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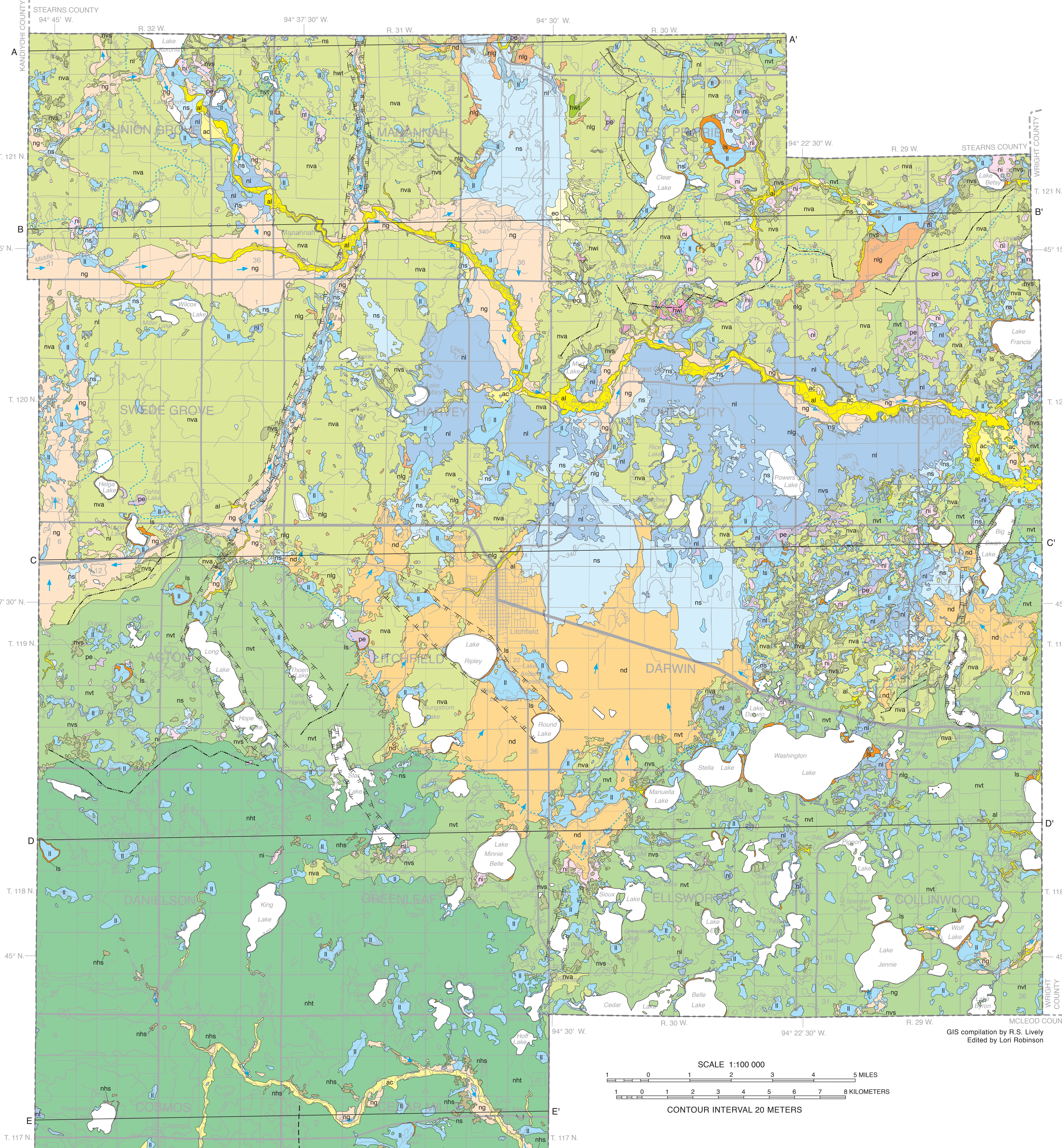


Digital base modified from the Minnesota Department of Transportation BaseMap data; digital base annotation by the Minnesota Geological Survey.

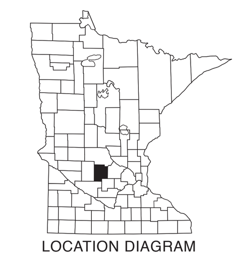
Elevation contours were derived from the U.S. Geological Survey 30-meter Digital Elevation Model (DEM) by the Minnesota Geological Survey.

