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_surficial_geology.pdf

Version: 8/29/2018

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, Minnesota and Wisconsin

Document to Accompany Digital Geologic-GIS Data

sacn_surficial_geology.pdf

Version: 8/29/2018

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, Minnesota and Wisconsin (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 Maps and Source Citations** – A listing of all GRI digital geologic-GIS maps produced for this project along with sources used in their 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 maps 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) **Additional GIS Tables --** Karst and drill-hole tables related to Hazard Point Features (SACNHZP) and Geologic Observation Localities (SACNGOL) feature classes.

7) **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.

8) **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:

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About the NPS Geologic Resources Inventory Program

Background

Recognizing the interrelationships between the physical (geology, air, and water) and biological (plants and animals) components of the earth is vital to understanding, managing, and protecting natural resources. The Geologic Resources Inventory (GRI) helps make this connection by providing information on the role of geology and geologic resource management in parks.

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 Geologic Resources Inventory aims to raise awareness of geology and the role it plays in the environment, and to provide natural resource managers and staff, park planners, interpreters, researchers, and other NPS personnel with information that can help them make informed management decisions.

The GRI team, working closely with the Colorado State University (CSU) Department of Geosciences and a variety of other partners, provides more than 270 parks with a geologic scoping meeting, digital geologic-GIS map data, and a park-specific geologic report.

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: http://science.nature.nps.gov/im/inventory/geology/GeologyGISDataModel.cfm

Geologic Reports: Park-specific geologic reports identify geologic resource management issues as well as features and processes that are important to park ecosystems. In addition, these reports present a brief geologic history of the park and address specific properties of geologic units present in the park.

For a complete listing of Geologic Resource Inventory products and direct links to the download site visit the GRI publications webpage http://go.nps.gov/gri_products

GRI geologic-GIS data is also available online at the NPS Data Store Search Application: http://irma.nps.gov/App/Reference/Search. 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: http://www.nps.gov/subjects/geology/gri.htm, or contact:

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The Geologic Resources Inventory (GRI) program is funded by the National Park Service (NPS) Inventory and Monitoring (I&M) Division.

GRI Digital Map and Source Map Citations

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

Digital Surficial Geologic-GIS Map of St. Croix National Scenic Riverway, Minnesota and Wisconsin (*GRI MapCode SACN*)

Source map and digital data, as well as prominent map components present in source data (e.g., related report, unit colors, units descriptions, and other ancillary map graphics and text) were incorporated into this GRI digital geologic-GIS dataset and product.

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 Geology). (*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 Metro Area Construction Aggregate). (*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 Geology). (*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 Geology). (*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 Region, Minnesota: Minnesota Geological Survey, Miscellaneous Map Series, M-178, scale 1:125,000 (Twin Cities

Metro Region Surficial Geology). (*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 1:100,000 (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, scale 1:100,000 (St. Croix NSR Quaternary Geology). (*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 (4 out of 6 plates used): Minnesota Geological Survey, County Atlas Series C-22 Part A, scale 1:100,000 (Chisago County Geologic Atlas). (*GRI Source Map IDs 76142, 76137, 76138, 76139, 76141*).

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. Plates 1 (Data-base 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. Data contained in a GIS database associated with this source but not appearing on any of the plates was used and given a map ID designated for the entire publication.

Boerboom, T.J., 2001, Geologic Atlas of Pine County, Minnesota (4 out of 7 plates used): Minnesota Geological Survey, County Atlas Series C-13 Part A, scale 1:100,000 (Pine County Geologic Atlas). (*GRI Source Map IDs 52582, 76143, 76146, 76147, 76149*).

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. Plates 1 (Data-base 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. Data contained in a GIS database associated with this source but not appearing on any of the plates was used and

given a map ID designated for the entire publication.

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).

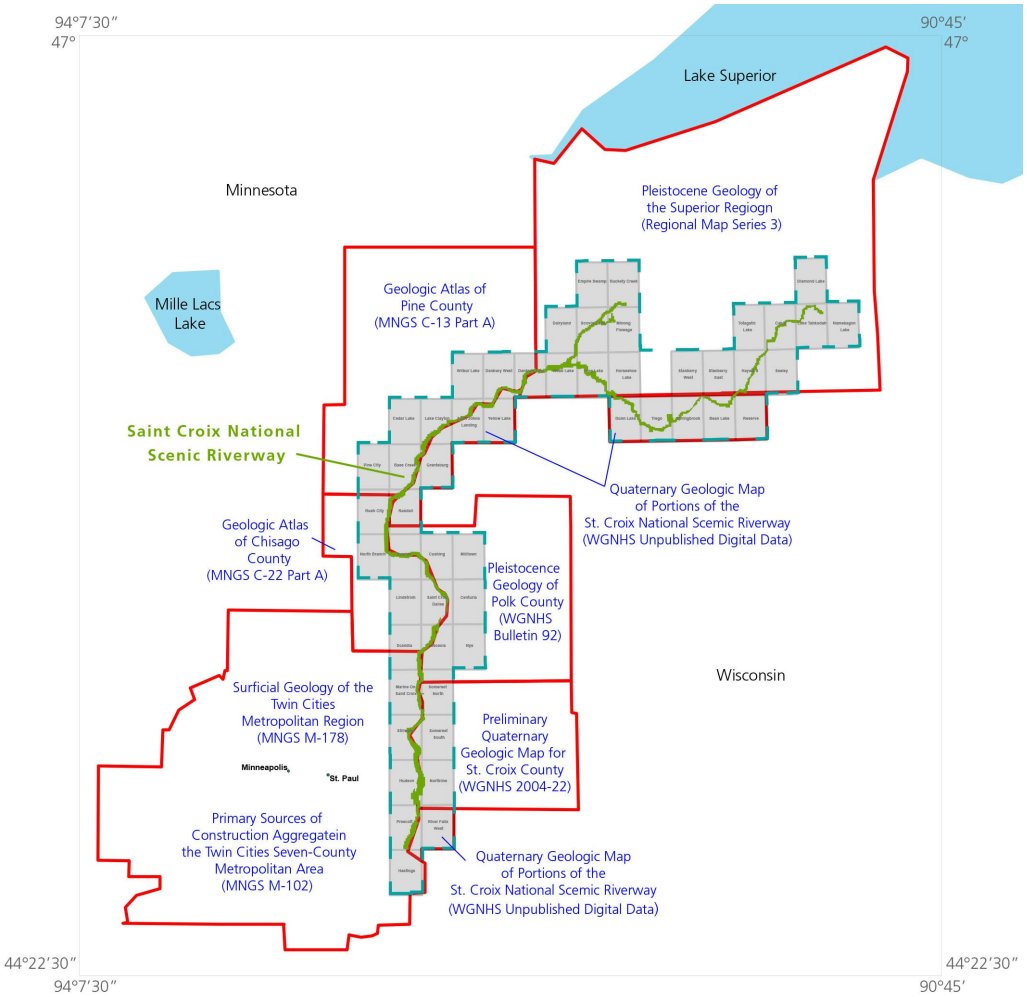
This data was included to provide a consistent representation of the St. Croix River. Data used from this source map was clipped to the quadrangles of interest for St. Croix NSR. See the index map below showing extents of map sources used. Only the St. Croix River was extracted from this dataset.

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

Index Map

The index map below shows the extent of the GRI Digital Surficial 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 August, 2018) is also presented in green. The index map also displays the extent of source maps used in completion of the map. Red outlines show source map extents, with source map titles and series number (e.g., MNGS C-22 Part A) in blue.

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).



Map Unit List

The surficial geologic units present in the digital geologic-GIS data produced for Saint Croix National Scenic Riverway, Minnesota and Wisconsin (SACN) are listed below. Units are listed with their assigned unit symbol and unit name (e.g., Qe- Eolian sand). 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 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
Holocene Epoch
Qe - Eolian sand
Ql - Lacustrine deposits
Qho - Organic deposits
Qa - Floodplain alluvium
Qf - Alluvial fan deposits
Qm - Marl
Qc - Colluvium

Holocene and Pleistocene Epochs
Qsp - Miller Creek Formation, spillway sediment
Qb - Miller Creek Formation, shoreline sediment
Qw - Miller Creek Formation, till, wave-planed topography
Qsp - Stream-eroded surface deposits

Pleistocene Epoch
Qws - West Campus formation, St. Mary's terrace
Qwg - West Campus formation, Grey Cloud terrace
Qwl - West Campus formation, Langdon terrace
Qma - West Campus formation, sandy alluvium and slopewash
Qmc - West Campus formation, bedrock colluvium
Qwr - West Campus formation, Richfield terrace
Qwf - West Campus formation, Richfield terrace, silt and sand facies
Qbc - New Brighton formation, silt and clay facies
Qbg - New Brighton formation, sand and gravel facies
Qbs - New Brighton formation, sand facies
Qno - New Ulm Formation, outwash
Qns - New Ulm Formation, lake sand
Qni - New Ulm Formation, ice-contact stratified deposits
Qnt - New Ulm Formation, loamy till (low relief)
Qnm - New Ulm Formation, loamy till (moderate relief)
Qna - New Ulm Formation, sandy till
Qnd - New Ulm Formation, Twin Cities member, undivided
Qgm - New Ulm Formation, Twin Cities member, glacial sediment of end moraines
Qggm - New Ulm Formation, Twin Cities member, glacial sediment with stream- and lake-modified

surface
Qggs - New Ulm Formation, Twin Cities member, glacial sediment and pond sediment accumulated in swales
Qgs - New Ulm Formation, Twin Cities member, stream sediment
Qgls - New Ulm Formation, Falun member, sandy sediment of Glacial Lake Grantsburg
Qglf - New Ulm Formation, Falun member, silt and sandy sediment of Glacial Lake Grantsburg
Qglc - New Ulm Formation, Falun member, silty and clayey sediment of Glacial Lake Grantsburg
Qgth - 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
Qoc - Trade River formation, Falun member, offshore clay
Qgsn - Copper Falls Formation, Sylvan Lake Member, glacial deposits
Qsu - Copper Falls Formation, Sylvan Lake Member, proglacial stream sediment, uncollapsed proglacial stream sediment
Qsuf - Copper Falls Formation, Sylvan Lake Member, proglacial stream sediment, uncollapsed proglacial stream sediment, Swill surface
Qsug - Copper Falls Formation, Sylvan Lake Member, proglacial stream sediment, uncollapsed proglacial stream sediment, Hayward surface
Qsuh - Copper Falls Formation, Sylvan Lake Member, proglacial stream sediment, uncollapsed proglacial stream sediment, Tiger Cat surface
Qush - Copper Falls Formation, Sylvan Lake Member, hummocks
Qusn - Copper Falls Formation, Sylvan Lake Member, low-relief hummocks
Qcfdb - Copper Falls diamicton, Sylvan Lake Member, steep hill slopes
Qssp - Copper Falls Formation, Sylvan Lake Member, outwash plains with limited collapsed surface
Qse - Copper Falls Formation, Sylvan Lake Member, meltwater stream sediment in eskers
Qsd - Copper Falls Formation, Sylvan Lake Member, meltwater stream sediment in deltas
Qcfspp - Copper Falls Formation, Sylvan Lake Member, sand and gravel in outwash deposits, between 20% and 50% collapsed surface
Qcfsh - Copper Falls Formation, Sylvan Lake Member, sand and gravel in outwash deposits, more than 50% collapsed surface
Qssv - Copper Falls Formation, Sylvan Lake Member, tributary valley floors
Qcfsb - Copper Falls Formation, Sylvan Lake Member, sand and gravel in outwash deposits, steep hill slopes
Qcfsl - Copper Falls Formation, Sylvan Lake Member, silt and sand
Qnsi - Copper Falls Formation, Sylvan Lake Member, nearshore ice-walled and ice-dammed lake plain deposits
Qosi - Copper Falls Formation, Sylvan Lake Member, offshore ice-walled and ice-dammed lake plain deposits
Qgmt - Copper Falls Formation, Sylvan Lake Member, till, subglacially molded topography
Qgt - Copper Falls Formation, Sylvan Lake Member, till, glacial thrust masses
Qgg - Copper Falls Formation, Sylvan Lake Member, till, thin mass-movement till
Qsgc - Cromwell Formation, clayey glacial sediment
Qsfm - Cromwell Formation, Kerrick phase and Split Rock phase, silty and clayey glacial sediment
Qsgf - Cromwell Formation, Kerrick phase, silty and clayey glacial sediment
Qcl - Cromwell formation, lake sand and silt
Qco - Cromwell formation, stream sediment
Qci - Cromwell formation, ice-contact stratified deposits
Qsli - Cromwell Formation, sediment of ice-walled lakes
Qssm - Cromwell Formation, sandy glacial sediment in moraine ridges
Qsgs - Cromwell Formation, sandy glacial sediment
Qsgw - Cromwell Formation, wave-washed glacial sediment

Qcs - Cromwell formation, till, sand and gravel
Qct - Cromwell formation, supraglacial till
Qcc - Cromwell Formation, lake clay and silt
Qcd - Cromwell Formation, subglacial till
Qro - River Falls Formation, outwash
Qrd - River Falls Formation, complex of sand, gravel, and till
Qrt - River Falls Formation, till
Qph - Pierce Formation, Hersey Member, glacial sediment
Qpg - Pierce Formation, glaciofluvial deposits
Qpt - Pierce Formation, till

Paleozoic Era

PZr - Paleozoic bedrock, undivided

Ordocivian Period
Opg - Platteville and Glenwood Formations, undivided
Osp - St. Peter Sandstone
Opc - Prairie du Chien Group, undivided

Ordovician and Cambrian Periods
OCu - Bedrock, undivided

Cambrian Period
Cj - Jordan Sandstone
Cu - Cambrian rocks, undivided

Proterozoic Eon

PCrs - Pre-Pleistocene rock, lithic sandstone, mudstone and conglomerate of the Oronto Group and quartz sandstone of the Bayfield Group
PCcgb - Chengwatana Group, basalt
PCmc - Clam Falls volcanics
PCrv - Pre-Pleistocene rock, volcanic rock
PCri - Pre-Pleistocene rock, intrusive rock

Map Unit Descriptions

Descriptions of all geologic map units, generally listed from youngest to oldest, are presented below.

Qe - Eolian sand (Holocene)

Qe - Eolian sand (Quaternary)
Very fine- to medium-grained sand; more than three feet (1 meter) thick; windblown. Generally forms low-lying dunes, except in the stippled area where dune relief exceeds 30 feet (9 meters). Description from source map: Twin Cities Metro Region Surficial Geology.

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 Geology.

Qe - Eolian sand (Postglacial)
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 Atlas.

Ql - Lacustrine deposits (Holocene)

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 Metro Region Surficial Geology.

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 Geology.

Ql - Lacustrine deposits (Postglacial)
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 Atlas.

Qhl - Lake sediment (Holocene)
Clay, silt, and fine sand deposited in basins by settling from calm water. Description from source map: Pine County Geologic Atlas.

Qho - Organic deposits (Holocene)

p - Post glacial, organic sediment (10,000 B.P.)
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 Geology.

pt - Marshes and wetlands (Quaternary)
Marshes and wetlands composed of peat and muck. Description from source map: Polk County Pleistocene Geology.

O - Postglacial organic sediment (Quaternary)
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 Geology.

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 Metro Region Surficial Geology.

p - Peat (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 Geology.

Qp - Peat and muck (Postglacial)
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 Atlas.

Qho - Organic deposits (Holocene)
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 Atlas.

Qa - Floodplain alluvium (Holocene)

sm - Post Glacial, stream sediment (10,000 B.P.)
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 Geology.

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

A - Postglacial sand and silt (Quaternary)
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 Geology.

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 Metro Region Surficial Geology:win Cities Metro Region Surficial Geology.

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 Geology.

Qa - Floodplain alluvium (Postglacial)
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 Atlas.

Qhs - Stream sediment (Holocene)
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 Atlas.

Qf - Alluvial fan deposits (Holocene)

Qf - Alluvial fan deposits (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 Metro Region Surficial Geology.

Qf - Alluvial Fan Deposits (Postglacial)
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 Atlas.

Qm - Marl (Holocene)

Qm - Marl (Postglacial)
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 Atlas.

Qc - Colluvium (Holocene)

hs - Steep slopes (Quaternary)
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 Geology.

Qc - Colluvium (Quaternary)
Reworked sediments on steep slopes, consisting of a variable, friable mixture of clay to boulders that resembles the upslope glacial or fluvial sediment from which it was derived. May contain disseminated organic debris. Includes till outcrops, small alluvial fans, and narrow bodies of alluvium. Description from source map: Twin Cities Metro Region Surficial Geology.

h - Hillslope deposits (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 Geology.

Qhc - Steep-slope and slope deposits (Holocene)
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 Atlas.

Miller Creek Formation

Qsp - Miller Creek Formation, spillway sediment (Holocene and late Pleistocene)

sp - Miller Creek Formation,spillway sediment (Holocene)
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 Geology.

Qb - Miller Creek Formation, shoreline sediment (Holocene and late Pleistocene)

b - Miller Creek Formation, shoreline sediment (Holocene)
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 Geology.

Qgw - Miller Creek Formation, till, wave-planed topography (Holocene and late Pleistocene)

gw - Miller Creek Formation, till, wave-planed topography (Holocene)
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 Geology.

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

st - Terraces (Quaternary)
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 Geology.

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 Atlas.

West Campus formation

Formation description derived from Twin Cities Metro Region Surficial Geology 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. (*GRI Source Map ID 75549)* (Twin Cities Metro Region Surficial Geology).

Qws - West Campus formation, St. Mary's terrace (Pleistocene)

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 Metro Region Surficial Geology.

Qws - West Campus formation, St. Mary's terrace (Last Glaciation)
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 Atlas.

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

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 Metro Region Surficial Geology.

Qwg - West Campus formation, Grey Cloud terrace (Last Glaciation)
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 Atlas
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Qwl - West Campus formation, Langdon terrace (Pleistocene)

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 Metro Region Surficial Geology.

Qwl - West Campus formation, Langdon terrace (Last Glaciation)
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 Atlas.

Qma - West Campus formation, sandy alluvium and slopewash (Pleistocene)

Qma - West Campus formation, 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 Metro Region Surficial Geology.

Qmc - West Campus formation, bedrock colluvium (Pleistocene)

Qmc - West Campus formation, 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 Metro Region Surficial Geology.

Qwr - West Campus formation, Richfield terrace (Pleistocene)

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 Metro Region Surficial Geology.

Qwr - West Campus formation, Richfield Terrace (Last Glaciation)
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 Atlas.

Qwf - West Campus formation, Richfield terrace, silt and sand facies (Pleistocene)

Qwf - West Campus formation, Richfield terrace, silt and sand facies (Quaternary)
Richfield terrace (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 Metro Region Surficial Geology.

New Brighton formation

Formation description derived from Twin Cities Metro Region Surficial Geology Map & Chisago County Geologic Atlas.

(Meyer and Patterson, 1999)—Mostly fine-grained sand, laid down in Glacial Lake Anoka. (*GRI Source Map ID 75549)* (Twin Cities Metro Region Surficial Geology).

(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. (*GRI Source Map ID 76137)* (Chisago County Geologic Atlas).

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; rare dropstones. Deposited in deeper, quiet water of Glacial Lake Anoka. Description from source map: Twin Cities Metro Region Surficial Geology.

Qbc - New Brighton formation, silt and clay facies (Last Glaciation)
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 Atlas.

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. May overlie coarser-grained fluvial sediment of the New Ulm or Cromwell formations. Deposited in deltaic or shallow-water environments in Glacial Lake Anoka. Description from source map: Twin Cities Metro Region Surficial Geology.

Qbg - New Brighton formation, sand to fine-grained gravel (Last Glaciation)
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 Atlas.

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 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 Metro Region Surficial Geology.

Qbs - New Brighton formation, lake sand (Last Glaciation)
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 Atlas.

New Ulm Formation

Formation description derived from Twin Cities Metro Region Surficial Geology Map & Chisago County Geologic Atlas.

(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. (*GRI Source Map ID 75549)* (Twin Cities Metro Region Surficial Geology).

(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. (*GRI Source Map ID 76137)* (Chisago County Geologic Atlas).

Qno - New Ulm Formation, outwash (Pleistocene)

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 Metro Region Surficial Geology.

Qno - New Ulm Formation, outwash (Last Glaciation)
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 Atlas.

Qns - New Ulm Formation, lake sand (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 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 Metro Region Surficial Geology.

Qns - New Ulm Formation, lake sand (Last Glaciation)
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 Atlas.

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

Qni - New Ulm Formation, ice-contact stratified deposits (Quaternary)
Sand, gravelly sand, and cobbly gravel. Deposited by meltwater flowing at or behind the ice margin. 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). Boulders are present in some deposits. In general, Superior provenance clasts decrease and shale clasts increase from east to west and from north to south across the map area. Many of the deposits toward the north and east consist largely of reworked Superior provenance sediment. Typically forms hills and ridges. Description from source map: Twin Cities Metro Region Surficial Geology.

Qni - New Ulm Formation, ice-contact deposits (Last Glaciation)
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 Atlas.

Qnt - New Ulm Formation, loamy till (low relief) (Pleistocene)

Qnt - New Ulm Formation, loamy till - low relief (Quaternary)
Chiefly loam-textured, unsorted sediment (diamicton); pebbly, with scattered cobbles and rare boulders. Shale clasts generally compose from 25 to 40 percent of the very coarse-grained (1-2 millimeters) sand fraction. Lenses of stratified sediment are uncommon in most areas. Overlain in some small, low-lying areas by 3 feet (1 meter) or more of loamy to clayey, organic-bearing colluvium. 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). 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 Metro Region Surficial Geology.

Qnt - New Ulm Formation, low-relief till (Last Glaciation)
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 Atlas.

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

Qnm - New Ulm Formation, loamy till - moderate relief (Quaternary)
Till as above; deposits generally form round or elliptical hills with an overall relief of about 40 to 70 feet (12 to 21 meters). Description from source map: Twin Cities Metro Region Surficial Geology.

Qnm - New Ulm Formation, moderate-relief till (Last Glaciation)
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 Atlas.

Qna - New Ulm Formation, sandy till (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. 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 Metro Region Surficial Geology.

Qna - New Ulm Formation, sandy till (Last Glaciation)
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 Atlas.

Qnd - New Ulm Formation, Twin Cities member, undivided (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 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 Metro Region Surficial Geology.

Qnd - New Ulm Formation, Twin Cities member (Last Glaciation)
(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 Atlas.

Qgm - New Ulm Formation, Twin Cities member, glacial sediment of end moraines (Pleistocene)

Qgm - New Ulm Formation, Twin Cities member, 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 Atlas.

Qggm - New Ulm Formation, Twin Cities member, glacial sediment with stream- and lake-modified surface (Pleistocene)

Qggm - New Ulm Formation, Twin Cities member, 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 Atlas.

Qggs - New Ulm Formation, Twin Cities member, glacial sediment and pond sediment accumulated in inter-morainic swales (Pleistocene)

Qggs - New Ulm Formation, Twin Cities member, glacial sediment and pond sediment accumulated in inter-morainic 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 Atlas.

Qgs - New Ulm Formation, Twin Cities member, stream sediment (Pleistocene)

Qgs - New Ulm Formation, Twin Cities member, 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 Atlas.

Qgls - New Ulm Formation, Falun member, sandy sediment of Glacial Lake Grantsburg (Pleistocene)

Qgls - New Ulm Formation, Falun member, sandy sediment of glacial lake Grantsburg (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 Atlas.

Qglf - New Ulm Formation, Falun member, silt and sandy sediment of Glacial Lake Grantsburg (Pleistocene)

Qglf - New Ulm Formation, Falun member, silt and sandy sediment of glacial lake Granstburg (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 Atlas.

Qglc - New Ulm Formation, Falun member, silty and clayey sediment of Glacial Lake Grantsburg (Pleistocene)

Qglc - New Ulm Formation, Falun member, silty and clayey sediment of glacial lake Grantsburg (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 Atlas.

Trade River formation

Qgth - Trade River formation, glacial sediment (Pleistocene)

gth - Trade River Formation, till plain (Pleistocene)
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 Geology.

gt - Trade River Formation, glacial sediment (Pleistocene)
Dark gray calcareous loam to clay loam glacial deposits of the Grantsburg Sublobe. Description from source map: St. Croix NSR Quaternary Geology.

Qgtm - Trade River formation, moraine ridges (Pleistocene)

gtm - Trade River Formation, moraine ridges (Pleistocene)
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 Geology.

Qstv - Trade River formation, stream sediment (Pleistocene)

stv - Trade River Formation, stream sediment (Pleistocene)
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 Geology.

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

oti - Trade River Formation, ice-dammed-lake plains (Pleistocene)
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 Geology.

Qsto - Trade River formation, Osceola bench (Pleistocene)

sto - Trade River Formation, Osceola bench (Pleistocene)
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 Geology.

Qoc - Trade River formation, Falun member, offshore clay (Pleistocene)

oc - Trade River Formation, Falun Member, 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 Geology.

Copper Falls Formation

Formation description derived from St. Croix County Quaternary Geology Map & Superior Region Pleistocene Geology Map.

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.(*GRI Source Map ID 75428)* (St. Croix County Quaternary Geology).

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. (*GRI Source Map ID 3795)* (Superior Region Pleistocene Geology).

Qgsn - Copper Falls Formation, Sylvan Lake Member, glacial deposits (Pleistocene)

gsn - Copper Falls Formation, Sylvan Lake Member, uplands (Pleistocene)
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 Geology.

Cfd - Copper Falls diamicton (Quaternary)
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 Geology.

