UNIVERSITY OF MINNESOTA
MINNESOTA GEOLOGICAL SURVEY
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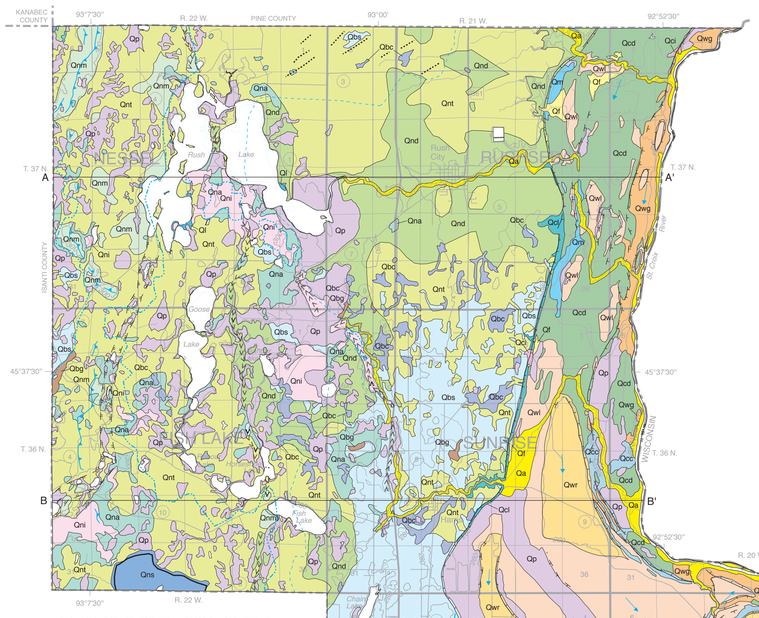
SURFICIAL GEOLOGY

By

Gary N. Meyer

2010

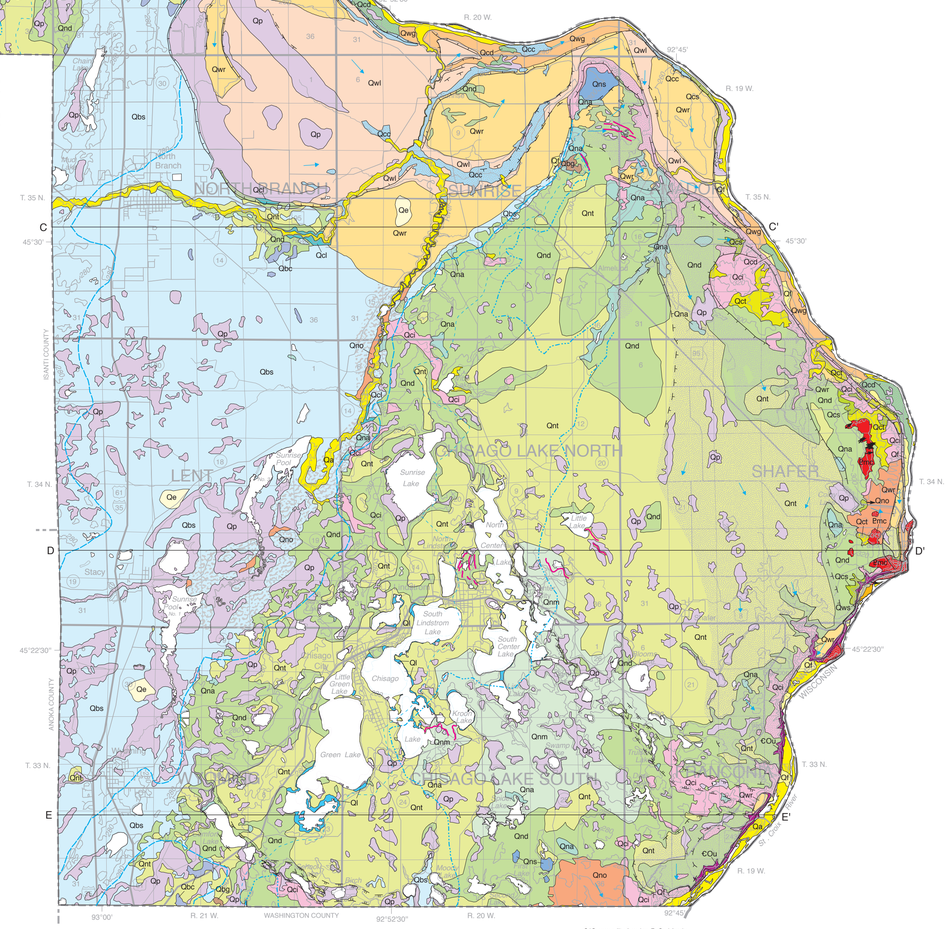


Digital base modified from the Minnesota Department of Transportation BaseMap data; digital base annotation by the Minnesota Geological Survey.

Elevation contours were derived from the U.S. Geological Survey 30-meter Digital Elevation Model (DEM) by the Minnesota Geological Survey.

Universal Transverse Mercator Projection, grid zone 15
1983 North American Datum

LOCATION DIAGRAM



GIS compilation by R.S. Lively
Edited by Lori Robinson

SCALE 1:100 000

CONTOUR INTERVAL 20 METERS

Table 1. General characteristics of mapped glacial deposits.

