 4/2); massive; predominantly igneous-metamorphic and carbonate rock types; massive; calcareous; lignite fragments at 40 and 45 feet; GLACIAL SEDIMENT
Otter Tail River Formation, New York Mills Member		
54-65	900-889	Pebble-loam; dark grayish brown (2.5Y 4/2) to very dark grayish brown (2.5Y 3/2); massive; predominantly igneous-metamorphic and carbonate rock types; carbonate rock types are abundant massive; calcareous; small shards of wood at 61 feet; GLACIAL SEDIMENT
Crow Wing River Formation, Marcoux Member		
65-87	889-867	Pebble-loam; dark grayish brown (2.5Y 4/2) to very dark grayish brown (2.5Y 3/2); massive; predominantly igneous-metamorphic and carbonate rock types; fist sized cobbles common; massive; calcareous; lignite fragments at 80 feet; GLACIAL SEDIMENT

87-97	867-857	NO RECOVERY

Thrust fault interpreted at 97.0 feet

Red Lake Falls Formation, Lower Red Lake Falls Member

97-97.5	857-856.5	Pebble-loam; dark grayish brown (2.5 4/2); predominantly igneous-metamorphic and carbonate rocks; massive; calcareous; small shards of wood and lignite fragments at 97 feet; GLACIAL SEDIMENT
97.5-103	856.5-851	Pebble-loam; dark grayish brown (2.5Y 4/2); predominantly igneous-metamorphic and carbonate rocks; massive; calcareous; very pebbly; GLACIAL SEDIMENT
103-103.5	851-850.5	Sand; fine to medium grained; dirty; contamination in the core barrel; debris accumulated on top of a new core point during withdrawal and reentry of the core barrel; SLUFF
103.5-110	850.5-844	Pebble-loam; dark grayish brown (2.5Y 4/2); predominantly igneous-metamorphic and carbonate rocks; massive; calcareous; very pebbly; GLACIAL SEDIMENT
110-113	844-841	Sand; medium grained; well sorted; well rounded; light olive brown (2.5Y 5/3); RIVER SEDIMENT

Older till, Old Marcoux till

113-142.5	841-811.5	Pebble-loam; dark grayish brown (2.5Y 4/2); predominantly igneous-metamorphic and carbonate rocks; massive; calcareous; very hard; ground up rock at 134.5 feet; GLACIAL SEDIMENT
142.5-142.8	811.5-811.5	Sand; fine-grained; well sorted; light brownish gray (2.5Y 6/2); RIVER SEDIMENT
142.8-146	811.5-808	Pebble-loam; very dark grayish brown (2.5Y 3/2); massive; predominantly igneous-metamorphic and carbonate rocks; calcareous; GLACIAL SEDIMENT
146-147	808-807	Sand; fine-grained; moderately well sorted; light olive brown (2.5Y 5/3); RIVER SEDIMENT
147-150	807-804	Pebble-loam; sandy; dark grayish brown (2.5Y 4/2); massive; predominantly igneous-metamorphic and carbonate rocks; calcareous; GLACIAL SEDIMENT
150-150.5	804-803.5	Sand; fine-grained; moderately well sorted; light olive brown (2.5Y 5/3); possibly an inclusion in the glacial sediment; RIVER SEDIMENT
150.5-153	803.5-801	Pebble-loam; sandy; dark grayish brown (2.5Y 4/2); massive; predominantly igneous-metamorphic and carbonate rocks; calcareous; GLACIAL SEDIMENT

Older Lake Sediment

153-159.5	801-794.5	Clay; with thin silt laminae; grayish brown (2.5Y 5/2) to dark olive gray (5Y 3/2); clay laminae are about 1.0 centimeter in thickness, silt laminae are about 1.0 millimeter in thickness; silt laminae are calcareous, clay laminae are very slightly calcareous; lamination more obscure 153 to 154.5 feet; more cohesive consistency 156 to 158 feet; stone free; fossil free; LAKE SEDIMENT
159.5-161	794.5-793	Silt; with thin clay laminae; olive gray (5Y 4/2); silt laminae are about 1.0 centimeter in thickness, clay laminae are about 1.0 millimeter in

		thickness; silt laminae are calcareous, clay laminae are very slightly calcareous; stone free; fossil free; LAKE SEDIMENT
161-163.5	793-790.5	Clay; with thin silt laminae; dark olive gray (5Y 3/2); clay laminae are about 1.0 centimeter in thickness, silt laminae are about 1.0 millimeter in thickness; silt laminae are calcareous, clay laminae are very slightly calcareous; stone free; fossil free; LAKE SEDIMENT
163.5-165.5	790.5-788.5	Silt; with minor clay laminae; olive gray (5Y 4/2); silt laminae are about 1.0 centimeter in thickness, clay laminae are about 1.0 millimeter in thickness; silt laminae are calcareous, clay laminae are very slightly calcareous; pebble zone at 163.5 feet; fossil free; LAKE SEDIMENT
165.5-172.257	88.5-781.75	Clay and Silt; eleven rhythmically bedded zones of laminated clay and silt and slightly clayey silt; 6 laminated clay and silt beds are consistently 3 to 6 inches in thickness; 5 slightly clayey-silt zones decrease in thickness upward, ranging from 3 inches to 2.75 feet thick. - Clay; with thin silt laminae; dark olive gray (5Y 3/2); clay laminae are about 1.0 centimeter in thickness, silt laminae are about 1.0 millimeter in thickness; silt laminae are calcareous, clay laminae are very slightly calcareous; scattered coarse sand to pea gravel at 165 feet; fossil free; LAKE SEDIMENT - Silt; slightly clayey; massive; olive gray (5Y 4/2); calcareous; fossil free; slightly sandy and weakly laminated 166 to 166.25 feet; LAKE SEDIMENT
172.25-179.57	81.75-774.5	Sand; silty; fine-grained; well sorted; olive gray (5Y 4/2); calcareous; RIVER SEDIMENT
Older Till, Unknown till		
179.5-180.25	774.5-773.75	Pebble-loam; sandy; olive gray (5Y 4/2); massive; igneous-metamorphic and predominantly carbonate rocks; very pebbly; fist sized cobbles are common; calcareous; GLACIAL SEDIMENT
180.25-182	773.75-772	Gravel; pea-sized with abundant cobbles; predominantly igneous-metamorphic and carbonate rock types; RIVER SEDIMENT
182	772	Total Depth

T. 139 N., R. 48 W., sec. 8 dad
Type Section, Poplar River Formation, West Fargo Member
Minnesota State University Moorhead
F-2 Dormitory; Composite Borings 1, 2, 3
Moorhead, Clay County, Minnesota
Surface elevation = 907 feet
Described by B. Michael Arndt (NDGS)

Depth	Elevation	Description
		HOLOCENE
Sherack Formation, Offshore facies (Lake Agassiz, Emerson Phase)		
0-3	907-904	Clay; silty; very dark grayish brown; mottled; calcareous; unbedded to vaguely Laminated; MODIFIED OFFSHORE SEDIMENT.
3-15	904-892	Clay; silty; dark grayish brown; oxidized; calcareous; laminated; OFFSHORE SEDIMENT
Poplar River Formation, West Fargo Member (Lake Agassiz, Moorhead Phase)		
15-33	892-874	Silt; clayey silt; very dark gray; laminated; some laminations contorted; organic laminae; thick bedded near base; peat; RIVER SEDIMENT
		PLEISTOCENE
Brenna Formation (Lake Agassiz, Lockhart Phase)		
33-40	874-867	Clay; very dark gray; vaguely laminated; calcareous; OFFSHORE SEDIMENT
40	867	Total Depth

T. 139 N., R. 49 W., sec. 26 ccc
Reference Section, Argusville Formation
North Dakota State Highway Department
Interstate 29, Structure 89, Boring # 1
Rose Coulee Bridge, Cass County, North Dakota
Surface elevation = 903 feet
Described by B. Michael Arndt (NDGS)