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

Qsu - Copper Falls Formation, Sylvan Lake Member, proglacial stream sediment, uncollapsed proglacial stream sediment (Pleistocene)

su - Copper Falls Formation, proglacial stream sediment, uncollapsed proglacial stream sediment (16,000-11,500 B.P.)
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 Geology.

su - Copper Falls Formation, Sylvan Lake Member, 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 Geology.

Qsuf - Copper Falls Formation, Sylvan Lake Member, proglacial stream sediment, uncollapsed proglacial stream sediment, Swill surface (Pleistocene)

suf - Copper Falls Formation, proglacial stream sediment, uncollapsed proglacial stream sediment - Swiss surface (16,000-11,500 B.P.)
Swiss surface. Description from source map: Superior Region Pleistocene Geology.

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

sug - Copper Falls Formation, proglacial stream sediment, uncollapsed proglacial stream sediment - Hayward surface (16,000-11,500 B.P.)

Hayward surface. Description from source map: Superior Region Pleistocene Geology.

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

suh - Copper Falls Formation, proglacial stream sediment, uncollapsed proglacial stream sediment - Tiger Cat surface (16,000-11,500 B.P.)
Tiger Cat surface. Description from source map: Superior Region Pleistocene Geology.

Qush - Copper Falls Formation, Sylvan Lake Member, hummocks (Pleistocene)

ush - Copper Falls Formation, Sylvan Lake Member, hummocks (Pleistocene)
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 Geology.

Qusn - Copper Falls Formation, Sylvan Lake Member, low-relief hummocks (Pleistocene)

usn - Copper Falls Formation, Sylvan Lake Member, low-relief hummocks (Pleistocene)
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 Geology.

Qcfdb - Copper Falls diamicton, Sylvan Lake Member, steep hill slopes (Pleistocene)

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

Qssp - Copper Falls Formation, Sylvan Lake Member, outwash plains with limited collapsed surface (Pleistocene)

sc - Copper Falls Formation, proglacial stream sediment, collapsed proglacial stream sediment (16,000-11,500 B.P.)
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: Superior Region Pleistocene Geology.

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

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 Geology.

Cfsp - Copper Falls sand and gravel in outwash deposits, less than 20% of original stream bed interrupted by depressions formed by melting ice blocks, (kettles) (Quaternary)
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 Geology.

Qse - Copper Falls Formation, Sylvan Lake Member, meltwater stream sediment in eskers (Pleistocene)

se - Copper Falls Formation, Sylvan Lake Member, 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 Geology.

Qsd - Copper Falls Formation, Sylvan Lake Member, meltwater stream sediment in deltas (Pleistocene)

sd - Copper Falls Formation, Sylvan Lake Member, 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 Geology.

Qcfspp - Copper Falls Formation, Sylvan Lake Member, sand and gravel in outwash deposits, between 20% and 50% collapsed surface (Pleistocene)

Cfspp - Copper Falls sand and gravel in outwash deposits, between 20% and 50% collapsed surface (Quaternary)
More than 20 but less than 50 percent collapsed surface. Description from source map: St. Croix County Quaternary Geology.

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

sg - Copper Falls Formation, proglacial stream sediment, hummocky stream sediment overlain by silty material (16,000-11,500 B.P.)
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 Geology.

ssh - Copper Falls Formation, Sylvan Lake Member, sand hummocks (Pleistocene)
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 Geology.

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

Qssv - Copper Falls Formation, Sylvan Lake Member, tributary valley floors (Pleistocene)

ssv - Copper Falls Formation, Sylvan Lake Member, tributary valley floors (Pleistocene)
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 Geology .

Qcfsb - Copper Falls Formation, Sylvan Lake Member, sand and gravel in outwash deposits, steep hill slopes (Pleistocene)

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

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

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

Qnsi - Copper Falls Formation, Sylvan Lake Member, nearshore ice-walled and ice-dammed lake plain deposits (Pleistocene)

nsi - Copper Falls Formation, Sylvan Lake Member, nearshore ice-walled and ice-dammed lake plain deposits (Pleistocene)
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 Geology.

Qosi - Copper Falls Formation, Sylvan Lake Member, offshore ice-walled and ice-dammed lake plain deposits (Pleistocene)

osi - Copper Falls Formation, Sylvan Lake Member, offshore ice-walled and ice-dammed lake plain deposits (Pleistocene)
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 Geology.

Qgmt - Copper Falls Formation, Sylvan Lake Member, till, subglacially molded topography (Pleistocene)

gmt - Copper Falls Formation, till, subglacially molded topography (16,000-11,500 B.P.)
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 Geology.

Qgt - Copper Falls Formation, Sylvan Lake Member, till, glacial thrust masses (Pleistocene)

gt - Copper Falls Formation, till, glacial thrust masses (16,000-11,500 B.P.)
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 Geology.

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

gg - Copper Falls Formation, till, thin mass-movement till (16,000-11,500 B.P.)
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 Geology.

Cromwell formation

Formation description derived from Twin Cities Metro Region Surficial Geology Map & Chisago County Geologic Atlas.

(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. (*GRI Source Map ID 75549)* (Twin Cities Metro Region Surficial Geology).

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. (*GRI Source Map ID 76137)* (Chisago County Geologic Atlas).

Qsgc - Cromwell formation, clayey glacial sediment (Pleistocene)

Qsgc - Cromwell formation, clayey glacial sediment (Pleistocene)
Locally thick morainic deposits of the Nickerson phase of the Superior lobe. Red where oxidized, reddish gray where unoxidized. Hummocky surface reflects stagnation and subsequent melting of ice along margin of lobe. May be interbedded with lake clay (a proglacial lake formed behind the moraine when ice retreated slightly to north). In cross section only. Description from source map: Pine County Geologic Atlas.

Qsfm - Cromwell formation, Kerrick phase and Split Rock phase, silty and clayey glacial sediment (Pleistocene)

Qsfm - Cromwell formation, Kerrick and Split Rock phases, silty and clayey glacial sediment (Pleistocene)
Silty and clayey glacial deposits that compose ice-marginal moraine ridges of the Kerrick and Split Rock phases. In cross section only. Description from source map: Pine County Geologic Atlas.

Qsgf - Cromwell formation, Kerrick phase, silty and clayey glacial sediment (Pleistocene)

Qsgf - Cromwell formation, Kerrick phase, silty and clayey glacial sediment (Pleistocene)
Silty and clayey glacial deposits associated mainly with the Kerrick phase; thin and discontinuous where associated with the Askov and Lookout Tower phases. In cross section only. Description from source map: Pine County Geologic Atlas.

Qcl - Cromwell formation, lake sand and silt (Pleistocene)

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 Metro Region Surficial Geology.

Qcl - Cromwell formation, lake sand and silt (Last Glaciation)
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 Atlas.

Qco - Cromwell formation, stream sediment (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 Metro Region Surficial Geology.

Qss - Cromwell formation, 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 Atlas.

Qci - Cromwell formation, ice-contact stratified deposits (Pleistocene)

Qci - Cromwell formation, ice-contact stratified deposits (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 Metro Region Surficial Geology.

Qci - Cromwell formation, ice contact deposits (Last Glaciation)
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 Atlas.

Qssi - Cromwell formation, 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 Atlas.

Qsli - Cromwell formation, sediment of ice-walled lakes (Pleistocene)

Qsli - Cromwell formation, sediment of ice-walled lakes (Pleistocene)
Lake sediment in elevated positions; consists of sand, silt, and clay that was deposited in calm water within depressions on former ice surface. Present in morainic areas in all phases of the Superior lobe. Description from source map: Pine County Geologic Atlas.

Qssm - Cromwell formation, sandy glacial sediment in moraine ridges (Pleistocene)

Qssm - Cromwell formation, sandy glacial sediment in moraine ridges (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 Atlas.

Qsgs - Cromwell formation, sandy glacial sediment (Pleistocene)

Qsgs - Cromwell formation, 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 Atlas.

Qsgw - Cromwell formation, wave-washed glacial sediment (Pleistocene)

Qsgw - Cromwell formation, 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 Atlas.

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

Qcs - Cromwell formation, till, sand and gravel (Quaternary)
Sandy till capped by, and/or interbedded with, sand and gravel. Locally consists of patchy till over thick deposits of sand and gravel. Includes areas too small to distinguish till from ice-contact deposits, and small areas of thick, loamy to sandy colluvium. Description from source map: Twin Cities Metro Region Surficial Geology.

Qcs - Cromwell formation, till, sand and gravel (Last Glaciation)
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: Chisago County Geologic Atlas.

Qct - Cromwell formation, supraglacial till (Pleistocene)

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 Metro Region Surficial Geology.

Qct - Cromwell formation, supraglacial Till (Last Glaciation)
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 Atlas.

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

Qcc - Cromwell formation, lake silt and clay (Last Glaciation)
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 Atlas.

Qsll - Cromwell formation, 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 Atlas.

Qcd - Cromwell formation, subglacial till (Pleistocene)

Qcd - Cromwell formation, subglacial till (Last Glaciation)
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 Atlas.

River Falls Formation

Formation description derived from Twin Cities Metro Region Surficial Geology Map.

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

Qro - River Falls Formation, outwash (Pleistocene)

Rfs - River Falls sand and gravel in outwash deposits (Quaternary)
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. Description from source map: St. Croix County Quaternary Geology.

Qro - River Falls Formation, outwash (Quaternary)
Sand, gravelly sand, and gravel. Strongly weathered from the top to a depth of about 10 feet (3 meters); contains some carbonate clasts below the leached zone; many coarse-grained fragments break apart easily; clasts coated with reddish clay occur in the upper part of the deposit. Description from source

map: Twin Cities Metro Region Surficial Geology.

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 Metro Region Surficial Geology.

Qrt - River Falls Formation, till (Pleistocene)

Rfd - River Falls diamicton (Quaternary)
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 Geology.

Qrt - River Falls Formation, till (Quaternary)
Chiefly sandy loam- to sandy clay loam-textured, unsorted sediment (diamicton), with pebbles, cobbles, and boulders. Interbedded in places with sorted sand and gravel. Deeply leached but calcareous below the leaching zone. Not mapped as a separate unit south of the Mississippi River. Preserved as patches on a stream dissected landscape. Description from source map: Twin Cities Metro Region Surficial Geology.

grf - River Falls Formation, glacial sediment (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 Geology.

Pierce Formation

Formation description derived from Twin Cities Metro Region Surficial Geology Map

(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. (Twin Cities Metro Region Surficial Geology).

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

He - Pierce Formation, Hersey diamicton (Quaternary)
Gray-dark gray clayey, compact, cohesive, interpreted as basal till or as colluvium in valleys, massive and structure-less, commonly contains limestone and organic matter, may be locally overlain by varved lake sediments of the Kinnickinic Member. Description from source map: (St. Croix County Quaternary Geology).

gh - Pierce Formation, Hersey Member, glacial sediment (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 Geology).

Qpg - Pierce Formation, glaciofluvial deposits (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 Metro Region Surficial Geology).

Qpt - Pierce Formation, till (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 Metro Region Surficial Geology).

PZr - Paleozoic bedrock, undivided (Paleozoic)

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

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 Geology.

Opg - Platteville and Glenwood Formations, undivided (Ordovician)

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 Metro Region Surficial Geology.

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 Metro Region Surficial Geology.

Opc - Prairie du Chien Group, undivided (Ordovician)

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

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 Metro Region Surficial Geology.

OCu - Bedrock, undivided (Ordovician and Cambrian)

OCu - Bedrock, undivided (Ordovician and Cambrian)
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 Metro Region Surficial Geology.

COu - Cambrian-Ordovician, Undivided (Pre-Last Glacial)
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 Atlas.

Cj - Jordan Sandstone (Cambrian)

Cj - Jordan Sandstone (Cambrian)
Medium- to coarse-grained, friable, cross-bedded sandstone. Discontinuously exposed, with a commonly sandy mantle generally less than 5 feet (1.5 meters) thick. Description from source map: Twin Cities Metro Region Surficial Geology.

Cu - Cambrian rocks, undivided (Cambrian)

Cu - Cambrian rocks, undivided (Cambrian)
Quartzose sandstone, feldspathic to glauconitic sandstone and siltstone, and dolomitic siltstone (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 Metro

Region Surficial Geology.

PCrs - Pre-Pleistocene rock, lithic sandstone, mudstone and conglomerate of the Oronto Group and quartz sandstone of the Bayfield Group (Cambrian or Late Proterozoic and Middle Proterozoic)

rs - Pre-Pleistocene rock, lithic sandstone, mudstone and conglomerate of the Oronto Group and quartz sandstone of the Bayfield Group (Middle Proterozoic and Late Proterozoic or 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 Geology.

PCcgb - Chengwatana Group, basalt (Precambrian)

PC - Chengwatana Group basalt (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 Geology.

PCmc - Clam Falls volcanics (Mesoproterozoic)

Pmc - Clam Falls volcanics (Pre-Last Glacial, 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 Atlas.

PCrv - Pre-Pleistocene rock, volcanic rock (Middle Proterozoic)

rv - Pre-Pleistocene rock, volcanic rock (Middle Proterozoic)
Middle Proterozoic volcanic rock Description from source map: Superior Region Pleistocene Geology.

PCri - Pre-Pleistocene rock, intrusive rock (Middle Proterozoic)

ri - Pre-Pleistocene rock, intrusive rock (Middle Proterozoic)
Middle Proterozoic intrusive rock Description from source map: Superior Region Pleistocene Geology.

Geologic Cross Sections

The geologic cross sections present in the GRI digital geologic-GIS data produced for Saint Croix National Scenic Riverway, Minnesota and Wisconsin (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.

Some unit symbols shown in the cross sections differ from their unit symbol present in the GRI digital geologic-GIS data.

Cross sections have been grouped into respective source map "books", accompanied by related source map cross section unit description and legend information. Only cross sections within or intersecting the GRI digital geologic-GIS data were included. 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).

Chisago County Cross Sections

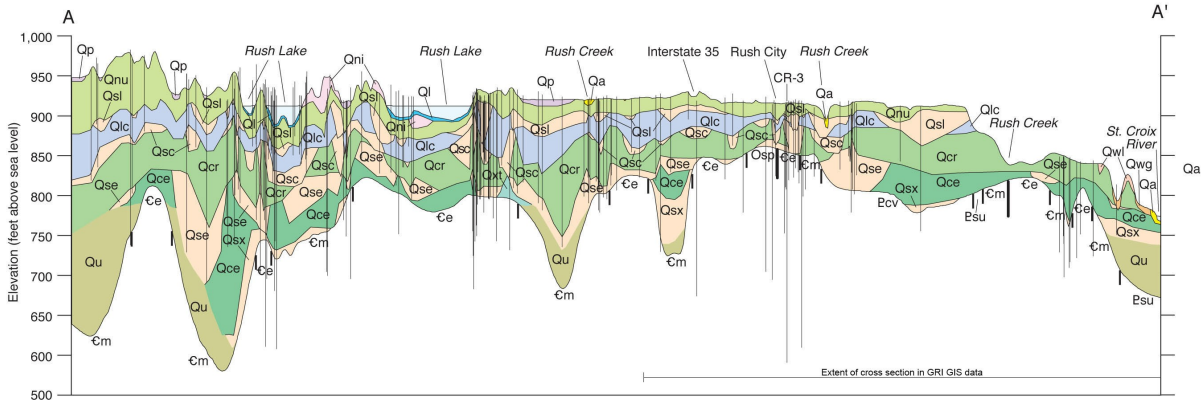
Description of Cross Section Units

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 having an identical description, label, and color as on Plate 3, Surficial Geology; see Plate 3 for detailed descriptions. 2. Modified unit-multiple units from Plate 3 combined into one unit on the cross sections. 3. New unit-unit that appears only on the cross sections that has a unique label and color (the new sand and gravel units have the same color to emphasize their status as potential aquifers). All the till units of the New Ulm Formation are combined into one unit, and the Cromwell Formation is depicted differently than on the surficial geology map to emphasize subsurface hydrogeologic characteristics. Deposits of the three phases of the Superior lobe that compose the Cromwell Formation 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 Automba phase deposits in Chisago County, the characteristics of the various tills of Superior provenance are quite similar (Table 1). Without the intervening yellow to gray, fine-textured till of unit Qxt, it was 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 units Qce and Qrt.

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: (Chisago County Geologic Atlas).

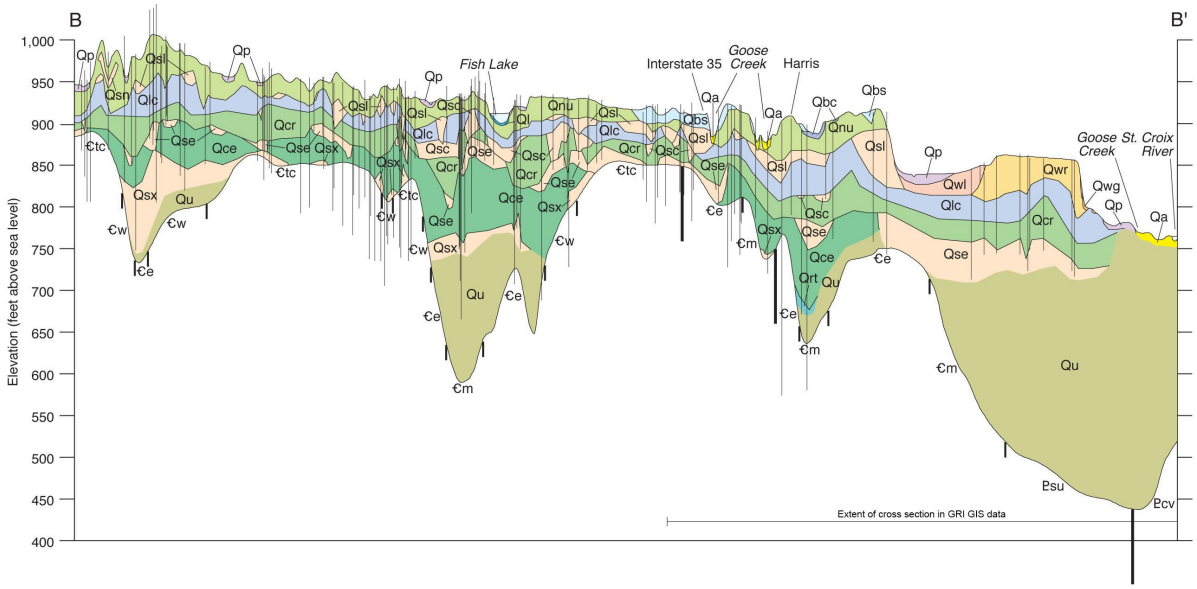
Cross Section A-A'



Graphic from source map: (Chisago County Geologic Atlas). 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).

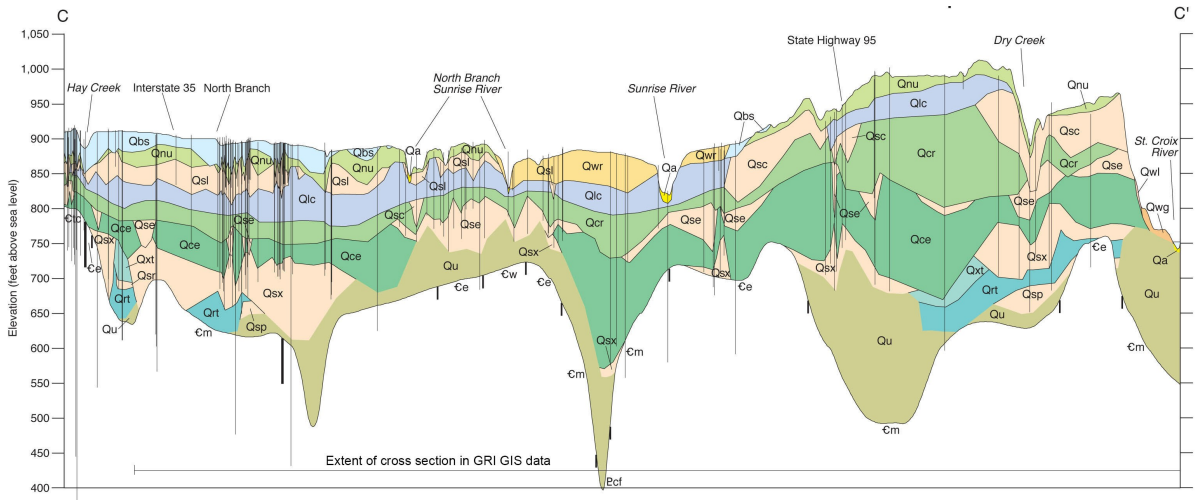
Cross Section B-B'



Graphic from source map: (Chisago County Geologic Atlas). 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).

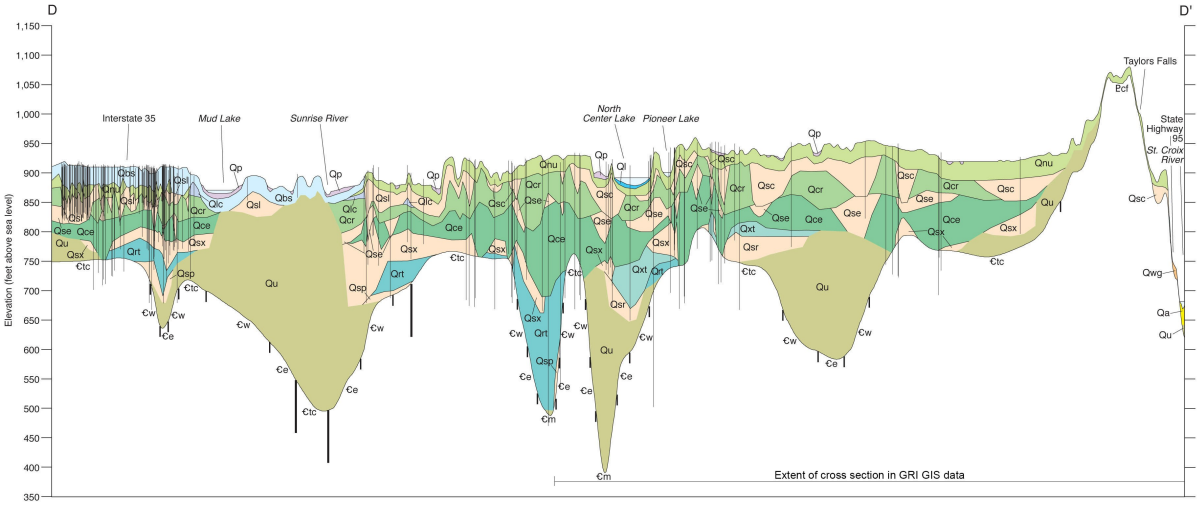
Cross Section C-C'



Graphic from source map: (Chisago County Geologic Atlas). 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).

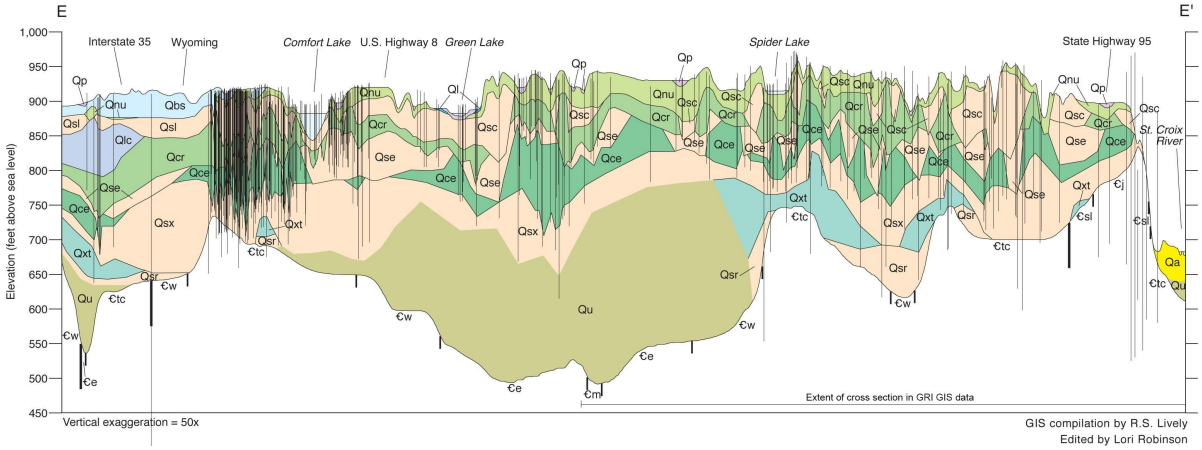
Cross Section D-D'



Graphic from source map: (Chisago County Geologic Atlas). 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 E-E'



Graphic from source map: (Chisago County Geologic Atlas). 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 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*.

Graphic from source map: (Chisago County Geologic Atlas).

Cross Section Symbols

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.

Graphic from source map: (Chisago County Geologic Atlas).