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	

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, 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 (Fig. 2). A brief summary of the glacial history of the county follows (a more detailed discussion is in Meyer, 1998).

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 prevalence 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 Qei).

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).

HUDSON EPISODE EVENTS

While the channels of the St. Croix River and its tributaries were being established, organic debris (unit Qp) 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.

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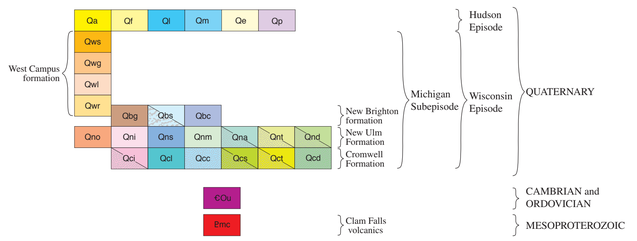
CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

QUATERNARY

Qe **Eolian sand**—Very fine- to medium-grained sand; more than 3 feet (1 meter) thick; windblown into low-lying dunes.

Ql **Lacustrine deposit**—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.

Qa **Floodplain alluvium**—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; those scarps are not shown by a symbol.

Qp **Peat and muck**—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.

Qm **Marl**—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.

Qf **Alluvial fan deposit**—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.

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

Qws **St. Mary's terrace**—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.

Qwg **Grey Cloud terrace**—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.

Qwl **Langdon terrace**—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.

Qwr **Richfield terrace**—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.

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

Qbs **Sand facies**—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.

Qbc **Silt and clay facies**—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.

Qbg **Sand and gravel facies**—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.

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

Qns **Lake sand**—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.

Qno **Outwash**—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.

Qni **Ice-contact stratified deposit**—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.

Qnt **Loamy till (low relief)**—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.

Qnm **Loamy till (moderate-relief)**—Till as above; deposits generally form elliptical hills or ridges with an overall relief of 40 to 70 feet (12 to 21 meters).

Qna **Sandy till**—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.

Qnd **Twin Cities member** (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.

Cromwell Formation (Meyer, 1999)—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.

Qcl **Lake sand and silt**—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.

Qcc **Lake clay and silt**—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.

Qci **Ice-contact stratified deposit**—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.

Qct **Supraglacial till**—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.

Qcd **Subglacial till**—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.

Qcs **Till, sand, and gravel**—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.

CAMBRIAN-ORDOVICIAN, UNDIVIDED

€Ou **Bedrock, undivided**—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; see Plate 2, *Bedrock Geology*). Discontinuously exposed; mantled by generally less than 5 feet (1.5 meters) of sandy to rocky colluvium or alluvium.

MESOPROTEROZOIC

Emc **Clam Falls volcanics**—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.

MAP SYMBOLS

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*.**

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

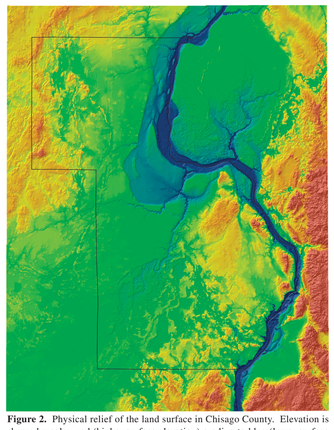


Figure 2. Physical relief of the land surface in Chisago County. Elevation is shown by color: red (higher surface elevation) grading to blue (lower surface elevation). A false sun illumination at an elevation of 30° from the northwest (315°) provides contrast (gray shadowing) to accent details of landforms.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

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.

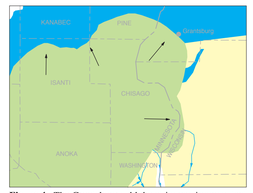


Figure 4. The Grantsburg sublobe at its maximum extent at the Pine City moraine. It is damming glacial Lake Grantsburg to the north, and is blocked by the St. Croix moraine to the southeast.

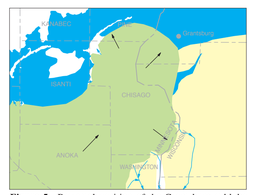


Figure 5. Retreatal position of the Grantsburg sublobe just prior to the drainage of glacial Lake Grantsburg down the St. Croix River valley.

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

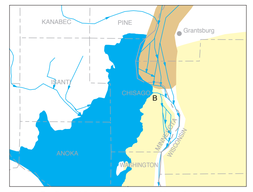


Figure 7. Glacial Lake Anoka at the Hugo level, following catastrophic drainage at outlet B. This new outlet must have become available as sediment-mantled ice in a buried valley melted, collapsing the overlying surface. A broad, water-washed area west of the St. Croix River valley from outlet B south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

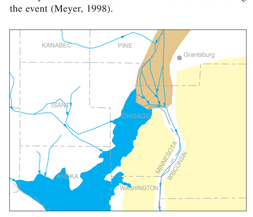


Figure 8. Glacial Lake Anoka at the Fridley level, prior to drainage of most of the lake when a southern outlet opened at Minneapolis.

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