Depth	Elevation	Description
		HOLOCENE
Sherack Formation, Offshore facies (Lake Agassiz, Emerson Phase)		
0-6	903-897	Clay, clay-silt; oxidized, gypsum crystals; mottled; granular texture. Sherack Formation Offshore facies; MODIFIED OFFSHORE SEDIMENT
6-10	897-893	Clay, silt; oxidized; laminated; OFFSHORE SEDIMENT
		PLEISTOCENE
Brenna Formation (Lake Agassiz, Lockhart Phase)		
10-55	893-848	Clay; gray; some white calcareous specks; marbled lean and fat clay; contorted gray color banding near base; OFFSHORE SEDIMENT
Argusville Formation (Lake Agassiz, Cass Phase)		
55-73	848-830	Clay; gray; clay stringers; sand grains; gritty appearance; OFFSHORE SEDIMENT
Red Lake Falls Formation, Lower Red Lake Falls Member		
73-91	830-812	Pebble-loam; silty; sandy; GLACIAL SEDIMENT
91	812	Total Depth

T. 139 N., R. 49 W., sec. 26 ccc
Type Section, Argusville Formation
North Dakota State Highway Department
Interstate 29, Structure 89, Boring # 2
Rose Coulee Bridge, Cass County, North Dakota
Surface elevation = 903 feet
Described by B. Michael Arndt (NDGS)

Depth	Elevation	Description
		HOLOCENE
Sherack Formation, Offshore facies (Lake Agassiz, Emerson Phase)		
0-8	903-895	Silt, clay; brown to black; granular; blocky structure; dispersed organics in the upper part. Sherack Formation Offshore facies; MODIFIED OFFSHORE SEDIMENT
8-10	895-893	No samples; OFFSHORE SEDIMENT
		PLEISTOCENE
Brenna Formation (Lake Agassiz, Lockhart Phase)		
10-55	893-848	Clay; brownish gray; mostly lean clay; some fat clay banding; vaguely laminated (?); mostly unbedded; OFFSHORE SEDIMENT
Argusville Formation (Lake Agassiz, Cass Phase)		
55-73	848-830	Clay; gray; unbedded; clay stringers (marbled); silt pebble inclusions; gritty appearance; OFFSHORE SEDIMENT
Red Lake Falls Formation, Lower Red Lake Falls Member		
73-96	830-807	Pebble-loam; silty; sandy; GLACIAL SEDIMENT
96	807	Total Depth

T. 140 N., R. 45 W., sec. 9 daa
Reference Section: Otter Tail Formation, Hawley Member
Minnesota Geological Survey Soil Boring (N-5942)
Clay County, Minnesota
Surface elevation = 1158 feet
Described by K. L. Harris (MGS), Mark Luther (NDGS)

Depth	Elevation	Description
		HOLOCENE
Soil Zone		
0-2.5	1058-1055.5	Loam; silty; black; organic rich; SOIL ZONE
		PLEISTOCENE
Otter Tail River Formation, Hawley Member		
2.5-9	1055.5-1049	Pebble-loam; clayey; mottled olive gray (5Y 3/2); massive; limestone, igneous-metamorphic, and shale rocks present; calcareous; GLACIAL SEDIMENT
9	1049	Total Depth

T. 142 N., R. 44 W., sec. 36 bcbb
Reference Section: Buffalo River Formation
North Dakota Geological Survey; Power-Auger Boring (N-1918)
Clay County, Minnesota
Surface elevation = 1172 feet
Described by S. R. Moran (NDGS), D. K. Sackreiter (UND), and K. L. Harris (UND)

Depth	Elevation	Description
		PLEISTOCENE
Red Lake Falls Formation, Upper Red Lake Falls Member		
0-14	1172-1158	Pebble-loam; silty, clayey; brown; GLACIAL SEDIMENT
14-16	1158-1156	Silt; sandy; greenish gray; LAKE OR RIVER SEDIMENT
Goose River Formation, St. Hilaire Member		
16-25	1156-1147	Pebble-loam; sandy, silty; carbonate, crystalline, and shale pebbles; gray; sand at 36 feet; GLACIAL SEDIMENT
Crow Wing River Formation, Marcoux Member		
25-48	1147-1124	Pebble-loam; sandy; GLACIAL SEDIMENT
James River Formation, Villard Member		
48-53	1124-1119	Sand; fine-grained; light gray; RIVER SEDIMENT
53-56	1119-1116	Silt; laminated; light gray; LAKE OR RIVER SEDIMENT
56-62	1116-1110	Sandy gravelly; RIVER SEDIMENT
62-68	1110-1104	Sand; fine-grained; abundant lignite below 65 feet; RIVER SEDIMENT
68-75	1104-1097	Silt; sandy; interbedded pebble-loam; LAKE OR RIVER SEDIMENT
Thrust fault interpreted at 75.0 feet		
Goose River Formation, St. Hilaire, Member		
75-94	1097-1078	Pebble-loam; silty, sandy; dark gray; abundant shale pebbles, lignite present; GLACIAL SEDIMENT
Goose River Formation, Heiberg, Member		
94-116	1078-1056	Pebble-loam; silty; carbonate, crystalline, and shale pebbles; gray; sand at 36 feet; GLACIAL SEDIMENT
Buffalo River Formation		
116-120	1056-1052	Pebble-loam; sandy; light gray; very hard; GLACIAL SEDIMENT
120	1052	Total Depth

T. 143 N., R. 50 W., sec. 15 dac
Reference Section: Argusville Formation
North Dakota State Highway Department
Interstate 29, Structure 68, Composite of Borings # 1, 2, 3
South of Grandin, Cass County, North Dakota
Surface elevation = 896 feet
Described by B. Michael Arndt (NDGS)

Depth	Elevation	Description
		HOLOCENE
Sherack Formation, Offshore facies (Lake Agassiz, Emerson Phase)		
0-7	896-889	Clay, silt; brown to black; dispersed organics; oxidized; MODIFIED OFFSHORE SEDIMENT
7-30	889-866	Clay; silty; grayish brown to light gray; laminated to vaguely laminated; lean to fat; soft white CO_3 pebbles; gypsum crystals; OFFSHORE SEDIMENT
		PLEISTOCENE
Brenna Formation (Lake Agassiz, Lockhart Phase)		
30-50	866-846	Clay; gray; unbedded to vaguely laminated; abundant soft CO_3 inclusions; gypsum crystals; lean to fat; OFFSHORE SEDIMENT
Argusville Formation (Lake Agassiz, Cass Phase)		
50-68	846-828	Clay; silty; gray; contorted laminations; clay stringers; abundant sand pebbles; silty inclusions; gritty appearance; OFFSHORE SEDIMENT
Red Lake Falls Formation, Lower Red Lake Falls Member		
68-101	828-795	Pebble-loam; sandy; silty; GLACIAL SEDIMENT
101	795	Total Depth

T. 144 N., R. 41 W., sec. 6 dccc
Reference Section: Goose River Formation, St. Hilaire Member
North Dakota Geological Survey; Power-Auger Boring (N-1917)
Mahnomen County, Minnesota
Surface elevation = 1225 feet
Described by S. R. Moran (NDGS), D. K. Sackreiter (UND), and K. L. Harris (UND)

Depth	Elevation	Description
		PLEISTOCENE
Red Lake Falls Formation, Lower Red Lake Falls Member		
0-25	1225-1200	Pebble-loam; sandy, silty; crystalline and carbonate pebbles dominate; GLACIAL SEDIMENT
25-27	1200-1198	Gravel; sandy; coarse-grained; 20 to 30 feet, fine-grained; RIVER SEDIMENT
Goose River Formation, St. Hilaire Member		
27-84	1198-1141	Pebble-loam; silty, clayey to clayey, silty; abundant shale pebbles; gray; GLACIAL SEDIMENT
Older till, Old Sebeka till		
84-108	1141-1117	Pebble-loam; silty, clayey to sandy, silty; light gray; crystalline pebbles dominate; stony; very hard; GLACIAL SEDIMENT
108-136	1117-1089	Silt; light gray; LAKE SEDIMENT
136-150	1089-1075	Pebble-loam; sandy, silty to silty, clayey; light gray; crystalline pebbles dominate; stony; very hard; GLACIAL SEDIMENT
150	1075	Total Depth

