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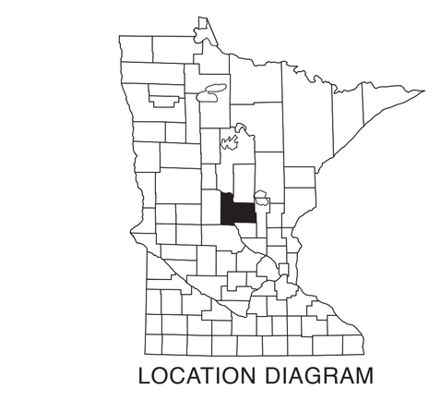

SURFICIAL GEOLOGY

By

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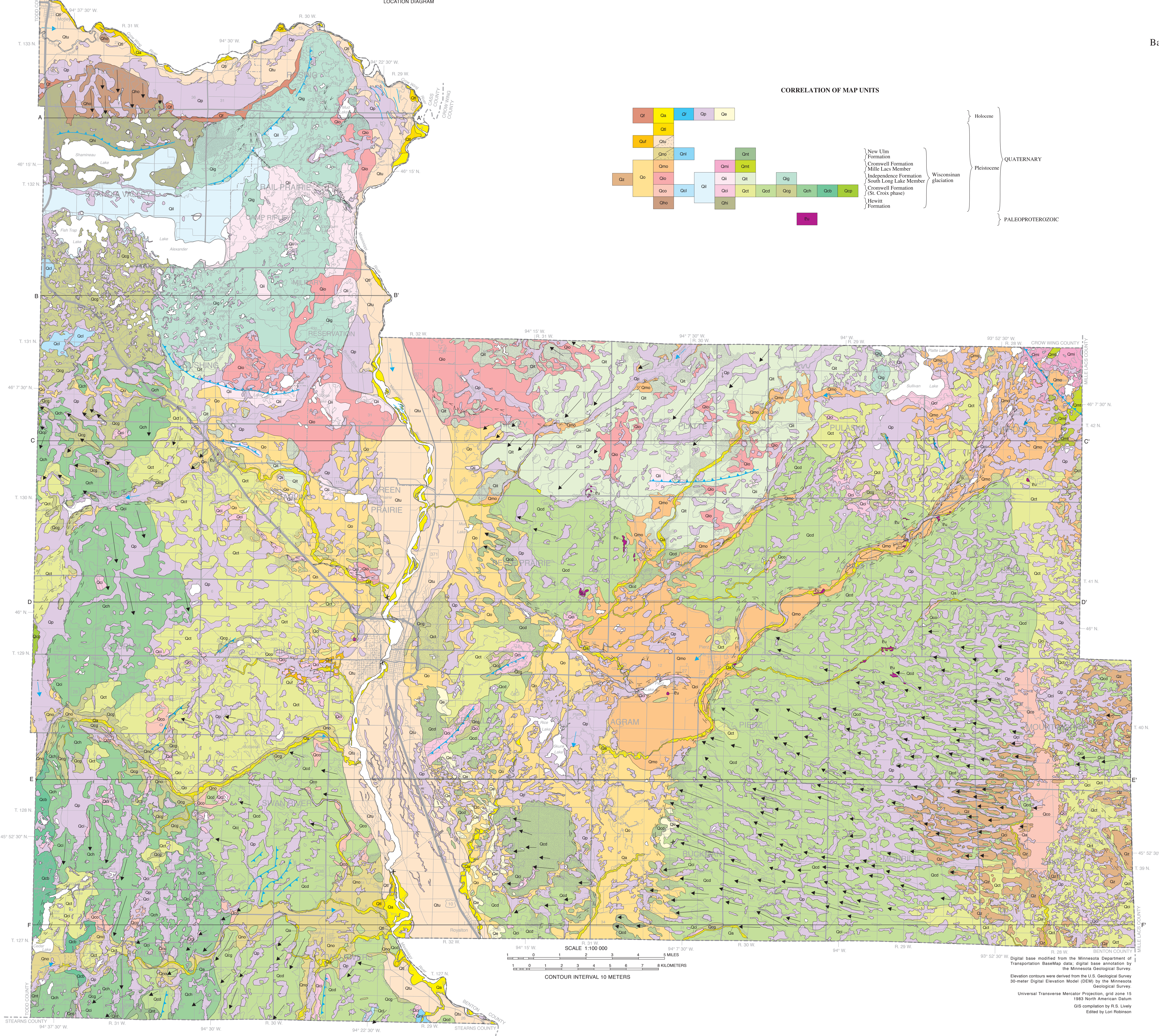
2014

CORRELATION OF MAP UNITS

Holocene
Pleistocene
QUATERNARY
New Ulm Formation
Cromwell Formation Mille Lacs Member
Independence Formation South Long Lake Member
Cromwell Formation (St. Croix phase)
Hewitt Formation
Wisconsinan glaciation
PALEOPROTEROZOIC



Digital base modified from the Minnesota Department of Transportation BaseMap 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

MAP SYMBOLS

Geologic contact—Approximately located.