Figure 1: Cross Section Unit Correlation

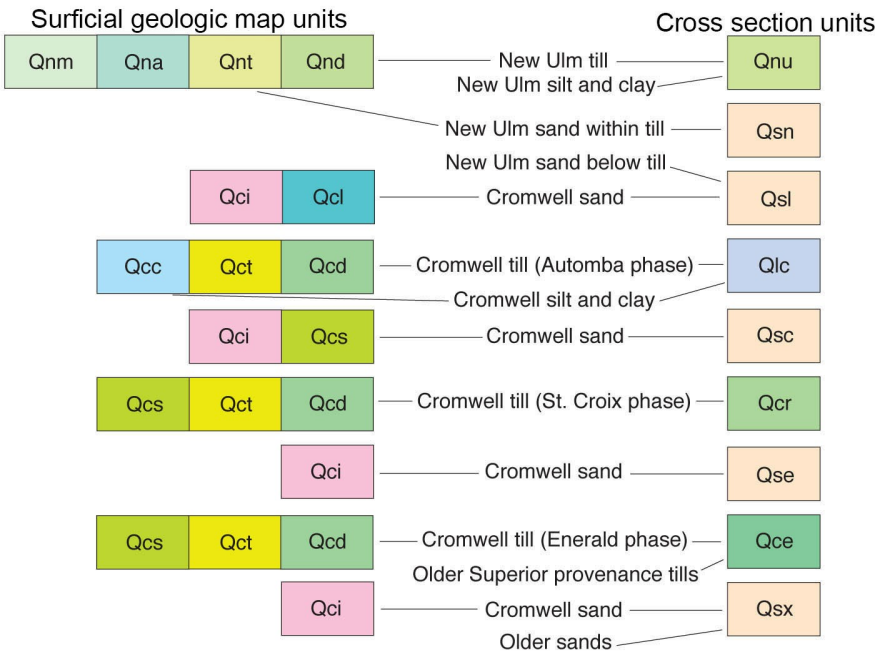


Figure 1. Diagram correlating the units on this plate to those on Plate 3, *Surficial Geology*.

Graphic from source map: (Chisago County Geologic Atlas).

Figure 2: Cross Section Location Map

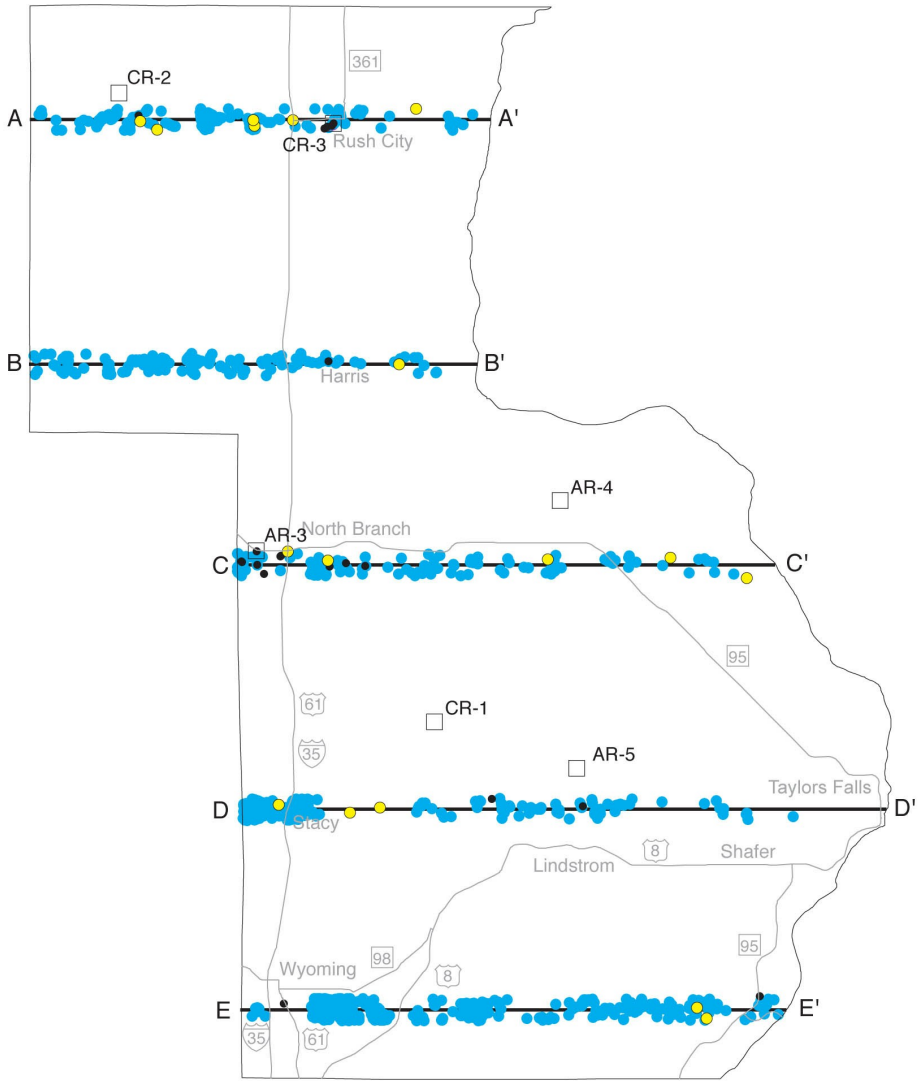
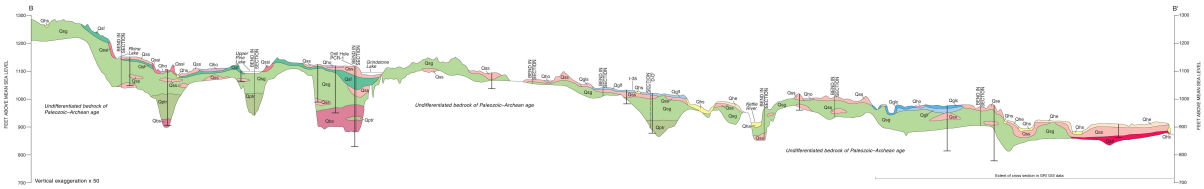


Figure 2. Diagram showing locations of cross sections A–A' through E–E', and the locations of the data points used in compiling stratigraphy for these five cross sections. Blue dots represent water-well drillers' sites with a log recorded in the County Well Index (only shown where within 0.3 mile [0.5 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 Atlas).

Pine County Cross Sections

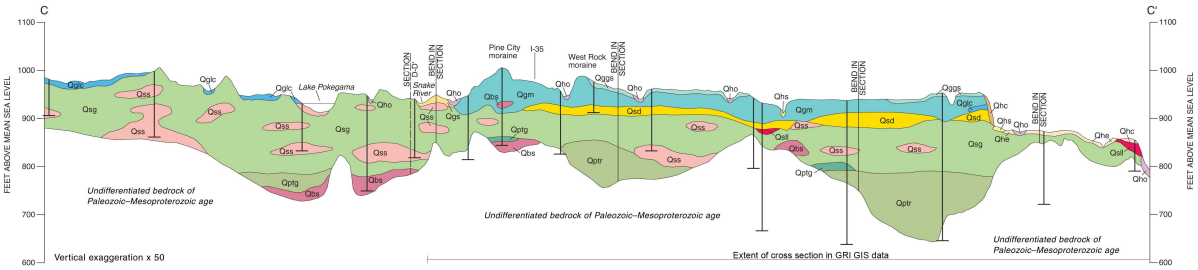
Cross Section F-F'



Graphic from source map: (Pine County Geologic Atlas). 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 G-G'



Graphic from source map: (Pine County Geologic Atlas). 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 Legend

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

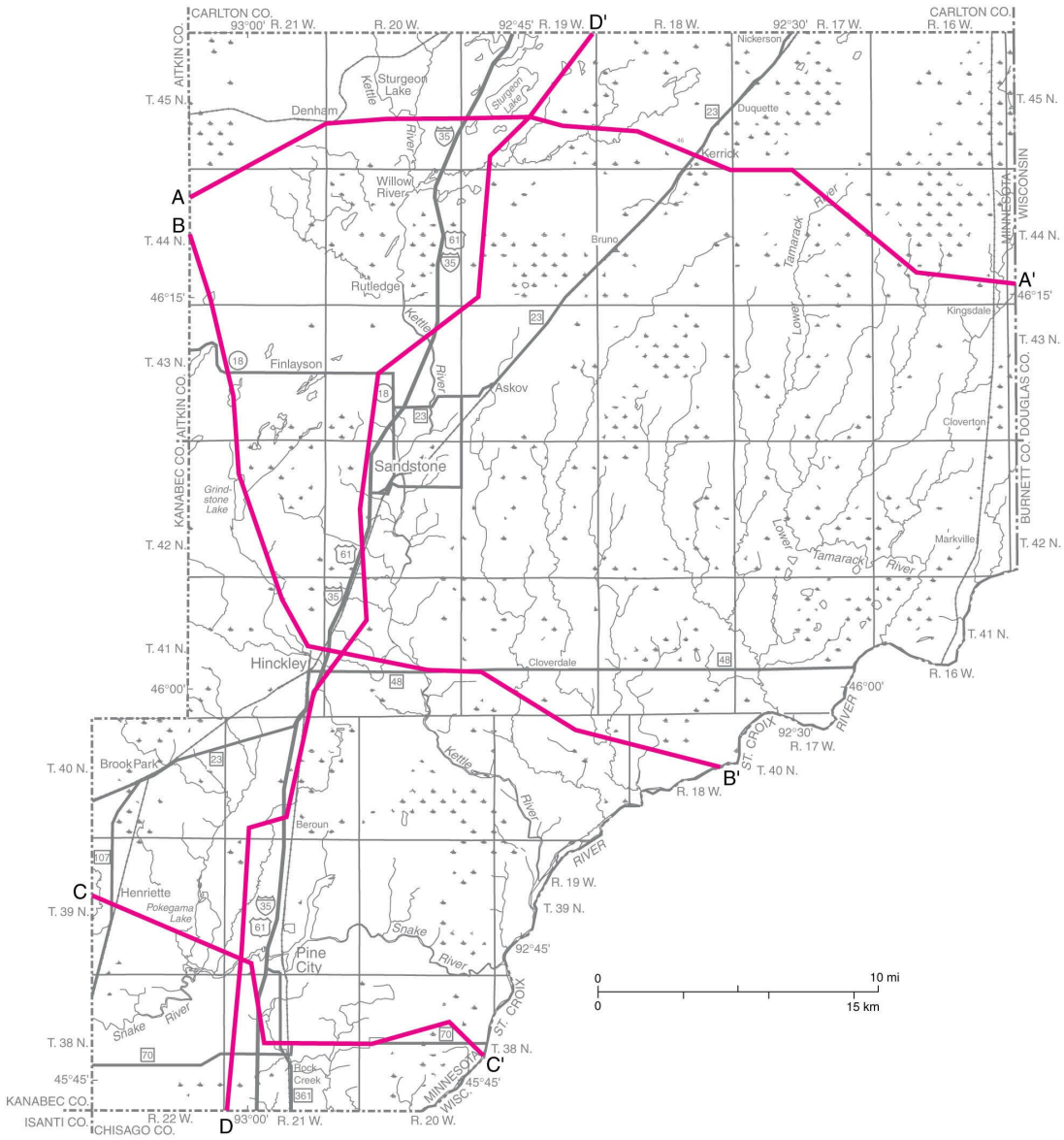
- Qsd — *Fluvial deltaic deposits*—Red, fine- to medium-grained, well-sorted, bedded sand. Interpreted as stream sediment deposited as a prograding delta into glacial Lake Lind (Johnson and others, 1999) by meltwater of the Superior lobe (Figs 3E, 3F, 3G, and 3H). Sediment filled much of the lake basin. 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

Graphic from source map: (Pine County Geologic Atlas).

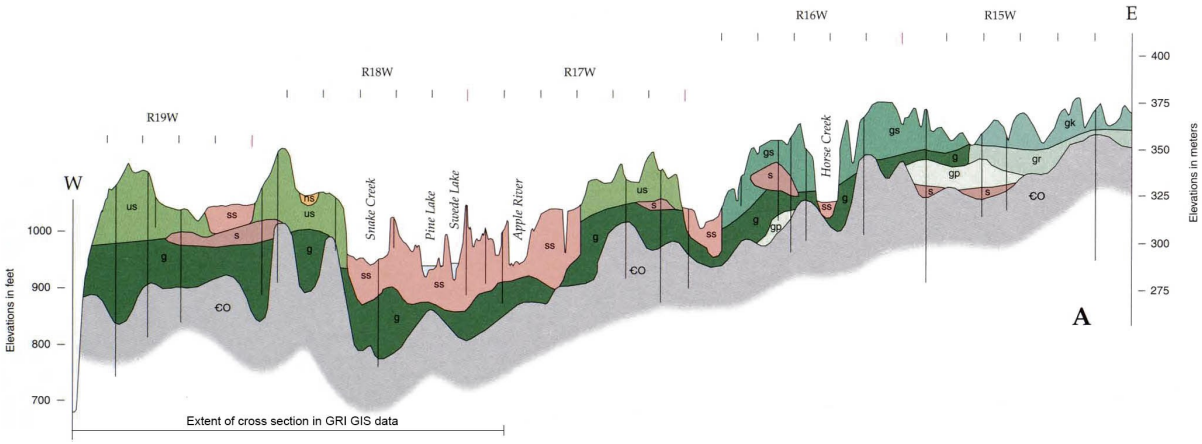
Cross Section Location Map



Graphic from source map: (Pine County Geologic Atlas).

Polk County Cross Sections

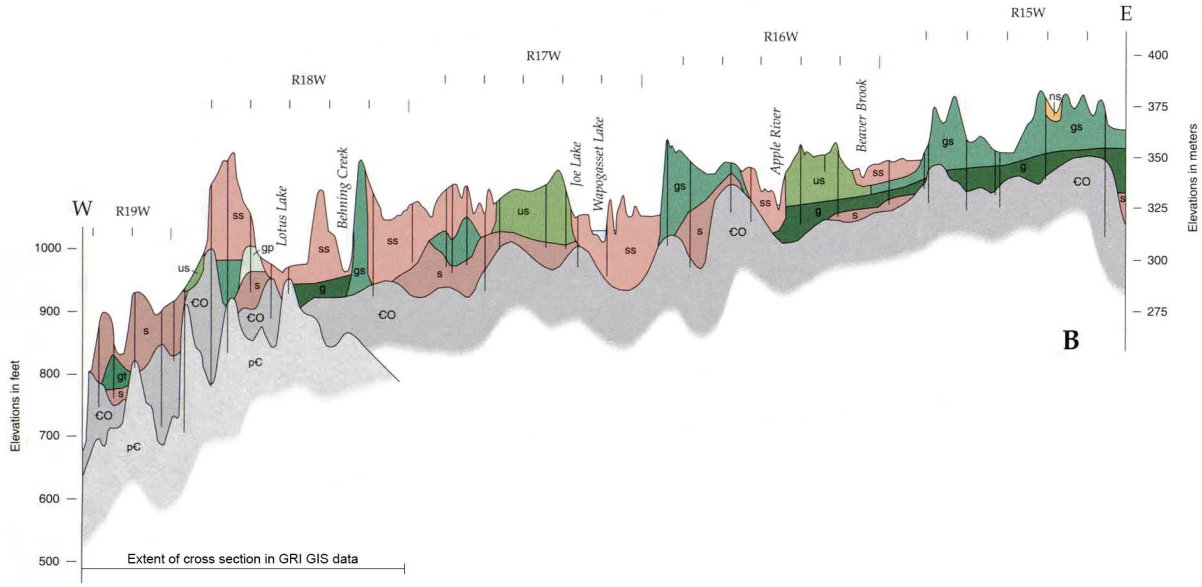
Cross Section H-H'



Graphic from source map: (Polk County Pleistocene Geology). 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).

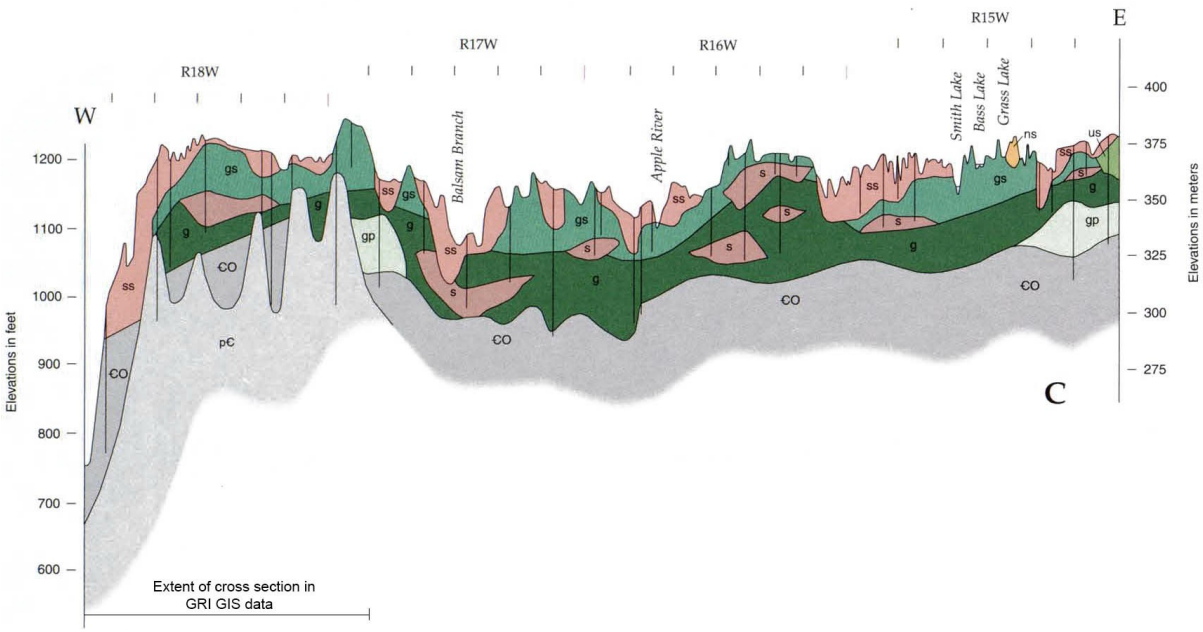
Cross Section I-I'



Graphic from source map: (Polk County Pleistocene Geology). 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).

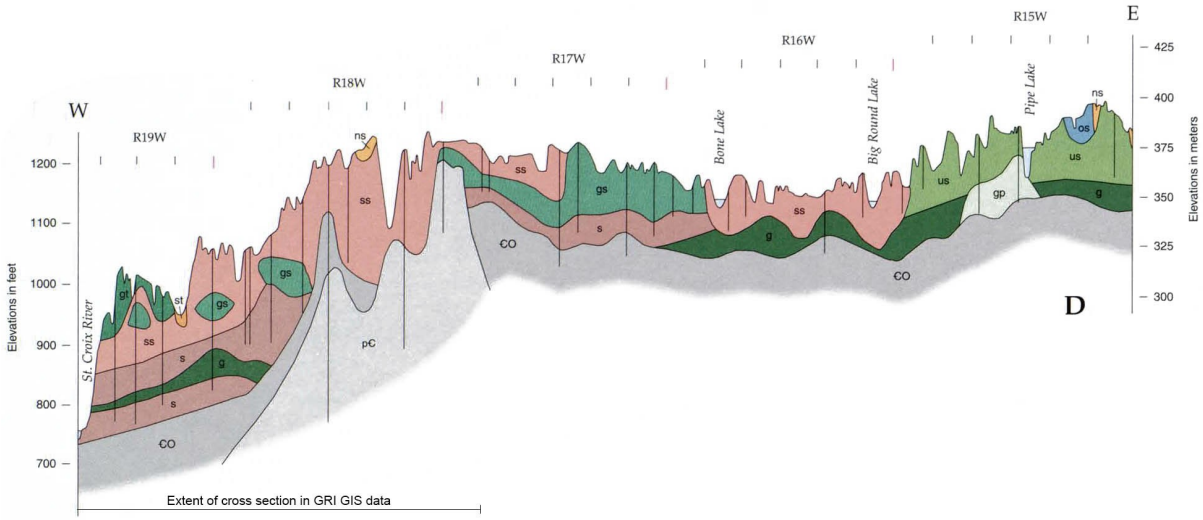
Cross Section J-J'



Graphic from source map: (Polk County Pleistocene Geology). 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).

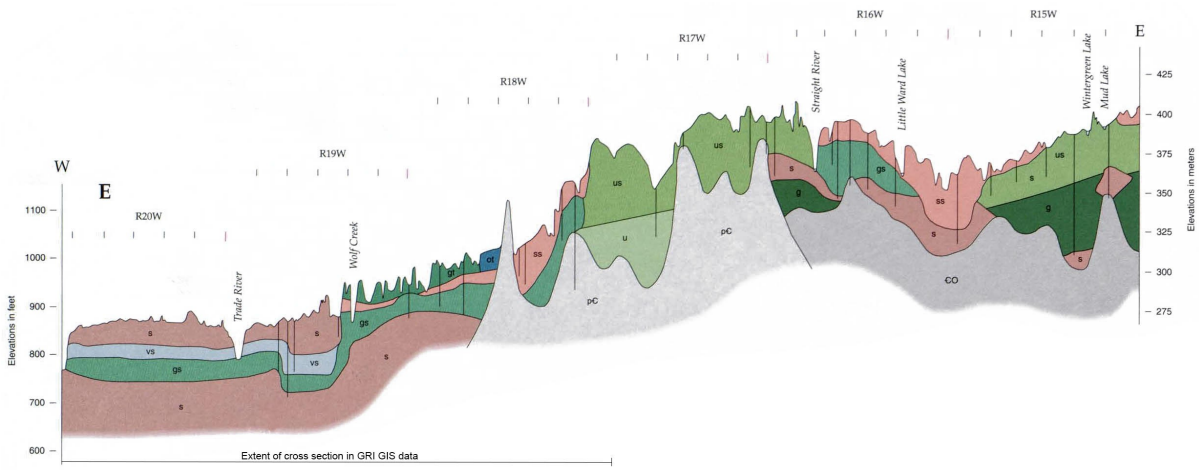
Cross Section K-K'



Graphic from source map: (Polk County Pleistocene Geology). 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).

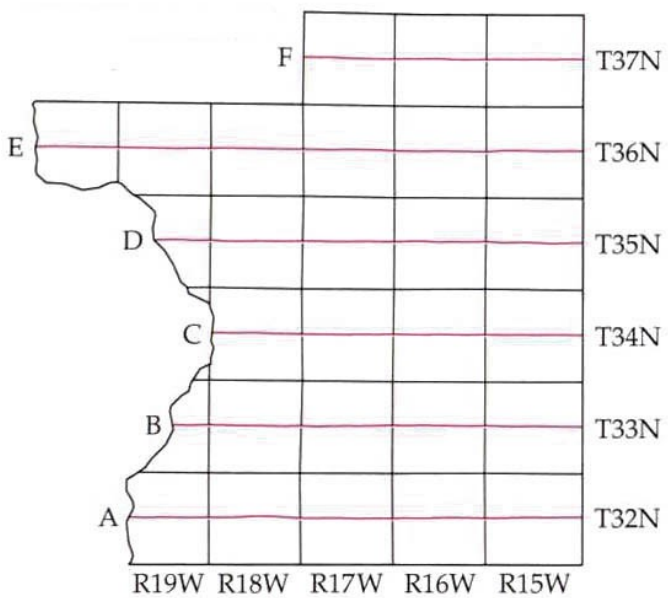
Cross Section L-L'



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

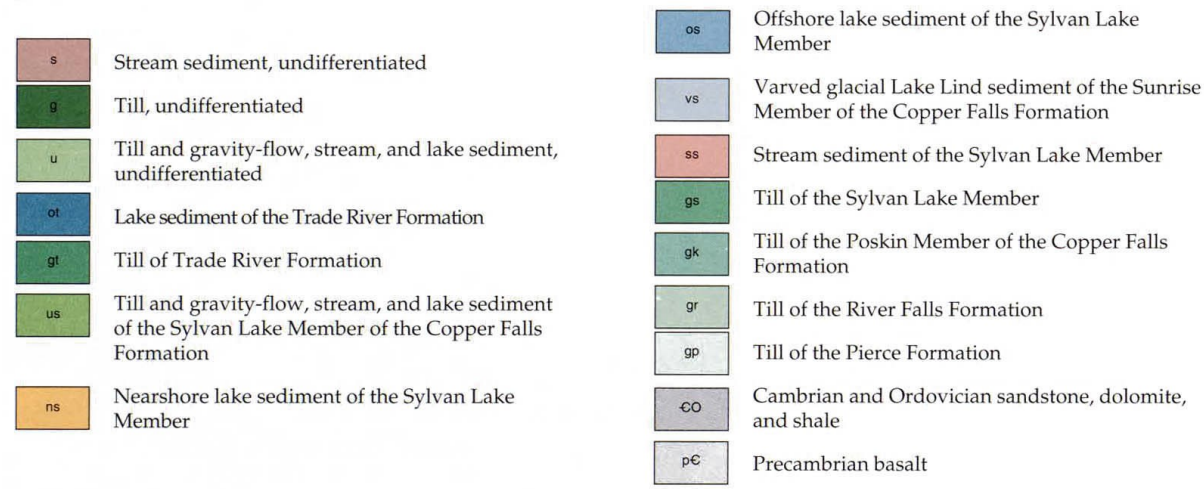
Only a limited extent of the cross section is within the extent of the GRI digital geologic-GIS data. This is indicated on the cross section graphic by the extent bar with text along the bottom of the graphic (beginning in the bottom left).

Cross Section Index Map



Graphic from source map: (Polk County Pleistocene Geology).

Cross Section Legend



Graphic from source map: (Polk County Pleistocene Geology).

Cross Section Explanation

Vertical lines on the cross sections represent the location and depth of drill holes within 2 km north or south of the cross-section line; data from these drill holes were used to compile the cross sections. Information sources include unpublished logs of test holes drilled for this study, Wisconsin Department of Natural Resources Well Constructor's Reports, and Wisconsin Geological and Natural History Survey Geologic Logs. The surface topography was taken form 7.5 minute quadrangles (U.S. Geological Survey, scale 1:24,000).

Text from source map: (Polk County Pleistocene Geology).