T. 144 N., R. 44 W., sec. 16 cccab
Type Section: Goose River Formation, Heiberg Member
Wild Rice River Cut Bank (N-5945, Heiberg Section)
Norman County, Minnesota
Surface elevation = 1035 feet
Described by K. L. Harris (MGS) and M. R. Luther (NDGS)

Depth	Elevation	Description
		HOLOCENE
Sherack Formation, Nearshore facies; Lake Agassiz Sediment (Emerson Phase)		
0-6	1305-1029	Sand, silty sand, and silt; yellow brown; variable thickness (6 to 10 feet thick); post-lake eolian modification; some channel cut and fill; NEARSHORE AND SHORELINE LAKE SEDIMENT
		PLEISTOCENE
Red Lake Falls Formation, Lower Red Lake River Member		
6-18	1029-1017	Pebble loam; silty; yellow brown; limestone and crystalline pebbles common; well-developed columnar joints; well indurated, very hard; GLACIAL SEDIMENT
Goose River Formation, St. Hilaire Member		
18-27	1017-1008	Pebble loam; silty; olive gray to dark olive gray; abundant shale pebbles, limestone, and crystalline pebbles common; lignite fragments common to abundant (large fragments are present); massive structure; well indurated, very hard; GLACIAL SEDIMENT
Goose River Formation, Heiberg Member		
27-40	1008-995	Pebble loam; silty; dark olive gray to black; abundant shale pebbles, limestone, and crystalline pebbles common; lignite fragments common to abundant (large fragments are present); massive structure; well indurated, very hard; GLACIAL SEDIMENT
40	995	Total Depth

T. 144 N., R. 44 W., sec. 23 cddddda
Reference Section: Browerville Formation
Reference Section: Gervais Formation
Minnesota Geological Survey
Rotasonic Core (N-6218, MGS-247578, RVR-1)
Norman County, Minnesota
Surface elevation = 1105 feet
Described by K. L. Harris (MGS), Mark Luther (NDGS), and Robert Biek (NDGS)

NOTE: This core is stored in the MN DNR Core Library in Hibbing, MN. A split of the core is stored in the NDGS Core and Sample Library at Grand Forks, ND.

Depth	Elevation	Description
		HOLOCENE
Soil Zone		
0-2.5	1105-1102.5	Loam; sandy-silty; very dark grey (5YR 3/1)
Lake Agassiz Sediment, undifferentiated		
2.5-10.5	1102.5-1094.5	Sand; silty; light brown (7.5YR 6/4); massive; NEARSHORE LAKE SEDIMENT
10.5-14.5	1094.5-1090.5	Sand; silty-clayey; dark grayish brown (10YR 4/2); weakly laminated; some clayey zones; NEARSHORE LAKE SEDIMENT
14.5-26	1090.5-1079	Sand; silty; yellowish brown (10YR 5/4); weakly laminated; some clay beds; NEARSHORE LAKE SEDIMENT
26-30.5	1079-1074.5	Clay; very dark gray (10YR 3/1); massive; thin silt lamina at 27.5 feet; OFFSHORE LAKE SEDIMENT
30.5-31.5	1074.5-1073.5	Clay; very dark gray (10YR 3/1); massive; calcareous; contains coarse sand to pea gravel; OFFSHORE LAKE SEDIMENT
31.5-32	1073.5-1073	Clay; silty; dark brown (10YR 4/3); massive; scattered coarse sand grains; calcareous; OFFSHORE LAKE SEDIMENT
32-34.5	1073-1070.5	Clay; silty; dark brown (10YR 3/2); massive; calcareous; OFFSHORE LAKE SEDIMENT
34.5-39	1070.5-1066	Silt; clayey; dark yellowish brown (10YR 3/4); massive; blocky fracture; scattered coarse sand at 38 feet; calcareous; NEARSHORE LAKE SEDIMENT
39-45	1066-1060	Silt; clayey; dark gray (10YR 4/1); massive; calcareous; NEARSHORE LAKE SEDIMENT
45-53	1060-1052	NO RECOVERY
53-57	1052-1048	Silt; slightly clayey; very dark gray (10YR 3/1); massive to weakly laminated; scattered coarse sand grains; NEARSHORE LAKE SEDIMENT
		PLEISTOCENE
Red Lake Falls Formation, Lower Red Lake Falls Member		
57-58.5	1048-1046.5	Pebble-loam; dark brown (7.5YR 3/2); massive; limestone and igneous- metamorphic rocks present; GLACIAL SEDIMENT

58.5-62	1046.5-1043	Pebble-loam; grayish brown (10YR 5/2); massive; limestone and igneous- metamorphic rocks present; calcareous; GLACIAL SEDIMENT

Goose River Formation, St. Hilaire Member

62-63	1043-1042	Pebble-loam; dark grayish brown (10YR 4/2); massive; limestone, shale, igneous-metamorphic, and lignite rocks present; calcareous; GLACIAL SEDIMENT
63-68	1042-1037	Pebble-loam; very dark grayish brown (10YR 3/2); massive; limestone, shale, igneous-metamorphic, and lignite rocks present; calcareous; GLACIAL SEDIMENT
68-71	1037-1034	Pebble-loam; dark grayish brown (10YR 4/2); massive; limestone and igneous- metamorphic rocks present; cobbly; calcareous; sharp contact at 71 feet; GLACIAL SEDIMENT

Crow Wing River Formation, Marcoux Member

71-76	1034-1029	Pebble-loam; sandy; dark gray (10YR 4/1); massive; igneous-metamorphic and limestone rocks present; very pebbly; calcareous; GLACIAL SEDIMENT
76-81.5	1029-1023.5	Pebble-loam; sandy; dark grayish brown (10YR 4/2); massive; igneous-metamorphic and limestone rocks present; very pebbly; calcareous; GLACIAL SEDIMENT
81.5-85	1023.5-1020	Sand and gravel; medium- to coarse-grained; cobbly; RIVER SEDIMENT
85-86	1020-1019	Sand; fine-grained; grayish brown (10YR 5/2); massive; RIVER SEDIMENT
86-86.5	1019-1018.5	Sand and gravel; medium-grained; RIVER SEDIMENT
86.5-88	1018.5-1017	Sand; medium- to fine-grained; cobbly; RIVER SEDIMENT
88-90	1017-1015	Pebble-loam; sandy; dark brown (10YR 3/3); massive; limestone and igneous- metamorphic rocks present; calcareous; GLACIAL SEDIMENT
90-95	1015-1010	Silt; sandy; dark grayish brown (10YR 4/2); massive; obscurely laminated in some zones; LAKE SEDIMENT
95-103	1010-1002	Silt; laminated with fine-grained sand and clay beds; contorted bedding; LAKE SEDIMENT
103-105.5	1002-999.5	Pebble-loam; sandy; light brownish gray; massive; limestone and igneous- metamorphic rocks present; calcareous; GLACIAL SEDIMENT
105.5-107.5	999.5-997.5	Sand and gravel; zone of pebble-loam at 107.5 feet; RIVER SEDIMENT
107.5-113	997.5-992	Sand; fine-grained; silty; pebbly; dark grayish brown (10YR 4/2); GLACIAL SEDIMENT (?)
113-125	992-980	Sand and gravel; coarse-grained; cobbly; limestone and igneous-metamorphic pebbles; RIVER SEDIMENT
125-126.5	980-978.5	Sand; medium- to coarse-grained; RIVER SEDIMENT
126.5-132	978.5-973	Sand and gravel; medium- to coarse-grained; limestone and igneous-metamorphic pebbles; RIVER SEDIMENT

Thrust fault interpreted at 132.0 feet

Red Lake Falls Formation, Lower Red Lake Falls Member

132-146	973-959	Pebble-loam; very dark grayish brown (10YR 3/2); limestone and igneous- metamorphic pebbles; calcareous; GLACIAL SEDIMENT