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

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

SCALE 1:100 000

CONTOUR INTERVAL 20 METERS



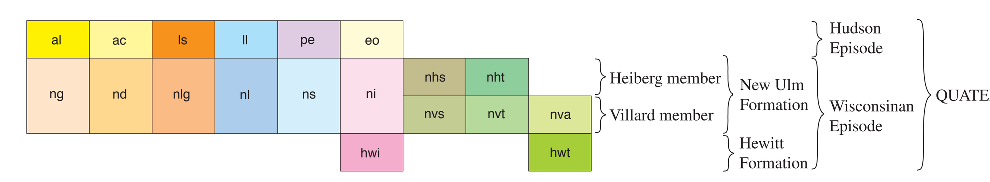
SURFICIAL GEOLOGY

By

Gary N. Meyer

2015

CORRELATION OF MAP UNITS



INTRODUCTION

The surficial geology map of Meeker County shows the earth material expected to be encountered below the topsoil, generally about 3 feet (1 meter) below the land surface. Mapping the detailed unit boundaries required extensive use of the county soil survey (Lueth, 1999; Natural Resources Conservation Service, 2012). Water well records from local drillers and engineering test boring logs from the state and county highway departments (Plate 1, *Data-Base Map*) were also helpful in delineating boundaries. Exposures examined and sampled in some of the larger gravel pits and along the banks of the North Fork of the Crow River were particularly helpful in deciphering the glacial history. Field work also included drilling 56 shallow auger holes and contracting 6 deep rotary-sonic core holes. Recent mapping of the aggregate resources of Meeker County by the Minnesota Department of Natural Resources (Arends, 2005) delineated the major landforms of the county and made many observations that contributed to this study. 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 largely by glacial sculpturing and meltwater deposition and erosion is displayed on the Digital Elevation Model (Fig. 2).

SUMMARY OF GLACIAL HISTORY

The surficial geology of Meeker 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 Wisconsinan Episode (Johnson and others, 1997). These sediments buried bedrock and eroded remnants left by multiple earlier glacial advances that once covered the county. During each of these advances, glacial ice from the continental ice sheet to the north (the Laurentide ice sheet) entered the county from different directions. The diverse deposits left behind by each ice advance reflect its provenance (Fig. 3; Table 1), the unique area of bedrock that the ice passed over and incorporated, and then deposited as it moved away from its source area.

During the Wisconsinan Episode, Wadena-lobe ice carrying debris of Rainy provenance covered the county (Fig. 3), depositing sediment of the Hewitt Formation (Knaeble, in press). During retreat of the Wadena lobe out of Meeker County, the confluent Superior lobe bulged into Wright County to the east during the Emerald phase (Fig. 4; Hobbs, 2013; Knaeble, 2013). Wood from below sediment interpreted to have been deposited during the Emerald phase in east-central Minnesota yielded a radiocarbon date of about 28,500 years before present (Meyer, 2010). During the retreat of the Wadena lobe, Rainy provenance sand and gravel of the Hewitt Formation were deposited in fans at the lobe margin and behind the margin by a subglacial stream; these deposits are exposed in gravel pits north of Forest City (unit hwi). Some time after the retreat of the Wadena lobe from Meeker County, the Des Moines lobe advanced from the southwest, moving into at least the southern and far eastern portions of the county, depositing sediment of Riding Mountain provenance, characterized by the presence of gray siliceous shale detritus (Table 1). This initial advance of the Des Moines lobe into Meeker County deposited the Moland Member of the New Ulm Formation (Hobbs, in press), now completely buried by younger deposits (Plate 4, *Quaternary Stratigraphy*). The advance of the lobe into northern Meeker County was likely hindered at this time by the presence of stagnant-ice-cored moraines left by the Wadena lobe in the central portion of the county.

A second pulse of the Des Moines lobe was able to override Wadena-lobe moraines to the northwest (the Alexandria moraine complex; Hobbs and Goebel, 1982) and enter Meeker County from that direction. All of Meeker County was covered at this time by sediment of the Villard Member of the New Ulm Formation (Lusardi and Harris, in press A). Till of the Villard Member (unit nva) is more sandy in northern Meeker County than in other areas, presumably due to glacial incorporation of proglacial outwash, and of sandy sediment of the underlying Hewitt Formation. Wood from sediment above till of the Villard Member in western Stearns County to the north was radiocarbon-dated at about 11,600 years before present (Knaeble and Meyer, 2007). The northeastward advance of the Des Moines lobe during deposition of the Villard Member was arrested just to the north in Stearns County by the St. Croix moraine (marked in Fig. 3 by the dotted line labeled St. Croix phase; Meyer and Knaeble, 1996; the Powder Ridge Ski Area is located on the St. Croix moraine).