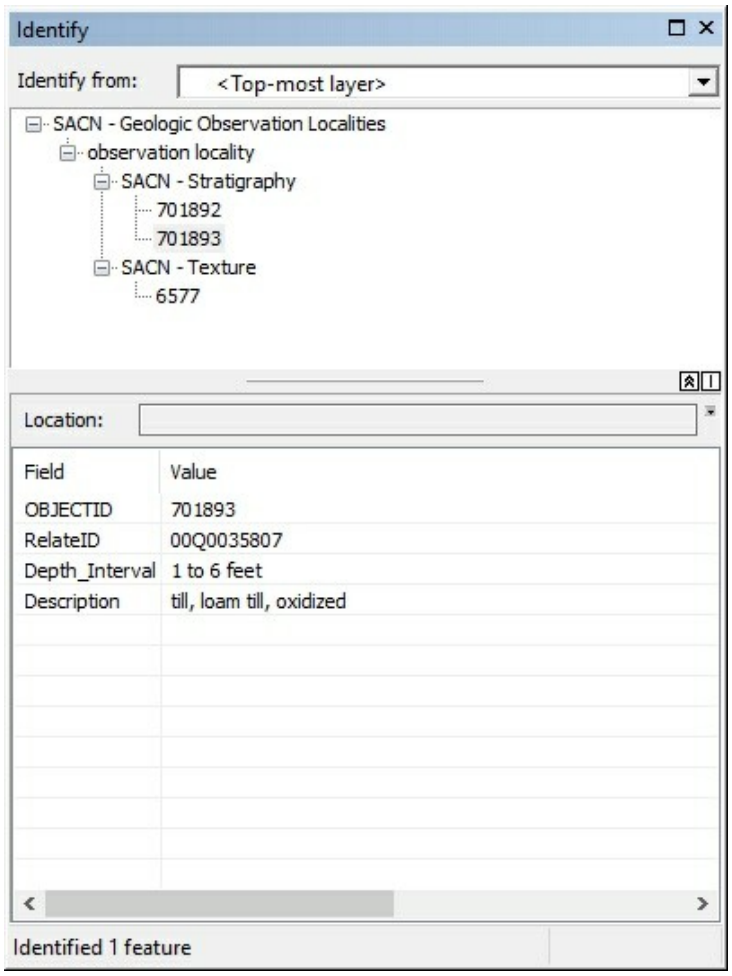
Additional GIS Tables

Four additional GIS tables were included in the GRI digital geologic-GIS data. These tables contain tabular information specific to certain points in the Geologic Observation Localities (SACNGOL) and Hazard Point Features (SACNHZP) feature classes, and are accessible through a GIS relationship class connecting the relevant point data to these tables. It is recommended to use the *Identify Tool* in ArcMap to select a point and view attribute table/related table information.

Quaternary Data Index Tables

The Geologic Observation Localities feature class (SACNGOL) contains point data representing core and drill hole information from the Minnesota Quaternary Data Index (Minnesota Quaternary Data Index). Two tables are related to SACNGOL, Stratigraphy and Texture. The Stratigraphy table holds depth interval and material description information derived from the core and drill hole data. The Texture table shows depth interval and percentage amounts for material, age and lithology for each respective depth interval. More than one record can be related to a single point showing information for multiple depth intervals. Not all points have respective records in each table.

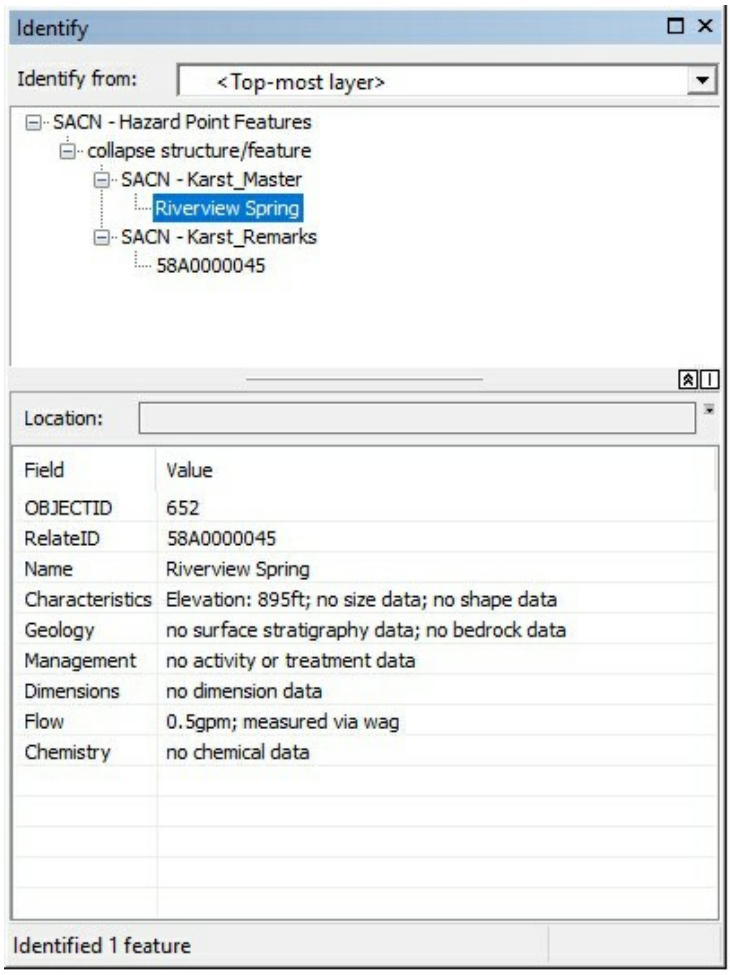
Use the *Identify Tool* in ArcMap to select a point and view related table information. See example below.



Minnesota Karst Features Tables

The Hazard Point Features feature class (SACNHZP) contains point data representing sinkhole, collapse structure and relate spring information from the Minnesota Karst Features (Minnesota Karst Features). Two tables are related to SACNHZP, Karst_Master and Karst_Remarks. The Karst_Master table holds identity, feature characteristic and flow data. The Karst_Remarks table stores general remarks about the feature. More than one record can be related to a single point showing information for multiple depth intervals. Not all points have respective records in each table.

Use the *Identify Tool* in ArcMap to select a point and view related table information. See example below.



GRI 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, Minnesota and Wisconsin (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.

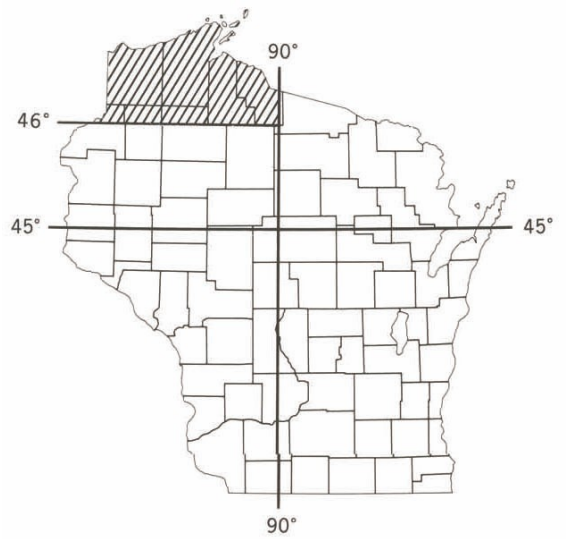
Superior Region Pleistocene Geology

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 Geology).

Map Legend

Abandoned beaches and wave-cut bluffs.

Cutbanks of large abandoned river channels.

Direction of flow of proglacial streams.

Low, narrow drumlins formed during the last glacial advance. Arrowhead indicates direction of glacial movement.

High, wide drumlins formed during an earlier glacial episode and only slightly modified during the last glacial episode.

Direction of subglacial scratches on rock surfaces.

Glacial ridges, transverse to ice-movement direction, including ice-thrust masses in map unit gt and small end moraines in map units gu, gc, gg, gm,sg, and p.

Eskers; arrowhead point in direction of stream flow.

Graphic from source map: (Superior Region Pleistocene Geology).

Twin Cities Metro Area Construction Aggregate

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 Metro Area Construction Aggregate).

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):

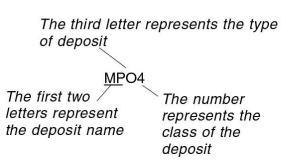
- Excellent to good (less than 1.5 percent total spall materials)
- Good to moderate (less than 5 percent total spall materials)
- Moderate to poor (generally more than 5 percent total spall materials)

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 Metro Area Construction Aggregate).

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 Metro Area Construction Aggregate).

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

Graphic from source map: (Twin Cities Metro Area Construction Aggregate).

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.

Graphic from source map: (Twin Cities Metro Area Construction Aggregate).

Polk County Pleistocene Geology

The formal citation for this source.

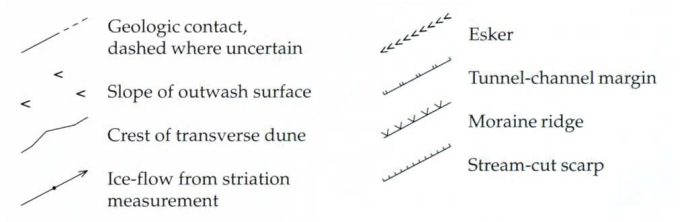
Johnson, M.D., 2000, Pleistocene Geology of Polk County, Wisconsin: Wisconsin Geological and Natural History Survey, Bulletin 92, scale 1:100,000 (*GRI Source Map ID 50580*).

Prominent graphics and text associated with this source.

Location Map

Graphic from source map: (Polk County Pleistocene Geology).

Map Legend



Graphic from source map: (Polk County Pleistocene Geology).

St. Croix County Quaternary Geology

The formal citation for this source.

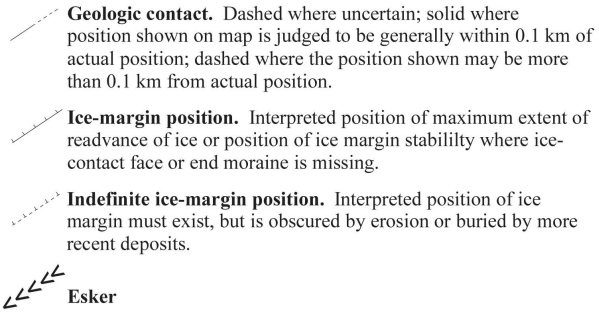
Kostka, S.J., Hinke, D.M., Mickelson, D.M., and Baker, R.W., 2004, Preliminary Quaternary Geologic Map for St. Croix County, Wisconsin: Wisconsin Geological and Natural History Survey, Open-File Report 2004-22, scale 1:100,000 (*GRI Source Map ID 75428*).

Prominent graphics and text associated with this source.

Location Map

Graphic from source map: (St. Croix County Quaternary Geology).

Map Legend



Graphic from source map: (St. Croix County Quaternary Geology).

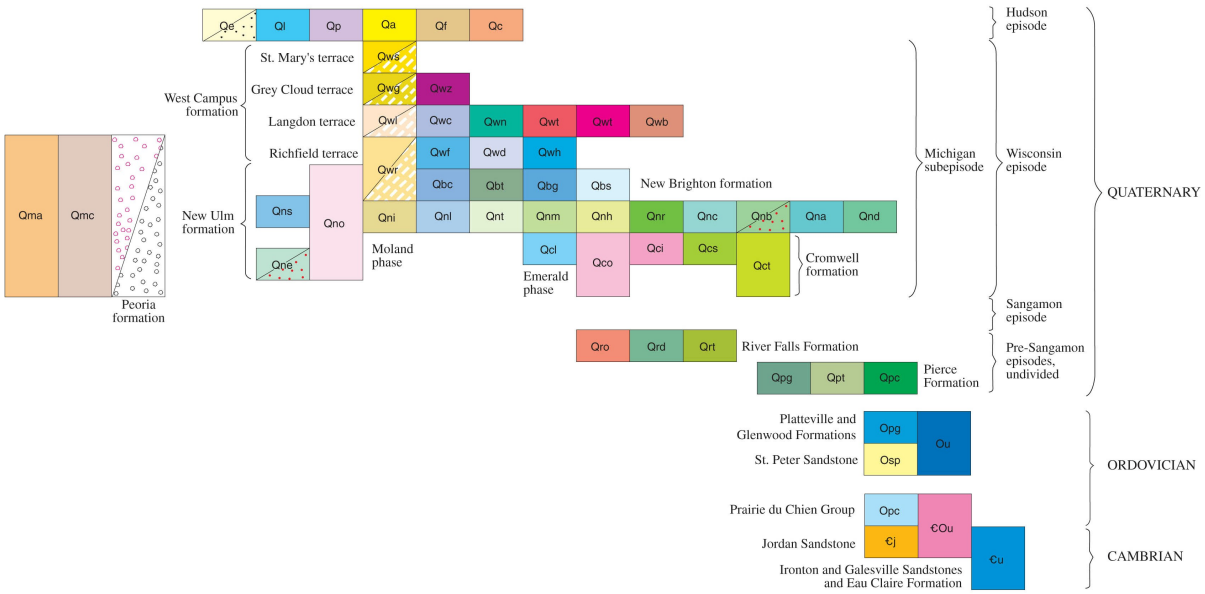
Twin Cities Metro Region Surficial Geology

The formal citation for this source.

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

Prominent graphics and text associated with this source.

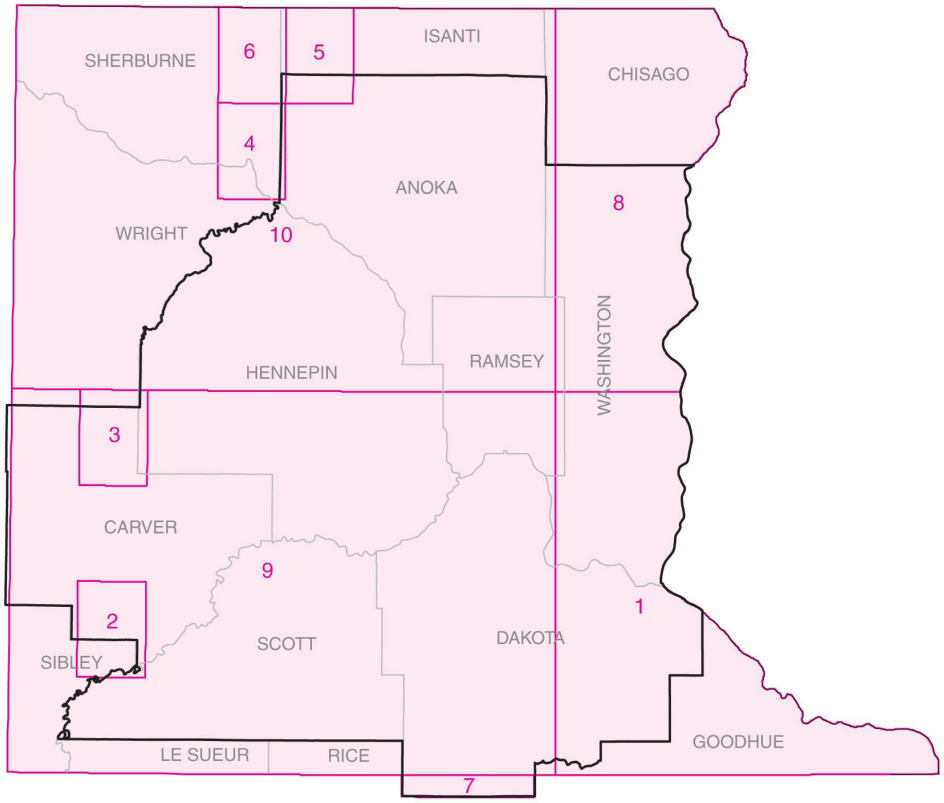
Correlation of Units



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 Metro Region Surficial Geology).

Index Map

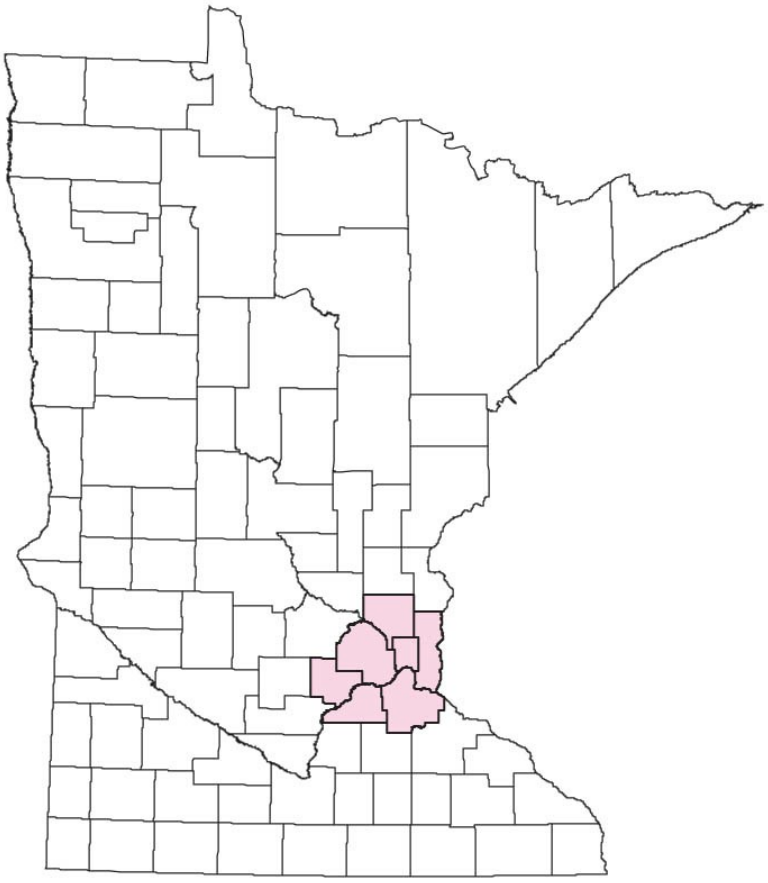


INDEX TO EXISTING QUATERNARY MAPPING

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 Metro Region Surficial Geology).

Location Map



Graphic from source map: (Twin Cities Metro Region Surficial Geology).

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 Metro Region Surficial Geology).

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

Graphic from source map: (Twin Cities Metro Region Surficial Geology).

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(4)———2002b, Surficial geology of the Elk River quadrangle, Sherburne, Wright, and Anoka Counties, Minnesota: Minnesota Geological Survey Miscellaneous Map M-124, scale 1:24,000.

(5)———2003a, Surficial geology of the Crown quadrangle, Anoka and Isanti Counties, east-central Minnesota: Minnesota Geological Survey Miscellaneous Map M-133, scale 1:24,000.

(6)———2003b, Surficial geology of the Lake Fremont quadrangle, Sherburne, Isanti, and Anoka Counties, east-central Minnesota: Minnesota Geological Survey Miscellaneous

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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.

Graphic from source map: (Twin Cities Metro Region Surficial Geology).

Chisago County Geologic Atlas

The formal citation for this source.

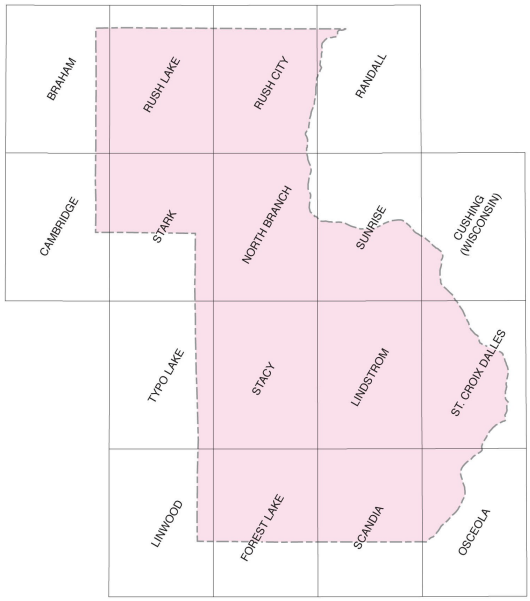
Setterholm, Dale R., 2010, Geologic Atlas of Chisago County, Minnesota (6 plates): Minnesota Geological Survey, County Atlas Series C-22 Part A, scale 1:100,000 (*GRI Source Map ID 76137*).

Prominent graphics and text associated with this source.

Location Map

Graphic from source map: (Chisago County Geologic Atlas).

Index Map



INDEX TO 7.5-MINUTE QUADRANGLES

Graphic from source map: (Chisago County Geologic Atlas).

Plate 1: Data-Base Map

Map Legend

- Record of water-well construction (well driller's log)
- Rotary-sonic core
- Cutting sample
- Borehole geophysical log
- Soil boring
- Giddings probe hole
- Field site
- Soil auger hole
- Gravel pit location
- Large gravel pit, or more than one gravel pit
- Seismic sounding
- Bedrock outcrop

Note: More than one symbol can occur at the same location

Graphic from source map: (Chisago County Geologic Atlas).

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 Atlas).

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 Atlas).

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 Atlas).

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 Atlas).

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 Atlas).

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 latitudelongitude 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 Atlas).

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 Atlas).

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

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:

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

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 Atlas).

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 Atlas).

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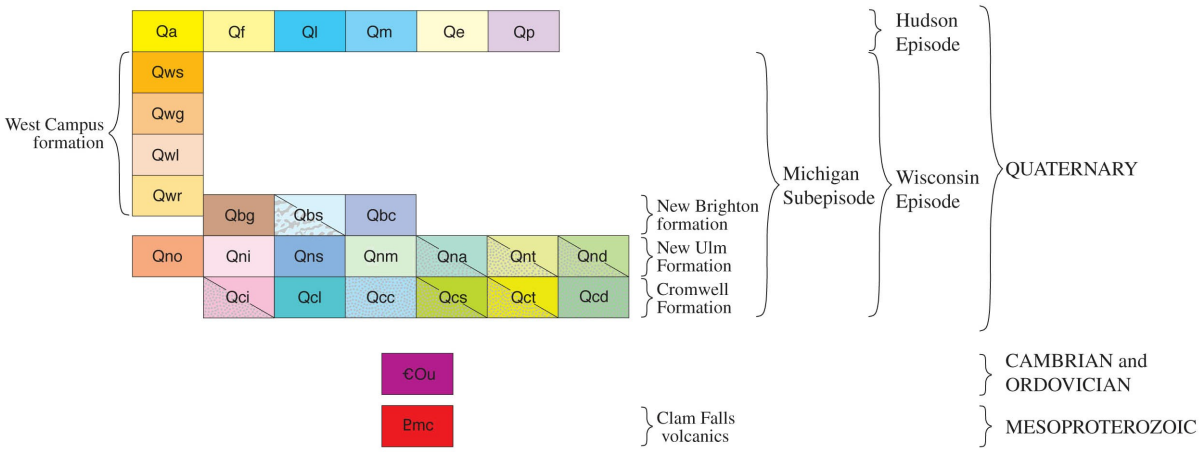
Text from source map: (Chisago County Geologic Atlas).

Plate 3: Surficial Geology

Correlation of Units



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

Graphic from source map: (Chisago County Geologic Atlas).

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 Atlas).

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

Graphic from source map: (Chisago County Geologic Atlas).

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 Atlas).

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 Atlas).

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 Atlas).

Figures 1 & 2: Rock Unit and Land Surface Classification

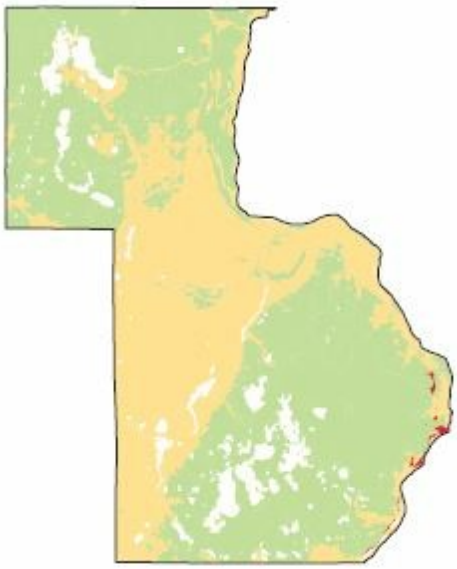


Figure 1. The map units from the 1:100,000 surficial geology map are combined into three simplified units in this figure: green is less permeable diamicton (glacial till) and bedded silt and clay; yellow is more permeable, bedded sand to gravel; and red is bedrock. Water bodies are white.

Graphic from source map: (Chisago County Geologic Atlas).

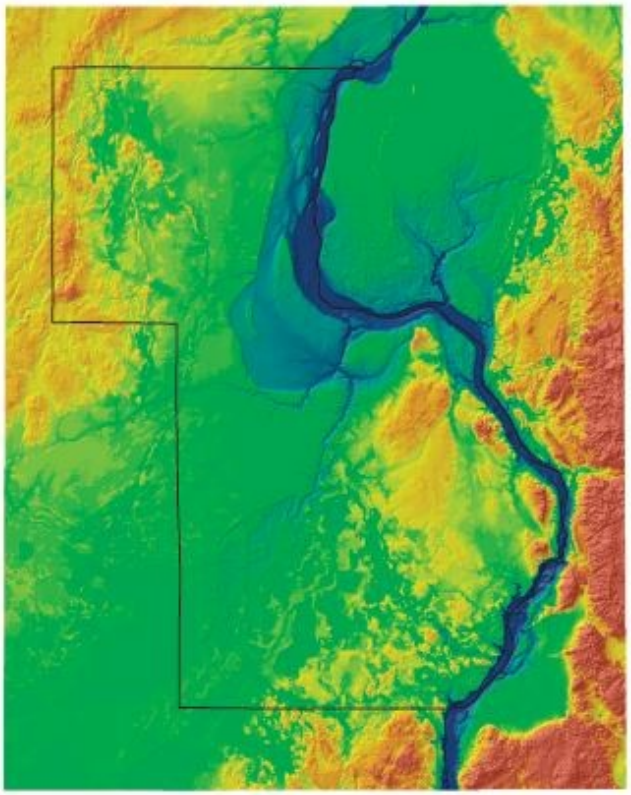


Figure 2. Physical relief of the land surface in Chisago County. Elevation is shown by color: red (higher surface elevation) grading to blue (lower surface elevation). A false sun illumination at an elevation of 30° from the northwest (315°) provides contrast (gray shadowing) to accent details of landforms.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

Graphic from source map: (Chisago County Geologic Atlas).

