U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science Directorate
Geologic Resources Division

Saint Croix National Scenic Riverway

GRI Ancillary Map Information Document

Produced to accompany the Geologic Resources Inventory (GRI) Digital Geologic Data for Saint Croix National Scenic Riverway

sacn_geology.pdf

Version: 3/2/2026

Geologic Resources Inventory Map Document for Saint Croix National Scenic Riverway

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Geologic Resources Inventory Map Document

Saint Croix National Scenic Riverway, Wisconsin and Minnesota

Document to Accompany Digital Geologic-GIS Data

sacn_geology.pdf

Version: 3/2/2026

This document has been developed to accompany the digital geologic-GIS data developed by the Geologic Resources Inventory (GRI) program for Saint Croix National Scenic Riverway, Wisconsin and Minnesota (SACN).

Attempts have been made to reproduce all aspects of the original source products, including the geologic units and their descriptions, geologic cross sections, the geologic report, references and all other pertinent images and information contained in the original publication.

This document contains the following information:

1) **About the NPS Geologic Resources Inventory Program** – A brief summary of the Geologic Resources Inventory (GRI) Program and its products. Included are web links to the GRI GIS data model, and to the GRI products page where digital geologic-GIS datasets, scoping reports and geology reports are available for download. In addition, web links to the NPS Data Store and GRI program home page, as well as contact information for the GRI coordinator, are also present.

2) **GRI Digital Map and Source Citations** – The GRI digital geologic-GIS map produced for this project along with source maps used in its completion. In addition, a brief explanation of how each source map was used is provided.

3) **Map Unit List** – A listing of all geologic map units present on the map for this project, generally listed from youngest to oldest.

4) **Map Unit Descriptions** – Descriptions for all geologic map units. If a unit is present on multiple source maps the unit is listed with its source geologic unit symbol, unit name and unit age followed by the unit's description for each source map.

5) **Geologic Cross Sections** – Geologic cross section graphics with source geologic cross section abbreviations.

6) **Ancillary Source Map Information** – Additional source map information presented by source map. For each source map this may include a stratigraphic column, index map, map legend and/or map notes.

7) **GRI Digital Data Credits** – GRI digital geologic-GIS data and ancillary map information document production credits.

For information about using GRI digital geologic-GIS data contact:

Stephanie O'Meara
Geologist/GIS Specialist/Data Manager
Colorado State University Research Associate, Cooperator to the National Park Service
Fort Collins, CO 80523
phone: (970) 491-6655
email: stephanie_o'meara@partner.nps.gov

About the NPS Geologic Resources Inventory Program

Background

The Geologic Resources Inventory (GRI) provides geologic map data and pertinent geologic information to support resource management and science-informed decision making in more than 270 natural resource parks throughout the National Park System. Geologic resources for management consideration include both the processes that act upon the Earth and the features formed as a result of these processes. Geologic processes include: erosion and sedimentation; seismic, volcanic, and geothermal activity; glaciation, rockfalls, landslides, and shoreline change. Geologic features include mountains, canyons, natural arches and bridges, minerals, rocks, fossils, cave and karst systems, beaches, dunes, glaciers, volcanoes, and faults.

The GRI is one of 12 inventories funded by the National Park Service (NPS) Inventory and Monitoring Program. The Geologic Resources Division of the NPS Natural Resource Stewardship and Science Directorate administers the GRI. The NPS Geologic Resources Division partners with the Colorado State University Department of Geosciences to produce GRI products. Many additional partners participate in the GRI process by contributing source maps or reviewing products.

The GRI team undertakes three tasks for each park in the Inventory and Monitoring program: (1) conduct a scoping meeting and provide a summary document, (2) provide digital geologic map data in a geographic information system (GIS) format, and (3) provide a GRI report. These products are designed and written for nongeoscientists.

Products

Scoping Meetings: These park-specific meetings bring together local geologic experts and park staff to inventory and review available geologic data and discuss geologic resource management issues. A summary document is prepared for each meeting that identifies a plan to provide digital map data for the park.

Digital Geologic Maps: Digital geologic maps reproduce all aspects of traditional paper maps, including notes, legend, and cross sections. Bedrock, surficial, and special purpose maps such as coastal or geologic hazard maps may be used by the GRI to create digital Geographic Information Systems (GIS) data and meet park needs. These digital GIS data allow geologic information to be easily viewed and analyzed in conjunction with a wide range of other resource management information data.

For detailed information regarding GIS parameters such as data attribute field definitions, attribute field codes, value definitions, and rules that govern relationships found in the data, refer to the NPS Geology-GIS Data Model document available at: https://www.nps.gov/articles/gri-geodatabase-model.htm

Geologic Reports: GRI reports synthesize discussions from the original scoping meeting, follow up conference call(s), and subsequent research. Chapters of each report discuss the geologic setting of the park, distinctive geologic features and processes within the park, highlight geologic issues facing resource managers, and describe the geologic history leading to the present-day landscape. Each report also includes a poster illustrating these GRI digital geologic-GIS data.

For a complete listing of GRI products visit the GRI publications webpage: https://go.nps.gov/gripubs. GRI digital geologic-GIS data is also available online at the NPS Data Store: https://irma.nps.gov/DataStore/Search/Quick. To find GRI data for a specific park or parks select the appropriate park(s), enter “GRI” as a Search Text term, and then select the Search button.

For more information about the Geologic Resources Inventory Program visit the GRI webpage: https://www.nps.gov/subjects/geology/gri.htm. At the bottom of that webpage is a "Contact Us" link if you need additional information. You may also directly contact the program coordinator:

Jason Kenworthy
Inventory Coordinator
National Park Service Geologic Resources Division
P.O. Box 25287
Denver, CO 80225-0287
phone: (303) 987-6923
fax: (303) 987-6792
email: Jason_Kenworthy@nps.gov

The Geologic Resources Inventory (GRI) program is funded by the National Park Service (NPS) Inventory and Monitoring (I&M) Division. Learn more about I&M and the 12 baseline inventories at the I&M webpage: https://www.nps.gov/im/inventories.htm.

GRI Digital Map and Source Map Citations

The GRI digital geologic-GIS map for Saint Croix National Scenic Riverway, Wisconsin and Minnesota (SACN):

Digital Geologic-GIS Map of Saint Croix National Riverway and Vicinity, Wisconsin and Minnesota (*GRI MapCode SACN*)

> Clayton, Lee, 1985, Pleistocene Geology of the Superior Region, Wisconsin, Wisconsin Geological and Natural History Survey, Regional Map Series 3, scale 1:250,000 (Superior Region Pleistocene Geologic Map). (*GRI Source Map ID 3795*).

Data used from this source map was clipped to the quadrangles of interest for St. Croix NSR. See the index map below showing extents of map sources used. All features present in the clipped area were captured.

> Meyer, G. N., and Mossler, J. H., 1999, Primary Sources of Construction Aggregate in the Twin Cities Seven-County Metropolitan Area, Minnesota: Minnesota Geological Survey, Miscellaneous Map Series M-102, scale 1:100,000 (Twin Cities Construction Aggregate Map). (*GRI Source Map ID 33853*).

Data used from this source map was clipped to the quadrangles of interest for St. Croix NSR. See the index map below showing extents of map sources used. All features present in the clipped area were captured.

> Johnson, M. D., 2000, Pleistocene Geology of Polk County, Wisconsin: Wisconsin Geological and Natural History Survey, Bulletin 92, scale 1:100,000 (Polk County Pleistocene Geologic Map). (*GRI Source Map ID 50580*).

Data used from this source map was clipped to the quadrangles of interest for St. Croix NSR. See the index map below showing extents of map sources used. All features present in the clipped area were captured.

> Kostka, S. J., Hinke, D. M., Mickelson, D. M., and Baker, R. W., 2004, Preliminary Quaternary Geologic Map for St. Croix County, Wisconsin: Wisconsin Geological and Natural History Survey, Open-File Report 2004-22, scale 1:100,000 (St. Croix County Quaternary Geologic Map). (*GRI Source Map ID 75428*).

Data used from this source map was clipped to the quadrangles of interest for St. Croix NSR. See the index map below showing extents of map sources used. All features present in the clipped area were captured.

> Meyer, Gary N., 2007, Surficial Geology of the Twin Cities Metropolitan Area, Minnesota: Minnesota Geological Survey, Miscellaneous Map Series, M-178, scale 1:125,000 (Twin Cities Surficial Geologic Map). (*GRI Source Map ID 75549*).

Data used from this source map was clipped to the quadrangles of interest for St. Croix NSR. See the index map below showing extents of map sources used. All features present in the clipped area were captured.

> Alexander, E. Calvin Jr., and Tipping, Bob, 2002, Karst Features of Minnesota: Minnesota Geological Survey, scale 1:24,000 (Minnesota Karst Features). (*GRI Source Map ID 75564*).

Data used from this source map was clipped to the quadrangles of interest for St. Croix NSR. See the index map below showing extents of map sources used. All features present in the clipped area were captured.

Carson, E., Rawling, J. E., III, and Rose, C., 2017, Quaternary Geologic Map of Portions of the St. Croix National Scenic Riverway, Wisconsin: Wisconsin Geological and Natural History Survey, unpublished digital data, scale 1:100,000 (St. Croix NSR Quaternary Geologic Map). (*GRI Source Map ID 76097*).

The full extent of the source map above was used and all geologic features present in the source digital data were captured.

Minnesota Geological Survey, 2018, Quaternary Data Index: Minnesota Geological Survey, internal working digital database (version date, March, 2018) (Minnesota Quaternary Data Index). (*GRI Source Map ID 76136*).

Data used from this source map was clipped to the quadrangles of interest for St. Croix NSR. See the index map below showing extents of map sources used. All features present in the clipped area were captured.

Setterholm, Dale R., 2010, Geologic Atlas of Chisago County, Minnesota: Minnesota Geological Survey, County Atlas Series C-22 Part A (Plates 1, 3, 4, 6), scale 1:100,000 (Chisago County Geologic Map). (*GRI Source Map 76142*).

Data used from this source map was clipped to the quadrangles of interest for St. Croix NSR. See the index map below showing extents of map sources used. Source GIS data depicted on Plates 1 (Database Map), 3 (Surficial Geology), 4 (Quaternary Cross Sections), and 6 (Bedrock Topography) were used from this source in the production of the Surficial Geologic Map of St. Croix NSR.

Boerboom, T. J., 2001, Geologic Atlas of Pine County, Minnesota: Minnesota Geological Survey, County Atlas Series C-13 Part A (Plates 1, 4, 5, 6), scale 1:100,000 (Pine County Geologic Map). (*GRI Source Map ID 52582*).

Data used from this source map was clipped to the quadrangles of interest for St. Croix NSR. See the index map below showing extents of map sources used. Source GIS data depicted on Plates 1 (Database Map), 4 (Surficial Geology), 5 (Quaternary Cross Sections), and 5 (Mineral Endowment) were used from this source in the production of the Surficial Geologic Map of St. Croix NSR.

Bauer, Emily J., Chandler, V.W., Steenberg, J.R., Retzler, A.J., Stanley, V.L., Meyer, G.N., and Lively, R.S., 2016, Geologic Atlas of Washington County, Minnesota: Minnesota Geological Survey, County Atlas Series C-39 Part A (Plates 3, 4, 6), scale 1:100,000 (Washington County Geologic Map). (*GRI Source Map ID 80002*).

Data used from this source map was clipped to the quadrangles of interest for St. Croix NSR. See the index map below showing extents of map sources used. Source GIS data depicted on Plates 3 (Surficial Geology), 4 (Quaternary Stratigraphy), and 6 (Depth to Bedrock) were used from this source in the production of the Surficial Geologic Map of St. Croix NSR.

National Park Service Water Resources Division, 2000, Saint Croix National Scenic River Small-scale Base GIS Data: National Park Service, Publication Date: 2000, scale 1:100,000 (St. Croix NSR Hydro Database). (*GRI Source Map ID 76264*).

This data was included to provide a consistent representation of the St. Croix River. Data used from this

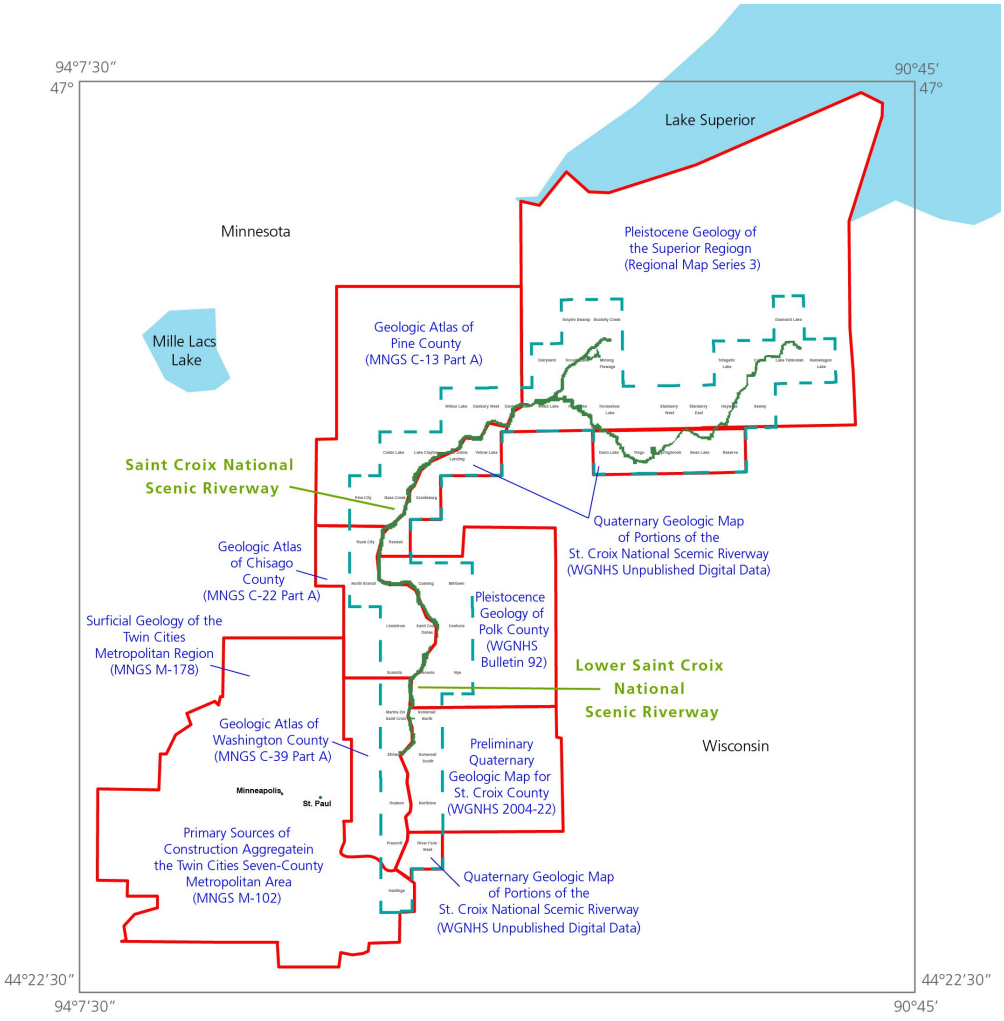
source map was clipped to the quadrangles of interest for St. Croix NSR. See the index map below showing extents of map sources used. Only the St. Croix River was extracted from this dataset.

Additional information pertaining to each source map is also presented in the GRI Source Map Information (SACNMAP) table included with the GRI digital geologic-GIS data.

Index Map

The index map below shows the extent of the GRI Digital Geologic-GIS Map of St. Croix National Scenic Riverway, Minnesota and Wisconsin, as well as 7.5' quadrangles that comprise and define the map extent (turquoise dotted lines with gray shading). The riverway boundary (as of July, 2025) is presented in green. The index map also displays the extent of source maps used in completion of the map. Red solid outlines show source map extents labeled with source map titles and series numbers (e.g., MNGS C-22 Part A).

Three additional source datasets were also used in completion of the GRI digital geologic-GIS data, however, these sources are not shown due their larger extents. These datasets are: "Karst Features of Minnesota" produced by the Minnesota Geological Survey (data covers entire state), the "Quaternary Data Index" produced by the Minnesota Geological Survey (data covers Pine and Chisago Counties and the seven counties area surrounding Minneapolis/St. Paul), and the "St. Croix NSR Small-Scale GIS Data" produced by the NPS Water Resources Division (data covers the St. Croix River for the entire extent of St. Croix NSR).



Index map by Dalton Meyer and updated by James Chappell (Colorado State University).

Map Unit List

The geologic units present in the digital geologic-GIS data produced for Saint Croix National Scenic Riverway, Wisconsin and Minnesota (SACN) are listed below. Units are listed with their assigned unit symbol and unit name (e.g., Qp - Peat and muck). Units are listed from youngest to oldest. No description for water is provided. Information about each geologic unit is also presented in the GRI Geologic Unit Information (SACNUNIT) table included with the GRI digital geologic-GIS data. Some source unit symbols, names and/or ages may have been changed in this document and in the GRI digital geologic-GIS data. This was done if a unit was considered to be the same unit as one or more units on other source maps used for this project, and these unit symbols, names and/or ages differed. In this case a single unit symbol and name, and the unit's now recognized age, was adopted. Unit symbols, names and/or ages in a unit descriptions, or on a correlation of map units or other source map figure were not edited. If a unit symbol, name or age was changed by the GRI the unit's source map symbol, name and/or age appears with the unit's source map description.

Cenozoic Era

Quaternary Period
Qp - Peat and muck
Qsp - Postglacial stream sediment
Qlp - Postglacial lake sediment
Qhc - Steep-slope and slope deposits
Qhe - Stream-eroded surface deposits
Qa - Gravelly sand, clay, and silt
Qpgs - Postglacial sand and silt
Qf - Alluvial fan deposit
Ql - Silt, clay, and sand
Qfg - Gravelly sand
Qm - Marl
Qws - Windblown sand

Peoria Formation
- Qpe - Peoria formation, silt
- Qps - Peoria formation, eolian sand

Qma - Sandy alluvium and slopewash
Qmc - Bedrock colluvium

West Campus Formation
- Qwsm - West Campus Formation, St. Mary's terrace
- Qwg - West Campus Formation, Grey Cloud terrace
- Qwl - West Campus Formation, Langdon terrace
- Qwr - West Campus Formation, Richfield terrace

New Brighton Formation
- Qbg - New Brighton Formation, sand and gravel facies
- Qbs - New Brighton Formation, sand facies
- Qbc - New Brighton Formation, silt and clay facies

Miller Creek Formation
- Qsps - Miller Creek Formation, spillway sediment
- Qb - Miller Creek Formation, shoreline sediment
- Qgw - Miller Creek Formation, wave-planted topography

Qst - Terraces

Trade River Formation
- Qgtr - Trade River Formation, glacial sediment
- Qgtm - Trade River Formation, moraine ridges
- Qstv - Trade River Formation, stream sediment
- Qoti - Trade River Formation, ice-dammed-lake plains
- Qsto - Trade River Formation, Osceola bench

New Ulm Formation
- Qnd - New Ulm Formation, Twin Cities Member
- Qno - New Ulm Formation, Twin Cities Member, fine-grained sand and gravelly sand
- Qnl - New Ulm Formation, Twin Cities Member, fine-grained sand, silt, and clay
- Qnt - New Ulm Formation, Twin Cities Member, diamicton
- Qni - New Ulm Formation, ice-contact stratified deposit
- Qnm - New Ulm Formation, loamy till (moderate-relief)
- Qna - New Ulm Formation, sandy till

Qoc - Offshore clay

Copper Falls Formation
- Qgs - Copper Falls Formation, Sylvan Lake Member, glacial sediment
- Qssp - Copper Falls Formation, Sylvan Lake Member, pitted outwash plains
- Qssh - Copper Falls Formation, Sylvan Lake Member, hummocks deposited by meltwater from the Superior Lobe
- Qssv - Copper Falls Formation, Sylvan Lake Member, valleys
- Qusn - Copper Falls Formation, Sylvan Lake Member, flat to low-relief-hummocky landscape
- Qush - Copper Falls Formation, Sylvan Lake Member, hummocky topography underlain by till
- Qnsi - Copper Falls Formation, Sylvan Lake Member, nearshore deposits
- Qosi - Copper Falls Formation, Sylvan Lake Member, offshore deposits
- Qcfd - Copper Falls Formation, diamicton
- Qcfdb - Copper Falls Formation, diamicton, steep hill slopes in areas of deeply dissected drainage
- Qcfsp - Copper Falls Formation, sand and gravel in outwash deposits, less than 20 percent collapsed surface
- Qcfspp - Copper Falls Formation, sand and gravel in outwash deposits, 20 to 50 percent collapsed surface
- Qcfsh - Copper Falls Formation, sand and gravel in outwash deposits, more than 50 percent collapsed surface
- Qcfsb - Copper Falls Formation, sand and gravel in outwash deposits, steep hill slopes in areas of deeply dissected drainage
- Qcfsl - Copper Falls Formation, silt and sand
- Qsu - Copper Falls Formation, uncollapsed meltwater stream sediment
- Qsuf - Copper Falls Formation, uncollapsed proglacial stream sediment, Swiss surface
- Qsug - Copper Falls Formation, uncollapsed proglacial stream sediment, Hayward surface
- Qsuh - Copper Falls Formation, uncollapsed proglacial stream sediment, Tiger Cat surface
- Qsc - Copper Falls Formation, collapsed meltwater stream sediment
- Qsg - Copper Falls Formation, hummocky stream sediment overlain by silty material
- Qgg - Copper Falls Formation, thin mass-movement till
- Qgsm - Copper Falls Formation, subglacially molded topography
- Qgt - Copper Falls Formation, glacial thrust masses

Cromwell Formation
- Qci - Cromwell Formation, ice-contact stratified deposit
- Qcl - Cromwell Formation, fine-grained sand, silt, and clay
- Qco - Cromwell Formation, sand to gravel
- Qcc - Cromwell Formation, lake clay and silt
- Qcs - Cromwell Formation, till, sand, and gravel
- Qct - Cromwell Formation, diamicton
- Qcd - Cromwell Formation, subglacial till

Qse - Meltwater-stream sediment in eskers
Qsd - Meltwater-stream sediment in deltas

River Falls Formation
- Qrc - River Falls Formation, complex of diamicton, sand, and gravel
- Qrfd - River Falls Formation, diamicton
- Qrd - River Falls Formation, complex of sand, gravel, and till

Pierce Formation
- Qpo - Pierce Formation, sand and gravel
- Qpt - Pierce Formation, diamicton
- Qpc - Pierce Formation, till, colluvium mantle
- Qgh - Pierce Formation, Hersey Member, glacial sediment

Qh - Hillslope deposit
Qgm - Glacial sediment of end moraines
Qggm - Glacial sediment with stream- and lake-modified surface
Qggs - Glacial sediment and pond sediment accumulated in intermorainic swales
Qgss - Stream sediment of the Grantsburg sublobe
Qgls - Lake sediment of glacial Lake Grantsburg, sandy sediment
Qglf - Lake sediment of glacial Lake Grantsburg, silty and sandy sediment
Qglc - Lake sediment of glacial Lake Grantsburg, silty and clayey sediment
Qss - Stream sediment of the Superior lobe
Qssi - Sorted sediment proximate to ice
Qssm - Sandy glacial sediment in moraine ridges
Qsgs - Sandy glacial sediment
Qsgw - Wave-washed glacial sediment
Qsll - Lake sediment of glacial Lake Lind

Paleozoic Era

PZr - Undefined Paleozoic rock

Ordovician and Cambrian Periods
OCu - Bedrock at or near the surface
OCo - Bedrock outcrop
Osp - St. Peter Sandstone
Opc - Prairie du Chien Group
OCub - Bedrock, undivided

Precambrian Supereon

CPRrs - Oronto and Bayfield Groups
PCc - Outcrops of Precambrian basalt of the Chengwatana Group

PRmc - Clam Falls volcanics
PRrv - Middle Proterozoic volcanic rock
PRri - Middle Proterozoic intrusive rock

Map Unit Descriptions

Descriptions of all geologic map units, generally listed from youngest to oldest, are presented below. The order of some units has been changed to keep units from the same formation together.

Qp - Peat and muck (Holocene and late Pleistocene)

Qp - Peat and muck (Quaternary)
Partially decomposed plant matter deposited in marshes, commonly formed in ice-block melt-out depressions and in former meltwater channels. Generally mapped only where greater than 4 feet (1.3 meters) thick. Includes fine-grained organic matter laid down in ponded water, and marl (calcareous clay) at depth in places. Also includes narrow deposits of alluvium along streams, narrow beach deposits, and small bodies of open water. In developed areas, many of these deposits have been buried under artificial fill; the organic sediment is commonly removed prior to filling in areas where major structures are built. Description from source map: Chisago County Geologic Map

Qho - Organic deposits (Holocene and late Pleistocene)
Peat and organic-rich sediment deposited in marshes and shallow lakes. Typically found in depressions interpreted to have formed through melting of buried glacial ice and along former glacial stream channels. Some deposits have been drained. Description from source map: Pine County Geologic Map

pt - Marshes and wetlands (age unspecified)
Marshes and wetlands composed of peat and muck. Description from source map: Polk County Pleistocene Geologic Map

O - Postglacial organic sediment (age unspecified)
Peat and muck generally found in low areas of the landscape, near lakes, rivers and other depressions; underlain by deposits of streams, glaciers, or lakes. Description from source map: St. Croix County Quaternary Geologic Map

p - Peat and Muck (Holocene)
Organic sediment overlying the adjacent map units; low-lying, typically wet, flat to very low relief surfaces. May include areas of postglacial stream sediment and windblown sand (units sp and ws). Description from source map: St. Croix NSR Quaternary Geologic Map

p - Postglacial deposits, organic sediment (age unspecified)
Peat; less than 1 m thick in some areas, but typically probably a few meters thick. Low-lying, flat swamps, bogs, and marshes. Most deposited since about 10,000 B.P. Description from source map: Superior Region Pleistocene Geologic Map

Qp - Peat and muck (Quaternary)
Partially decomposed plant matter deposited in marshes. Includes fine-grained organic matter laid down in ponded water, and marl (calcareous clay) at depth in places. Also includes narrow deposits of alluvium along streams, narrow beach deposits, and small bodies of open water. In developed areas, many of these deposits have been buried under artificial fill (Meyer, 1985; Meyer and Hobbs, 1989; Lusardi, 1999); the organic sediment is commonly removed prior to filling in areas where major structures are built. Description from source map: Twin Cities Surficial Geologic Map

Qp - Peat and muck (Holocene and late Pleistocene)
Massive, dark brown, fine- and coarse-grained organic material found in post-glacial land surface depressions, on alluvial floodplains, and on glaciofluvial terraces; commonly underlain by lake sediments. Wetland sediment. Sediments deposited after approximately 14,000 cal yr BP (includes

modern, Holocene [after 11,700 cal yr BP], and Late Pleistocene material; Marine Isotope Stage 1). Description from source map: Washington County Geologic Map

Qsp - Postglacial stream sediment (Holocene)

Qhs - Stream sediment (Holocene and late Pleistocene)
Sand, gravel, and silt deposited by modern streams. May include minor organic deposits; includes areas of steep slopes created by stream incision. Description from source map: Pine County Geologic Map

sp - Post Glacial Stream Sediment (Holocene)
Silty and sandy sediment deposited by postglacial streams; flat to low-relief floodplains. Mapped where extensive; present but unmapped adjacent to most streams. Description from source map: St. Croix NSR Quaternary Geologic Map

sm - Postglacial deposits, Stream sediment (age unspecified)
Sand and gravel (channel deposits); generally more than 1 m thick. In many places overlain by silt and clay (overbank deposits) or peat. Floodplains of modern streams. Most deposited since about 10,000 B. P. Description from source map: Superior Region Pleistocene Geologic Map

Qlp - Postglacial lake sediment (Holocene)

lp - Post Glacial Lake Sediment (Holocene)
Sandy and gravelly wave-washed nearshore sediment deposited along the shores of postglacial lakes occupying collapse depressions. May include areas of organic sediment (unit Qho). Description from source map: St. Croix NSR Quaternary Geologic Map

Qhc - Steep-slope and slope deposits (Holocene)

Qhc - Steep-slope and slope deposits (Holocene and late Pleistocene)
Steep slopes mainly along incised streams where older glacial sediment and bedrock may be exposed but typically partially covered with debris shed from slopes. Description from source map: Pine County Geologic Map

hs - Steep slopes (age unspecified)
Steep slopes with gullies and scarps along margins of St. Croix River valley and its tributaries and along the Horse Creek channel; composed predominantly of unlithified sediment. Paleozoic bedrock exposed along St. Croix River valley at Osceola and farther south; formed by fluvial and hillslope erosion. Description from source map: Polk County Pleistocene Geologic Map

Qhe - Stream-eroded surface deposits (Holocene and late Pleistocene)

Qhe - Stream-eroded surface deposits (Holocene and late Pleistocene)
Coarse sand and gravel stream deposits of the Kettle and St. Croix Rivers and erosional (strath) terraces exposing older glacial sediment or bedrock. Related to drainage of glacial lakes Duluth and Nemadji. Thickness of sand and gravel varies and is thickest in bar forms. In areas of thin to no sand and gravel the underlying unit exposed by erosion is commonly glacial sediment but may also be glacial-lake sediment and bedrock. Description from source map: Pine County Geologic Map

Qa - Gravelly sand, clay, and silt (Holocene and late Pleistocene)

Qa - Floodplain alluvium (Quaternary)
Sediment of modern rivers. Typically coarser-grained (sand and gravel) in the channels, and finer-grained (fine-grained sand and silt) on floodplains. Generally coarsens with depth. Wider areas are typically topped and interbedded with thin, organic-rich layers, and some depressions within the floodplains have been filled with thick, silty to clayey sediment. Unit consists chiefly of sand along the St. Croix and Sunrise Rivers, commonly overlain by about 5 feet (1.5 meters) of sandy loam to loamy sand, with interbeds of organic-rich layers; gravelly in some places. Contacts with other map units (except peat) are at the base of scarps along all narrow deposits of tributary streams of the St. Croix River. Description from source map: Chisago County Geologic Map

sm - Modern floodplains (age unspecified)
Modem floodplains predominantly composed of noncalcareous sand, with some gravel and finer sediment deposited by modern streams. Description from source map: Polk County Pleistocene Geologic Map

Qa - Floodplain alluvium (Quaternary)
Sediment of modern rivers. Typically coarser-grained (sand and gravel) in the channels, and finer-grained (fine-grained sand and silt) on floodplains. Mississippi River alluvium above downtown St. Paul consists of generally less than 6 feet (2 meters) of silt loam to loamy sand overlying sand, gravelly sand, or cobbly gravel, with scattered wood and shell fragments. Alluvium downstream from St. Paul and in the Minnesota River valley is generally finer-grained, consisting of a mixture of silt and clay with variable amounts of very fine-grained sand and organic matter. Coarser-grained sediment is present in places along the channel. Sand is chiefly present within the floodplain of the St. Croix and Vermillion Rivers, commonly overlain by about 5 feet (1.5 meters) of sandy loam to loamy sand, with interbeds of organic-rich layers; gravelly in some places. Alluvium of smaller streams is generally sandy but finer-grained than that of the larger streams, and is typically topped and interbedded with thin, organic-rich layers. Some depressions within the floodplains have been filled with thick silty to clayey sediment. Covered by thick artificial fill in developed areas. Contacts with other map units are commonly at the base of scarps. Description from source map: Twin Cities Surficial Geologic Map

Qa - Gravelly sand, clay, and silt (Holocene and late Pleistocene)
Very coarse- to very fine-grained sediment found in modern rivers and streambeds. Coarser-grained sediments (gravelly sands) occupy river channels and streambeds, finer-grained sediments (clays and silts) mostly occupy floodplains. Can be interbedded with peat, contains modern fluvial plant and faunal macrofossils. Sediments deposited by modern rivers and streams. Can be less than 10.0 feet (3.0 meters) thick over bedrock, and outcrops are common along major rivers (unit OCo). Alluvium. Sediments deposited after approximately 14,000 cal yr BP (includes modern, Holocene [after 11,700 cal yr BP], and Late Pleistocene material; Marine Isotope Stage 1). Description from source map: Washington County Geologic Map

Qpgs - Postglacial sand and silt (Holocene)

A - Postglacial sand and silt (age unspecified)
Commonly a mixture of sand, silt and clay with various amounts of organic matter; found mostly along edges of modern streams and rivers as flood plain and low fluvial terraces; boundaries between this unit and postglacial organic sediment have been drawn arbitrarily in many places. Description from source map: St. Croix County Quaternary Geologic Map

Qf - Alluvial fan deposit (Holocene)

Qf - Alluvial fan deposit (Quaternary)
Slopewash and stream sediment consisting of loam to loamy fine-grained sand, with beds of silt loam, silty clay loam, fine-grained sand, and gravel. Lithology reflects the material upslope from which the sediment was derived. Contains variable amounts of disseminated organic debris. Unit was deposited at the base of steep slopes and at the mouths of deep gullies. Description from source map: Chisago County Geologic Map

Qf - Alluvial fan deposit (Quaternary)
Slopewash sediment consisting of loam to loamy fine-grained sand, with beds of silt loam, silty clay loam, fine-grained sand, and gravel. Lithology reflects material upslope from which the sediment was derived. Unit contains variable amounts of disseminated organic debris. Deposited at the base of steep slopes and at the mouths of deep gullies. Description from source map: Twin Cities Surficial Geologic Map

Ql - Silt, clay, and sand (Holocene and late Pleistocene)

Ql - Lacustrine deposit (Quaternary)
Sand, loamy sand, and loam, with local organic-rich layers; includes human-made beaches. In places overlies muck or peat. The width of exposure varies depending on the water level in the lake. Many deposits along the edges of lakes and bogs are too narrow to be shown. Description from source map: Chisago County Geologic Map

Ql - Lacustrine deposits (Quaternary)
Sand, loamy sand, and loam, with local organic-rich layers; includes human-made beaches. In places overlies muck or peat. Covered by thick, artificial fill in developed areas. Width of exposure varies depending on the water level in the lake. Many deposits along the edges of lakes and bogs are too narrow to be shown. Description from source map: Twin Cities Surficial Geologic Map

Ql - Silt, clay, and sand (Holocene and late Pleistocene)
Very fine-grained organic matter (sapropel), to organicrich, massive, dark brown, silty clays and clayey silts, and sand found in modern lake basins, along lakeshores, and beneath wetland sediment (unit Qp). Unit is 12.4 feet (3.8 meters) thick at the depositional center of White Bear Lake (Jones and others, 2013). Consists of sediments deposited in non-flowing water. Sediments become more clastic with depth and can be laminated. Slumping is common at the edges of steep sided basins within unconsolidated glacial sediments. Includes shoreline sediments deposited by wave action, interbedded with sapropel at depth due to past lake level fluctuations. Lakeshore beach sediment can be sandy, especially where lakes are within outwash plains (units Qno, Qco). Map unit includes human-made beaches. Lacustrine deposits. Sediments deposited after approximately 14,000 cal yr BP (includes modern, Holocene [after 11,700 cal yr BP], and Late Pleistocene material; Marine Isotope Stage 1). Description from source map: Washington County Geologic Map

Qfg - Gravelly Sand (Holocene and late Pleistocene)

Qf - Gravelly Sand (Holocene and late Pleistocene)
Very coarse- to very fine-grained sand, mainly gravelly sand. Occurs as flat plains (benches) at different

elevations separated by very steep slopes (scarps). Modern rivers occupy low elevation benches. Sediment is less than 10.0 feet (3.0 meters) thick where bedrock is near the surface and over 125.0 feet (38.0 meters) thick in depositional terraces. Consists of sediments deposited by glacial Rivers St. Croix and Warren. Glaciofluvial terrace deposits. Sediments deposited after approximately 14,000 cal yr BP (includes modern, Holocene [after 11,700 cal yr BP], and Late Pleistocene material; Marine Isotope Stage 1). Description from source map: Washington County Geologic Map

Qm - Marl (Holocene)

Qm - Marl (Quaternary)
Calcareous clay deposited in ponded water; mollusk shells are common. Generally greater than 3 feet (1 meter) thick; covered by 1 to 4 feet (0.3 to 1.2 meters) of peat. Description from source map: Chisago County Geologic Map

Qws - Windblown sand (Holocene)

Qe - Eolian sand (Quaternary)
Very fine- to medium-grained sand; more than 3 feet (1 meter) thick; windblown into low-lying dunes. Description from source map: Chisago County Geologic Map

ws - Windblown Sand (Holocene)
Fine to medium grained windblown sand; more than 1.5 m thick; dunes typically have 5-6 meters of relief. Some dunes are likely modified levees of former meltwater stream channels. May include areas of organic sediment (unit Qho). Description from source map: St. Croix NSR Quaternary Geologic Map

Peoria Formation

(Peoria Silt of Hansel and Johnson, 1996)—Eolian sediment. Eroded by wind from outwash surfaces and older till surfaces, transported and deposited generally southeast of its source areas. Mapped as a stipple pattern only where thicker than 5 feet (1.5 meters), but thin, unmapped Peoria formation overlies much of the southeast portion of the map area. Loess is the predominant facies of this formation. Description from source map: Twin Cities Surficial Geologic Map

Qpe - Peoria Formation, silt (Holocene and late Pleistocene)

Loess - Peoria formation, Loess (Quaternary)
Chiefly silt, but includes minor amounts of very fine-grained sand and clay. The latter was probably deposited as silt-sized aggregates. Underlain and interbedded with eolian sand in places. Description from source map: Twin Cities Surficial Geologic Map

Qpe - Peoria formation, silt (Holocene and late Pleistocene)
Massive, brown silt that drapes many other units and geomorphic features, but mostly found on topographically high ground, about 1.5 to 6.0 feet (0.5 to 1.8 meters) thick; eolian sediment blown by katabatic winds from glacial river floodplains, outwash plains, and dry lakebeds. Loess. Sediments deposited during the Late Pleistocene Epoch during the Last Glacial Maximum during the Wisconsinan glaciation (about 33,000 to 13,300 cal yr BP; Marine Isotope Stage 2). Description from source map: Washington County Geologic Map

Qps - Peoria Formation, eolian sand (Pleistocene)

Eolian sand - Peoria formation, Eolian sand (Quaternary)
Fine- to medium-grained; lacks gravel; unbedded. Description from source map: Twin Cities Surficial Geologic Map

Qma - Sandy alluvium and slopewash (Pleistocene)

Qma - Sandy alluvium and slopewash (Quaternary)
Sand and gravelly or loamy sand; deposited in valleys and gently sloping plains above the level of outwash plains. Deposited as a response to a rising base level, as the Mississippi River and its tributaries were filling with outwash. Sediment was derived from adjacent uplands, which were eroding in response to reduced vegetation during the Michigan Subepisode. Pebble assemblage is a mixture of local bedrock fragments from valley walls and erratics derived from old glacial sediments on the uplands. Water was supplied by precipitation rather than melting of glacial ice. Commonly stands above modern floodplains as terraces, but also underlies modern alluvium in the same valleys. Where this unit merges downslope with outwash, commonly includes fine-grained slackwater sediment near the junction. Description from source map: Twin Cities Surficial Geologic Map

Qmc - Bedrock colluvium (Pleistocene)

Qmc - Bedrock colluvium (Quaternary)
Angular, unsorted fragments of local bedrock, commonly overlain by massive to crudely bedded silt that contains a few angular rock clasts. Rock fragments were derived by mechanical weathering from the hillslopes above; silt was deposited as mudflow and slopewash from loess on the uplands. Deposited chiefly at the foot of steep bedrock slopes; the thickness of both units typically diminishes upslope. Generally mapped to the top of the steep slopes; in the upper parts of the slopes, both layers are thin and bedrock outcrops are common. Description from source map: Twin Cities Surficial Geologic Map

West Campus Formation

(Meyer, 1999; Meyer and Patterson, 1999)—Sand and gravelly sand of mixed Riding Mountain and Superior provenance (Table 1). Coarsens to cobbly gravel in places. Laid down during early, higher stages of the St. Croix River, and preserved in terraces above the modern floodplain. The West Campus formation is mapped at four major terrace levels, described from youngest (lowest) to oldest (highest above the modern river). Description from source map: Chisago County Geologic Map

(Meyer, 1999; Meyer and Patterson, 1999; Meyer and Lusardi, 2000)—Fluvial sand and gravelly sand of mixed provenance (Table 1). In general, shale clast content increases upstream and up-section. Coarsens to cobbly gravel in places. Laid down during early, higher stages of the Mississippi, Minnesota, and St. Croix Rivers, and preserved in terraces above the modern floodplain. During these early stages, the rivers served as outlet streams for retreating glacial ice lobes and various glacial lakes (Meyer, 1998). The West Campus formation is mapped at four major terrace levels. A pattern indicates areas where bedrock is generally within 10 feet (3 meters) of the surface. Boulder lags are common at the contact with bedrock. Description from source map: Twin Cities Surficial Geologic Map

Qwsm - West Campus Formation, St. Mary's terrace (Pleistocene)

Qws - West Campus formation, St. Mary's terrace (Quaternary)
Clasts are mostly of Superior provenance. The terrace is about 10 to 30 feet (3 to 9 meters) above floodplain level, at an elevation of about 710 feet (216 meters). It does not extend above the dam at Taylors Falls. In its only location in the county, within Interstate State Park, the terrace has subsequently been partially buried by an alluvial fan. Description from source map: Chisago County Geologic Map

Qws - West Campus formation, St. Mary's terrace (Quaternary)
(Meyer, 1999)—The terrace is 10 to 30 feet (3 to 9 meters) above floodplain level, rising from an elevation of about 700 feet (213 meters) at the east edge of the map to about 725 feet (221 meters) in the Minnesota River valley. Upstream from Belle Plaine the terrace merges with and is buried by the modern floodplain. It is not present in the Mississippi River valley above St. Anthony Falls in Minneapolis. Most contacts with other map units (except peat, unit Qho, and alluvium, unit Qa) are scarps. Description from source map: Twin Cities Surficial Geologic Map

Qwg - West Campus Formation, Grey Cloud terrace (Pleistocene)

Qwg - West Campus formation, Grey Cloud terrace (Quaternary)
Clasts are mostly of Superior provenance. The terrace has two distinct surfaces separated by a scarp. The lower surface is about 65 feet (20 meters) above floodplain level below the dam at Taylors Falls, and only about 20 feet (6 meters) above floodplain level above the dam. The surface ranges in elevation from about 760 feet (232 meters) at Taylors Falls, to about 805 feet (245 meters) near the northern county boundary. The upper surface is about 40 feet (12 meters) above floodplain level above the dam, ranging in elevation from about 790 feet (241 meters) east of Palmdale to 815 feet (248 meters) near the mouth of Rock Creek. Large areas of scoured till (unit Qcd) and lake sediment (unit Qcc) of the Cromwell Formation are present at this terrace level. Description from source map: Chisago County Geologic Map

Qwg - West Campus formation, Grey Cloud terrace (Quaternary)
(Matsch, 1962)—The terrace ranges from about 50 to 80 feet (15 to 24 meters) above floodplain level, ranging in elevation from about 740 feet (216 meters) at the southeast edge of the map to about 770 feet (235 meters) at Belle Plaine to the west and at the north edge of the map in the St. Croix River valley. The terrace is not present in the Mississippi River valley north of St. Anthony Falls. Most contacts with other map units (except peat, unit Qho) are scarps. Description from source map: Twin Cities Surficial Geologic Map

Qwl - West Campus Formation, Langdon terrace (Pleistocene)

Qwl - West Campus formation, Langdon terrace (Quaternary)
Clasts are mostly of Superior provenance; rare shale. The terrace has two surfaces separated in places by a scarp, but in general is about 80 feet (24 meters) above floodplain level, rising in elevation at its higher surface from about 835 feet (255 meters) northeast of Almelund to about 865 feet (264 meters) east of Rush City. The terrace consists largely of scoured till of the Cromwell Formation north of Goose Creek, where only patches of fluvial sediment are preserved. Description from source map: Chisago County Geologic Map

Qwl - West Campus formation, Langdon terrace (Quaternary)
(Matsch, 1962)—This terrace has two distinct surfaces separated by a scarp in the St. Croix and lower

Mississippi River valleys. Upstream along the Mississippi and Minnesota Rivers, the upper surface is a broad terrace cut by anastomosing channels whose bottoms are at the lower surface. Below St. Anthony Falls, the lower surface is about 90 to 110 feet (27 to 34 meters) above floodplain level, rising in elevation from about 770 feet (235 meters) near the southeast edge of the map to about 800 feet (244 meters) at Shakopee and Marine on St. Croix. The upper surface is about 120 to 150 feet (37 to 46 meters) above floodplain level, ranging in elevation from about 800 feet (244 meters) at the southeast edge of the map area to 840 feet (256 meters) at Belle Plaine, and up to 880 feet (268 meters) at the northwest edge of the map. A scarp symbol separates the two surfaces. Most contacts with other map units (except peat, unit Qho) are also scarps. North of St. Anthony Falls the Langdon terrace is only about 10 to 40 feet (3 to 12 meters) above the modern floodplain. Description from source map: Twin Cities Surficial Geologic Map

Qwr - West Campus Formation, Richfield terrace (Pleistocene)

Qwr - West Campus formation, Richfield terrace (Quaternary)
Clasts of Riding Mountain provenance are common in most areas, mixed with clasts of Superior provenance. This terrace has two distinct surfaces. The small areas mapped just to the north and down river from Almelund formed prior to the draining of glacial Lake Anoka, when the St. Croix River served as the lake's outlet stream. This upper surface rises in elevation from about 900 feet (274 meters) in the area east of Duck Lake to 950 feet (290 meters) north of Almelund; it is about 210 feet (64 meters) above the modern floodplain below the Taylors Falls dam, and 170 to 190 feet (52 to 58 meters) above the floodplain up river from the dam. The remainder of the area mapped as the Richfield terrace, at an elevation of about 880 feet (268 meters), 125 feet (38 meters) above the modern floodplain, formed after the drainage of glacial Lake Anoka. Description from source map: Chisago County Geologic Map

Qwr - West Campus formation, Richfield terrace (Quaternary)
(Meyer and Jirsa, 1982)—This terrace has two distinct surfaces within the St. Croix River valley. Most of the Richfield terrace south of Stillwater, at an elevation of about 870 feet (265 meters), is interpreted to have formed following drainage of Glacial Lake Anoka (Meyer, 1998). All the mapped areas of Richfield terrace north of Stillwater, and a small area west of Lakeland, were formed prior to drainage of the lake when the St. Croix River served as the outlet stream of Glacial Lake Anoka (and possibly even earlier, by the drainage of Glacial Lake Grantsburg). This upper surface rises in elevation from about 885 feet (270 meters) near Lakeland to 900 feet (274 meters) toward the north edge of the map, about 190 to 220 feet (58 to 67 meters) above the modern floodplain. The terrace within the Minnesota River valley and along the Mississippi River below St. Anthony Falls is about 160 feet (49 meters) above floodplain level, ranging in elevation from about 840 feet (256 meters) northwest of Hastings to about 880 feet at the west edge of the map. The terrace is not recognized south of Hastings, where it merges with the level of the Mississippi River valley train (Hobbs, 1999). North of St. Anthony Falls the terrace ranges from 40 to 70 feet (12 to 21 meters) above the modern floodplain, ranging in elevation from about 850 feet (259 meters) to 910 feet (277 meters) at the northwest edge of the map. This portion is younger than, and inset into, deposits of Glacial Lake Anoka. Most contacts with other map units are scarps. Description from source map: Twin Cities Surficial Geologic Map

New Brighton Formation

(Meyer and Patterson, 1999)—Mostly yellowish-brown to gray, fine grained sand, laid down in glacial Lake Anoka. Included in these map units are some low-lying areas where New Brighton formation sediment may be overlain by 3 feet (1 meter) or more of sandy to clayey, organic-bearing colluvium, or by thin peat. Description from source map: Chisago County Geologic Map

(Meyer and Patterson, 1999)—Mostly fine-grained sand, laid down in Glacial Lake Anoka. Description from source map: Twin Cities Surficial Geologic Map

Qbg - New Brighton Formation, sand and gravel facies (Pleistocene)

Qbg - New Brighton formation, Sand and gravel facies (Quaternary)
Medium- to coarse-grained sand to fine-grained gravel. Deposited in deltaic or shallow-water environments in glacial Lake Anoka. May overlie coarser-grained fluvial sediment of the New Ulm or Cromwell Formations. Description from source map: Chisago County Geologic Map

Qbs - New Brighton Formation, sand facies (Pleistocene)

Qbs - New Brighton formation, Sand facies (Quaternary)
Very fine- to medium-grained sand; silty in places; scattered lenses of silt to silty clay occur at depth, mainly at the base. Pattern indicates where the fine-grained sand of the New Brighton formation (unit Qbs) covers stream-deposited sand, gravelly sand, and gravel of the New Ulm Formation (unit Qno) by less than 15 feet (5 meters). Gravelly sand occurs locally near the surface, especially where adjacent to glacial or fluvial sediment, and at depth in places. Following drainage of glacial Lake Anoka, the surface became pitted primarily due to melting of buried stagnant ice. The upper few feet (1 meter) of sand has commonly been reworked by wind. Description from source map: Chisago County Geologic Map

Qbs - New Brighton formation, Sand facies (Quaternary)
Very fine- to medium-grained sand; silty in places; scattered lenses of silt to silty clay at depth. Gravelly sand occurs locally where adjacent to glacial or fluvial sediment. The surface has been modified in places by fluvial processes during drainage of Glacial Lake Anoka. The upper few feet (1 meter) of sand has commonly been reworked by wind action. Description from source map: Twin Cities Surficial Geologic Map

Qbc - New Brighton Formation, silt and clay facies (Pleistocene)

Qbc - New Brighton formation, Silt and clay facies (Quaternary)
Silt and clay; interbedded with fine-grained sand in places; locally rhythmically bedded. Capped by less than 3 feet (1 meter) of fine-grained sand, and generally less than 10 feet (3 meters) thick. Deposited in deeper, quiet water of glacial Lake Anoka, in depressions on the lake bottom. Unit occurs at the surface likely where the overlying sand facies was stripped away by wave action as the lake level was lowered, and finally drained. Where present at the surface above the Hugo level, the unit was likely deposited in calm bays isolated from the main body of the lake, where the prograding sand facies was laid down. Description from source map: Chisago County Geologic Map

