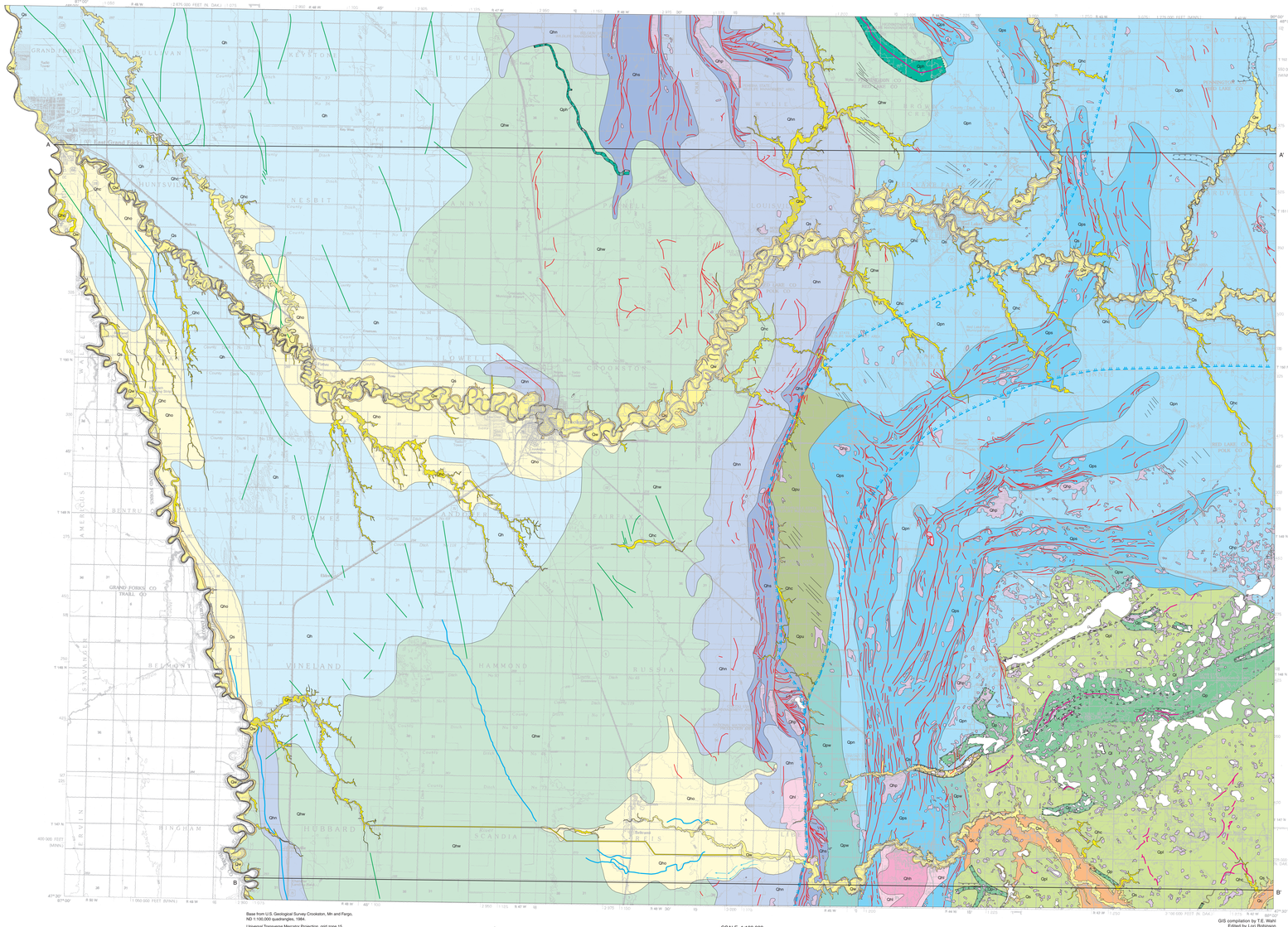
UNIVERSITY OF MINNESOTA
MINNESOTA GEOLOGICAL SURVEY
Harvey Thorleifson, Director

Prepared and Published with the Support of
THE U.S. GEOLOGICAL SURVEY AS PART OF THE 2005 STATE GEOLOGIC MAPPING PROGRAM ELEMENT (STATEMAP)
OF THE NATIONAL GEOLOGIC MAPPING PROGRAM