Drumlin—A streamlined hill or ridge composed typically of glacial till; in places may include sand and gravel. Feature formed at the base of moving ice; commonly composed of subglacial sediment but also includes older pre-Wisconsinan deposits, which are deformed in places. Drumlins may be partially covered by supraglacial sediment and in places are partially or totally buried by subsequent glacial and fluvial deposits. Arrow shows the inferred direction of ice movement; the length of the arrow is approximately equivalent to drumlin length.

Elongate ridge—A sinuous ridge of sand and gravel deposited in an ice-walled channel either on top of or underneath the ice. The subglacial fluvial sediment may be covered by 10 feet (3 meters) or more of till. Interpreted to be an esker, although no flow direction is inferred.

Esker—A sinuous ridge of sand and gravel deposited in an ice-walled channel. The subglacial fluvial sediment may be covered by 10 feet (3 meters) or more of till. Arrows indicate inferred flow direction. Esker ridge may no longer exist due to mining of sand and gravel deposits. In those localities, the esker position is inferred from the presence of narrow, elongate lakes and from aerial photographs taken prior to excavation.

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

Ice margin—Ticks on up-ice side.

Irregular trough—Hachures point downslope; may be occupied by aligned depressions and lakes. Indicates that the ice surface collapsed over a subglacial ice cavern, called a tunnel valley.

Stream-cut scarp—Hachures point down scarp. Marks the bank 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.

Scroll bars—Indicate the migration of a river channel; may be slightly elevated. Symbol is a schematic representation; individual bars are not mapped. Interpreted from aerial photographs and topographic maps.

Washed—Pattern indicates where unit has been washed by meltwater. These areas typically are lower in elevation and display scoured surfaces that may include a thin cap of fine-grained sand to gravel.

x **Bedrock outcrop**—Too small to map.