During the retreat of the Des Moines lobe from its maximum advance, not all meltwater was able to escape as lower ground became exposed in Meeker County, and glacial Lake Litchfield formed, dammed by glacial ice still present to the east in Wright County (Fig. 5). Outlets to the north at Eden Valley to the Sauk River, and possibly to the northeast at Lake Francis to the Clearwater River, were not low enough to drain the lake due to buried stagnant ice. The lake drained when ice blocking the valley of the North Fork of the Crow River melted enough to open a pathway to the east (Fig. 6).

A second phase of glacial Lake Litchfield developed when the ice stream within the Des Moines lobe that deposited the Heiberg Member (Lusardi and others, 2011; Lusardi and Harris, in press B) moved northeast over part of the area covered by Villard Member deposits, again blocking the valley of the North Fork of the Crow River east of Meeker County (Fig. 7; Hobbs, 2013). The advance that deposited the Heiberg Member also moved into southwest Meeker County, laying down glacial sediment (unit nht) interbedded and mixed with silt and clay deposited in proglacial lakes between the ice front and high ground to the north. As the ice advance stalled and stagnated, short-lived lakes formed on top of the ice, leaving behind generally thin lake sediment on top of clayey till (Jennings and Adams, 2013). Melting of this last ice advance to the east in Wright County once again allowed drainage of glacial Lake Litchfield (Fig. 8).

HUDSON EPISODE EVENTS

While the channels of the North, Middle, and South Forks of the Crow River and their tributaries were being established (units al and ac), organic-rich deposits (units pe and ll) began to accumulate in low-lying portions of the glacial Lake Litchfield plain, and in ice-block melt-out depressions and abandoned drainageways across Meeker County. A study of sediments cored from Lake Ann to the northeast in Sherburne County (Keen and Shane, 1990) indicated the eolian sand dunes (unit eo) in Meeker County may not have formed until an extended dry period beginning about 8,000 years ago (based on radiocarbon dating).

DESCRIPTION OF MAP UNITS

QUATERNARY

Hudson Episode

al **Alluvium**—Typically coarser-grained (sand and gravel) in channels, and finer-grained (fine-grained sand and silt) on floodplains. Generally coarsens with depth, with scattered wood and shell fragments. Wider areas are typically topped and interbedded with thin organic-rich layers. Unit comprises sediment of modern streams. Contacts with glacial deposits are commonly scarps.

ac **Clayey alluvium**—Organic-bearing silty clay loam, clay loam, silt loam, and loam, deposited by modern streams. Thin beds of more sandy sediment are present at depth in places, and along smaller streams sand and gravel may be within 5 feet (1.5 meters) of the surface. Unit comprises sediment of modern streams. Contacts with glacial deposits are commonly scarps.

ll **Lake silt and clay**—Organic-rich, deposited in ponded water (sapropel); interbedded with sand at the margins in places; mollusk shells are common in places. Generally greater than 3 feet (1 meter) thick, and more than 30 feet (9 meters) thick in the center of some deposits; in places covered by up to 4 feet (1.2 meters) or more of peat and muck. Marl may be present at depth. In developed areas, some of these deposits have been drained and buried under artificial fill; the organic sediment is commonly removed prior to filling in areas where structures are built.

ls **Lake sand**—Sand to gravelly sand, with local organic-rich layers; loamy in places where bordering glacial sediment (till); deposited in a beach or shallow water environment; includes human-made beaches. In places, underlies or overlies muck, peat, or sapropel. Width of exposure varies depending on the water level in the lake. Includes ice ramparts (sediment pushed into ridges by expansion of lake ice; Zumberge, 1952), such as along the north shore of Round Lake south of Litchfield. Sand also heaped up into dunes by wind action in places.

pe **Peat and muck**—Partially decomposed plant matter deposited in swamps, commonly formed in ice-block melt-out depressions and in former meltwater channels. Generally mapped only where greater than 4 feet (1.2 meters) thick. Includes fine-grained organic matter laid down in ponded water (sapropel), marl at depth in places, and small bodies of open water.

eo **Eolian sand**—Well-sorted, very fine- to medium-grained sand; blown by predominantly northwest winds into low-lying dunes. Generally only mapped where greater than 3 feet (1 meter) thick—much of the mapped areas consist of eolian sand reworked and washed into drainageways by rainwater.