MISCELLANEOUS MAP SERIES
MAP M-173
Plate 2 —Quaternary Lithostratigraphic Map,
Crookston Quadrangle



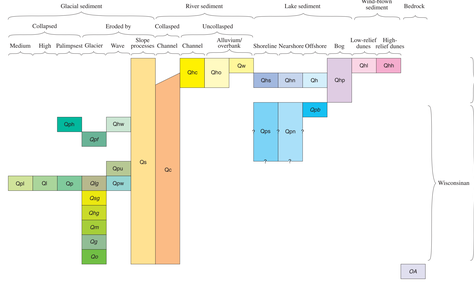
QUATERNARY GEOLOGY OF THE CROOKSTON 30' X 60' QUADRANGLE, NORTHWEST MINNESOTA

by
Kenneth L. Harris

2006

The University of Minnesota is an equal opportunity educator and employer

CORRELATION OF MAP UNITS



INTRODUCTION

This plate presents a lithostratigraphic interpretation of the surface and subsurface geology of the Crookston 30' x 60' quadrangle (Fig. 1). Lithostratigraphic units are defined by sediment type (lithology) and stratigraphic position. The lithostratigraphic map shows areas of surface exposure of these units and the cross sections show the interpreted spacial relationship. The basic data used for the lithologic interpretation consisted of: 1. Interpretation of aerial photography; 2. Field observations; 3. Interpretation of sample data contained in a regional database, QBASE (Minnesota Geological Survey, 2006b); and 4. General soils maps (Nikiforoff and others, 1939; U.S. Department of Agriculture, 1996). The basic data used for the stratigraphic interpretation consisted of: 1. Interpretation of sample data contained in a regional database, QBASE (Minnesota Geological Survey, 2006b); 2. Previous work in the Red River Valley (Harris, 1973, 1975, 1995, 1999; Harris and others, 1974, 1996; Moran and others, 1976; Arndt, 1977; Thorleifson and others, 2005); and 3. Interpretation of water-well and other data (Fig. 2) from field work and the Minnesota Geological Survey's County Well Index (Minnesota Geological Survey, 2006a). There are 29 lithostratigraphic units displayed on the surficial map and cross sections. The textural and lithologic attributes of the primary glacial units are given in Table 1.

Quaternary sediments were deposited in the map area by glacial ice, rivers, the wind, and gravity. Figure 1 shows the location of the map area and regional glacial and lacustrine events influencing the area. The two ice margins shown on the lithostratigraphic map and Figure 1 mark stable positions of glacial ice that deposited the Upper Red Lake Falls Formation (Upper Red Lake River group; ice margin 1) and the Huot Formation (Forest River group; ice margin 2). They do not necessarily mark glacial maximums, but probably indicate relatively short-lived recessional ice positions.

DESCRIPTION OF MAP AND CROSS SECTION UNITS

The descriptions of sediment texture and coarse-grained sand fraction lithology are shown below in parentheses using the following notations (percent sand-percent silt-percent clay) and (percent crystalline rock fragments-percent carbonate rock fragments-percent shale rock fragments). U.S. Department of Agriculture textural classification terms are used to describe sediment texture.

QUATERNARY PERIOD

The geologic period covering the last 2 million years, includes glacial and post-glacial epochs.

HOLOCENE EPOCH

The post-glacial period in which we now live (10,000 years ago to the present).

River sediment—Sediment deposited in river channels and on river flood plains.

Qw

Walsh Formation—Sand, silt clay, gravel, and organic debris; dark gray, generally dirty appearance; *alluvium* (Bluemle, 1973).

Sand, silt, clay, and disseminated organic debris—Obscurely bedded; dark colored; in many places associated with sand and gravel of older river-channel sediment; commonly more than 3 feet (1 meter) thick; *modern alluvium and overbank sediment*.

Qho

Sand, silt, clay—Obscurely bedded; dark colored; commonly more than 3 feet (1 meter) thick; deposited on the flood plains of ancient rivers and on the Glacial Lake Agassiz plain; *ancient alluvium and overbank sediment*.

Qhc

Sand and gravel—Moderately to poorly sorted; crossbedded to flatbedded; as much as 10 feet (3 meters) thick; *channel sediment deposited in modern rivers*.

Lake sediment—Deposited in poorly drained depressions in the landscape.