Gervais Formation

146-154	959-951	Pebble-loam; very dark grayish brown (10YR 3/2); limestone and igneous- metamorphic pebbles; calcareous; GLACIAL SEDIMENT
154-154.5	951-950.5	Sand; fine- to medium-grained; RIVER SEDIMENT
154.5-157	950.5-948	Pebble-loam; very dark grayish brown (10YR 3/2); limestone and igneous- metamorphic pebbles; calcareous; GLACIAL SEDIMENT
157-163.5	948-941.5	Pebble-loam; dark gray (10YR 4/1); limestone and igneous-metamorphic pebbles; calcareous; GLACIAL SEDIMENT
163.5-166	941.5-939	Pebble-loam; very dark grayish brown (10YR 3/2); limestone and igneous- metamorphic pebbles; calcareous; GLACIAL SEDIMENT
166-168.5	939-936.5	Pebble-loam; dark brown (10YR 3/3); limestone and igneous-metamorphic pebbles; calcareous; GLACIAL SEDIMENT
168.5-171.5	936.5-933.5	Sand; silty; dark grayish brown (10YR 4/2) fine- to medium-grained; well sorted; RIVER SEDIMENT
171.5-172.5	933.5-932.5	Pebble-loam; very dark gray (10YR 3/1); limestone and igneous-metamorphic pebbles; calcareous; GLACIAL SEDIMENT
172.5-173	932.5-932	Sand; brown (10YR 4/3); fine-grained; some pebbles; LAKE SEDIMENT
173-175.5	932-929.5	Pebble-loam; limestone and igneous-metamorphic pebbles; calcareous; GLACIAL SEDIMENT
175.5-182	929.5-923	Sand; silty; gray (10YR 5/1); fine-grained; well sorted; LAKE SEDIMENT
182-182.5	923-922.5	Clay and silt; laminated; very dark gray (10YR 3/1); LAKE SEDIMENT
182.5-206.5	922.5-898.5	Sand; fine-grained; dark brown (10YR 4/3); massive; silt laminae in some zones; coarse-grained and cobbly at 203.5 feet; LAKE SEDIMENT

Thrust fault interpreted at 206.5 feet

Browerville Formation

206.5-207	898.5-898	Pebble-loam; dark gray (10YR 4/1); limestone and igneous-metamorphic pebbles; slightly calcareous; wood at 206.5 feet; GLACIAL SEDIMENT
207-212	898-893	Sand; slightly silty; dark gray (10YR 4/1); fine- to medium-grained; well sorted; massive; silty at 211.5; RIVER SEDIMENT
212-214	893-891	Pebble-loam; dark grayish brown (10YR 4/2); limestone and igneous-metamorphic pebbles; calcareous; GLACIAL SEDIMENT
214-216	893-889	Pebble-loam; dark gray (10YR 4/1); limestone and igneous-metamorphic pebbles; calcareous; GLACIAL SEDIMENT
216-225	889-880	Pebble-loam; dark grayish brown (10YR 4/2); limestone and igneous-metamorphic pebbles; calcareous; GLACIAL SEDIMENT
225-225	880-880	Sand; yellowish brown (10YR 5/4); thin zone; RIVER SEDIMENT
225-231	880-874	Pebble-loam; dark grayish brown (10YR 4/2); limestone and igneous-metamorphic pebbles; stony; calcareous; GLACIAL SEDIMENT
231-231.5	874-873.5	Sand; coarse-grained; dirty; RIVER SEDIMENT

Thrust fault interpreted at 231.5 feet

Crow Wing River Formation, Sebeka Member

231.5-232	873.5-873	Pebble-loam; sandy; very dark gray (10YR 3/1); limestone and igneous- metamorphic pebbles; calcareous; GLACIAL SEDIMENT

232-233	873-872	Pebble-loam; sandy; very dark grayish brown (10YR 3/2); mottled with pebble-loam reddish brown (pinkish, 2.5YR 4/3); cobbly; limestone and igneous-metamorphic pebbles; calcareous; GLACIAL SEDIMENT
233-239	872-866	Pebble-loam; sandy; grayish brown (10YR 5/2); limestone and igneous- metamorphic pebbles; calcareous; GLACIAL SEDIMENT
239-241	866-864	Pebble-loam; sandy; dark grayish brown (10YR 4/2); limestone and igneous- metamorphic pebbles; calcareous; GLACIAL SEDIMENT

Browerville Formation

241-250	864-855	Pebble-loam; sandy; dark gray (10YR 4/1); limestone and igneous-metamorphic pebbles; calcareous; GLACIAL SEDIMENT

Thrust fault interpreted at 250.0 feet

Crow Wing River Formation, Sebeka Member

250-257	855-848	Pebble-loam; sandy; dark gray (10YR 4/1); limestone and igneous-metamorphic pebbles; calcareous; GLACIAL SEDIMENT
257-262	848-843	Pebble-loam; sandy; dark gray (10YR 4/1); limestone and igneous-metamorphic pebbles; calcareous; GLACIAL SEDIMENT
262-268.5	843-836.5	Pebble-loam; sandy; dark grayish brown (10YR 4/2); limestone and igneous-metamorphic pebbles; calcareous; core is coated with fine sand; brown (10YR 4/3); GLACIAL SEDIMENT
268.5-273	836.5-832	Pebble-loam; sandy; dark grayish brown (olive brown, 2.5Y 4/2); limestone and igneous-metamorphic pebbles; calcareous; NO RECOVERY
273-278	832-827	NO RECOVERY
278-284.5	827-820.5	Pebble-loam; sandy; dark grayish brown (2.5Y 4/2); limestone and igneous-metamorphic pebbles; calcareous; loose sandy zones; GLACIAL SEDIMENT
284.5-285.5	520.5-819.5	Sand and Gravel; coarse-grained; RIVER SEDIMENT
285.5-296.5	819.5-808.5	Pebble-loam; sandy; dark grayish brown (2.5Y 4/2); limestone and igneous-metamorphic pebbles; calcareous; GLACIAL SEDIMENT
296.5	808.5	Total Depth

T. 147 N., R. 49 W., sec. 11 ccc
Type Section: Poplar River Formation, Harwood Member
North Dakota Geological Survey, Boring (T-18)
Traill County, North Dakota
Surface elevation = 865 feet
Described by B. Michael Arndt (NDGS)

Depth	Elevation	Description
		HOLOCENE
Sherack Formation, Offshore facies (Lake Agassiz, Emerson Phase)		
0-3	865-862	Clay; gray to black; abundant organics; MODIFIED OFFSHORE SEDIMENT
3-9	862-856	Clay; silty; yellowish brown to gray; soft CO_3 nodules; laminated; some coarse sand near base; OFFSHORE SEDIMENT
Poplar River Formation, Harwood Member (Lake Agassiz, Moorhead Phase)		
9-14	856-851	Clay; gray; mealy; slickensides; very hard; stones; unbedded with depth; RIVER AND GLACIAL SEDIMENT
14	851	Total Depth

T. 151 N., R. 43 W., sec. 5 addd
Type Section: Red Lake Falls Formation, Lower Red Lake Falls Member
Type Section: Goose River Formation, St. Hilaire Member
Reference Section: Red Lake Falls Formation, Upper Red Lake Falls Member
Red Lake River Cut Bank; Powerline Section (N-226, C-2)
Red Lake County, Minnesota
Surface elevation = 1082 feet
Modified from Harris, Moran, and Clayton, 1974

Depth	Elevation	Description
		PLEISTOCENE
Red Lake Falls Formation, Upper Red Lake Falls Member		
0-11	1082-1071	Pebble-loam; unbedded; friable; light gray (5Y 6/1); abundant sand lenses present; shale pebbles common; lower contact gradational; GLACIAL SEDIMENT
Red Lake Falls Formation, Lower Red Lake Falls Member		
11-29	1071-1053	Pebble-loam; unbedded; friable; light gray (5Y 6/1); abundant sand lenses present; shale pebbles rare; lower contact gradational; cobble, sand, and gravel concentrations occur at contact; GLACIAL SEDIMENT
Goose River Formation, St. Hilaire Member		
29-32	1053-1050	Pebble-loam; clayey; unbedded; friable; gray (5Y 5/1); sharp lower contact; GLACIAL SEDIMENT
Crow Wing River Formation, Marcoux Member		
32-47	1050-1035	Pebble-loam; sandy; unbedded; hard; light gray (2.5Y 6/2); sand and silt near river level, lower contact not exposed; GLACIAL SEDIMENT
47	1035	Total Depth