Wisconsinan Episode

New Ulm Formation (Lusardi, in press)—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 Des Moines lobe. 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 up to 4 feet (1.2 meters) of peat.

Heiberg Member (Lusardi and Harris, in press B)

nht **Clayey till**—Chiefly loam- to clay loam-textured, unsorted sediment (diamicton); pebbly, with scattered cobbles and rare boulders. Moderate to high amounts of Cretaceous shale clasts (Plate 4, Table 1). The unit south of the South Fork of the Crow River in Cedar Mills Township is interpreted to be thin and patchy over reworked sediment of unit nvt. The till surface is generally rolling and hummocky towards the margin of unit nht, with many ice-block melt-out depressions, and flat away from the margin, where the till is commonly overlain and interbedded with thin beds of lacustrine silt and clay (Jennings and Adams, 2013).

nhs **Clayey till, sand, and gravel**—Loam- to clay loam-textured, unsorted sediment (diamicton), pebbly, with scattered cobbles and rare boulders; commonly capped by, or interbedded with, thin deposits of sandy 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 may be present at depth in places. Near present-day lakes the unit may include Hudson Episode beach deposits.

Heiberg and Villard Members

ng **Outwash**—Sand, gravelly sand, and gravel. Deposited by meltwater streams issuing from the ice margin and flowing across the stagnation moraine and the drained plain of glacial Lake Litchfield. Deposits laid down within the lake plain following drainage of glacial Lake Litchfield I (Fig. 6) were likely reworked when glacial Lake Litchfield II formed (Fig. 7). The unit is commonly bounded by scarps.

nl **Lake clay and silt**—Laminated clay to silt, with beds of very fine-grained sandy silt in places; generally greater than 5 feet (1.5 meters) thick. Beds of silty, fine-grained sand to gravelly sand occur at boundaries with till units, and at depth within the unit in places in the vicinity of the North Fork of the Crow River. Deposited in deeper, quiet water of glacial Lake Litchfield (Figs. 5, 7), and in smaller ice-walled lakes during retreat and stagnation of the Des Moines lobe.

ns **Lake sand and silt**—Mostly very fine- to fine-grained sand with interbeds of very fine-grained sandy silt to silt; includes medium-grained sand beds and lenses of thick silt in places; coarse-grained, gravelly sand occurs locally in the vicinity of till units. Where patchy, unit ns is commonly less than 10 feet (3 meters) thick. Deposited in shallower, more active water of glacial Lake Litchfield (Figs. 5, 7), and in smaller ice-walled lakes during retreat and stagnation of the Des Moines lobe. The unit outlines the abandoned Eden Valley drainageway (Meyer and Knaeble, 1996).

nlg **Lake sand and gravel**—Medium- to coarse-grained sand to gravel. Deposited in shallow-water environments in glacial Lake Litchfield (Figs. 5, 7), and in smaller ice-walled lakes during retreat and stagnation of the Des Moines lobe.

nd **Deltaic sediment**—Interbedded, fine-grained sand to sand and gravel, laid down by meltwater flowing into glacial Lake Litchfield (Figs. 5, 7). Bedding is collapsed in places near the margin where the unit was deposited over buried ice.

ni **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 Des Moines lobe. 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). Unit typically forms hills and ridges. The upper part has been reworked within the bounds of glacial Lake Litchfield.

Villard Member (Lusardi and Harris, in press A)

nvt **Loamy till**—Chiefly loam-textured, unsorted sediment (diamicton); pebbly, with scattered cobbles and rare boulders. Moderate amounts of Cretaceous shale clasts (Plate 4, Table 1). Commonly includes layers of coarser textured till at depth. Lenses of stratified sediment are uncommon in most areas. The till surface is generally rolling and hummocky, with many ice-block melt-out depressions.

nva **Sandy till**—Chiefly loam- to sandy loam-textured, unsorted sediment (diamicton), pebbly, with cobbles and some boulders; low to moderate amounts of Cretaceous shale clasts (Plate 4, Table 1). Where thick, the unit commonly includes loamy-textured layers at depth. The till surface ranges from flat and wave-washed beneath the glacial Lake Litchfield plain, to rolling and hummocky beyond the margins of the former lake.

nvs **Till, sand, and gravel**—Loam- to sandy loam-textured, unsorted sediment (diamicton), pebbly, with cobbles and some boulders; commonly capped by, or interbedded with, thin deposits of sandy 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 may be present at depth in places. In the vicinity of unit hwi, unit is commonly less than 20 feet (6 meters) thick over Hewitt Formation deposits. Near present-day lakes the unit may include Hudson Episode beach deposits.