Organic debris, clay, and silt—Obscurely bedded; dark colored; generally more than 3 feet (one meter) thick. Thin peat deposits are not shown on cross sections. *Recent bog sediment*.

Windblown sediment—Silt and sand eroded, transported, and deposited by wind.

Qhh

Sand and silty sand—Medium- to fine-grained; generally well sorted; obscurely bedded; associated with older lake and river deposits; as much as 30 feet (10 meters) thick; *high-relief sand dunes*.

Qhl

Sand and silty sand—Medium- to fine-grained; generally well sorted; obscurely bedded; associated with older lake and river deposits; as much as 10 feet (3 meters) thick; *wind scoured surfaces and low-relief sand dunes*.

Lake sediment (Figs. 1, 3)—Deposited in the Lake Agassiz basin, south of glacial ice that occupied Red River lowland.

Sherack Formation—Clay, silty clay, silt, and sand; thinly laminated; clayey in the central part of the lake plain and silty toward the margins; light gray when unoxidized and yellowish-gray to olive-brown where oxidized; wood fragments are common at the base; *offshore lake sediment* (Ryan, 1973, 1975; Harris and others, 1974; Moran and others 1976; Arndt, 1977; Thorleifson and others, 2005).

Qh

Clay and silty clay—Laminations are generally only a few millimeters thick, but some of the silty beds are locally several centimeters thick, in some places the bedding has been deformed into folds a few feet high and several feet across; light gray where unoxidized and yellowish-gray to olive-brown where oxidized; as much as 100 feet (33 meters) thick; deposited in deep water; *Glacial Lake Agassiz offshore sediment*.

Qhs

Sand and silt with gravel ridges—Moderately to well sorted; plane bedded to crossbedded; as much as 18 feet (6 meters) thick; deposited along the shoreline of Glacial Lake Agassiz, commonly on eroded till; beach ridges and off shore bars are shown as line symbols; *Glacial Lake Agassiz shoreline sediment*.

Qhn

Silt, clay, and sand—Moderately to well sorted; flatbedded to crossbedded; light gray where unoxidized and yellowish-gray to olive-brown where oxidized; as much as 15 feet (5 meters) thick; deposited in shallow water; *Glacial Lake Agassiz nearshore sediment*.

Buried river sediment (Figs. 1, 3)—Deposited on early Lake Agassiz offshore sediment and buried by younger offshore sediment when Lake Agassiz re-flooded. Differential compaction between the lake clay and river sediment is expressed at the surface as compaction ridges.

Poplar River Formation—Sand; fine- to coarse-grained; and associated silt and clay; crossbedded; significant thicknesses of gravel are present in some areas; shown on the surface map using the compaction ridge line symbol; *compaction ridge; buried river sediment* (Harris and others, 1974; Moran and others, 1976; Arndt, 1977; Thorleifson and others, 2005).

HOLOCENE EPOCH AND OLDER

Qs

Sand, silt and clay—Unsorted; unbedded; commonly pebbly; steeply sloping and eroded by mass movement and slope wash; lithology reflects the up-slope material; colluvium is commonly present at the base of the steep slopes; *sediment eroded by slope processes*.

Qc

Sand and gravel—Moderately to poorly sorted; crossbedded to flatbedded; as much as 50 feet (15 meters) thick; *channel sediment deposited by meltwater rivers*.

PLEISTOCENE EPOCH

The most recent glacial epoch (2,000,000 to 10,000 years ago). All of the surface sediments mapped in the study area are thought to be less than 15,000 years old.

Lake sediment (Figs. 1, 3)—Deposited in the Lake Agassiz basin, south of glacial ice that occupied the Red River lowland.

Qpb

Brenna Formation (shown only on cross section A)—Clay; obscurely laminated to unbedded; dark gray to black; very high natural water content; very low shear strength; typically contains small, white, silty, calcareous fragments; slump prone; not exposed at the land surface in the map area; *offshore lake sediment* (Harris and others, 1974; Moran and others 1976; Arndt, 1977; Thorleifson and others, 2005).

Qps

Sand and silt with gravel ridges—Moderately to well sorted; plane bedded to crossbedded; as much as 18 feet (6 meters) thick; deposited along the shoreline of Glacial Lake Agassiz, commonly on eroded till; beach ridges and off shore bars are shown as line symbols; deposition of this unit was most likely associated with the Brenna Formation, but may in part be associated with the Wylie Formation; *Glacial Lake Agassiz shoreline sediment*.