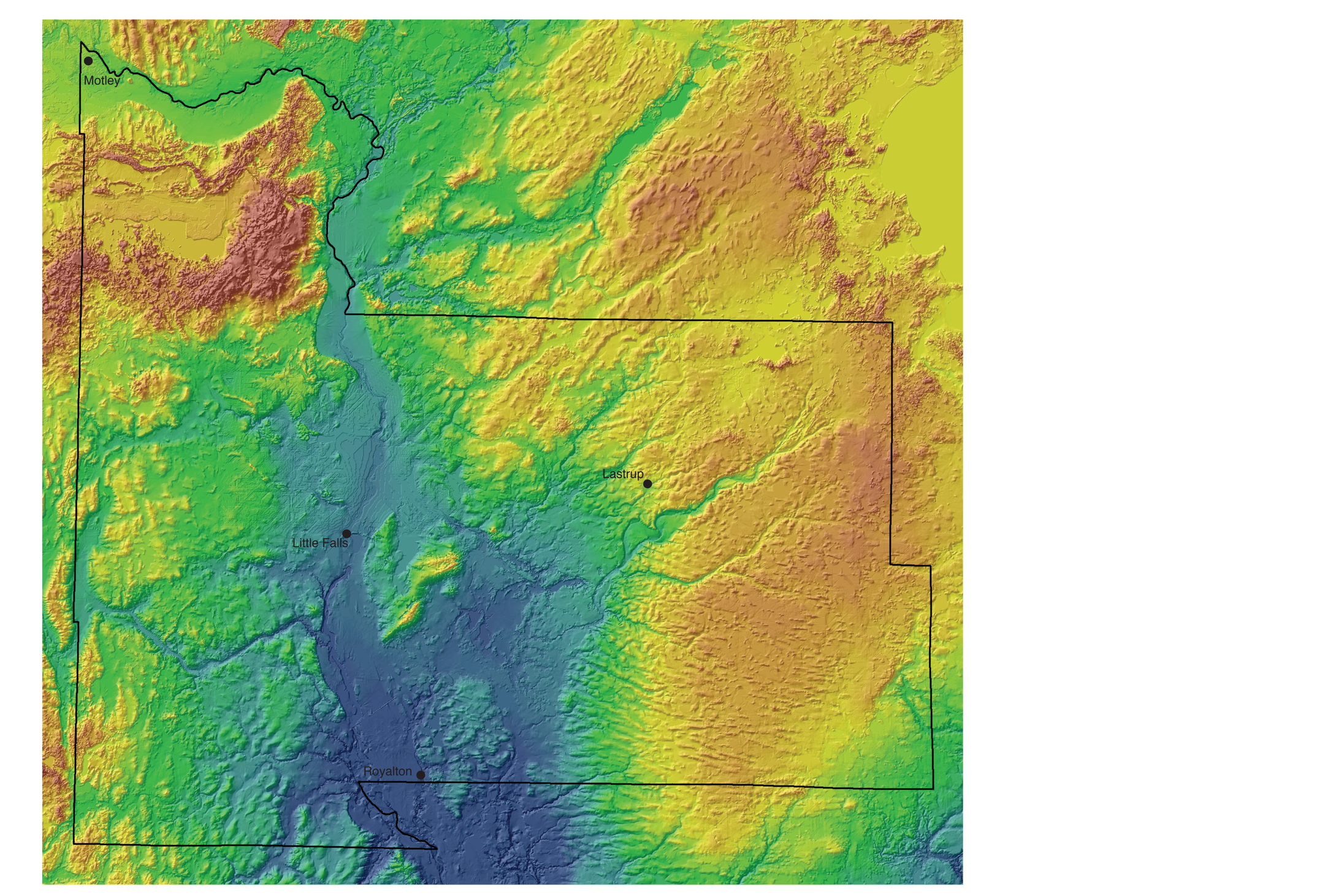


Figure 1. Physical relief of the land surface in Morrison County (vertically exaggerated 5 times). Elevation is shown by color: red-orange (higher elevation) grading to blue (lower elevation). Elevation ranges from about 842 to 1,117 feet (257 to 340 meters) above sea level. A false sun illumination at an elevation of 30° from the northwest (315°) provides contrast to accent landform details. This map was created using the U.S. Geological Survey's Digital Elevation Model with a 10-meter grid; scale 1:400,000.