T. 151 N., R. 43 W., sec. 18 dadbc
Reference Section: Red Lake Falls Formation, Upper Red Lake Falls Member
Reference Section: Crow Wing River Formation, Marcoux Member
Red Lake River Cut Bank; Needles Eye Section (N-1008, C-7)
Red Lake County, Minnesota
Surface Elevation = 1055 feet
Section described by K. L. Harris
Modified from: Harris, Moran and Clayton, 1974

Depth	Elevation	Description
		PLEISTOCENE
Wylie Formation, Lake Agassiz Sediment (Cass Phase)		
0-6	1055-1049	Clay and silt; thinly laminated; clay is olive gray (5Y 6/2); silt is light brownish gray (2.5Y 6/2); laminae thicken upward; sharp lower contact; OFFSHORE SEDIMENT
Red Lake Falls Formation, Upper Red Lake Falls Member		
6-35	1049-1020	Pebble4oam; clayey; unbedded; columnar jointing; hard; pale olive (5Y 6/3); up to a foot of sand and gravel present at sharp lower contact; GLACIAL SEDIMENT
Crow Wing River Formation, Marcoux Member		
35-56	1020-999	Pebble-loam; sandy; unbedded; hard; light gray (5Y 6/1); abundant pebbles, cobbles, and boulders; lower contact not exposed; GLACIAL SEDIMENT
56	999	Total Depth

T. 151 N., R. 44 W., sec. 14 bddba
Reference Section, Wylie Formation
Red Lake River Cut Bank; Old Dam Section (N-1025, D-3)
Red Lake County, Minnesota
Surface elevation = 1030 feet
Described by K. L. Harris (UND)

Depth	Elevation	Description
		PLEISTOCENE
Forest River Formation, Huot Member		
0-3	1030-1027	Clay; slightly pebbly; unbedded; gray (5Y 5/1); contains tan, pebble-sized, calcareous inclusions; sharp lower contact; GLACIAL SEDIMENT
Wylie Formation (Lake Agassiz, Cass Phase)		
3-8	1027-1022	Silt and sand; fine-grained; ripple cross bedded to flat bedded; interbedded lower contact; OFFSHORE SEDIMENT
8-10	1022-1020	Clay and silt; thinly laminated; clay is olive gray (5Y 5/2); silt is light brownish gray (2.5Y 6/2); interbedded lower contact; OFFSHORE SEDIMENT
Red Lake Falls Formation, Upper Red Lake Falls Member		
10-49	1020-981	Pebble-loam; silty, clayey to silty, sandy; crystalline pebbles abundant, carbonate pebbles common, and shale pebbles present; unbedded; light olive gray (5Y 6/2); strong to weak columnar jointing; frequent channel scours with cross bedded sand and gravel fill; GLACIAL SEDIMENT
Red Lake Falls Formation, Lower Red Lake Falls Member		
49-69	981-961	Pebble-loam; sandy, silty; crystalline pebbles and carbonate pebbles abundant, occasional shale pebble present; unbedded; light olive gray (5Y 6/2); massive; lower contact not exposed; GLACIAL SEDIMENT
69	961	Total Depth

T. 151 N., R. 44 W., sec. 18 cbaac
Reference Section: Sherack Formation, Offshore facies
Reference Section: Forest River Formation, Huot Member
Red Lake River Cut Bank; Snake Curve North Section (N-1018, D-12)
Red Lake County, Minnesota
Surface elevation = 985 feet
Described by K. L. Harris (UND)

Depth	Elevation	Description
		HOLOCENE
Sherack Formation, Offshore facies (Lake Agassiz, Emerson Phase)		
0-5	985-980	Silt and clay; laminated with some sand in lower laminae; light yellowish brown (2.5Y 6/4); gradational lower contact; OFFSHORE SEDIMENT
		PLEISTOCENE
Forest River Formation, Huot Member		
5-20	980-965	Clay; slightly pebbly; unbedded; gray (5Y 5/1); contains tan, pebble-sized, calcareous inclusions; lower contact gradational; GLACIAL SEDIMENT
Wylie Formation (Lake Agassiz, Cass Phase)		
20-21	965-964	Clay and silt; thinly laminated; clay is olive gray (5Y 5/2); silt is light brownish gray (2.5Y 6/2); lower contact gradational and interbedded; OFFSHORE SEDIMENT
Red Lake Falls Formation, Upper Red Lake Falls Member		
21-28	964-957	Clay; silty; pebbly; unbedded; friable; light olive gray (2.5Y 7/2); strong columnar jointing; gradational lower contact; silt bed at base.
28-40	957-945	Pebble-loam; unbedded; hard; light brownish gray (2.5Y 6/2); lower contact not exposed; GLACIAL SEDIMENT
40	945	Total Depth

T. 151 N., R. 44 W., sec. 21 babaa
Type Section: Gervais Formation
Reference Section: Red Lake Falls Formation, Lower Red Lake Falls Member
Red Lake River Cut Bank; Three Creeks Section (N1012, D-5)
Red Lake County, Minnesota
Surface elevation = 1025 feet
Described by K. L. Harris (UND)

Depth	Elevation	Description
		PLEISTOCENE
Forest River Formation, Huot Member		
0-15	1025-1010	Clay; very slightly pebbly; unbedded; gray (5Y 5/1); contains tan, pebble-sized, calcareous inclusions; highly slumped; gradational contact with Wylie Formation; GLACIAL SEDIMENT
Wylie Formation, Lake Agassiz Sediment (Cass Phase)		
15-19	1010-1006	Clay and silt; thinly laminated; clay is olive gray (5y 5/2); silt is light brownish gray (2.5Y 6/2); laminae thicken upward; gradational contact with Upper Red Lake Falls Formation.
Red Lake Falls Formation, Upper Red Lake Falls Member		
19-35	1006-990	Pebble-loam; silty, clayey to sandy, silty; unbedded; friable; light brownish gray (2.5Y 6/2); lower contact gradational; laminated clay at contact; GLACIAL SEDIMENT.
Red Lake Falls Formation, Lower Red Lake Falls Member		
35-41	990-984	Pebble-loam; sandy, silty; unbedded; friable; light brownish gray (2.5Y 6/2); abundant sand inclusions; sharp contact with Browerville Formation; GLACIAL SEDIMENT
41-60	984-965	Sand, alternating fine and medium grained; flat bedded to ripple cross-bedded; jointed; limonitic stains; gradational lower contact; LAKE OR RIVER SEDIMENT
Browerville Formation		
60-61	965-964	Pebble-loam; sandy, silty; unbedded; friable; light gray (5Y 6/1); lower contact is sharp; cobbles are common at contact; GLACIAL SEDIMENT
Gervais Formation		
61-85	964-940	Pebble-loam; silty, clayey; very slightly pebbly; unbedded; friable; light olive-gray (5Y 6/2); wood chips, and logs abundant near base; pebbles and sand lens inclusions increase upward; mollusk fragments and charcoal flakes present; lower contact not exposed; GLACIAL SEDIMENT
85	940	Total Depth

T. 151 N., R. 44 W., sec. 22 aabda
Type Section: Huot Formation
Type Section: Wylie Formation;
Type Section: Red Lake Falls Formation, Upper Red Lake Falls Member
Type Section: Crow Wing River Formation, Marcoux Member
Reference Section: Red Lake Falls Formation, Lower Red Lake Falls Member
Clearwater River Cut Bank; Clearwater Section (N-113, CW-1)
Red Lake County, Minnesota
Surface elevation = 1030 feet
Modified from: Harris, Moran and Clayton, 1974