Qpn

Silt, clay, and sand—Moderately to well sorted; flatbedded to crossbedded; light gray where unoxidized and yellowish-gray to olive-brown where oxidized; as much as 15 feet (5 meters) thick; deposition of this unit was most likely associated with the Brenna Formation, but may in part be associated with the Wylie Formation; *Glacial Lake Agassiz nearshore sediment*.

Forest River group (Figs. 1, 3)—Deposited northwest of ice margin 2 by glacier ice as a result of a readvance of the generally retreating Late Wisconsinan glacier in the Red River lowland.

Huot Formation—Pebble-clay; very few pebbles; unbedded; unsorted; massive; gray to very dark gray/ish-brown; high natural water content; low shear strength; slump prone; deposited near the ice margin, in or near the Glacial Lake Agassiz basin; lateral equivalent of the Falconer Formation; calcareous; average texture (7-23-70); average coarse-sand lithology (44-50-6); *glacial sediment* (Harris, 1973, 1975; Harris and others, 1974; Moran and others, 1976; Arndt, 1977; Thorleifson and others, 2005).

Qfhw

Clay-slightly pebbly—Unsorted; unbedded; contains very few pebbles; as much as 100 feet (30 meters) thick; flat to undulating surface with generally less than 6 feet (2 meters) of relief; *wave-eroded, low-relief glacial sediment*.

Qph

Clay-slightly pebbly—Unsorted; unbedded; contains very few pebbles; glacial sediment covering, but not obscuring, preexisting topography; buried meltwater channels are the most common feature present; may include exposures of sand and gravel; draped (palimpsest) features are visible on aerial photographs through the collapsed glacial sediment; deposited on an ice cored landscape; *collapsed glacial sediment draped over preexisting landscape*.

Falconer Formation—Pebbly clay-loam; unbedded; unsorted; massive; light gray; the lateral equivalent of the Huot Formation, deposited up glacier of the Huot Formation; average texture (27-40-33); average coarse-grained sand lithology (39-28-33); not present on the surface in the map area; *glacial sediment* (Harris and others, 1974; Moran and others, 1976; Arndt, 1977; Thorleifson and others, 2005).

Qpf

Clay-loam-pebbly (shown only on cross section A)—Unsorted; unbedded; contains cobbles and boulders; as much as 50 to 80 feet (15 to 24 meters) thick; deposited by glacial ice on an ice-cored, glaciated landscape; eroded by subsequent glacial events; *glacier-eroded glacial sediment*.

Lake sediment (Figs. 1, 3)—Deposited in the Lake Agassiz basin, south of glacial ice that occupied Red River lowland.

Wiley Formation—Clay and silt; generally thinly laminated (millimeters to centimeters); olive-gray to dark gray clay; light brownish-gray to olive-brown silt; in outcrops along the Red Lake River thickness ranges from 2 to 7 feet (0.6 to 2 meters); unit is not exposed at the land surface and is too thin to show on the cross sections; *Glacial Lake Agassiz offshore sediment* (Harris, 1973, 1975; Harris and others, 1974; Moran and others, 1976; Arndt, 1977; Thorleifson and others, 2005).

Red Lake River group (Figs. 1, 3)—Deposited by glacier ice as a result of a readvance of the generally retreating Late Wisconsinan glacier in the Red River lowland.

Upper Red Lake Falls Formation—Pebble-loam; unbedded; unsorted; conspicuous columnar jointing; brownish-gray to olive-brown; calcareous; average texture (36-40-24); average coarse-grained sand lithology (53-34-13); deposited north and west of ice margin 1 (or the Perley moraine; Fig. 1); *glacial sediment* (Harris, 1973, 1975; Harris and others, 1974; Moran and others, 1976; Arndt, 1977; Thorleifson and others, 2005).

Qpu

Loam-pebbly—Unsorted; unbedded; commonly contains cobbles and boulders; as much as 50 feet (15 meters) thick, but generally 15 to 30 feet thick (5 to 9 meters); unit has a flat to undulating surface commonly with a veneer of sand and gravel; generally less than 6 feet (2 meters) of relief; deposited by glacial ice on an ice-cored, glaciated landscape; eroded by waves of Glacial Lake Agassiz; *wave-eroded, low-relief glacial sediment*.