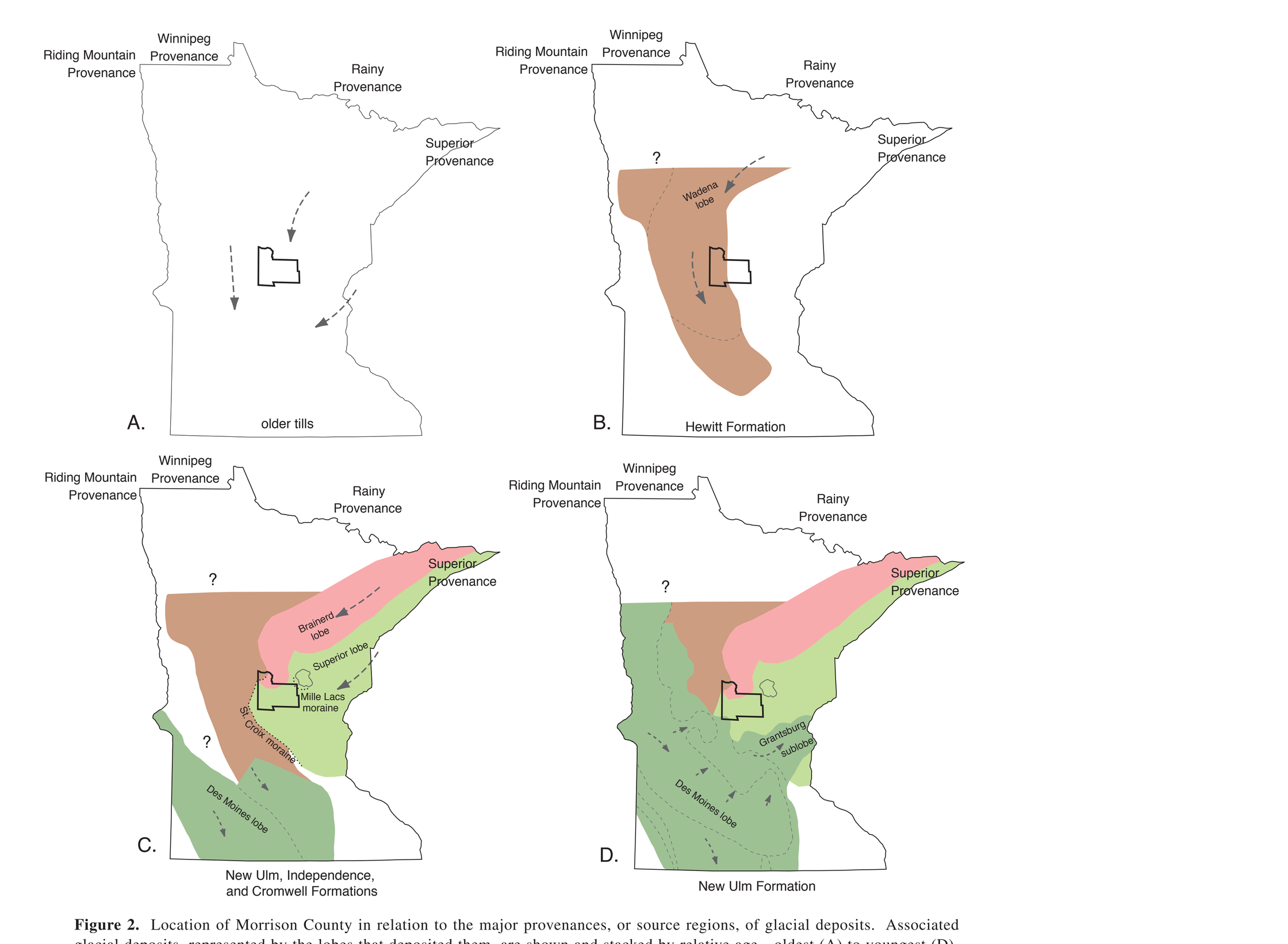


Figure 2. Location of Morrison County in relation to the major provenances, or source regions, of glacial deposits. Associated glacial deposits, represented by the lobes that deposited them, are shown and stacked by relative age—oldest (A) to youngest (D). Deposits introduced together on the same diagram (for example D) are not necessarily contemporaneous and the specific timing of events may be uncertain, especially in separate areas of the state.

A. Pre-Wisconsinan glacial deposits identified in Morrison County are patchy and represent ice advances from multiple directions (see Table 1).

B. Inferred extent of the Hewitt Formation deposited by the Wadena lobe.

C. Inferred extent of the Cromwell Formation (St. Croix phase) and the Independence Formation deposited by the Superior and Brainerd lobes. The St. Croix moraine marks the furthest extent of the Superior lobe during this phase. The Mille Lacs moraine indicates a later advance of the Superior lobe, during which the Mille Lacs Member of the Cromwell Formation was deposited.

D. The Des Moines lobe, depositing the New Ulm Formation, reached the southwestern corner of Morrison County after the Superior and Brainerd lobes had retreated.

INTRODUCTION

This map emphasizes the distribution and origin of surficial materials in Morrison County. The map is based on a variety of data sources. The depiction of landform distribution and sediment character was initially based on early spring stereo-pair aerial photographs taken in 1977 and 1978 (1:80,000). Light patterns on photographs are interpreted as dry, sandy sediment, whereas dark patterns indicate finer-grained material. The interpretations were drawn on 1:24,000 U.S. Geological Survey topographic maps that were overlain on a 10-meter digital elevation model that covered the area (Fig. 1). These interpretations were compared to a soil map for Morrison County (Natural Resources Conservation Service, 2010), national wetlands inventory maps (U.S. Fish and Wildlife Service, 2010), and to well logs included in the Minnesota Geological Survey County Well Index. Fieldwork to verify and augment these interpretations was conducted from 2010 to 2012. Most described and sampled exposures consisted of excavations, including gravel pits, construction sites, and road cuts. These were supplemented with 40 auger borings drilled to a depth of about 11 feet (3.4 meters) and 6 rotary-sonic drill cores drilled to an average depth of 205 feet (62 meters). Additional data from previous mapping (see Index to Previous Mapping), including samples from 66 auger borings, were included in the analyses and interpretation of map units. Textural analyses and grain counts were done on over 380 samples.