Qbc - New Brighton formation, Silt and clay facies (Quaternary)
Silt and clay; interbedded with fine-grained sand in places; locally rhythmically bedded; rare dropstones. Deposited in deeper, quiet water of Glacial Lake Anoka. Description from source map: Twin Cities Surficial Geologic Map

Miller Creek Formation

Qsps - Miller Creek Formation, spillway sediment (Pleistocene)

sp - Miller Creek Formation, spillway sediment (age unspecified)
Boulder gravel, commonly overlain by sand or gravelly sand (deposited in bottoms of channels of deep meandering rivers discharging from proglacial lakes). Deposited between about 11,500 and 9500 B.P. Description from source map: Superior Region Pleistocene Geologic Map

Qb - Miller Creek Formation, shoreline sediment (Pleistocene)

b - Miller Creek Formation, shoreline sediment (age unspecified)
Well sorted sand and gravel (deposited along beaches of proglacial lakes); generally 1 to 10 m thick. Deposited between about 11,500 and 9500 B.P. Description from source map: Superior Region Pleistocene Geologic Map

Qgw - Miller Creek Formation, wave-planted topography (Pleistocene)

gw - Miller Creek Formation, wave-planted topography (age unspecified)
Occurs on higher and steeper parts of the Superior lowland than map unit gl, where waves have been more active. In some areas Miller Creek till is overlain by a thin (typically 1 m) layer of near-shore sand, and in some areas the Miller Creek till has been eroded away, exposing underlying Copper Falls till, stream sediment, or shoreline sediment. Description from source map: Superior Region Pleistocene Geologic Map

Qst - Terraces (Pleistocene)

st - Terraces (age unspecified)
Terraces developed along the St. Croix River valley during postglacial valley incision; composed of sand and some gravel derived from Copper Falls and Trade River Formations. In the northwest, the terrace with transverse dunes is composed of noncalcareous sand derived primarily from the Superior Lobe and built initially by meltwater flowing from the north and later modified by westerly and southwesterly winds; sand between dunes is 5 to 15 m thick. Description from source map: Polk County Pleistocene Geologic Map

Trade River Formation

Qgtr - Trade River Formation, glacial sediment (Pleistocene)

gth - Trade River Formation, pitted to hummocky till (age unspecified)
Pitted to hummocky till plain underlain by calcareous, gray loamy Trade River till deposited by the Grantsburg Sublobe; shale, dolomite, limestone, and other rock types are present in till pebbles; till is several meters thick and underlain in most places by Copper Falls stream sediment that contained blocks of Superior Lobe ice that melted out after the Pine City Phase, collapsing the Trade River till and producing the collapse topography. Description from source map: Polk County Pleistocene Geologic Map

gt - Glacial Sediment of the Trade River Formation (Pleistocene)
Dark gray calcareous loam to clay loam glacial deposits of the Grantsburg Sublobe. Description from

source map: St. Croix NSR Quaternary Geologic Map

Qgtm - Trade River Formation, moraine ridges (Pleistocene)

gtm - Trade River Formation, moraine ridges (age unspecified)
Moraine ridges marking the edge of the Grantsburg Sublobe at its maximum extent and during its retreat; composed of Trade River till. Description from source map: Polk County Pleistocene Geologic Map

Qstv - Trade River Formation, stream sediment (Pleistocene)

stv - Trade River Formation, stream sediment (age unspecified)
Trade River stream sediment occurring in ice-marginal channels and outwash plains; sediment is predominantly calcareous pebbly sand; in places, it contains significant admixtures of sediment eroded from the Copper Falls Formation; deposited by meltwater from the Grantsburg Sublobe. Description from source map: Polk County Pleistocene Geologic Map

Qoti - Trade River Formation, ice-dammed-lake plains (Pleistocene)

oti - Trade River Formation, Ice-dammed-lake plains (age unspecified)
Ice-dammed-lake plains occurring at the ice-margin limit of the Grantsburg Sublobe; composed of gravel, sand, silt, and clay; lake sediment is calcareous and includes sediment derived from the Grantsburg Sublobe as well as sediment that was eroded from the Copper Falls Formation and carried to the lakes by streams. Description from source map: Polk County Pleistocene Geologic Map

Qsto - Trade River Formation, Osceola bench (Pleistocene)

sto - Trade River Formation, Osceola bench (age unspecified)
Osceola bench; composed of Trade River sand, pebbly sand, and coarse gravel, Trade River till, and Ordovician dolomite. Description from source map: Polk County Pleistocene Geologic Map

New Ulm Formation

(Meyer and Patterson, 1999)—Glacial, fluvial, and lacustrine sediment of Riding Mountain provenance (Table 1) deposited by ice and meltwater of the last glacial advance into the area, that of the Grantsburg sublobe (Fig. 3). Included in these map units are some low-lying areas where New Ulm Formation sediment may be overlain by 3 feet (1 meter) or more of sandy to clayey, organic-bearing colluvium, or by thin peat. Description from source map: Chisago County Geologic Map

(Meyer and Patterson, 1999)—Glacial, fluvial, and lacustrine sediment of Riding Mountain provenance (Table 1) deposited by ice and meltwater of the last glacial advance into the area—the Des Moines lobe and its Grantsburg sublobe. Description from source map: Twin Cities Surficial Geologic Map

Qnd - New Ulm Formation, Twin Cities member (late Pleistocene)

Qnd - New Ulm Formation, Twin Cities member (Quaternary)
(Meyer and Patterson, 1999)—Complexly intermixed yellowish-brown to gray and reddish-brown to reddish-gray, loam- to sandy loam-textured, unsorted sediment (diamicton), pebbly, with cobbles and boulders. This mixture of both Riding Mountain and Superior provenance sediment formed by the erosion and incorporation of Cromwell Formation material by the overriding ice of the Grantsburg sublobe. Small lenses of stratified sediment are common in many areas. Covered in places by as much as 20 feet (6 meters) of the loamy till facies of the New Ulm Formation. Cromwell Formation deposits are commonly within 20 feet (6 meters) of the surface. Where topography is steeply rolling or gullied, Cromwell Formation deposits are locally at or very near the surface. Commonly water-washed and overlain in places by a few feet (1 meter) of lacustrine, fluvial, or eolian sand in the vicinity of units Qns, Qno, and Qna, within areas covered by glacial Lake Anoka, and within the patterned area of fluvial scouring. Description from source map: Chisago County Geologic Map

Qnd - New Ulm Formation, Twin Cities member (Quaternary)
(Meyer and Patterson, 1999)—Complexly intermixed yellowish brown to gray and reddish-brown to reddish-gray, loam- to sandy loam-textured unsorted sediment (diamicton); pebbly, with cobbles and boulders. This mixture of both Riding Mountain and Superior provenance sediment formed by the erosion and incorporation of Cromwell and River Falls formation material by the overriding ice of the Des Moines lobe and the Grantsburg sublobe. Small lenses of stratified sediment are common in many areas. Covered in places by as much as 20 feet (6 meters) of the loamy till facies of the New Ulm formation. Cromwell formation deposits are commonly within 20 feet (6 meters) of the surface. Where topography is steeply rolling or gullied, Cromwell formation deposits are locally at or very near the surface. Commonly water-washed and overlain in places by a few feet (1 meter) of lacustrine, fluvial, or eolian sand in the vicinity of sand deposits, within the Glacial Lake Anoka basin, and within areas bounded by scarps. Description from source map: Twin Cities Surficial Geologic Map

Qno - New Ulm Formation, Twin Cities member, fine-grained sand and gravelly sand (late Pleistocene)

Qno - New Ulm Formation, Outwash (Quaternary)
Sand, gravelly sand, and gravel. Includes clasts of Superior provenance eroded from older sediment; shale is common. Deposited by meltwater issuing from the ice margin. Unit occurs at or near the surface along the Sunrise River, where overlying New Brighton formation sand (unit Qbs) has been eroded. Description from source map: Chisago County Geologic Map

Qno - New Ulm Formation, Outwash (Quaternary)
Sand, gravelly sand, and gravel. Deposited by meltwater issuing from the ice margin. Includes in the eastern portion of the map area abundant clasts of Superior provenance eroded from older sediment. Shale content generally increases from east to west across the map area (Meyer and Mossler, 1999). The upper few feet (1 meter) have been reworked in many places by wind action. Commonly capped by a mantle of wind-blown silt (loess) less than 4 feet (1 meter) thick. Commonly bounded by scarps where laid down in channels. Description from source map: Twin Cities Surficial Geologic Map

Qno - New Ulm Formation, Twin Cities member, fine-grained sand and gravelly sand (late Pleistocene)
Occurs as low hills and contains many modern lake basins where the postglacial land surface collapsed. Locally cross-bedded. Consists of material carried by glacial meltwater and laid down as stratified sediment. Outwash. Sediments deposited during the Late Pleistocene Epoch during the Last Glacial Maximum during the Wisconsinan glaciation (about 33,000 to 13,300 cal yr BP; Marine Isotope Stage 2). Description from source map: Washington County Geologic Map

Qnl - New Ulm Formation, Twin Cities Member, fine-grained sand, silt, and clay (late Pleistocene)

Qns - New Ulm Formation, Lake sand (Quaternary)
Very fine- to fine-grained sand and silty sand, with minor interbeds of silt and medium-grained sand. Capped and underlain in places by sandy silt. Coarse-grained, gravelly sand occurs locally along margins and at or near the base. Where patchy it is commonly less than 10 feet (3 meters) thick. Deposited in ice-walled lakes during retreat and stagnation of the Grantsburg sublobe. Description from source map: Chisago County Geologic Map

Qns - New Ulm Formation, Lake sand (Quaternary)
Very fine- to fine-grained sand and silty sand, with minor interbeds of silt and medium-grained sand. Capped in places by sandy silt. Coarse-grained, gravelly sand occurs locally along boundaries and at or near the base. Deposited in ponded water in depressions between the margin of the Grantsburg sublobe and the stagnant ice-cored St. Croix moraine, and in small, ice-walled lakes. Description from source map: Twin Cities Surficial Geologic Map

Qnl - New Ulm Formation, Twin Cities Member, fine-grained sand, silt, and clay (late Pleistocene)
Laminated reddish-brown clay, yellowish-brown to grayish-brown silt, and strong brown, fine-grained sand capped by yellowish-brown fine-grained sand. Occurs as lobate
plateaus. Deposits are 12 to 15 feet (3.7 to 4.6 meters) thick where drilled. Underlain by unit Qnt. Lakes formed in the ice where the edge of the Grantsburg sublobe overlapped the St. Croix moraine. Sediments are interpreted to have settled through meltwater within an ice-walled basin. Once the ice retreated, some deposits collapsed, but many lakefloors remained as positive relief on the modern land surface. Ice-walled lake plains. Sediments deposited during the Late Pleistocene Epoch during the Last Glacial Maximum during the Wisconsinan glaciation (about 33,000 to 13,300 cal yr BP; Marine Isotope Stage 2). Description from source map: Washington County Geologic Map

Qnt - New Ulm Formation, Twin Cities member, diamicton (late Pleistocene)

Qnt - New Ulm Formation, Loamy till (low relief) (Quaternary)
Chiefly loam-textured, unsorted sediment (diamicton); pebbly, with scattered cobbles and rare boulders. Lenses of stratified sediment are uncommon in most areas. Includes sediment both deposited beneath active ice and on stagnant ice. Generally more than 20 feet (6 meters) thick over the Cromwell Formation. Commonly water-washed and overlain in places by a few feet (1 meter) of lacustrine, fluvial, or eolian sand in the vicinity of units Qns, Qni, and Qna, within areas covered by glacial Lake Anoka, and within the patterned area of fluvial scouring. In general, at elevations above the Hugo level of glacial Lake Anoka and stream-scoured areas (pattern), the till deposits form a low, undulating topography with widely-spaced, circular, flat-topped hills, with an overall relief of about 10 to 30 feet (3 to 9 meters). Within the stream-scoured areas and below the Hugo level the till surface is relatively flat, except for depressions created by ice-block melt-out. Description from source map: Chisago County Geologic Map

Qnt - New Ulm Formation, Twin Cities member, diamicton (late Pleistocene)
Laminated reddish-brown clay, yellowish-brown to grayish-brown silt, and strong brown, fine-grained sand capped by yellowish-brown fine-grained sand. Occurs as lobate plateaus. Deposits are 12 to 15 feet (3.7 to 4.6 meters) thick where drilled. Underlain by unit Qnt. Lakes formed in the ice where the edge of the Grantsburg sublobe overlapped the St. Croix moraine. Sediments are interpreted to have settled through meltwater within an ice-walled basin. Once the ice retreated, some deposits collapsed,

but many lakefloors remained as positive relief on the modern land surface. Ice-walled lake plains. Sediments deposited during the Late Pleistocene Epoch during the Last Glacial Maximum during the Wisconsinan glaciation (about 33,000 to 13,300 cal yr BP; Marine Isotope Stage 2). Description from source map: Washington County Geologic Map

Qni - New Ulm Formation, ice-contact stratified deposit (late Pleistocene)

Qni - New Ulm Formation, Ice-contact stratified deposit (Quaternary)
Sand, gravelly sand, and cobbly gravel. Deposited by meltwater flowing at or behind the ice margin, during retreat and stagnation of the Grantsburg sublobe. Sediment can be quite variable and is typically faulted and folded. Commonly includes interbeds of, and in places is capped by, sandy to loamy diamicton (mudflow sediment) and silt (lake sediment). Shale clasts are common to abundant. Unit typically forms hills and ridges. Lower-lying deposits were likely reworked during the higher stages of glacial Lake Anoka, and may include some sediment deposited as deltas into the lake. Description from source map: Chisago County Geologic Map

Qnm - New Ulm Formation, loamy till (moderate-relief) (late Pleistocene)

Qnm - New Ulm Formation, Loamy till (moderate-relief) (Quaternary)
Till as above; deposits generally form elliptical hills or ridges with an overall relief of 40 to 70 feet (12 to 21 meters). Description from source map: Chisago County Geologic Map

Qna - New Ulm Formation, sandy till (late Pleistocene)

Qna - New Ulm Formation, Sandy till (Quaternary)
Loam- to sandy loam-textured, unsorted sediment (diamicton), pebbly, with cobbles and boulders; commonly capped by, or interbedded with, thin deposits of silty to gravelly stratified sediment. Includes complex deposits of thick sand and gravel too small to distinguish on the map from adjacent till bodies. Large bodies of sand and gravel are present at depth in places. In the vicinity of the Twin Cities member (unit Qnd), unit is commonly less than 20 feet (6 meters) thick over Cromwell Formation deposits. Within the bounds of glacial Lake Anoka the unit may include beach or nearshore sediment of the New Brighton formation. Near present-day lakes the unit may include modern beach deposits. Description from source map: Chisago County Geologic Map

Qna - New Ulm Formation, Sandy till (Quaternary)
Loam- to sandy loam-textured, unsorted sediment (diamicton), pebbly, with cobbles and boulders; commonly capped by, or interbedded with, thin deposits of silty to gravelly stratified sediment. Includes complex deposits of thick sand and gravel too small to distinguish on the map from adjacent till bodies. Large bodies of sand and gravel are present at depth in places. The unit is commonly less than 20 feet (6 meters) thick over Cromwell formation deposits, with an intervening layer of the Twin Cities member. Description from source map: Twin Cities Surficial Geologic Map

Qoc - Offshore clay (Pleistocene)

oc - Offshore Clay (Pleistocene)
Dark grayish brown to brown, calcareous, massive or rhythmically bedded clay deposited in glacial Lake Grantsburg. Unit is at most 1.5 meters thick although typically thinner and overlies unit Qsu. Description

from source map: St. Croix NSR Quaternary Geologic Map

Copper Falls Formation

Sorted and bedded deposits of sand and gravel; often overlain by less than one meter of loess; dominant lithologies are red-brown sandstones and mafic rocks derived from the Lake Superior basin, includes river terraces of Pleistocene age. Description from source map: St. Croix County Quaternary Geologic Map

Proglacial Stream Sediment. Cross-bedded sand and gravelly sandy and some plane-bedded sandy gravel; typically 5 to 20 m thick (channel deposits of shallow braided proglacial streams). Deposited between roughly 16,000 B.P. and about 11,500 B.P. Description from source map: Superior Region Pleistocene Geologic Map

Qgs - Copper Falls Formation, Sylvan Lake Member, glacial sediment (Pleistocene)

gsn - Copper Falls Formation, Sylvan Lake Member (age unspecified)
Gently rolling to streamlined upland areas underlain by thick, reddish- brown, sandy loam till of the Sylvan Lake Member; deposited by the Superior Lobe during the St. Croix and later phases. Description from source map: Polk County Pleistocene Geologic Map

gs - Glacial Sediment of the Sylvan Lake Member of Copper Falls Formation (Pleistocene)
Reddish brown slightly gravelly to gravelly loamy sand glacial deposits of the Superior Lobe. Description from source map: St. Croix NSR Quaternary Geologic Map

Qssp - Copper Falls Formation, Sylvan Lake Member, pitted outwash plains (Pleistocene)

ssp - Copper Falls Formation, Sylvan Lake Member, pitted outwash plains (age unspecified)
Pitted outwash plains composed of noncalcareous sand, slightly pebbly sand, and pebbly sand deposited by meltwater from the Superior Lobe; cobbles and boulders are common near former ice-margin positions; pits are as large a 1 sq. km.; abandoned channels and terrace scarps present in places. Description from source map: Polk County Pleistocene Geologic Map

Qssh - Copper Falls Formation, Sylvan Lake Member, hummocks deposited by meltwater from the Superior Lobe (Pleistocene)

ssh - Copper Falls Formation, Sylvan Lake Member, hummocks deposited by meltwater from the Superior Lobe (age unspecified)
Hummocks composed of noncalcareous sand, slightly pebbly sand, and pebbly sand deposited by meltwater from the Superior Lobe; formed by extensive collapse of outwash plains as buried Superior Lobe ice melted; small marshes present in places. Description from source map: Polk County Pleistocene Geologic Map

Qssv - Copper Falls Formation, Sylvan Lake Member, valleys (Pleistocene)

ssv - Copper Falls Formation, Sylvan Lake Member, valleys (age unspecified)
Broad, flat floors of St. Croix River tributary valleys in northwestern Polk County and the channel bottom of the Horse Creek Channel in southwestern Polk County; terrace scarps present in places; composed of sand to pebbly sand. Includes aprons of sandy hillslope sediment deposited at base of scarps. Valleys in northwestern Polk County were cut following retreat of the Superior Lobe ice and prior to the advance of the Grantsburg Sublobe; the Horse Creek Channel was cut during or after the Centuria Phase and prior or during the Pine City Phase. Description from source map: Polk County Pleistocene Geologic Map

Qusn - Copper Falls Formation, Sylvan Lake Member, flat to low-relief-hummocky landscape (Pleistocene)

usn - Copper Falls Formation, Sylvan Lake Member, flat to low-relief-hummocky landscape (age unspecified)
Gently rolling, flat, to low-relief-hummocky landscape underlain by till and stream sediment of the Sylvan Lake Member. West of Luck, this unit overlies thick stream sediment. This unit is used also to represent a relatively young wave-cut surface around Bone Lake. Description from source map: Polk County Pleistocene Geologic Map

Qush - Copper Falls Formation, Sylvan Lake Member, hummocky topography underlain by till (Pleistocene)

ush - Copper Falls Formation, Sylvan Lake Member, hummocky topography underlain by till (age unspecified)
Hummocky topography underlain by till, gravity-flow sediment, stream sediment, and lake sediment of the Sylvan Lake Member; small marshes present in places. Description from source map: Polk County Pleistocene Geologic Map

Qnsi - Copper Falls Formation, Sylvan Lake Member, nearshore deposits (Pleistocene)

nsi - Copper Falls Formation, Sylvan Lake Member, nearshore deposits (age unspecified)
Nearshore deposits of ice-walled-lake plains and ice-dammed-lake plains; composed of silt, sand, pebbly sand, and unsorted material; deposited by streams, waves, and sediment gravity flow; deposited along the shorelines of ice-walled and ice-dammed lakes when stagnant ice of the Superior Lobe was present. Description from source map: Polk County Pleistocene Geologic Map

Qosi - Copper Falls Formation, Sylvan Lake Member, offshore deposits (Pleistocene)

osi - Copper Falls Formation, Sylvan Lake Member, offshore deposits (age unspecified)
Offshore deposits of ice-walled-lake plains and ice-dammed-lake plains; composed primarily of silt with some sand and clay; deposited from suspension and by turbidity currents in the centers of ice-walled and ice-dammed lakes when stagnant ice of the Superior Lobe was present. Description from source map: Polk County Pleistocene Geologic Map

Qcfd - Copper Falls Formation, diamicton (Pleistocene)

Cfd - Copper Falls Formation, diamicton (age unspecified)
Reddish-brown, unsorted or poorly sorted, non-stratified, slightly-cohesive, variable in grain-size distribution, lacks significant amounts of silt and clay; commonly contains areas of bedded sand and gravel; interpreted as melt-out and flow till, often overlain by less than one meter of loess, commonly displays high relief hummocky topography in some areas, dominant lithologies are red-brown sandstones and mafic rocks derived from the Lake Superior basin. Description from source map: St. Croix County Quaternary Geologic Map

Qcfdb - Copper Falls Formation, diamicton, steep hill slopes in areas of deeply dissected drainage (Pleistocene)

Cfdb - Copper Falls Formation, diamicton, steep hill slopes in areas of deeply dissected drainage (age unspecified)
steep hill slopes in areas of deeply dissected drainage. Description from source map: St. Croix County Quaternary Geologic Map

Qcfsp - Copper Falls Formation, sand and gravel in outwash deposits, less than 20 percent collapsed surface (Pleistocene)

Cfsp - Copper Falls Formation, sand and gravel in outwash deposits, less than 20 percent collapsed surface (age unspecified)
Less than 20 percent of original stream bed interrupted by depressions formed by melting ice blocks, (kettles). Description from source map: St. Croix County Quaternary Geologic Map

Qcfspp - Copper Falls Formation, sand and gravel in outwash deposits, 20 to 50 percent collapsed surface (Pleistocene)

Cfspp - Copper Falls Formation, sand and gravel in outwash deposits, 20 to 50 percent collapsed surface (age unspecified)
More than 20 but less than 50 percent collapsed surface. Description from source map: St. Croix County Quaternary Geologic Map

Qcfsh - Copper Falls Formation, sand and gravel in outwash deposits, more than 50 percent collapsed surface (Pleistocene)

Cfsh - Copper Falls Formation, sand and gravel in outwash deposits, more than 50 percent collapsed surface (age unspecified)
More than 50 percent collapsed surface. Description from source map: St. Croix County Quaternary Geologic Map

Qcfsb - Copper Falls Formation, sand and gravel in outwash deposits, steep hill slopes in areas of deeply dissected drainage (Pleistocene)

Cfsb - Copper Falls Formation, sand and gravel in outwash deposits, steep hill slopes in areas of deeply dissected drainage (age unspecified)
Steep hill slopes in areas of deeply dissected drainage. Description from source map: St. Croix County Quaternary Geologic Map

Qcfsl - Copper Falls Formation, silt and sand (Pleistocene)

Cfsl - Copper Falls Formation, silt and sand (age unspecified)
Found in glacial lake deposits; most is in former ice walled lake plains. Description from source map: St. Croix County Quaternary Geologic Map

Qsu - Copper Falls Formation, uncollapsed meltwater stream sediment (Pleistocene)

su - Uncollapsed meltwater stream sediment (Pleistocene)
Stratified sand and gravelly sand deposited by streams carrying meltwater from the Superior Lobe; flat to low relief outwash plains and terraces. Original depositional surface recognizable in most areas. Description from source map: St. Croix NSR Quaternary Geologic Map

su - Copper Falls Formation, uncollapsed proglacial stream sediment (age unspecified)
Undisturbed bedding (deposited on solid ground). Flat topography. No surface boulders. Many deposits can be assigned to named stability surfaces. Description from source map: Superior Region Pleistocene Geologic Map

Qsuf - Copper Falls Formation, uncollapsed proglacial stream sediment, Swiss surface (Pleistocene)

suf - Copper Falls Formation, uncollapsed proglacial stream sediment, Swiss surface (age unspecified)
Swiss surface. Description from source map: Superior Region Pleistocene Geologic Map

Qsug - Copper Falls Formation, uncollapsed proglacial stream sediment, Hayward surface (Pleistocene)

sug - Copper Falls Formation, uncollapsed proglacial stream sediment, Hayward surface (age unspecified)
Hayward surface. Description from source map: Superior Region Pleistocene Geologic Map

Qsuh - Copper Falls Formation, uncollapsed proglacial stream sediment, Tiger Cat surface (Pleistocene)

suh - Copper Falls Formation, uncollapsed proglacial stream sediment, Tiger Cat surface (age unspecified)

Tiger Cat surface. Description from source map: Superior Region Pleistocene Geologic Map

Qsc - Copper Falls Formation, collapsed meltwater stream sediment (Pleistocene)

sc - Collapsed meltwater stream sediment (Pleistocene)
Stratified sand and gravelly sand deposited by streams carrying meltwater from the Superior Lobe and deposited on ice. Moderate to high relief surfaces. Original depositional surface recognizable in few areas because it was destroyed when buried ice melted. Description from source map: St. Croix NSR Quaternary Geologic Map

sc - Copper Falls Formation, collapsed proglacial stream sediment (age unspecified)
Faulted bedding (deposited on stagnant glacial ice). Hummocky collapse topography. Rare surface boulders. Description from source map: Superior Region Pleistocene Geologic Map

Qsg - Copper Falls Formation, hummocky stream sediment overlain by silty material (Pleistocene)

sg - Copper Falls Formation, hummocky stream sediment overlain by silty material (age unspecified)
Collapsed proglacial stream sediment, englacial stream sediment, or subglacial stream sediment overlain by a thin (about a meter) layer of till or wind-blown or offshore silt mixed with the underlying stream sediment. Surface boulders fairly common. Description from source map: Superior Region Pleistocene Geologic Map

Qgg - Copper Falls Formation, thin mass-movement till (Pleistocene)

gg - Copper Falls Formation, thin mass-movement till (age unspecified)
Hummocky topography composed of mass-movement till (a few meters thick) and probably also melt-out till and lodgement till, draped over till of earlier glacial advances. Surface boulders moderately abundant. Description from source map: Superior Region Pleistocene Geologic Map

Qgsm - Copper Falls Formation, subglacially molded topography (Pleistocene)

gm - Copper Falls Formation, subglacially molded topography (age unspecified)
Drumlinized lodgement till, typically a few meters or less in thickness; commonly overlain by thin mass-movement till and melt-out till. Drumlins are commonly cored by older till, stream sand and gravel, or pre-Pleistocene rock. Surface boulders abundant. Description from source map: Superior Region Pleistocene Geologic Map

Qgt - Copper Falls Formation, glacial thrust masses (Pleistocene)

gt - Copper Falls Formation, glacial thrust masses (age unspecified)
Transversely ridged topography, probably resulting from glacial thrusting of pre-existing till or stream sediment. Surface boulders moderately abundant. Description from source map: Superior Region

Pleistocene Geologic Map

Cromwell Formation

Glacial, fluvial, and lacustrine sediment of Superior provenance (Table 1), deposited by the Superior lobe (Fig. 3) and its meltwater. Included in these map units are some low-lying areas where Cromwell Formation sediment may be overlain by 3 feet (1 meter) or more of sandy to clayey, organic-bearing colluvium, or by thin peat. The upper part of Cromwell Formation deposits in Chisago County are commonly reworked (by the overriding Grantsburg sublobe or subsequent hydraulic action) and mantled in places too patchy to show by generally less than 10 feet (3 meters) of younger deposits. Description from source map: Chisago County Geologic Map

(Meyer, 1999)—Glacial, fluvial, and lacustrine sediment of Superior provenance (Table 1), deposited by the Superior lobe and its meltwater. Where mapped within or in the vicinity of New Ulm formation deposits, Cromwell formation deposits are commonly reworked at the top (by the overriding Des Moines lobe and Grantsburg sublobe) and mantled in places by generally less than 10 feet (3 meters) of younger deposits. Description from source map: Twin Cities Surficial Geologic Map

Qci - Cromwell Formation, ice-contact stratified deposit (Pleistocene)

Qci - Cromwell Formation, Ice-contact stratified deposit (Quaternary)
Sand, gravelly sand, and cobbly gravel; deposited by meltwater flowing at or behind (beneath) the retreating ice margin. Sediment can be quite variable and is typically faulted and folded owing to collapse upon melting of supporting ice. Commonly includes interbeds of, and in places is capped by, sandy to silty diamicton (mudflow sediment) and silt (lake sediment). Some deposits contain boulders. Deposits generally stand as positive features in the landscape. Description from source map: Chisago County Geologic Map

Qci - Cromwell Formation, Ice-contact stratified deposit (Quaternary)
Sand, gravelly sand, and cobbly gravel; deposited by meltwater flowing at or behind the ice margin. Commonly includes interbeds of, and in places is capped by sandy to loamy diamicton (mudflow sediment) and silt (lake sediment). Some deposits contain boulders. Many of the ice-contact deposits were laid down in coalescing fans at the mouths of tunnel valleys at the glacial ice margin, or as deltas in ice-walled lakes. Other deposits (eskers) were laid down along the courses of subglacial streams. After the ice melts, these deposits generally stand as positive features. Description from source map: Twin Cities Surficial Geologic Map

Qcl - Cromwell Formation, fine-grained sand, silt, and clay (late Pleistocene)

Qcl - Cromwell Formation, Lake sand and silt (Quaternary)
Silt to medium-grained sand deposited in glacial Lakes Lind I and II; interbeds and lenses of silty clay to gravelly sand, and scattered dropstones; rhythmically layered in places. Likely includes deltaic sediment. Exposed along the valley walls of the St. Croix River and its tributaries. Description from source map: Chisago County Geologic Map

Qcl - Cromwell Formation, Lake sand and silt (Quaternary)
Silt to medium-grained sand; interbeds and lenses of silty clay to gravelly sand, including sandy diamicton (mudflow sediment), and scattered dropstones. Rhythmically layered in places. Thick silty to clayey sediments dominate the center of the more extensive deposits. Primarily deposited in ice-walled

lakes following ice stagnation. Coarse-grained sand and gravel occurs locally along edges of the ice-walled lake plains. Also includes silty sediment in pitted outwash plains, where the sediment commonly consists largely of loess washed into ponds formed in ice-block melt-out depressions. Description from source map: Twin Cities Surficial Geologic Map

Qcl - Cromwell Formation, fine-grained sand, silt, and clay (late Pleistocene)
Laminated, red clay and light brown, fine-grained sandy silt, capped by brown, fine-grained sand. Poorly sorted gravel, sand, and silt are common at contacts. Unit occurs as plateaus 0.2 to 3.1 miles (0.3 to 5.1 kilometers) in diameter. Plateaus are as much as 60 feet (18.3 meters) higher than the surrounding terrain. These represent stagnation features of the St. Croix moraine. Sediment began to accumulate in lakes filled with meltwater within the ice surface, depositing silt and clay at the depositional center. Poorly sorted gravel, sand, and silt at contacts represent material slumped into the lake off of the ice. Once the surrounding ice melted, some deposits collapsed, but many lakefloors remained as positive relief on the modern land surface. Ice-walled lake plains. Sediments deposited during the Late Pleistocene Epoch during the Last Glacial Maximum during the Wisconsinan glaciation (about 33,000 to 13,300 cal yr BP; Marine Isotope Stage 2). Description from source map: Washington County Geologic Map

Qco - Cromwell Formation, sand to gravel (late Pleistocene)

Qco - Cromwell Formation, Outwash (Quaternary)
Sand, gravelly sand, and gravel. Cobbly in places, especially near till and ice-contact deposits. Commonly overlain by 2 to 5 feet (0.6 to 1.5 meters) of loess. Laid down by meltwater issuing from the ice margin. The surface of the outwash is irregular in most places behind the maximum margin (Emerald phase) of the Superior lobe, due to the melting of underlying buried ice-blocks following deposition of the sand and gravel. Description from source map: Twin Cities Surficial Geologic Map

Qco - Cromwell Formation, sand to gravel (late Pleistocene)
Bedded sand, gravelly sand, and gravel forming low hills. Commonly found at a lower elevation than associated till (unit Qct). Over 100 feet (30.5 meters) thick where filling bedrock valleys. Ice wedge polygons are most common in this unit (Fig. 3). Consists of sediments deposited by glacial meltwater. Outwash. Sediments deposited during the Late Pleistocene Epoch during the Last Glacial Maximum during the Wisconsinan glaciation (about 33,000 to 13,300 cal yr BP; Marine Isotope Stage 2). Description from source map: Washington County Geologic Map

Qcc - Cromwell Formation, lake clay and silt (Pleistocene)

Qcc - Cromwell Formation, Lake clay and silt (Quaternary)
Rhythmically bedded clay and silt laid down mostly in glacial Lake Lind I. Exposed in the bottoms and walls of channels formed by the downcutting glacial St. Croix River and its tributaries. At higher elevations, the unit is topped in places by clayey to loamy diamicton of the Automba phase. Towards the base, unit may include thin interbeds of diamicton. Locally capped with alluvium or colluvium. Description from source map: Chisago County Geologic Map

Qcs - Cromwell Formation, till, sand, and gravel (Pleistocene)

Qcs - Cromwell Formation, Till, sand, and gravel (Quaternary)
<insert unit description> Description from source map: Chisago County Geologic Map

Qcs - Cromwell Formation, Till, sand, and gravel (Quaternary)
Sandy till capped by, and/or interbedded with, sand and gravel. Locally, patchy till over thick deposits of sand and gravel. May include small bodies of thick silt. Unit has gradational contacts with units Qct and Qci. Glacial and fluvial sediment are too intricately associated to distinguish at map scale. Description from source map: Twin Cities Surficial Geologic Map

Qct - Cromwell Formation, diamicton (late Pleistocene)

Qct - Cromwell Formation, Supraglacial till (Quaternary)
Chiefly sandy loam-textured, unsorted sediment (diamicton), with pebbles, cobbles, and boulders; sandy silt to cobbly gravel lenses are commonly present, particularly in the vicinity of units Qci and Qcs. Description from source map: Chisago County Geologic Map

Qct - Cromwell Formation, Till (Quaternary)
Chiefly sandy loam-textured, unsorted sediment (diamicton), with pebbles, cobbles, and boulders; silty sand to cobbly gravel lenses are commonly present. Most of this unit is part of the St. Croix moraine, laid down at the terminus of the St. Croix phase of the Superior lobe, consisting largely of thick, supraglacial sediment deposited as knobs and kettles. Beyond the St. Croix phase margin the unit is thinner, generally lacking the well-developed, hummocky topography. Where beyond the margin of the Grantsburg sublobe, the till is commonly overlain by 2 to 5 feet (0.6 to 1.5 meters) of loess. Commonly water-washed and overlain in places by a few feet (1 meter) of fluvial or lacustrine sand in the vicinity of sand deposits. Includes small areas of thick, loamy to sandy colluvium in depressions. Description from source map: Twin Cities Surficial Geologic Map

Qct - Cromwell Formation, diamicton (late Pleistocene)
Unsorted, reddish-brown to brown, gravelly loamy sand to gravelly sandy loam. Found within hummocky topography or irregular mounds and swales, and hosts many thin, discontinuous eskers as well as crevasse-fill ridges. Deposits are about 8.0 to 56.0 feet (2.4 to 17.1 meters) thick. Consists of supraglacial sediment deposited during stagnation and melt-out of the Superior lobe during the St. Croix phase in the St. Croix moraine. The till beyond the St. Croix phase ice margin was deposited by the Emerald-phase advance of the Superior lobe. This till has the same material characteristics. The Emerald phase association can be inferred by indistinct geomorphology, generally thinner deposits (less than 20 feet [6.1 meters]), a deeper weathering profile, and common loess cover. Glacial till. Sediments deposited during the Late Pleistocene Epoch during the Last Glacial Maximum during the Wisconsinan glaciation (about 33,000 to 13,300 cal yr BP; Marine Isotope Stage 2). Description from source map: Washington County Geologic Map

Qcd - Cromwell Formation, subglacial till (Pleistocene)

Qcd - Cromwell Formation, Subglacial till (Quaternary)
Chiefly dense, sandy loam-textured, unsorted sediment (diamicton), with pebbles, cobbles, and boulders; stratified lenses are uncommon in most places. Exposed in the bottom of channels formed by the downcutting glacial St. Croix River. Commonly topped by a lag of boulders. Description from source map: Chisago County Geologic Map

Qse - Meltwater-stream sediment in eskers (Pleistocene)

se - Meltwater-stream sediment in eskers (Pleistocene)
Stratified sand, gravelly sand, and silty sand deposited by rivers flowing in subglacial tunnels. Occurs in

somewhat sinuous ridges typically oriented parallel to the direction of ice flow. Description from source map: St. Croix NSR Quaternary Geologic Map

Qsd - Meltwater-stream sediment in deltas (Pleistocene)

sd - Meltwater-stream sediment in deltas (Pleistocene)
Stratified sand and gravelly sand deposited in ice-marginal deltas or fans. Description from source map: St. Croix NSR Quaternary Geologic Map

River Falls Formation

(Mickelson and others, 1984)—Glacial and glaciofluvial deposits of Superior provenance (Table 1). The upper part contains a truncated paleosol in places, indicating deposition prior to the Michigan sub-episode. Description from source map: Twin Cities Surficial Geologic Map

Qrc - River Falls Formation, complex of diamicton, sand, and gravel (late Pleistocene)

grf - Glacial Sediment of the River Falls Formation (Pleistocene)
Yellowish red to reddish brown sandy clay loam glacial deposits of the Superior Lobe deposited prior to the last part of the Wisconsin Glaciation (Marine Isotope Stage 2). Description from source map: St. Croix NSR Quaternary Geologic Map

Qrc - River Falls Formation, complex of diamicton, sand, and gravel (late Pleistocene)
Gravelly sand, cobbles, and diamicton. Diamicton is unsorted, strong brown to reddish-brown, sandy clay loam to sandy loam with gravel. The entire unit is deeply weathered and commonly covered by loess; occurs as discontinuous areas on a stream-dissected landscape. Till and outwash are too complexly commingled to depict at this scale. Eroded glacial till and outwash. Glacial sediments deposited during the Late Pleistocene Epoch during the Illinoian glaciation (191,000 to 130,000 cal yr BP; speculated Marine Isotope Stage 6; Syverson and others, 2011). Description from source map: Washington County Geologic Map

Qrfd - River Falls Formation, diamicton (Pleistocene)

Rfd - River Falls Formation, diamicton (age unspecified)
Reddish-brown, unsorted or poorly sorted, non-stratified, slightly-cohesive, variable in grain-size distribution, lacks significant amount of silt and clay; commonly contains areas of bedded sand and gravel; often overlain by less than one meter of loess, same appearance and grain-size distribution as Copper Falls Formation but lacks glacial landforms and hummocky topography, has a generally rolling surface topography with few kettles, deposits of variable thickness on hill tops, local shallow bedrock exists. Description from source map: St. Croix County Quaternary Geologic Map

Qrd - River Falls Formation, complex of sand, gravel, and till (Pleistocene)

Qrd - River Falls Formation, Complex of sand, gravel, and till (Quaternary)
Sand and gravel with cobbles (ice-contact stratified sediment), and sandy loam- to sandy clay loam-textured till, undivided. Till is only a minor component in most places. Hillier and higher than nearby outwash unit Qro. Description from source map: Twin Cities Surficial Geologic Map

Pierce Formation

(Mickelson and others, 1984)—Glacial and glaciofluvial deposits of Winnipeg provenance (Table 1). Represents deposits of four or more glacial advances, undivided. Most of the Pierce Formation underlies the River Falls Formation, but the uppermost till of the Pierce Formation may be contemporary with the River Falls Formation. Description from source map: Twin Cities Surficial Geologic Map

Qpo - Pierce Formation, sand and gravel (early Pleistocene)

Qpg - Pierce Formation, Glaciofluvial deposits (Quaternary)
Sorted sediment ranging from fine-grained sand to coarse grained gravel. Most commonly a mixture of sand and gravel. Strongly weathered from the top to a depth of about 10 feet (3 meters); contains many carbonate clasts below the leached zone; many coarse-grained fragments break easily; many clasts are coated with brown clay. Occurs as eroded remnants of ice-contact stratified deposits and outwash, undivided. In places, covered by a layer of till less than 5 feet (1.5 meters) thick. Some deposits may include material of Superior provenance. Description from source map: Twin Cities Surficial Geologic Map

Qpo - Pierce Formation, sand and gravel (early Pleistocene)
Gravel to gravelly sand with localized cobbles. Geomorphologic characteristics are indistinct; identified in soil borings, soil datasets, and well logs. Sediments were deposited by glacial meltwater during the Early Pleistocene Epoch. Later, unit was heavily eroded and mostly the coarser-grained materials remained. Eroded outwash. Glacial sediments deposited during the Early Pleistocene Epoch (sediments deposited 781,000 to 2,588,000 cal yr BP; speculated Marine Isotope Stage 20 or greater). Description from source map: Washington County Geologic Map

Qpt - Pierce Formation, diamicton (early Pleistocene)

Qpt - Pierce Formation, Till (Quaternary)
Chiefly firm, loam- to clay loam-textured, unsorted sediment (diamicton), pebbly, with cobbles and rare boulders. Contains lenses of sorted sand and gravel in places. Originally gray and calcareous, but the surface is highly oxidized and deeply leached in places. Exhibits stream-dissected topography with no closed depressions. Description from source map: Twin Cities Surficial Geologic Map

Qpt - Pierce Formation, diamicton (early Pleistocene)
Well-compacted, yellowish-brown to dark gray loam with gravel, commonly covered by loess; deeply eroded and weathered, and commonly present on hilltops. Geomorphologic characteristics are indistinct; identified in soil borings, soil datasets, and well logs. Locally contains buried soil horizons. Correlates with diamicton in Wisconsin that is magnetically reversed, indicating deposition prior to 781,000 years ago (Baker and others, 1983). Sediment was deposited directly by ice of Winnipeg provenance (Fig. 2). Glacial till. Glacial sediments deposited during the Early Pleistocene Epoch (sediments deposited 781,000 to 2,588,000 cal yr BP; speculated Marine Isotope Stage 20 or greater). Description from source map: Washington County Geologic Map

Qpc - Pierce Formation, till, colluvium mantle (Pleistocene)

Qpc - Pierce Formation, Till, colluvium mantle (Quaternary)
Till as above, distinguished from unit Qc where the till is extensively exposed along the steep slopes of the Minnesota River valley. In places the unit is overlain by Superior provenance sediment that may be equivalent to the River Falls Formation, and by sandy-textured till, which may be equivalent to the

"Wadena" till of central Minnesota (Meyer and Knaeble, 1996). Description from source map: Twin Cities Surficial Geologic Map

Qgh - Pierce Formation, Hersey Member, glacial sediment (Pleistocene)

gh - Glacial Sediment of the Hersey Member of Pierce Formation (Pleistocene)
Yellowish brown to dark gray calcareous loam glacial deposits derived from the Northwest possibly prior to the Illinoian Glaciation (Marine Isotope Stage 6). May be overlain by rhythmically bedded lake sediments of the Kinnickinic Member. Description from source map: St. Croix NSR Quaternary Geologic Map

Qh - Hillslope deposit (Pleistocene)

h - Hillslope Deposit (Pleistocene)
Slightly gravelly, clayey, silty sand deposited by hillslope processes such as slopewash, creep and solifluction, and eolian processes. Derived from residuum from underlying Paleozoic rock and younger stream and glacial sediment. Typically a few meters thick. May include areas of rock (unit r). Description from source map: St. Croix NSR Quaternary Geologic Map

Qgm - Glacial sediment of end moraines (Pleistocene)

Qgm - Glacial sediment of end moraines (Pleistocene)
Thick deposits of loamy, yellow brown (oxidized) and gray (unoxidized) glacial sediment; it may be complexly mixed with underlying reddish Superior-lobe sediments, which are evident near the western margin of the lobe in Pine County and near the lower contact. Collapsed areas are mainly restricted to where the Grantsburg sublobe advanced over what must have been ice-filled tunnel valleys of the Superior lobe. Description from source map: Pine County Geologic Map

Qggm - Glacial sediment with stream- and lake-modified surface (Pleistocene)

Qggm - Glacial sediment with stream- and lake-modified surface (Pleistocene)
Loamy glacial sediment; may be covered by a thin layer of fine or sandy sediment; in places a stony surface lag may be present due to washing away of fine sediment from till matrix. Description from source map: Pine County Geologic Map

Qggs - Glacial sediment and pond sediment accumulated in intermorainic swales (Pleistocene)

Qggs - Glacial sediment and pond sediment accumulated in intermorainic swales (Pleistocene)
Commonly resedimented loamy glacial sediment intermixed with fine sand, silt, and clay from meltwater and ponded water. Found in low areas between moraines. Constitutes a thin, discontinuous but significant unit that overlies thick Grantsburg till. Not interpreted as the deposits of a continuous lake but rather short-lived small ponds and interconnecting streams. Description from source map: Pine County Geologic Map

Qgss - Stream sediment of the Grantsburg sublobe (Pleistocene)

Qgs - Stream sediment (Pleistocene)
Sand and gravel deposited by meltwater streams of the Grantsburg sublobe along its margin. Deposited as ice wasted and after glacial Lake Grantsburg drained. Additional contributions from non meltwater streams of a northerly source. Collapsed in places due to deposition on or with the ice that later melted. Description from source map: Pine County Geologic Map

Qgls - Lake sediment of glacial Lake Grantsburg, sandy sediment (Pleistocene)

Qgls - Lake sediment of glacial Lake Grantsburg, Sandy sediment (Pleistocene)
Sandy deposits found in only two locations along the southeasterly and northwesterly extent of the former lake in Pine County. Interpreted as Superior-lobe sediment reworked by wave action of glacial Lake Grantsburg and redeposited near shore. Description from source map: Pine County Geologic Map

Qglf - Lake sediment of glacial Lake Grantsburg, silty and sandy sediment (Pleistocene)

Qglf - Lake sediment of glacial Lake Grantsburg, Silty and sandy sediment (Pleistocene)
Gray to yellow brown. Commonly deposited in a thin drape (less than 1.5 meters) over extant sandy Superior-lobe deposits. Deposited in shallow water. Extent may be discontinuous. Description from source map: Pine County Geologic Map

Qglc - Lake sediment of glacial Lake Grantsburg, silty and clayey sediment (Pleistocene)

Qglc - Lake sediment of glacial Lake Grantsburg, Silty and clayey sediment (Pleistocene)
Gray; in places thinly laminated with alternating clay- and silt-rich layers. Deposited in deep water. Generally greater than 1.5 meters thick. Description from source map: Pine County Geologic Map

Qss - Stream sediment of the Superior lobe (Pleistocene)

Qss - Stream sediment (Pleistocene)
Stratified sand and gravel deposited mainly by meltwater streams from all phases of the Superior lobe. Collapsed in places owing to deposition on or with melting ice, resulting in local disruption of bedding. Description from source map: Pine County Geologic Map

Qssi - Sorted sediment proximate to ice (Pleistocene)

Qssi - Sorted sediment proximate to ice (Pleistocene)
Sand and gravel sorted by meltwater in close proximity to ice. May constitute eskers, tunnel-valley fill, conical hills (kames), and ice marginal fans. Esker symbol shown where the esker form is prominent. Description from source map: Pine County Geologic Map

Qssm - Sandy glacial sediment in moraine ridges (Pleistocene)

Qssm - Sandy glacial sediment (Pleistocene)
Similar to unit above (Qsgs) but in moraine ridges of the Automba, Beroun, Hinckley, North Hinckley, Grindstone, and Sandstone phases. The moraine ridge of the Askov–Lookout Tower phase is also sandy, and contains boulders of sandstone; however, the till of this phase is fine-grained silty clay. Description from source map: Pine County Geologic Map

Qsgs - Sandy glacial sediment (Pleistocene)

Qsgs - Sandy glacial sediment (Pleistocene)
Red where oxidized, reddish gray where unoxidized; sandy matrix; pebbles, cobbles, and boulders common. Collapsed in places owing to deposition with or on ice that subsequently melted. Description from source map: Pine County Geologic Map

Qsgw - Wave-washed glacial sediment (Pleistocene)

Qsgw - Wave-washed glacial sediment (Pleistocene)
Sandy red glacial sediment modified by flowing stream water of glacial Lake Grantsburg. May have a concentration of coarse clasts near the surface or be covered by a thin drape of fine sediment. Description from source map: Pine County Geologic Map

Qsll - Lake sediment of glacial Lake Lind (Pleistocene)

Qsll - Lake sediment of glacial Lake Lind (Pleistocene)
Laminated lake sediment; varves of red clay and gray silt are common. Exposed by erosion in the strath terrace along the St. Croix River. Description from source map: Pine County Geologic Map

PZr - Undefined Paleozoic Rock (Paleozoic)

R - Rock (age unspecified)
Bedrock or very shallow (generally less than 1.5 meters) bedrock, commonly exposed on steep slopes. Description from source map: St. Croix County Quaternary Geologic Map

r - Rock (Paleozoic)
Paleozoic Bedrock or very shallow (generally less than 1.5 meters) bedrock, commonly exposed on steep slopes. May include areas of hillslope deposits (unit h). Description from source map: St. Croix NSR Quaternary Geologic Map

OCu - Bedrock at or near the surface (Ordovician and Cambrian)

Pzu - Bedrock at or near the surface (Ordovician and Cambrian)
Paleozoic bedrock is locally found within about 10 feet (3 meters) of the land surface in this unit. Can be covered with topsoil, loess, colluvium, or residuum where mapped. The thickness of unconsolidated sediments varies with the undulating bedrock surface beneath those sediments. See Plate 2, *Bedrock Geology*, for differentiation of units (Plate 2 is not included in this dataset, see original publication for

additional information). Description from source map: Washington County Geologic Map

OCo - Bedrock outcrop (Ordovician and Cambrian)

Pz - Bedrock outcrop (Ordovician and Cambrian)
Paleozoic sedimentary bedrock identified at the land surface. Description from source map: Washington County Geologic Map

Osp - St. Peter Sandstone (Ordovician)

Osp - St. Peter Sandstone (Ordovician)
Massive, very fine- to medium-grained quartzose sandstone. Interbedded with siltstone and shale in its lower part. Discontinuously exposed, with a commonly sandy mantle less than 5 feet (1.5 meters) thick. Description from source map: Twin Cities Surficial Geologic Map

Opc - Prairie du Chien Group (Ordovician)

Op - Outcrops of Ordovician dolomite of the Prairie du Chien Group (Ordovician)
Outcrops of Ordovician dolomite of the Prairie du Chien Group. Description from source map: Polk County Pleistocene Geologic Map

Opc - Prairie du Chien Group (Ordovician)
Oolitic sandy dolostone and sandstone of the Shakopee Formation overlies massive dolostone of the Oneota Dolomite; sandy transitional zone at the base. Discontinuously exposed, with a sandy to rocky mantle generally less than 5 feet (1.5 meters) thick. Most areas of this unit mapped within the major river valleys are quarries. Description from source map: Twin Cities Surficial Geologic Map

OCub - Bedrock, undivided (Ordovician and Cambrian)

COu - Bedrock, undivided (Cambrian to Ordovician)
Outcrops and near-surface Cambrian and Ordovician bedrock. Quartzose sandstone, feldspathic to glauconitic sandstone and siltstone, dolomitic siltstone, and dolostone (Oneota Dolomite, Jordan Sandstone, St. Lawrence Formation, Tunnel City Group, Wonewoc Sandstone, and Eau Claire Formation). Discontinuously exposed; mantled by generally less than 5 feet (1.5 meters) of sandy to rocky colluvium or alluvium. Description from source map: Chisago County Geologic Map

COu - Bedrock, undivided (Cambrian to Ordovician)
Outcrops and near-surface Cambrian and Ordovician bedrock on steep slopes; not practical to map individual units. Ranges from the Prairie du Chien Group to the Jordan Sandstone, St. Lawrence and Franconia Formations. Discontinuously exposed, with a sandy to rocky mantle generally less than 5 feet (1.5 meters) thick. Description from source map: Twin Cities Surficial Geologic Map

CPRrs - Oronto and Bayfield Groups (Middle Proterozoic to Cambrian)

rs - Oronto and Bayfield Groups (Middle Proterozoic to Cambrian)
Middle Proterozoic lithic sandstone, mudstone, and conglomerate of the Oronto Group and Late

Proterozoic or Cambrian quartz sandstone of the Bayfield Group. Description from source map: Superior Region Pleistocene Geologic Map

PCc - Outcrops of Precambrian basalt of the Chengwatana Group (Precambrian)

pC - Outcrops of Precambrian basalt of the Chengwatana Group (Precambrian)
Outcrops of Precambrian basalt of the Chengwatana Group; basalt is amygdaloidal and vesicular in places, and displays a high concentration of magnetic minerals in places; outcrops have high relief, are polished, grooved, striated, and weathered; potholes occur at St. Croix Falls. Description from source map: Polk County Pleistocene Geologic Map

PRmc - Clam Falls volcanics (Middle Proterozoic)

Pmc - Clam Falls volcanics (Mesoproterozoic)
Basalt and associated rocks (see Plate 2, Bedrock Geology); discontinuously exposed; mantled by generally less than 5 feet (1.5 meters) of sandy to rocky colluvium. Description from source map: Chisago County Geologic Map

PRrv - Middle Proterozoic volcanic rock (Middle Proterozoic)

rv - Middle Proterozoic volcanic rock (Middle Proterozoic)
Middle Proterozoic volcanic rock. Description from source map: Superior Region Pleistocene Geologic Map

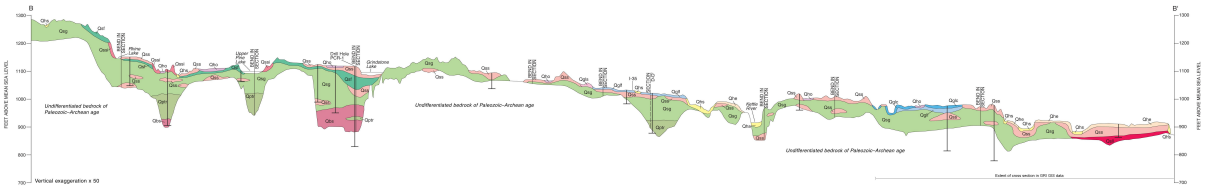
PRri - Middle Proterozoic intrusive rock (Middle Proterozoic)

ri - Middle Proterozoic intrusive rock (Middle Proterozoic)
Middle Proterozoic intrusive rock. Description from source map: Superior Region Pleistocene Geologic Map

Geologic Cross Sections

The geologic cross sections present in the GRI digital geologic-GIS data produced for Saint Croix National Scenic Riverway, Wisconsin and Minnesota (SACN) are presented below. Note that some cross section abbreviations (e.g., A - A') may have been changed from their source map abbreviation in the GRI data so that each cross section abbreviation in the GRI data is unique. Cross section graphics were scanned at a high resolution and can be viewed in more detail by zooming in (if viewing the digital format of this document). Some of the cross sections shown below include legends on their original source maps. Please follow the provided links to view the legends, where available.