Depth	Elevation	Description
		PLEISTOCENE
Forest River Formation, Huot Formation		
0-14	1030-1016	Clay, very slightly pebbly; unbedded; gray (5Y 5/1); contains abundant tan, pebble-sized, calcareous inclusions; lower contact interbedded; highly slumped; GLACIAL SEDIMENT
Wylie Formation, Lake Agassiz Sediment (Cass Phase)		
14-19	1016-1011	Clay and silt; thinly laminated; clay is olive gray (5Y 5/2); silt is light brownish gray (2.5Y 6/2); laminae thicken upward; interbedded lower contact; OFFSHORE SEDIMENT
Red Lake Falls Formation, Upper Red Lake Falls Member		
19-39	1011-991	Pebble-loam; silty, sandy; unbedded; friable; light brownish gray (2.5Y 6/2); weak columnar jointing; abundant sand and gravel lenses; crystalline and metamorphic pebbles abundant, carbonate pebbles common, shale pebbles present; gradational lower contact; GLACIAL SEDIMENT
Red Lake Falls Formation, Lower Red Lake Falls Member		
39-55	991-975	Pebble-loam; silty, sandy; unbedded; friable; light brownish gray (2.5Y 6/2); massive; abundant sand and gravel lenses; crystalline and metamorphic pebbles abundant, carbonate pebbles abundant, shale pebbles rare; sharp lower contact; GLACIAL SEDIMENT
Crow Wing River Formation, Marcoux Member		
55-74	975-956	Pebble-loam; sandy, silty; unbedded; hard; light olive gray (5Y 6/2); crystalline and metamorphic pebbles dominate, carbonate pebbles common, shale pebbles absent; lower contact not exposed; GLACIAL SEDIMENT
74	956	Total Depth

T. 151 N., R. 45 W., sec. 13 dadda
Type Section: Poplar River Formation
Reference Section: Sherack Formation, Nearshore facies
Reference Section: Poplar River Formation, West Fargo Member
Red Lake River Cut Bank, Snake Curve South Section
Red Lake County, Minnesota
Surface elevation = 985 feet
Described by S. R. Moran (NDGS) and Lee Clayton (UND)

Depth	Elevation	Description
		HOLOCENE
Sherack Formation, Nearshore facies (Lake Agassiz, Emerson Phase)		
0-15	985-970	Sand; fine grained; well sorted; thin bedded, contains ripple cross bedding; a layer of pebbles and cobbles about 6 inches thick occurs at the top of the sand; the lower contact of the sand is gradational; SHORELINE SEDIMENT
Sherack Formation, Offshore facies (Lake Agassiz, Emerson Phase)		
15-30	970-955	Silt; thin laminated; contains some beds of clay and very line sand; both upper and lower contacts are gradational; OFFSHORE SEDIMENT
Poplar River Formation, West Fargo Member (Lake Agassiz, Moorhead Phase)		
30-40	955-945	Sand; fine grained; thin bedded; contains ripple cross bedding; contains a few interbeds of silt and clay; shells of gastropods and small bivalves are abundant near the base; lower contact is gradational; RIVER AND LAKE SEDIMENT
40-55	945-930	Sand; gravelly, grading downward into sandy gravel; gravel is flat bedded and sand has dune cross bedding; shells of gastropods and small bivalves are abundant at the top of the unit, large mussels occur throughout the unit, and a large conifer log was exposed near the base; the lower contact is sharp; RIVER SEDIMENT
		PLEISTOCENE
Red Lake Falls Formation, Upper Red Lake Falls Member		
55-70	930-915	Pebble-loam; silty, sandy; hard; columnar jointing; stands in vertical cliffs; lower 5 to 10 feet above the river are covered; upper contact is sharp with the gravel of the Poplar River Formation but gradational with the clay of the Wylie Formation both north and south of the measured section; GLACIAL SEDIMENT
70	915	Total Depth

T. 151 N., R. 45 W., sec. 26 bbbac
Reference Section, Forest River Formation, Huot Member
Red Lake River Cut Bank; Schist Cliff Section (E-6)
Red Lake County, Minnesota
Surface elevation = 960 feet
Described by K. L. Harris (UND)

Depth	Elevation	Description
		PLEISTOCENE
Forest River Formation, Huot Member		
0-67	960-893	Clay; very slightly pebbly; unbedded; gray (5Y 5/1); contains pebble-sized, tan, calcareous inclusions; contains boulder-sized inclusions of light-colored pebbly loam; lower contact not exposed; GLACIAL SEDIMENT
67	893	Total Depth

T. 151 N., R. 50 W., sec. 5 dddb
Type Section: Brenna Formation
Type Section: Forest River Formation, Falconer Member
Reference Section: Sherack Formation, Offshore facies
University of North Dakota, Witmer Hall Boring No. 3
Grand Forks, Grand Forks County, North Dakota
Surface elevation = 831 feet
Described by S. R. Moran (NDGS)

Depth	Elevation	Description
		HOLOCENE
Sherack Formation Offshore facies (Lake Agassiz, Emerson Phase)		
0-20	831-811	Clay, silt, clayey silt, and silty clay; thinly laminated; ripple cross bedding in some coarse silt beds; brown to olive (5Y 4/3 wet); near base, only coarser beds are oxidized; finer beds are gray; OFFSHORE SEDIMENT
20-36	811-795	Clay, silt, clayey silt, and silty clay; thinly laminated; black to dark gray (5Y 2/1 to 5Y 4/1 wet), dark gray to light gray (5Y 4/1 to 5Y 6/1 dry); OFFSHORE SEDIMENT
		PLEISTOCENE
Brenna Formation (Lake Agassiz, Lockhart Phase)		
36-84	795-747	Clay, obscurely laminated to unbedded; slick; sticky; soft; contains white to tan coarse sand and small pebble-sized grains of chalky shale and limestone; from 75 feet to 84 feet, pebbles become more abundant; very dark gray (5Y 3/1 wet), dark gray to gray (5Y 4/1 to 5Y 5/1 dry); OFFSHORE SEDIMENT
Forest River Formation, Falconer Member		
84-123	747-708	Pebble-loam; unbedded; hard; few pebbles; very dark gray (5Y 3/1 wet) to gray or light gray (5Y 5/1 or 5Y 6/1 dry); contains an average of 16% sand, 46% silt and 38% clay; the total carbonate content is 25.1% (5.5% calcite, 19.6% dolomite); contains 14% kaolinite and chlorite, 17% illite, and 68% montmorillonite.
Wylie Formation (Lake Agassiz, Cass Phase)		
123-141	708-690	Clay; unbedded to obscurely bedded; very dark gray to dark gray (5Y 3/1 to 5Y 4/1 wet); OFFSHORE SEDIMENT
141-150	690-681	Sand; fine-grained; grayish brown; LAKE OR RIVER SEDIMENT
150	681	Total Depth

T. 151 N., R. 50 W., sec. 6 dad
Reference Section: Sherack Formation, Offshore facies
Reference Section: Brenna Formation
Reference Section: Forest River Formation, Falconer Member
North Dakota State Water Commission, Testhole #2433
Grand Forks, Grand Forks County, North Dakota
Surface elevation = 835 feet
Description and electric-log interpretation by S. R. Moran (NDGS)

Depth	Elevation	Description
		HOLOCENE
Sherack Formation, Offshore facies (Lake Agassiz, Emerson Phase)		
0-18	835-817	Silt; clayey; and clay; laminated; pale yellow (2.5Y 7/3); oxidized; OFFSHORE SEDIMENT
18-36	817-799	Clay; silty; laminated; light gray (5Y 6/1); unoxidized; OFFSHORE SEDIMENT
		PLEISTOCENE
Brenna Formation (Lake Agassiz, Lockhart Phase)		
36-76	799-759	Clay; unbedded to obscure laminated; slick; gray (5Y 5/1); unoxidized, contains calcareous white specks; OFFSHORE SEDIMENT
Forest River Formation, Falconer Member		
76-124	759-711	Pebble-loam; light gray (5Y 6/1); unoxidized; contains 13% sand, 44% silt, and 43% clay; total carbonate content is 26.5% (6.0% calcite and 20.5% dolomite); GLACIAL SEDIMENT
Wylie Formation (Lake Agassiz, Cass Phase)		
124-138	711-697	Clay; light gray (10YR 6/1); unoxidized; OFFSHORE SEDIMENT
Red Lake Falls Formation (undifferentiated)		
138-144	697-691	Pebble-loam; light gray (5Y 6/1); unoxidized; poor samples; GLACIAL SEDIMENT
144-185	691-650	Clay; light gray (5Y 6/1); unoxidized; LAKE SEDIMENT
185-196	650-639	Pebble-loam; sandy; light gray (5Y 6.5/1); poor samples; GLACIAL SEDIMENT
196-220	639-615	Gravel; sandy; very fine to fine grained; poorly sorted; RIVER SEDIMENT
220-228	615-607	Pebble-loam; brownish gray to olive gray; sandy to very gravelly; very poor samples; GLACIAL SEDIMENT
228-241	607-594	Gravel; sandy; very fine to fine grained; poorly sorted; RIVER SEDIMENT
Crow Wing River Formation, Marcoux Member		
241-262	594-573	Pebble-loam; light gray (10YR 6/1); unoxidized; contains 46% sand, 31% silt, and 23% clay; total carbonate content is 27.3% (9.8% calcite and 17.5% dolomite); GLACIAL SEDIMENT