GLACIAL HISTORY

The Pleistocene Epoch began about 2.5 million years ago. During this time, glaciers advanced and retreated across the region many times. The glaciers advanced from many different directions, called provenances, leaving behind sediment of a particular color and containing distinct rock types indicative of the terrain over which they passed (Fig. 2; Table 1). The most recent glacial episode in this area, the Wisconsinan glacial episode, extended from about 110,000 years ago to the start of the Holocene Epoch 10,000 years ago. The Holocene marks the end of the ice age in Minnesota and the transition to the warm conditions we experience today.

Pre-Wisconsinan

Figure 2 illustrates the sequence of glacial advances that passed through the Morrison County area. The oldest recorded events are combined on the figure even though they likely span a long time and include ice advances from multiple directions (Fig. 2A). These pre-Wisconsinan advances are represented in the subsurface of Morrison County by a series of discontinuous gray and red tills indicating ice from the northeast Superior provenance, and from the north and northwest Rainy and Winnipeg provenances. Although none are exposed at the surface in Morrison County, some of these older till units are close to the surface along the western border of the county. General unit descriptions are included here for comparison with younger till units (for additional details, see Plate 4, *Quaternary Stratigraphy*).

Wisconsinan

The Wadena lobe is the earliest glacial advance for which there is widespread surficial evidence. South-trending drumlins (elongate hills that are streamlined in the direction of ice flow), attributed to the advance of the Wadena-lobe ice, are clearly visible in the western part of the county (Fig. 1). Glacial sediment deposited by the Wadena lobe (Fig. 2B), the Hewitt Formation (Johnson and others, in press), is close to the surface across the western half of Morrison County.

As the Wadena lobe retreated northward, the Superior lobe advanced into the region (Figs. 2C, 3A). West-trending drumlins across the eastern portion of the county indicate the direction of ice flow that deposited sediments assigned to the Cromwell Formation (Fig. 1; Johnson and others, in press). Deposition of the St. Croix moraine (Fig. 2C) is attributed to the Superior lobe (Wright, 1972; Knaeble and Meyer, 2007).

The northern part of the St. Croix moraine, where it crosses Morrison County, was constructed in part by ice of the Brainerd lobe as it squeezed in from the north–northeast, overriding the existing ice-cored moraine and adding more glacial sediment (assigned to the Independence Formation [Johnson and others, in press]) to the feature (Figs. 2C, 3B-D). At this time, the Superior and the Brainerd lobes were confluent as they advanced and retreated across the county, leaving deposits of mixed provenance and creating a somewhat arbitrary border between the Cromwell and Independence Formations.

The final phases of ice in Morrison County came from opposite directions (Figs. 2C, D). In what is called the Automba phase, the northeast-source Superior lobe, after retreating far enough to the northeast for a lake to form, readvanced as far as Mille Lacs Lake. The resulting deposits are the Mille Lacs Member of the Cromwell Formation (Johnson and others, in press) in the northeastern part of the county, which are slightly finer-grained than Cromwell Formation deposits of the St. Croix phase because of incorporated lake sediment as the ice readvanced. Meltwater from this advance flowed south and west toward what is now the Mississippi River valley (Fig. 3D). Later, the northwest-source Des Moines lobe advance reached the very southwestern corner of the county, depositing the New Ulm Formation (Fig. 2D). Meltwater from this advance flowed north and east, also draining to the ancestral Mississippi River (Fig. 3E).

POSTGLACIAL HISTORY

While the channels of the Mississippi River and its tributaries were being established and terrace sediments were being deposited (units Qtu, Qtl, and Qa), organic-rich deposits (units Qp, and Ql) accumulated in low-lying areas of the landscape including ice-block melt-out depressions and abandoned drainageways. In addition, wind eroded and piled sand into dunes (unit Qe) east of the Mississippi River.

DESCRIPTION OF MAP UNITS

Holocene

Qp **Organic debris, clay, and silt**—Partially decomposed plant matter (peat) and fine-grained organic matter deposited in marshes and ponded water. Includes minor alluvial deposits along streams as well as beach deposits. *Wetland sediment.*

Ql **Silt, clay, and loamy sand (shown only on digital files)**—Unit is not exposed at the surface in Morrison County. Locally includes organic-rich layers and may overlie or be overlain by muck or peat. May be sandy at the margins, especially where bordering glacial till because sand is winnowed out of the till by waves; includes artificial beaches. The extent of exposure depends on the water level in the lake. Deposited in modern lakes. *Lake deposits.*