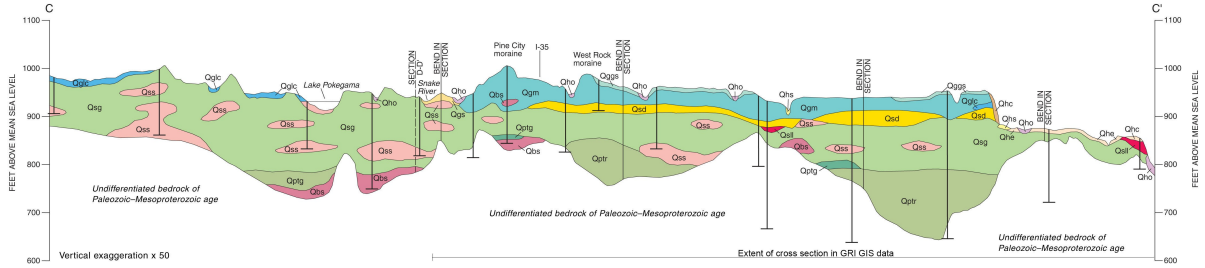
Cross Section A-A'



Graphic from source map: Pine County Geologic Map. Cross section abbreviation B-B' on source map. Vertical exaggeration: 50X.

Only a limited extent of the cross section is within the extent of the GRI digital geologic-GIS data. This is indicated on the cross section graphic by the extent bar with text along the bottom of the graphic (beginning in the bottom right).

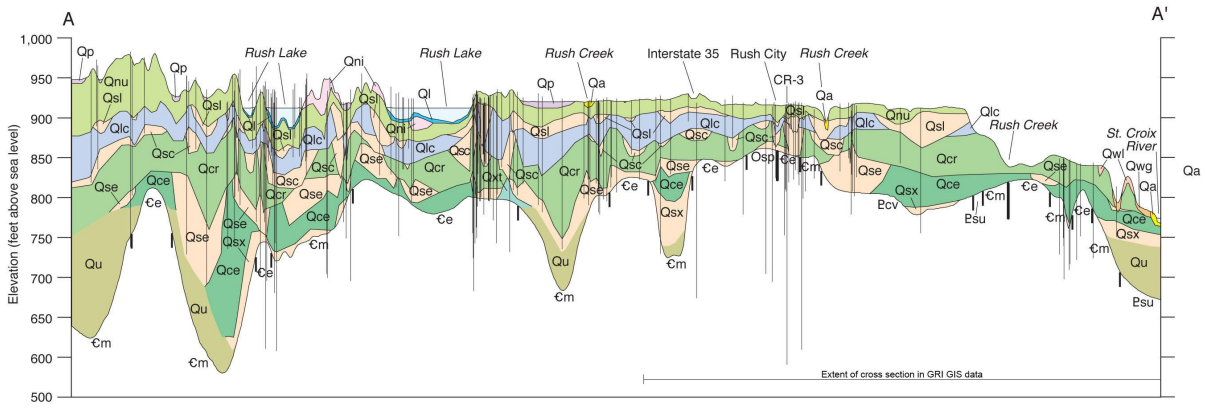
Cross Section B-B'



Graphic from source map: Pine County Geologic Map. Cross section abbreviation C-C' on source map. Vertical exaggeration: 50X.

Only a limited extent of the cross section is within the extent of the GRI digital geologic-GIS data. This is indicated on the cross section graphic by the extent bar with text along the bottom of the graphic (beginning in the bottom right).

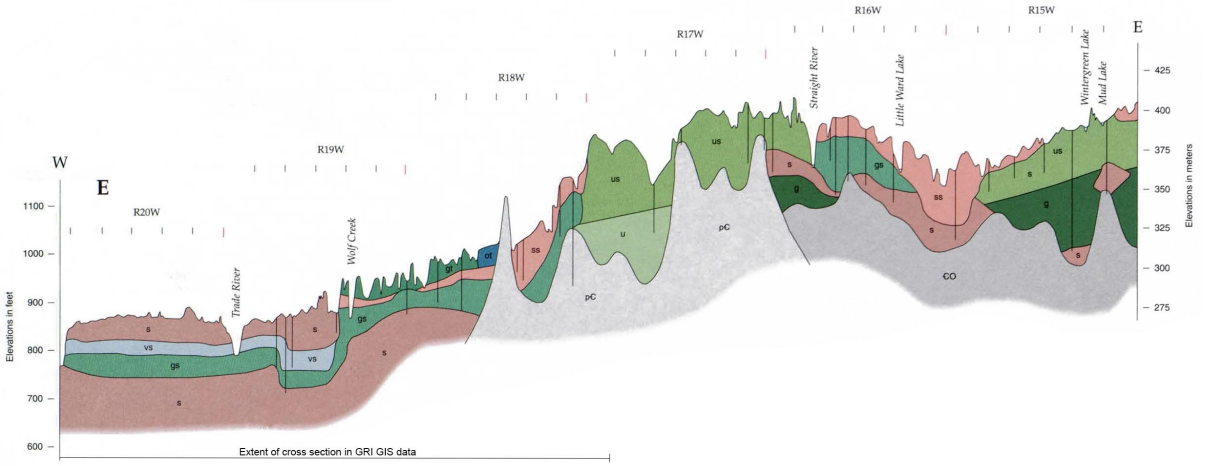
Cross Section C-C'



Graphic from source map: Chisago County Geologic Map. Cross section abbreviation A-A' on source map. Vertical exaggeration: 50X.

Only a limited extent of the cross section is within the extent of the GRI digital geologic-GIS data. This is indicated on the cross section graphic by the extent bar with text along the bottom of the graphic (beginning in the bottom right).

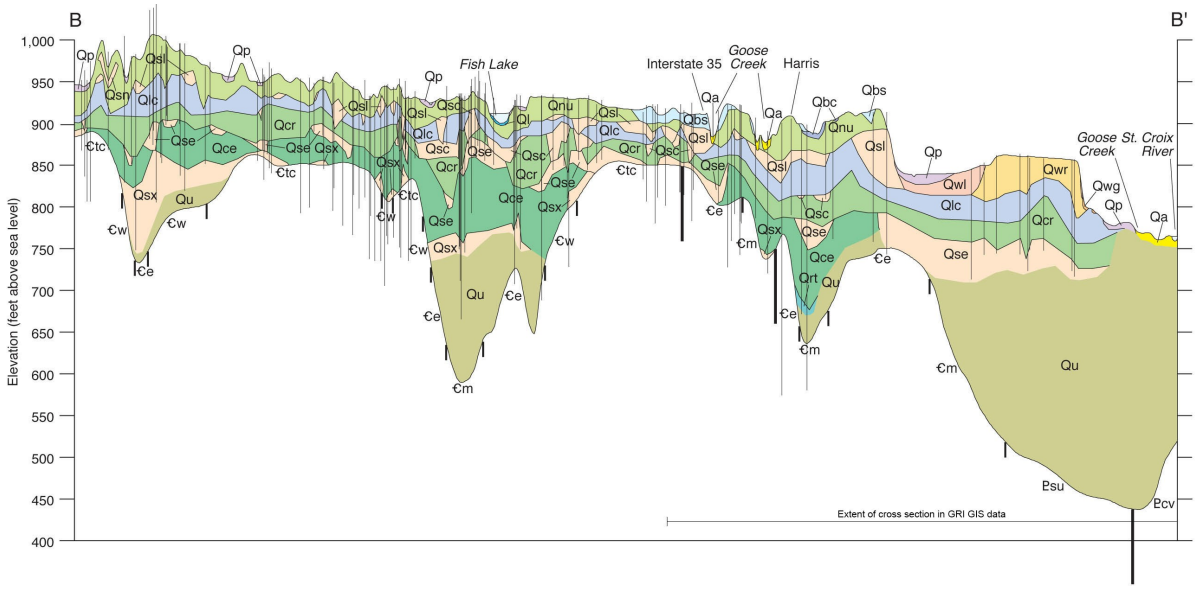
Cross Section D-D'



Graphic from source map: Polk County Pleistocene Geologic Map. Cross section abbreviation E on source map. Cross section scale: 1:200,000. Vertical exaggeration: 85X.

Only a limited extent of the cross section is within the extent of the GRI digital geologic-GIS data. This is indicated on the cross section graphic by the extent bar with text along the bottom of the graphic (beginning in the bottom left).

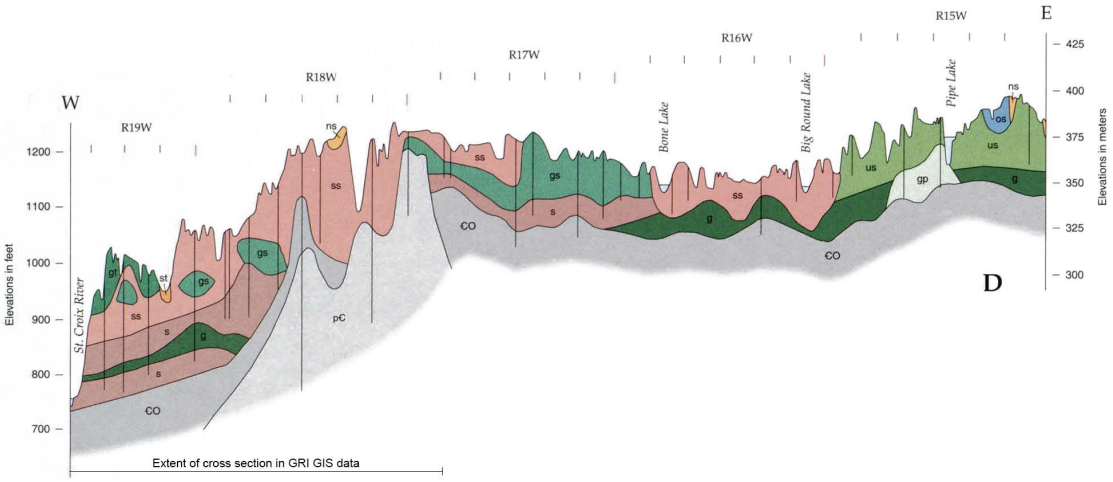
Cross Section E-E'



Graphic from source map: Chisago County Geologic Map. Cross section abbreviation B-B' on source map. Vertical exaggeration: 50X.

Only a limited extent of the cross section is within the extent of the GRI digital geologic-GIS data. This is indicated on the cross section graphic by the extent bar with text along the bottom of the graphic (beginning in the bottom right).

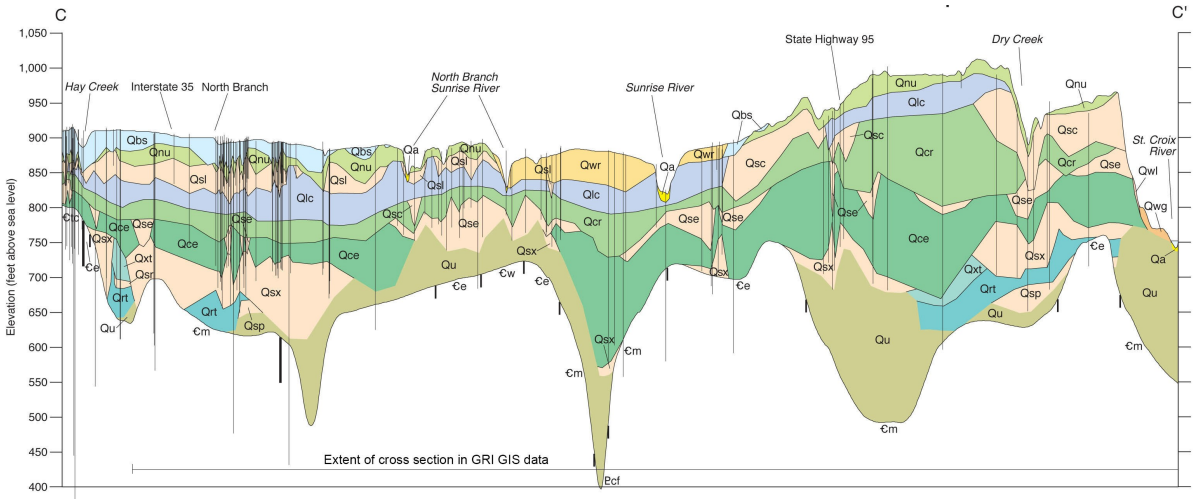
Cross Section F-F'



Graphic from source map: Polk County Pleistocene Geologic Map. Cross section abbreviation D on source map. Cross section scale: 1:200,000. Vertical exaggeration: 85X.

Only a limited extent of the cross section is within the extent of the GRI digital geologic-GIS data. This is indicated on the cross section graphic by the extent bar with text along the bottom of the graphic (beginning in the bottom left).

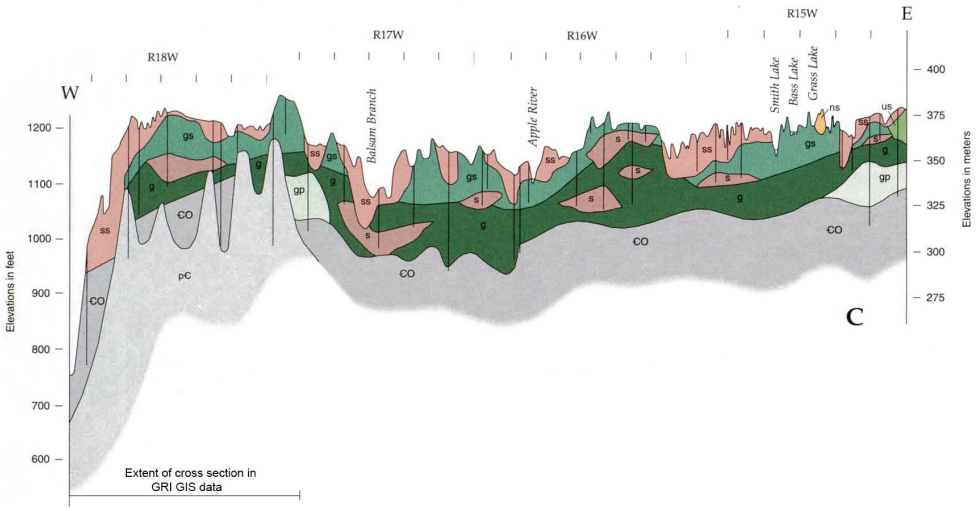
Cross Section G-G'



Graphic from source map: Chisago County Geologic Map. Cross section abbreviation C-C' on source map. Vertical exaggeration: 50X.

Only a limited extent of the cross section is within the extent of the GRI digital geologic-GIS data. This is indicated on the cross section graphic by the extent bar with text along the bottom of the graphic (beginning in the bottom right).

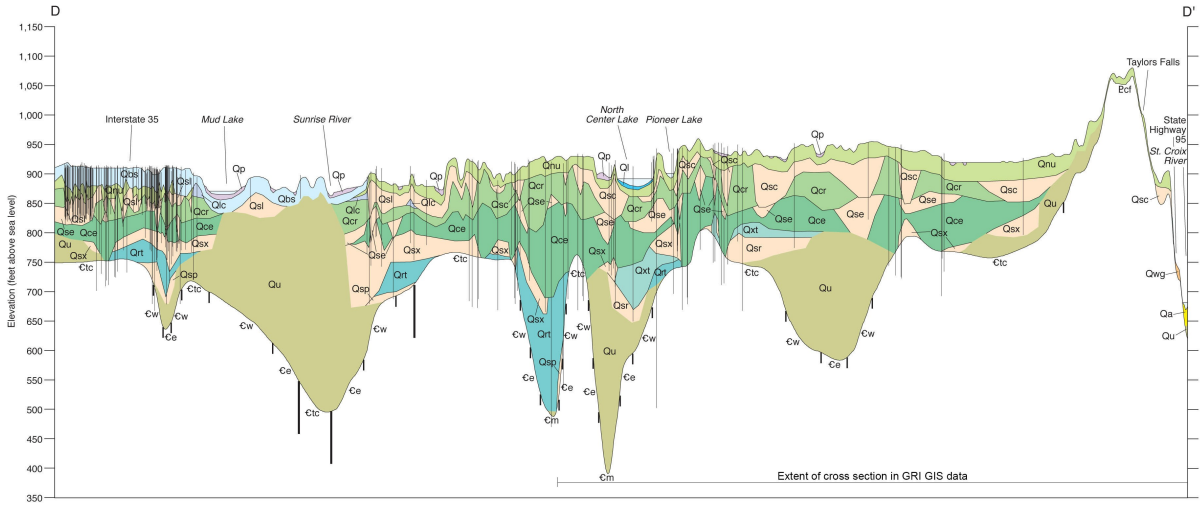
Cross Section H-H'



Graphic from source map: Polk County Pleistocene Geologic Map. Cross section abbreviation C on source map. Cross section scale: 1:200,000. Vertical exaggeration: 85X.

Only a limited extent of the cross section is within the extent of the GRI digital geologic-GIS data. This is indicated on the cross section graphic by the extent bar with text along the bottom of the graphic (beginning in the bottom left).

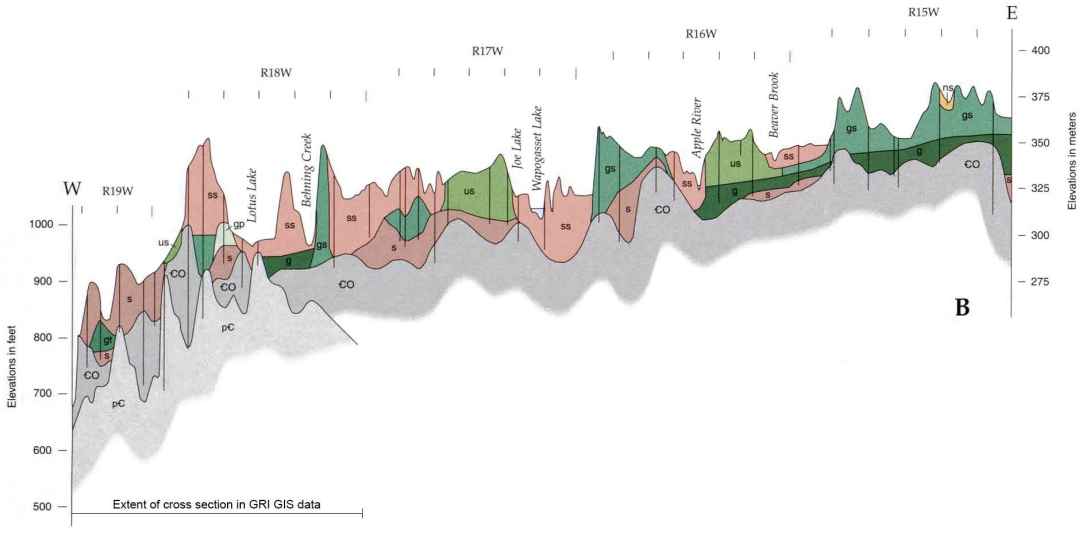
Cross Section I-I'



Graphic from source map: Chisago County Geologic Map. Cross section abbreviation D-D' on source map. Vertical exaggeration: 50X.

Only a limited extent of the cross section is within the extent of the GRI digital geologic-GIS data. This is indicated on the cross section graphic by the extent bar with text along the bottom of the graphic (beginning in the bottom right).

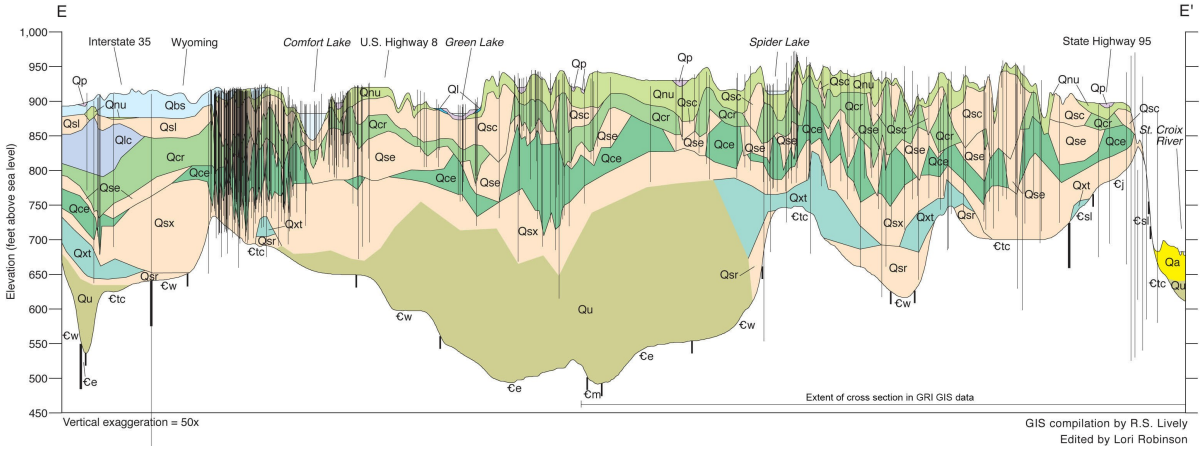
Cross Section J-J'



Graphic from source map: Polk County Pleistocene Geologic Map. Cross section abbreviation B on source map. Cross section scale: 1:200,000. Vertical exaggeration: 85X.

Only a limited extent of the cross section is within the extent of the GRI digital geologic-GIS data. This is indicated on the cross section graphic by the extent bar with text along the bottom of the graphic (beginning in the bottom left).

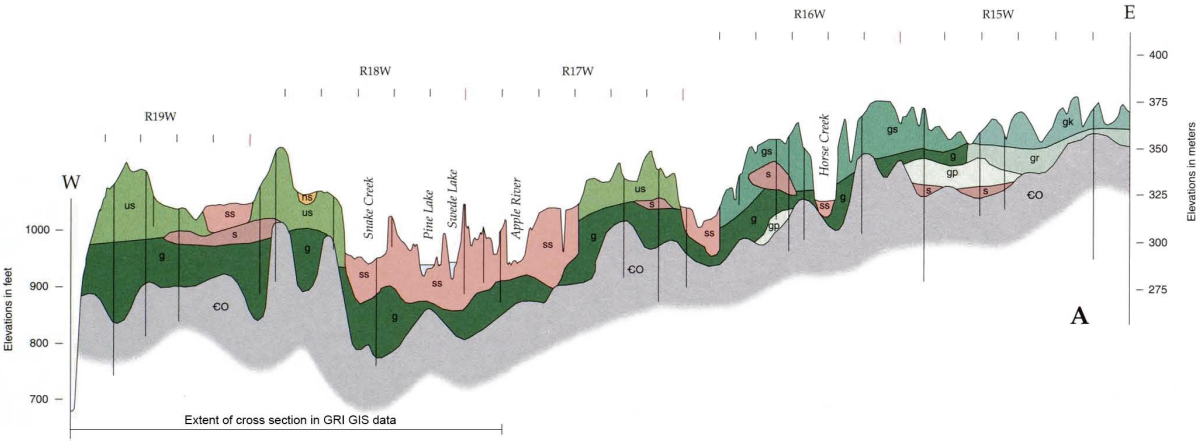
Cross Section K-K'



Graphic from source map: Chisago County Geologic Map. Cross section abbreviation E-E' on source map. Vertical exaggeration: 50X.

Only a limited extent of the cross section is within the extent of the GRI digital geologic-GIS data. This is indicated on the cross section graphic by the extent bar with text along the bottom of the graphic (beginning in the bottom right).

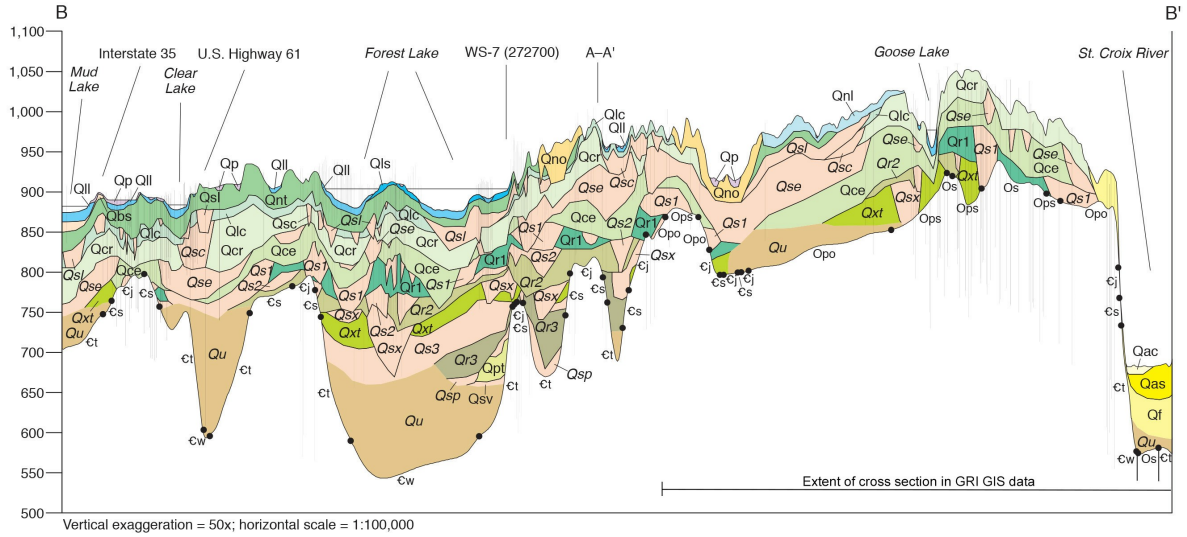
Cross Section L-L'



Graphic from source map: Polk County Pleistocene Geologic Map. Cross section abbreviation A on source map. Cross section scale: 1:200,000. Vertical exaggeration: 85X.

Only a limited extent of the cross section is within the extent of the GRI digital geologic-GIS data. This is indicated on the cross section graphic by the extent bar with text along the bottom of the graphic (beginning in the bottom left).

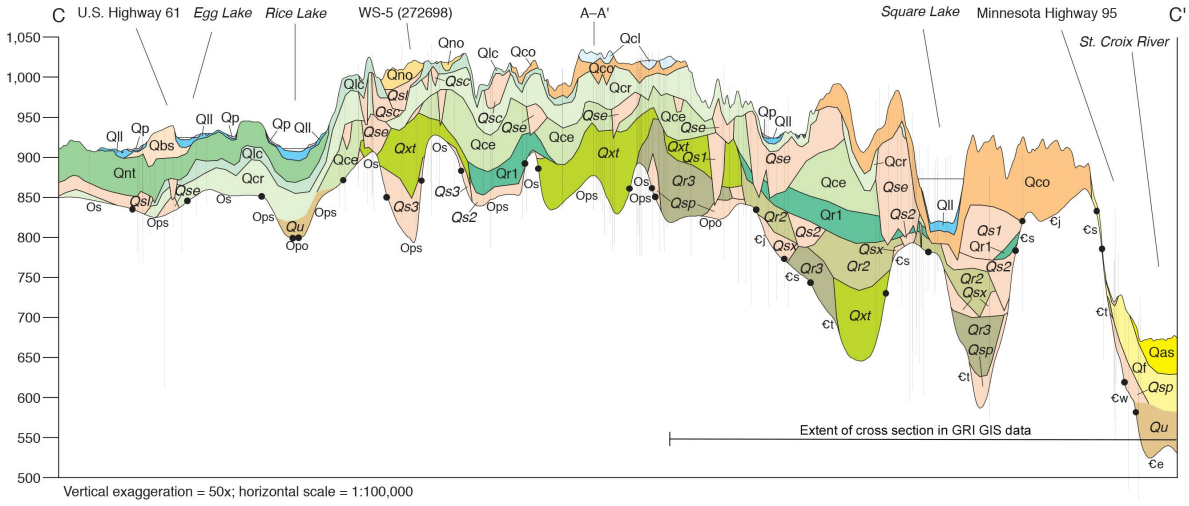
Cross Section M-M'



Graphic from source map: Washington County Geologic Map. Cross section abbreviation B-B' on source map.

Only a limited extent of the cross section is within the extent of the GRI digital geologic-GIS data. This is indicated on the cross section graphic by the extent bar with text along the bottom of the graphic (beginning in the bottom right).

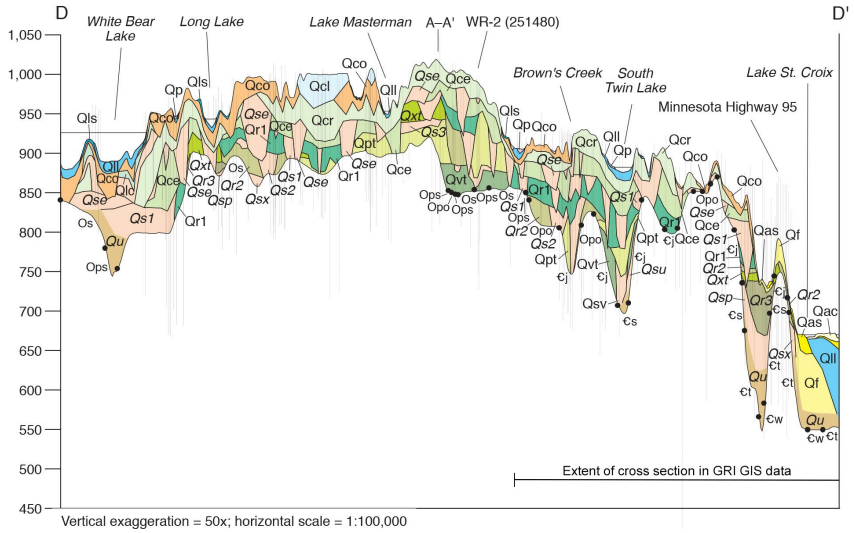
Cross Section N-N'



Graphic from source map: Washington County Geologic Map. Cross section abbreviation C-C' on source map.

Only a limited extent of the cross section is within the extent of the GRI digital geologic-GIS data. This is indicated on the cross section graphic by the extent bar with text along the bottom of the graphic (beginning in the bottom right).

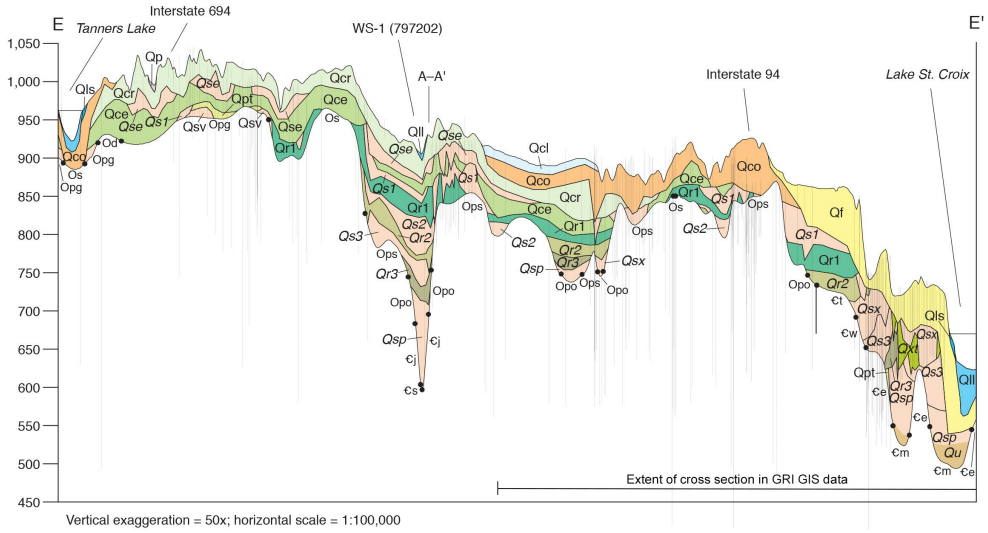
Cross Section O-O'



Graphic from source map: Washington County Geologic Map. Cross section abbreviation D-D' on source map.

Only a limited extent of the cross section is within the extent of the GRI digital geologic-GIS data. This is indicated on the cross section graphic by the extent bar with text along the bottom of the graphic (beginning in the bottom right).

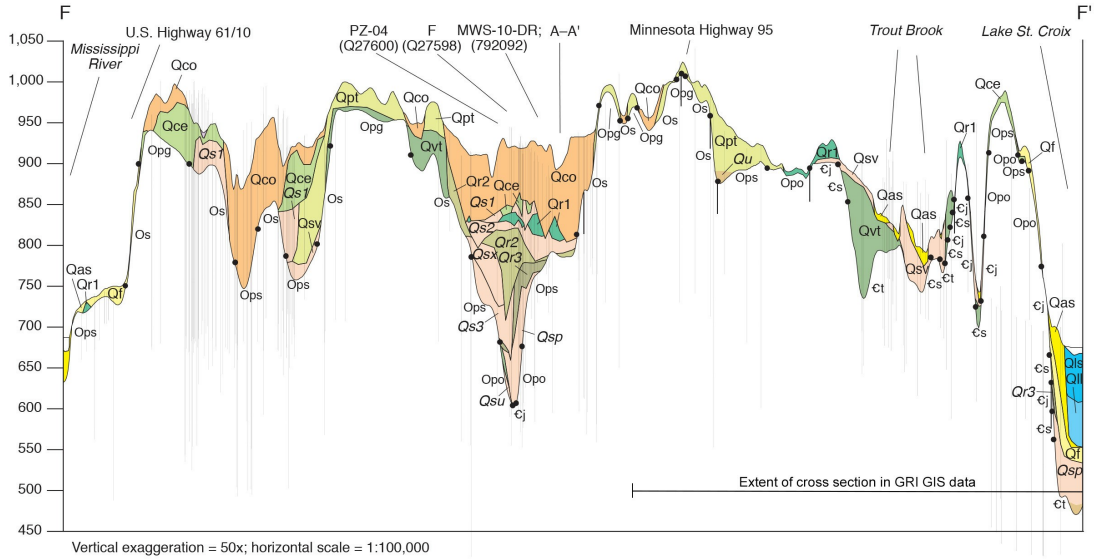
Cross Section P-P'



Graphic from source map: Washington County Geologic Map. Cross section abbreviation E-E' on source map.

Only a limited extent of the cross section is within the extent of the GRI digital geologic-GIS data. This is indicated on the cross section graphic by the extent bar with text along the bottom of the graphic (beginning in the bottom right).

Cross Section Q-Q'



Graphic from source map: [Washington County Geologic Map]. Cross section abbreviation F-F' on source map.

Only a limited extent of the cross section is within the extent of the GRI digital geologic-GIS data. This is indicated on the cross section graphic by the extent bar with text along the bottom of the graphic (beginning in the bottom right).

Ancillary Source Map Information

The following sections present ancillary source map information associated with sources used for the GRI digital geologic-GIS data produced for Saint Croix National Scenic Riverway, Wisconsin and Minnesota (SACN. Note that for some sources only a portion of that source was used, and so only information present on the used source component (e.g., a plate) was included in the GRI digital geologic-GIS data or this document.

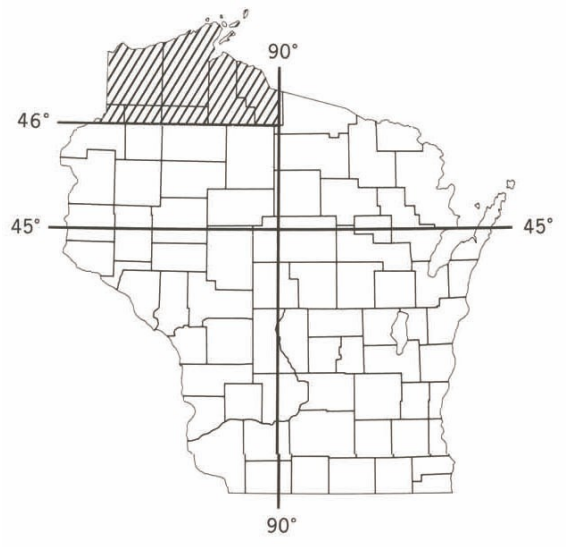
Superior Region Pleistocene Geologic Map

The formal citation for this source.

> Clayton, Lee, 1985, Pleistocene Geology of the Superior Region, Wisconsin, Wisconsin Geological and Natural History Survey, Regional Map Series 3, scale 1:250,000 (*GRI Source Map ID 3795*).

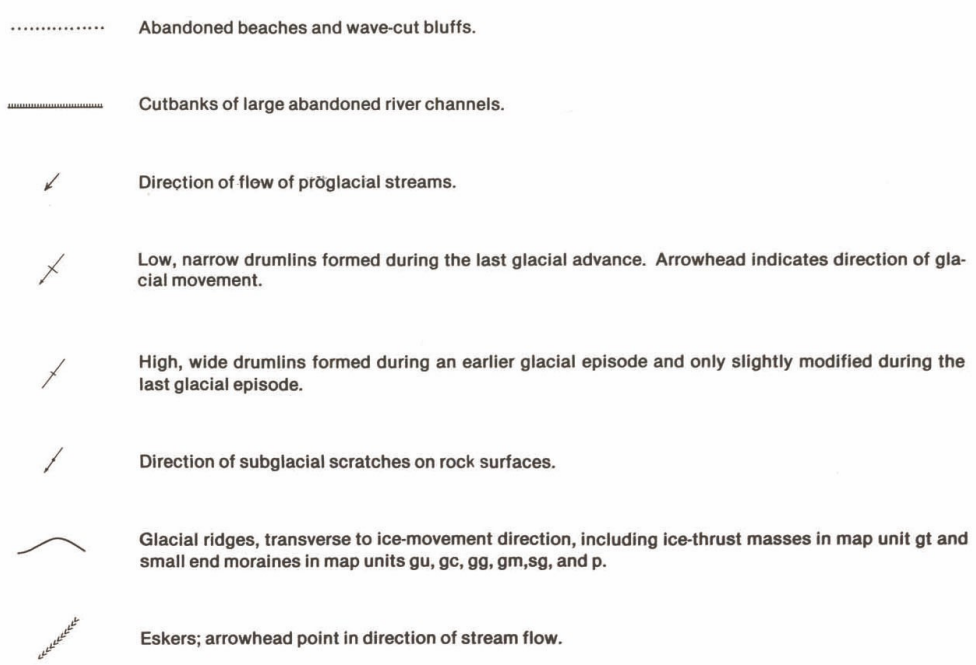
Prominent graphics and text associated with this source:

Location Map



Graphic from source map: Superior Region Pleistocene Geologic Map

Map Legend



Graphic from source map: Superior Region Pleistocene Geologic Map

Twin Cities Construction Aggregate Map

The formal citation for this source.

> Meyer, G. N., and Mossler, J. H., 1999, Primary Sources of Construction Aggregate in the Twin Cities Seven-County Metropolitan Area, Minnesota: Minnesota Geological Survey, Miscellaneous Map Series M-102, scale 1:100,000 (*GRI Source Map ID 33853*).

Prominent graphics and text associated with this source:

Map Legend

Record of water-well construction (well driller's log)

Engineering test boring

Soil borings carried out as part of this study

Six-inch auger—Depth generally greater than 40 feet

Three-inch auger—Depth no greater than 25 feet; commonly about 15 feet

Graphic from source map: Twin Cities Construction Aggregate Map

Sand and Gravel Sources

Sand and gravel deposits were mapped and named as simple land forms (Table 1) and divided into different classifications (Table 2) using various criteria. Several operators and consultants in the aggregate industry, staff of the Materials Division of the Minnesota Department of Transportation and the Division of Minerals of the Minnesota Department of Natural Resources helped to establish the criteria. Deposits are classified by percentage of material retained on the number 4 sieve (4.76-millimeter pore space), sand and gravel thickness, thickness of overlying deposits, location of the water table, and relative amounts of subsurface information available (Table 2).

Source Evaluation

Primary Sources—For classification as a primary source, the following criteria must be met: (1) more than 20 percent of the material is retained on a number 4 sieve; (2) the deposit is thicker than 10 feet; and (3) overlying sediment is no thicker than 10 feet.

Quality of source where the water table is more than 20 feet below land surface (classifications 1, 2, 3, and 6):

Excellent to good (less than 1.5 percent total spall materials)

Good to moderate (less than 5 percent total spall materials)

Moderate to poor (generally more than 5 percent total spall materials)

Quality of sources where the water table is less than 20 feet below land surface (classifications 7 and 8):

Excellent to good (less than 1.5 percent total spall materials)

Good to moderate (less than 5 percent total spall materials)

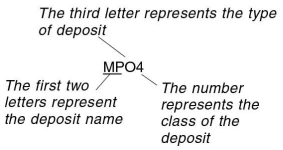
Moderate to poor (generally more than 5 percent total spall materials)

Secondary Sources—A secondary source must meet one or more of the following conditions: (1) less than 20 percent of the material is retained on a number 4 sieve; and/or (2) the deposit is less than 20 feet thick; and/or overlying sediment is more than 10 feet.

Potential secondary source—Classifications 4 and 5

Gravel pit—Active or inactive pit

Large gravel pit, or an area of more than one gravel pit or gravel-pit operation



Four-character code indicating deposit name, deposit type, and aggregate-quality classification—In the example shown, the code indicates a deposit named Minneapolis outwash that has a classification of 4. Refer to Tables 1 and 2 for further information.

Graphic from source map: Twin Cities Construction Aggregate Map

Bedrock Aggregate Sources

Source Evaluation and Reliability of Data

The only available bedrock aggregate source in the Seven-County Metropolitan Area is Prairie du Chien dolostone where overburden is thinner than ten feet. Both quality and quantity of data determine how reliably the various units of Prairie du Chien are delineated on the map. Information that was used to map bedrock source units includes bedrock outcrops, water-well and soil-boring records, soil maps, and topographic maps.

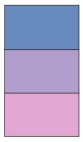
Excellent Reliability—Areas shown as having excellent reliability are characterized by

1. outcrops of Prairie du Chien dolostone;
2. numerous, evenly distributed water-well and soil-boring records that indicate carbonate bedrock at less than ten feet below the land surface;
3. soils characterized by parent material or substratum of carbonate bedrock; and
4. the presence of bluffs, flat plateaus, ridges, or rock terraces—landforms that typically form in areas underlain by carbonate bedrock.

Good reliability—Areas shown as having good reliability are delineated using criteria 3 and 4 above and criterion 1 or 2. Characteristically, areas mapped as having good reliability have fewer outcrops and water-well and soil-boring records. Where such data are available, they are not as evenly distributed as those in areas mapped as having excellent reliability

Fair reliability—Areas shown as having fair reliability are delineated mainly by criteria 3 and 4. The mapping is primarily based on soil maps and topographic expression. There are no outcrops and only a few water-well and soil-boring records to support the distribution of bedrock shown.

Where Prairie du Chien dolostone is thicker than 30 feet.

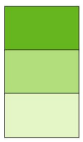


Excellent reliability

Good reliability

Fair reliability

Where Prairie du Chien dolostone is 10–30 feet thick.

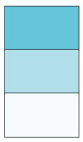


Excellent reliability

Good reliability

Fair reliability

Where Prairie du Chien dolostone is less than 10 feet thick.



Excellent reliability

Good reliability

Fair reliability

Quarry



Large quarry, or area of more than one quarry or quarry operation

Graphic from source map: Twin Cities Construction Aggregate Map

Table 1: Sand and Gravel Codes

AFV ..... Afton valley fill
ARK ..... Arsenal kame
AVO ..... Apple valley outwash
BFG ..... Bluff gravel (Dakota & Ramsey Cos.)
BLG ..... Bluff gravel (Carver Co.)
BLO ..... Bloomington outwash
BMO ..... Big Marine outwash
BRI ..... Burns ice contact
BVK ..... Burnsville kame
BVO ..... Burnsville outwash
CGO ..... Cottage Grove outwash
CLS ..... Crystal Lake sand
COO ..... Crow River outwash (Hennepin Co.)
CRI ..... Credit River ice contact
CRO ..... Cannon River outwash
CSV ..... Castle Rock valley fill
CWO .... Crow River outwash (Carver Co.)
DEI ..... Des Moines ice contact (Scott Co.)
DM ..... Des Moines ice contact (Dakota & Scott Cos.)
DMU ..... Denmark upland gravel
EAK ..... Eagan kame
EPO ..... Eden Prairie outwash
ERO ..... Elk River outwash
FLE ..... Fish Lake esker
GB ..... Grantsburg ice contact
GCT ..... Grey Cloud terrace
GRT ..... Grey Cloud terrace (Carver & Scott Cos.)
GVO ..... Golden Valley outwash
HAM ..... Hampton moraine
HLG ..... Hillside gravel
LDT ..... Langdon terrace (St. Croix River)
LEO ..... Lake Elmo outwash
LGT ..... Langdon terrace (Mississippi River)
LVO ..... Lakeville outwash
MHO ..... Mendota Heights outwash
MPF ..... Mississippi floodplain (Anoka & Hennepin Cos.)
MPO ..... Minneapolis outwash
MSF ..... Mississippi floodplain
MTK ..... Minnetonka kame
MYO ..... May outwash
NOI ..... North Oaks ice contact
OSK ..... Osseo kame
OSO ..... Osseo outwash
PLI ..... Piersons Lake ice contact
PRI ..... Prior Lake ice contact
RFT ..... Richfield terrace
RHT ..... Richfield terrace (Washington Co.)
RIV ..... Rich valley train
RSO ..... Rosemount outwash
SCI ..... Sand Creek ice contact
SCO ..... St. Croix outwash
SCV ..... Sand Creek valley fill
SFI ..... San Francisco ice contact
SMT ..... St. Mary's terrace
SPO ..... St. Paul outwash
SUI ..... Superior ice contact
TOK ..... Tower kame
VDG ..... Valley delta gravel
VRO ..... Vermilion River outwash
WFO ..... Waterford outwash

Table from source map: Twin Cities Construction Aggregate Map

Table 2: Sand and Gravel Classifications

CLASSIFICATION NO.	PROPORTION OF MATERIAL RETAINED ON NO. 4 SIEVE[1]		THICKNESS OF SAND & GRAVEL DEPOSIT		THICKNESS OF OVERLYING SEDIMENTS	POSITION OF WATER TABLE	QUALITY OF SUBSURFACE DATA
1	More than 20%	***and***	More than 40 ft	***and***	10 ft or less	More than 20 ft below land surface	Good subsurface data: Deep Minn. Dept. of Transportation test borings or many detailed water-well records from several drillers
2	More than 20%	***and***	10–40 ft	***and***	10 ft or less	More than 20 ft below land surface	Good subsurface data
3	More than 20%	***and***	More than 20 ft	***and***	10 ft or less	More than 20 ft below land surface	Limited subsurface data: Few borings or water-well records. Soil maps and surficial geology suggest the presence of gravel deposits. Some good deposits probably available, but boundaries uncertain.
4	Less than 20%	***and/or***	Less than 20 ft	***and/or***	More than 10 ft	May be less than 20 feet below land surface	Limited subsurface data. Few or no soil-boring or water-well records, or well records are too generalized. Soil maps and surficial geology indicate possible sand and gravel deposits. Good deposits may be present in places, but in most cases this classification represents gravel-poor sand deposits or thick sand overlying gravel.
5	Less than 20%	***and/or***	Less than 10 ft	***and/or***	More than 10 ft	May be less than 20 feet below land surface	Good subsurface data
6	More than 20%	***and***	10–40 ft thick over dolostone	***and***	10 ft or less	More than 20 ft below land surface	Good to fair subsurface data. Presence of carbonate bedrock generally well established, but percentage of gravel in overlying sediments may vary, especially in the larger areas mapped.
7	More than 20%	***and***	More than 20 ft	***and***	10 ft or less	Less than 20 ft below land surface	Good subsurface data
8	More than 20%	***and***	More than 20 ft	***and***	10 ft or less	Less than 20 ft below land surface	Limited subsurface data. Few soil-boring or water-well records. Soil maps and surficial geology suggest gravel deposits. Good deposits probably available, but boundaries uncertain.