262-267	573-568	Gravel; sandy; mottled gray; fine to very coarse grained; poorly sorted; RIVER SEDIMENT

ORDOVICIAN

Winnipeg Group

267-279	568-556	Shale; variegated green gray red; noncalcareous.
279-294	556-541	Sandstone; dark reddish brown; fine; well sorted; very clayey; iron-oxide cement.
294	541	Total Depth

T. 151 N., R. 50 W., sec. 22 bbb
Reference Section: Sherack Formation, Offshore facies
Reference Section: Brenna Formation
Reference Section: Forest River Formation, Falconer Member
North Dakota State Water Commission, Testhole #2431
Grand Forks, Grand Forks County, North Dakota
Surface elevation = 835 feet
Description and electric-log interpretation by S. R. Moran (NDGS)

Depth	Elevation	Description
		HOLOCENE
Sherack Formation, Offshore facies (Lake Agassiz, Emerson Phase)		
0-16	835-819	Silt; clayey; light gray (2.5Y 7/2); oxidized; OFFSHORE SEDIMENT
16-40	819-795	Clay; silty; laminated; light gray (5Y 6/1); unoxidized; OFFSHORE SEDIMENT
		PLEISTOCENE
Brenna Formation (Lake Agassiz, Lockhart Phase)		
40-60	795-775	Clay; unbedded; gray (5Y 4.5/1); unoxidized; contains white calcareous specks; OFFSHORE SEDIMENT
60-68	775-767	Clay; unbedded; pebbly; gray (5Y 6/1); unoxidized; contains white calcareous specks; OFFSHORE SEDIMENT
Forest River Formation, Falconer Member		
68-118	767-717	Pebble-loam; silty; light gray (5Y 6/1); unoxidized; contains 12% sand, 46% silt, and 42% clay; total carbonate content 22.8% (5.3% calcite and 17.5% dolomite); GLACIAL SEDIMENT
Wylie Formation (Lake Agassiz, Cass Phase)		
118-128	717-707	Clay; light gray (5Y 6/1); unoxidized; OFFSHORE SEDIMENT
Red Lake Falls Formation (undifferentiated)		
128-143	707-692	Sand; fine grained at the top; grading downward into coarse to very coarse grained at the base; pale yellowish brown; RIVER SEDIMENT
143-148	692-687	Gravel; fine to medium grained; poorly sorted; RIVER SEDIMENT
Goose River Formation, St. Hilaire Member		
148-166	687-669	Pebble-loam; light gray (5Y 6/1); unoxidized; poor samples; GLACIAL SEDIMENT
166-188	669-647	Pebble-loam; light gray (5Y 6.5/0.5); unoxidized; poor samples; GLACIAL SEDIMENT
188-194	647-641	Pebble-loam; light gray (2.5Y 7/1); poor samples; GLACIAL SEDIMENT
194-200	641-635	Gravel; fine to medium grained; poorly sorted; RIVER SEDIMENT

Crow Wing River Formation, Marcoux Member

200-220	635-615	Pebble-loam; sandy; light brownish gray (10YR 6.5/2); unoxidized; contains 51% sand, 34% silt, and 15% clay; total carbonate content 28.1% (9.3% calcite and 18.8% dolomite); GLACIAL SEDIMENT
220-236	615-599	Sand; fine grained; well sorted; RIVER SEDIMENT

ORDOVICIAN

Winnipeg Group

236-244	599-591	Shale; pale reddish brown; dusky red becoming yellow downward; noncalcareous at top; calcareous at base.
244-252	591-583	Limestone; grayish red; microcrystalline.
252	583	Total Depth

T. 152 N., R. 50 W., sec. 29 dda
Reference Section: Sherack Formation, Offshore facies
Reference Section: Brenna Formation
Reference Section: Forest River Formation, Falconer Member
North Dakota State Water Commission, Testhole #2430
Grand Forks, Grand Forks County, North Dakota
Surface elevation = 830 feet
Description and electric-log interpretation by S. R. Moran (NDGS)

Depth	Elevation	Description
		HOLOCENE
Sherack Formation, Offshore facies (Lake Agassiz, Emerson Phase)		
0-17	830-813	Clay; silty; and silt; laminated; yellowish gray; oxidized; OFFSHORE SEDIMENT
17-37	813-793	Clay; silty; and silt; laminated; light gray; unoxidized; OFFSHORE SEDIMENT
		PLEISTOCENE
Brenna Formation (Lake Agassiz, Lockhart Phase)		
37-74	793-756	Clay; obscurely laminated to unbedded; gray to dark gray; contains white calcareous specks; OFFSHORE SEDIMENT
Forest River Formation, Falconer Member		
74-118	7 56-712	Pebble-loam; silty; light gray (5Y 6.5/1); unoxidized; contains 18% sand, 53% silt, and 29% clay; total carbonate content is 26.9% (5.5% calcite and 21.4% dolomite); GLACIAL SEDIMENT
Wylie Formation (Lake Agassiz, Cass Phase)		
118-133	712-697	Clay; gray; unoxidized; OFFSHORE SEDIMENT
Red Lake Falls Formation (undifferentiated)		
133-138	697-692	Pebble-loam; gray; unoxidized; poor samples; GLACIAL SEDIMENT
138-176	692-654	Clay; dark greenish gray to olive black; unoxidized; OFFSHORE SEDIMENT
176-183	654-647	Pebble-loam; gray (5Y 6/1); unoxidized; poor samples; GLACIAL SEDIMENT
Goose River Formation, St. Hilaire Member		
183-199	647-631	Clay; slightly pebbly; gray (5Y 6/1); unoxidized; may be till; LAKE OR GLACIAL SEDIMENT.
199-214	631-616	Gravel; fine- to coarse-grained; poorly sorted; sandy; contains clay and silt beds; LAKE SEDIMENT
Crow Wing River Formation, Marcoux Member		
214-240	616-590	Pebble-loam; sandy; light gray (10YR 6/1); contains 55% sand, 26% silt, and 19% clay; total carbonate content is *31.3%* (9.9% calcite and 21.4% dolomite); GLACIAL SEDIMENT

240-278	590-552	Pebble-loam; sandy; light gray (10YR 6/1); contains 63% sand, 23% silt, and 14% clay; total carbonate content is 24.0% (6.9% calcite and 17.1% dolomite); GLACIAL SEDIMENT
278-284	552-546	Sand; very poor samples; LAKE OR RIVER SEDIMENT

ORDOVICIAN

Winnipeg Group

284-292	546-538	Clay; pale reddish brown to dusky red; silty; thin, very light gray limestone interbedded with clay.
292-295	538-535	Sandstone; dark reddish brown; medium-grained; well sorted; well rounded; calcium carbonate and iron-oxide cement.
295	535	Total Depth

T. 152 N., R. 51 W., sec. 36 ddd
Reference Section: Sherack Formation, Offshore facies
Reference Section: Brenna Formation
Reference Section: Forest River Formation, Falconer Member
North Dakota State Water Commission, Testhole #2609
Grand Forks, Grand Forks County, North Dakota
Surface elevation = 835 feet
Description and electric-log interpretation by S. R. Moran (NDGS)