Figure 3: Glacial Events

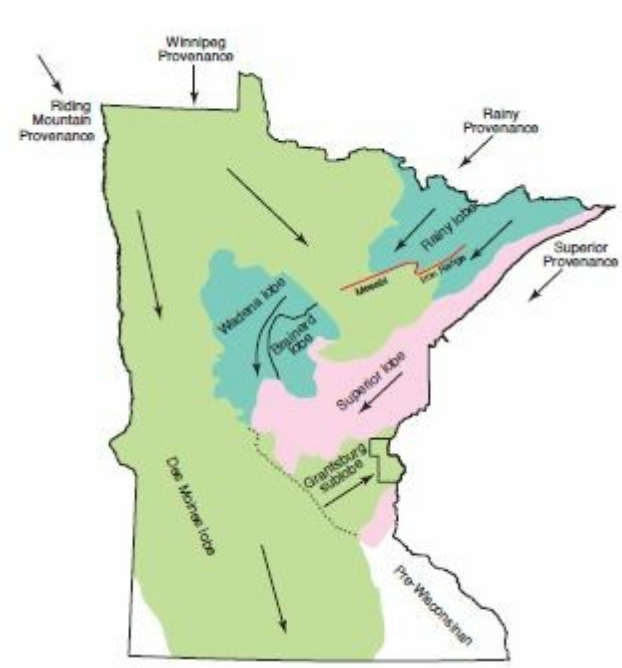


Figure 3. Location of major provenances (source regions). Glacial sediments deposited in the county derive their distinct material content from bedrock and sediment found in the region of these provenances. During the last glaciation, the Michigan Subepisode, Chisago County was repeatedly covered by 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 Atlas).

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.

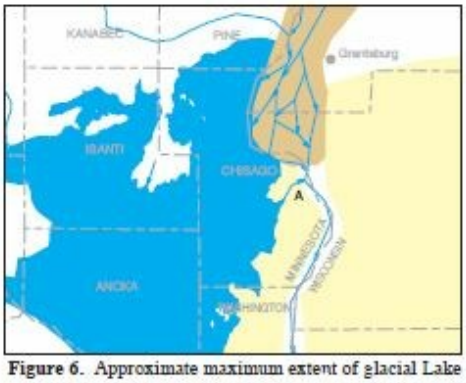


Figure 6. Approximate maximum extent of glacial Lake Anoka, dammed by the Barrens fan. An early secondary (overflow?) outlet is shown at A.

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).

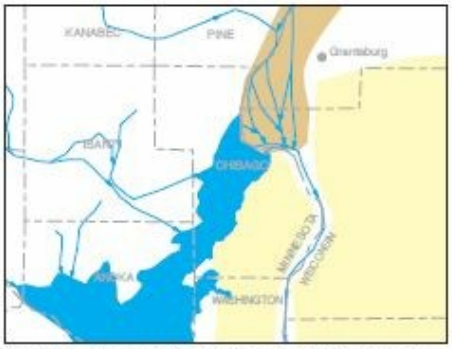


Figure 8. Glacial Lake Anoka at the Fridley level, prior to drainage of most of the lake when a southern outlet opened at Minneapolis.

Graphics from source map: (Chisago County Geologic Atlas).

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Text from source map: (Chisago County Geologic Atlas).

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 Atlas).

Figure 3: Relative Age Diagram

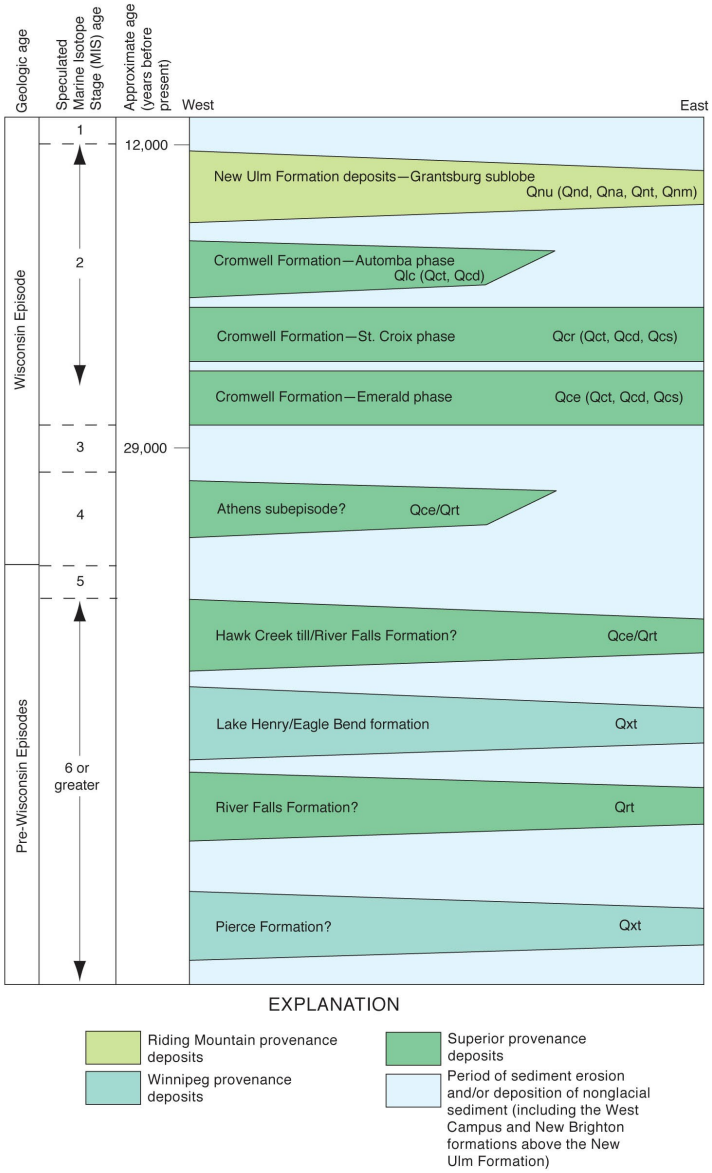


Figure 3. Diagram showing relative age, locations (across Chisago County from west to east), provenance (on Plate 3 see Fig. 3 and Table 1), and related unit labels from the cross sections for Wisconsin Episode and pre-Wisconsin Episode glacial deposits (Table 1); corresponding units from the surficial 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 Atlas).

Figure 4: Core Pollen Diagram

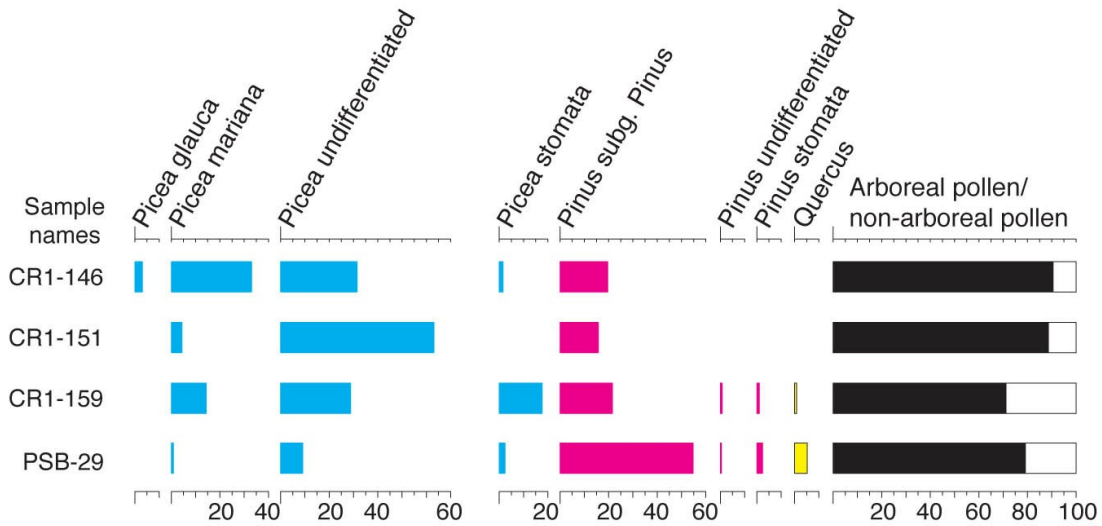


Figure 4. Diagram showing percent of pollen in an organic-bearing interval in core CR-1 (Fig. 5) with emphasis on spruce (Picea, blue), pine (Pinus, magenta), and oak (Quercus, yellow). Sample CR1-146 was taken at a depth of 146 feet (45 meters), CR1-151 at 151 feet (46 meters; and radiocarbon-dated 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 Atlas).

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

Graphic from source map: (Chisago County Geologic Atlas).

Acknowledgements

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 Atlas).

Borehole Cores

Figure 5: CR-1

Borehole name: CR-1 Unique number: 763777
T. 34 N., R. 21 W., sec. 12; CDDCBA
Elevation in feet above mean sea level: 875

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 Atlas).

Figure 6: CR-2

Borehole name: CR-2 Unique number: 763776
T. 37 N., R. 22 W., sec. 16; ACCDDC
Elevation in feet above mean sea level: 924

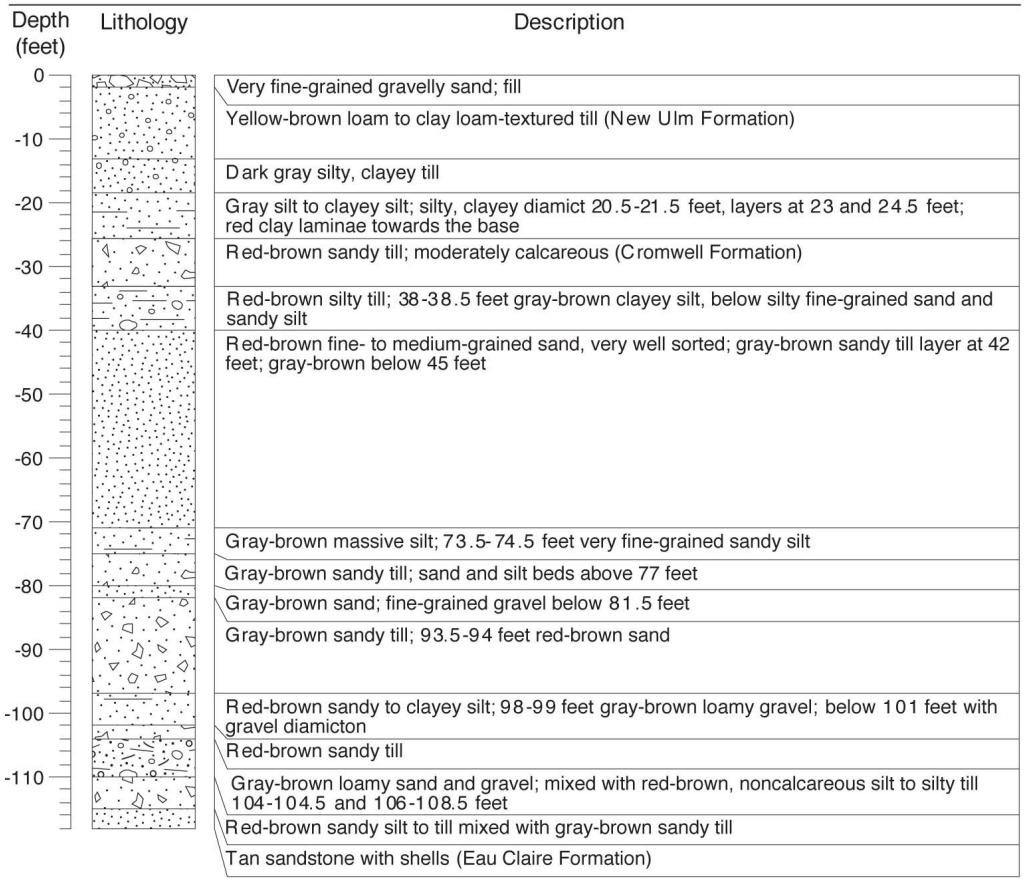


Figure 6. Descriptive log of rotary-sonic core CR-2, drilled by Mark J. Traut Wells for this study. Location of drilling is shown on Figure 2 and Plate 1, *Data-Base Map*.

Graphic from source map: (Chisago County Geologic Atlas).

Figure 7: CR-3

Borehole name: CR-3 Unique number: 270111
T. 37 N., R. 21 W., sec. 21; ACACDD
Elevation in feet above mean sea level: 910

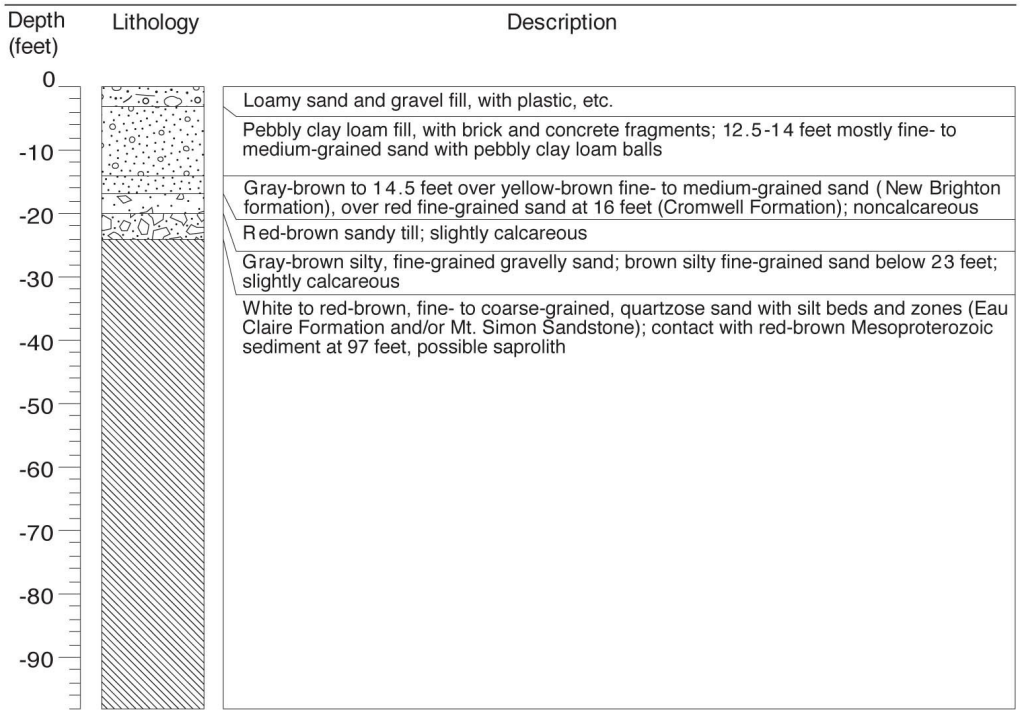
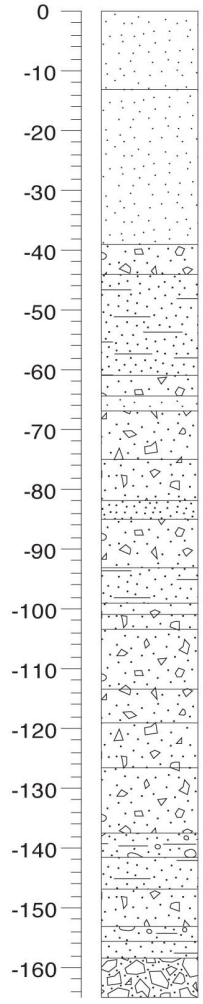


Figure 7. Descriptive log of rotary-sonic core CR-3, drilled by Mark J. Traut Wells for this study. Location of drilling is shown on Figure 2 and Plate 1, *Data-Base Map*.

Graphic from source map: (Chisago County Geologic Atlas).

Figure 8: AR-3

Borehole name: AR-3 Unique number: 247207
T. 35 N., R. 21 W., sec. 19; ACBBBC
Elevation in feet above mean sea level: 890



Description
Yellow-orange fine-grained sand (New Brighton formation) ; 12-12.5 feet gravelly sand; 12.5-13 feet yellow sandy till (New Ulm Formation)
Red-brown fine-grained sand, very well sorted (Cromwell Formation)
Red-brown till, calcareous; 39-40 feet silt, few clay laminae
Gray-brown silt; red clay laminae 46-50.5, 51.5-56, and at 58 feet
Red-brown sandy till; silt and clay beds below 63 feet
Red-brown fine-grained sand; well sorted
Red-brown sandy till; silt and clay inclusions 70-70.5 feet
Gray-brown sandy till; inclusions of laminated silt and clay; silty fine-grained sand 80-80.5 feet
Gray-brown fine-grained sand to silty gravelly sand
Gray-brown sandy till with gravelly sand; 86-87 feet silty gravelly sand
Gray-brown finely laminated sandy to clayey silt; grades to silty diamict below 97 feet
Gray-brown very sandy till
Red-brown very gravelly sandy till
Gray-brown sandy till; fine-grained sand 107-107.5 feet
Gray-olive sandy till; common local bedrock clasts; laminated silt at 118 feet
Gray-brown sandy till; sand 121.5-122 feet; gray till inclusions at 122, 124.5 feet; red-brown below 123 feet
Gray fine loamy-textured till; abundant carbonate decreases with depth; Winnipeg provenance
Gray silty till, grades to silt below 141 feet; mixed provenance
Gray-brown fine-grained sand with silt inclusions; gray silt to clayey silt below 146 feet
Gray to dark brown diamict with organics; noncalcareous; Superior provenance
Gray-brown coarse-grained sand to silty, cobbly sand
Gray to brown clayey silt to silt; noncalcareous
Brown to gray-brown, silty gravelly sand; 158.5-159.5 feet fine-grained to silty very fine-grained sand

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 Atlas).

Figure 9: AR-4

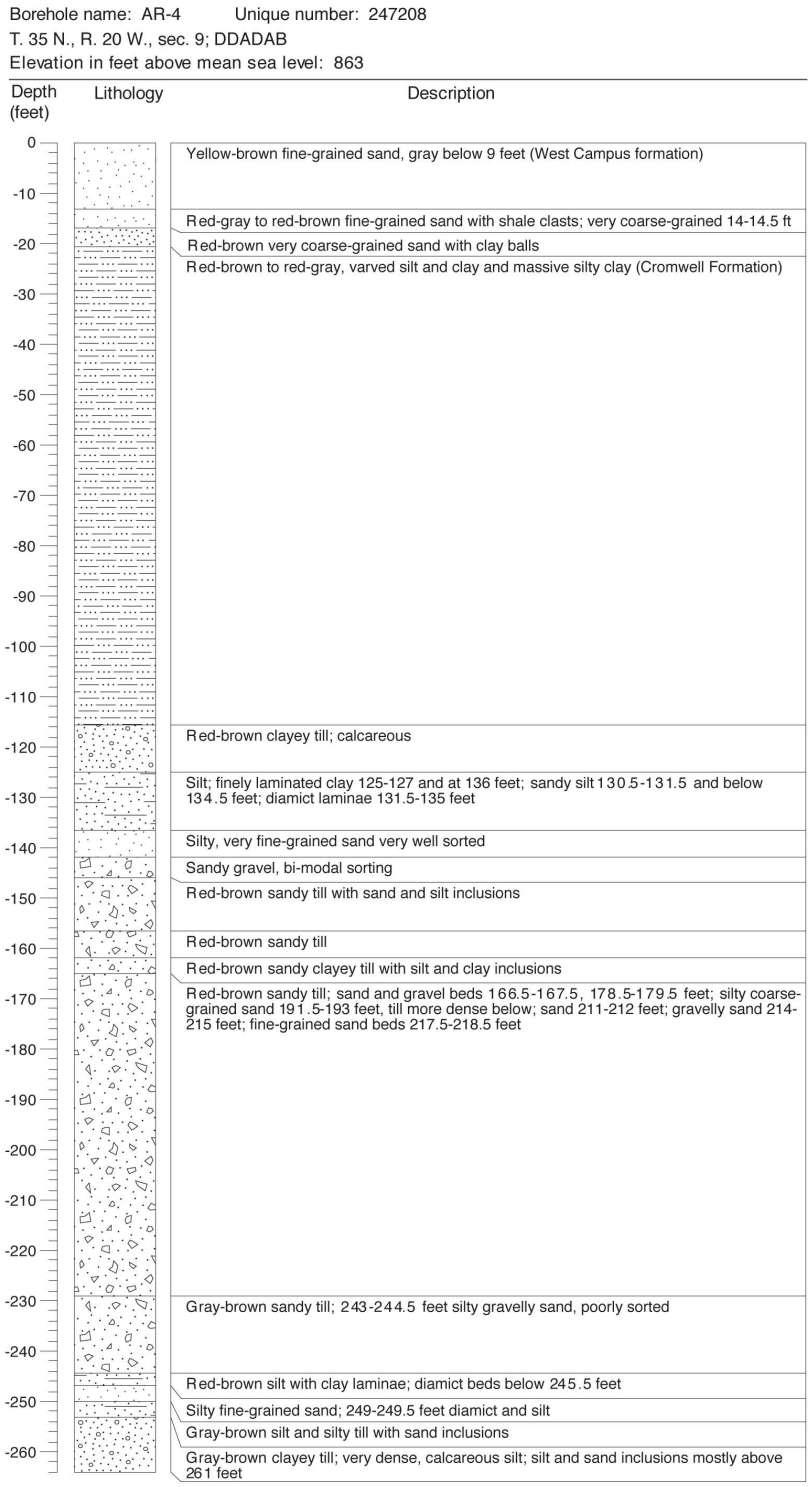


Figure 9. Descriptive log of rotary-sonic core AR-4, drilled by North Star Drilling for an earlier study (Meyer, 1993). Location of drilling is shown on Figure 2 and Plate 1, *Data-Base Map*.

Graphic from source map: (Chisago County Geologic Atlas).

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 Atlas).

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Text from source map: (Chisago County Geologic Atlas).

Plate 5: Sand Distribution Model

Introduction

The sand and gravel deposits of Minnesota are products of a long and complex history of multiple glacial events that makes mapping of these potential aquifers difficult. However, establishing the location and characteristics of sand and gravel aquifers is an important step toward their wise use and protection. In Chisago County, this project employed a process that combined the understanding of a geologist with the data-handling ability of a geographic information system (GIS) to create models showing the distribution of Quaternary sand and gravel deposits that may be aquifers. The three-dimensional models relate aquifers to the glacial events that formed them. Although the models and interpretations are based on the best available data, they are unavoidably incomplete due to a lack of data in some areas.

The distribution of sand (which in the following text implies sand and gravel) at the land surface was mapped by the geologist from exposures, shallow drill holes, soil maps, and landforms. In contrast, interpreting sand distribution in the subsurface relied primarily on well records, scientific drill core, and drill cuttings. Sand distribution models were based on the assessment of these data, consideration of the processes that deposited the glacial sediment, and an understanding of the glacial history.

The unconsolidated Quaternary sediments that overlie the bedrock in Chisago County vary greatly in character and thickness. These deposits are largely the result of more than six distinct glacial ice advances during the Pleistocene Epoch (Plate 4), so most of the Quaternary aquifers within Chisago County consist of sand and gravel beds laid down by meltwater that emanated from these glaciers. Layers of unsorted sediment deposited directly from the ice, termed "till," as well as fine-grained bedded sediment deposited in ponded meltwater in front of the glaciers, form confining layers (aquitards) that enclose the aquifers. The till layers left by each ice sheet tend to be more laterally persistent than the sand layers, as ice usually spread across the entire county, whereas meltwater streams that deposited the sand and gravel were generally confined to drainages at the lower elevations of the evolving landscape. Sand and gravel may be deposited by both an advancing glacier and a retreating glacier of the same cycle, thus till from an ice advance may bury its own sand and gravel as well as material deposited during a previous glacial event. The sand and gravel bodies depicted in this report are associated with the underlying till or lake sediment (except for those at the land surface; Fig. 1).

Glacial ice and meltwater not only deposited sediments, but also eroded older, underlying sediments, creating a very disturbed "layer cake." A new layer of sand or till could fill a void eroded into an older layer or could completely take the place of an older layer, given sufficient erosion. The net effect of this depositional and erosional activity is that sand bodies that provide water to wells in Chisago County tend to be discontinuous. Over relatively short distances in most directions, the extent and thickness of any given aquifer is difficult to predict. In order to address this problem, 51 closely spaced (1 kilometer) cross section lines were generated in a west to east direction (Fig. 2). Along these lines, water well records, and records of scientific and engineering test holes (Plate 1, Data-Base Map), were used by the geologist to identify contacts between units in the subsurface. The results from the cross section analysis were compiled digitally into grids of top and bottom surfaces and grid thicknesses for each interpreted unit of till and sand. Final interpretations along five of these cross sections are shown on Plate 4.

Till is generally described as "clay" by well drillers. Where two clay (till) layers related to different depositional events were not separated by a sand layer, their contact was recognized by a change in the driller's description of the clay's texture (for example clay/sandy clay/clay and gravel), density, or color. Using the available data, contact lines were drawn along each cross section, with each line representing the base of a unit of sand and gravel or till. GIS software was used to extract elevation values from vertices along each unit line, and convert those into a gridded elevation surface representing the distribution of the unit over the county. The till and sand surfaces were iteratively modified until the geologist was confident that they adequately represented the areal distribution and stratigraphic

interpretation derived from the water well data. When the till and sand surface grids representing the base of each unit were final, they were processed through GIS raster calculations to create top and bottom surfaces and a thickness for each geologic unit. The result is a three-dimensional geologic model of tills and sands for the county. The more extensive sands portrayed by the geologic model are shown in Figures 3 through 8. Note that contours showing thickness of sand and gravel units do not close within the outline of each unit. This is an artifact of the GIS processing of surfaces. The figures show sand units ranging from the youngest sands at the land surface to buried, progressively older sands (Fig. 1).