[1]The width of the pore space on a number 4 sieve is 4.76 millimeters.

Table from source map: Twin Cities Construction Aggregate Map

Polk County Pleistocene Geologic Map

The formal citation for this source.

Johnson, M. D., 2000, Pleistocene Geology of Polk County, Wisconsin: Wisconsin Geological and Natural History Survey, Bulletin 92, scale 1:100,000 (*GRI Source Map ID 50580*).

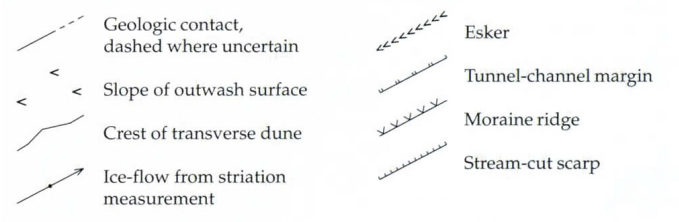
Prominent graphics and text associated with this source:

Location Map



Graphic from source map: Polk County Pleistocene Geologic Map

Map Legend



Graphic from source map: Polk County Pleistocene Geologic Map

St. Croix County Quaternary Geologic Map

The formal citation for this source.

Kostka, S. J., Hinke, D. M., Mickelson, D. M., and Baker, R. W., 2004, Preliminary Quaternary Geologic Map for St. Croix County, Wisconsin: Wisconsin Geological and Natural History Survey, Open-File Report 2004-22, scale 1:100,000 (*GRI Source Map ID 75428*).

Prominent graphics and text associated with this source:

Location Map



Graphic from source map: St. Croix County Quaternary Geologic Map.

Map Legend

Geologic contact. Dashed where uncertain; solid where position shown on map is judged to be generally within 0.1 km of actual position; dashed where the position shown may be more than 0.1 km from actual position.

Ice-margin position. Interpreted position of maximum extent of readvance of ice or position of ice margin stabililty where ice-contact face or end moraine is missing.

Indefinite ice-margin position. Interpreted position of ice margin must exist, but is obscured by erosion or buried by more recent deposits.

Esker

Graphic from source map: St. Croix County Quaternary Geologic Map.

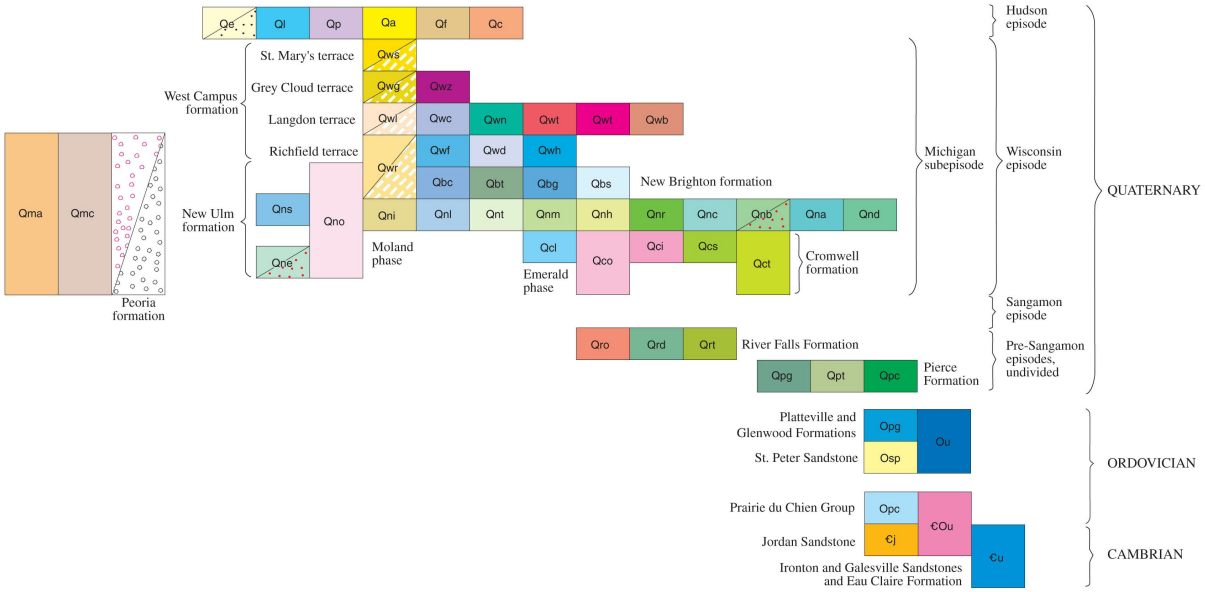
Twin Cities Metro Region Surficial Geology

The formal citation for this source.

> Meyer, Gary N., 2007, Surficial Geology of the Twin Cities Metropolitan Area, Minnesota: Minnesota Geological Survey, Miscellaneous Map Series, M-178, scale 1:125,000 (*GRI Source Map ID 75549*).

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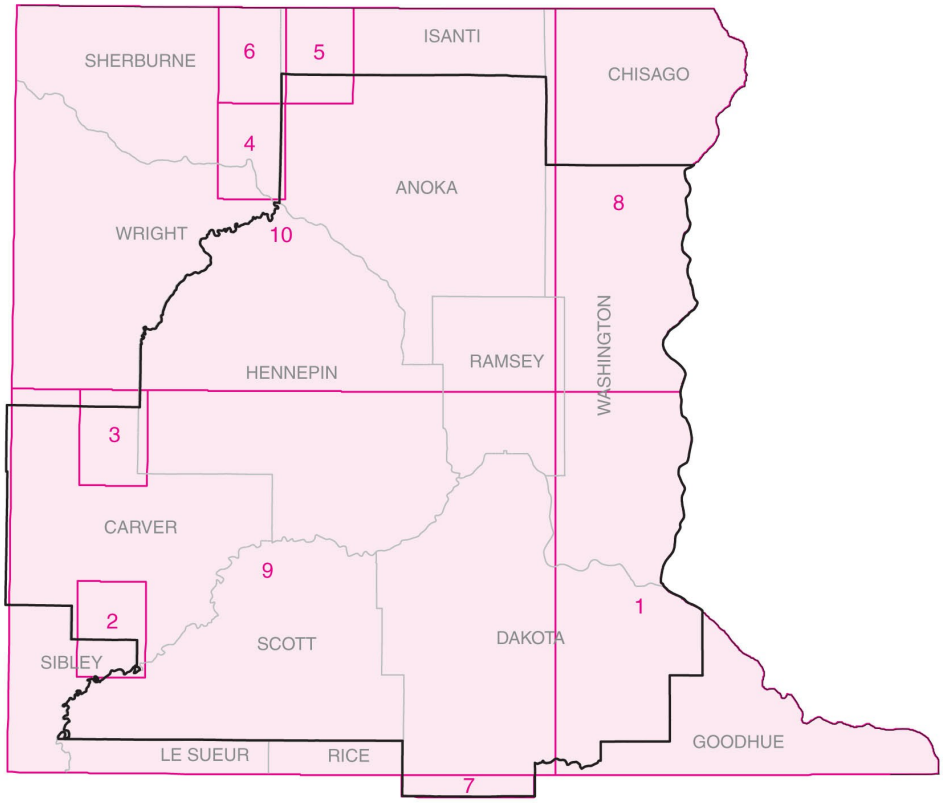
Correlation of Units



Units symbols on this graphic may differ slightly from respective units in the GRI digital geologic-GIS data. This is due to resolving unit symbols across multiple maps used in this compilation.

Graphic from source map: Twin Cities Surficial Geologic Map

Index Map

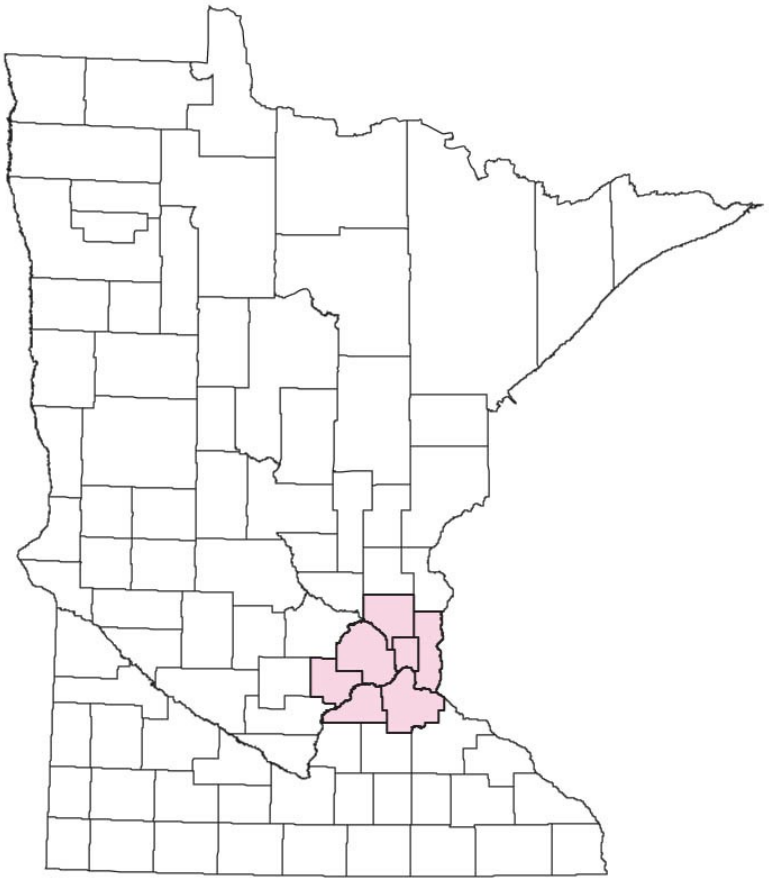


INDEX TO EXISTING QUATERNARY MAPPING

The map above shows the location of previous mapping in the study area. Citations 1 through 10 in the references were used to compile the geology of the map area. An updated version of the Hennepin County soil survey (Steffen, 2004), logs of recently located water wells and soil borings, and unpublished studies by the Minnesota Geological Survey were also used to compile the surficial geology. The thin white strip along the west edge of Carver County was newly mapped for this project.

Graphic from source map: Twin Cities Surficial Geologic Map

Location Map



Graphic from source map: Twin Cities Surficial Geologic Map

Map Legend

Geologic contact—Approximately located.

General flow direction of braided streams—Arrow points downstream in the direction glacial meltwater once flowed.

Stream-cut scarp—Hachures point downslope; dashed where discontinuous or obscure; marks the flanks of a former fluvial channel. Boundaries of terrace units and alluvium are commonly at scarps, so are not shown by a scarp symbol. Where paired, scarps bound stream-scoured areas. Till surfaces on the hachured side of scarps are fluvially scoured and mantled in places by sand and gravel too thin and patchy to map separately.

Linear feature—Identified from aerial photographs. Symbol schematically represents the ridge-and-valley topography of slump blocks within map unit Qnr.

Approximate shorelines of Glacial Lake Anoka—The maximum extent of the lake is difficult to determine, because in many places it was likely ponded against landforms created by buried stagnant ice. The ice-cored landscape was lowered when this ice melted. Till of the New Ulm formation within the mapped shorelines of Glacial Lake Anoka has been wave-washed and covered in places with thin beds of silt, sand, or gravel. The till in some of these areas has subsequently collapsed due to melt-out of underlying ice. Some of the collapsed till areas now lower in elevation than adjacent areas of New Brighton formation sediment were likely islands or peninsulas in Glacial Lake Anoka.

Fridley level—About 915 feet (274 meters) above mean sea level.

Hugo level—About 940 feet (287 meters) above mean sea level.

Maximum extent—About 960 feet (293 meters) above mean sea level where mapped along the eastern shore.

Plateau—A broad, relatively level area in a zone of hummocky topography. Plateaus range from 40 to over 640 acres (0.16 to 2.59 square kilometers). Predominantly till; capped in places by 3 to 17 feet (1 to 5 meters) of lake sediment. The plateaus are interpreted to represent saturated debris that was deposited in lows on stagnant ice; the deposits now stand as topographic highs on the landscape. Sorted sediment in the center of the plateau was deposited in standing water.

Esker—A sinuous ridge of sand and gravel, interpreted to have been deposited in an ice-walled channel of a glacial meltwater stream flowing at the base of the ice. The fluvial sediment may be covered by 10 feet (3 meters) or more of till, especially in areas where the New Ulm formation is the surficial unit. Arrows show the inferred flow direction.

Broad, irregular trough—Hachures point downslope; identified by alignment of depressions and lakes. Symbol likely marks collapsed and filled channels. Many of these troughs are interpreted to reflect valleys cut by meltwater flowing beneath Superior lobe ice that were partially buried by subsequent glacial events. Drainage channels beneath the Superior lobe ice locally eroded deeply into the substrate, exploiting pre-existing bedrock valleys in places. These tunnel valleys in places were likely reoccupied by proglacial meltwater of both the receding Superior lobe and the advancing Des Moines lobe.

Ice-marginal ridge of Superior lobe ice—Teeth are on the up-ice side.

Inferred ice margin—Approximate maximum extent of an ice advance; labels are on the up-ice side of the margin.

St. Croix phase (Wright, 1972)—Marks the outside margin of the St. Croix Moraine. Most of the deposits of the Cromwell Formation mapped at the surface in the metropolitan area were deposited by this advance of the Superior lobe during the Michigan subepisode.

Emerald phase (Johnson and Mooers, 1998)—This most extensive advance of the Superior lobe during the Michigan subepisode deposited outwash and till of the Cromwell formation. Till is only patchily preserved between this margin and the St. Croix moraine because of subsequent erosion and burial by outwash of the St. Croix phase.

Pre-Michigan advance—Inferred extent of ice that deposited the River Falls Formation.

Graphic from source map: Twin Cities Surficial Geologic Map

Table 1: Glacial Deposit Characteristics

PROVENANCE	RIDING MOUNTAIN	WINNIPEG	SUPERIOR
TILL TEXTURE	Mostly loamy	Loamy to clayey	Mostly sandy
TILL COLOR			
Oxidized	Yellow to olive-brown	Yellow-brown	Red-brown
Unoxidized	Gray to dark gray	Gray to dark gray	Gray to red-gray
PEBBLE TYPE			
Carbonate	Common	Common to abundant	Uncommon to common
Gray-green rock	Uncommon	Uncommon	Common
Red felsite	Absent to uncommon	Rare to uncommon	Uncommon to common
Gray shale	Uncommon to abundant	Absent to rare	Absent

Table from source map: Twin Cities Surficial Geologic Map

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References from source map: Twin Cities Surficial Geologic Map

Chisago County Geologic Map

The formal citation for this source.

> Setterholm, Dale R., 2010, Geologic Atlas of Chisago County, Minnesota: Minnesota Geological Survey, County Atlas Series C-22 Part A, scale 1:100,000 (*GRI Source Map ID 76142*).

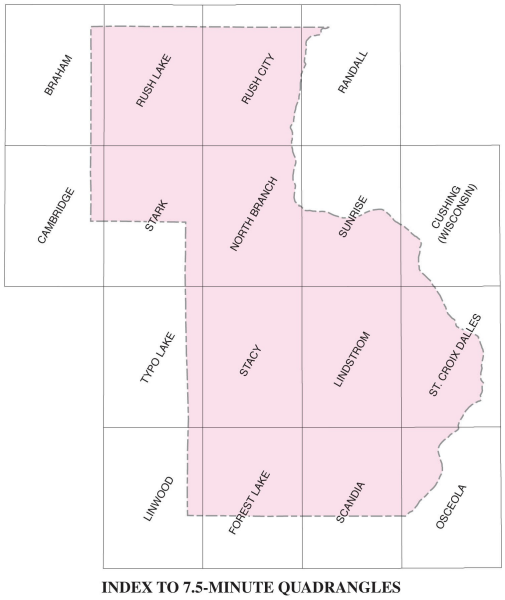
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Location Map



Graphic from source map: Chisago County Geologic Map.

Index Map

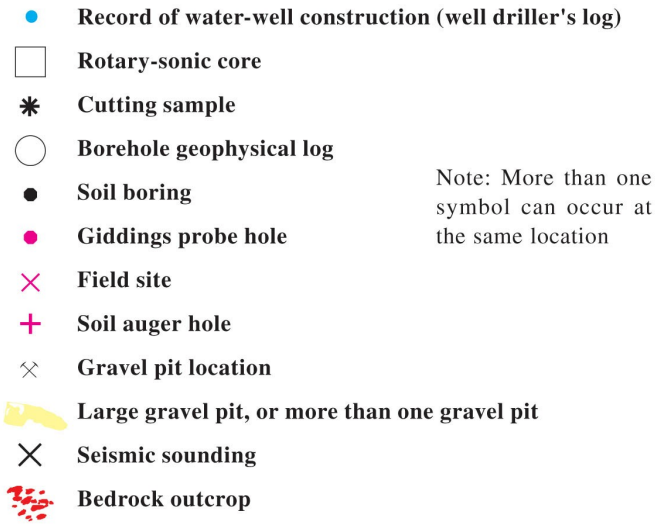


INDEX TO 7.5-MINUTE QUADRANGLES

Graphic from source map: Chisago County Geologic Map.

Plate 1: Data-Base Map

Map Legend



Graphic from source map: Chisago County Geologic Map.

Report

Introduction

The public health and economic development of Chisago County are directly dependent on the wise use and management of its land and water resources. Accurate geologic and hydrologic information are essential before decisions are made that affect natural resources. Although the amount of geologic information required for making specific decisions can vary, the information will not be used if it is unavailable when needed, or if it is available only in a highly technical form, or scattered in many different maps and reports.

County atlases, prepared jointly by the Minnesota Geological Survey and the Minnesota Department of Natural Resources, Division of Waters, present detailed geologic and hydrologic information in an interpretive as well as descriptive form. Maps and texts either summarize basic geologic and hydrologic conditions at a county scale, or interpret these conditions in terms of the impacts of possible land- and water-use decisions. Site-specific information is also available at a greater level of technical detail than shown on the maps of this atlas. The data are too voluminous to present in the atlas, but have been incorporated into readily accessible files housed at the Minnesota Geological Survey.

Several sources commonly provide information about an area or an individual property, but they may use different classification schemes to describe the same geologic materials. As a result, discrepancies in interpreting the data may arise or the different sources may appear to contradict each other. For example, water-well drillers may describe glacial till as "clay," but engineering records will describe it as "clayey sand." Both descriptions are acceptable for their original purpose of describing the physical attributes of the material. "Clay," the term used by well drillers, defines the general inability of the till to yield ground water to a well. "Clayey sand," the term from the engineering record, defines the physical

composition of the till relative to particle size and engineering properties. The geologist must take the analysis one step further and define the material in terms of how it formed rather than how it is to be used. In this example, till consists of an unsorted mixture of rock fragments ranging in size from clay to cobbles and boulders, and it is interpreted by the geologist as having been deposited directly by glacial ice.

All of the types of data described on this plate had to be interpreted by geologists or hydrogeologists before they were meaningful for mapping purposes. The 1:100,000 and 1:200,000 scales of the maps in this atlas were chosen because they can show the geologic and topical studies of the county while keeping the physical size of each plate to a manageable level. As a result, some detailed information that was gained by data interpretation and mapping cannot be shown on these maps or discussed in the texts.

Whether to use the atlas alone, or in combination with the data bases, depends on the amount of detail needed. Generally, data-base information must be used to evaluate site-specific conditions.

Text from source map: Chisago County Geologic Map.

Data-Base Map Explanation

The types, locations, and density of information used to prepare the Chisago County atlas are shown on this map. The data are described below to aid the user in assessing what types may be useful for a particular information need. The Data-Base Map serves as a guide to the precision of the other maps in the atlas. It shows where data are sparse or lacking and interpretation and extrapolation were required to prepare the maps. All data were collected by Minnesota Geological Survey staff unless otherwise specified.

Text from source map: Chisago County Geologic Map.

Drill-Hole Information

A **record of water-well construction (well driller's log)** is a water-well contractor's description of the geologic materials penetrated during drilling and the construction materials used to complete the well. Not all wells extend to bedrock. In areas of thick, unconsolidated Quaternary deposits, drillers usually do not need to drill through the entire thickness of overburden to find sufficient ground water. Hydrologic data, such as the static water level and test-pumping results, are commonly included. Before any driller's log can be used, the location of the well must be verified, and a geologist must interpret the log. Driller's logs are the primary source of subsurface geologic and hydrologic data for Chisago County; about 9,200 logs were used for this atlas.

Rotary-sonic cores were collected at six sites in Chisago County as a means to help establish the nature of the subsurface material. The coring technique enables recovery of a continuous core, 3.5 inches (8.9 centimeters) in diameter, from glacial deposits and bedrock (if present). It provides excellent subsurface samples for detailed study and comparison with cuttings, geophysical logs, and driller's logs from surrounding sites. The core is available for inspection at the Minnesota Department of Natural Resources, Division of Lands and Minerals offices.

Cutting samples collected during drilling provide physical evidence of subsurface geologic materials. Cuttings are the samples generated as the drill bit cuts through the subsurface material and are used to interpret and verify driller's logs. They are logged and stored at the Minnesota Geological Survey or the

Minnesota Department of Natural Resources, Division of Lands and Minerals.

Borehole geophysical logs are created by lowering instruments down a well or drill hole and measuring the physical and chemical properties of the geologic materials through which the hole passes. Different logging techniques measure naturally occurring gamma radiation, spontaneous potential, and resistivity. Gamma logs characterize in graphic form the geologic formations penetrated. Spontaneous potential and resistivity are mainly used to locate water levels in wells and the depth of the well casing. An interpretive log is prepared from the geophysical log and correlated with drilling samples from the same hole, information obtained from nearby outcrops, or a geophysical log from a nearby drill hole. Geophysical logs can provide high-quality subsurface geologic and hydrologic information for wells that have little or no other information available. The information obtained from a geophysical log is added to the County Well Index (CWI) and the paper log is on file at the Minnesota Geological Survey.

Soil borings are test holes drilled to obtain information about the physical properties of subsurface materials for engineering, mapping, or exploration purposes. Most terminate at very shallow depths or where bedrock is encountered. They are logged by an engineer or a geologist using a variety of classification schemes based on particle sizes, penetration rate, moisture content, and color. Soil-boring data were collected by the Minnesota Department of Transportation and the U.S. Geological Survey. They are limited in distribution; in Chisago County they are concentrated along the Interstate 35 corridor. These data are most useful in determining the composition of unconsolidated deposits.

Text from source map: Chisago County Geologic Map.

Other Information

Giddings probe holes allow description and sampling of continuous glacial materials, 2 inches (5.1 centimeters) in diameter, collected by a truck-mounted hydraulic auger. Samples were generally taken about every 5 feet (1.5 meters), at unit contacts, or where the geologist believed it was important. A description was generated at every site and almost always a sample or samples were taken for textural analyses.

Field sites are natural and artificial exposures of unconsolidated Quaternary deposits that were described in detail; some sites were texturally analyzed.

Textural analyses express the proportion of sand-, silt-, and clay-size particles that make up a sample. They are helpful in identifying and mapping unconsolidated materials like Quaternary glacial deposits. The samples analyzed were taken from natural and artificial exposures, Giddings holes, and the rotary-sonic cores.

Soil auger holes are shallow borings created with a hand auger to generate a description of the subsurface material. They are generally less than 5 feet (1.5 meters) in depth.

Gravel pit locations were taken from the Minnesota Department of Transportation's Aggregate Source Information System listing of aggregate sources. Test hole logs, sieve, and quality test data are available.

Seismic soundings measure the time required for sound or pressure waves to travel from a source through the subsurface, and be refracted back to a receiver. Travel time can be correlated with the density and rigidity of the geologic material and the depth where these properties change. Most bedrock exhibits acoustic- or pressure-wave velocities 1.5 to 2.5 times those of unconsolidated Quaternary sediments below the water table. The spacing of the receivers (geophones) and the arrival times (measured in milliseconds) are used to calculate the depth to bedrock. Seismic soundings are labor

intensive but can provide high-quality data where no other sources of subsurface information are available. In Chisago County and adjacent areas, a total of 16 seismic-refraction lines were used to delineate the depth to bedrock buried beneath Quaternary deposits where greater detail was needed beyond what was available with existing water well data. These consist of seven lines that were acquired by the Minnesota Department of Natural Resources, Division of Waters, as part of this project; and nine historical lines that were acquired by Mooney and others (1970).

Bedrock outcrops are exposures of solid rock at the land surface. Most are natural outcrops; however, some are exposures created during construction. They serve as reference points for mapping and for checking the accuracy of subsurface data. Bedrock at or near the surface must be considered in land-use planning decisions such as pipeline routing, sewage-system design, and excavation.

Text from source map: Chisago County Geologic Map.

Data-Base Management

All of the data shown on the maps were plotted on 7.5-minute topographic quadrangle maps or highway alignment maps. Inventory numbers were assigned to all data sources. Automated data bases and a few manual files were developed to provide easy access and rapid retrieval of these site-specific data. The data may be obtained from the Minnesota Geological Survey.

Computer storage and retrieval systems are better than manual files for manipulating large amounts of data because automated geologic data bases can be designed to interact with other computer files, such as land-use data. Such interaction permits more efficient assessment of cause-and-effect relationships concerning natural resources than is commonly possible with manual files.

Text from source map: Chisago County Geologic Map.

Chisago County Data Bases

Computerized files were developed for point-source data such as wells and borings in Chisago County. They use Public Land Survey descriptions, Universal Transverse Mercator (UTM), and latitude longitude coordinates as location criteria; thus, they are compatible with the natural-resource data bases housed at the Minnesota Land Management Information Center (LMIC). The computerized data bases developed for Chisago County by the Minnesota Geological Survey are County Well Index (CWI) and Quaternary Samples Data Base (QBASE).

County Well Index (CWI)—Information from water-well records and exploration holes was entered into this statewide data base. Each well log is assigned a six-digit unique number and each exploration drill hole is assigned either a five- or six-digit unique number. These reference numbers are also used by state agencies and the Water Resources Division of the U.S. Geological Survey. Elevations, expressed in feet above sea level, were determined from topographic maps (see the index to 7.5-minute quadrangles) and are generally accurate to plus or minus 5 feet (1.5 meters). The street address of each well is also included wherever possible to provide data users with a well-location system that is compatible with local regulatory programs. Software at the Minnesota Geological Survey is used to display and tabulate many of the data elements contained on the original well log.

The County Well Index is currently stored in a data base that consists of nine related tables. These tables contain information such as well depths, well construction, addresses, aquifers, dates drilled, static water levels, and pumping test data. They also contain alternate well identifiers such as permit

numbers or emergency-service numbers, and the well stratigraphy (the geologic materials encountered during drilling).

CWI application software developed by the Minnesota Department of Health provides two types of reports:

-WELL LOG contains all the information about the well as it was reported by the contractor (Figure 1: Well Log Record Example). There may also be additional location information, land-surface elevation, aquifer designation, and remarks about the drill holes.

-WELL STRATIGRAPHY contains the geologic log with a geologist's stratigraphic interpretations, which are based on her or his knowledge and understanding of the geology of Chisago County (Figure 2: Well Stratigraphy Example). Only those drill holes with verified locations have stratigraphy assigned to them.

Quaternary Samples Data Base (QBASE)—Information from Quaternary samples collected and analyzed is entered into this data base. QBASE contains locations, the name of the sample collector, elevations, depths from where the samples were collected, proportions of sand, silt, and clay, and proportions of crystalline, carbonate, and shale. Information pertaining to borings obtained from the Minnesota Department of Transportation and the U.S. Geological Survey can also be found in this database.

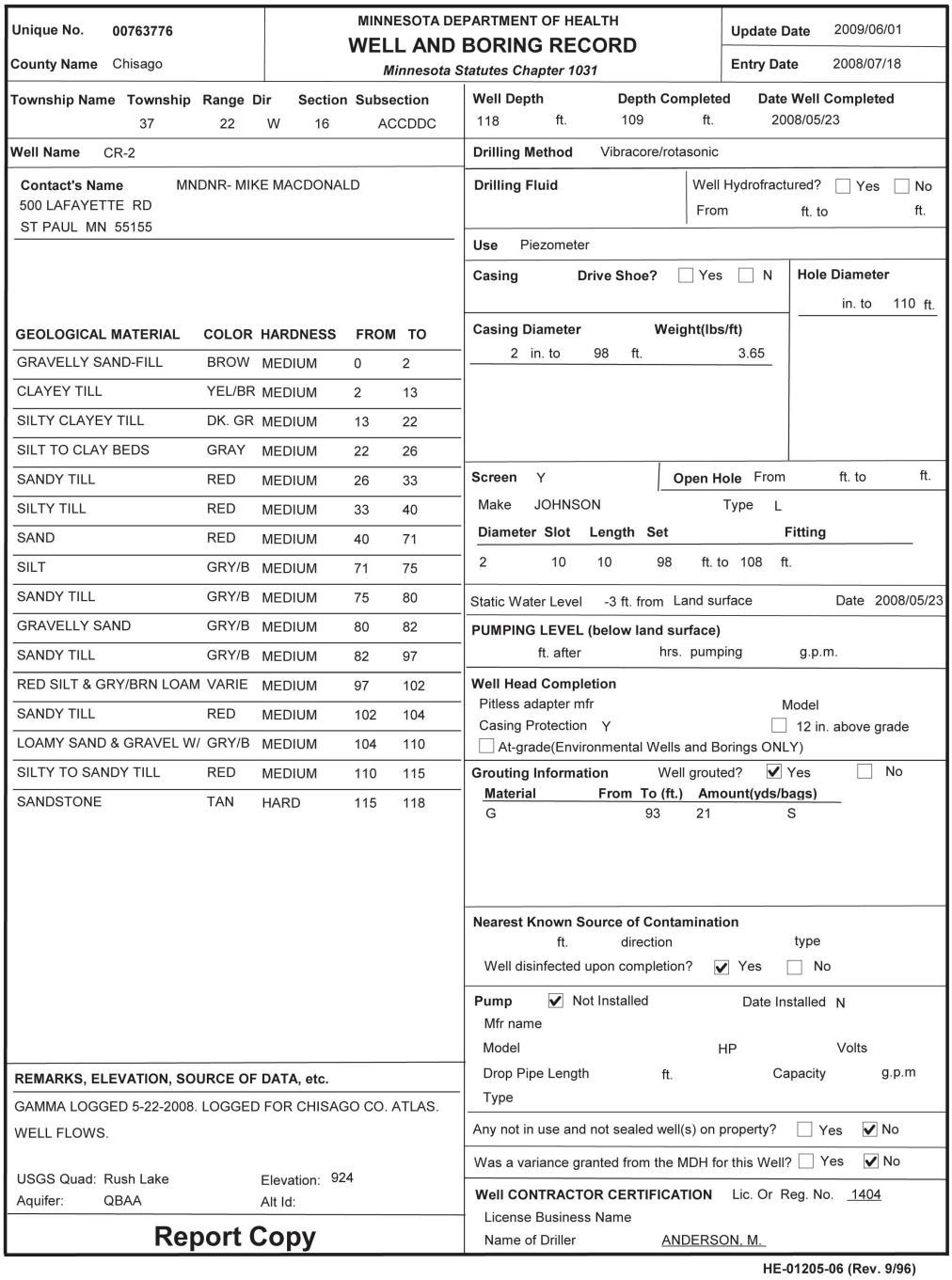
Text from source map: Chisago County Geologic Map.

Future Data Collection

A data-base map is out of date even before it is printed because additional information is continually generated as new water wells are drilled, construction activities expose more bedrock, or additional wells are tested for water quality. The library of geologic information prepared for Chisago County is flexible so that old data can be reevaluated in light of new information, and new forms of data can be added if required. The need to manage ground water and other natural resources wisely will never become outdated. Future demands on these resources will require current data to assess the impacts.

Text from source map: Chisago County Geologic Map.

Figure 1: Well Log Record Example



Unique No. 00763776
County Name Chisago

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING RECORD
Minnesota Statutes Chapter 1031

Update Date 2009/06/01
Entry Date 2008/07/18

Township Name	Township	Range	Dir	Section	Subsection
	37	22	W	16	ACCDDC

Well Depth 118 ft. | Depth Completed 109 ft. | Date Well Completed 2008/05/23

Well Name CR-2

Drilling Method Vibracore/rotasonic

Contact's Name MNDNR- MIKE MACDONALD
500 LAFAYETTE RD
ST PAUL MN 55155

Drilling Fluid

Well Hydrofractured? ☐ Yes ☐ No
From ft. to ft.

Use Piezometer

Casing Drive Shoe? ☐ Yes ☐ N

Hole Diameter
in. to 110 ft.

Casing Diameter 2 in. to 98 ft. Weight(lbs/ft) 3.65

GEOLOGICAL MATERIAL	COLOR	HARDNESS	FROM	TO
GRAVELLY SAND-FILL	BROW	MEDIUM	0	2
CLAYEY TILL	YEL/BR	MEDIUM	2	13
SILTY CLAYEY TILL	DK. GR	MEDIUM	13	22
SILT TO CLAY BEDS	GRAY	MEDIUM	22	26
SANDY TILL	RED	MEDIUM	26	33
SILTY TILL	RED	MEDIUM	33	40
SAND	RED	MEDIUM	40	71
SILT	GRY/B	MEDIUM	71	75
SANDY TILL	GRY/B	MEDIUM	75	80
GRAVELLY SAND	GRY/B	MEDIUM	80	82
SANDY TILL	GRY/B	MEDIUM	82	97
RED SILT & GRY/BRN LOAM	VARIE	MEDIUM	97	102
SANDY TILL	RED	MEDIUM	102	104
LOAMY SAND & GRAVEL W/	GRY/B	MEDIUM	104	110
SILTY TO SANDY TILL	RED	MEDIUM	110	115
SANDSTONE	TAN	HARD	115	118

Screen Y | Open Hole From ft. to ft.
Make JOHNSON Type L

Diameter	Slot	Length	Set	Fitting
2	10	10	98 ft. to 108 ft.	

Static Water Level -3 ft. from Land surface Date 2008/05/23

PUMPING LEVEL (below land surface)
ft. after hrs. pumping g.p.m.

Well Head Completion
Pitless adapter mfr Model
Casing Protection Y ☐ 12 in. above grade
☐ At-grade(Environmental Wells and Borings ONLY)

Grouting Information Well grouted? ☑ Yes ☐ No

Material	From	To (ft.)	Amount(yds/bags)
G		93	21 S

Nearest Known Source of Contamination
ft. direction type
Well disinfected upon completion? ☑ Yes ☐ No

Pump ☑ Not Installed Date Installed N
Mfr name
Model HP Volts
Drop Pipe Length ft. Capacity g.p.m
Type

Any not in use and not sealed well(s) on property? ☐ Yes ☑ No

Was a variance granted from the MDH for this Well? ☐ Yes ☑ No

Well CONTRACTOR CERTIFICATION Lic. Or Reg. No. 1404
License Business Name
Name of Driller ANDERSON, M.

REMARKS, ELEVATION, SOURCE OF DATA, etc.
GAMMA LOGGED 5-22-2008. LOGGED FOR CHISAGO CO. ATLAS.
WELL FLOWS.

USGS Quad: Rush Lake Elevation: 924
Aquifer: QBAA Alt Id:

Report Copy

HE-01205-06 (Rev. 9/96)

Figure 1. An example of a WELL LOG record, showing all the information about the well as reported by the well driller.

Graphic from source map: Chisago County Geologic Map.

Figure 2: Well Stratigraphy Example

Unique No. 00763776			MINNESOTA DEPARTMENT OF HEALTH WELL AND BORING RECORD *Minnesota Statutes Chapter 1031*						Update Date 2009/06/01		
County Name Chisago									Entry Date 2008/07/18		
Township Name	Township	Range	Dir	Section	Subsection	Well Depth		Depth Completed		Date Well Completed	
	37	22	W	16	ACCDDC	118	ft.	109	ft.	2008/05/23	
Well Name CR-2					Lic. Or Reg. No. 1404			Name of Driller ANDERSON, M.			
USGS Quad Rush Lake		Elevation 924			Aquifer QBAA			Alternative Id			

GEOLOGICAL MATERIAL	COLOR	HARDNESS	FROM	TO	STRAT	LITH PRIM	LITH SEC	LITH MINOR
GRAVELLY SAND-FILL	BROWN	MEDIUM	0	2	RMMF	FILL	SAND	GRVL
RMMF = Man-made fill	FILL = Fill			SAND = Sand			GRVL = Gravel	
CLAYEY TILL	YEL/BRN	MEDIUM	2	13	QTUU	TILL	CLAY	
QTUU = Till	TILL = Till,tillite			CLAY = Clay				
SILTY CLAYEY TILL	DK. GRY	MEDIUM	13	22	QTUG	TILL	CLSN	SILT
QTUG = Till	TILL = Till,tillite			CLSN = Claystone			SILT = Silt	
SILT TO CLAY BEDS	GRAY	MEDIUM	22	26	QJUB	SILT	CLAY	
QJUB = Silt & clay	SILT = Silt			CLAY = Clay				
SANDY TILL	RED	MEDIUM	26	33	QTUR	TILL	SAND	
QTUR = Till	TILL = Till,tillite			SAND = Sand				
SILTY TILL	RED	MEDIUM	33	40	QTUR	TILL	SILT	
QTUR = Till	TILL = Till,tillite			SILT = Silt				
SAND	RED	MEDIUM	40	71	QFUR	SAND		
QFUR = Sand	SAND = Sand							
SILT	GRY/BRN	MEDIUM	71	75	QIUU	SILT		
QIUU = Silt	SILT = Silt							
SANDY TILL	GRY/BRN	MEDIUM	75	80	QTUU	TILL	SAND	
QTUU = Till	TILL = Till,tillite			SAND = Sand				
GRAVELLY SAND	GRY/BRN	MEDIUM	80	82	QHUU	SAND	GRVL	
QHUU = Sand & larger	SAND = Sand			GRVL = Gravel				
SANDY TILL	GRY/BRN	MEDIUM	82	97	QTUU	TILL	SAND	
QTUU = Till	TILL = Till,tillite			SAND = Sand				
RED SILT & GRY/BRN LOAMY GRAVEL	VARIED	MEDIUM	97	102	QPUU	SILT	GRVL	LOAM
QPUU = Pebbly sand/silt/clay	SILT = Silt			GRVL = Gravel			LOAM = Loam	
SANDY TILL	RED	MEDIUM	102	104	QTUR	TILL	SAND	
QTUR = Till	TILL = Till,tillite			SAND = Sand				

Figure 2. Example of a WELL STRATIGRAPHY record, which contains a geologist's interpretation of the geologic materials listed by the driller in the WELL LOG record (Fig. 1). The headings (such as GEOLOGICAL MATERIAL, COLOR, and HARDNESS) pertain to information in the first line of each entry; the second line contains explanations of most of the four-letter codes used in the first line. The first word (in capital letters) in each entry is the well driller's original description for that interval. All depths are measured in feet. Heading abbreviations: STRAT, stratigraphy (the name of the stratigraphic unit; note, all abbreviations starting with Q are glacial deposits and are not further delineated); LITH PRIM, primary lithology (rock type); LITH SEC, secondary lithology; LITH MINOR, minor lithology.

Graphic from source map: Chisago County Geologic Map.

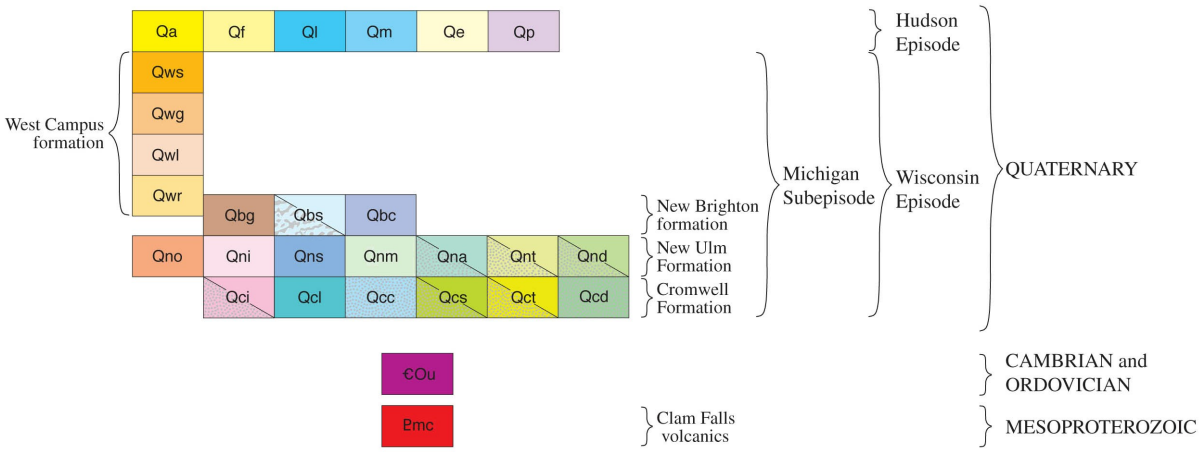
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References from source map: Chisago County Geologic Map.

Plate 3: Surficial Geology

Correlation of Units



Units symbols on this graphic may differ slightly from respective units in the GRI digital geologic-GIS data. This is due to resolving unit symbols across multiple maps used in this compilation.

Graphic from source map: Chisago County Geologic Map.

Symbol Legend

Geologic contact—Approximately located.

General flow direction of a former stream—Arrow points downstream in the direction glacial meltwater last flowed.

Stream-cut scarp—Hachures point downslope; dashed where discontinuous or obscure; marks the flanks of a former fluvial channel.

Stream-scoured surface—Stream-planed; in places glacial and lacustrine units are mantled by sand and gravel too thin and patchy to map separately. The pattern covers areas subsequently eroded during the Hudson Episode by various means, including gravel mining.

Approximate shoreline of glacial Lake Anoka—The maximum extent of the lake is obscure because it was supported by buried stagnant ice. The landscape was lowered as the ice melted. Lake sediments on the northwest side of glacial Lake Anoka are up to 20 feet (6 meters) higher than those on the southeast side, apparently reflecting post-depositional uplift due to isostatic rebound still in effect from the off-loading of Superior-lobe ice (Meyer, 1998, 2007, 2008). Sediment of the New Ulm and Cromwell Formations mapped within the bounds of glacial Lake Anoka have been wave-washed and covered in places with thin beds of silt, sand, or gravel. The sediment in some of these areas has subsequently collapsed due to melt-out of underlying stagnant ice. However, some of the collapsed areas now lower in elevation than adjacent areas of New Brighton formation likely were once islands or peninsulas in glacial Lake Anoka.

Fridley level—About 915 feet (279 meters) above mean sea level.

Hugo level—About 940 feet (287 meters) above mean sea level.

Maximum extent—About 960 feet (293 meters) above mean sea level where mapped along the southeast shore, somewhat higher in the northwest part of the county.

Esker—A sinuous ridge of predominantly sand and gravel, interpreted to have been deposited in an ice-walled stream or subglacial tunnel. Arrowheads show the inferred flow direction. The north-flowing esker in northern Chisago County is interpreted to have been deposited by Grantsburg sublobe meltwater, whereas the other eskers are interpreted to have been laid down by Superior-lobe meltwater. The fluvial sediment of the Superior-lobe eskers is generally covered by 10 to 30 feet (3 to 9 meters) or more of till.

Minor linear ridge—A narrow, discontinuous ridge topped by thick till, but likely cored with sand and gravel, such as an esker segment; or possibly a crevasse-fill ridge, which would be cored with less stratified sediment. Flow direction and provenance are undetermined.

Ice-walled lake-plain rim—Line marks the rim of an elevated plateau of lake sediment interpreted to be the deposits of a former lake once walled by glacial ice.

Ice-marginal ridge—Teeth are on the up-ice side. Line marks the former edge of the Grantsburg sublobe. The ridge in the extreme northwest corner of the county is part of the terminal moraine of the sublobe, the Pine City moraine.

Minor morainic ridge—May mark a temporary ice marginal position, where the retreating Grantsburg sublobe paused for only a short time (Johnson, 2000; Patterson and Knaeble, 2002).

Broad, irregular trough—Hachures point downslope; identified by alignment of depressions and lakes. Likely marks partially filled, preexisting channels. These troughs are interpreted to reflect valleys cut by meltwater flowing beneath Superior-lobe ice that were buried by subsequent glacial events. Drainage channels beneath the Superior-lobe ice locally eroded deeply into the substrate, and in places may have exploited preexisting bedrock valleys. These tunnel valleys in places were reoccupied by proglacial meltwater of the receding Superior lobe.

Glacial striation measurement—Arrow shows the direction of ice flow (Terrence Boerboom, unpub. data; see Johnson, 2000).

A—A' **Line of geologic cross section illustrated on Plate 4, *Quaternary Stratigraphy*.**

Graphic from source map: Chisago County Geologic Map.

Table 1: Glacial Deposits Characteristics

PROVENANCE	RIDING MOUNTAIN (NW)	SUPERIOR (NE)
TILL TEXTURE	Loamy	Sandy
TILL COLOR		
Oxidized	Yellow-brown to olive-brown	Red-brown
Unoxidized	Gray	Gray and red-gray
PEBBLE TYPE		
White to buff carbonate	Common	Rare to uncommon
Dark-gray to gray-green rocks	Uncommon to common	Common to abundant
Red felsite & sandstone	Rare to uncommon	Common
Gray shale	Uncommon to abundant	Absent

Table from source map: Chisago County Geologic Map.

Report

Introduction

The surficial geologic map of Chisago County shows the earth material expected to be encountered below the topsoil, generally about 3 feet (1 meter) below the land surface. This map is a revision of Minnesota Geological Survey Miscellaneous Map M-116, Plate 1 (Meyer and Lusardi, 2001), based largely on a three-fold increase in water-well log data collected for this atlas. A reexamination of the county soil survey (Anderson, 1995) and an evolving philosophy of surficial mapping led to some changes-for example, more mapping of fine-grained lake sediment and less mapping of thin peat deposits. Little additional fieldwork was carried out, other than drilling three rotary-sonic core holes. In Figure 1 (Figures 1 & 2: Rock Unit and Land Surface Classification), the surficial sediments are grouped into more permeable (bedded sand to gravel) and less permeable (bedded silt to clay and diamicton) units. The topographic expression created mainly by glacial sculpturing and subsequent meltwater erosion and deposition is displayed on the Digital Elevation Model (Figures 1 & 2: Rock Unit and Land Surface Classification). A brief summary of the glacial history of the county follows (a more detailed discussion is in Meyer, 1998).

Text from source map: Chisago County Geologic Map.

Summary of Glacial History

The surficial geology of Chisago County, like most of Minnesota, is dominated by unconsolidated sediments laid down by glacial ice and meltwater towards the end of the "Ice Age," during the Wisconsin Episode (Johnson and others, 1997). These sediments bury eroded remnants left by multiple earlier glacial advances that once covered the county (Plate 4, Quaternary Stratigraphy). During each of these advances, glacial ice from the continental ice sheet to the north entered the county from different directions, reflected in the diverse deposits they left behind. The provenance of an ice advance (Fig. 3, Table 1) is the unique area of bedrock that the ice passed over and incorporated, and then deposited as it moved away from its source area. Sediment deposited in the county during earlier glaciations, except for a few exposures in deep gullies adjacent to the St. Croix River, is found only in the subsurface.

At the onset of the most recent glaciation, the Michigan Subepisode of the Wisconsin Episode, ice carrying debris of Superior provenance covered the county (Fig. 3). Wood and in-place roots from a depth of 151 feet (46 meters) in a core taken near Stacy yielded a radiocarbon date of 28,580 = 220 years before present. This finding creates a maximum date for the Emerald phase (Johnson, 2000), the first advance of the Superior lobe across Chisago County during the Michigan Subepisode. Following the Emerald phase, the Superior lobe melted back at least as far as central Chisago County, and then readvanced during the St. Croix phase (Wright, 1972) to once again completely cover the county. As the front of the Superior lobe reached its maximum extent during the St. Croix phase and then slowly retreated, it formed the St. Croix moraine, a linear series of high hills enclosing the Twin Cities area (Hobbs and Goebel, 1982; Meyer and others, 1990) and extending across southeastern Chisago County and northwestern Wisconsin. During the retreat of the ice front, meltwater issuing from the Superior lobe became channelized to escape through the moraine. Some meltwater was ponded in stagnant, ice-walled lake basins within the St. Croix moraine (Meyer, 1993, 2007). Large fans of sand and gravel formed as the ice front periodically stabilized during its retreat. Prominent hills in southeastern Chisago County are cored by these Superior lobe ice-contact deposits (unit Qci).