Depth	Elevation	Description
		HOLOCENE
Sherack Formation, Offshore facies (Lake Agassiz, Emerson Phase)		
0-14	835-821	Clay; silty; laminated; yellowish brown to yellowish gray; oxidized; OFFSHORE SEDIMENT
14-30	821-805	Clay; silty; laminated; light gray (5Y 6/1); unoxidized; OFFSHORE SEDIMENT
		PLEISTOCENE
Brenna Formation (Lake Agassiz, Lockhart Phase)		
30-69	805-766	Clay; obscurely laminated to unbedded; gray; unoxidized; contains white calcareous specks; OFFSHORE SEDIMENT
Forest River Formation, Falconer Member		
69-124	766-711	Pebble-loam; silty; light gray (5Y 6/1); unoxidized; contains 15% sand, 47% silt, and 38% clay; total carbonate content is 25.4% (5.8% calcite and 19.6% dolomite); GLACIAL SEDIMENT
Wylie Formation (Lake Agassiz, Cass Phase)		
124-134	711-701	Clay; gray; unoxidized; OFFSHORE SEDIMENT
Red Lake Falls Formation (undifferentiated)		
134-174	701-661	Pebble-loam; gray (5Y 6/1); unoxidized; contains 38% sand, 36% silt, and 6% clay; total carbonate content is 26.1% (6.7% calcite and 19.4% dolomite); contains a bed of clay from 153 to 158 feet; GLACIAL SEDIMENT
174-183	661-652	Gravel
Goose River Formation, St. Hilaire Member		
183-196	652-639	Pebble-loam; gray (5Y 5/1); unoxidized; GLACIAL SEDIMENT
196-212	639-623	Sand and gravel; RIVER SEDIMENT
Crow Wing River Formation, Marcoux Member		
212-232	623-603	Pebble-loam; sandy, very poor samples; GLACIAL SEDIMENT
232-251	603-584	Pebble-loam; sandy; gray; very poor samples; GLACIAL SEDIMENT

ORDOVICIAN

Winnipeg Group

251-257	584-578	Clay, silty; reddish brown; very calcareous.
257	578	Total Depth

T. 154 N., R. 55 W., sec. 10 ada
Original Type Section: Dahlen Formation
Forest River Cut Bank; Forest River Cut I (N-518)
Grand Forks County, North Dakota
Surface elevation = 1095 feet*
Description by N. L. Salomon (NDGS)

Depth	Elevation	Description
		HOLOCENE
0-9	1095-1086	Interbedded sand and silt.
9-10	1086-1085	Organic rich silt.
10-15	1085-1080	Sandy silt, very well sorted, contorted, and involuted bedding near the top.
15-21	1080-1074	Sand, medium-grained, poorly sorted, large-scale trough-shaped cross bedding.
21-26	1074-1069	Sand, coarse-grained, well sorted.
26-39	1069-1056	Sand, medium-grained, moderate to well sorted, small-scale cross bedding.
		PLEISTOCENE
"Falconer Formation"		
39-79	1056-1016	Pebble-loam, compact, fissile to massive, olive gray, silt and sand lenses, abundant shale pebbles.
Wylie Formation		
79-83	1016-1012	Silt, laminated, brown pebble-loam interbedded with silt in upper 2 feet; upper boundary of this unit is the top of the uppermost continuous silt layer.
"Dahlen Formation"		
83-89	1012-1006	Pebble-loam, compact, olive gray, abundant shale pebbles.
89	1006	Total Depth

* Elevation adjusted based on USGS 1:24,000 scale topographic maps by K. L. Harris

T. 154 N., R. 55 W., sec. 10 ada
Redefined Type Section: Goose River Formation, Dahlen Member
Forest River Cut Bank; Forest River Cut I (N-5943)
Grand Forks County, North Dakota
Surface elevation = 1095 feet*
Description by K. Harris (MGS) and Mark Luther (NDGS)

Depth	Elevation	Description
		HOLOCENE
Sherack Formation, Nearshore facies (Lake Agassiz, Emerson Phase)		
0-9	1095-1086	Interbedded sand and silt; SHORELINE AND NEARSHORE SEDIMENT
9-10	1086-1085	Organic rich silt; SHORELINE AND NEARSHORE SEDIMENT
10-15	1085-1080	Sandy silt, very well sorted, contorted, and involuted bedding near the top; SHORELINE AND NEARSHORE SEDIMENT
15-21	1080-1074	Sand, medium-grained, poorly sorted, large-scale trough-shaped cross bedding; SHORELINE AND NEARSHORE SEDIMENT
21-26	1074-1069	Sand, coarse-grained, well sorted; SHORELINE AND NEARSHORE SEDIMENT
26-34	1069-1061	Sand, medium-grained, moderate to well sorted, small-scale cross bedding; SHORELINE AND NEARSHORE SEDIMENT
		PLEISTOCENE
Forest River Formation, Inkster member (informal)		
34-70	1061-1025	Pebble-loam, compact, fissile to massive, olive gray, silt and sand lenses, abundant shale pebbles; GLACIAL SEDIMENT
Goose River Formation, Dahlen Member		
70-89	1025-1006	Pebble-loam, compact, olive gray, abundant shale pebbles; GLACIAL SEDIMENT
89	1006	Total Depth

* Elevation adjusted based on USGS 1:24,000 scale topographic maps by K. L. Harris

T. 155 N., R. 50 W., sec. 31 dda
Type Section: Sherack Formation
Reference Section: Brenna Formation
U.S. Army Corps of Engineers; Oslo Dike Boring (68-12M)
Marshall County, Minnesota
Surface elevation = 806 feet
Described by S. R. Moran (NDGS)

Depth	Elevation	Description
		HOLOCENE
Oahe Formation		
0-3	806-803	Clay, silty; brown to tan; interbedded with gravelly clay; brown; calcareous, artificial fill; ALLUVIUM AND FILL
3-12	803-794	Clay, silty; brown to tan; contains scattered plant fragments and some beds of organic material; locally secondary carbonate occurs; ALLUVIUM
Sherack Formation, Offshore facies (Emerson Phase)		
12-34	794-772	Clay, silty; thinly laminated; olive brown (2.5Y 4/4 wet); contains silt interbeds; some silt beds are cross bedded; oxidized; OFFSHORE SEDIMENT
34-46	772-760	Clay, silty; silt; clayey; and clay; very dark gray (5Y 3/1 wet); laminated with unbedded subzones; cross bedding occurs in thicker silt beds throughout the interval; lamination less evident in lower 5 feet; some slick, laminated beds toward the base; OFFSHORE SEDIMENT
		PLEISTOCENE
Brenna Formation (Lake Agassiz, Lockhart Phase)		
46-52	760-754	Clay; obscurely laminated; very dark gray (5Y 3/1 wet); slickensided surfaces developed readily by shearing; OFFSHORE SEDIMENT
52-112	754-694	Clay; unbedded to obscurely laminated; laminations are commonly irregular and lenticular; very dark gray (5Y 3/1 wet); soft; slickensides characteristic of entire section; soft, white, gray and brown, silty, calcareous pebbles abundant in upper 5 to 10 feet and continue to be present but in considerably reduced numbers throughout the unit; a few hard carbonate pebbles also present; OFFSHORE SEDIMENT
Forest River Formation, Falconer Member		
112-118	694-688	Pebble-loam; silty, clayey; gray (5Y 6/1); contains 17% sand, 43% silt, and 40% clay; total carbonate content is 29.6% (5.4% calcite and 24.2% dolomite); GLACIAL SEDIMENT
118	688	Total Depth

T. 159 N., R. 56 W., sec. 16 dad
Original Type Section: Gardar Formation
NDGS Boring (N-35)
Cavalier County, North Dakota
Surface elevation = 980 feet
Described by N. L. Salomon (UND)

Depth	Elevation	Description
		HOLOCENE
0-3	980-977	Silt, clay; brown to black; granular; blocky structure; dispersed organics in the upper part; SOIL ZONE
		PLEISTOCENE
Gardar Formation		
3-6	977-974	Boulder lag, gravel with abundant carbonate rocks.
6-11	974-969	Pebble loam, friable, sand, silt, and gravel lenses, abundant shale pebbles, GLACIAL SEDIMENT
11-21	969-959	Pebble-loam, blocky, iron-stained joints, abundant shale pebbles, GLACIAL SEDIMENT
21	959	Total Depth

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