Hewitt Formation (Knaeble, in press)—Primarily glacial and fluvial sediment deposited by the Wadena lobe and its meltwater. The sediment is of Rainy provenance (Table 1), but in northeast Meeker County especially, the formation contains many clasts of Superior provenance due to its deposition near the confluence of the Wadena and Superior lobes (Fig. 4). The upper part of the Hewitt Formation is commonly reworked (by the overriding Des Moines lobe or subsequent hydraulic action) and mantled in places by generally less than 10 feet (3 meters) of younger deposits too patchy to show at this scale.

hwi ***Ice-contact stratified deposit***—Sand, gravelly sand, and cobbly gravel; deposited by meltwater flowing at or behind the retreating ice margin. Sediment can be variable and is typically faulted and folded because of the collapse of melting supporting ice. Deposits generally stand as positive features on the landscape.

hwt ***Sandy till***—Chiefly loam- to sandy loam-textured, unsorted sediment (diamicton), pebbly, with cobbles and some boulders. Cretaceous shale clasts are absent to very rare (Plate 4, Table 1). The till also differs from that of unit nva by having more red Precambrian clasts, somewhat less carbonate, and a slightly browner oxidized color (10YR versus 2.5Y-10YR). Unit hwt is mapped in two places where it was encountered at or near the surface in auger holes: in Forest Prairie Township (T. 121 N., R. 30 W., sec. 7) and Manannah Township (T. 121 N., R. 31 W., sec. 5). Hewitt Formation till was also recognized in exposures along the North Fork of the Crow River, at the town of Manannah, and in Forest City Township (T. 120 N., R. 30 W., secs. 11 and 14); these exposures were too small to map at this scale.

MAP SYMBOLS

Geologic contact—Approximately located.

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

Stream-cut scarp—Hachures point downslope; marks the flanks of a former fluvial channel. Boundaries of outwash and alluvium are commonly at scarps, so are not shown by a scarp symbol. 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.

Approximate shoreline of glacial Lake Litchfield—About 1,190 feet (363 meters) above mean sea level. The maximum extent of the lake is obscure because it was supported in places by buried stagnant ice. The landscape lowered as the ice melted. Glacial and fluvial sediment of the New Ulm and Hewitt Formations mapped within the bounds of glacial Lake Litchfield 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 lake sediment likely were once islands or peninsulas in glacial Lake Litchfield. The lake existed in two phases, with both possibly reaching the same maximum extent.

Esker—Sinuous ridge of predominantly sand and gravel, interpreted to have been deposited in an ice-walled stream or subglacial tunnel. Arrows show inferred flow direction. The sand and gravel of the eskers, interpreted to have been deposited by Wadena lobe meltwater, is buried by more than 30 feet (9 meters) of New Ulm Formation sediment across most of the mapped features.

Des Moines lobe ice marginal ridge—Moraine formed during a brief still stand during retreat of the lobe from the county.

Buried Wadena lobe ice marginal ridge—Ridge interpreted to be a buried moraine formed during a still stand during retreat of the lobe from the county.

Broad, irregular trough—Hachures point downslope; identified by alignment of depressions and lakes. Likely mark partially filled, pre-existing channels. These troughs are interpreted to reflect valleys cut by meltwater flowing beneath ice that were buried by subsequent glacial events.