When the Superior lobe eventually melted back into the lower terrain behind the St. Croix moraine, its meltwater became ponded, forming glacial Lake Lind. Reddish, rhythmically bedded silt and clay exposed in central Chisago County (unit Qcc) and in nearby Wisconsin are interpreted to represent seasonal depositional cycles, indicating that the lake existed for about a thousand years (Johnson and others, 1999). Exposures along the Sunrise River in Chisago County, together with core and drilling logs from the region (Meyer, 1998), indicate a readvance of Superior-lobe ice into the lake basin and at least to the inner flank of the St. Croix moraine during the Automba phase (Wright, 1972; Patterson and Knaeble, 2002). This readvance led to incorporation of glacial Lake Lind sediment and deposition of finer-grained glacial till than that of the Automba phase north of the county. Following final retreat of the Superior lobe, a second lake, glacial Lake Lind II, formed in the same basin. This lake eventually filled and may have completely drained prior to the last glacial advance into the area, the Grantsburg sublobe.

The Grantsburg sublobe was an offshoot of the Des Moines lobe (Fig. 3), a tongue of ice that flowed down the Minnesota River valley and then south to Des Moines, Iowa. The northeast flank of the Des Moines lobe was able to override the St. Croix moraine and extend to Grantsburg, Wisconsin (Fig. 4). The maximum extent of the Grantsburg sublobe is marked by the Pine City moraine (Patterson and Knaeble, 2002), which passes across the northwest corner of Chisago County. On the southern side of the sublobe, however, no distinct moraine is discernible, in part because the ice front rested against the St. Croix moraine. Here Grantsburg sublobe meltwater was able to escape via preexisting channels through the St. Croix moraine. To the north, however, meltwater was dammed by the sublobe and formed glacial Lake Grantsburg (Fig. 4), the outlet of which may have been over the terminus of the ice itself (Cooper, 1935), or possibly beneath the ice, because no other outlet is apparent. A study of varved sediment deposited in the lake provided an estimate that the lake lasted for about 100 years (Johnson and Hemstad, 1998).

When the Grantsburg sublobe began to pull back from the Pine City moraine, glacial Lake Grantsburg encroached on areas formerly occupied by glacial ice (Fig. 5; Patterson and Knaeble, 2002). Ice-contact fans (unit Qni) formed in northwestern Chisago County as the ice began to stagnate during the later stages of retreat. Glacial Lake Grantsburg drained when it was able to gain direct access to the St. Croix River valley. Apparently soon after, the flow of new ice to the sublobe was cut off, and it was transformed into a large, "dead" ice mass across much of the county. Large, ice-walled lakes (unit Qns) formed, as not all meltwater was able to escape eastward to the St. Croix River valley outlet. The large volume of meltwater that was able to reach the valley was soon blocked by the Barrens fan, an alluvial fan created by meltwater flowing from the Superior lobe to the north (Meyer, 1998). The dammed meltwater formed glacial Lake Anoka (Meyer, 1993), which extended over much of Chisago County and large portions of Anoka and Isanti Counties and the surrounding region (Fig. 6). Meltwater flowing from

the stagnant Grantsburg sublobe and the retreating margin of the Des Moines lobe quickly began to fill the generally shallow lake with mostly fine-grained sand (unit Qbs).

Geomorphic evidence in southeastern Chisago County indicates that a new outlet south of the Barrens fan temporarily opened and allowed the catastrophic draining of glacial Lake Anoka to the Hugo level (Fig. 7). The lake was lowered yet again to the Fridley level (Fig. 8), presumably due to downcutting by the outlet stream, the St. Croix River (Meyer, 1998). The lake finally drained when a southern outlet opened at north Minneapolis (Meyer and Hobbs, 1989), establishing the present course of the Mississippi River. The course of the St. Croix River varied widely across the former bottom of glacial Lake Anoka, leaving behind a wide, high terrace above the former outlet (unit Qwr). Lower terrace levels formed as the river continued to be lowered as the master stream, glacial River Warren (the outlet stream of glacial Lake Agassiz), lowered its valley, which is the present Minnesota and lower Mississippi River valleys (Johnson and others, 1998; Wright and others, 1998). The St. Croix River valley also was affected by catastrophic outbursts of water from proglacial lakes fronting the Superior lobe in the Lake Superior basin (Clayton, 1984; Patterson and Knaeble, 2002; Knaeble and Hobbs, 2009).

Text from source map: Chisago County Geologic Map.

Hudson Episode Events

While the channels of the St. Croix River and its tributaries were being established, organic debris (unit Qho) began to accumulate in low-lying portions of the glacial Lake Anoka plain, and in ice-block melt-out depressions and abandoned drainageways across Chisago County. When glacial Lakes Agassiz and Superior found lower outlets to the east less than 10,000 years ago, flow down the St. Croix River decreased, and alluvium (unit Qa) began to fill its valley. A study of sediments cored from Lake Ann in Sherburne County (Keen and Shane, 1990) indicated the eolian sand dunes (unit Qe) in Chisago County may not have formed until an extended dry period beginning about 8,000 years ago (based on radiocarbon dating). However, evidence elsewhere in Minnesota (Marlow and others, 2005) and dating of nearby dune fields in Wisconsin (Young, 2008), implies some eolian activity began earlier, possibly following drainage of glacial Lake Anoka, when sand was at the surface over much of the area.

Text from source map: Chisago County Geologic Map.

Figures 1 & 2: Rock Unit and Land Surface Classification

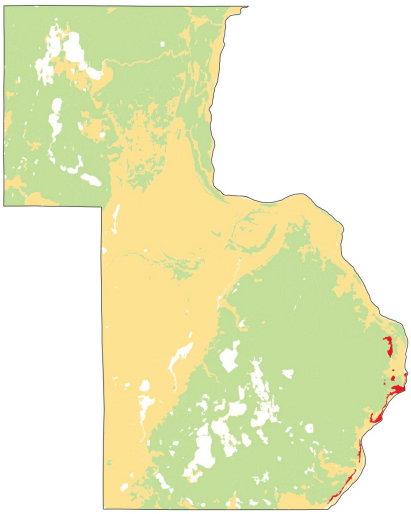


Figure 1. The map units from the 1:100,000 surficial geology map are combined into three simplified units in this figure: green is less permeable diamicton (glacial till) and bedded silt and clay; yellow is more permeable, bedded sand to gravel; and red is bedrock. Water bodies are white.

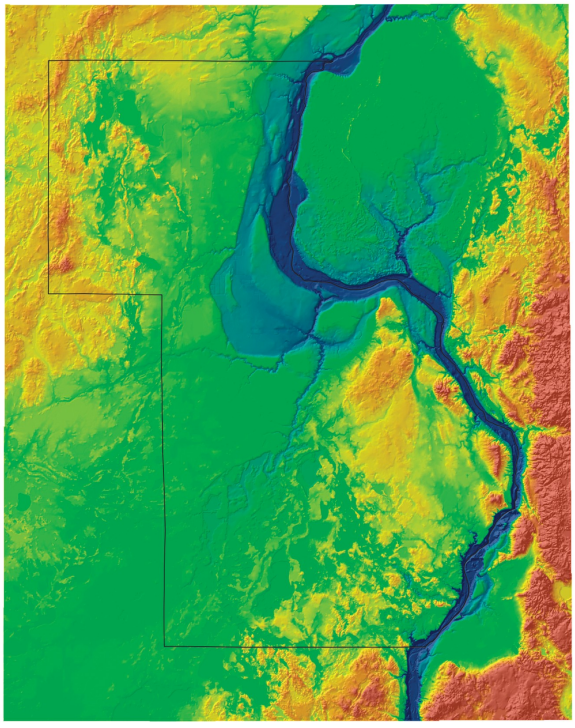


Figure 2. Physical relief of the land surface in Chisago County. Elevation is shown by color: red (higher surface elevation) grading to blue (lower surface elevation). A false sun illumination at an elevation of 30° from the northwest (315°) provides contrast (gray shadowing) to accent details of landforms. The map was created using the U.S. Geological Survey's Digital Elevation Model with a 30-meter grid.

Graphics from source map: Chisago County Geologic Map.

Figure 3: Glacial Events

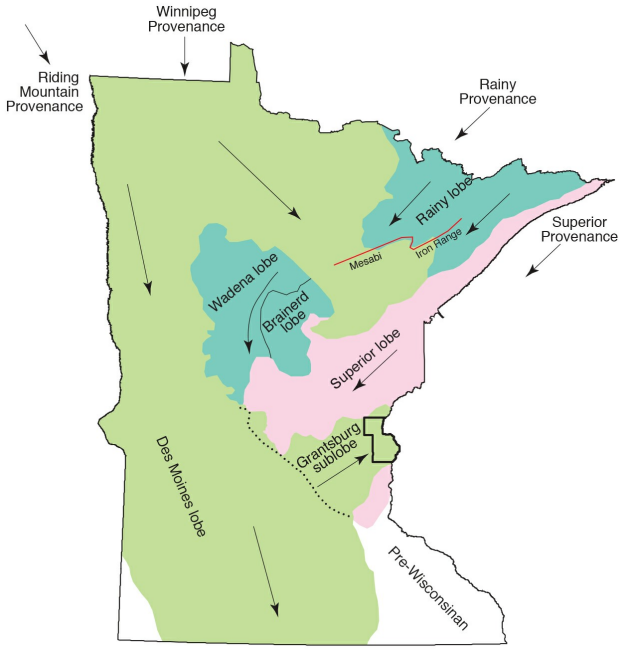


Figure 3. Location of major provenances (source regions). Glacial sediments deposited in the county derive their distinct material content from bedrock and sediment found in the region of these provenances. During the last glaciation, the Michigan Subepisode, Chisago County was repeatedly covered by ice carrying debris of Superior provenance, the Superior lobe (the line of maximum extent is dotted where covered by the Des Moines lobe). After the final retreat of the Superior lobe, the Grantsburg sublobe of the Des Moines lobe, carrying debris of Riding Mountain provenance, moved into the county from the southwest, covering it with ice one last time.

Graphic from source map: Chisago County Geologic Map.

Figures 4-8: Glacial Characteristics

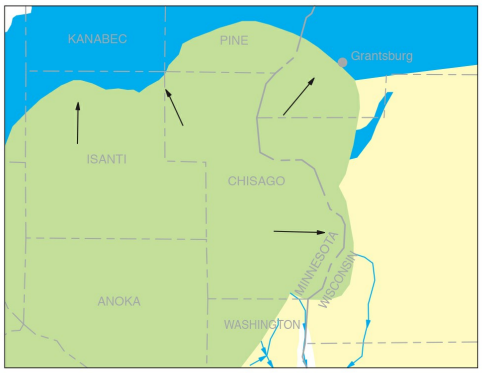


Figure 4. The Grantsburg sublobe at its maximum extent at the Pine City moraine. It is damming glacial Lake Grantsburg to the north, and is blocked by the St. Croix moraine to the southeast.



Figure 5. Retreatal position of the Grantsburg sublobe just prior to the drainage of glacial Lake Grantsburg down the St. Croix River valley.

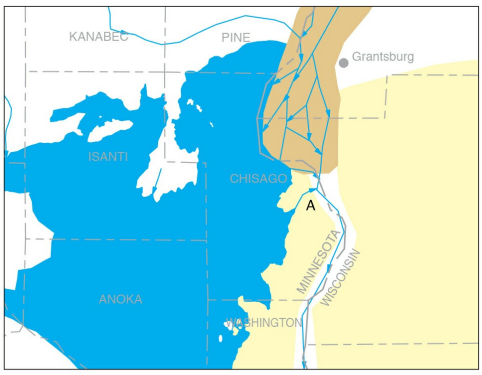


Figure 6. Approximate maximum extent of glacial Lake Anoka, dammed by the Barrens fan. An early secondary (overflow?) outlet is shown at A.

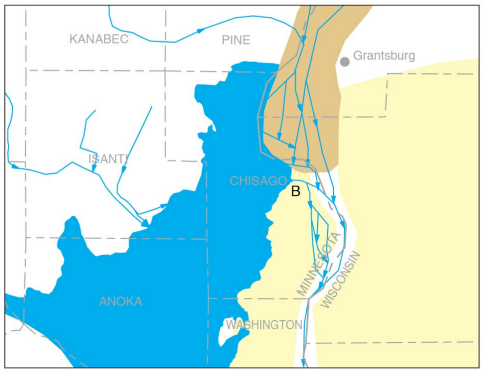


Figure 7. Glacial Lake Anoka at the Hugo level, following catastrophic drainage at outlet B. This new outlet must have become available as sediment-mantled ice in a buried valley melted, collapsing the overlying surface. A broad, water-washed area west of the St. Croix River valley from outlet B south to Franconia is evidence that the valley was initially unable to contain all the water released during the event (Meyer, 1998).

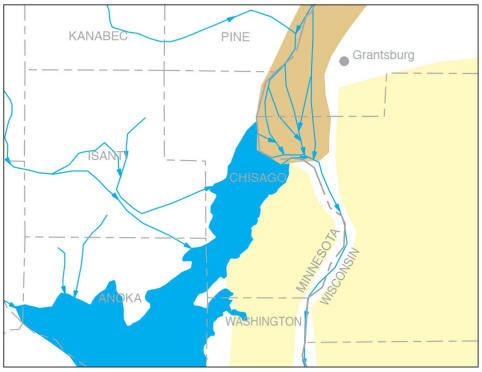


Figure 8. Glacial Lake Anoka at the Fridley level, prior to drainage of most of the lake when a southern outlet opened at Minneapolis.

Graphics from source map: Chisago County Geologic Map.

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References from source map: Chisago County Geologic Map.

Plate 4: Quaternary Stratigraphy

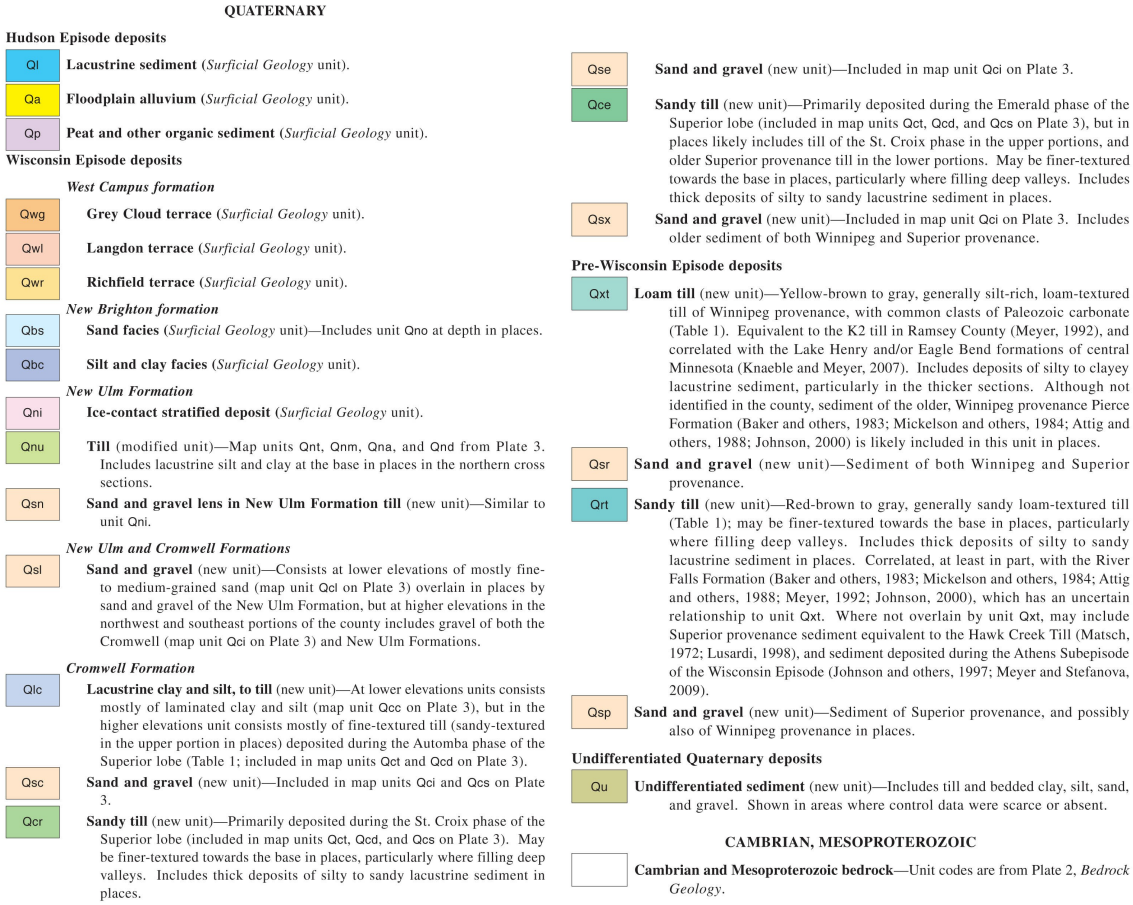
Introduction

The Quaternary Stratigraphy plate shows the unconsolidated sediment expected to be encountered between the land surface and bedrock in Chisago County. The geologic units shown on the cross sections were defined using data from previous studies completed in the area (see Plate 3, Introduction) and through the interpretation of new data collected for this study. Some units match those on Plate 3, Surficial Geology, some new units appear only on the cross sections, others are a combination of multiple units from Plate 3, and still others are the result of dividing a unit from Plate 3 (Fig. 1). Outcrops, auger samples, drill core, drill cuttings, and water-well drillers' logs (see Plate 1, Data-Base Map) were used to interpret the stratigraphy. The locations of auger, core, and cuttings holes, and water wells are shown on Figure 2, but are undifferentiated on the cross sections. Vertical exaggeration is 50x for all cross sections.

Figure 3 is a schematic illustration showing the relationships between age, provenance, stratigraphic position, and location of the sediments deposited by major glacial episodes (on Plate 3 see Fig. 3, Table 1, and the Summary of Glacial History section for supplementary information). Analysis of the texture and rock types of the Quaternary sediments was done for selected geologic units, as listed in Table 1. Figure 4 is a pollen diagram for samples from a rotary-sonic core drilled for this atlas, and logs of six rotary-sonic cores drilled for the Minnesota Geological Survey for this and an earlier study (Meyer, 1993) are shown in Figures 5 through 10.

Text from source map: Chisago County Geologic Map.

Cross Section Units



QUATERNARY

Hudson Episode deposits

Ql — **Lacustrine sediment** (*Surficial Geology* unit).

Qa — **Floodplain alluvium** (*Surficial Geology* unit).

Qp — **Peat and other organic sediment** (*Surficial Geology* unit).

Wisconsin Episode deposits

West Campus formation

Qwg — **Grey Cloud terrace** (*Surficial Geology* unit).

Qwl — **Langdon terrace** (*Surficial Geology* unit).

Qwr — **Richfield terrace** (*Surficial Geology* unit).

New Brighton formation

Qbs — **Sand facies** (*Surficial Geology* unit)—Includes unit Qno at depth in places.

Qbc — **Silt and clay facies** (*Surficial Geology* unit).

New Ulm Formation

Qni — **Ice-contact stratified deposit** (*Surficial Geology* unit).

Qnu — **Till** (modified unit)—Map units Qnt, Qnm, Qna, and Qnd from Plate 3. Includes lacustrine silt and clay at the base in places in the northern cross sections.

Qsn — **Sand and gravel lens in New Ulm Formation till** (new unit)—Similar to unit Qni.

New Ulm and Cromwell Formations

Qsl — **Sand and gravel** (new unit)—Consists at lower elevations of mostly fine- to medium-grained sand (map unit Qcl on Plate 3) overlain in places by sand and gravel of the New Ulm Formation, but at higher elevations in the northwest and southeast portions of the county includes gravel of both the Cromwell (map unit Qci on Plate 3) and New Ulm Formations.

Cromwell Formation

Qlc — **Lacustrine clay and silt, to till** (new unit)—At lower elevations units consists mostly of laminated clay and silt (map unit Qcc on Plate 3), but in the higher elevations unit consists mostly of fine-textured till (sandy-textured in the upper portion in places) deposited during the Automba phase of the Superior lobe (Table 1; included in map units Qct and Qcd on Plate 3).

Qsc — **Sand and gravel** (new unit)—Included in map units Qci and Qcs on Plate 3.

Qcr — **Sandy till** (new unit)—Primarily deposited during the St. Croix phase of the Superior lobe (included in map units Qct, Qcd, and Qcs on Plate 3). May be finer-textured towards the base in places, particularly where filling deep valleys. Includes thick deposits of silty to sandy lacustrine sediment in places.

Qse — **Sand and gravel** (new unit)—Included in map unit Qci on Plate 3.

Qce — **Sandy till** (new unit)—Primarily deposited during the Emerald phase of the Superior lobe (included in map units Qct, Qcd, and Qcs on Plate 3), but in places likely includes till of the St. Croix phase in the upper portions, and older Superior provenance till in the lower portions. May be finer-textured towards the base in places, particularly where filling deep valleys. Includes thick deposits of silty to sandy lacustrine sediment in places.

Qsx — **Sand and gravel** (new unit)—Included in map unit Qci on Plate 3. Includes older sediment of both Winnipeg and Superior provenance.

Pre-Wisconsin Episode deposits

Qxt — **Loam till** (new unit)—Yellow-brown to gray, generally silt-rich, loam-textured till of Winnipeg provenance, with common clasts of Paleozoic carbonate (Table 1). Equivalent to the K2 till in Ramsey County (Meyer, 1992), and correlated with the Lake Henry and/or Eagle Bend formations of central Minnesota (Knaeble and Meyer, 2007). Includes deposits of silty to clayey lacustrine sediment, particularly in the thicker sections. Although not identified in the county, sediment of the older, Winnipeg provenance Pierce Formation (Baker and others, 1983; Mickelson and others, 1984; Attig and others, 1988; Johnson, 2000) is likely included in this unit in places.

Qsr — **Sand and gravel** (new unit)—Sediment of both Winnipeg and Superior provenance.

Qrt — **Sandy till** (new unit)—Red-brown to gray, generally sandy loam-textured till (Table 1); may be finer-textured towards the base in places, particularly where filling deep valleys. Includes thick deposits of silty to sandy lacustrine sediment in places. Correlated, at least in part, with the River Falls Formation (Baker and others, 1983; Mickelson and others, 1984; Attig and others, 1988; Meyer, 1992; Johnson, 2000), which has an uncertain relationship to unit Qxt. Where not overlain by unit Qxt, may include Superior provenance sediment equivalent to the Hawk Creek Till (Matsch, 1972; Lusardi, 1998), and sediment deposited during the Athens Subepisode of the Wisconsin Episode (Johnson and others, 1997; Meyer and Stefanova, 2009).

Qsp — **Sand and gravel** (new unit)—Sediment of Superior provenance, and possibly also of Winnipeg provenance in places.

Undifferentiated Quaternary deposits

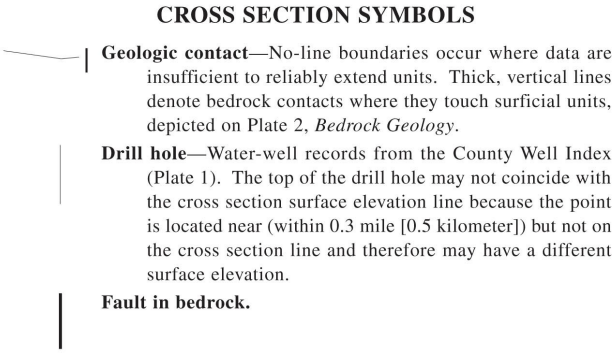
Qu — **Undifferentiated sediment** (new unit)—Includes till and bedded clay, silt, sand, and gravel. Shown in areas where control data were scarce or absent.

CAMBRIAN, MESOPROTEROZOIC

Cambrian and Mesoproterozoic bedrock—Unit codes are from Plate 2, *Bedrock Geology*.

This graphic describing cross section geologic units accompanies cross section graphics contained in the Geologic Atlas for Chisago County. Go to Geologic Cross Sections in this document to view cross section graphics for Chisago County.
Graphic from source map: Chisago County Geologic Map.

Cross Section Legend



CROSS SECTION SYMBOLS

Geologic contact—No-line boundaries occur where data are insufficient to reliably extend units. Thick, vertical lines denote bedrock contacts where they touch surficial units, depicted on Plate 2, *Bedrock Geology*.

Drill hole—Water-well records from the County Well Index (Plate 1). The top of the drill hole may not coincide with the cross section surface elevation line because the point is located near (within 0.3 mile [0.5 kilometer]) but not on the cross section line and therefore may have a different surface elevation.

Fault in bedrock.

This legend accompanies cross section graphics contained in the Geologic Atlas for Chisago County. Go to Geologic Cross Sections in this document to view cross section graphics for Chisago County.
Graphic from source map: Chisago County Geologic Map.

Figure 1: Correlation of Cross Section Unit to Surficial Map Units

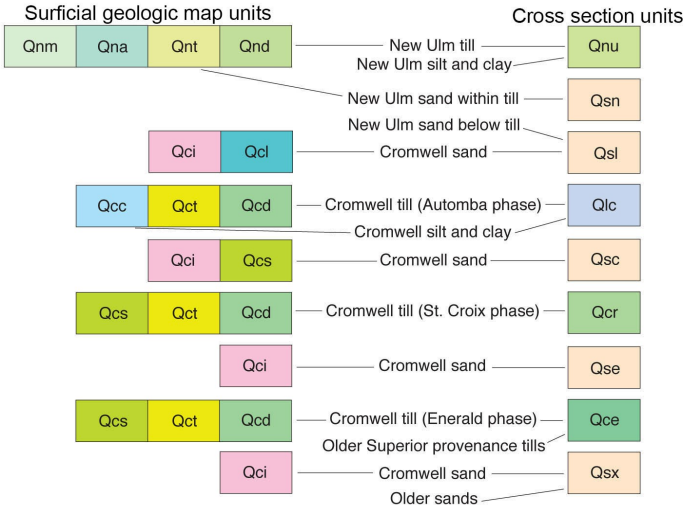


Figure 1. Diagram correlating the units on this plate to those on Plate 3, *Surficial Geology*.

This correlation accompanies cross section graphics contained in the Geologic Atlas for Chisago County. Go to Geologic Cross Sections in this document to view cross section graphics for Chisago County.
Graphic from source map: Chisago County Geologic Map.

Figure 2: Location of Cross Sections

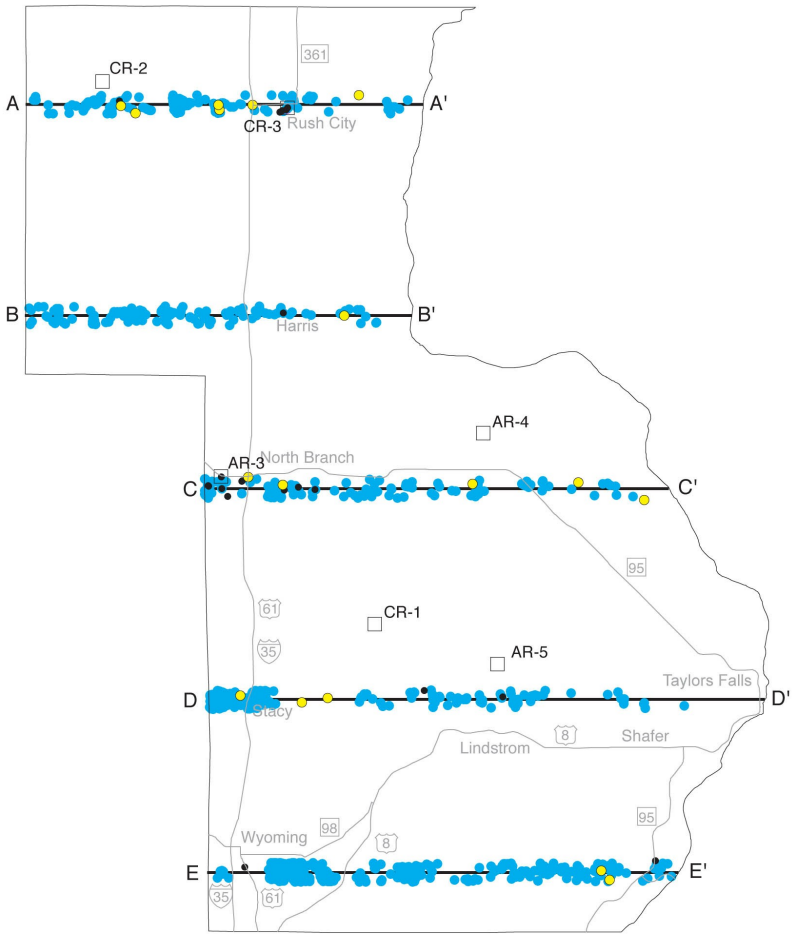


Figure 2. Diagram showing locations of cross sections A–A' through E–E', and the locations of the data points used in compiling stratigraphy for these five cross sections. Blue dots represent water-well drillers' sites with a log recorded in the County Well Index (only shown where within 0.3 mile [0.5 kilometer] of the cross section). Yellow dots include auger borings completed by the Minnesota Geological Survey, the U.S. Geological Survey, and the Minnesota Department of Transportation (not shown on cross sections). Boxes show Minnesota Geological Survey rotary-sonic core sites, and black dots depict drill cutting sites.

Graphic from source map: Chisago County Geologic Map.

Figure 3: Relative Age Diagram

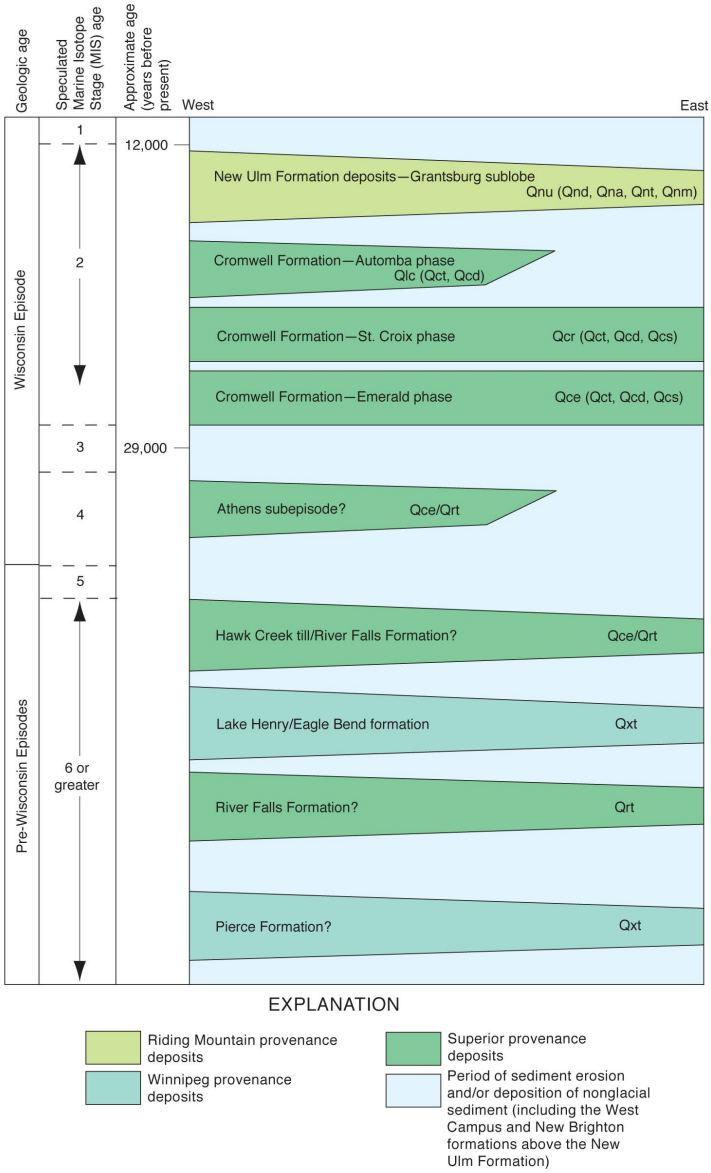


Figure 3. Diagram showing relative age, locations (across Chisago County from west to east), provenance (on Plate 3 see Fig. 3 and Table 1), and related unit labels from the cross sections for Wisconsin Episode and pre-Wisconsin Episode glacial deposits (Table 1); corresponding units from the surficial geology map (Plate 3) are shown in parentheses. The age column and deposit drawings are not to scale. Marine Isotope Stage correlations were estimated using figures in Jennings and others (2006). The approximate age shown for deglaciation of the Grantsburg sublobe (12,000 years before present) was based on radiocarbon dates from six sites in the Chisago County area (Meyer, 1998). Deposits of the Emerald phase bury an organic horizon in rotary-sonic core CR-1 that yielded a radiocarbon date of about 29,000 years before present (Meyer and Stefanova, 2009).

Graphic from source map: Chisago County Geologic Map.

Figure 4: Core Pollen Diagram

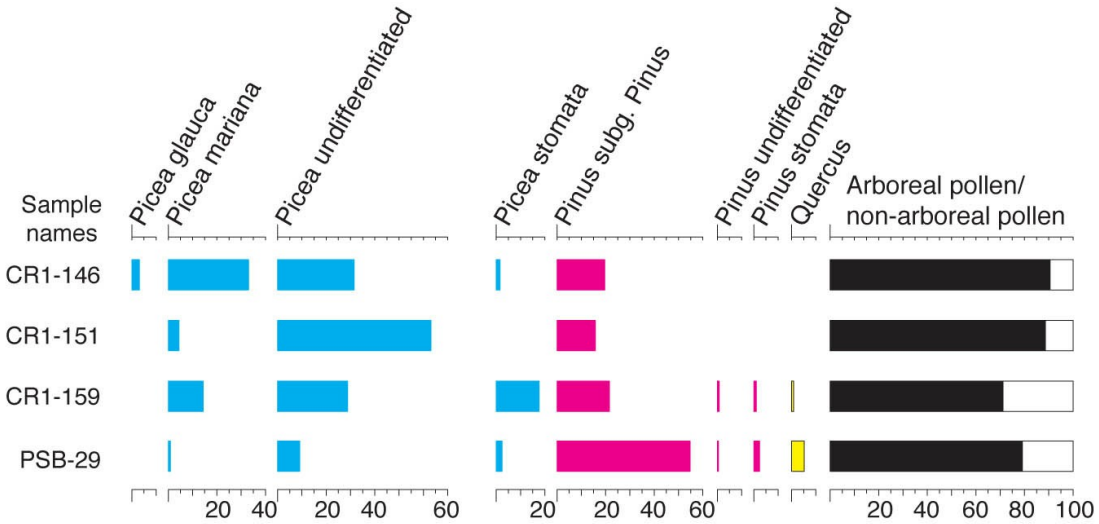


Figure 4. Diagram showing percent of pollen in an organic-bearing interval in core CR-1 (Fig. 5) with emphasis on spruce (Picea, blue), pine (Pinus, magenta), and oak (Quercus, yellow). Sample CR1-146 was taken at a depth of 146 feet (45 meters), CR1-151 at 151 feet (46 meters; and radiocarbon-dated at about 29,000 years before present), and CR1-159 at 159 feet (48 meters). Sample PSB-29 was taken from a similar stratigraphic setting in a hole in Ramsey County, and was radiocarbon-dated at about 32,000 years before present (Meyer, 1992). Pollen in sample PSB-29 indicates a warmer climate at that time, with low amounts derived from spruce and high amounts from pine and oak. A little oak pollen is present in the lower (older) sample in core CR-1, but increased spruce pollen and less pine pollen indicates a cooling climate from 32,000 to 29,000 years ago (Meyer and Stefanova, 2009), reflecting the onset of the last glaciation, the Michigan Subepisode of the Wisconsin Episode.

Graphic from source map: Chisago County Geologic Map.

Table 1: Matrix Texture Table

Table 1. Average values for the matrix texture and composition of tills recognized in Chisago County. Matrix texture (the less than 2 millimeter grain size fraction of the sample) is expressed as relative proportions of sand, silt, and clay in percent. The lithologic composition of the very coarse-grained sand fraction (1 to 2 millimeters) is expressed in percent as relative proportions of Precambrian rocks, Paleozoic (mostly carbonate) rocks, and Cretaceous rocks (mostly shale and limestone) using the classification system of Hobbs (1998). The Precambrian 1 to 2 millimeter fraction is further differentiated by rock type—light (granite and gneiss), monomineralic quartz, dark (mafic-rich igneous and metamorphic rocks), red (rhyolite and agate), sandstone, and other; T = trace amount.

	MATRIX TEXTURE							CLAST TYPE								
			Percentage of the less than 2 millimeter fraction					Percentage of total grains counted of the 1-2 millimeter fraction				Percentage of total crystalline grains counted				
Deposit description and geologic unit shown on cross sections and Plate 3	Total number of samples	Gravel (percentage of total sample weight)	Sand	Silt	Clay	Percentage of sand greater than 1 mm	Total number of samples	Precambrian	Paleozoic	Cretaceous	Unknown	Light	Monomineralic quartz	Dark	Red	Sandstone	Other
New Ulm Formation till (unit Qnu)	115	5	48	33	19	7.0	29	64	18	18	3	69	9	15	4	2	1
Cromwell Formation till (Automba phase; till portion of unit Qlc)	26	4	35	42	23	4.6 (unleached)	12 (all) 6	99	1	0	1	22	16	38	16	5	3
Cromwell Formation till (St. Croix and Emerald phases; units Qcr and Qce)	115	9	63	25	12	6.6 (unleached)	64 (all) 44	98	2	T	1	30	20	31	14	4	1
Pre-Wisconsin Episode, Winnipeg provenance till (unit Qxt)	12	3	34	43	23	7.2 (unleached)	8 (all) 5	65	35	T	T	61	18	14	4	1	1
Pre-Emerald phase, Superior provenance till (unit Qrt)	17	9	65	23	12	7.9 (unleached)	15 (all) 8	99	1	0	2	32	20	28	13	4	2

Table from source map: Chisago County Geologic Map.

Acknowledgments

Many water well companies contributed valuable subsurface information used in this atlas, but special recognition is given to the George Johnson Well Drilling Company for exceptionally useful well logs.

Text from source map: Chisago County Geologic Map.

Borehole Cores

Figure 5: CR-1



Figure 5. Descriptive log of rotary-sonic core CR-1, drilled by Mark J. Traut Wells for this study. Location of drilling is shown on Figure 2 and Plate 1, *Data-Base Map*.

Graphic from source map: Chisago County Geologic Map.

Figure 6: CR-2

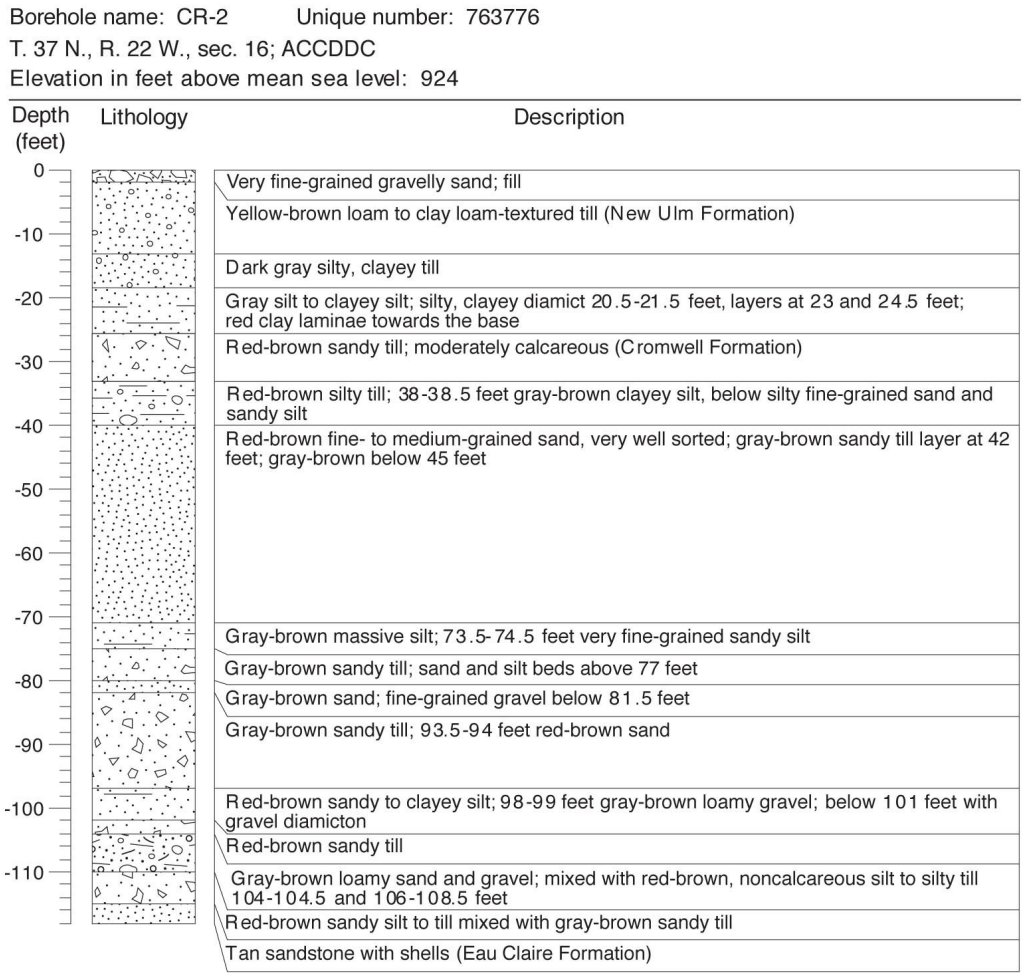


Figure 6. Descriptive log of rotary-sonic core CR-2, drilled by Mark J. Traut Wells for this study. Location of drilling is shown on Figure 2 and Plate 1, *Data-Base Map*.

Graphic from source map: Chisago County Geologic Map.

Figure 7: CR-3

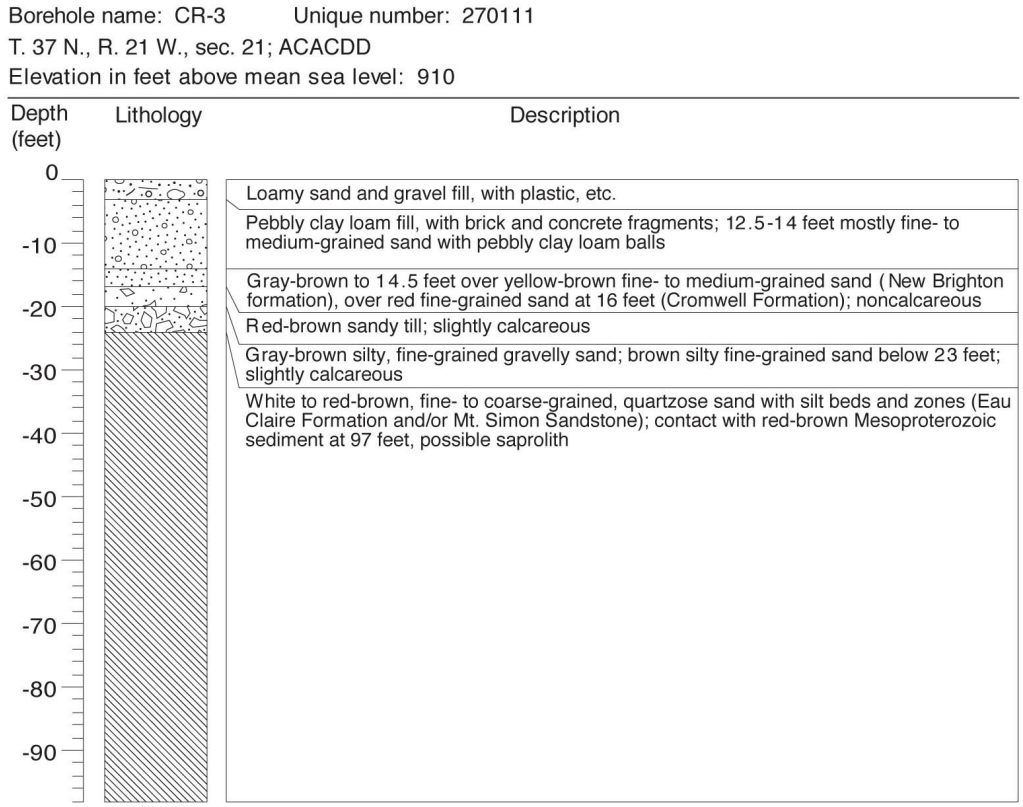


Figure 7. Descriptive log of rotary-sonic core CR-3, drilled by Mark J. Traut Wells for this study. Location of drilling is shown on Figure 2 and Plate 1, *Data-Base Map*.

Graphic from source map: Chisago County Geologic Map.

Figure 8: AR-3

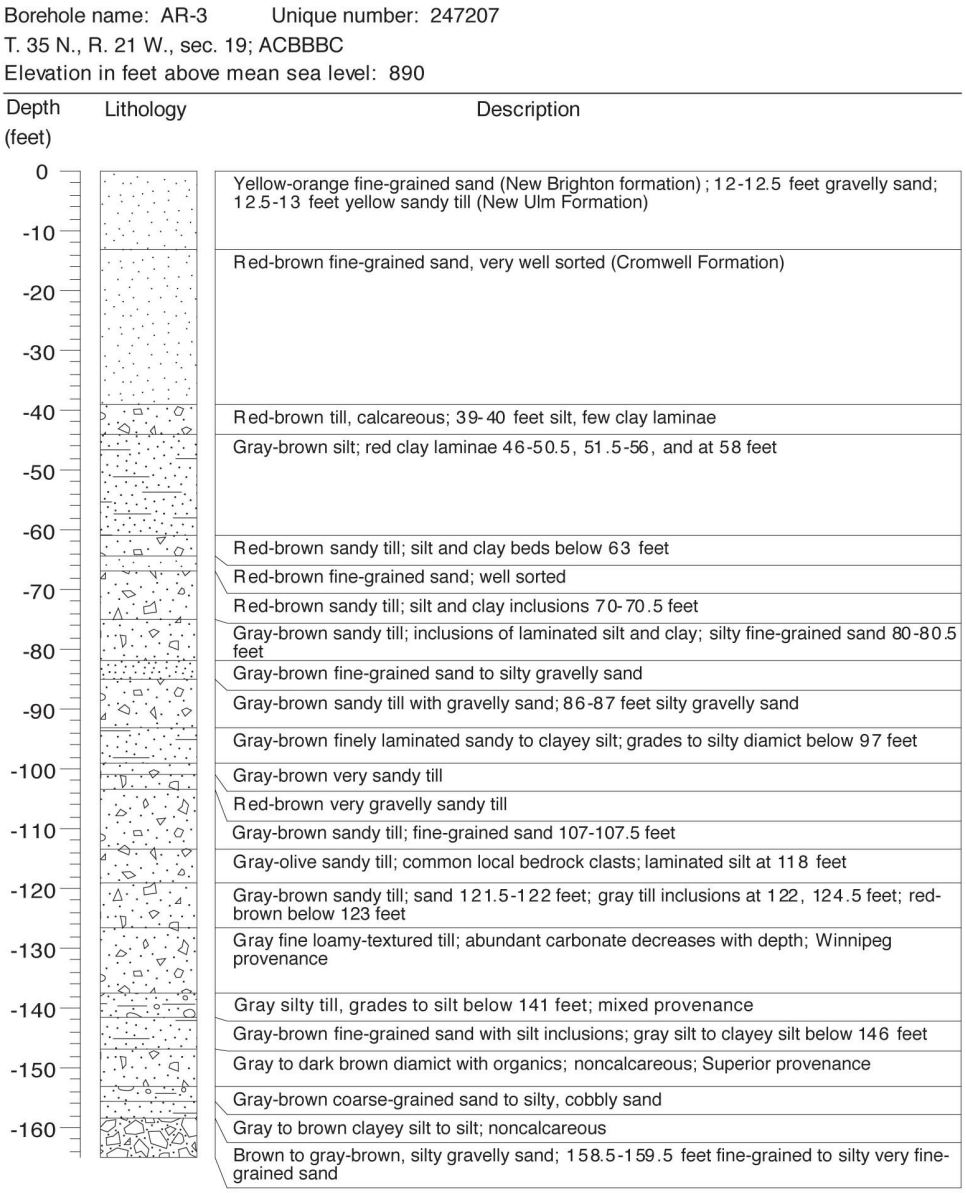


Figure 8. Descriptive log of rotary-sonic core AR-3, drilled by North Star Drilling for an earlier study (Meyer, 1993). Location of drilling is shown on Figure 2 and Plate 1, *Data-Base Map*.

Graphic from source map: Chisago County Geologic Map.