Where saturated, these sand bodies are aquifers. Their capacities for water yield depend on the extent and thickness of the body, as well as factors such as sediment coarseness, degree of sorting, and consolidation. In many places two or more of these sand units form a single aquifer where they are juxtaposed with no intervening till layer (see cross sections on Plate 4). Data from other, less extensive sand bodies, as well as from the eight till/fine-grained lake sediment bodies that were created in the geologic model, are not shown on the printed map plates, but are provided with the digital files for this atlas.

The geologic model should be considered a probability map for the occurrence and approximate thicknesses of major sand bodies. The model does not guarantee sand and gravel will be found at all places shown, nor does it preclude them being found where they are not shown. In areas where numerous wells penetrated the shallower sands, too much data were available and much of the small detail could not be shown at the map scale. Elsewhere, sands that were too thin or did not extend to neighboring cross sections do not appear on the figures. Because wells typically do not penetrate the complete thickness of sand layers, drillers' logs commonly underreport sand body thickness. As a result, some of the sands shown on the cross section (but not necessarily on the final sand distribution map) may be thicker and more widespread than they are portrayed. At increasing depths in the stratigraphic section, data availability diminishes and delineated sand bodies could be more or less discontinuous than shown.

In many parts of Chisago County water wells do not extend through the full thickness of the Quaternary deposits. The cross sections on Plate 4 indicate that the characteristics of deeper Pleistocene deposits cannot be differentiated in many places (Fig. 9). However, where deep drill holes occur locally, thicker sands are commonly present. Additional sand bodies, or extensions of those mapped, are undoubtedly present in these undifferentiated parts of the Pleistocene section. In spite of these limitations, the geologic model provides a realistic interpretation of where and what kind of geologic units would be encountered in the subsurface of Chisago County. However, given the limits of the data, as noted above, the model should be used as a guide and should not preclude further site-specific investigations or inspection of individual well logs.

Text from source map: (Chisago County Geologic Atlas).

Figure 1: Sand Distribution Legend

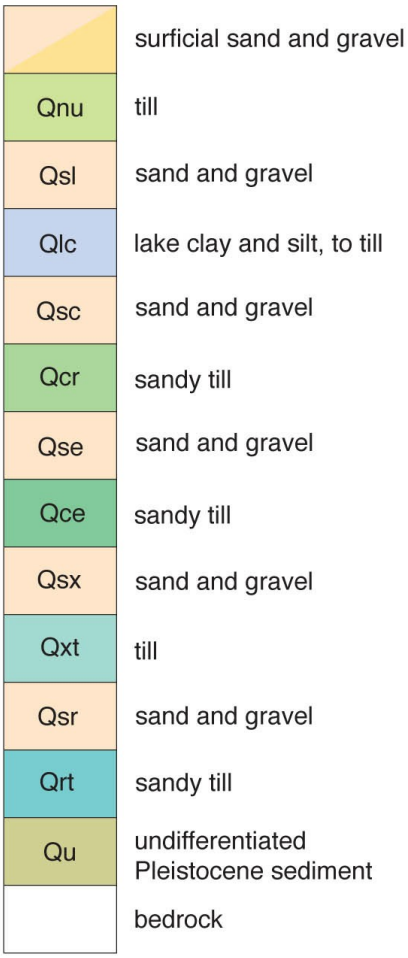


Figure 1. Stratigraphic position of sand and gravel bodies shown on the sand distribution diagrams (Figs. 3 through 8)—Undifferentiated Pleistocene sediment (Fig. 9) may include any unit older than the New Brighton formation (Plate 4).

Graphic from source map: (Chisago County Geologic Atlas).

Figure 2: Cross Section Location Map

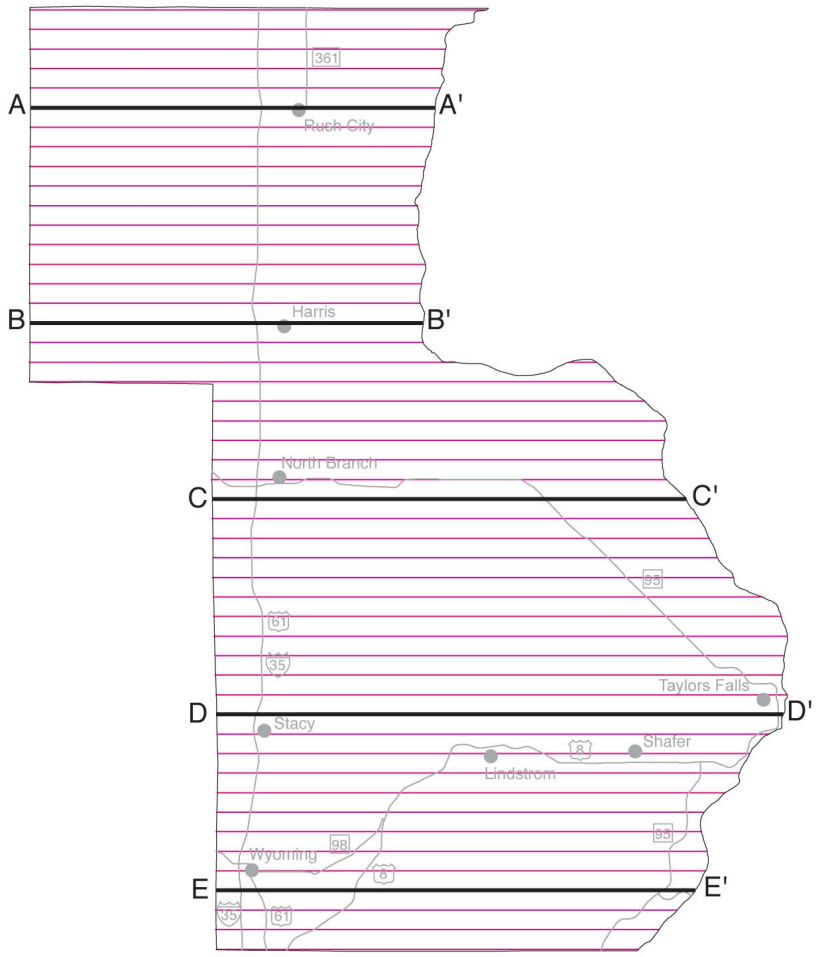
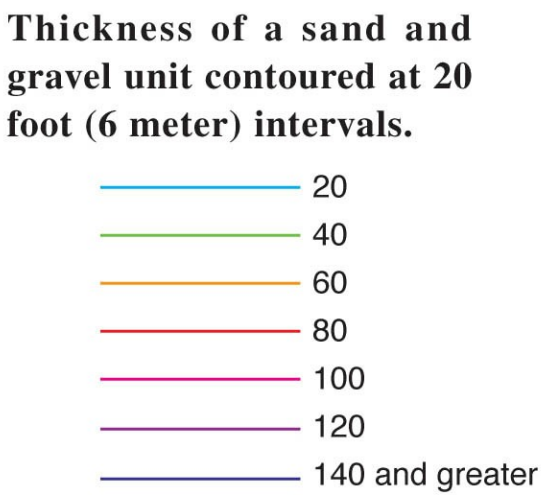


Figure 2. Cross section location map—Location of the 51 cross sections, constructed at regular 0.6 mile (1 kilometer) intervals, used to create a three-dimensional model of the Quaternary deposits of Chisago County. Cross sections A–A' through E–E' appear on Plate 4, *Quaternary Stratigraphy,* and their locations are also shown on Plate 3, *Surficial Geology.*

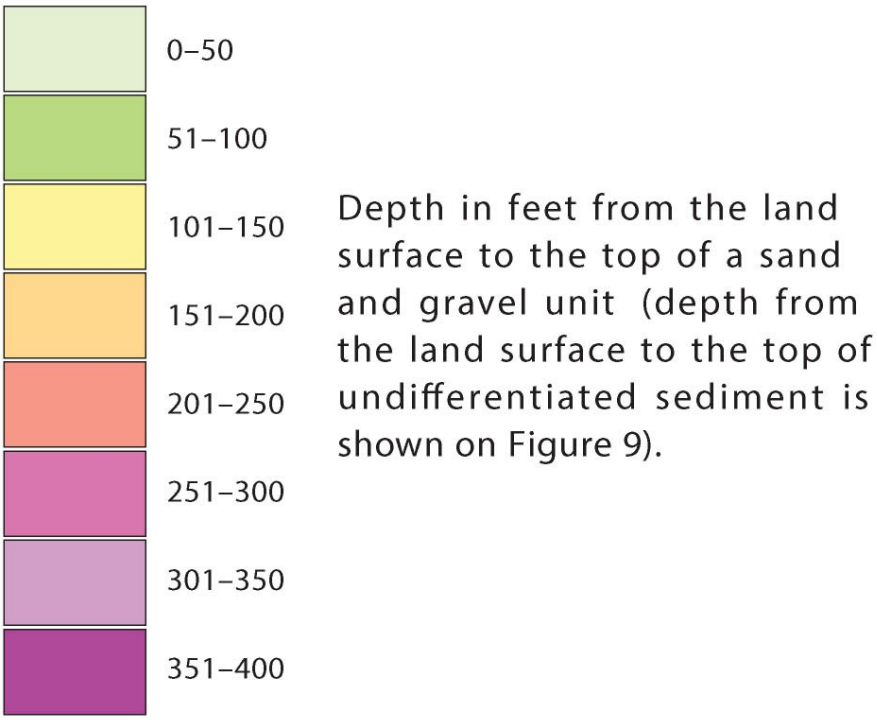
Graphic from source map: (Chisago County Geologic Atlas).

Contour Legend (Figures 3 through 8)



Graphic from source map: (Chisago County Geologic Atlas).

Depth Color Legend (Figures 4 through 9)



Graphic from source map: (Chisago County Geologic Atlas).

Figure 3: Surficial Sand and Gravel

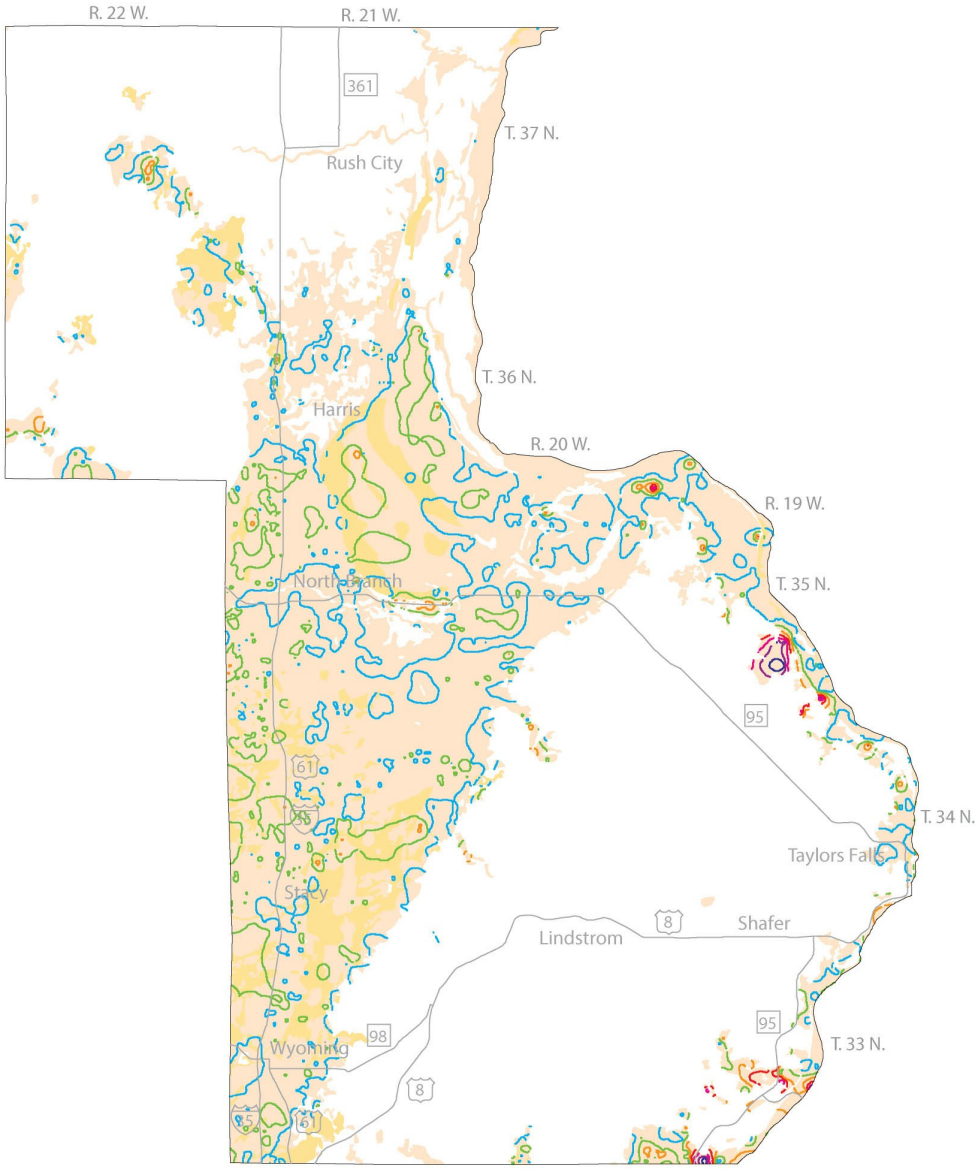


Figure 3. Surficial sand and gravel —Model-generated map showing the extent and thickness of sand and gravel bodies occurring at the land surface (cream colored) or below peat (orange) in Chisago County. Includes units Qe, Qa, Qf, Qws, Qwg, Qwl, Qwr, Qbs, Qbg, Qns, Qno, Qni, Qcl, and Qci from Plate 3, Surficial Geology. The surficial aquifer of the county is that portion of these sand and gravel bodies that is below the water table.

Graphic from source map: (Chisago County Geologic Atlas).

Figure 4: Qsl Surficial Sand and Gravel

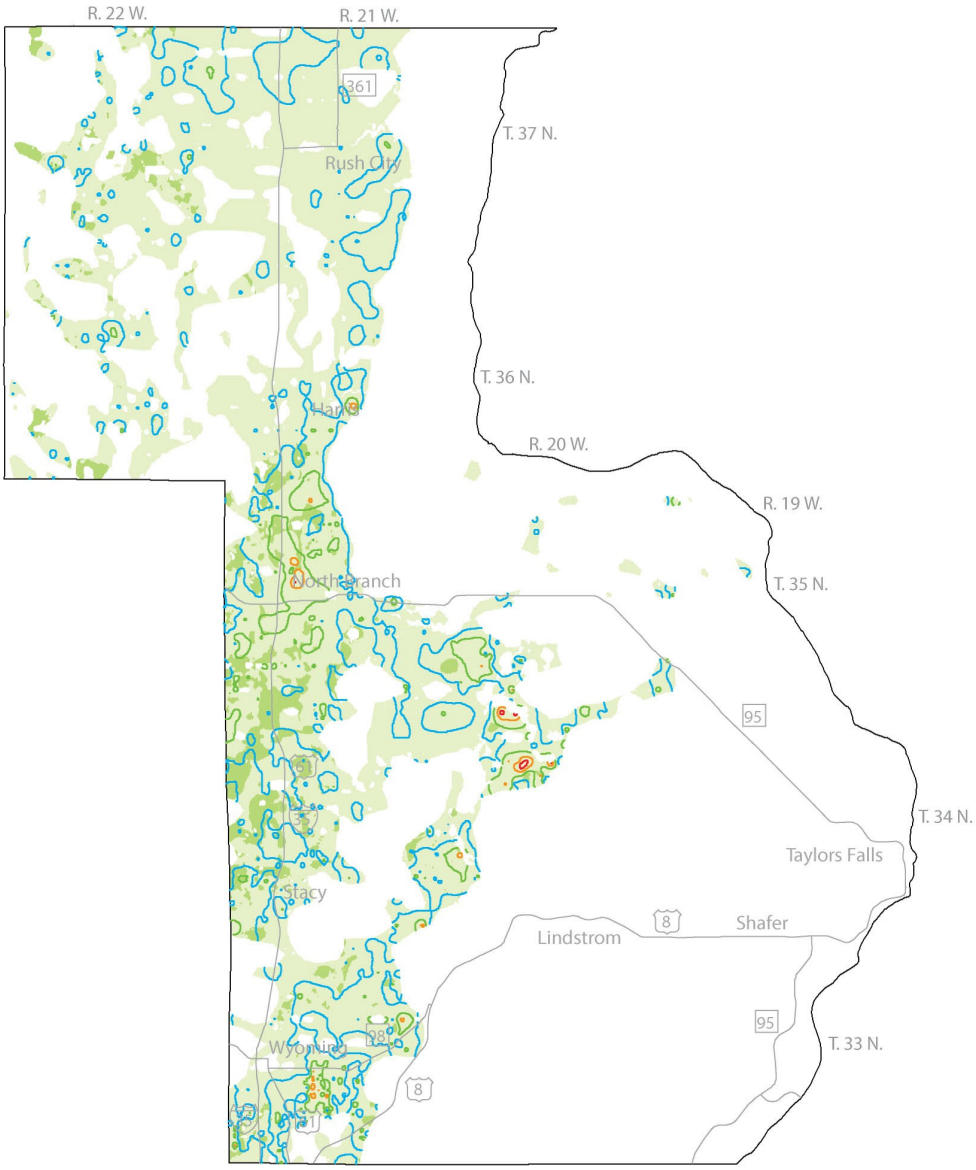


Figure 4. Qsl sand and gravel —Model-generated map of the extent, depth from the surface, and thickness of sand and gravel bodies stratigraphically immediately above laminated silt and clay or fine-textured till of unitQlc. The nearly continuous strip of sand from Rush City to Wyoming was laid down primarily in glacial Lake Lind II. The large gap mapped in the sand body east of Stacy is likely due to the lack of data in the area. The more discontinuous bodies in the northwest part of the county were likely laid down by streams draining into glacial Lake Lind from the retreating Automba phase of the Superior lobe, but may include some pro-glacial sediment from the advancing Grantsburg sublobe.

Graphic from source map: (Chisago County Geologic Atlas).

Figure 5: Qsc Surficial Sand and Gravel

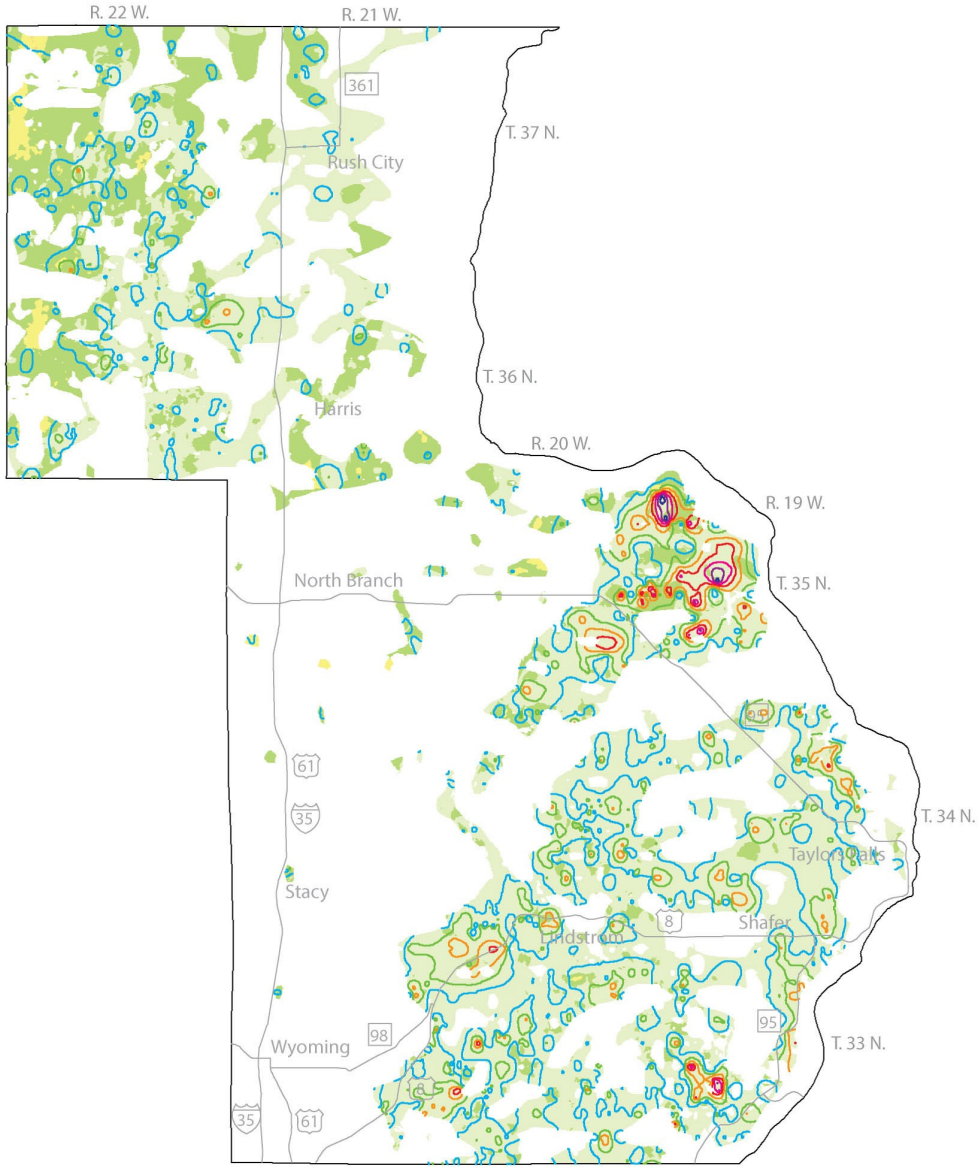


Figure 5. Qsc sand and gravel —Model-generated map of the extent, depth from the surface, and thickness of sand and gravel bodies stratigraphically immediately above (mostly) sandy till of unit Qcr. Mostly fluvial or deltaic sediment deposited by meltwater from the receding St. Croix phase and advancing Automba phase of the Superior lobe. The thicker deposits are fans laid down at the ice margin.

Graphic from source map: (Chisago County Geologic Atlas).

Figure 6: Qse Surficial Sand and Gravel

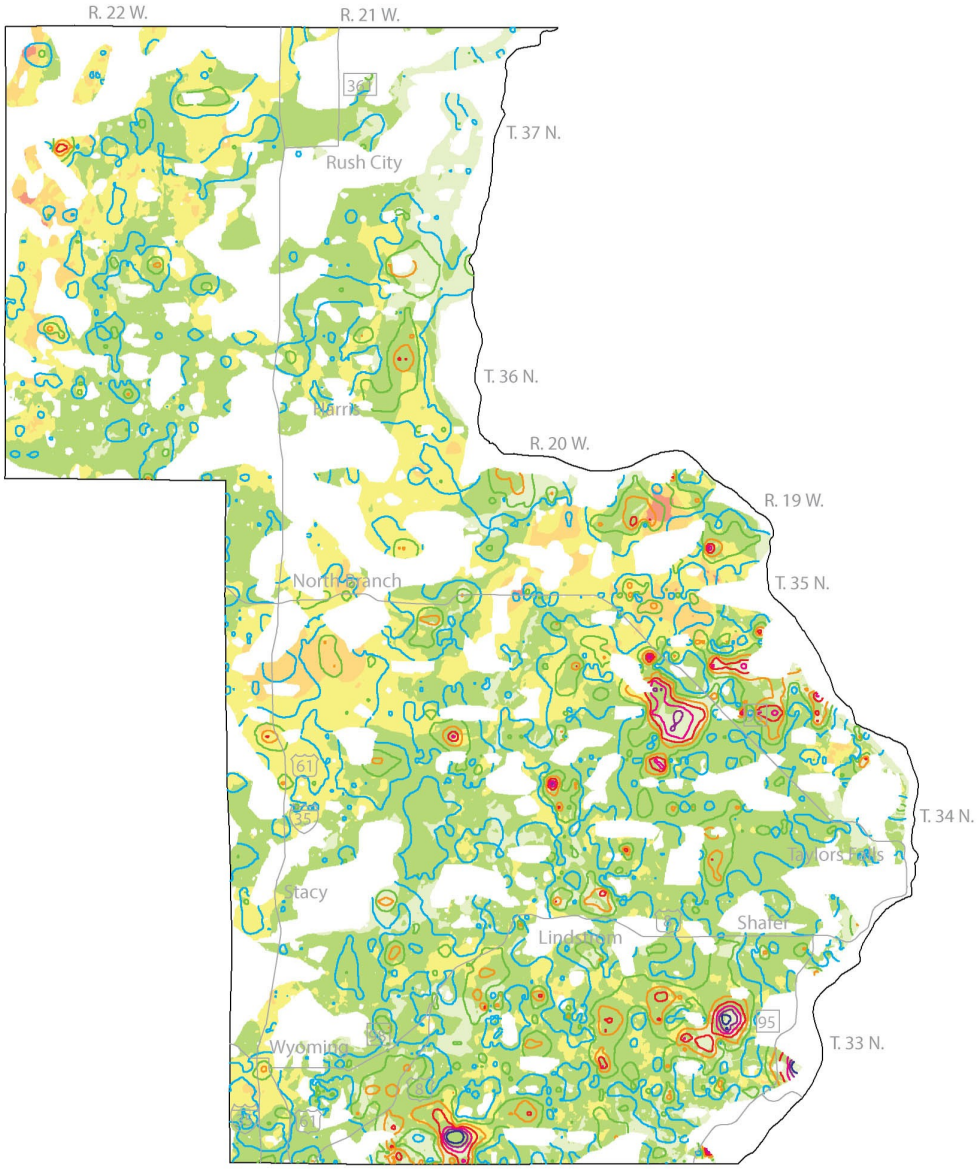


Figure 6. Qse sand and gravel —Model-generated map of the extent, depth from the surface, and thickness of sand and gravel bodies stratigraphically immediately above (mostly) sandy till of unit Qce. Mostly fluvial sediment deposited by meltwater from the receding Emerald phase and advancing St. Croix phase of the Superior lobe. The thicker deposits are fans laid down at the ice margin.