Lower Red Lake Falls Formation—Pebble-loam; unbedded; unsorted; massive; brownish-gray to olive-brown; calcareous; average texture (36-44-20); average coarse-grained sand lithology (56-40-4); deposited north of the Comstock moraine (Fig. 1); *glacial sediment* (Harris, 1973, 1975; Harris and others, 1974; Moran and others, 1976; Arndt, 1977; Thorleifson and others, 2005).

Qpl

Loam-pebbly—Unsorted; unbedded; commonly contains cobbles and boulders; generally more than 33 feet (10 meters) thick; undulating to rolling surface with 10 to 33 feet (3 to 10 meters) of relief; deposited by glacial ice on an ice-cored, glaciated landscape; *collapsed medium-relief glacial sediment*.

Qf

Loam-pebbly—Unsorted; unbedded; includes inclusions of sand and gravel; commonly contains cobbles and boulders; generally more than 33 feet (10 meters) of relief; deposited by glacial ice on an ice-cored, glaciated landscape; *collapsed high-relief glacial sediment*.

Qlp

Loam-pebbly—Unsorted; unbedded; glacial sediment covering, but not obscuring, preexisting topography; buried meltwater channels and broad areas of collapsed subglacial drainage are the most common feature present; may include exposures of sand and gravel; draped (palimpsest) features are visible on aerial photographs through the collapsed glacial sediment; deposited on an ice cored landscape; *collapsed glacial sediment draped over preexisting landscape*.

Qlg

Loam-pebbly (shown only on cross section B)—Unsorted; unbedded; includes inclusions of sand and gravel; contains abundant cobbles and boulders; as much as 70 feet (21 meters) thick; but generally 15 to 30 feet thick (5 to 9 meters); deposited by glacial ice on an ice-cored, glaciated landscape; eroded by subsequent glacial events; *glacier-eroded glacial sediment*.

Qpw

Loam-pebbly—Unsorted; unbedded; contains abundant cobbles and boulders; as much as 50 feet (15 meters) thick, but generally 15 to 30 feet thick (5 to 9 meters); flat to undulating surface commonly with a veneer of sand and gravel; generally less than 6 feet (2 meters) of relief; deposited by glacial ice on an ice-cored, glaciated landscape; eroded by waves of Glacial Lake Agassiz; *wave-eroded, low-relief glacial sediment*.

Goose River group (Figs. 1, 3)—Deposited by glacier ice as a result of a readvance of the generally retreating Late Wisconsinan glacier in the Red River lowland.

St. Hilaire Formation—Pebbly clay-loam; unbedded; unsorted; columnar structure or weak vertical jointing common; shale pebbles common; lignite fragments; gray to very dark gray; calcareous; average texture (31-42-27); average coarse-grained sand lithology (42-33-25); not present on the surface in the map area; *glacial sediment* (Harris, 1973, 1975, 1999; Harris and others, 1974, 2003; Moran and others, 1976; Arndt, 1977; Thorleifson and others, 2005).

Qhg

Clay-loam-pebbly (shown only on cross sections)—Unbedded; unsorted; includes inclusions of sand and gravel; contains cobbles and boulders; as much as 70 feet (21 meters) thick; but generally 15 to 30 feet thick (5 to 9 meters); deposited by glacial ice on an ice-cored, glaciated landscape; eroded by subsequent glacial events; *glacier-eroded glacial sediment*.

Hesberg formation—Pebbly clay-loam; unbedded; unsorted; massive; shale pebbles abundant; lignite fragments are common; dark olive-brown to very dark gray; calcareous; average texture (32-41-27); average coarse-grained sand lithology (32-25-43); not present on the surface of the map area; *glacial sediment* (Harris, 1995, 1999; Harris and others, 2003; Thorleifson and others, 2005).

Qhp

Clay-loam-pebbly (shown only on cross section A)—Unsorted; unbedded; contains cobbles and boulders; as much as 100 feet (33 meters) thick; deposited by glacial ice on an ice-cored, glaciated landscape; eroded by subsequent glacial events; *glacier-eroded glacial sediment*.

Qhh

Loam-pebbly (shown only on cross section A)—Silty, unbedded; unsorted; slightly pebbly; at least 30 feet (9 meters) thick, but unit thickness is not known; deposited by glacial ice on an ice-cored, glaciated landscape; eroded by subsequent glacial events; *glacier-eroded glacial sediment*.