Figure 9: AR-4

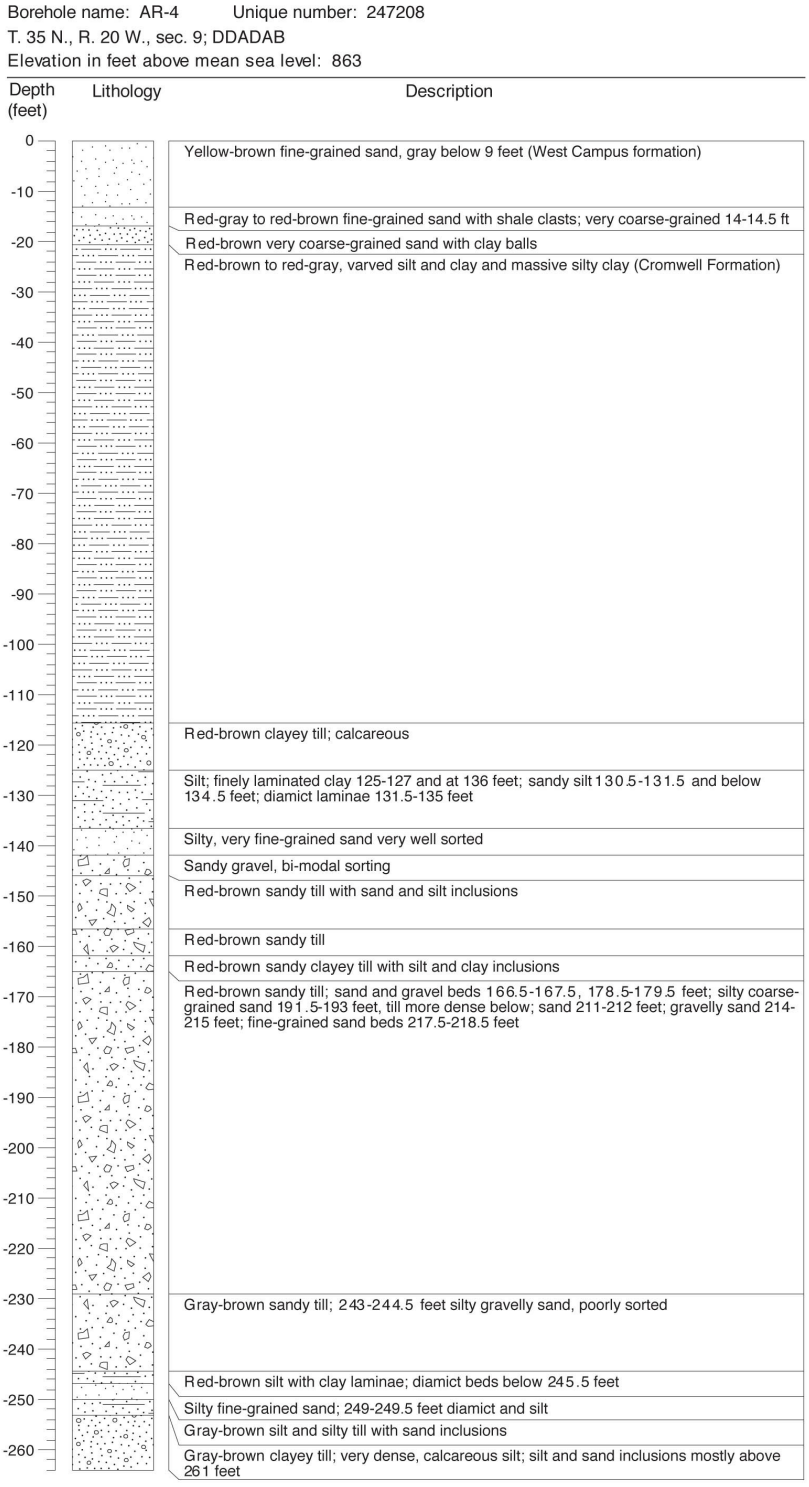


Figure 9. Descriptive log of rotary-sonic core AR-4, drilled by North Star Drilling for an earlier study (Meyer, 1993). Location of drilling is shown on Figure 2 and Plate 1, *Data-Base Map*.

Graphic from source map: Chisago County Geologic Map.

Figure 10: AR-5

Borehole name: AR-5 Unique number: 247209
T. 34 N., R. 20 W., sec. 22; BDAACC
Elevation in feet above mean sea level: 915

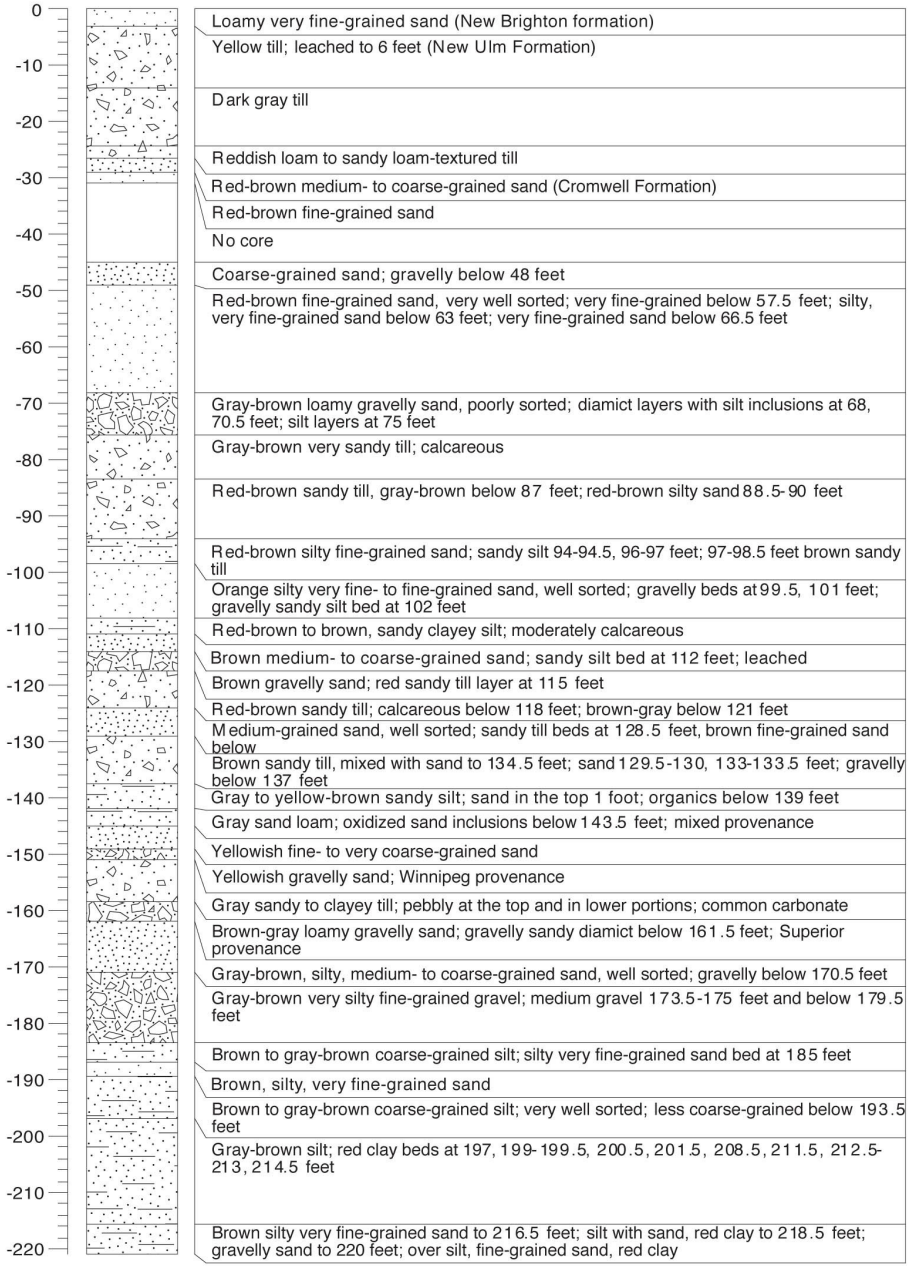


Figure 10. Descriptive log of rotary-sonic core AR-5, drilled by North Star Drilling for an earlier study (Meyer, 1993). Location of drilling is shown on Figure 2 and Plate 1, *Data-Base Map*.

Graphic from source map: Chisago County Geologic Map.

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Text from source map: Chisago County Geologic Map.

Plate 6: Depth to Bedrock

This plate contains information about bedrock topography and depth the bedrock. The GRI only uses information pertaining to depth to bedrock from this plate.

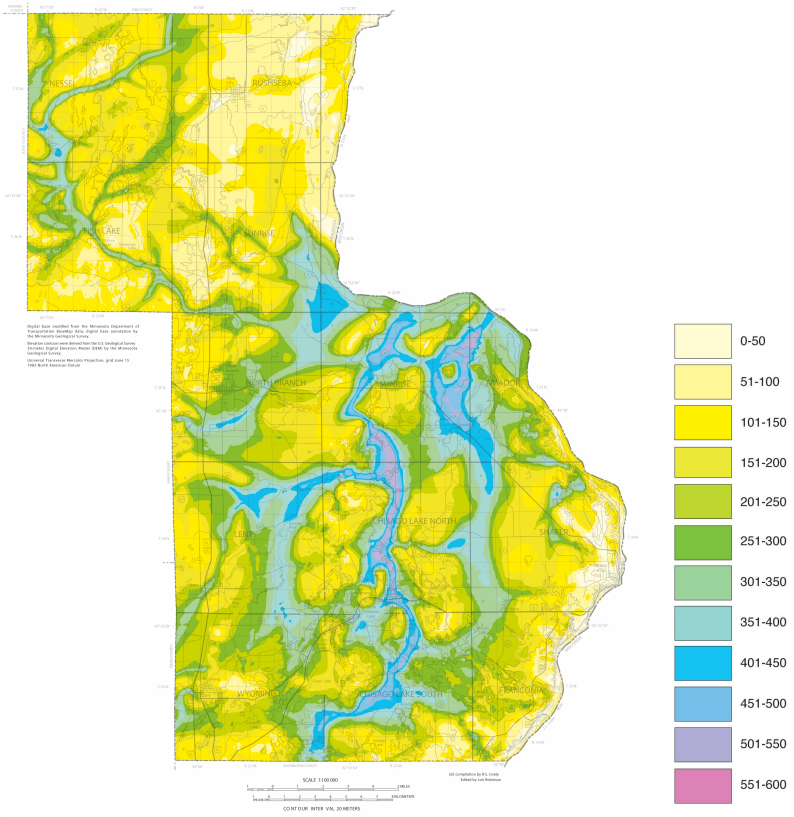
Depth to Bedrock Introduction

The thickness of the glacial sediment is equal to the depth from the land surface to the bedrock surface. To calculate this thickness, a grid of bedrock-surface elevations was subtracted from a corresponding grid of land-surface elevations (30-meter cell size). The surface elevation grid was resampled from the National Elevation 10-meter data set of the U.S. Geological Survey, whereas the bedrock elevation grid was interpolated from interpretations of water well and seismic refraction data (see Bedrock Topography explanation, left). The residual grid was then classified at a 50-foot (15-meter) interval to produce the color-coded Depth to Bedrock map. Because the surface of a lake is regarded as the land surface elevation, the thickness of glacial sediment within lake boundaries includes the depth of the lake water. To calculate the true thickness of sediment beneath the lake it is necessary to subtract the water depth at that location. In places the thickness of the glacial sediment varies greatly over short distances, and mapping at this scale (1:100,000) may not properly resolve such prominent variations. For that reason it is best to consult site-specific data, such as well records and seismic soundings, wherever they are available.

The thickest sediments in Chisago County occur over deep, pre-glacial valleys in the bedrock surface. These occur in the southern half of the county where a network of deep buried valleys have more than 500 feet (152 meters) of sediment overlying the bedrock. In contrast, bedrock is at or within 50 feet (15 meters) of the land surface across much of the southeastern part of the county near the St. Croix River. Most of the details in the Depth to Bedrock map are related to landforms because the model of the bedrock surface is based on much less data than the land surface topography model.

Text from source map: Chisago County Geologic Map.

Depth to Bedrock Map



Graphics from source map: Chisago County Geologic Map.

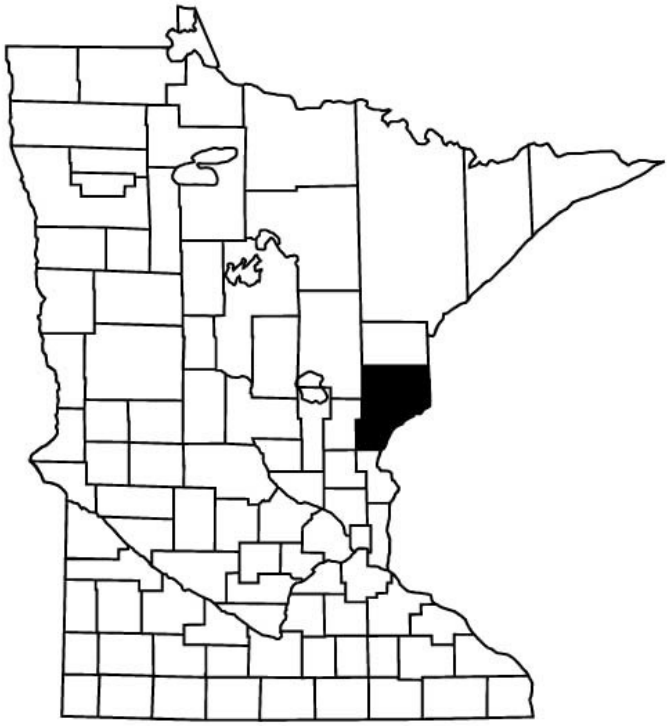
Pine County Geologic Map

The formal citation for this source.

Boerboom, T. J., 2001, Geologic Atlas of Pine County, Minnesota: Minnesota Geological Survey, County Atlas Series C-13 Part A, scale 1:100,000 (*GRI Source Map ID 52582*).

Prominent graphics and text associated with this source:

Location Map



Graphic from source map: Pine County Geologic Map

Plate 1: Data-Base Map

Map Legend

- Record of water-well construction (well driller's log)
- Exploratory boring (exploration hole)—All are located in northwestern Pine County
- Scientific hole
- Cutting sample
- Borehole geophysical log
- Soil boring

Bedrock outcrop

- *Outcrop identified during preparation of this atlas*
- *Outcrop identified through field mapping in 1968*

- Rotary-sonic core
- Textural analysis
- Seismic sounding
- Gravity station

Graphic from source map: Pine County Geologic Map

Report

Introduction

The public health and economic development of Pine County are directly dependent on the wise use and management of its land and water resources. Geologic and hydrologic information is essential before decisions are made that affect natural resources. Although the amount of geologic information required for making specific decisions can vary, the information will not be used at all if it is not available when it is needed, or if it is available only in a highly technical form, or scattered in many different maps and reports.

County atlases, prepared jointly by the Minnesota Geological Survey and the Minnesota Department of Natural Resources, Division of Waters, present detailed geologic and hydrologic information in an interpretive as well as descriptive form. Maps and texts either summarize basic geologic and hydrologic conditions at a county scale or interpret these conditions in terms of the impacts of possible land- and water-use decisions. Site-specific information is also available at a greater level of technical detail than shown on the maps of this atlas. The data are too voluminous to present in the atlas but have been incorporated into readily accessible files housed at the Minnesota Geological Survey.

Several sources commonly provide information about an area or an individual property, but they may use different classification schemes to describe the same geologic materials. As a result, discrepancies in interpreting the data may arise or the different sources may appear to contradict each other. For

example, water-well drillers may describe glacial till as "clay," but engineering records will describe it as a "clayey sand." Both descriptions are acceptable for their original purpose of describing the physical attributes of the material. "Clay," the term used by well drillers, defines the general inability of the till to yield ground water to a well. "Clayey sand," the term from the engineering record, defines the physical composition of the till relative to particle size and engineering properties. The geologist must take the analysis one step further and define the material in terms of how it formed rather than how it is to be used. In this example, till consists of an unsorted mixture of rock fragments ranging in size from clay to cobbles and boulders, and it is interpreted by the geologist as having been deposited directly by glacial ice.

All of the types of data described on this plate had to be interpreted by geologists or hydrogeologists before they were meaningful for mapping purposes. The 1:100,000 scale of the maps in this atlas was chosen because it can show the geologic and topical studies of the county while keeping the physical size of each plate to a manageable level. As a result, some detailed information that was gained by data interpretation and mapping cannot be shown on these maps or discussed in the texts.

Whether to use the atlas alone, or in combination with the data bases, depends on the amount of detail needed. Generally, data-base information must be used to evaluate site specific conditions.

Text from source map: Pine County Geologic Map

The Data-Base Map Explanation

The types, locations, and density of information used to prepare this atlas are shown on the map. The data are described below to aid the user in assessing which types may be useful for a particular information need. The Data-Base Map serves as a guide to the precision of the other maps in the atlas. It shows where data are sparse or lacking and interpretation and extrapolation were required to prepare maps.

Text from source map: Pine County Geologic Map

Drill-Hole Information

A **record of water-well construction (well driller's log)** is a water-well contractor's description of the geologic materials penetrated during drilling and the construction materials used to complete the well. Not all wells extend to bedrock. In areas of thick, unconsolidated Quaternary deposits, drillers usually do not have to drill through the entire thickness of overburden to find sufficient ground water. Hydrologic data, such as the static water level and test-pumping results, are commonly included. Before any driller's log can be used, the location of the well must be verified, and a geologist must interpret the log. Drillers' logs are the primary source of subsurface geologic and hydrologic data for Pine County; about 3050 logs were used for this atlas.

An **exploratory boring (exploration hole)** is an explorationist's description of the geologic materials penetrated during mineral exploration. Exploratory work may include the collection of core samples of the bedrock encountered for descriptive and analytical purposes. In Minnesota, such core is eventually transferred to the Minnesota Department of Natural Resources, Division of Minerals, and is available for inspection by the public at their offices.

Four **scientific holes** were drilled in the county to establish the nature of the bedrock at those locations. Core samples of the bedrock were collected for later description and analysis. Two of the holes were

drilled in conjunction with the U.S. Geological Survey.

Cutting samples collected during drilling and exploration provide physical evidence of subsurface geologic materials. They are the principal means of establishing the nature of the subsurface materials and are used to interpret and verify drillers' logs. Borehole geophysical logs are created by lowering instruments down the well or drill hole and measuring the physical and chemical properties of the geologic materials through which the hole passes. Different logging techniques measure naturally occurring gamma radiation, spontaneous potential, and resistivity. Gamma logs characterize in graphic form the geologic formations penetrated. Spontaneous potential and resistivity are mainly used to locate water levels in wells and the depth of the well casing. An interpretive log is prepared from the geophysical log and correlated with drilling samples from the same hole, information obtained from nearby outcrops, or a geophysical log from a nearby drill hole. Geophysical logs can provide high-quality subsurface geologic and hydrologic information from wells for which little or no other information is available.

Soil borings are test holes drilled by the Minnesota Department of Transportation to obtain information about the physical properties of subsurface materials for engineering, mapping, or exploration purposes. Most terminate at very shallow depths or where bedrock is encountered. They are logged by an engineer or a geologist using a variety of classification schemes based on particle sizes, penetration rate, moisture content, and color. Soil-boring data are limited in distribution; in Pine County they are concentrated along the U.S. Interstate Highway 1-35 corridor. These data are most useful in determining the composition of unconsolidated deposits. Some logs include the depth to bedrock and the lithology (rock type) of the first bedrock encountered.

Text from source map: Pine County Geologic Map

Other Information

Bedrock outcrops are exposures of solid rock at the land surface. Most are natural outcrop: however, some are exposures created during construction. They serve as reference points for mapping and for checking the accuracy of subsurface data. Bedrock at or near the surface must be considered in land-use planning decisions, such as pipeline routing, sewage-system design, and excavations. Outcrops were mapped by T.J. Boerboom as part of field work for the atlas; additional outcrops mapped by G.B. Morey in 1968 (unpublished mapping, Bruno and Danbury 15-minute quadrangles, Minn. Geol. Survey) are also included.

Rotary-sonic cores were collected from three sites in the county to aid the interpretation of the Quaternary deposits. The coring technique enables recovery of a continuous core, 3.5 inches in diameter, from the glacial deposits and bedrock (if present). It provides excellent subsurface samples for detailed study and comparison with cuttings, geophysical logs, and drillers' logs from surrounding sites.

Textural analyses express the proportion of sand-, silt-, and clay-size particles that make up a sample. They are helpful in identifying and mapping unconsolidated materials like glacial deposits. The samples analyzed were taken from natural and artificial exposures, shallow borings, and the rotary-sonic cores.

Seismic soundings measure the time required for sound or pressure waves to travel from a source to a receiver. Travel time can be correlated with the density and rigidity of the geologic material. Paleozoic and Precambrian rocks exhibit acoustic- or pressurewave velocities 1.5-2.5 times those of unconsolidated Quaternary sediments below the water table. The spacing of the receivers (geophones) and the arrival times (measured in milliseconds) are used to calculate the depth to bedrock. Seismic soundings are labor intensive but can provide high-quality data when no other sources of subsurface information are available.

In Pine County, 21 seismic-refraction lines were established in the area around Grindstone Lake (most are between the lake and Hinckley) to acquire data to verify the location of a bedrock valley buried by Quaternary sediments. The seismic lines were targeted along a weak (10–30 nanoteslas), sinuous to linear high in the magnetic anomaly data (Chandler and others, 1984). The source of the anomaly is assumed to be magnetite bearing glacial deposits of the Superior lobe within a valley of nonmagnetic Hinckley Sandstone. A 12-channel signal-enhancement seismograph was used; the 40-hertz geophones were spaced 6–12 meters apart. A 10-pound sledge hammer provided the energy for the signal; offsets were 1-200 meters. In every instance, refraction lines located off the magnetic high yielded depths from the land surface to the bedrock surface of 3–25 meters, whereas lines located over the magnetic high yielded bedrock depths in excess of 60 meters. As a result, the weak, sinuous to linear magnetic highs elsewhere in the Hinckley and Sandstone areas are also assumed to indicate buried bedrock valleys. One of these magnetic anomalies just north of Grindstone Lake (sec. 9, T. 42 N., R. 21 W.) was subsequently cored; the seismic and aeromagnetic data were used to locate the hole precisely.

Gravity data were used to aid mapping of the bedrock topography and the thickness of the overlying glacial deposits in certain areas of the county. The mass difference between high-density Precambrian and Paleozoic rocks and low-density glacial deposits produces small anomalies in the gravity field. The gravity-geologic method incorporates geologic control from drill holes and seismic soundings to isolate the residual gravity signature of pre-Cretaceous bedrock and the differences in thickness of glacial deposits from the much larger gravity signatures arising from deep, intra-basement (Precambrian) sources. The residual signature can be converted to estimate bedrock elevation and the thickness of glacial deposits. Sixty-three gravity stations were added in Pine County during the summer and fall of 1999, primarily to fill gaps that existed in the older coverage (Chandler and Schaap, 1991). Most of the new stations were located along the east-central and northeastern margin of the county to help delineate structures in the Keweenawan volcanic rocks lying along and southeast of the Douglas fault. The remaining new stations were located along the west-central margin of the county to help delineate a buried bedrock valley south of Grindstone Lake.

Text from source map: Pine County Geologic Map

Data Base Management

All of the data shown on the maps were plotted on 7.5-minute topographic quadrangle maps or highway alignment maps. Inventory numbers were assigned to all data sources except some soil borings. Automated data bases and a few manual files were developed to provide easy access and rapid retrieval of these site-specific data. The data may be obtained from the Minnesota Geological Survey.

Computer storage and retrieval systems are better than manual files for manipulating large amounts of data. Automated geologic data bases may also be designed to interact with other computer files, such as land-use data. Such interaction permits more efficient assessment of cause-and-effect relationships concerning natural resources than is commonly possible with manual files.

Pine County Data Bases
Computerized files were developed for point-source data in Pine County. They use Public Land Survey descriptions, Universal Transverse Mercator (UTM), and latitude-longitude coordinates as location criteria; thus, they are compatible with the natural-resource data bases housed at the Minnesota Land Management Information Center (LMIC). The computerized data bases developed for Pine County by the Minnesota Geological Survey are County Well Index (CWI) and Test Borings Data Base (TESTHOLE).

County Well Index (CWI). Information from water-well records and exploration holes was entered into this statewide data base. Each well log is assigned a six-digit unique number and each exploration drill

hole is assigned either a five- or six-digit unique number. These reference numbers are also used by state agencies and the Water Resources Division of the U.S. Geological Survey. Elevations, expressed in feet above sea level, were determined from topographic maps (see the index to 7.5-minute quadrangles). The street address of each well is also included whenever possible to provide data users with a well-location system that is compatible with local regulatory programs. Software at the Minnesota Geological Survey is used to display and tabulate many of the data elements contained on the original well log.

The County Well Index is currently stored in a data base that consists of nine related tables. These tables contain information such as well depths, well construction, addresses, aquifers, dates drilled, static water levels and pumping test data. They also contain alternate well identifiers such as permit numbers or emergency-service numbers, and the well stratigraphy (the geologic materials encountered during drilling).

CWI application software developed by the Minnesota Department of Health provides two types of reports:

1. WELL LOG contains all the information about the well as it was reported by the contractor. There may also be additional location information, land-surface elevations, aquifer designations, and remarks about the drill holes (Fig. 1).

2. WELL STRATIGRAPHY contains the geologic log with a geologist's stratigraphic interpretations, which are based on her or his knowledge and understanding of the geology of Pine County. Only those drill holes with verified locations have stratigraphy assigned to them (Fig. 2).

Test Borings Data Base (TESTHOLE). Information from soil borings and engineering test holes is stored in this data base. Descriptions of the types of geologic materials penetrated and the soils classification system used are entered together with specific field and laboratory tests. The most common tests are blow counts, liquid and plastic limits, water content, and dry density. The depth to the water table is entered if available. Each test hole receives a unique number, and the location is digitized from the site plan.

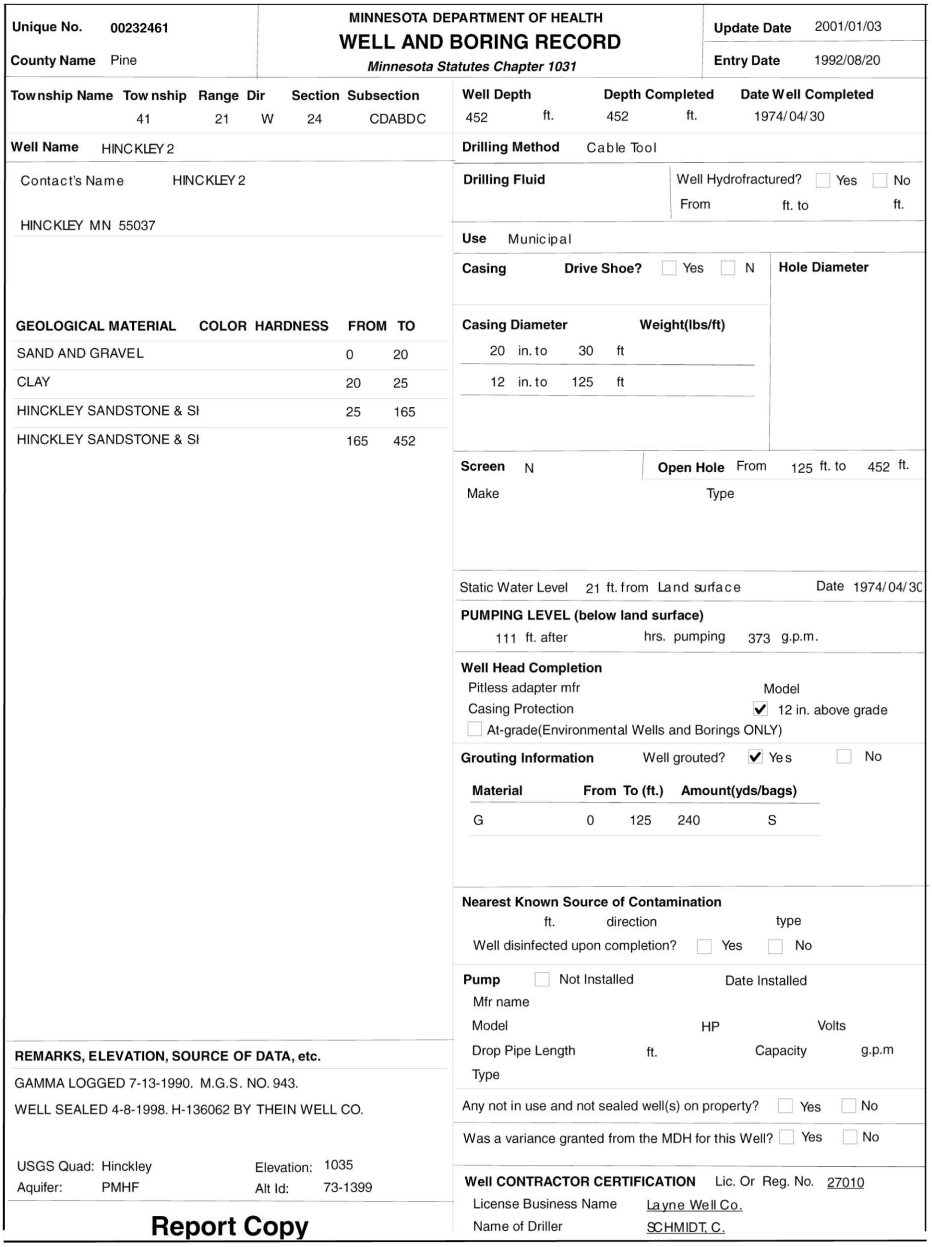
Text from source map: Pine County Geologic Map

Future Data Collection

A data-base map is out of date even before it is printed because additional information is continually generated as new water wells are drilled, construction activities expose more bedrock, or additional wells are tested for water quality. The library of geologic information prepared for Pine County is flexible so that old data can be reevaluated in light of new information, and new forms of data can be added if required. The need to manage ground water and other natural resources wisely will never become outdated. Future demands on these resources will require current data to assess the impacts.

Text from source map: Pine County Geologic Map

Figure 1: Well Log Example



MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING RECORD
Minnesota Statutes Chapter 1031

Unique No. 00232461 | Update Date 2001/01/03
County Name Pine | Entry Date 1992/08/20

Township Name	Township	Range	Dir	Section	Subsection
	41	21	W	24	CDABDC

Well Depth 452 ft. | Depth Completed 452 ft. | Date Well Completed 1974/04/30

Well Name HINCKLEY 2

Drilling Method Cable Tool

Contact's Name HINCKLEY 2

HINCKLEY MN 55037

Drilling Fluid | Well Hydrofractured? ☐ Yes ☐ No
From ft. to ft.

Use Municipal

Casing | Drive Shoe? ☐ Yes ☐ N | Hole Diameter

Casing Diameter | Weight(lbs/ft)
20 in. to 30 ft
12 in. to 125 ft

GEOLOGICAL MATERIAL	COLOR	HARDNESS	FROM	TO
SAND AND GRAVEL			0	20
CLAY			20	25
HINCKLEY SANDSTONE & SI			25	165
HINCKLEY SANDSTONE & SI			165	452

Screen N | Open Hole From 125 ft. to 452 ft.
Make | Type

Static Water Level 21 ft. from Land surface | Date 1974/04/30

PUMPING LEVEL (below land surface)
111 ft. after hrs. pumping 373 g.p.m.

Well Head Completion
Pitless adapter mfr | Model
Casing Protection ☑ 12 in. above grade
☐ At-grade(Environmental Wells and Borings ONLY)

Grouting Information | Well grouted? ☑ Yes ☐ No

Material	From	To (ft.)	Amount(yds/bags)	
G	0	125	240	S

Nearest Known Source of Contamination
ft. direction type
Well disinfected upon completion? ☐ Yes ☐ No

Pump ☐ Not Installed | Date Installed
Mfr name
Model HP Volts
Drop Pipe Length ft. Capacity g.p.m
Type

Any not in use and not sealed well(s) on property? ☐ Yes ☐ No

Was a variance granted from the MDH for this Well? ☐ Yes ☐ No

REMARKS, ELEVATION, SOURCE OF DATA, etc.
GAMMA LOGGED 7-13-1990. M.G.S. NO. 943.
WELL SEALED 4-8-1998. H-136062 BY THEIN WELL CO.

USGS Quad: Hinckley | Elevation: 1035
Aquifer: PMHF | Alt Id: 73-1399

Well CONTRACTOR CERTIFICATION Lic. Or Reg. No. 27010
License Business Name Layne Well Co.
Name of Driller SCHMIDT, C.

Report Copy

Figure 1. An example of a WELL LOG record, showing all the information about the well as reported by the well driller.

Graphic from source map: Pine County Geologic Map

Figure 2: Well Stratigraphy Example

Unique No. 00232461				MINNESOTA DEPARTMENT OF HEALTH					**Update Date** 2001/01/03		
County Name Pine				**WELL AND BORING RECORD**					**Entry Date** 1992/08/20		
				Minnesota Statutes Chapter 1031							
Township Name	**Township**	**Range**	**Dir**	**Section**	**Subsection**	**Well Depth**		**Depth Completed**		**Date Well Completed**	
	41	21	W	24	CDABDC	452	ft.	452	ft.	1974/04/30	
Well Name HINCKLEY 2					**Lic. Or Reg. No.** 27010			**Name of Driller** SCHMIDT, C.			
USGS Quad Hinckley				**Elevation** 1035	**Aquifer** PMHF			**Alternate Id** 73-1399			

GEOLOGICAL MATERIAL	COLOR	HARDNESS	FROM	TO	STRAT	LITH PRIM	LITH SEC	LITH MINOR
SAND AND GRAVEL			0	20	QHUU	SAND	GRVL	
SAND = Sand			GRVL = Gravel					
CLAY			20	25	PMHN	SNDS		
PMHN = Hinckley Sandstone		SNDS = Sandstone						
HINCKLEY SANDSTONE & SHALES			25	165	PMHN	SNDS		
PMHN = Hinckley Sandstone		SNDS = Sandstone						
HINCKLEY SANDSTONE & SHALES			165	452	PMFL	SNDS	SHLE	
PMFL = Fond Du Lac Formation		SNDS = Sandstone			SHLE = Shale			

Figure 2. The WELL STRATIGRAPHY record is a geologist's interpretation of the geologic materials listed by the driller in the WELL LOG record (Fig. 1). The headings (**GEOLOGICAL MATERIAL**, **COLOR**, **HARDNESS**, etc.) pertain to information in the first line of each entry; the second line contains explanations of the four-letter codes used in the first line. The first word (in capital letters) in each entry is the well driller's description for that interval. Color and hardness were not determined for geologic material from this hole. All depths are measured in feet. Heading abbreviations: **STRAT**, stratigraphy (the name of the stratigraphic unit—for example, PMHN for the Hinckley Sandsone); **LITH PRIM**, primary lithology (rock type—for example, SNDS for sandstone); **LITH SEC**, secondary lithology; **LITH MINOR**, minor lithology.

Graphic from source map: Pine County Geologic Map

References

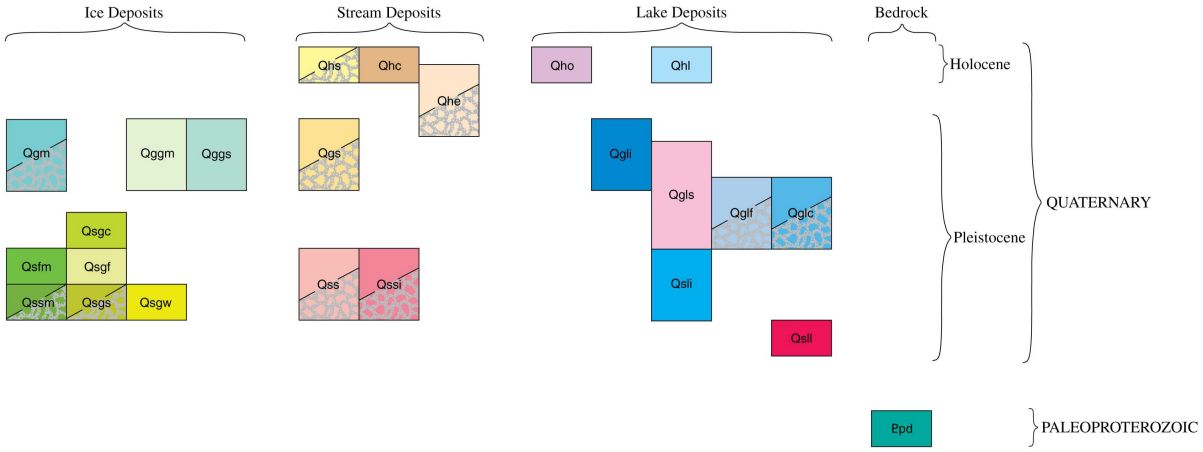
Chandler, V.W., Nordstrand, E., and Anderson, S., 1984, Shaded-relief aeromagnetic anomaly map of northeastern and east-central Minnesota: Minnesota Geological Survey Miscellaneous Map Series M-53, scale 1:100,000.

Chandler, V.W., and Schaap, B.D., compilers, 1991, Bouguer gravity anomaly map of Minnesota: Minnesota Geological Survey State Map Series S-16, scale 1:500,000.

References from source map: Pine County Geologic Map

Plate 4: Surficial Geology

Correlation of Units



Units symbols on this graphic may differ slightly from respective units in the GRI digital geologic-GIS data. This is due to resolving unit symbols across multiple maps used in this compilation.

Graphic from source map: Pine County Geologic Map

Map Legend

Geologic contact—Approximately located; established from geomorphology and materials as interpreted from aerial photographs, examination of surficial material, and soil maps.

Sinuous narrow ridge (esker)—Linear ridge of predominantly sand and gravel. Interpreted as having been deposited in an ice-tunnel or ice-walled channel by a glacial meltwater stream. Arrowheads show inferred flow direction. The fluvial sediment may be covered by as much as three meters of till. All eskers are interpreted to be of Superior-lobe origin, although thin sediments of the Grantsburg sublobe may in places cover those in the southern half of the county.

Conical hill (kame)—Predominantly sand and gravel. Interpreted as deposit of meltwater within confines of supporting ice. When ice melted, gravel and sand assumed angle of repose. Bedding likely collapsed.

Streamlined hill or ridge (drumlin)—Typically composed of glacial sediment deposited at the base of moving Superior-lobe ice. Arrowhead on long axis shows inferred direction of ice movement. Evident in northwest corner of county.

Block of thrusted sediment—Sawteeth point in direction of thrusting agent; interpreted to be glacially thrusted ice-marginal sediment. Present in places along the Superior-lobe ice margins. Probably indicates sudden advance or surge of ice.

Fan-shaped sloping hill—Interpreted to be an alluvial fan composed of sand and gravel.

Sharp-crested ridge—Interpreted as a former ice margin.

Scarp—Ticks point downscarp. Established from aerial photographs and topographic maps. Where paired, interpreted to be a former drainageway. Not indicated where scarp coincides with stream-related unit. Former drainageways may in places control the direction of present-day surface and near-surface water flow, especially flood waters.

Irregular, broad trough—Ticks point downslope. Interpreted to be a collapsed subglacial drainage channel or buried valley.

Irregular, hummocky topography—Interpreted to have formed as sediments were deposited with or on stagnant ice; material collapsed when ice melted.

Irregular sandy hills—Interpreted as weakly expressed windblown dunes. Most are located in forested area in northern part of map area.

Lineations apparent in areas of thin glacial sediment—Interpreted as a reflection of bedrock structure and bedding in areas of glacial erosion or nondeposition. The lineations in areas underlain by basaltic rocks (see Plate 2) may correspond to the pattern of deposition of glacial sediment; in areas underlain by sandstone, the lineations may indicate the location and orientation of sinkholes.

Curvilinear ridges—Interpreted as clay-rich landforms. Found exclusively in the Nickerson moraine (Fig. 1).

Graphic from source map: Pine County Geologic Map

Figure 1: Ice Margin Map

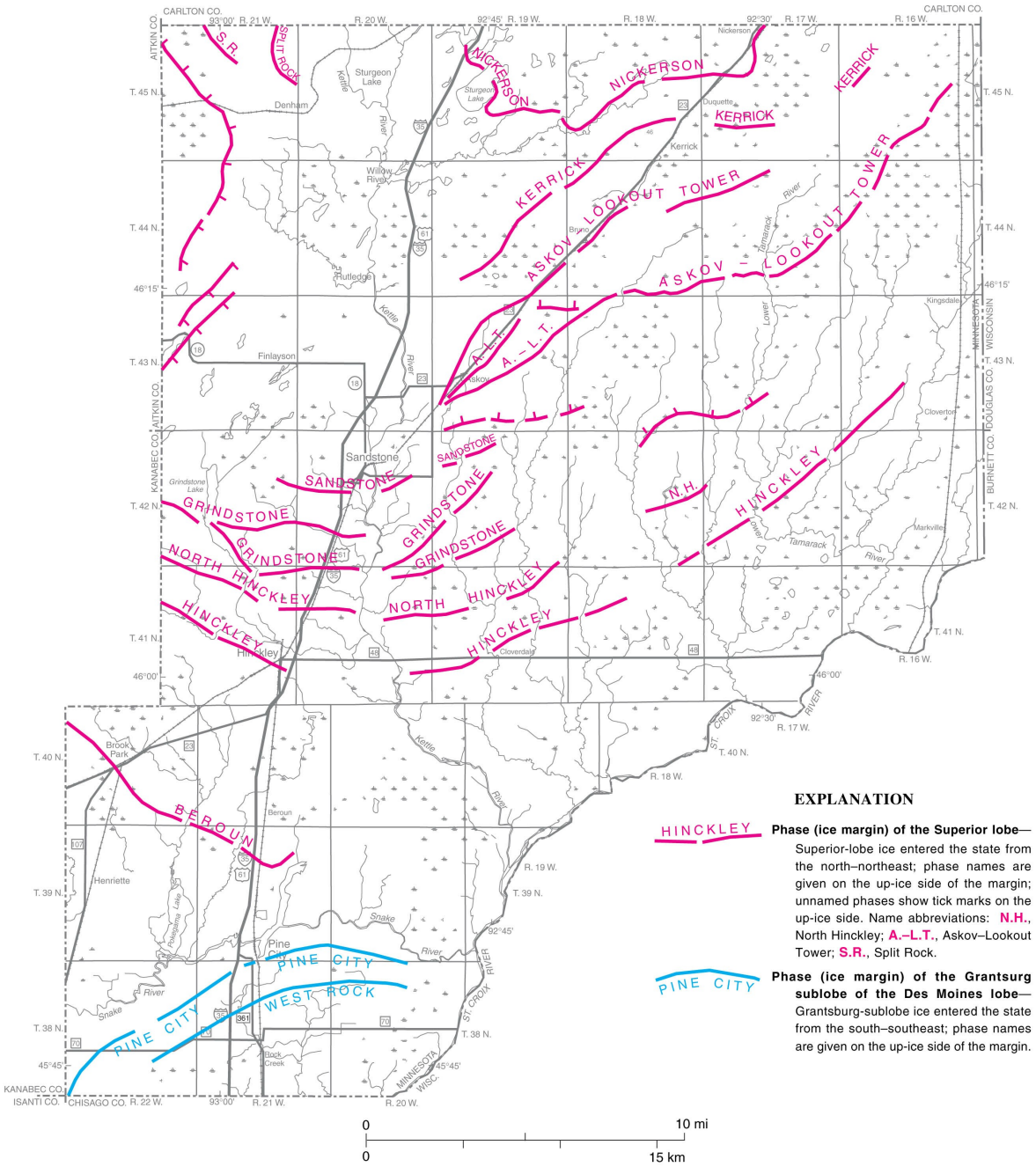


Figure 1. Distinct phases, or ice margins, of the Grantsburg sublobe of the Des Moines lobe (blue) and of the Superior lobe (magenta). The Grantsburg sublobe entered the county from the south–southeast. The Superior lobe entered Pine County from the north–northeast. The margins represent positions where advancing or receding ice stood long enough to leave distinctive landforms at the surface. Quaternary geologists use such markers to reconstruct the glacial history of Pine County.

Graphic from source map: Pine County Geologic Map

Plate 5: Quaternary Stratigraphy

Quaternary Stratigraphy of Pine County

Outcrops, drill cuttings, auger samples, water-well drillers' logs, and cores were used to interpret the Quaternary stratigraphy of Pine County. Geologic units were defined using previous studies completed in the area and through the interpretation of new data collected by the above mentioned methods. Analysis of the texture and rock types of Quaternary sediments was done for selected geologic units as listed in Table 1 as an aid to understanding the characteristics of each. A series of diagrams (Figure 1) presents an interpretation of the sequence of glacial and postglacial events that were responsible for the deposition of the sediments and the shaping of the landforms of the county. The topographic expression determined by glacial sculpturing and bedrock structure is displayed on the Digital Elevation Model (Figure 2). The Quaternary cross sections show the stratigraphic position of the geologic units in the subsurface.

Text from source map: Pine County Geologic Map

Cross Section Units

UNITS FROM THE SURFICIAL MAP—See Plate 4 for fuller descriptions of geologic units.

Holocene and Late Pleistocene

- Qho — Organic deposits
- Qhs — Stream sediment
- Qhc — Steep-slope and slope deposits
- Qhe — Stream-eroded surface deposits

Pleistocene

Deposits of the Grantsburg sublobe of the Des Moines lobe

- Qgm — Glacial sediment (till) of end moraines
- Qggs — Glacial sediment (till) and pond sediment accumulated in intermorainic swales
- Qgs — Stream sediment
- Qgls — Sandy lake sediment of glacial Lake Grantsburg
- Qglf — Silty and sandy lake sediment of glacial Lake Grantsburg
- Qglc — Silty and clayey lake sediment of glacial Lake Grantsburg

Deposits of the Superior lobe

- Qsgc — Clayey glacial sediment (till)
- Qssi — Sorted ice-contact sediment
- Qss — Stream sediment
- Qsll — Lake sediment of glacial Lake Lind

UNITS MODIFIED FROM THE SURFICIAL MAP (Plate 4)

Deposits of the Superior lobe

- Qsf — Silty and clayey glacial sediment (till)—Map units Qsgf and Qsfm from Plate 4
- Qsg — Sandy glacial sediment (till)—Map units Qsgs, Qssm, and Qsgw from Plate 4

UNITS ON THE CROSS SECTIONS ONLY

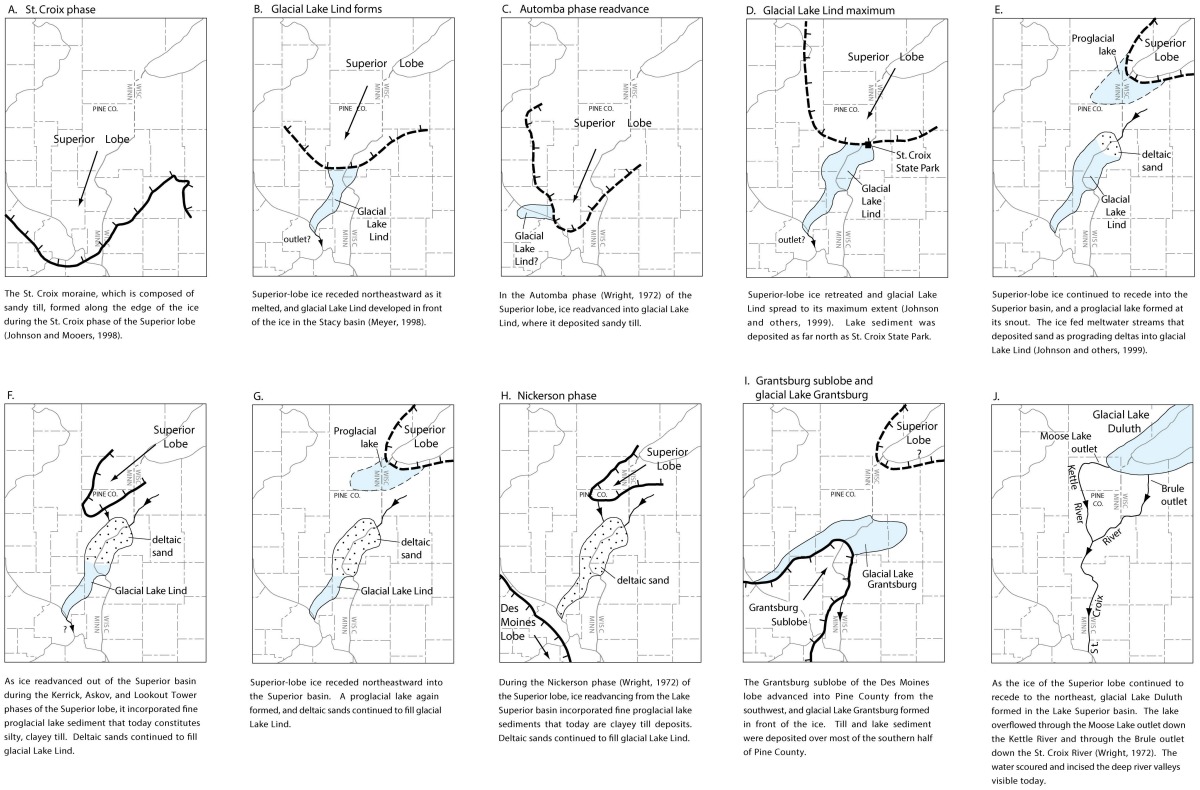
- Qsd — *Fluvial deltaic deposits*—Red, fine- to medium-grained, well-sorted, bedded sand. Interpreted as stream sediment deposited as a prograding delta into glacial Lake Lind (Johnson and others, 1999) by meltwater of the Superior lobe (Figs 3E, 3F, 3G, and 3H). Sediment filled much of the lake basin. This unit is commonly found underlying Grantsburg sublobe sediments south of the Snake River.
- Qbs — *Bedded sediment*—Chiefly sand and gravel; clay and silt beds in places, especially where unit is thick. Where found above pre-late Wisconsin deposits, the unit commonly includes sediment laid down by meltwater of the Superior lobe.
- Qptg — *Sandy loam to loam (till)*—Chiefly yellow brown where oxidized, gray where unoxidized. Dense sediments attributed to pre-late Wisconsin ice deposits of northwesterly origin. The characteristics of this unit are interpreted from well drillers' logs; it is found only in the subsurface, commonly in bedrock valleys.
- Qptr — *Sandy glacial sediment (till)*—Commonly red where oxidized, reddish gray where unoxidized. Dense sediments deposited by pre-late Wisconsin ice of northeasterly origin. The characteristics of the unit are interpreted from well drillers' logs; it is found only in the subsurface, commonly in bedrock valleys.

Geologic contact

Drill hole

This graphic describing cross section geologic units and related features *accompanies cross section graphics contained in the Geologic Atlas for Pine County. Go to Geologic Cross Sections in this document to view cross section graphics for Pine County.
Graphic from source map: Pine County Geologic Map

Figure 1: Glacial Events



Graphic from source map: Pine County Geologic Map

Figure 1. Glacial events that affected the deposition of Quaternary sediments in Pine County, Minnesota.

MAP SYMBOLS

Proglacial lake —A lake that forms along the edge of a ice sheet (ice margin). Line dashed where approximately located.

Deltaic sand plain.

Ice margin —Ticks point toward ice; line dashed where approximately located.

General direction of ice flow.

Meltwater stream —Showing direction of flow.