Graphic from source map: (Chisago County Geologic Atlas).

Figure 7: Qsx Surficial Sand and Gravel

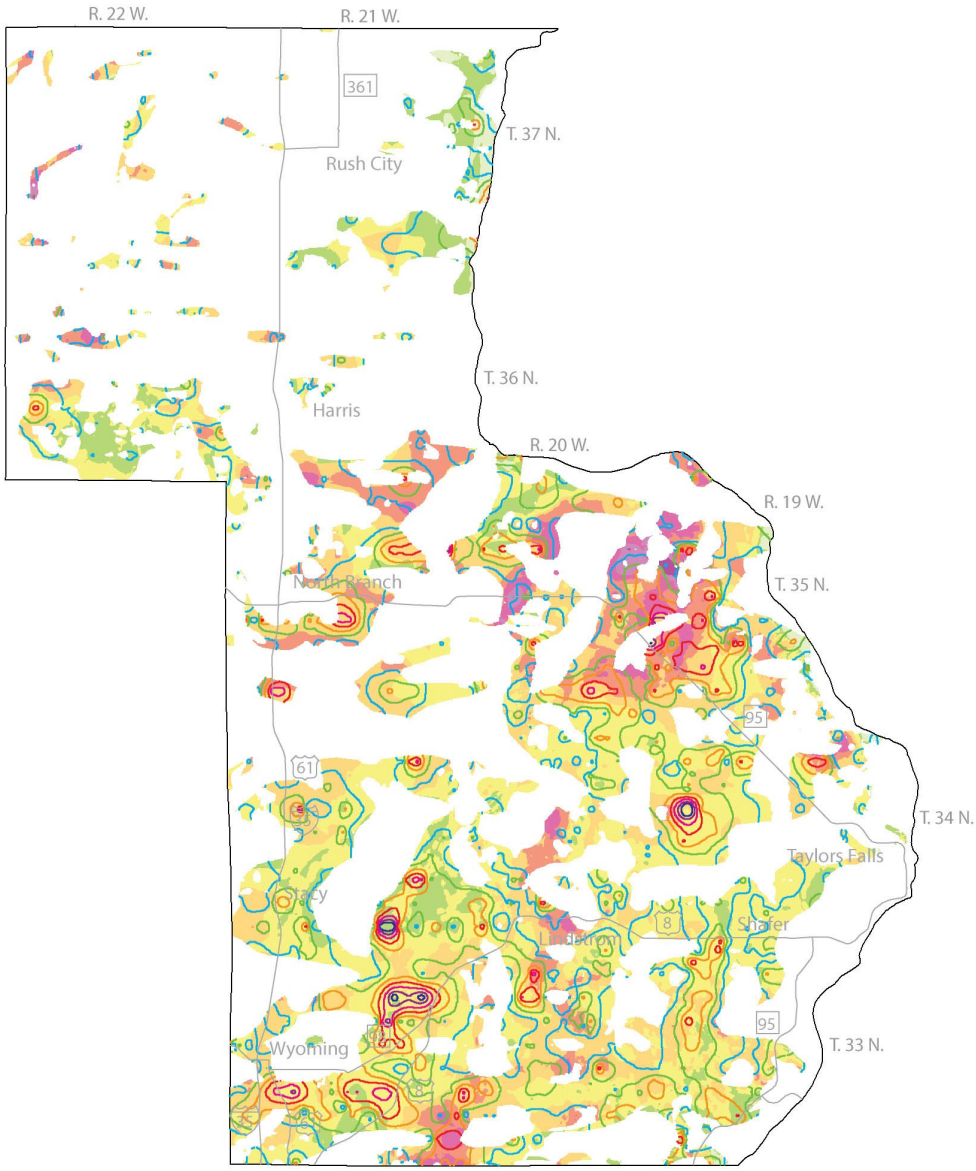


Figure 7. Qsx sand and gravel —Model-generated map of the extent, depth from the surface, and thickness of sand and gravel bodies stratigraphically immediately above (mostly) fine-textured till of unit Qxt. Mostly pro-glacial outwash of the Emerald phase of the Superior lobe, but includes older deposits.

Graphic from source map: (Chisago County Geologic Atlas).

Figure 8: Qsr Surficial Sand and Gravel

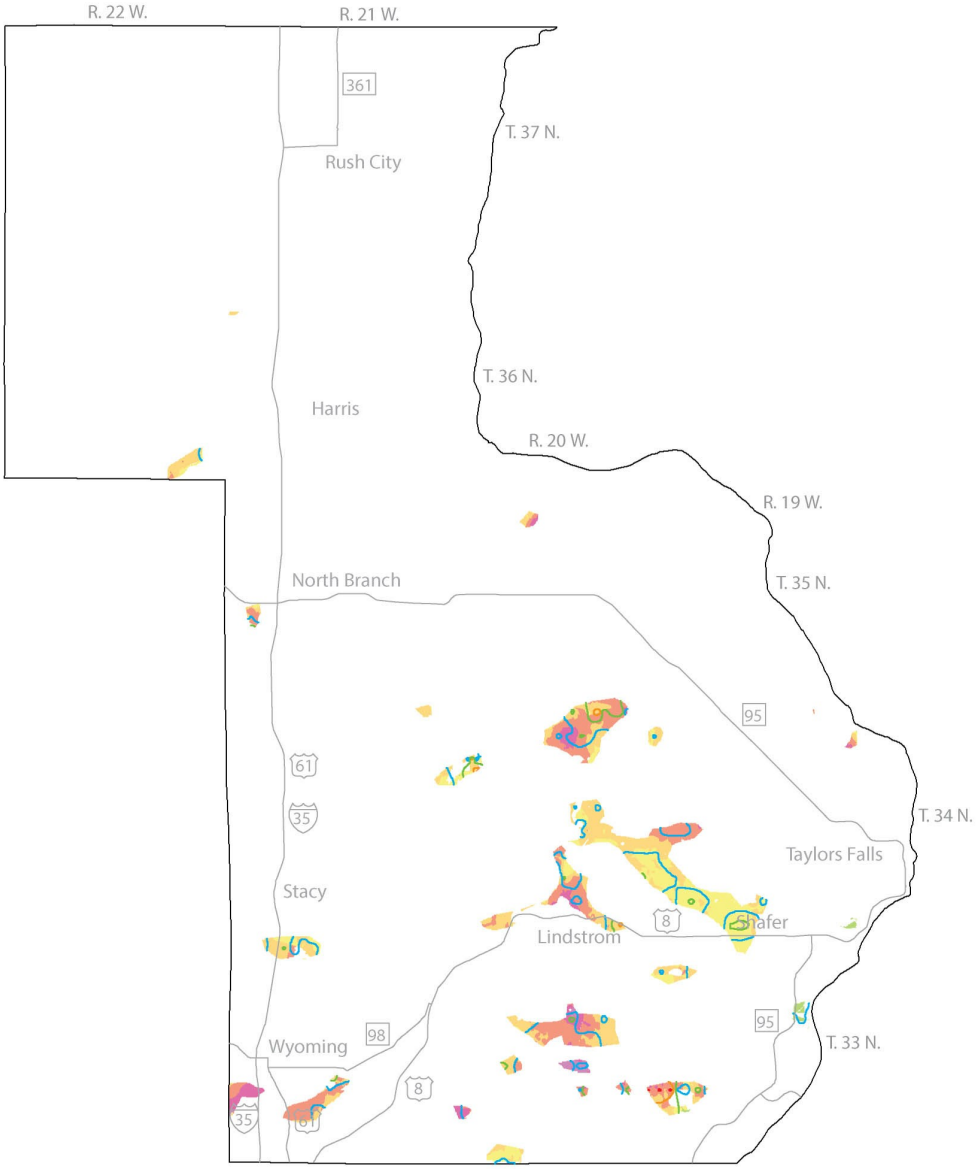


Figure 8. Qsr sand and gravel —Model-generated map of the extent, depth from the surface, and thickness of sand and gravel bodies stratigraphically immediately above (mostly) sandy till of unit Qrt.

Graphic from source map: (Chisago County Geologic Atlas).

Figure 9: Undifferentiated Sediment

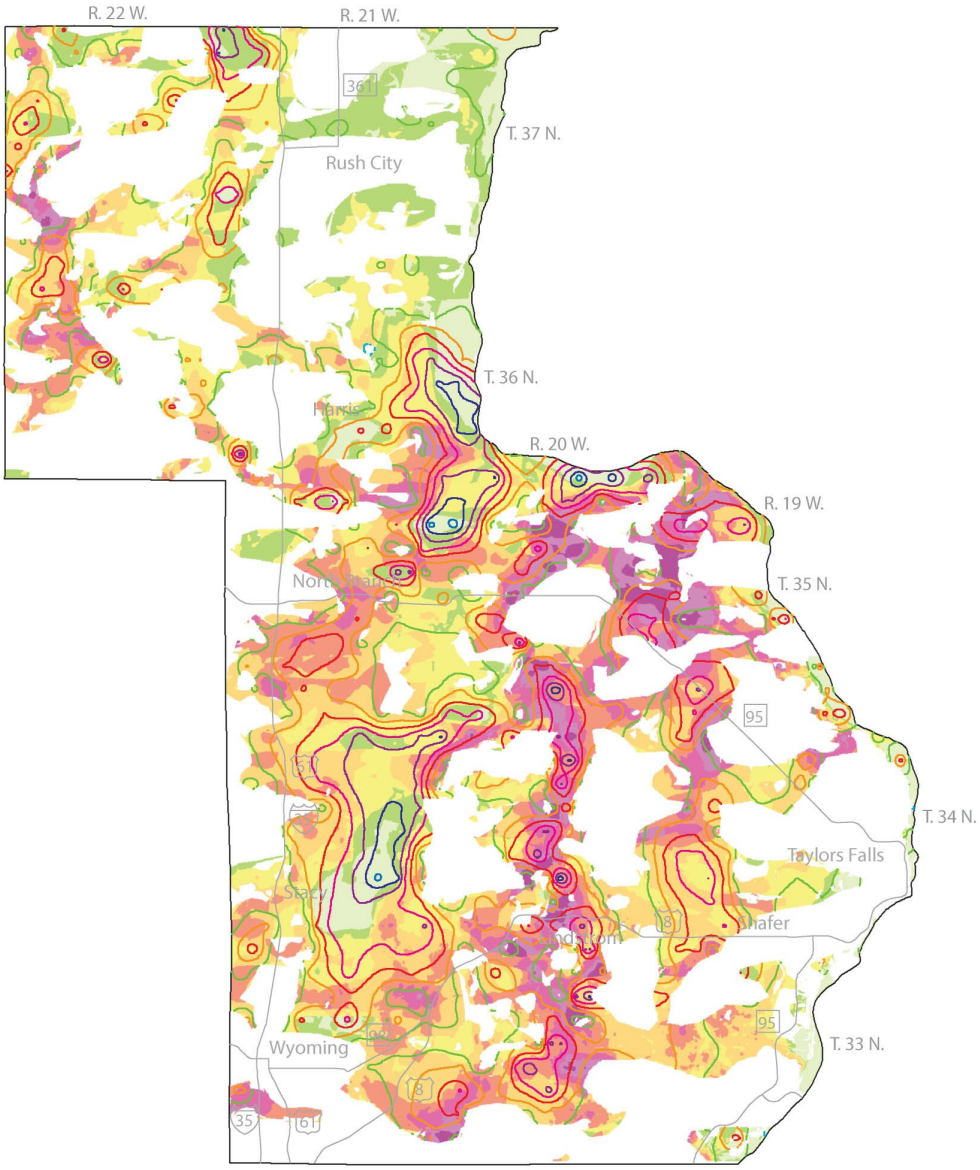
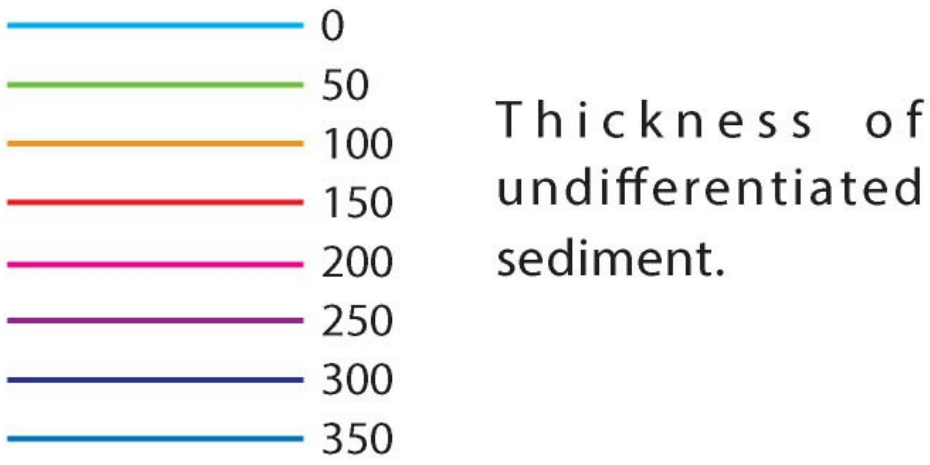


Figure 9. Undifferentiated sediment —Model-generated map of the extent, depth from the surface, and thickness of Quaternary sediment for which little or no descriptive data are available, contoured at 50-foot (15-meter) intervals. In white areas, numerous data exist and the geology between the land surface and bedrock is generally known.

Graphic from source map: (Chisago County Geologic Atlas).

Contour Legend (Figure 9)



Graphic from source map: (Chisago County Geologic Atlas).

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Text from source map: (Chisago County Geologic Atlas).

Plate 6: Bedrock Topography & Depth to Bedrock

Bedrock Topography Introduction

The configuration of the bedrock surface is represented by the colors assigned to 50-foot (15-meter) elevation intervals (example: 751 to 800 feet above sea level) on the Bedrock Topography map. The position of the contour intervals was determined mostly from bedrock outcrop mapping and records of water-well construction. Seismic-refraction techniques were also used to determine the elevation of the bedrock surface in some areas, and linear, sinuous, aeromagnetic anomalies were used to constrain the position of channels on the bedrock surface in the northwestern part of the county (Plate 2, Fig. 4). The geophysical data were collected by the Minnesota Geological Survey (Chandler and others, 2004), the Minnesota Department of Natural Resources, and the Department of Geology and Geophysics at the University of Minnesota. The somewhat irregular distribution of data can be seen on the Data-Base Map (Plate 1) and should be considered when assessing the reliability of the map at any particular location.

The bedrock surface in Chisago County varies from more than 1,100 feet (335 meters) above mean sea level in the southeastern part to less than 400 feet (122 meters) above sea level in buried valleys in the southern part of the county. The most prominent feature of the bedrock topography is an anomalously deep and linearly extensive buried valley in the southern part of the county that approximates the position of the modern Sunrise River system and chain of lakes around the cities of Lindstrom and Chisago City (see cross-section, Plate 2). The buried valley deepens to the north, and crosses beneath the St. Croix River into Wisconsin near the town of Sunrise, where the base of the valley reaches an elevation of less than 400 feet (122 meters). Bedrock topographic constraints in Minnesota south of the county (Mossler and Tipping, 2000), and limited data from the adjacent area in Wisconsin (Johnson, 2000), indicate that this valley either drained to the northeast, towards what is now Lake Superior, or turned south within Wisconsin and ultimately entered the ancestral Mississippi River drainage south of the Twin Cities metropolitan region.

Other highlights of the bedrock topography are the knobs of relatively hard, resistant Mesoproterozoic basalt (Clam Falls Volcanics) that stand at high elevation near Taylors Falls. The tops of some of the highest knobs exceed 1,050 feet (320 meters), about 300 feet (91 meters) above the bedrock surface across most of the rest of the county. Erosion by the St. Croix River and its tributaries through this mass of basalt resulted in the development of the pronounced topographic relief and landscape around Taylors Falls that is more akin to the North Shore of Lake Superior, than to the landscape elsewhere along the St. Croix River.

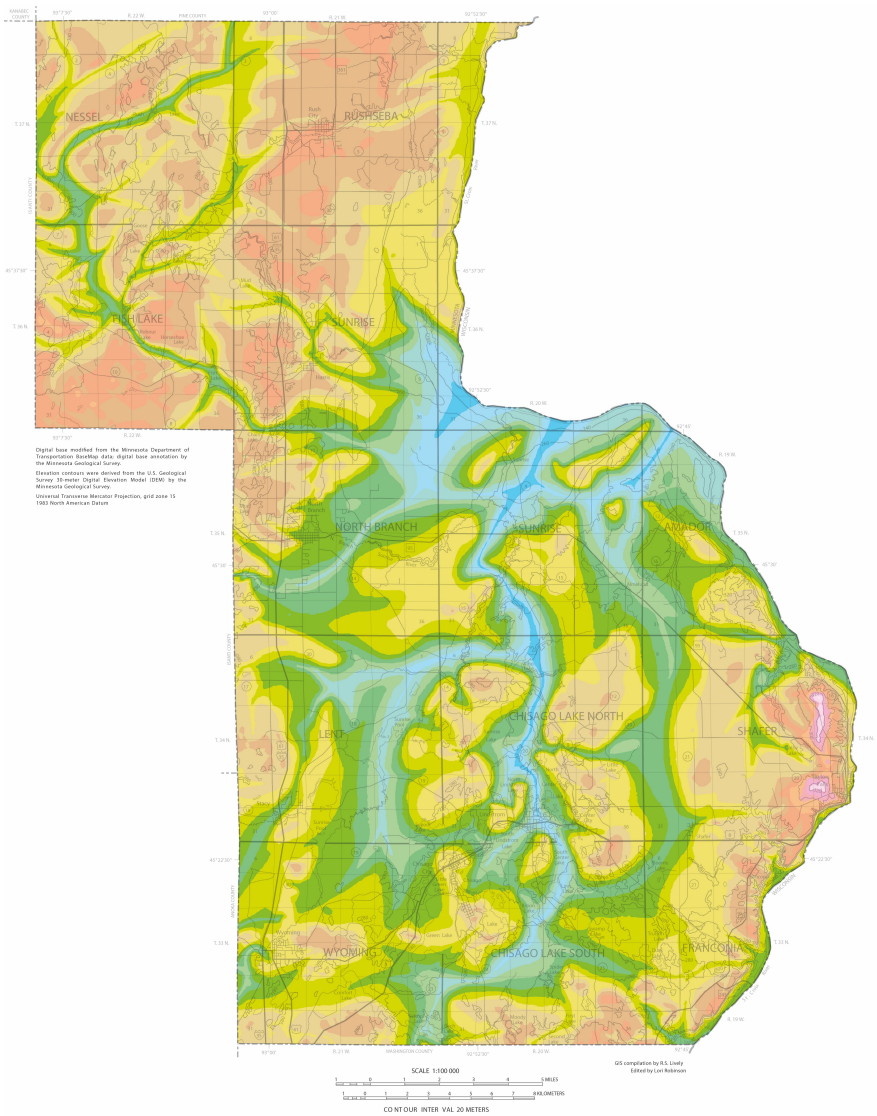
Text from source map: (Chisago County Geologic Atlas).

Bedrock Topography Legend

- 1,101-1,150
- 1,051-1,100
- 1,001-1,050
- 951-1,000
- 901-950
- 851-900
- 801-850
- 751-800
- 701-750
- 651-700
- 601-650
- 551-600
- 501-550
- 451-500
- 401-450
- 351-400

Graphic from source map: (Chisago County Geologic Atlas).

Bedrock Topography Map



Graphic from source map: (Chisago County Geologic Atlas).

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.

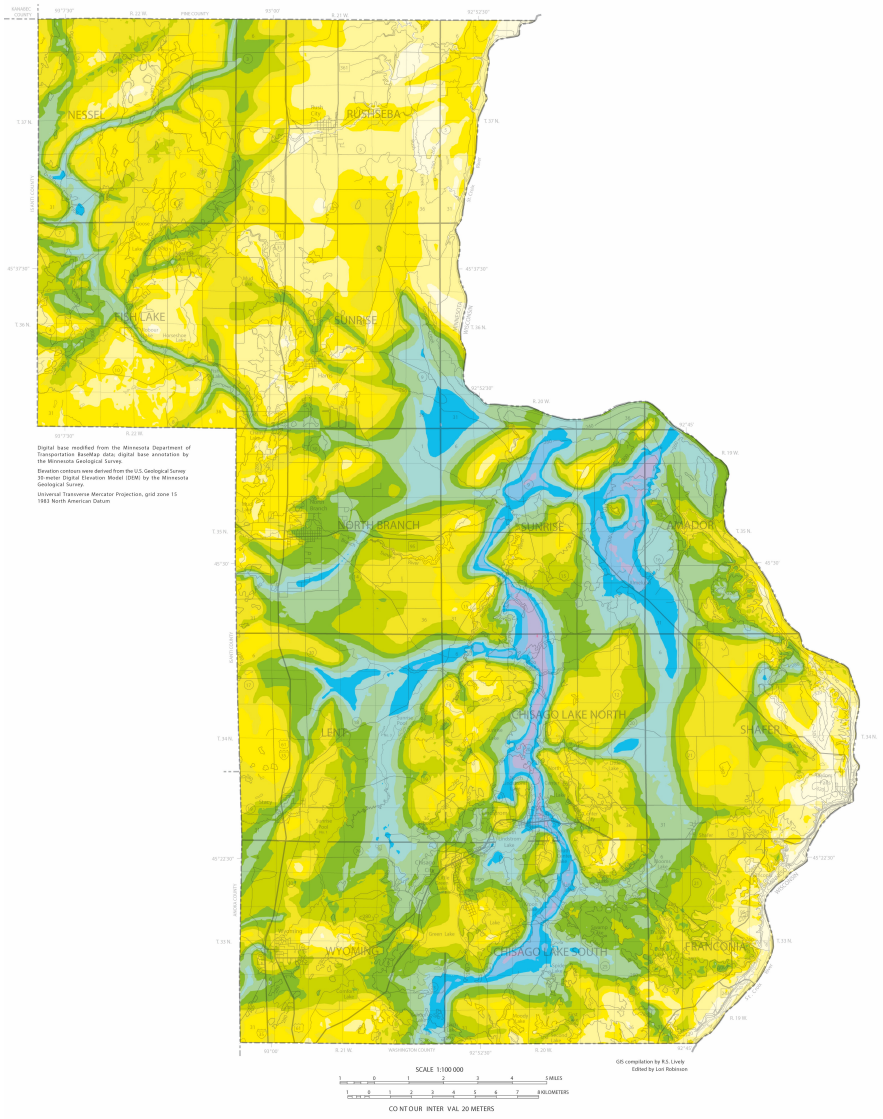
The thickest sediments in Chisago County occur over deep, pre-glacial valleys in the bedrock surface. These occur in the southern half of the county where a network of deep buried valleys have more than 500 feet (152 meters) of sediment overlying the bedrock. In contrast, bedrock is at or within 50 feet (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 Atlas).

Depth to Bedrock Legend

Graphic from source map: (Chisago County Geologic Atlas).

Depth to Bedrock Map



Graphic from source map: (Chisago County Geologic Atlas).

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Text from source map: (Chisago County Geologic Atlas).

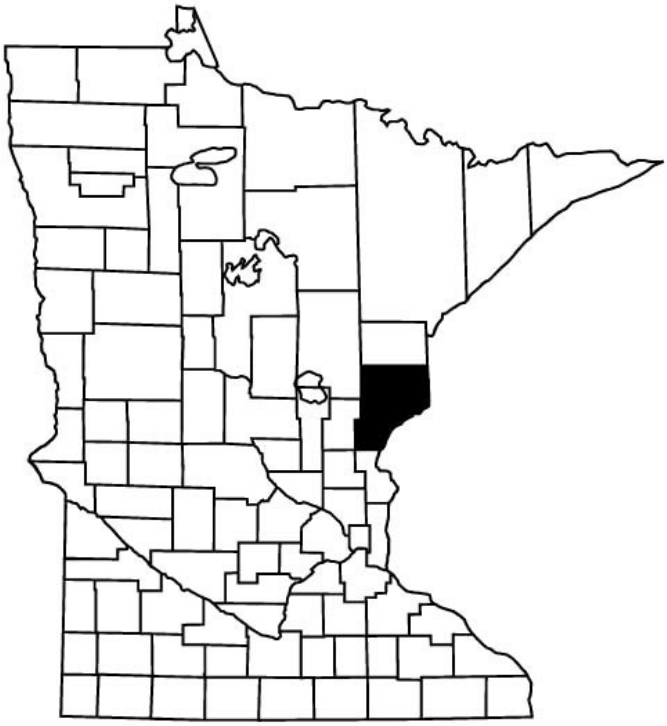
Pine County Geologic Atlas

The formal citation for this source.

Boerboom, T.J., 2001, Geologic Atlas of Pine County, Minnesota (7 plates): Minnesota Geological Survey, County Atlas Series C-13 Part A, scale 1:100,000 (*GRI Source Map ID 76143*).