Older glacial deposits

Qh

Older till (shown only on cross sections)—Glacial sediment present between the lowest recognized units and the interpreted top of the bedrock surface. Sedimentary character and thickness of the individual units is unknown. They are not present at the surface, in the map area. *Older glacier-eroded glacial sediment.*

ORDOVICIAN AND ARCHEAN

Bedrock

OA

Undifferentiated bedrock (shown only on cross sections)—Bedrock in the map area consists predominantly of weathered Precambrian igneous and metamorphic rocks; however, a thin layer of Ordovician Winnipeg Formation (sandstone and shale) overlies the Precambrian rocks in the western part of the map area (Ilrva and others, 1994, 1999).

MAP SYMBOLS

Geologic contacts:

Approximate—Judged to be within 0.25 mile (0.4 kilometer) of the true boundary along most of its length.

Inferred—Judged to be between 0.25 mile (0.4 kilometer) and 0.5 mile (0.8 kilometer) from the true boundary along most of its length.

Speculated—Judged likely to be more than 0.5 mile (0.8 kilometer) from the true boundary.

Beach ridge—Established from aerial photographs; line indicates the crest of the ridge; interpreted to be a beach ridge or offshore bar deposited along the margin of Glacial Lake Agassiz; discernible on topographic maps and on the ground.

Channel scour—Established from aerial photographs; the arrow indicates the probable direction of water flow. Interpreted to be anastomosing stream channels eroded during episodes of overland flow; generally not apparent on topographic maps or on the ground.

Compaction ridge—Established from aerial photographs; line marks the crest of the ridge located in the Glacial Lake Agassiz basin; interpreted to mark the location of stream sediment buried by lake sediment or thin glacial sediment; generally difficult to discern on topographic maps and on the ground.

Discontinuous channel—Established from aerial photographs; paired discontinuous scarps; lines indicate the crests of the scarps and hachures point downslope; interpreted to be an eroded or collapsed meltwater channel; generally apparent on topographic maps and on the ground.

Esker—Established from aerial photographs; line indicates the crest of a sinuous ridge, located in collapsed glacial sediment; interpreted to mark the location of a stream channel (commonly sand and gravel) that formed on top of, in, or under glacial ice; apparent on topographic maps, generally apparent on the ground.

Sharp-walled channel—Established from aerial photographs; paired sharp scarps; lines indicate the crests of the scarps and hachures point downslope; interpreted to be a meltwater channel; apparent on topographic maps and on the ground.

Palimpsest channel—Established from aerial photographs; lines indicate the crests of the scarps; half-circles indicate the downslope direction; interpreted to be a buried meltwater channel; generally apparent on topographic maps, may not be apparent on the ground.

Ice-drag mark—Established from aerial photographs; line marks the crest of a subtle ridge or the bottom of a subtle trough; located in the Glacial Lake Agassiz basin; interpreted to be iceberg drag marks preserved on the lake bed; generally difficult to discern on topographic maps and on the ground (Clayton and others, 1965).

Ice margin—Position established from aerial photographs, topographic cross section, and analysis of sediment samples; hachures point toward the glacier; interpreted to be the approximate position of a glacial margin; may mark a glacial maximum or recessional position; not generally discernible on topographic maps or on the ground.

Tunnel valley—Established from aerial photographs; lines indicate paired sharp scarps; ticks point downslope. Interpreted to be collapsed subglacial drainage channels. Apparent on topographic maps and on the ground.

Other lineation—Established from aerial photographs; line marks the long dimension of the feature; located in glacial sediment and thinly veneered glacial sediment; interpreted to be disintegration trenches, steam lined bedforms associated with the movement of glacial ice, or lineations of unknown origin; generally difficult to discern on topographic maps and on the ground.

REFERENCES

Arndt, B.M., 1977, Stratigraphy of offshore sediment Lake Agassiz–North Dakota: North Dakota Geological Survey, Report of Investigation 60, 58 p.

Ashworth, A.C., 1980, Environmental implications of a beetle assemblage from the Gervais Formation (Early Wisconsinan?), Minnesota: Quaternary Research, v. 13, p. 200-212.

Bluemle, J.P., 1973, Part I—Geology of Nelson and Walsh Counties, North Dakota: North Dakota Geological Survey Bulletin 57, pt. I, p. 70, 4 pls., scale 1:126,000.