Qe **Very fine- to medium-grained sand**—Forms dunes in places; relief locally exceeds 20 feet (6 meters). *Windblown sand.*

Holocene and Pleistocene

Qf **Sand to sandy loam**—Includes beds of silt loam and gravel. Contains variable amounts of disseminated organic debris. Forms coalescing fan-shaped deposits at the base of steep slopes. *Alluvial fan sediment.*

Qa **Sand, sandy loam to silt loam**—Generally coarse-grained sediment (sand and gravel) in channels, and finer-grained sediment (fine-grained sand and silt) on floodplains; coarsens with depth. May be capped and/or interbedded with organic-rich layers. Low areas may be filled with thick silty to clayey sediment. Along the Mississippi River, the unit 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. Sediment along smaller streams is generally finer-grained. Deposited by modern streams in channels and on floodplains. *Floodplain alluvium.*

Sand and gravelly sand—Coarsens to cobbly gravel locally; capped in places by loamy fine-grained sand. Deposited as fluvial sediment during higher stages of flow on the Crow Wing and Mississippi Rivers when the rivers served as outlets for glacial meltwater from the north and west. Sediments are of mixed provenance and include abundant crystalline rocks (basalt and granite), some red sandstones, some carbonate rocks, and few gray, siliceous shale fragments. Sediment on lower terrace surfaces grades into floodplain alluvium. Terraces are separated into upper and lower surfaces based on general differences in elevation. In some places, there is a distinct scarp marking the edge of one terrace surface against another. In other places, the slope between surfaces is gradational and the contact line distinguishing the upper and lower surfaces is drawn to the elevation contour. *Alluvial terrace deposits.*

Qtl ***Lower terrace***—Surface on the Crow Wing River banks ranges in elevation from approximately 1,210 feet (369 meters) on the west bank to 1,160 feet (354 meters) on the east bank, and from 1,160 feet (354 meters) on the north bank to 1,060 feet (323 meters) on the south bank along the Mississippi River.

Qtu ***Upper terrace***—Surface on the Crow Wing River banks ranges in elevation from approximately 1,230 feet (375 meters) on the west bank to 1,190 feet (363 meters) on the east bank, and from 1,190 feet (363 meters) on the north bank to 1,075 feet (328 meters) on the south bank along the Mississippi River. Patterned area indicates places where terrace sediments are thin (less than 10 feet or 3 meters) and overlie glacial till (unit Qcd).

Quf **Clay to clayey silt**—Silty fine-grained sand beds or zones are present in places; yellow-brown to gray. Deposited by slackwater of the Mississippi River. Mapped above the upper terrace level (unit Qtu) west of the Mississippi along Pike Creek. *Slackwater deposits.*

Pleistocene

New Ulm Formation (Johnson and others, in press)—Sediment deposited by ice of the Riding Mountain-provenance Des Moines lobe.

Qno ***Sand to gravelly sand***—Moderately to poorly sorted; interbedded in places with unsorted glacial sediment that is interpreted to be till. Contains sediment from Riding Mountain and Superior provenances (Table 1). Pattern indicates where unit is thin (less than 10 feet [3 meters]) over underlying glacial till (units Qch, Qcd, and Qct). Deposited in meltwater streams that issued from the Des Moines lobe ice margin (Fig. 2D). *Outwash.*

Qnl ***Silt to clay***—Laminated to thick bedded; generally greater than 5 feet (1.5 meters) thick. Covered by patches of silty, fine-grained sand. Thin beds of silty, fine-grained sand to gravelly sand occur at boundaries and at or near the base in places. The unit was deposited in deep water of glacial Lake Grantsburg. Mapped only in one location along the southern county border west of the Mississippi River. *Glacial lake deposits.*

Qnt ***Loam to sandy loam***—Pebbly, unsorted; pockets of silt, sand, and gravel in places. Generally light olive-brown (2.5Y5/4) where oxidized and dark gray (2.5Y4/1) where unoxidized. Average composition of the very coarse-grained sand fraction includes 83 percent crystalline rocks, 13 percent carbonate rocks, and 4 percent gray shale fragments (Table 1). Deposits are few and scattered in the far southwestern corner of the county. *Glacial till.*

Qo **Sand to gravelly sand**—Well-sorted in fining-upward layers; the upper layer is predominantly fine-grained sand with minor gravel; interbedded in places with unsorted glacial sediment that is interpreted to be till (see core log Mo-06, Plate 4). Contains sediment from multiple provenances (Table 1). Deposited in meltwater streams. *Outwash, undifferentiated.*

Cromwell Formation—Mille Lacs Member—Sediment deposited during the Automba phase by ice of the Superior-provenance Superior lobe.