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

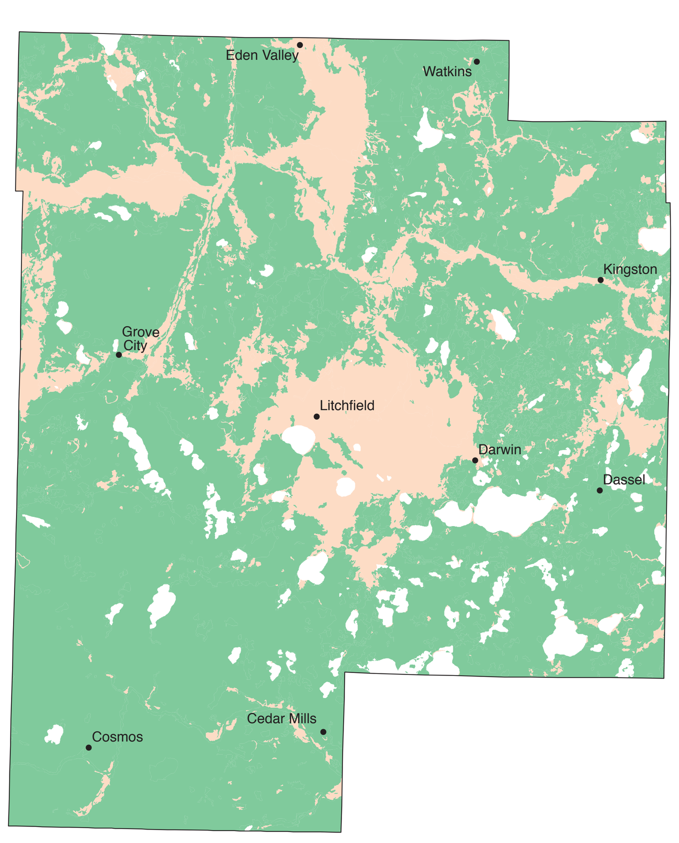


Figure 1. In this figure the map units from the 1:100,000 surficial geology map are combined into two simplified units: green is less permeable diamicton (glacial till—deposited more or less directly from glacial ice) and bedded silt and clay (deposited primarily in standing water environments); tan is more permeable, bedded sand to gravel (deposited primarily in active water environments). Water bodies are white. Peat (unit pe) is included in the less permeable unit. Scale is 1:300,000.

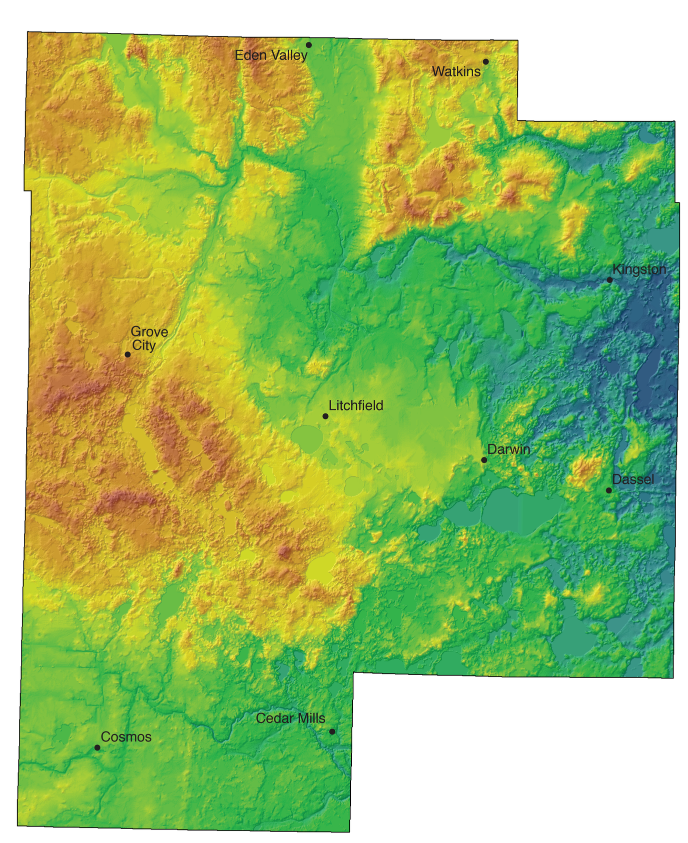


Figure 2. Physical relief of the land surface in Meeker County. Elevation is shown by color: red (higher surface elevation) grading to blue (lower surface elevation). A false sun illumination at an elevation of 30° from the northwest (315°) provides contrast (gray shadowing) to accent details of landforms. The map was created using the U.S. Geological Survey's Digital Elevation Model with a 10-meter grid; scale is 1:300,000.

Table 1. Physical characteristics of glacial deposits in Meeker County.