Clayton, L., Laird, W.M., Klausen, R.W., and Kupsch, W.O., 1965, Intersecting minor lineations on the Lake Agassiz plain: Journal of Geology, v. 73, p. 652-656.

Clayton, L., and Moran, S.R., 1982, Chronology of Late Wisconsinan Glaciation in Middle North America: Quaternary Science Reviews, v. 1, p. 55-82.

Harris, K.L., 1973, Pleistocene stratigraphy of the Red Lake Falls area, Minnesota: Grand Forks, North Dakota, University of North Dakota, M.S. thesis, 117 p.

———1975, Pleistocene geology of the Grand Forks-Bemidji area, northwestern Minnesota: Grand Forks, N. Dak., University of North Dakota, Ph.D. dissertation, 142 p.

———project manager, 1995, Regional hydrogeologic assessment: Quaternary geology-southern Red River Valley, Minnesota: Minnesota Geological Survey Regional Hydrogeologic Assessment RHA-3, pt. A, 2 pls, scales 1:200,000 and 1:750,000.

———project manager, 1999, Regional hydrogeologic assessment: Quaternary geology-Otter Tail area, west-central Minnesota: Minnesota Geological Survey Regional Hydrogeologic Assessment RHA-5, pt. A, 2 pls, scales 1:200,000 and 1:400,000.

Harris, K.L., Moran, S.R., and Clayton, L., 1974, Late Quaternary stratigraphic nomenclature, Red River Valley, North Dakota and Minnesota: North Dakota Geological Survey Miscellaneous Series 52, 47 p.

Harris, K.L., Reid, J.R., and Luther, M.L., eds., 1996, Quaternary geology of the southern Lake Agassiz basin, North Dakota and Minnesota—Midwest Friends of the Pleistocene 43rd Annual Meeting: North Dakota Geological Survey Miscellaneous Series 82, 165 p.

Jirsa, M.A., Chandler, V.W., and Runkel, A.C., 1999, Bedrock geologic map of northwestern Minnesota: Minnesota Geological Survey Miscellaneous Map M-92, scale 1:200,000.

Jirsa, M.A., Runkel, A.C., and Chandler, V.W., 1994, Bedrock geologic map of northwestern Minnesota: Minnesota Geological Survey, Miscellaneous Map M-80, scale 1:250,000.

Johnson, M.D., 2000, unpublished compilation of Minnesota ice margins: St. Peter, Minn., Gustavus Adolphus College, Department, p. 1, scale 1:3,000,000.

Lusardi, B.A., Hobbs, H.C., and Patterson, C.J., 2002, Surface geology of the Fairbault 30 x 60 minute quadrangle, south-central Minnesota: Minnesota Geological Survey Miscellaneous Map M-130, scale 1:100,000.

Minnesota Geological Survey, 2006a, County Well Index–Crookston 30 x 60 Quadrangle: Minnesota Geological Survey, digital database.

———2006b, QBASE–Northwestern Minnesota: Minnesota Geological Survey, digital database.

Moran, S.R., Arndt, B.M., Bluemle, J.P., Camara, M., Clayton, L., Fenton, M.W., Harris, K.L., Hobbs, H.C., Keatinge, R., Sackreiter, D.K., Salomon, N.L., and Teller, J., 1976, Quaternary stratigraphy and history of North Dakota, southern Manitoba, and northwestern Minnesota, in Mahaney, W.C., ed., Quaternary stratigraphy of North America, Stroudsburg, Penn., Dowden, Hutchinson and Ross, p. 133-158.

Nikiforoff, C.C., Hasty, A.H., Swenson, G.A., Gray, A.L., Fieger, E.A., Hill, S., Newman, H.C., Mattson, C.H., Hilde, J.C., and Knoen, E., 1939, Soil Survey (reconnaissance), The Red River Valley area, Minnesota: U.S. Department of Agriculture, Bureau of Chemistry and Soils, series 1933, no. 25, Washington.

Patterson, C.J., project manager, 1999, Regional hydrogeologic assessment: Quaternary geology-Upper Minnesota River Basin: Minnesota Geological Survey Regional Hydrogeologic Assessment RHA-4, pt. A, 2 pls., scale 1:200,000.

Setterholm, D.R., project manager, 1995, Regional hydrogeologic assessment: Quaternary geology-Southwestern Minnesota: Minnesota Geological Survey Regional Hydrogeologic Assessment RHA-2, pt. A, 2 pls., scale 1:200,000.