Prominent graphics and text associated with this source.

Location Map



Graphic from source map: (Chisago County Geologic Atlas).

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 Atlas).

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 Atlas).

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 Atlas).

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 Atlas).

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 Atlas).

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 Atlas).

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 Atlas).

Figure 1: Well Log Example

Unique No. 00232461
County Name Pine

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

Update Date 2001/01/03
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
Make Type

Open Hole From 125 ft. to 452 ft.

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 Atlas).

Figure 2: Well Stratigraphy Example

Unique No. 00232461	MINNESOTA DEPARTMENT OF HEALTH **WELL AND BORING RECORD** *Minnesota Statutes Chapter 1031*	**Update Date** 2001/01/03	
County Name Pine		**Entry Date** 1992/08/20	

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 Atlas).

References

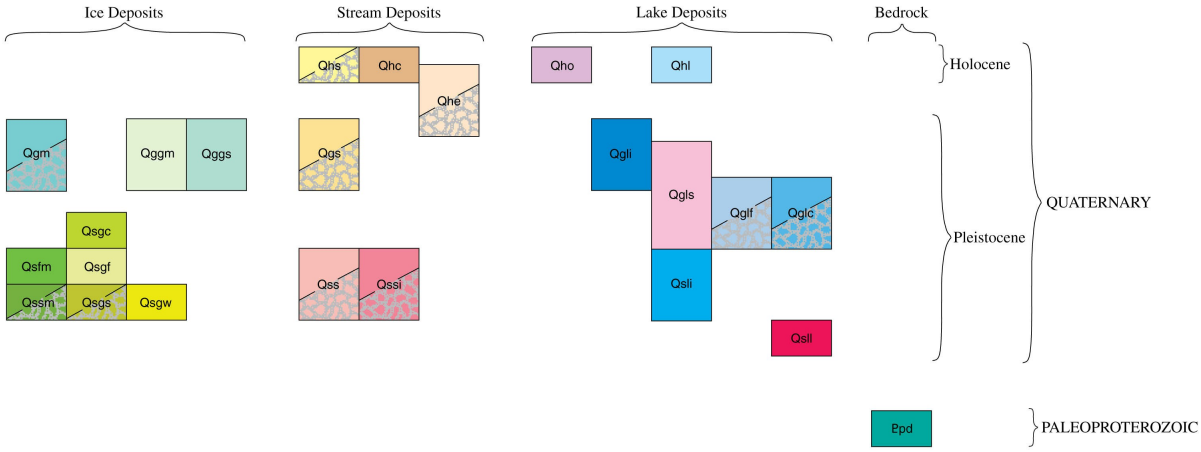
Chandler, V.W., Nordstrand, E., and Anderson, S., 1984, Shaded-relief aeromagnetic anomaly map of northeastern and east-central Minnesota: Minnesota Geological Survey Miscellaneous Map Series M-53, scale 1:100,000.

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.

Text from source map: (Pine County Geologic Atlas).

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 Atlas).

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 Atlas).

Figure 1: Ice Margin Map

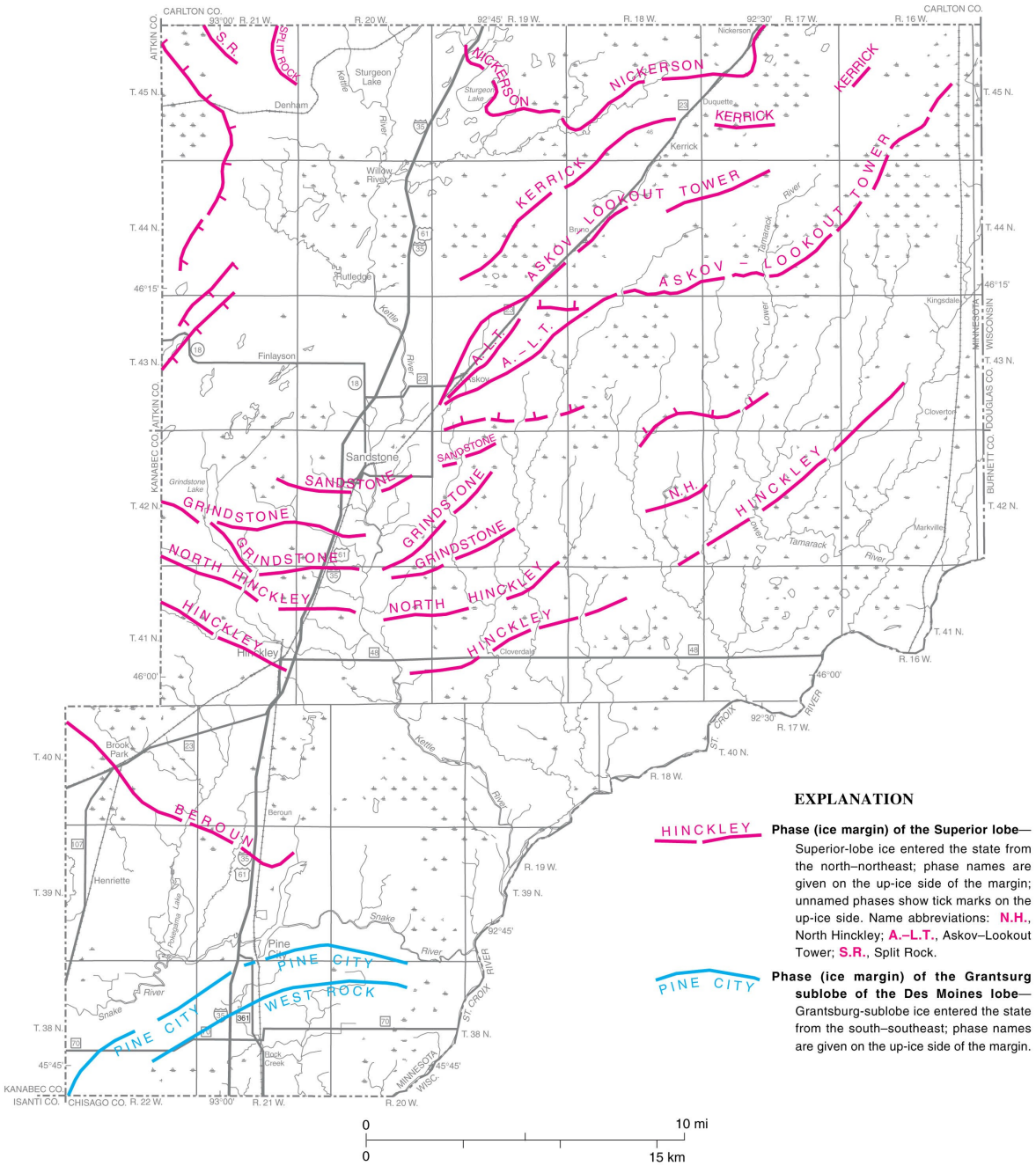


Figure 1. Distinct phases, or ice margins, of the Grantsburg sublobe of the Des Moines lobe (blue) and of the Superior lobe (magenta). The Grantsburg sublobe entered the county from the south–southeast. The Superior lobe entered Pine County from the north–northeast. The margins represent positions where 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 Atlas).

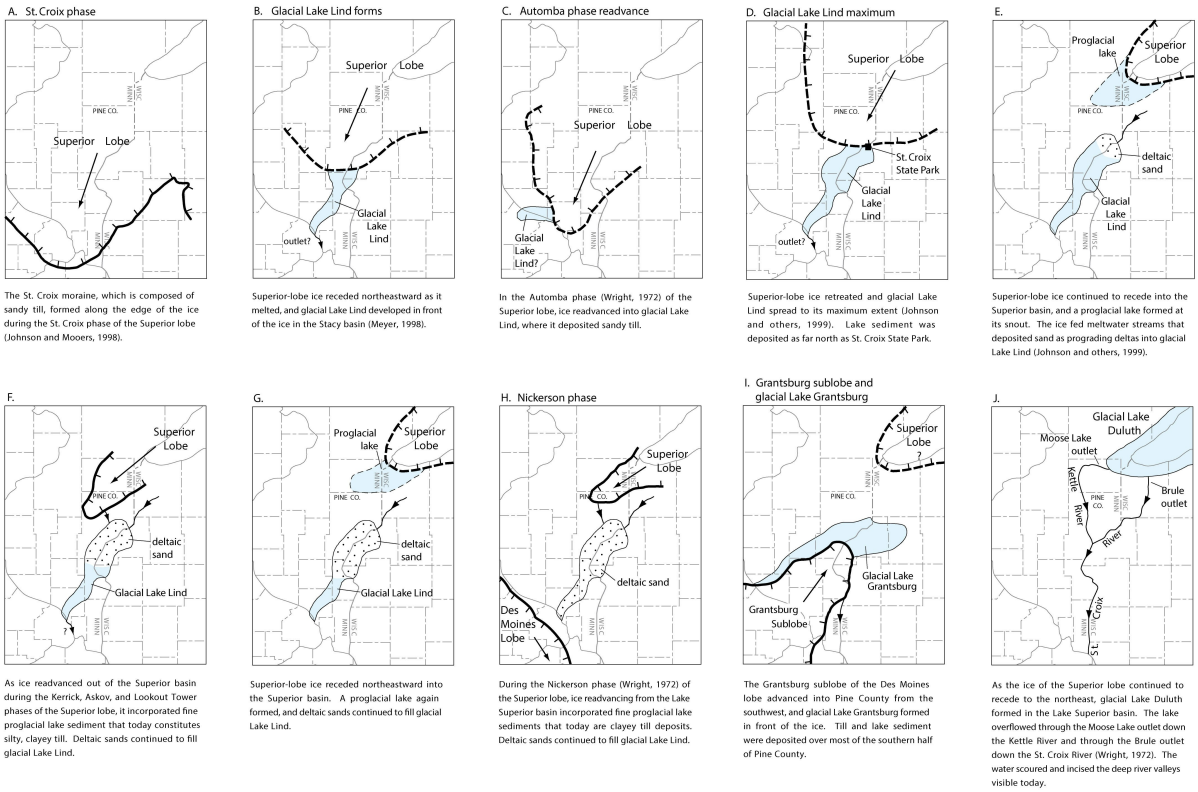
Plate 5: Quaternary Stratigraphy

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 Atlas).

Figure 1: Glacial Events



The St. Croix moraine, which is composed of sandy till, formed along the edge of the ice during the St. Croix phase of the Superior lobe (Johnson and Mooers, 1998).

Superior-lobe ice receded northeastward as it melted, and glacial Lake Lind developed in front of the ice in the Stacy basin (Meyer, 1998).

In the Automba phase (Wright, 1972) of the Superior lobe, ice readvanced into glacial Lake Lind, where it deposited sandy till.

Superior-lobe ice retreated and glacial Lake Lind spread to its maximum extent (Johnson and others, 1999). Lake sediment was deposited as far north as St. Croix State Park.

Superior-lobe ice continued to recede into the Superior basin, and a proglacial lake formed at its snout. The ice fed meltwater streams that deposited sand as prograding deltas into glacial Lake Lind (Johnson and others, 1999).

As ice readvanced out of the Superior basin during the Kerrick, Askov, and Lookout Tower phases of the Superior lobe, it incorporated fine proglacial lake sediment that today constitutes silty, clayey till. Deltaic sands continued to fill glacial Lake Lind.

Superior-lobe ice receded northeastward into the Superior basin. A proglacial lake again formed, and deltaic sands continued to fill glacial Lake Lind.

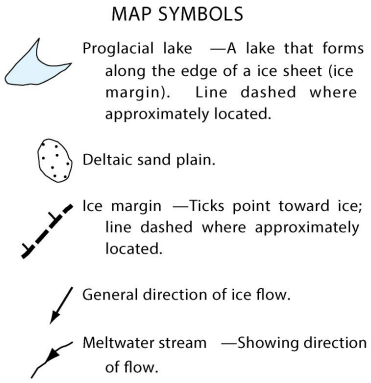
During the Nickerson phase (Wright, 1972) of the Superior lobe, ice readvancing from the Lake Superior basin incorporated fine proglacial lake sediments that today are clayey till deposits. Deltaic sands continued to fill glacial Lake Lind.

The Grantsburg sublobe of the Des Moines lobe advanced into Pine County from the southwest, and glacial Lake Grantsburg formed in front of the ice. Till and lake sediment were deposited over most of the southern half of Pine County.

As the ice of the Superior lobe continued to recede to the northeast, glacial Lake Duluth formed in the Lake Superior basin. The lake overflowed through the Moose Lake outlet down the Kettle River and through the Brule outlet down the St. Croix River (Wright, 1972). The water scoured and incised the deep river valleys visible today.

Graphic from source map: (Pine County Geologic Atlas).

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



Graphic from source map: (Pine County Geologic Atlas).

Figure 2: Digital Elevation Model

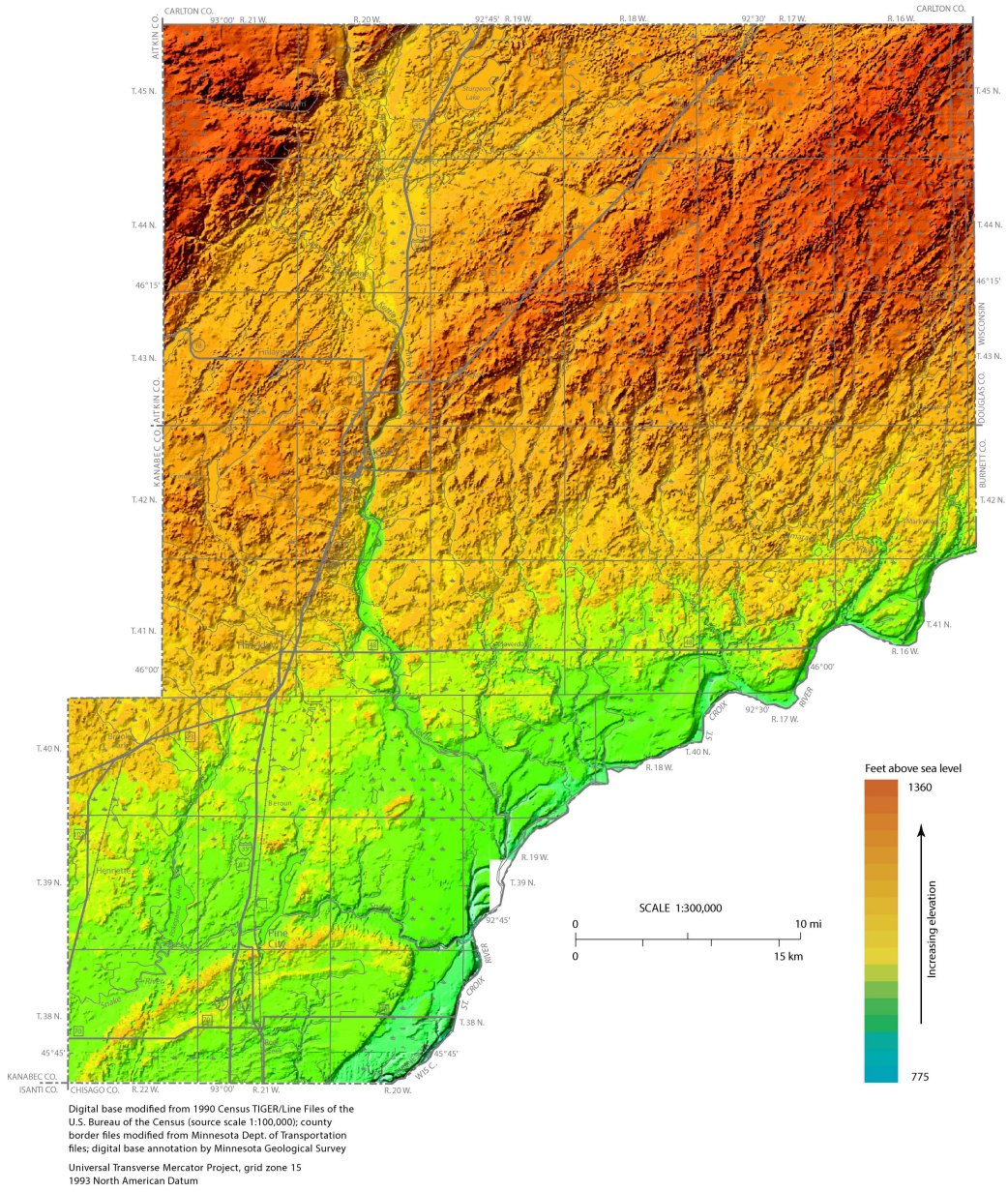


Figure 2. Physical relief on the land surface in Pine County. Elevation is shown by color, and a false sun illumination from the northwest provides contrast (gray shadowing) to accent details of landforms. The map was created using the U.S. Geological Survey's Digital Elevation Model. The county has 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 Atlas).

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)		*Total number*	*Percentage of total sample weight*	*Percentage in 1–2 mm fraction*	*Total number*	*Percentage of total grains counted*	*Percentage of total crystalline grains counted*
UNIT LABELS	DEPOSIT TYPE (AND ASSOCIATED ICE PHASES AND GLACIAL LAKES)	SAMPLES	GRAVEL	SAND–SILT–CLAY	SAMPLES	CRYSTALLINE–CARBONATE–SHALE	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	--	--	--

Graphic from source map: (Pine County Geologic Atlas).

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 Atlas).

References

Hobbs, H.H., 1998, Use of 1-2 millimeter sand-grain composition in Minnesota Quaternary studies, in Patterson, C.J., and Wright, H.E., Jr., eds., Contributions to Quaternary studies in Minnesota: Minnesota Geological Survey Report of Investigations 49, p. 193–208.

Johnson, M.D., Addis, K.L., Ferber, L.R., Hemstad, C.B., Meyer, G.N., Komai, L.T., 1999, Glacial Lake Lind, Wisconsin and Minnesota: Geological Society of America Bulletin, v. 111, p. 1371–1386.

Johnson, M.D., and Mooers, H.D., 1998, Ice-margin positions of the Superior lobe during Late Wisconsinan deglaciation, in Patterson, C.J., and Wright, H.E., Jr., eds., Contributions to Quaternary studies in Minnesota: Minnesota Geological Survey Report of Investigations 49, p. 7–14.

Meyer, G.N., 1998, Glacial lakes of the Stacy basin, east-central Minnesota and northwest Wisconsin, in Patterson, C.J., and Wright, H.E., Jr., eds., Contributions to Quaternary studies in Minnesota: Minnesota Geological Survey Report of Investigations 49, p. 35–48.

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.

Text from source map: (Pine County Geologic Atlas).

Plate 7: Mineral Endowment

Bedrock Endowment Legend

Areas where depth to bedrock is less than 25 feet.

Sandstone and siltstone—Includes Paleozoic rocks, Hinckley Sandstone, and Fond du Lac Formation.

Basalt.

Dolomitic marble.

Schistose rocks—Includes metamorphosed graywacke, basalt, and arkose.

McGrath Gneiss.

Quarries.

Inactive dimension-stone quarry.

Active quarry for production of crushed rock.

Copper showings.

Float of epidote-altered basalt containing disseminated copper.

Outcrop of basalt showing disseminated copper.

Native copper in prehnite vein.

Basalt with pervasive epidote alteration.

Uranium exploration drill hole.

Test pits and shafts.

Test pit observed by Minnesota Geological Survey field geologist—The four test pits shown in the far northwestern corner of the county were observed during the course of field work. Two are located in the McGrath Gneiss and may have been excavated during early uranium exploration activities. The other two are located on and adjacent to a narrow northwest-trending diabase dike that contains substantial pyrrhotite. Because pyrrhotite is magnetic, it is assumed that these excavations were made as a follow-up to early dip-needle magnetic surveys. Test pits in southern Pine County were excavated as part of copper exploration efforts prior to 1900; these include water-filled shafts of unknown depth.

Shaft reported but location could not be verified during field work for this atlas.

Graphic from source map: (Pine County Geologic Atlas).

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 Atlas).

Report

Introduction

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), and the natural aggregate is further 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.

Text from source map: (Pine County Geologic Atlas).

Bedrock Aggregate (Crushed Rock)

Only one quarry in Pine County is presently in operation; it is located east of the City of Askov in Fleming Township (T. 43 N., R. 18 W.). Basalt extracted from the quarry is crushed to produce traprock aggregate materials, which are used mainly for resurfacing local township and private gravel roads. To date, the material from this quarry has not been tested by the Minnesota Department of Transportation for suitability in bituminous or concrete paving. Other near-surface or surface exposures of basalt may also contain material suited for crushed-rock aggregate production. As a general rule, outcrops of basalt that are located away from the Douglas fault are more likely to contain fresh, hard crystalline bedrock that will meet the testing criteria for construction of paved roads.

The Hinckley and Fond du Lac sandstones (see Plate 2) are not suitable for use as road aggregate, as they are relatively soft and friable in comparison to crystalline rocks in Pine County. Given its uniform fine-grained sandy texture, the Hinckley Sandstone could potentially be crushed to form industrial quartz sand similar to that currently being produced from the Jordan Sandstone in southeastern Minnesota, but the material would need to be tested to determine suitability for this purpose.

The northwest corner of Pine County contains numerous surface exposures of crystalline bedrock, including schist and gneiss (Plate 2). These rocks have not been tested for aggregate suitability. However, they are similar in composition and texture to bedrock presently quarried in other parts of the state for this purpose. In particular, the McGrath Gneiss is similar to rocks quarried near St. Cloud, Granite Falls, and Ortonville for highquality aggregate used for bituminous and concrete road surfaces, among other uses. The schistose rocks located to the north of the McGrath Gneiss may provide aggregate suitable for use in pavement.

Text from source map: (Pine County Geologic Atlas).

Copper Showings

Several copper exploration shafts have been reported in Pine County-for example, Upham (1888) and Martin (1985 and references therein). The shafts were constructed prior to 1900. They were reportedly located along the banks of the Snake River downstream from Cross Lake and Pine City, the banks of the Kettle River east and southeast of the City of Hinckley, and along the Kettle and St. Croix Rivers in and near St. Croix State Park. The exploration shafts followed showings of native copper in veins and flow features within the volcanic rocks of the Chengwatana Volcanic Group (Plate 2). Some shafts reportedly were several hundred feet in depth. Although copper was apparently found in sufficient quantity to spur

exploration, none of the reports indicate that any copper was actually shipped as ore. The copper exploration in Pine County and adjacent areas of Wisconsin was spurred by the discovery of native copper deposits of large tonnage in the Upper Peninsula of Michigan and the similarity of those rocks to the volcanic rocks in Pine County.

The locations of test shafts shown on the bedrock endowment map were gleaned from historical reports and from observation of extant shafts. Effort was made to locate all of the reported test shafts, with limited success. The map also shows locations where finely disseminated copper was noted during field work completed as part of the study, locations where basalt has been pervasively altered to epidote, and locations where float copper has been found by the author during field mapping.

Text from source map: (Pine County Geologic Atlas).

Dimension Stone

Material from the Hinckley Sandstone was formerly quarried for use as dimension stone. Dimension stone is rock that is fabricated into tiles, slabs, or blocks. The quarries in Pine County operated from 1885 until the late 1930s (information from the Sandstone Historical Society); they are located in what is now Robinson Park in the City of Sandstone, and in Banning State Park. The sandstone was fashioned into building materials that included flagstone, curbing, and blocks for buildings and bridge footings.

Material from the McGrath Gneiss, and possibly the marble unit within the Denham Formation, may have value as dimension (or building) stone (refer to Plates 2 and 3 for additional information on rock units). Market demand, accessibility, and the suitability of stone for quarrying determine the feasibility of quarrying rock. Potential dimension stone must (1) be of a desired color and/or texture, (2) be relatively free of fractures, and (3) pass a series of physical and chemical tests for strength and durability. Cores from drill holes that have penetrated the marble unit immediately north of the Denham Formation outcrops indicate that the marble persists several hundred feet in depth. Although the marble is generally tan where it is exposed at the land surface, in the subsurface it is generally gray to (in places) pale pink, green, or white.

Text from source map: (Pine County Geologic Atlas).

Natural-Aggregate Introduction

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 from source map: (Pine County Geologic Atlas).

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 dep**osits 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 Atlas).

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 Atlas).

Natural-Aggregate Acknowledgments

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

Text from source map: (Pine County Geologic Atlas).

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

Figure from source map: (Pine County Geologic Atlas).

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

Figure from source map: (Pine County Geologic Atlas).

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.

Text from source map: (Pine County Geologic Atlas).

Bedrock Endowment References

Martin, D.P., 1985, A compilation of ore mineral occurrences, drill core, and test pits in the State of Minnesota: Minnesota Department of Natural Resources, Division of Minerals Report 231, 266 p.

Upham, Warren, 1888, Copper-bearing trap, a section in Upham, Warren, Geology of Pine County: Geological and Natural History Survey of Minnesota Final Report, v. 2, p. 632–637.

Text from source map: (Pine County Geologic Atlas).

St. Croix NSR Quaternary Geology

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.

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 1:100,000 (*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 Dalton Meyer, Sarah Lowe and James Chappell (Colorado State University) for the NPS Geologic Resources Division (GRD) Geologic Resources Inventory (GRI) Program. Quality control of this document by James Chappell and Stephanie O'Meara. (Colorado State University).

The information in this document was compiled from GRI source maps, and intended to accompany the digital geologic-GIS map and other digital data for Saint Croix National Scenic Riverway, Minnesota and Wisconsin (SACN) developed by James Chappell, James Winter, Dylan Rolley, Dalton Meyer and Stephanie O'Meara (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 the related GRI digital geologic-GIS map).

GRI finalization by James Chappell (Colorado State University).

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