PROVENANCE	RIDING MOUNTAIN	WINNIPEG	RAINY	SUPERIOR
TILL TEXTURE	Sandy loam to clay loam	Loam to silt loam	Coarse loam to sandy loam	Sandy loam
TILL COLOR				
Oxidized	Light olive-brown	Light olive-brown	Yellow-brown	Brown to red-brown
Unoxidized	Gray to dark gray	Gray to dark gray	Gray to brown-gray	Gray to red-gray
PEBBLE TYPE				
Carbonate	Common	Common to abundant	Uncommon to common	Rare to uncommon
Gray-green rock	Uncommon to common	Uncommon to common	Uncommon to common	Common
Red felsite	Absent to rare	Absent to uncommon	Rare to common	Common
Gray shale	Uncommon to abundant	Absent to rare	Absent to very rare	Absent

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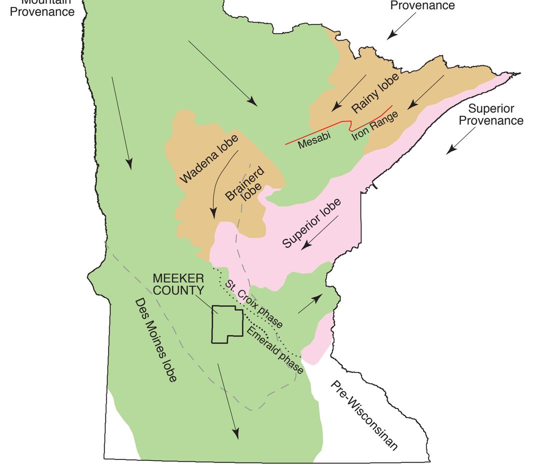

Figure 3. Location of major provenances (source regions). Glacial sediments deposited in the county derive their distinct material content from bedrock and sediment found in the region of these provenances. During the last glaciation, the Wisconsinan Episode, Meeker County was covered by ice carrying debris of Rainy provenance, the Wadena lobe. The dashed line approximates the maximum extent of the Wadena lobe, whose deposits have subsequently been covered by sediment of later glacial advances. During the retreat of the Wadena lobe from Meeker County, the confluent Superior lobe during its Emerald phase moved into Wright County to the east and contributed some debris to the Wadena lobe (Fig. 4). After the exit of the Wadena lobe, the Des Moines lobe, carrying debris of Riding Mountain provenance, moved into Meeker County from the northwest, covering it with ice one last time.

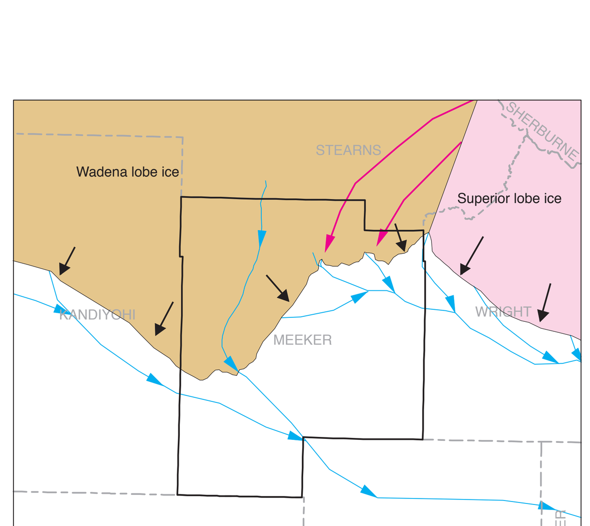

Figure 4. Retreatal position of the Wadena lobe (tan), with the confluent Superior lobe (pink) at its maximum advance during the Emerald phase. Magenta lines represent contribution of Superior provenance detritus to Wadena lobe ice and meltwater. Black arrows indicate ice flow direction. Blue lines indicate meltwater flow.