Qmo ***Sand, gravelly sand, and cobble gravel***—Moderately sorted within individual beds. May include material incorporated from underlying glacial deposits. Deposited in meltwater streams that issued from the Mille Lacs moraine. *Outwash.*

Qmi ***Sand, gravelly sand, and cobble gravel***—Poorly sorted; includes unsorted glacial sediment that is interpreted to be till. Deposited by water flowing on top of or beneath the ice. Unit displays collapsed, irregular topography. Commonly mapped along ice marginal ridges and eskers. *Ice contact deposits.*

Qmt ***Sandy loam to loam***—Unsorted, with pebbles, cobbles, and boulders; pockets of silt, sand, and gravel in places. In general, this till of the Mille Lacs Member is finer-grained than that of the older, St. Croix phase Cromwell Formation due to overriding and mixing with underlying glacial lake sediment to the northeast (Knaeble and others, 2004). Generally reddish-brown (5YR5/4) where oxidized and gray (5YR4/1) where unoxidized. Crystalline rock fragments make up nearly the entire 1-2 millimeter very coarse-grained sand fraction (Figs. 4B, C; Table 1). *Glacial till.*

Sediment of mixed provenance—Sediment associated with the Brainerd, Superior, and Wadena lobes.

Qil ***Fine- to medium-grained sand***—Includes layers of finer-grained sediment (silt, clayey silt, and clay) as well as coarse-grained sediment (sand and some gravel) in places. Includes sediment of mixed provenance associated with the South Long Lake Member of the Independence Formation, the Cromwell Formation (St. Croix phase), and the Hewitt Formation. Deposited in a glacial lake that formed as meltwater ponded in and around the stagnant, melting ice and moraine sediments of the Brainerd, Superior, and Wadena lobes. *Glacial lake sediment.*

Independence Formation—South Long Lake Member (Johnson and others, in press)—Sediment deposited by ice of the Rainy-provenance Brainerd lobe.

Qio ***Sand to gravelly sand***—Moderately sorted; cross-bedded to flat-bedded; interbedded in places with glacial sediment interpreted to be till. May include outwash from the underlying Cromwell Formation (St. Croix phase). Deposited in meltwater streams that issued from the Brainerd lobe ice margin. *Outwash.*

Qii ***Sand, gravelly sand, and cobble gravel***—Poorly sorted; includes glacial sediment interpreted to be till. Deposited by water flowing on top of or beneath the ice. Unit displays collapsed, irregular topography. Commonly mapped along ice marginal ridges and eskers. *Ice contact deposits.*

Qit ***Sandy loam to loamy sand***—Unsorted, with pebbles, cobbles, and boulders; pockets of silt, sand, and gravel in places. Generally pale-brown (10YR7/3) to brownish-gray (10YR6/2). Crystalline rock fragments make up nearly the entire very coarse-grained (1-2 millimeters) sand fraction (Figs. 4B, C; Table 1). This unit is difficult to distinguish from the underlying till of the Cromwell Formation (St. Croix phase; units Qct and Qcd). In general, till of the South Long Lake Member of the Independence Formation is sandier in texture and contains more clear quartz grains and fewer red rock fragments in the very coarse-grained (1-2 millimeter) sand fraction than the underlying Cromwell Formation (St. Croix phase) till (Figs. 4, 5; Table 1), which is consistent with its derivation from the Rainy provenance. In places, directional landforms indicating ice flow from the north–northeast (Fig. 1) have been used to delineate the extent of this formation. *Glacial till.*

Qig ***Sandy loam to cobble gravel***—Complex of units Qii and Qit as described above. Includes areas of sandy loam till, capped by or interbedded with sand and gravel; areas of thick sand and gravel occur in places. Glacial and fluvial sediments are too intricately associated to map separately. Mapped along the western margin of the Brainerd lobe that advanced on top of the ice-cored St. Croix moraine (Figs. 3B, C). May include sediment of the Cromwell (St. Croix phase) and Hewitt Formations. *Glacial till and ice contact sediments.*

Cromwell Formation—Unnamed member—Sediment deposited during the St. Croix phase of the Superior lobe.