Graphic from source map: Pine County Geologic Map

Figure 2: Digital Elevation Model

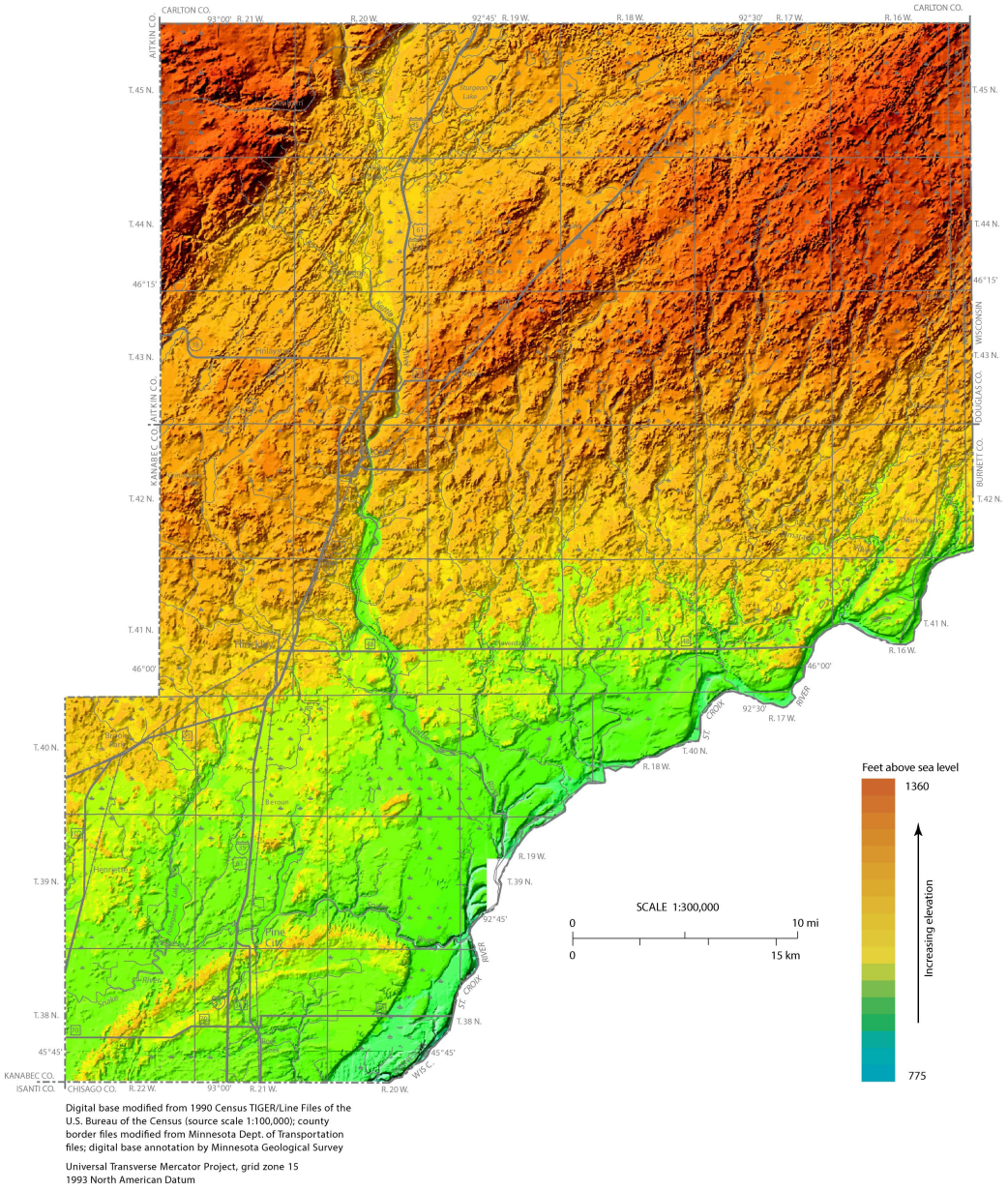


Figure 2. Physical relief on the land surface in Pine County. Elevation is shown by color, and a false sun illumination from the northwest provides contrast (gray shadowing) to accent details of landforms. The map was created using the U.S. Geological Survey's Digital Elevation Model. The county has 585 feet (178 meters) of relief. The lowest elevations are in the extreme southeastern part of the county, along the St. Croix River (about 775 feet, or 235 meters, above sea level); the highest elevations are near the center of Nickerson Township (T. 45 N., R. 16 W.) in northeastern Pine County (about 1360 feet, or 415 meters, above sea level). No data are available for the small uncolored area within T. 39 N., R. 19 W.

Graphic from source map: Pine County Geologic Map

Table 1: Matrix Texture Table

Table 1. Average values for the matrix texture of tills and associated sediments recognized in Pine County, Minnesota.

[Samples were analyzed to determine matrix texture and lithology (rock type). Matrix texture is expressed as relative proportions of sand–silt–clay in percent. The lithology of the coarse sand (1–2 millimeters) fraction is expressed as relative proportions of crystalline–carbonate–shale rock types in percent. The crystalline samples were further differentiated by crystalline rock type—light (granite and gneiss), dark (mafic-igneous and other metamorphic rocks), and red (iron-formation, rhyolite, agate, and sandstone). Abbreviations: mm, millimeter; leaders (--), no data available. See the explanation of the sections for brief descriptions of the geologic units; fuller descriptions of surficial units are given on Plate 4.]

GEOLOGIC UNITS		MATRIX TEXTURE			LITHOLOGY (ROCK TYPE)		
Shown on cross sections (this plate) and surficial map (Plate 4) UNIT LABELS	DEPOSIT TYPE (AND ASSOCIATED ICE PHASES AND GLACIAL LAKES)	*Total number* SAMPLES	*Percentage of total sample weight* GRAVEL	*Percentage in 1–2 mm fraction* SAND–SILT–CLAY	*Total number* SAMPLES	*Percentage of total grains counted* CRYSTALLINE–CARBONATE–SHALE	*Percentage of total crystalline grains counted* LIGHT–DARK–RED
Deposits of the Grantsburg sublobe of the Des Moines lobe							
Qgm, Qggm	Grantsburg till (Pine City & West Rock phases)	46	4	43–33–24	25	57–21–22	82–14–4
Qglf	Sand and silt of glacial Lake Grantsburg	15	1	39–47–14	--	--	--
Qglc	Silt and clay of glacial Lake Grantsburg	29	0	10–34–56	--	--	--
Deposits of the Superior lobe							
Qssm, Qsgw, Qsgs, Qsg	Superior till (St. Croix and Automba phases)	311	8	62–26–12	26	100–0–0	43–39–18
Qsfm, Qsfg, Qsf	Superior till (Kerrick, Askov, and Lookout Tower phases)	63	3	37–37–26	19	100–0–0	49–30–21
Qsgc	Superior till (Nickerson phase)	21	2	28–34–38	15	100–0–0	51–30–19
Qsll	Sediment of glacial Lake Lind	3	2	37–32–31	--	--	--

Table from source map: Pine County Geologic Map

Acknowledgments

Mark Johnson of Gustavus Adolphus College provided personal file materials and publications of recently mapped areas near Pine County. His insights and perspectives were greatly appreciated. Randy Bradt of the Minnesota Department of Natural Resources assisted in field work. Brom Griffin, the Natural Resource Specialist at St. Croix State Park, arranged permission for auger drilling in the park. The county office of the United States Natural Resources Conservation Service provided information and aid to Survey staff. We thank the many landowners who allowed access to sites throughout the county, and especially to those who allowed core drilling on their properties.

Text from source map: Pine County Geologic Map

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Wright, H.E., Jr., 1972, Quaternary history of Minnesota, in Sims, P.K., and Morey, G.B., eds., Geology of Minnesota—A centennial volume: Minnesota Geological Survey, p. 515-547.

References from source map: Pine County Geologic Map

Plate 7: Mineral Endowment

The two maps on this plate show the distribution of historic test pits and showings of native copper (all subeconomic) and established and potential sources of construction aggregate and dimension stone. The construction aggregate is classified into bedrock aggregate (crushed rock) and natural aggregate (gravel and sand). The GRI used information only pertaining to natural aggregate from this plate.

Text modified from source map: Pine County Geologic Map

Natural-Aggregate Endowment Legend

Potential primary resources—This unit includes portions of the stream-eroded terrace deposits along the St. Croix and Kettle Rivers (Qhe), where high-energy streams have concentrated gravel and created bar forms that add to the thickness of the overall stream deposit. In addition, the terraces lie high above the current stream level, and there is no evidence of perched water near the surface. Also included are large eskers and ice marginal fans (Qssi).

Potential secondary resources—Most of the ice-contact deposits fall within this category (Qssi), as do areas of shallowly buried or surficial glacial stream sediment (Qss). These deposits typically have more variability in the sand-to-gravel ratio than those classed as potential primary resources, as well as varying amounts of cover.

Speculative secondary resources—This unit includes sandy stream sediment (Qsh and Qss), areas of the terrace (Qhe) that have a perched water table or thin deposit, sandy-ice contact deposits (Qssi) or those with high water table or thick cover, or deposits for which there is very little specific information.

Gravel pit or potential area included in the Minnesota Department of Transportation data base—See also Table 1.

Other pit noted during the course of field work or indicated on topographic maps—No tests were run on these pits.

Esker—Linear ridge composed predominantly of sand and gravel. The fluvial sediment may be covered by as much as ten feet of till. All eskers are interpreted to be of Superior-lobe origin, although thin sediment of the Grantsburg sublobe may in places cover eskers in the southern half of the county.

Kame—Conical hill predominantly composed of sand and gravel.

Graphic from source map: Pine County Geologic Map

Report

Natural-Aggregate Introduction

Natural aggregate is classified into three classes based on quantity and quality criteria that affect the potential viability of the deposits as economic resources.

The terms **mineral endowment**, **geological endowment**, or **endowment** refer to the geologic materials that have intrinsic economic value and thus, potentially, could be mined and marketed. A **mineral resource** is a narrower or more restricted portion of the geological endowment; it is "a concentration or occurrence of material of intrinsic economic interest in or on the Earth's crust (a deposit) in such form and quantity that there are reasonable prospects for eventual economic extraction. ... Portions of a deposit that do not have reasonable prospects for eventual economic extraction must not be included in a mineral resource" (Resources and Reserves Committee, 1999). Among the factors that may remove some portion of an endowment from consideration as a resource are zoning restrictions, landownership considerations, prohibitive taxation, competing surface uses, and environmental considerations, in addition to the supply-demand price fluctuations of the commodity marketplace. The authors of this plate did not take into account these socioeconomic factors, and therefore the map portrays the mineral endowment of Pine County, not the mineral resources.

The **geological endowment** of a mineral commodity can be defined and quantified on observable physical and compositional attributes of the deposit, such a deposit thickness, overburden thickness, horizontal dimensions, measures of crushing strength, particle-size distribution, etc. A mineral resource must possess favorable attributes of this type, but in addition it must be relatively unencumbered by socioeconomic factors that would remove it from consideration as the basis of a business enterprise.

The geological endowment of natural aggregate in Pine County consists of sand and gravel deposited by glacial meltwater and postglacial streams. Gravel of good quality is relatively abundant in Pine County. Most of it is nearly free of deleterious materials (for example, shale, limestone, iron oxide, and chert) and has little cover. Drawbacks include a shallow water table in much of the county, deposits that are more sand-rich than desirable, and the thinness of some deposits. Many of the gravel pits in Pine County were tested and developed during the construction of local roads, and Interstate Highway I-35. As aggregate resources become depleted or made inaccessible to the south in the seven-county metropolitan area of Minneapolis and St. Paul, the resources in Pine County may become more important regionally.

In the following discussion frequent reference is made to surficial units on Plate 4. Four- and three-letter codes (for example, Qci), which are the unit labels on the surficial geology map, are used to designate individual units in the discussion below and in Table 1.

Text modified from source map: Pine County Geologic Map

Natural-Aggregate Mapping and Evaluation Criteria

Criteria Shown on this map are geologic units in which there is some potential (as judged solely from geological criteria) for the existence of commercially viable gravel and sand deposits. Where available, Minnesota Department of Transportation data that describe aggregate quality and quantity for specific pits were used to identify the geologic units that have the greatest potential. The most highly rated map units have demonstrated aggregate potential as documented by the Department of Transportation reports. Some pits within these areas may be depleted, but the unit is still rated high to indicate its former potential and the extension of the potential to similar units. Geologic units that do not have demonstrated potential as indicated by Minnesota Department of Transportation data are rated lower because they are somewhat speculative, but they may still be of high quality. In all cases, site-specific evaluation is required.

The following geologic map units are described and depicted on Plate 4 (Surficial Geology) and have the best potential for sand and gravel. They are:

1. **Ice-contact deposits** of map unit Qci on Plate 4 (Surficial Geology) and related landforms, including

eskers, esker-related collapsed glacial-stream sediment, and kames, as well as fans and bars on stream-eroded terraces (found within map unit Qhe on Plate 4)

2. **Glacial stream sediment**, which includes map units Qgs and Qco on Plate 4 (Surficial Geology) and Holocene stream sediment, which includes reworked glacial stream sediment (map unit Qa over map unit Qco). These units typically contain sorted sand and gravel with little silt and clay.

3. **Shallowly buried sand and gravel deposits** are more difficult to detect by simply using the surficial distribution of geologic units. They are indicated on the Surficial Geology map (Plate 4) by a collapsed surface expression, or they have been identified where they lie beneath thin lake sediment (map unit Qgl on Plate 4) and windblown sand. 4. Especially good, gravel-rich deposits may be the end-product of two geologic processes that sorted material by size and density. For example, one deposit was interpreted to have begun as an ice-contact stream deposit that formed as water flowed from a wasting glacier (map unit Qci on Plate 4–Surficial Geology); it was later reworked by water along the vigorous glacial stream course of the St. Croix River (map unit Qhe), and was then left as a terrace-high above the current water table—as the river continued to incise, resulting in the best quality aggregate found in the county.

The geological units are subdivided into one of these subclasses (defined further below) on the basis of the following factors:

1. Sand and gravel thickness;

2. Percentage of material retained on the number 4 sieve (4.76-millimeter mesh) and/or percentage of material retained on the number 10 sieve (2–millimeter mesh);

3. Thickness of the overlying deposit;

4. Depth to water table;

5. Percentage of shale retained on the number 4 sieve (4.76-millimeter pore space);

6. Total spall content; and

7. Hardness test (Los Angeles rattler) results.

All deposits in the county meet the shale (less than 0.7 percent by weight), total spall content (less than 1.5 percent by weight), and Los Angeles-rattler (less than 40 percent) standards. The resulting unit classification is therefore based on whether or not the first four criteria could be determined to be satisfied. In some cases a lower ranking resulted from an absence of data.

Text from source map: Pine County Geologic Map

Natural-Aggregate Mapped Classes of Resource Potential

Potential primary resources (corresponds to the "highly desirable" potential-resource category employed by the Minnesota Department of Natural Resources). These deposits are defined as having (1) a sand and gravel thickness greater than 20 feet; (2) generally less than 5 feet of cover; (3) on average greater than 20 percent of material retained on the number 4 sieve and/or 35 percent of material retained on the number 10 sieve, and (4) a water table at least 20 feet below the surface as interpreted from topographic maps. Probability that sand and gravel deposits exist within these units is high.

Potential secondary resources (corresponds to the "moderately desirable" potential resource category employed by the Minnesota Department of Natural Resources). These deposits do not meet one or two of the above criteria or there is no data available for one or two of the categories. Sand and gravel thickness (1) may be 10–20 feet; (2) cover may be more than 5 feet; (3) there may be less than 20 percent of material retained on the number 4 sieve or 35 percent on the number 10 sieve, or (4) water may be within 20 feet of the surface. The probability that sand and gravel deposits exist within these units is moderate to high, but the limiting factors (for example, limited thickness or shallow water table) may make them less valuable.

Speculative secondary resources (corresponds to the "less desirable" potential resource category employed by the Minnesota Department of Natural Resources). These deposits have three or more of the above-mentioned limitations or at least three fields of missing data. The probability of encountering sand and gravel may still be moderate, but owing to the lack of existing pits within these locations they are considered more speculative.

Text from source map: Pine County Geologic Map

Natural-Aggregate Acknowledgments

Randy Tilseth, Minnesota Department of Transportation, provided specifications for aggregate issued by the Department.

Text from source map: Pine County Geologic Map

Aggregate Specifications

A Selection of Minnesota Department of Transportation Specifications for Aggregate

AGGREGATE CLASSES

Class A—"crushed quarry or mine trap rock (basalt, diabase, gabbro or other related igneous rock types), quartzite, or granite." *These are rocks that are more uniform throughout a quarry and generally have fewer deleterious qualities.* ***Note: No class A aggregate has been identified in Pine County, although trap rock (basalt) and granitic rock (McGrath Gneiss) are present, and a deposit of Class A material could potentially be developed.***

Class B—"all other crushed quarry or mine rock: i.e., carbonates, rhyolite, schist." *These are rocks that are not as uniform within quarries and have some deleterious qualities. In the case of carbonate rock, it is void space in the rocks that absorbs moisture, which freezes and causes cracking of pavement.* ***Note: No class B aggregate has been identified in Pine County.***

Class C—*natural or partly crushed natural gravel;* ***class D****—100 percent crushed natural gravel;* ***class E****—mixtures of two or more classes of aggregate; and* ***class R****—recycled concrete.*

GRADED AGGREGATE USED IN ASPHALT MIXTURES

Quality tests include crushed rock, natural gravel, and mixtures.

Los Angeles rattler loss in the coarse fraction [material retained on the 4.75-millimeter (#4) sieve (gravel sized or coarser)] shall not exceed 40 percent for any individual source used in the mix.

Magnesium sulfate loss in the coarse fraction [material retained on the 4.75-millimeter (#4) sieve (gravel sized or coarser)] shall not exceed:

a. more than 14 percent on the 19-millimeter (3/4 inch) to 12.5-millimeter (1/2 inch) and larger fractions;
b. more than 18 percent on the 12.5-millimeter (1/2 inch) to 9.5-millimeter (3/8 inch) fraction;
c. more than 18 percent on the 9.5-millimeter (3/8 inch) to 4.75-millimeter (#4 sieve) fraction;
d. more than 18-percent composite loss (applies only if all three size fractions are tested).

Spall materials and lumps

Low volume mixtures—

Total spall in total sample 5.0%

Data From Minn. Dept. of Transportation and Milestone Materials, Onalaska, Wisconsin

Graphic from source map: Pine County Geologic Map

Table 1: Gravel Test Data

[-- (leaders), no data available; the columns are numbered for convenience.]

The test data summarized here were obtained on samples from Minnesota Department of Transportation pits. The entire data set is available; contact the Minnesota Department of Transportation for further information. The results of tests are grouped by the geologic interpretation of the units. The unit labels in **column 1** are the same as used on the Surficial Geology map (Plate 4), except that Qglf and Qgls are lumped into one unit, Qgl. In cases where the unit being mined was not at the surface, the units overlying and underlying the producing unit are indicated. **Note that the producing units are shown in boldface type.**

Column 2 shows the average percentage of shale retained on the number 4 screen (gravel). Shale is an undesirable component in aggregate because it is soft and swells when wetted. It can cause a "pop-out" to form in asphalt or concrete—that is, a hole or pit in the surface—as a result of the swelling. All pits tested easily met the Minnesota Department of Transportation shale standard. Shale is not likely to be a problem anywhere in Pine County.

Column 3 shows the average percentage of total spall material determined for the pits where tests were conducted. Spall material includes shale, chert, and iron oxide, and also causes pop-outs. All pits tested met the spall standards and it is unlikely that this will be a problem in the county.

The Los Angeles–rattler (LAR) test (**column 4**) is a measure of resistance of the aggregate to abrasion. Coarse aggregate is tumbled in a steel cylinder for a specified time. The percentage of fine material that is abraded from the aggregate in relation to the amount of coarse aggregate originally placed in the cylinder is the LAR loss percent. The more resistant the aggregate, the lower the LAR values. The LAR standard is 40 and all tests run in Pine County were well within this limit.

The average point score for all pits within a given geologic unit as determined for this assessment is shown in **column 5**. There were a total of 9 points possible for each site. Points were lost if (1) the aggregate at the site did not meet the cutoff value for the standard or (2) no data were available. Individual sites that rated 9 were considered highly desirable and selected areas within the geologic units containing these pits were considered to have primary resource potential. Individual sites that rated 8 or 7 were rated as moderately desirable and selected areas within the geologic units containing these pits were considered to have secondary resource potential. Individual sites that rated 6 or below were considered to have speculative resource potential. More data are required to determine if they fall into the primary or secondary categories, but the geologic units were formed by a process that sorts sand and gravel from finer material.

1	2	3	4	5	6	7	8
Surficial geologic units from Plate 4, showing stratigraphic order	**Shale** (mean percent)	**Spall materials** (total)	**LAR Test** (average)	**Rating** (average, all pits)	**Rating** (range, all pits)	**Pits that have data** (number)	**Comments**
Qgl *over* **Qgs** *over* **Qss**	--	--	--	7.00	7	1	Burial and reworking of Superior-lobe outwash
Qhe *over* **Qssi**	--	1.18	--	7.00	7	1	Stream intersected pre-existing Qssi unit (Plate 4) and deposited it in bar forms now on a terrace
Qhe	0.09	0.22	23.08	6.58	3– 9	19	Best in bar forms on terrace where sand and gravel are thickest. Perched water table in some areas
Qss collapsed	0.09	0.10	18.48	6.50	6–7	2	No comments
Qgm *over* **Qss** collapsed	0.08	0.13	26.50	6.33	5–8	3	Buried by variable thickness of Grantsburg till. Collapse pattern on surficial map on Plate 4 shows probable extent
Qssi	0.07	0.19	21.99	6.30	4–9	43	Easily recognized esker forms; variable texture; lower ratings due to lack of data
Qgs	0.26	0.26	19.45	6.00	4–7	3	Highest shale values in Pine County and sandy in places
Qgl *over* **Qss**	--	0.04	16.73	5.14	2–8	7	Sandy texture and/or depth of burial result in lower rating
Qhs *over* **Qss**	0.06	0.22	21.43	4.73	3–6	11	High water table and less than 20-foot aggregate thickness result in lower rating
Qss *over* **Qssi**	0.05	0.18	17.65	4.67	4–5	3	No sieve data results in lower rating
Qgl *over* **Qss** collapsed	0.07	0.26	19.73	4.60	3–5	5	Lake sediment may have sieved into gravel matrix making it "dirty"
Qss	--	--	22.65	4.00	2–6	5	Sandy
Qsgs	--	--	19.40	4.00	4	1	A single sample with little data results in low rating.
Qgm *over* **Qssi** collapsed	--	--	8.48	3.33	3–4	3	Buried by a variable thickness of Grantsburg till. Collapse pattern on Plate 4 shows probable extent
Qgl *over* **Qsgs**	--	--	--	2.00	2	1	A single sample with little data results in low rating
Qgl *over* **Qssi**	--	--	--	2.00	2	1	A single sample with little data results in low rating

Table from source map: Pine County Geologic Map

References

Mineral Endowment Reference

Resources and Reserves Committee, 1999, A guide for reporting exploration information, mineral resources, and mineral reserves: Littleton, Colo., report submitted to the Board of Directors, Society for Mining, Metallurgy and Exploration, 17 p.

References from source map: Pine County Geologic Map

Washington County Geologic Map

The formal citation for this source.

> Bauer, Emily J., Chandler, V.W., Steenberg, J.R., Retzler, A.J., Stanley, V.L., Meyer, G.N., and Lively, R.S., 2016, Geologic Atlas of Washington County, Minnesota: Minnesota Geological Survey, County Atlas Series C-39 Part A (Plates 3, 4, 6), scale 1:100,000 (Washington County Geologic Map). (*GRI Source Map ID 80002*).

Prominent graphics and text associated with this source:

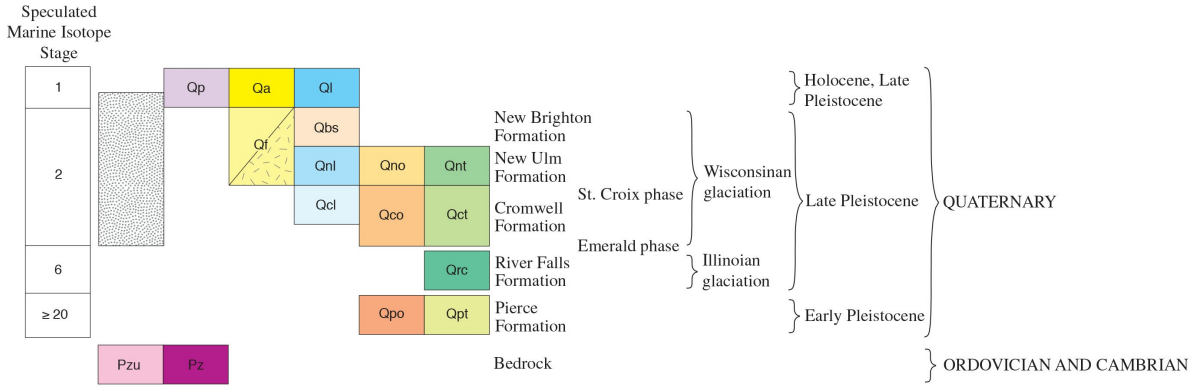
Location Map



Graphic from source map: Washington County Geologic Map.

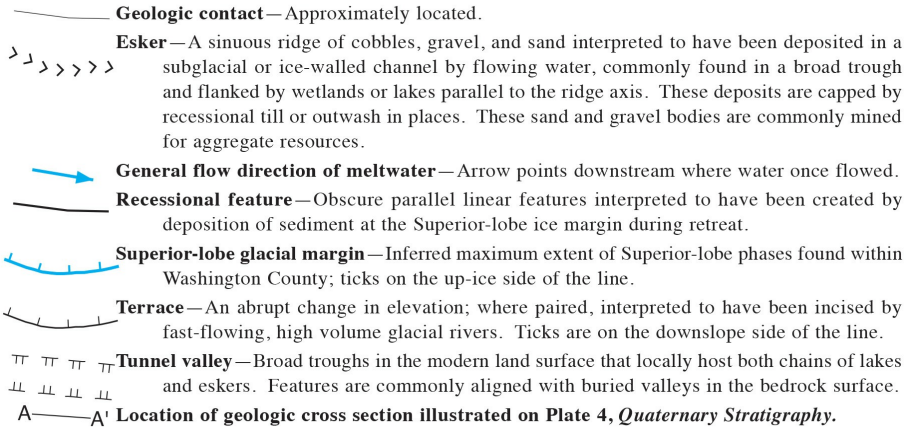
Plate 3: Surficial Geology

Correlation of Units



Graphic from source map: Washington County Geologic Map.

Symbol Legend



Geologic contact—Approximately located.

Esker—A sinuous ridge of cobbles, gravel, and sand interpreted to have been deposited in a subglacial or ice-walled channel by flowing water, commonly found in a broad trough and flanked by wetlands or lakes parallel to the ridge axis. These deposits are capped by recessional till or outwash in places. These sand and gravel bodies are commonly mined for aggregate resources.

General flow direction of meltwater—Arrow points downstream where water once flowed.

Recessional feature—Obscure parallel linear features interpreted to have been created by deposition of sediment at the Superior-lobe ice margin during retreat.

Superior-lobe glacial margin—Inferred maximum extent of Superior-lobe phases found within Washington County; ticks on the up-ice side of the line.

Terrace—An abrupt change in elevation; where paired, interpreted to have been incised by fast-flowing, high volume glacial rivers. Ticks are on the downslope side of the line.

Tunnel valley—Broad troughs in the modern land surface that locally host both chains of lakes and eskers. Features are commonly aligned with buried valleys in the bedrock surface.

Location of geologic cross section illustrated on Plate 4, *Quaternary Stratigraphy.*

Graphic from source map: Washington County Geologic Map.

Table1: Physical characteristics of glacial deposits

PROVENANCE	RIDING MOUNTAIN	WINNIPEG	SUPERIOR
TILL TEXTURE	Loam to sandy loam	Loam to clay loam	Sandy loam to loamy sand
TILL COLOR			
Oxidized	Grayish-brown	Yellowish-brown	Brown
Unoxidized	Gray to dark gray	Gray to dark gray	Reddish-brown
GRAVEL TYPE			
Carbonate	Common	Common to abundant	Rare to uncommon
Gray-green rock	Uncommon to common	Uncommon to common	Common to abundant
Red felsite	Rare to uncommon	Absent to uncommon	Uncommon to common
Gray shale	Uncommon to common	Absent to rare	Absent

Table from source map: Washington County Geologic Map.

Figure 1: Physical Relief of Land Surface

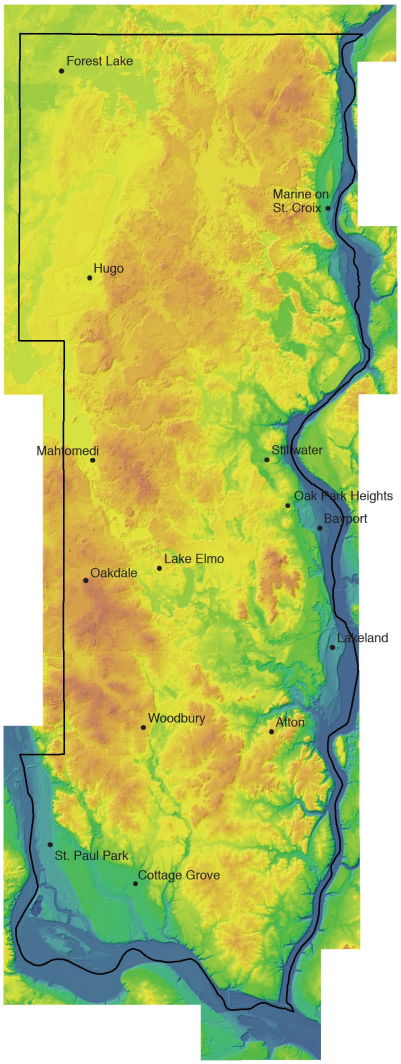


Figure 1. Physical relief of the land surface in Washington County (vertically exaggerated 3x). Elevation is shown by color: red (higher elevation) grading to blue (lower elevation). Elevation ranges from 634 to 1,101 feet (193 to 336 meters) above sea level. A false sun illumination at an elevation of 45° from the northwest (315°) provides contrast to accent landform details at one-meter resolution. Scale 1:300,000.

Graphic from source map: Washington County Geologic Map.

Figure 2: Minnesota Major Glacial Deposit Provences

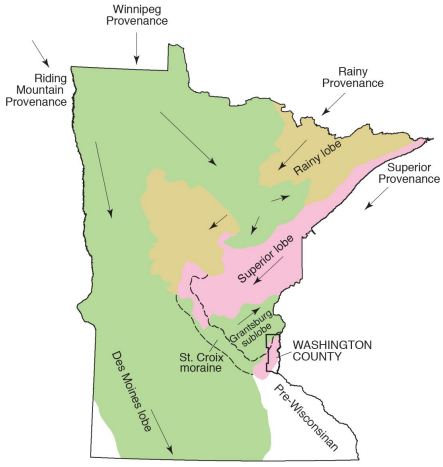


Figure 2. Map of Minnesota showing Washington County in relation to the major provenances, or source regions, of glacial deposits. Associated ice lobes that deposited the materials at the land surface are shown in different colors. Arrows indicate ice flow direction. Dashed lines represent the inferred extent of the St. Croix moraine, including where it was later overridden by the Des Moines lobe. The white area in southeastern Washington County (Denmark Township) was not covered by ice during these more recent glaciations.

Graphic from source map: Washington County Geologic Map.

Figure 3: St. Croix Moraine Ice-Wedge Polygons

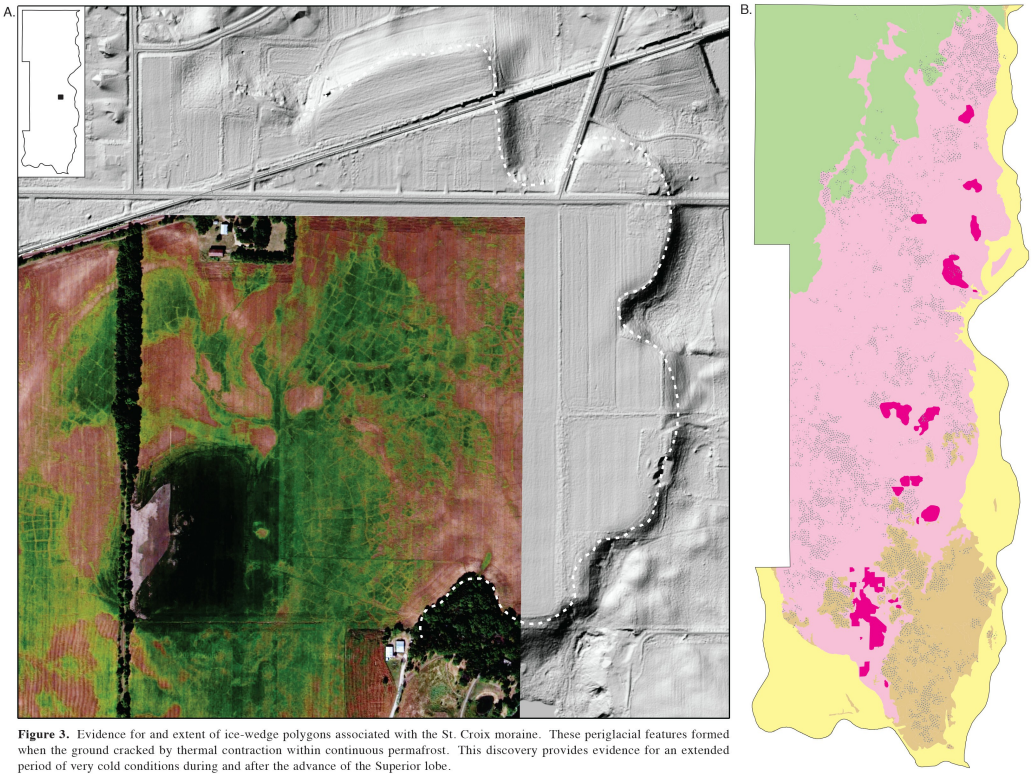


Figure 3. Evidence for and extent of ice-wedge polygons associated with the St. Croix moraine. These periglacial features formed when the ground cracked by thermal contraction within continuous permafrost. This discovery provides evidence for an extended period of very cold conditions during and after the advance of the Superior lobe.

A. Ice-wedge polygons identified on top of an ice-walled lake plain at the Lake Elmo Airport. Figure was created using Google Earth aerial imagery draped over one-meter lidar to show the relationship of the permafrost features to the ice-walled lake plain. The aerial image shows farm fields in September, 2013. Although ice-wedge polygon features are likely present across most of the field of view, they are more easily distinguished at the boundaries of green (wet) and brown (dry) areas. The steep slope (highlighted with white dotted line) in the eastern half of the image is the edge of the ice-walled lake plain. Inset shows the location of this image within Washington County.

B. Map of periglacial features in Washington County; the extent of ice-wedge polygons identified using aerial imagery are mapped in magenta. Grantsburg sublobe associated materials are green, Superior lobe—St. Croix phase associated materials are pink, bedrock near the surface and materials from earlier glacial advances are brown, glaciofluvial material is yellow, and loess is the stippled pattern. Ice-wedge polygons occur commonly in units Qco and Qcl.

Graphic from source map: Washington County Geologic Map.

Figure 4: Former Glacial Lakes and Rivers in Minnesota

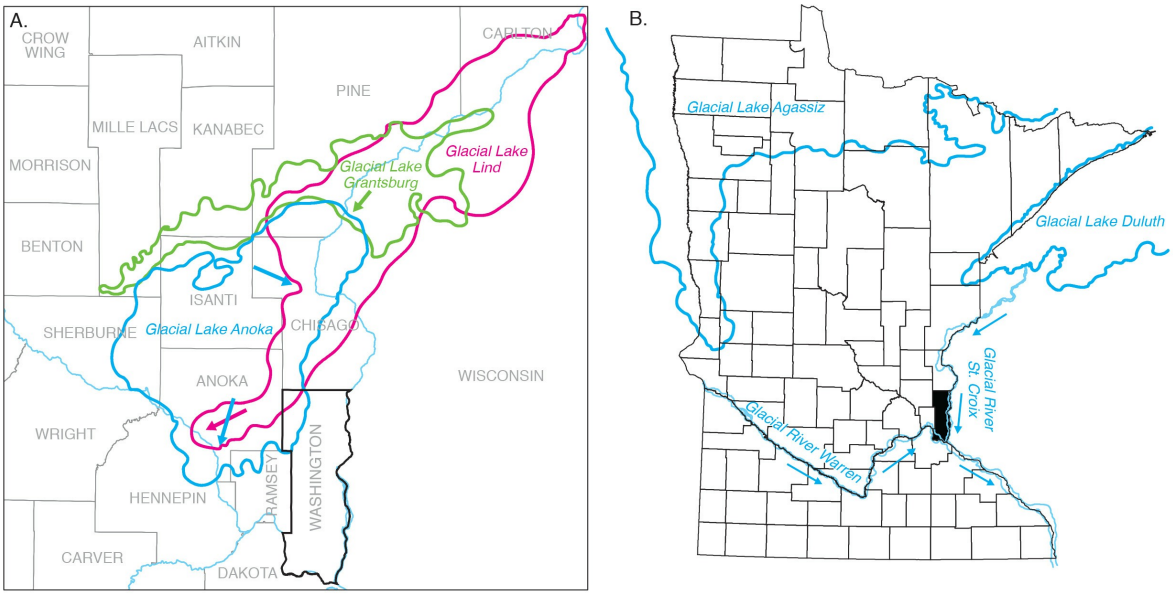


Figure 4. Maps showing approximate locations of former glacial lakes and rivers in Minnesota.

A. Three different glacial lakes (thick lines) shown on this map occupied an area in east-central Minnesota, each at a different time during the Quaternary Period. Potential outlets for lake drainage are shown by arrows. Major modern river flowlines are shown as thin blue lines. Washington County is shown in black outline.

B. Map showing other major glacial lakes and rivers. Arrows point downstream to show flow direction of glacial rivers. Note that these features are not all contemporaneous.

Graphic from source map: Washington County Geologic Map.

Figure 5: LiDAR Map of Southern Washington County

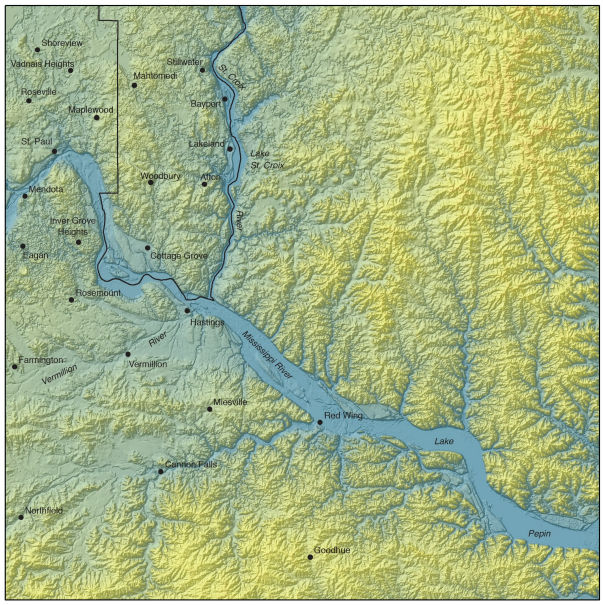


Figure 5. Lidar map of southern Washington County showing modern rivers and riverine lakes associated with postglacial terrace deposits. Riverine lakes are formed when alluvial fans of tributary rivers grow so large that they dam main channels. Color shows the elevation of the modern land surface at 10-meter resolution. The outline of southern Washington County is shown. Scale 1:500,000.

Graphic from source map: Washington County Geologic Map.

Report

Introduction

This map is a revision of the previous surficial map of Washington County (Meyer and others, 1990). The updated data include: new well logs from the Minnesota Geological Survey County Wells Index, new soil boring data from the Minnesota Department of Transportation and the Washington County Highway Department, digitized soils maps and datasets (National Resources Conservation Service, 2012), new aerial photographic imagery, LacCore repository information from lake coring expeditions, digitized lake bathymetry information, other academic studies conducted in the county cited herein, and county-wide one-meter-resolution lidar coverage (Fig. 1). Additional data from previous mapping (Index to Previous Mapping) were included in the analysis and interpretation of map units.

This map of surficial geology shows the materials present at the land surface in Washington County. Fieldwork included soil borings drilled from 4.0 (1.2 meters) to 20.0 feet (6.1 meters) in depth, and rotary-sonic core drilling to verify three- dimensional geologic interpretations. Exposures at gravel pits, construction sites, and roadsides were observed, sampled, and interpreted. Minnesota Geological Survey staff provided lithologic description of all samples and cores. Samples were analyzed for grain-size distribution, lithology of the very coarse-grained (1-2 millimeter) sand fraction, natural remanent magnetization, and Munsell color, and one was dated using radiocarbon methods. All analytical results were digitized and compiled geospatially for mapping. All radiocarbon dates are reported in calendar years before present (cal yr BP). Dates, both new and previously reported, were calibrated using the program CALIB 7.0.2 (Stuiver and Reimer, 1993) and calibration datasets of Reimer and others (2013), and include 2-sigma error. Marine Isotope Stages (MIS) are correlated wherever possible with depositional events, which can be tied to some surficial and subsurface lithostratigraphic units. Studies of oxygen isotopes from deep sea sediment cores show periods of global cooling and warming called Marine Isotope Stages that can be traced to 5.3 million years ago (Lisiecki and Raymo, 2005). Odd numbers indicate warming periods, or interglacial episodes. Even numbers indicate cool periods, or glacial episodes. Larger numbers indicate older glacial or interglacial episodes. Marine Isotope Stages are defined by climate trends through time rather than a specific number of years. By using Marine Isotope Stages, depositional events can be tied to past fluctuations in climate, and used as a proxy for advances and retreats of the Laurentide Ice Sheet. Materials redistributed by human modification of the land surface are not mapped in this publication.

Text from source map: Washington County Geologic Map.

Summary of Quaternary Geology

Glaciers, rivers, and wind shaped the Minnesota landscape throughout the Quaternary Period during both the Pleistocene (2,600,000 to 11,700 years ago) and Holocene (11,700 years ago to present) Epochs. The surficial geologic materials and associated landforms found in Washington County record numerous depositional events that occurred throughout this time, and as a result, are key to our understanding of Minnesota geologic history. These events can be mapped based on landforms, and verified by analysis of associated unlithified sediments overlying the bedrock, and exposed bedrock.

Glaciers transformed the landscape of Minnesota during the Pleistocene Epoch. The oldest dated glacial advance in Washington County deposited sediments of the Pierce Formation earlier than 781,000 years ago (unit Qpt; Baker and others, 1983; Meyer and others, 1990; Syverson and others, 2011) in the Early Pleistocene Epoch. The county is unusual in that older glacial deposits can be found at or near the surface (units Qpt, Qrc), particularly in the southeast (Fig. 2), where deeply incised valleys dominate the topography. In places, bedrock is at the land surface (unit OCo; also shown to be near the surface by

unit OCu and the pattern in unit Qf), and in Denmark Township is on average within about 25 feet (7.5 meters) of the land surface. This valley-dominated terrain in Denmark Township was not covered by ice during more recent glaciations. As a result, the bedrock and Early Pleistocene and Illinoian glaciation glacial deposits of the River Falls Formation have been eroded by fluvial processes and mass wasting of hillslopes. The cold climate of subsequent glaciations accelerated hillslope erosion and caused creep by freezing and thawing of permafrost, or solifluction (Clayton and others, 2001). Bluffs along the Mississippi and St. Croix Rivers commonly expose bedrock. Both bedrock and glacially deposited sediments are locally covered with windblown loess (pattern) deposited during and after more recent glaciations.

Elsewhere in Washington County, the landscape records fluctuations in the margins of the Laurentide Ice Sheet since the Last Glacial Maximum, known as the Wisconsinan glaciation in North America. The earliest Wisconsinan glaciation event is marked by the Emerald-phase advance of the Superior lobe 30,597 ± 763 cal yr BP (Meyer and Stefanova, 2009). Emerald-phase deposits lack distinctive landforms, are more deeply weathered, and are more likely to be buried by a few feet (one meter) of loess than the younger glacial deposits to the north. During this phase, sediments were incorporated from local bedrock into the ice as the glacier advanced southward from the ice accumulation center in what is now Labrador, Canada. The glacier passed over Precambrian crystalline bedrock, Cambrian sandstone, and basalt in northeastern Minnesota, and Paleozoic sedimentary rock in east-central Minnesota (Fig. 2; Table 1). These lithologies are a key component of the Cromwell Formation (unit Qct). During the subsequent warming period, about 24,000 to 30,000 cal yr BP, the Superior lobe retreated at least to what is now central Chisago County (Meyer, 2010). The ice readvanced during the St. Croix phase, forming the St. Croix moraine (Fig. 2) at its maximum extent during the Last Glacial Maximum (approximately 20,000 cal yr BP), or when the ice sheets were at their largest during the last glacial period as a result of global cooling, before retreating about 18,250 cal yr BP (Johnson and others, in press). The St. Croix-phase ice advance did not reach the maximum extent of the Emerald-phase advance. Large, well-developed, subglacial fluvial channels, or tunnel valleys, formed at the glacial margin. The meltwater that flowed out from these channels deposited large proglacial fans of sorted sediment (unit Qco). Southeast of Battle Creek Lake in Woodbury, a curvilinear depression interpreted to be a tunnel valley opens into a broad plain of gravel and sand.

The Superior lobe stagnated across Washington County for an unknown duration of time at the St. Croix moraine when the ice ceased to advance. Evidence for stagnation includes ice-walled lake plains, such as the broad plateau where the Lake Elmo Airport is located. Features on the land surface called ice-wedge polygons (Fig. 3) indicate an annual mean air temperature below the freezing point of water (32°F [0°C]), strong winds, and low precipitation that continued long enough to develop widespread permafrost at the St. Croix moraine (Fig. 3B; Johnson, 1990). Although these features have been reported in Wisconsin (Clayton and others, 2001), this is the first time they have been observed in Minnesota. Previously, climate conditions were inferred based on tundra pollen assemblages and the scarcity of wood debris (Johnson, 1990; Clayton and others, 2001; French and Millar, 2014).

The size of the St. Croix moraine influenced ice flow of the subsequent glacial advance of the Des Moines lobe (Fig. 2). This lobe advanced from the northwest across limestone, shale, and crystalline bedrock to its maximum extent in Des Moines, Iowa (Fig. 2; Table 1; Johnson and others, in press). This source region, or provenance, is expressed in the lithology of the sediments that were deposited directly by Des Moines-lobe ice (unit Qnt). The Grantsburg sublobe, a northeast-flowing branch of the Des Moines lobe, overrode the St. Croix moraine and flowed across the northwest corner of Washington County to its maximum extent near Grantsburg, Wisconsin. The Grantsburg sublobe likely had one advance between 19,000 and 14,450 cal yr BP (Johnson and others, in press), incorporating the sediments of the older Superior lobe into its bed as evidenced by sediments of a mixed provenance (unit Qnt), and then actively retreated (Johnson and Hemstad, 1998). As the Grantsburg sublobe retreated, meltwater filled glacial Lake Anoka (Fig. 4A; Meyer, 1998) until at least 13,863 ± 118 cal yr BP (dated from a wood fragment collected at a depth of 27 feet [8.2 meters] from rotary-sonic core WS-6 in brown,

fine-grained sand [unit Qbs]).

The broad terraces and benches that occur along the modern Mississippi and St. Croix River valleys are evidence for the complex evolution of those channels. Glacial River St. Croix may have drained glacial Lake Lind about 16,990 cal yr BP near Minneapolis (Fig. 4A; Johnson and others, 1999). The Mississippi River valley along the southern boundary of Washington County previously was occupied by glacial River Warren. This ancestral river drained glacial Lake Agassiz (Fig. 4B) across the state from west to east in a wide valley that is now occupied by the modern Minnesota River. Outbursts from glacial lakes upstream modified the base levels of glacial Rivers Warren and St. Croix (Fig. 4B) by increased flows leading to incision.

The St. Croix River valley was formed episodically by incision and deposition. When the Grantsburg sublobe advanced to its maximum extent, it crossed over the St. Croix River valley from west to east, damming water flowing from the north, resulting in the formation of glacial Lake Grantsburg (Fig. 4A; Johnson and Hemstad, 1998). Once the Grantsburg sublobe retreated, glacial Lake Grantsburg may have drained via glacial River St. Croix about 14,000 cal yr BP, forming the present day valley (Clayton and Moran, 1982; Johnson and others, 1999). The subsequently formed glacial Lake Anoka's outlet was also to the north via glacial River St. Croix. Later the lake drained through an outlet near north Minneapolis to the Mississippi River (Meyer, 1998), forming the broad upper terraces. The St. Croix River valley also records terrace formation as a result of later multiple flood events from glacial Lake Duluth (Farrand and Drexler, 1985; Carney, 1996; Larson and Schaetzl, 2001). Glacial Lake Duluth occupied what is now the southwestern end of Lake Superior (Fig. 4B). Glacial Lake Duluth receded by about 11,000 cal yr BP and likely shaped the modern St. Croix River valley (Landmesser and others, 1982; Drexler and others, 1983).

After the drainage of glacial Lake Duluth, Lake St. Croix initially formed about 10,800 cal yr BP when an alluvial fan of the Vermillion River (Fig. 5) dammed the Mississippi River near what is now Hastings, Minnesota (Blumentritt and others, 2009). This created a lake extending north along the St. Croix River valley at least to Bayport, Minnesota and west along the Mississippi River valley to St. Paul. The St. Croix River then occupied its modern course, depositing alluvium (unit Qa) north of Stillwater, and modern lake sediment in Lake St. Croix to the south (unit Ql).

Windblown sediment known as loess (pattern) accumulated during a period of sustained aridity and cold during and after the Wisconsinan glaciation, and is commonly the surficial Quaternary unit exposed in southeastern Minnesota. Deposition of this loess (the Peoria Formation) began about 29,000 cal yr BP (Leigh and Knox, 1994), and continued until 10,600 cal yr BP (Rawling and others, 2008). In Washington County, loess is thickest on high topography near the St. Croix and Mississippi Rivers, particularly in Denmark Township in the southeast corner of the county. The unit is a massive, yellowish-brown silt, 1.5 to 6.0 feet (0.5 to 1.8 meters) thick at the land surface. Loess is commonly redeposited on slopes as the silty component of colluvium (Mason and others, 1999).