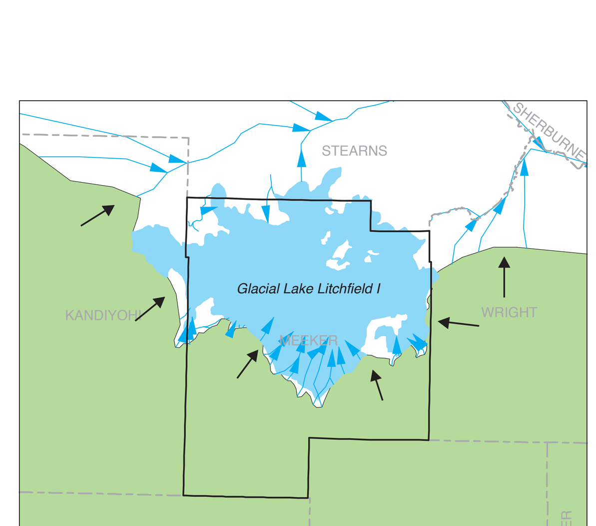

Figure 5. Approximate maximum extent of glacial Lake Litchfield I (blue), dammed by Des Moines lobe ice (green). Black arrows indicate ice flow direction. Blue lines indicate inferred meltwater flow.

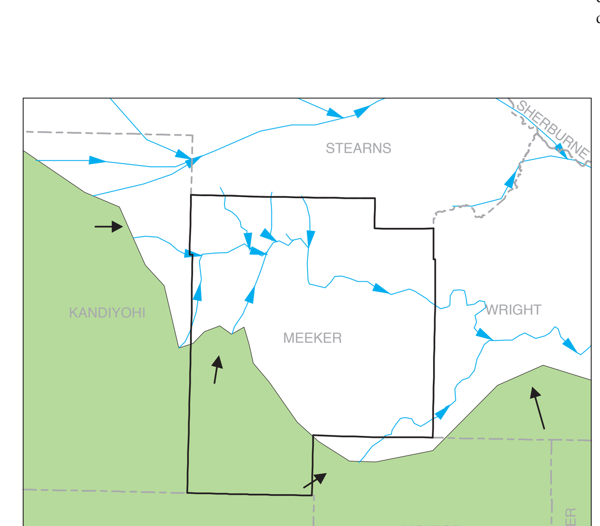

Figure 6. Drainage of glacial Lake Litchfield I following melting of Des Moines lobe ice to the east of Meeker County.

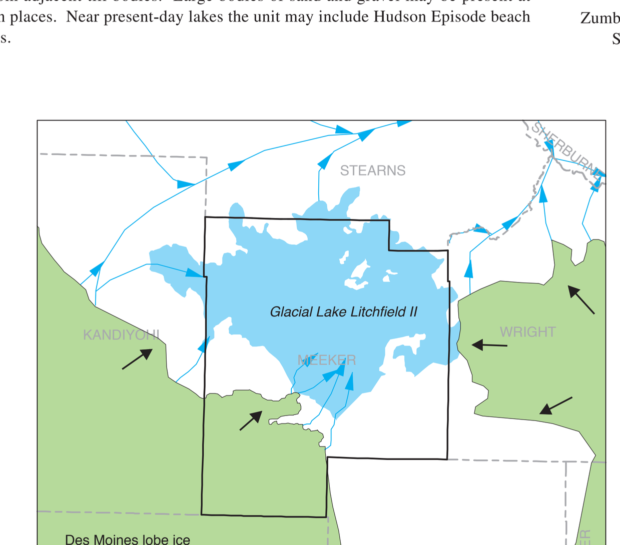

Figure 7. Glacial Lake Litchfield II, dammed by a readvance of the Des Moines lobe.

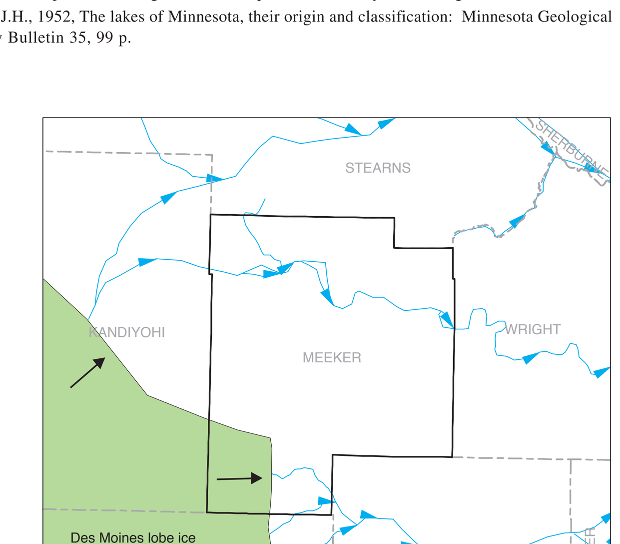

Figure 8. Retreatal position of the Des Moines lobe following drainage of glacial Lake Litchfield II.