Thorleifson, H., Harris, K.L., Berg, J., Tipping, R., Maltsbyegy, Z, Lusardi, B.A., Setterholm, D.R., and Anderson, F., 2005, Geologic mapping and 3D model of deposits that host ground-water systems in the Fargo-Moorhead region, Minnesota and North Dakota: Minnesota Geological Survey, Report submitted to the U.S. Department of the Interior, Bureau of Reclamation in fulfillment of Cooperative Agreement No. 04FG601925 in support of the Red River Valley Water Supply Project, 155 p., 2 pls., scales 1:200,000 and 1:400,000.

U.S. Department of Agriculture, 1996, General soils map of Polk County Minnesota: Natural Resources Conservation Service, Soil Survey Staff.

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

The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government. This map is submitted for publication with the understanding that the U.S. Government is authorized to reproduce and distribute reprints for governmental use. Supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program, under assistance Award No. 05HQAG0065.

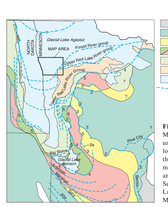


Figure 1. Occurrence of glacial sediment in western Minnesota and eastern North Dakota. Named lithostratigraphic units are associated with the Red River and Des Moines lobes only. Ice marginal positions are included to show the extent of Des Moines lobe ice and location of minor moraines developed by the receding glacial ice. Named and numbered ice margins are from Harris (1995, 1999), Setterholm (1995), Patterson (1999), Johnson (2000), and Lusardi and others (2002). Modified from Clayton and Moran (1982).

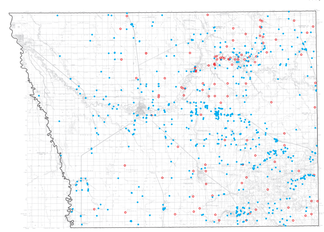


Figure 2. Location of water wells (•)and shallow test borings and river cut banks (o) used to construct the surficial geology map and cross sections.

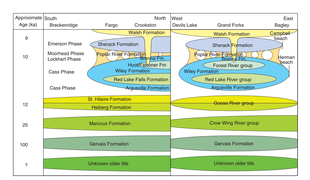


Figure 3. Event diagram showing a spacial and chronologic depiction of Lake Agassiz and glacial events in the Crookston map area.

Table 1. Summary of distinguishing characteristics of recognized glacial units in the Crookston map area; values in percent (xt = crystalline rocks fragments, co = carbonate rock fragments, sh = shale fragments).

	Huot Formation			Falconer Formation			Upper Red Lake Falls Formation			Lower Red Lake Falls Formation			St. Hilaire Formation			Hesberg formation			Marcoux Formation			Gervais Formation		
texture	sand 7	silt 23	clay 70	sand 27	silt 40	clay 33	sand 36	silt 40	clay 24	sand 36	silt 44	clay 20	sand 31	silt 42	clay 27	sand 32	silt 41	clay 27	sand 50	silt 35	clay 15	sand 28	silt 42	clay 30
	clay			clay loam			loam			loam			clay loam			clay loam			loam			clay loam		
coarse-grained sand composition	xt 44	co 50	sh 6	xt 39	co 28	sh 33	xt 53	co 34	sh 13	xt 56	co 40	sh 4	xt 42	co 33	sh 25	xt 32	co 25	sh 43	xt 75	co 22	sh 3	xt 45	co 53	sh 2
	low	low	high	medium	medium	medium	medium	medium	low	medium	medium	low	medium	medium	medium	medium	medium	medium	high	medium	low	medium	medium	medium
color, dry and wet	gray (5Y 5/1) to very dark grayish-brown (2.5Y 3/2)			light gray (5Y 5/1) to very dark gray (5Y 3/1)			brownish-gray (2.5Y 6/2) to olive-brown (2.5Y 4/4)			brownish-gray (2.5Y 6/2) to olive-brown (2.5Y 4/4)			gray (5Y 5/1) to very dark gray (10Y 3/2)			yellowish-brown (5Y 5/1) to very dark gray (10Y 3/2)			light gray (5Y 6/1) to grayish-brown (2.5Y 5/2)			light gray (5Y 6/1) to grayish-brown (2.5Y 5/2)		
	low 0-24	medium 25-49	high 50-74	very high 75-100																				