More than 200 bodies of water are present in Washington County. The large lakes in the county formed when the Superior lobe pressed blocks of ice into the sediments beneath the glacier, commonly in tunnel valleys. The detached ice was buried, subsequently insulated by sediments, and eventually melted to form depressions in the land surface (Zumberge, 1952). Smaller lakes and wetlands are inferred to represent thawed permafrost, creating irregular topography at or below the water table. This postglacial land surface was forested before the buried ice melted, as evidenced by terrestrial plant debris found at the base of lake sediment, just above coarse-grained glacial sediments (Florin and Wright, 1969). A radiocarbon date obtained from plant debris collected at the base of lake sediment from Lily Lake in Stillwater (13,588 ± 228 cal yr BP; Eyster-Smith and others, 1991) indicated that ice from the St. Croix phase of the Superior lobe could have remained buried in the frozen ground for more than 4,000 years. Pollen collected from this stratigraphic horizon confirmed a spruce forest grew on top of the postglacial land surface (Eyster-Smith and others, 1991).

Organic material (peat) accumulated in land surface depressions (unit Qp) as global temperatures rose after the end of the last glacial period. In most cases, peat is underlain by lake sediment and represents basins that were filled with sapropel after the glaciers retreated. A basal radiocarbon date from Kirchner marsh in Dakota County to the south indicated sedimentation began 15,904 ± 598 cal yr BP (Wright and others, 1963). Another radiocarbon date from the base of a peat bog located on a St. Croix River terrace indicated sedimentation began about 11,400 cal yr BP (Hudak and Hajic, 2005).

Text from source map: Washington County Geologic Map.

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References from source map: Washington County Geologic Map.

Plate 4: Quaternary Stratigraphy

Introduction

The Quaternary Stratigraphy plate shows the unconsolidated sediment expected to be encountered between the land surface and bedrock in Washington County. Cross sections A-A' through F-F' are representative of 64 cross sections (Fig. 1) that were constructed to create a three-dimensional model of the Quaternary deposits of Washington County. The major sand bodies from this model are depicted on Plate 5, Sand Distribution Model; the full model and all the cross sections used to develop it can be accessed through the digital files of the Minnesota Geological Survey. The geologic units shown on the cross sections were defined using data from previous studies completed in the area (see Plate 3) and through the interpretation of new data collected for this study. Some units match those on Plate 3, Surficial Geology, some new units appear only on the cross sections, and others are the result of dividing a unit from Plate 3. Outcrops, auger samples, drill core, drill cuttings, and water-well and soil boring drillers' logs (Plate 1, Data-Base Map) were used to interpret the stratigraphy. Samples and descriptions from 17 rotary-sonic core sites (Fig. 1), and drill cuttings from the Quaternary section of about 200 wells were examined for this study. The vertical dimension in the cross sections is exaggerated to 50 times the horizontal dimension in order to show the commonly thin, complex units of the Quaternary section.

Figure 2 is a schematic illustration showing the relationships between age, provenance, stratigraphic position, and location of the tills deposited by major glacial episodes (see Plate 3, Fig. 2 and Table 1). The texture and composition of till units are summarized in Table 1. Logs of selected rotary-sonic cores drilled in the county, with discussion of remanent magnetic polarity data, are shown in Figures 3 through 7.

Text from source map: Washington County Geologic Map.

Description of Cross Section Units

Each unit description on the cross sections is placed in one of three categories, as indicated in parentheses after the description: 1. Surficial Geology unit-unit that has an identical description, label, and color as on Plate 3, Surficial Geology. See Plate 3 for detailed descriptions; 2. New unit-unit that is depicted only in the subsurface that has a unique label and color (the new sand and gravel units have the same color to emphasize their status as potential aquifers); 3. Modified unit—a unit from Plate 3 that is divided into two or three units in subsurface depictions (Fig. 8).

Deposits of the three phases of the Superior lobe that compose the Cromwell Formation (see the Summary of Quaternary Geology on Plate 3) are divided into finer- and coarser-grained sediment, with

the till and fine-grained lake sediment combined as aquitards, and the fluvial and coarser-grained lake sediment combined as potential aquifers. Sand bodies were assumed to divide the deposits of the different phases of the Superior lobe. Except for the finer-grained texture of some Automba-phase deposits in Washington County (Fig. 4, unit Qlc), the characteristics of the various tills of the Cromwell Formation are generally similar to one another (Table 1). They were distinguished in the subsurface primarily on the basis of intervening beds of sand and gravel.

In general, older Superior-provenance tills (units Qr1, Qr2, Qr3, and Qvt) have less dark and red clasts and more quartz and carbonate in the 1 to 2 millimeter grain size than till of the Cromwell Formation. Without the intervening yellow to gray, fine-textured till of unit Qxt or Qpt, however, it is difficult using primarily water-well records to distinguish the Cromwell Formation from older deposits of Superior provenance. It is likely that deposits from three (or more) pre-Emerald phase advances of the Superior lobe are included in unit Qce.

Buried leached and oxidized tills separated by sand and gravel beds (Figs. 3, 6, 7) give evidence that sediment from multiple, pre-Wisconsinan Episode ice advances of Superior provenance are present in Washington County. However, water well records commonly lack sufficient detail to allow individual tills of the various advances to be confidently traced across the county. Carbonate content increases southwards in all Superior-provenance units including the Cromwell Formation, presumably due to incorporation of local carbonate bedrock. The high carbonate content of till units Qr1 and Qr2 (Table 1) are also likely due to extensive incorporation of the carbonate-rich upper portion of the underlying unit Qxt. Older Superior-provenance till units are preferentially preserved in bedrock valleys in southern Washington County, where many are finer-textured than typical Superior-provenance till. The finer-grained texture of these tills is interpreted to be due to glacial incorporation of lacustrine sediment that once filled these valleys during previous episodes of hydrologic damming of tributaries of the Mississippi River, similar to the current damming of the St. Croix River that forms Lake St. Croix.

Loess of the Peoria Formation (mapped as an overlay on Plate 3) is too thin to show on the cross sections. Creation of the bedrock surface shown on the cross sections through interpolation from the Bedrock Topography map (Plate 5) gives an exaggerated thickness to the Quaternary section in some places mapped as bedrock at or near the surface on the Surficial Geology map (unit Pzu on Plate 3). Underlying bedrock units are indicated by unit boundaries and labels corresponding to those described on Plate 2, Bedrock Geology. Faults in the bedrock are also indicated.

Text from source map: Washington County Geologic Map.

Cross Section Units

QUATERNARY

Holocene to Late Pleistocene

Qp **Peat** (*Surficial Geology* unit)—Too small or thin to show in places on the cross sections.

Qac **Clay and silt** (modified unit)—The fine-grained portion of *Surficial Geology* unit Qa.

Qas **Gravelly sand** (modified unit)—The coarse-grained portion of *Surficial Geology* unit Qa. Too small or thin to show in places on the cross sections.

Qll **Silt and clay** (modified unit)—The fine-grained portion of *Surficial Geology* unit Ql.

Qls **Sand** (modified unit)—The coarse-grained portion of *Surficial Geology* unit Ql. Too small or thin to show in places on the cross sections.

Qf **Gravelly sand** (*Surficial Geology* unit)—Too narrow to show in places on steep valley walls on the cross sections.

Late Pleistocene

New Brighton Formation

Qbs ***Fine-grained sand*** (*Surficial Geology* unit).

New Ulm Formation—Twin Cities Member

Qnl ***Fine-grained sand, silt, and clay*** (*Surficial Geology* unit).

Qno ***Sand and gravelly sand*** (*Surficial Geology* unit).

Qnt ***Diamicton*** (*Surficial Geology* unit).

New Ulm and Cromwell Formations

Qsl ***Sand and gravel*** (new unit)—At lower elevations consists of reddish, fine- to medium-grained sand of the Cromwell Formation, overlain in places by sand and gravel of the New Ulm Formation, but at higher elevations includes gravel of both the Cromwell and New Ulm Formations.

Cromwell Formation

Qcl ***Fine-grained sand, silt, and clay*** (*Surficial Geology* unit).

Qco ***Sand to gravel*** (*Surficial Geology* unit).

Qlc ***Clay and silt and/or clayey diamicton, to sandy diamicton*** (modified unit)—In the northwest corner of the county, unit consists of reddish, laminated clay and silt (glacial Lake Lind sediment; Sunrise Member of the Cromwell Formation; Johnson and others, in press), overlain or interbedded with fine-textured till; at higher elevations to the east and southeast unit consists of reddish, loamy to sandy-textured till deposited during the Automba phase of the Superior lobe (Fig. 2; Table 1), included in map unit Qct on Plate 3 (Coon Creek till of Meyer, 1998). In places includes reddish clayey sediment reworked by the Grantsburg sublobe, and possibly some fine-textured lake sediment deposited in front of the advancing sublobe.

Qsc ***Sand and gravel*** (new unit).

Qcr ***Sandy diamicton*** (modified unit)—Reddish, sandy loam-textured till (Table 1) primarily deposited during the St. Croix phase of the Superior lobe (Fig. 2). Included in map unit Qct on Plate 3. Sand and gravel lenses are common. May be finer-textured towards the base in places, particularly where filling deep valleys. Includes thick deposits of silty lacustrine sediment in places.

Qse ***Sand and gravel*** (new unit).

Qce ***Sandy diamicton*** (modified unit)—Reddish, sandy loam-textured till (Table 1) primarily deposited during the Emerald phase of the Superior lobe (Fig. 2), but in places likely includes till of the St. Croix phase in the upper portions, and older Superior-provenance till in the lower portions. Included in map unit Qct on Plate 3. Sand and gravel lenses are common. May be finer-textured towards the base in places, particularly where filling deep valleys. Includes thick deposits of silty lacustrine sediment in places. Too narrow to show in places on steep valley walls on the cross sections.

Qs1 ***Sand and gravel*** (new unit)—Includes older sediment of Superior provenance.

Pleistocene

Qr1 **Sandy diamicton** (modified unit)—Reddish-brown to brown to gray, generally sandy loam-textured till of Superior provenance (Table 1); finer-textured in places, particularly where filling deep valleys. Includes thick deposits of silty lacustrine sediment in places. Correlated, at least in part, with the River Falls Formation (Baker and others, 1983; Mickelson and others, 1984; Attig and others, 1988; Johnson, 2000), which has an uncertain relationship to unit *Qxt* (Fig. 2). Equivalent to the Henderson Formation of south-central Minnesota (Johnson and others, in press), but includes younger and older sediment of Superior provenance in places. May include sediment deposited during the Athens Subepisode of the Wisconsinan Episode (Johnson and others, 1997; Meyer, 2010). Included in unit Qrc on Plate 3. All unleached samples in Table 1 are from core WS-7 (Fig. 3).

Qs2 **Sand and gravel** (modified unit)—Primarily sediment of Superior provenance. Included in unit Qrc on Plate 3.

Qr2 **Sandy to loamy diamicton** (new unit)—Reddish-brown to brown to gray, generally sandy loam-textured till of Superior provenance, but finer-textured in places, particularly where filling deep valleys. Most samples for this unit, summarized in Table 1, are from thick till filling a deep valley in northeast Cottage Grove (Fig. 7; cross section F–F'), and may not be representative of the unit elsewhere. The unit includes thick deposits of silty lacustrine sediment in places. Correlated, at least in part, with the upper member of the St. Francis Formation of central Minnesota (Johnson and others, in press). May also correlate with the River Falls Formation, which has an uncertain relationship to unit *Qxt* (Fig. 2).

Qsx **Sand and gravel** (new unit)—Sediment of both Winnipeg and Superior provenance.

Qxt **Loamy diamicton** (new unit)—Yellow-brown to gray, loam-textured till of Winnipeg provenance (see Plate 3, Fig. 2). The upper part of the till is generally rich in carbonate, but the lower portion commonly is lower in carbonate content, higher in red Precambrian clasts, and more silty-textured. This difference is interpreted to be due to extensive glacial incorporation of local interglacial and Superior provenance glacial sediment. Most samples for this unit, summarized in Table 1, are interpreted to be from the lower, carbonate-poor mixed zone. The unit includes deposits of silty to clayey lacustrine sediment, particularly in the thicker sections. Correlated with the Meyer Lake Member of the Lake Henry Formation (Fig. 2) of central Minnesota (Johnson and others, in press), and the second till of the Good Thunder formation of south-central Minnesota (Lusardi and others, 2012). In places likely includes the younger Sauk Centre Member of the Lake Henry Formation, and older sediment of Winnipeg provenance.

Qs3 **Sand and gravel** (new unit)—Sediment of both Winnipeg and Superior provenance.

Qr3 **Sandy diamicton** (new unit)—Reddish-brown to brown to gray, generally sandy loam-textured till of Superior provenance (Table 1); finer-textured in places, particularly where filling deep valleys. Includes thick deposits of silty lacustrine sediment in places. Correlated, at least in part, with the lower member of the St. Francis Formation of central Minnesota (Johnson and others, in press). May also correlate with the River Falls Formation, which has an uncertain relationship to unit *Qxt* (Fig. 2). Likely includes Superior-provenance sediment that predates the St. Francis Formation.

Qsp **Sand and gravel** (modified unit)—Sediment of Superior provenance, and also of Winnipeg provenance in places. Included in unit Qpo on Plate 3.

Qpt **Loamy to clayey diamicton** (*Surficial Geology* unit)—Till of the Pierce Formation as described on Plate 3, but ranges to clay loam-textured in the subsurface. Till of Winnipeg provenance, but commonly with a lower percentage of Paleozoic carbonate clasts than unit *Qxt* (Table 1). The units, however, are difficult to distinguish in well log records, so unit Qpt as mapped in the subsurface likely includes till of the Lake Henry Formation and possibly other Winnipeg-provenance tills. A rotary-sonic core drilled in Grant (Fig. 5) contains two tills within the Pierce Formation, likely correlative to the Hersey and Woodville Members (Mickelson and others, 1984; Attig and others, 1988). Unit Qpt likely includes deposits of silty to clayey lacustrine sediment, particularly in the thicker sections. Where at the surface and thin over bedrock, the unit may consist entirely of silt (loess).

Qsv **Sand and gravel** (modified unit)—Sediment of Superior, Winnipeg (included in unit Qpo on Plate 3), and possibly Rainy provenance in places.

Qvt **Sandy diamicton** (new unit)—Reddish-brown to brown to gray, generally sandy loam-textured till (colluvium in places) of Superior provenance (Table 1); finer-textured in places, particularly where filling deep valleys. Correlates with till VS of central Minnesota (Meyer and Knaeble, 1996), but where not overlain by unit Qpt, likely includes sediment of the St. Francis Formation or older, unnamed units of Superior provenance. Likely includes sediment of Rainy provenance because a rotary-sonic core (RR-3, unique number 247095) drilled to the west in Ramsey County (Fig. 1; Meyer, 1992) contains Rainy-provenance till (Table 1) below till interpreted to be equivalent to that of the Pierce Formation, despite the latter exhibiting normal polarity for the two samples analyzed. The earth's polarity evidently switched during deposition of the uppermost Pierce Formation (Kinnickinnic Member) in western Wisconsin (Baker and others, 1983), so till deposited later during the same glaciation in Minnesota could have normal polarity.

Qsu **Sand and gravel** (new unit)—Sediment of Superior provenance, and possibly Rainy and Winnipeg provenance in places.

Undifferentiated Quaternary deposits

Qu **Undifferentiated sediment** (new unit)—Includes diamicton and bedded clay, silt, sand, and gravel. Shown in areas where control data were absent.

Graphic from source map: Washington County Geologic Map.

Cross Section Legend

Geologic contact—Approximately located. No-line boundaries occur where data were insufficient to reliably extend units.

Drill hole—Well records from the County Well Index within 0.3 mile (0.5 kilometer) of the cross section line. Rotary-sonic core holes are labeled by hole number and unique number (in parentheses). The top of the drill hole may not coincide with the cross section surface elevation line because the point is located near but not on the cross section line and therefore may have a different surface elevation. In areas of less data, subsurface records (not shown) from greater than 0.3 mile (0.5 kilometer) were used to depict the units. Data from cuttings samples, soil boring logs, and outcrops were also used in constructing the cross sections—see Plate 1, *Data-Base Map*.

Bedrock contact and fault—Dots at the base of the Quaternary section denote bedrock contacts. Vertical lines depict bedrock faults. Bedrock labels are included where space permits. See Plate 2, *Bedrock Geology*, for details of the bedrock geology.

Graphic from source map: Washington County Geologic Map.

Table 1: Matrix Texture and Composition of Tills

Table 1. Average values for the matrix texture and composition of tills recognized in Washington County. Matrix texture (the less than 2 millimeter grain size fraction of the sample) is expressed as relative proportions of sand, silt, and clay in percent. The lithologic composition of the very coarse-grained sand fraction (1-2 millimeters) is expressed in percent as relative proportions of Precambrian rocks, Paleozoic rocks (mostly carbonate), and Cretaceous rocks (mostly shale and limestone) using the classification system of Hobbs (1998). The Precambrian 1-2 millimeter fraction is further differentiated by rock type—light (granite and gneiss), monomineralic quartz, dark (mafic-rich igneous and metamorphic rocks), red (rhyolite, iron formation), and sandstone; T = trace amount.

	MATRIX TEXTURE					CLAST TYPE									
			Percentage of the less than 2 millimeter fraction				Percentage of total grains counted of the 1-2 millimeter fraction				Percentage of total Precambrian grains counted				
Geologic units shown on cross sections	Total number of samples	Gravel (percentage of total sample weight)	Sand	Silt	Clay		Total number of samples	Precambrian	Paleozoic	Cretaceous	Light	Monomineralic quartz	Dark	Red	Sandstone
New Ulm Formation, unit Qnt	53	4	48	33	19		17	64	19	17	65	15	15	3	2
Cromwell Formation, till portion of unit Qlc	9	6	57	27	16		4	98	2	0	39	14	26	15	6
Cromwell Formation, unit Qcr	113	9	68	21	11	Leached	22	100	0	0	44	19	20	13	4
						Unleached	27	98	2	0	37	16	26	16	5
Cromwell Formation, unit Qce	64	8	64	25	11	Leached	9	100	0	0	33	17	27	16	7
						Unleached	31	95	5	0	40	22	22	12	4
Henderson Formation, unit Qr1	52	6	61	25	14	Leached	24	100	0	0	48	25	14	9	4
						Unleached	6	82	18	0	45	22	19	9	5
St.Francis Formation (upper member), unit *Qr2*	62	4	48	39	13	Leached	4	100	0	0	46	24	17	9	4
						Unleached	55	81	19	T	43	27	21	6	3
Lake Henry Formation (Meyer Lake Member), unit *Qxt*	47	3	40	41	19		35	79	21	T	51	28	14	4	3
St. Francis Formation (lower member), unit *Qr3*	15	5	56	30	14	Leached	8	99	1	0	40	29	17	8	6
						Unleached	5	92	8	0	45	35	11	5	4
Pierce Formation, unit Qpt	53	3	38	36	26	Leached	4	100	0	T	58	34	6	1	1
						Unleached	27	86	13	1	50	35	13	1	1
Rainy provenance, included in unit Qvt	7	27	64	22	14		3	85	15	T	43	43	10	3	1
VS (Superior provenance), unit Qvt	8	13	57	30	13	Leached	2	100	0	0	48	22	16	10	4
						Unleached	4	93	7	0	41	35	15	7	2

Table from source map: Washington County Geologic Map.

Figure 1: Location of Cross Sections

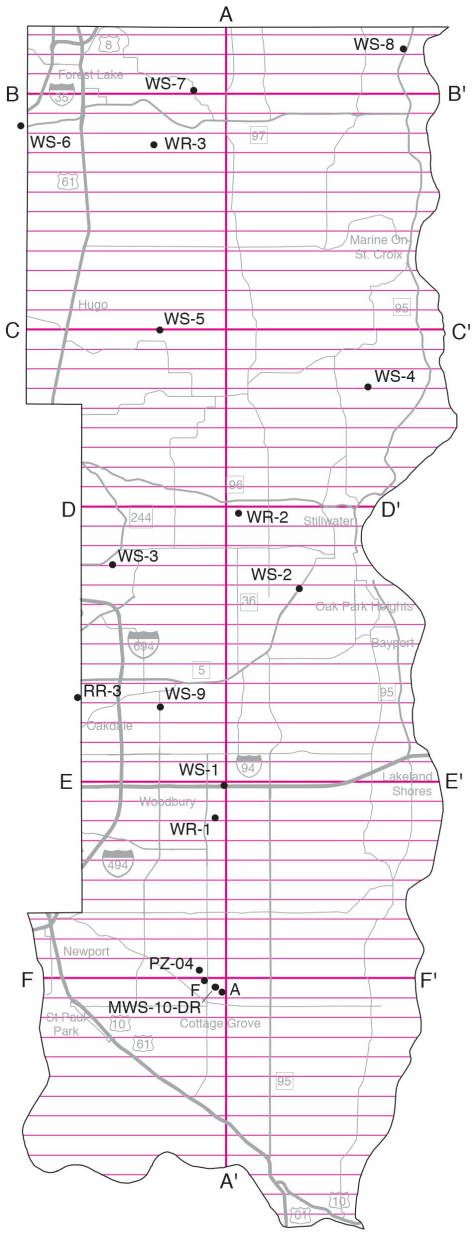


Figure 1. Location of 63 east–west cross sections, constructed at regular 0.6 mile (1 kilometer) intervals, and one north–south cross section, used to create a three-dimensional model of the Quaternary deposits of Washington County. The locations of cross sections A–A' through F–F' are shown here, and are also shown on Plate 3, *Surficial Geology*. Rotary-sonic core sites are labeled. Scale is 1:300,000.

Graphic from source map: Washington County Geologic Map.

Figure 2: Glacial Provences and Related Cross Section Unit Labels

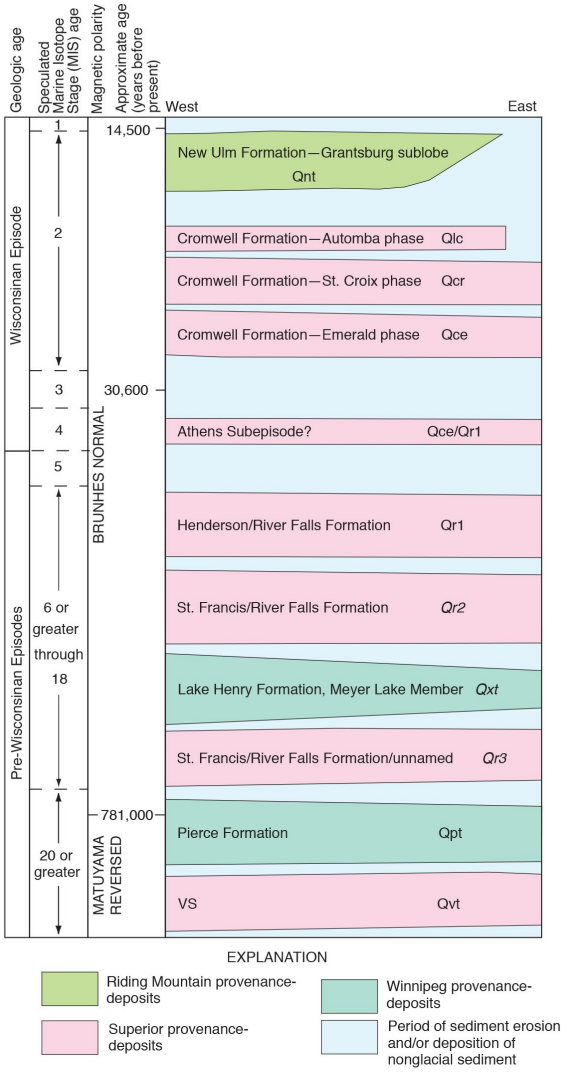


Figure 2. Diagram showing relative age, locations (across Washington County from west to east), provenance (Plate 3, Fig. 2 and Table 1), and related unit labels from the cross sections for Wisconsinan Episode and pre-Wisconsinan Episode tills (diamictons; Table 1). The age column and deposit drawings are not to scale. See the text on Plate 3 for a discussion of the geologic history.

Graphic from source map: Washington County Geologic Map.

Figure 3: Rotary Sonic Log WS-7

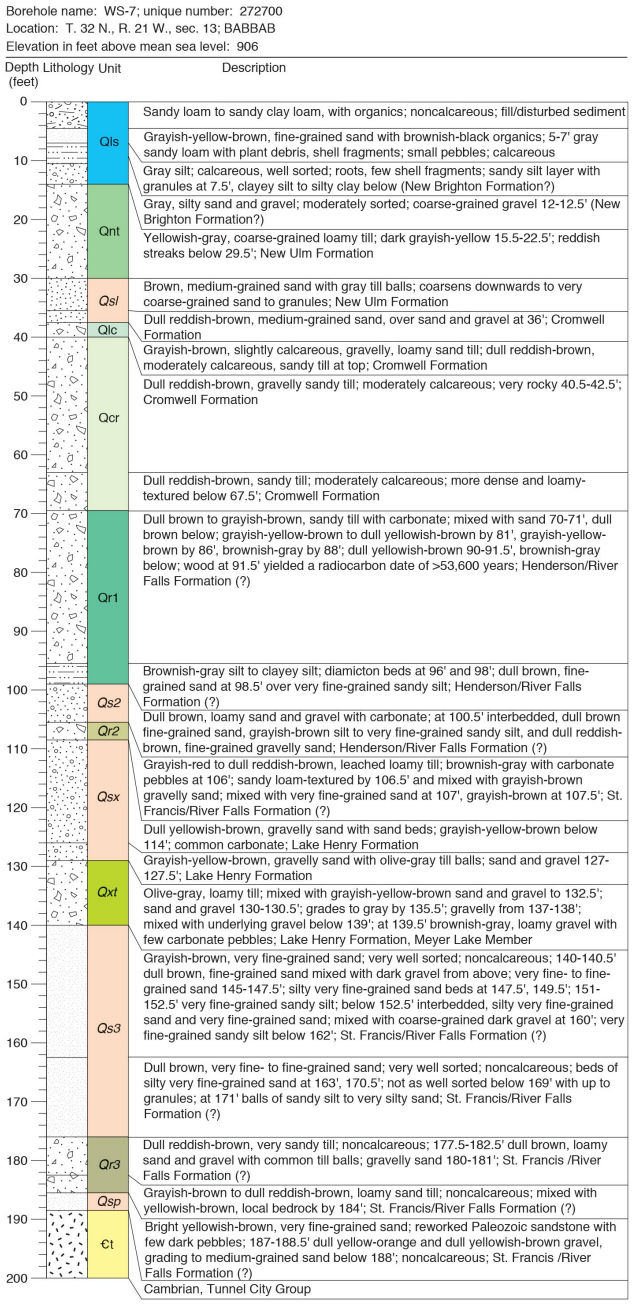


Figure 3. Descriptive log of rotary-sonic core WS-7 drilled by Traut Companies for this study. A till sample from 135 feet (41.1 meters) exhibited reversed polarity, but samples from 136 and 137 feet (41.5 and 41.8 meters) had normal polarity. A till sample from 183 feet (55.8 meters) was equivocal and another at 184 feet (56.1 meters) had normal polarity. The sediment is all interpreted to have been deposited during the Brunhes normal magnetic polarity chron (Fig. 2). Core location is shown on Figure 1 and Plate 1, *Data-Base Map*.

Graphic from source map: Washington County Geologic Map.

Figure 4: Rotary Sonic Log WS-5

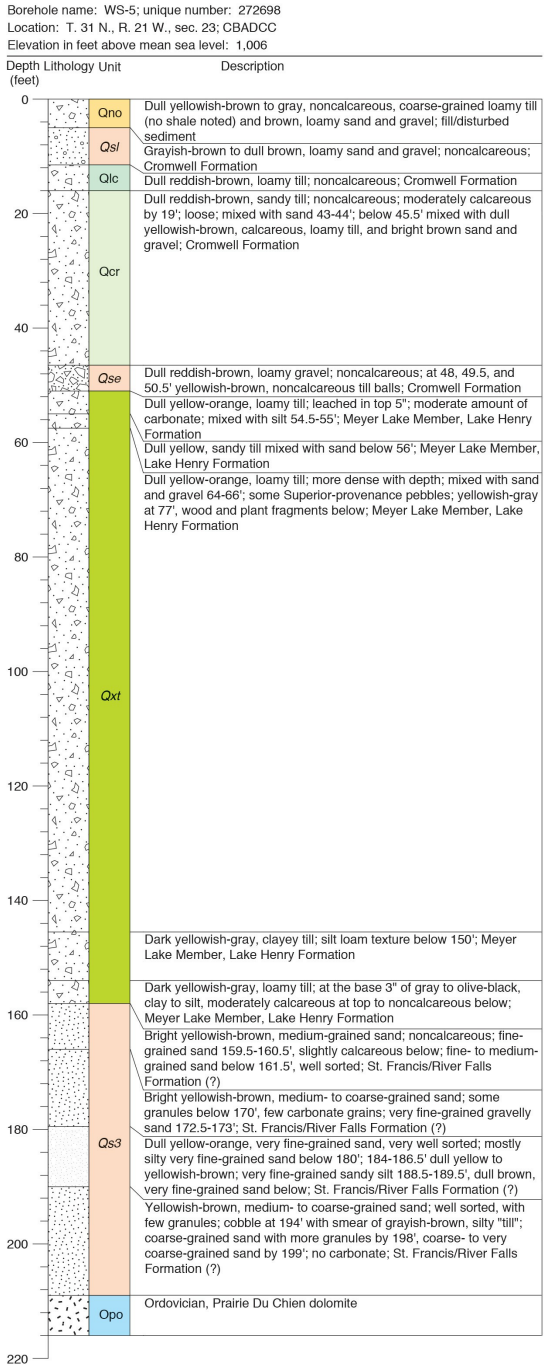


Figure 4. Descriptive log of rotary-sonic core WS-5 drilled by Traut Companies for this study. All 20 till samples from 58 to 150 feet (18 to 46 meters) exhibited normal polarity, but one of two samples taken from bedded clay and silt at 158 feet (48 meters) had reversed polarity. This may indicate the underlying sand predates the St. Francis/River Falls Formation. Core location is shown on Figure 1 and Plate 1.

Graphic from source map: Washington County Geologic Map.

Figure 5: Rotary Sonic Log WR-2

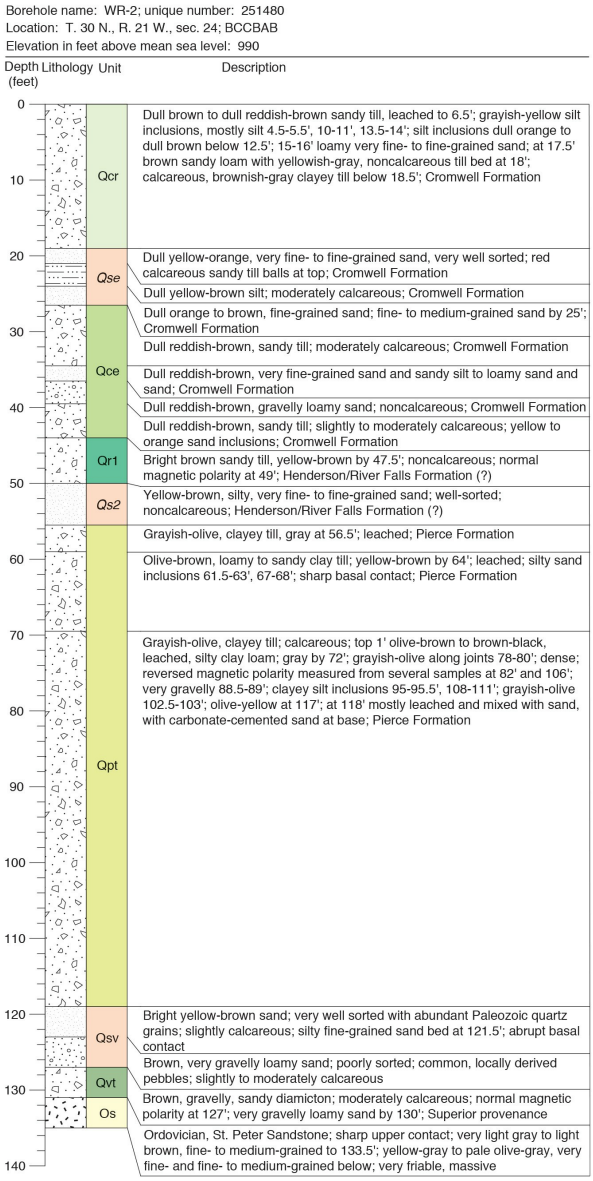


Figure 5. Descriptive log of rotary-sonic core WR-2 drilled by Boart Longyear for an earlier study (Meyer and others, 1998). Sediment from a depth of 82 feet (25 meters) down to bedrock is interpreted to have been deposited during the Matuyama reversed polarity chron (Fig. 2). The sediment included in unit Qvt at a depth of 127 feet (39 meters) may have been deposited during one of the brief, normal polarity subchrons within the Matuyama chron (Lisiecki and Raymo, 2005). Core location is shown on Figure 1 and Plate 1, *Data-Base Map*.

Graphic from source map: Washington County Geologic Map.

Figure 6: Rotary Sonic Log WS-1

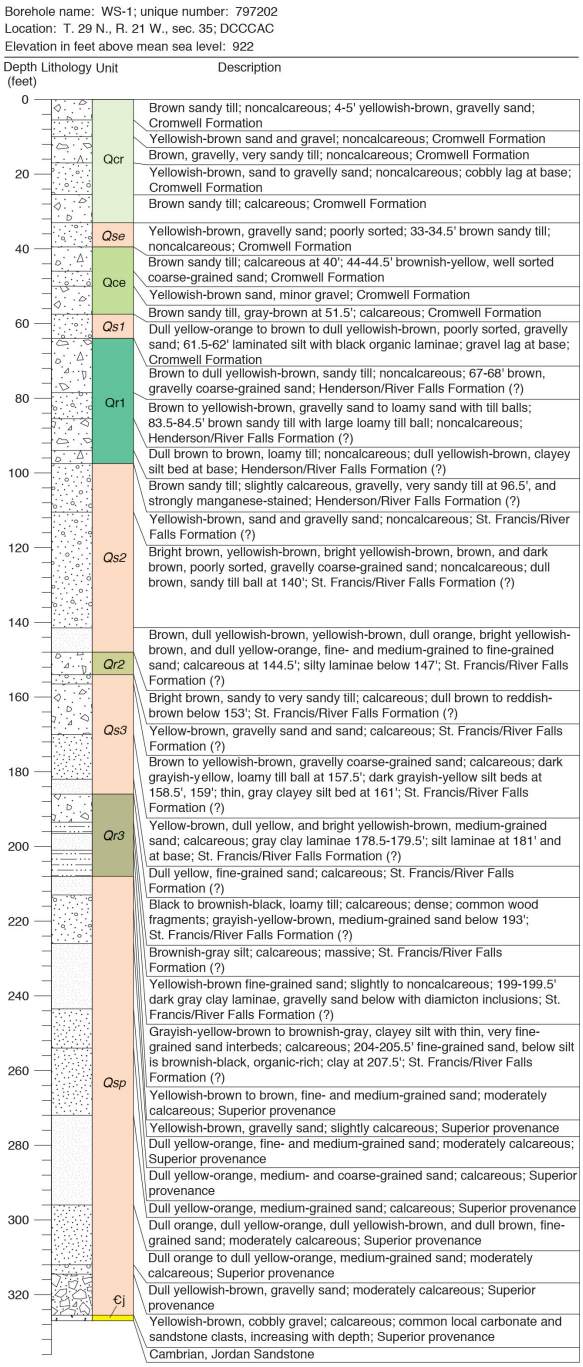


Figure 6. Descriptive log of rotary-sonic core WS-1 drilled by Traut Companies for this study. All but one of 15 samples from 94 to 208 feet (29 to 63 meters) exhibited normal magnetic polarity, so sediment to a depth of at least 208 feet (63 meters) is interpreted to have been deposited during the Brunhes normal magnetic polarity chron (Fig. 2). Core location is shown on Figure 1 and Plate 1.

Graphic from source map: Washington County Geologic Map.

Figure 7: Rotary Sonic Log PZ-04

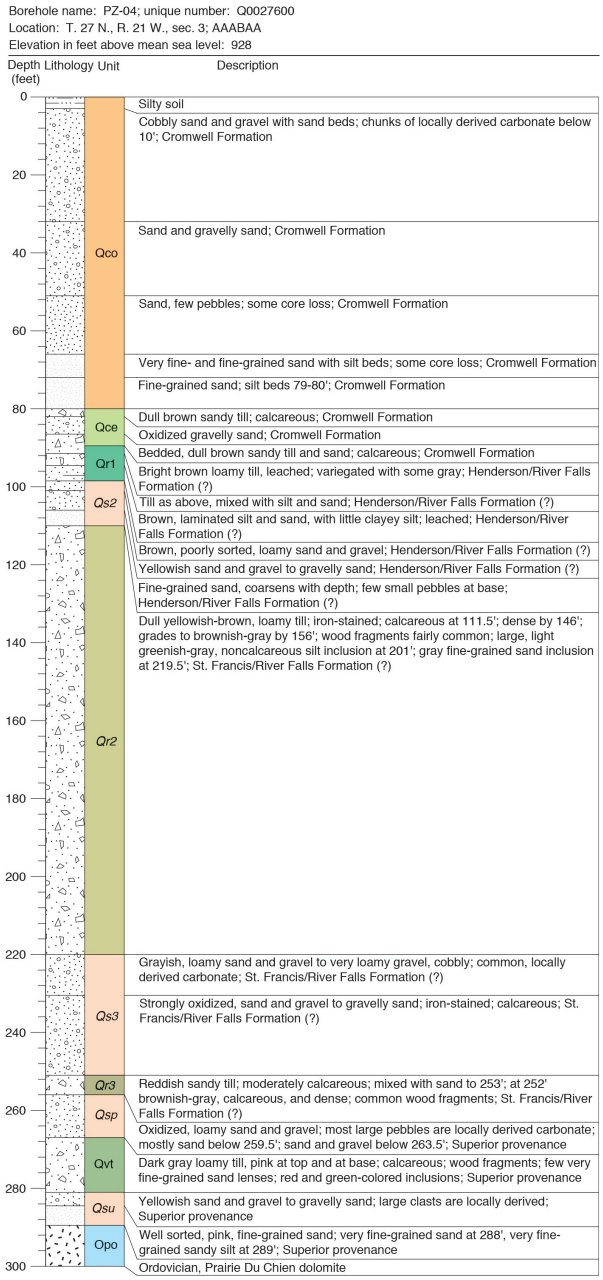


Figure 7. Descriptive log of rotary-sonic core PZ-04 drilled by Traut Companies for 3M. Although samples from depths of 179 and 269 feet (55 and 82 meters) were shallowly reversed, samples from 169, 189, 199, and 279 feet (52, 58, 61, and 85 meters) all exhibited normal magnetic polarity. Most sediment cored is interpreted to have been deposited during the Brunhes normal magnetic polarity chron (Fig. 2), although the sediment included in unit Qvt is interpreted to be older (Fig. 5). Core location is shown on Figure 1 and Plate 1.

Graphic from source map: Washington County Geologic Map.

Figure 8: Correlation of Cross Section Unit to Surficial Map Units

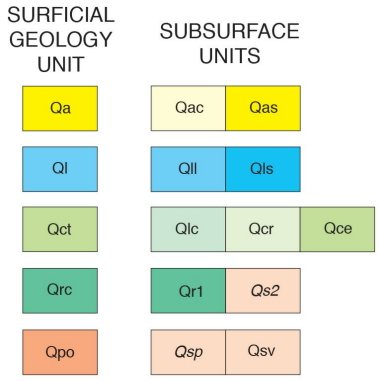


Figure 8. Units from Plate 3, *Surficial Geology* (left), expanded into the subsurface

Graphic from source map: Washington County Geologic Map.

Plate 6: Depth to Bedrock

This plate contains information about bedrock topography and depth the bedrock. The GRI only use information pertaining to depth to bedrock from this plate.

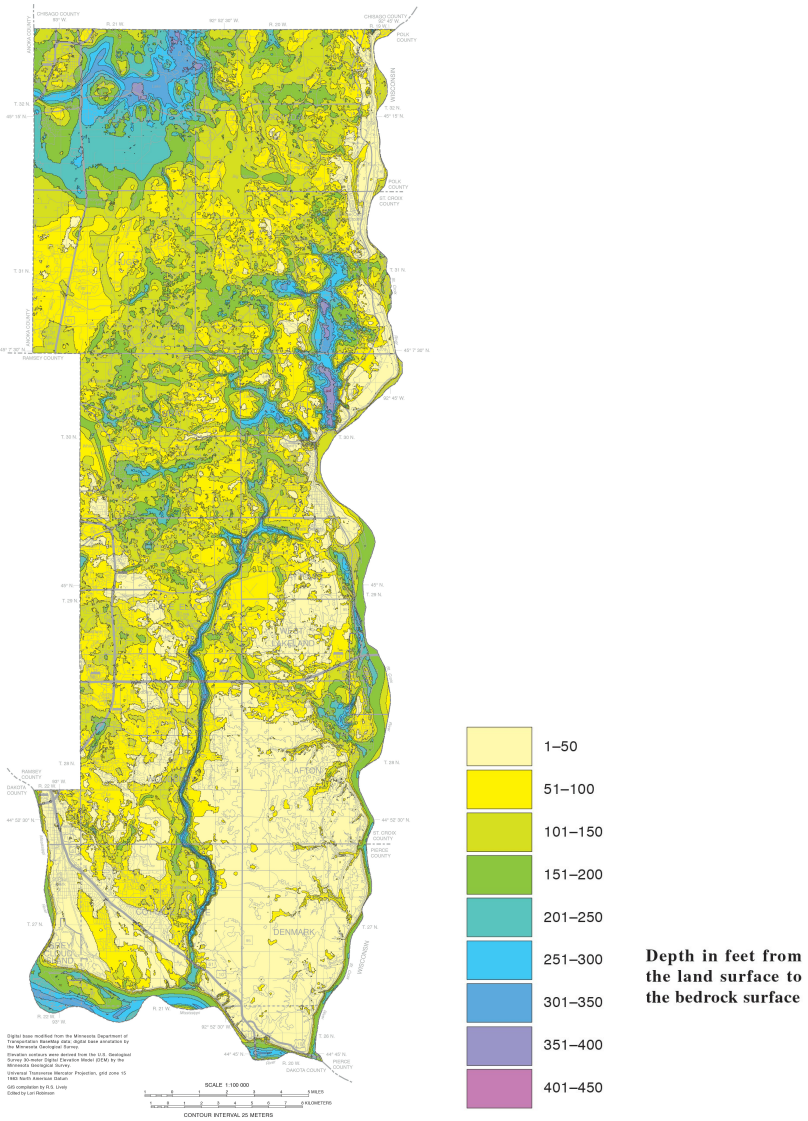
Depth to Bedrock Introduction

The depth to bedrock is equal to the depth from the land surface to the underlying bedrock surface, and represents the thickness of Quaternary sediment cover over bedrock. To calculate this thickness, a digital grid of bedrock-surface elevations was subtracted from a corresponding digital grid of land-surface elevations. The surface elevation grid was resampled from a 1-meter digital elevation model derived from lidar by the Minnesota Department of Natural Resources, whereas the bedrock elevation grid was derived from the Bedrock Topography map, which was inferred from outcrop mapping and interpretation of water well records, engineering test borings, passive seismic data, and geomorphic features. The residual grid was then classified at 50-foot (15-meter) intervals to produce the color-coded Depth to Bedrock map. Thickness of the Quaternary sediments can vary greatly over short distances, and mapping at this scale (1:100,000) may not properly resolve prominent variations. For this reason, it is best to consult site-specific data (such as water well records, engineering test borings, and passive seismic soundings) wherever available. The detailed appearance of the Depth to Bedrock map is related to surficial landforms because the land surface topography model is based on higher resolution data than the interpreted bedrock surface model.

The thickest Quaternary sediments in Washington County occur within the Mississippi and St. Croix River valleys and their tributaries, where the depth to bedrock is as much as 400 feet (122 meters). Elsewhere, more than 300 feet (91 meters) of overlying sediment occurs within a buried bedrock valley in the northwest corner of the county near Forest Lake, and in the 20-mile-long (32-kilometer-long) valley passing through the south-central part of the county near Cottage Grove. Areas where bedrock is at or within 50 feet (30 meters) of the land surface occur within the southern one-third of Washington County, and along the eastern part of the county following the St. Croix River bluff.

Text from source map: Washington County Geologic Map.

Depth to Bedrock Map



Graphics from source map: [Washington County Geologic Map].

St. Croix NSR Quaternary Geologic Map

The formal citation for this source.

> Carson, E., Rawling, J.E., III, and Rose, C., 2017, Quaternary Geologic Map of Portions of the St. Croix National Scenic Riverway, Wisconsin: Wisconsin Geological and Natural History Survey, scale 1:100,000 (*GRI Source Map ID 76097*).

The NPS GRI contracted with the Wisconsin Geological and Natural History Survey to produce surficial geologic maps at the 1:100,000 scale for the areas delineated by the parts of nine 7.5-minute quadrangles along the St. Croix River in Wisconsin (Bass Creek, Danbury East, Danbury West, Grantsburg, Lake Clayton, Monson Lake, Randall, Rush City, and Yellow Lake) and all of three quadrangles along the Namekagon River (Dunn Lake, Springbrook and Trego), all within the St. Croix National Scenic Riverway. This data was used to fill in areas along the St. Croix National Scenic Riverway where no detailed surficial geologic data existed.

A brief geologic description of the area extracted from the Wisconsin Geological and Natural History Survey statement of work.

Geologic Description

The surficial geology of the area is of considerable scientific and technical interest as a result of the complex interactions of retreating ice lobes during the most recent glaciation. The St. Croix River valley was glaciated at least four separate times during the Quaternary (Chamberlin, 1905; Wright et al., 1973; Clayton, 1984; Johnson, 1986, 1998), although landforms and surficial deposits are largely related to the most recent glaciation. At the peak of the most recent glaciation, historically known as the Wisconsin Glaciation, fundamentally the entire area of the St. Croix National Scenic Riverway was covered by ice of the Superior Lobe of the Laurentide Ice Sheet, flowing southwest out of the Lake Superior basin. As ice retreated to the northeast, glacial Lake Lind formed in the isostatically depressed St. Croix lowland (Johnson et al., 1999), and was eventually covered by fluvial sands derived from the Superior basin. Subsequently the Grantsburg Sublobe of the Des Moines Lobe advanced from the southwest (out of southeastern Minnesota) to the northeast, to where it blocked the St. Croix River in Polk and Burnett Counties, Wisconsin (Johnson and Hemstad, 1998). This damming of the Mississippi and St. Croix waterways formed glacial Lake Grantsburg in the same location as the earlier glacial Lake Lind. Based on varve chronology, glacial Lake Grantsburg is believed to have been short-lived, existing for perhaps as little as ~100 years. After the Grantsburg Sublobe retreated, allowing glacial Lake Grantsburg to drain, the Superior Lobe retreated into the Lake Superior basin and glacial Lake Duluth formed (largely in the area currently occupied by westernmost Lake Superior). Water from glacial Lake Duluth drained southward, cutting the deep channel and Dalles now occupied by the St. Croix River (Hack, 1965; Moss et al., 1979).

Much of what is known about glacial Lakes Lind and Grantsburg is based on sedimentological studies; the absolute chronology of advance and retreat of the Superior Lobe and Grantsburg Sublobe is much less constrained. The relatively few radiocarbon dates that exist provide ample opportunity for multiple interpretations for the geologic history (Wright et al., 1973; Clayton and Moran; 1982; Mooers, 1997). Johnson (1998) suggests that glacial Lake Lind formed as early as 18,500 years BP and that glacial Lake Grantsburg formed at approximately 14,000 years BP; however, Williams et al. (2011) argue that glacial Lake Grantsburg drained as recently as 11,000 years BP. The proposed mapping project will combine the goals of providing high-quality surficial mapping for the National Park Service to assist with land-use decisions and of improving our understanding of the timing and processes associated with glacial advances and retreats and ice-marginal lake formation and demise in the area.

Text from source map: St. Croix NSR Quaternary Geologic Map

Minnesota Karst Features

The formal citation for this source.

Alexander, E. Calvin Jr., and Tipping, Bob, 2002, Karst Features of Minnesota: Minnesota Geological Survey, scale 1:24,000 (*GRI Source Map ID 75564*).

No ancillary source map information is provided from this source.

Minnesota Quaternary Data Index

The formal citation for this source.

Minnesota Geological Survey, 2018, Quaternary Data Index: Minnesota Geological Survey, internal working digital database (version date, March, 2018) (*GRI Source Map ID 76136*).

No ancillary source map information is provided from this source.

St. Croix NSR Hydro Database

The formal citation for this source.

National Park Service Water Resources Division, 2000, Saint Croix National Scenic River Small-scale Base GIS Data: National Park Service, Publication Date: 2000, scale 1:100,000 (*GRI Source Map ID 76264*).

No ancillary source map information is provided from this source.

GRI Digital Data Credits

This document was developed and completed by James Chappell (Colorado State University) for the NPS Geologic Resources Division (GRD) Geologic Resources Inventory (GRI) Program. Quality control of this document by Ronald Karpilo (Colorado State University).

The information in this document was compiled from GRI source maps, and is intended to accompany the digital geologic-GIS map and other digital data for Saint Croix National Scenic Riverway, Wisconsin and Minnesota (SACN) developed by Ronald Karpilo and James Chappell (Colorado State University) (see the GRI Digital Map and Source Map Citations section of this document for all sources used by the GRI in the completion of this document and related GRI digital geologic-GIS map).

GRI finalization by James Chappell (Colorado State University).

Legacy data for this project was completed by James Winter, James Chappell, Stephanie O'Meara, Dalton Meyer, Sarah Lowe, Kajsa Holland-Goon, Dylan Rolley, and Dalton Meyer (Colorado State University).

GRI program coordination and scoping provided by Bruce Heise, Jason Kenworthy, Tim Connors, and Rebecca Port (NPS GRD, Lakewood, Colorado).