Qz ***Silt to very fine-grained sand***—Forms a cap over underlying glacial till (unit Qcd). *Loess.*

Qcl ***Fine- to medium-grained sand***—Includes layers of finer-grained sediment (silt, clayey silt, and clay) as well as coarse-grained sediment (sand and some gravel) in places. Differs from unit Qil in being composed of only Superior provenance material. Sediment deposited in glacial lakes that formed as the Superior lobe melted. *Glacial lake sediment.*

Qco ***Sand, gravelly sand, and cobble gravel***—Moderately to poorly sorted; cross-bedded to horizontally-bedded; interbedded in places with unsorted glacial sediment that is interpreted to be till. *Outwash.*

Qci ***Sand, gravelly sand, and cobble gravel***—Poorly sorted; includes glacial sediment that is interpreted to be till. Deposited by water flowing on top of or beneath the ice. Commonly mapped along ice marginal ridges and eskers. *Ice contact deposits.*

Qct ***Sandy loam to loamy sand***—Pebbly, unsorted; pockets of silt, sand, and gravel in places. Generally red-brown (10YR to 7.5YR) in color. Crystalline rock fragments make up nearly the entire 1-2 millimeter very coarse-grained sand fraction and red rock fragments (sandstone and volcanic rocks) make up a significant proportion (Figs. 4B, C; Table 1). *Glacial till.*

Qcd ***Sandy loam to loamy sand***—Glacial till as above; sculpted into drumlin landforms. Interpreted to have been deposited underneath the ice. *Subglacial till.*

Qcg ***Sandy loam to cobble gravel***—Complex of units Qci, Qct, Qcd, and Qcl as described above. Includes areas of unsorted sediment having a sandy loam texture, capped by or interbedded with sand and gravel; areas of thick sand and gravel occur in places. Glacial, fluvial, and lacustrine sediments are too intricately associated to map separately. Generally mapped along drainageways and along ice marginal features where ice contact sand, gravel, and till were deposited in close proximity. *Glacial till and ice contact sediments.*

Qch ***Sandy loam to loamy sand***—Glacial till as above (unit Qct) that is relatively thin (less than 20 feet [6 meters]) over underlying glacial sediments attributed to the Hewitt Formation (see units Qho, Qhi, and till description below). Includes bedded sediment at or near the surface in places. Deposits generally contain more carbonate grains, fewer red rocks, and a higher percentage of clear quartz grains than typical Cromwell Formation (St. Croix phase) till, and thus look much like those of the South Long Lake Member of the Independence Formation (Figs. 4B, C). Till of the Hewitt Formation is similar in texture to the overlying Cromwell Formation till, but is generally yellow-brown (10YR5/4) where oxidized and dark gray (10YR4/1) where unoxidized. The Hewitt Formation till also contains an average of 13 percent carbonate rock fragments in the 1-2 millimeter very coarse-grained sand fraction (Table 1; Plate 4, Table 2). Drumlins formed in the Hewitt Formation till are visible through the thin cover of overlying Cromwell Formation till. *Glacial till, mixed provenance—Cromwell Formation thin over Hewitt Formation.*

Qcb ***Sandy loam to loam***—Glacial till as above (unit Qct) that is relatively thin (less than 20 feet [6 meters]) over underlying glacial sediments attributed to the Browerville Formation (Johnson and others, in press). Till of the Browerville Formation may be slightly finer-grained than unit Qcb (loam vs. loamy sand) and is generally light olive-brown (2.5Y5/4 to 2.5Y5/6) where oxidized and very dark gray (2.5Y3/1) where unoxidized. The Browerville Formation till contains abundant carbonate rock fragments (35 percent of the 1-2 millimeter very coarse-grained sand fraction). Dark gray Cretaceous limestone is a key indicator of this unit (Table 1; Plate 4, Table 2). *Glacial till, mixed provenance—Cromwell Formation thin over Browerville Formation.*

Qcp ***Sandy loam to loam***—Glacial till as above (unit Qct) that is relatively thin (less than 20 feet [6 meters]) over older glacial sediments deposited by ice of Winnipeg provenance (Lake Henry and Eagle Bend Formations), and Superior provenance (St. Francis Formation; Johnson and others, in press). See Table 1 for general characteristics of these units and Plate 4, Figure 12 for average texture and lithology. *Glacial till, mixed provenance—Cromwell Formation thin over older tills.*

Hewitt Formation—Sediment deposited by the mixed Winnipeg/Rainy-provenance Wadena ice lobe.

Qho ***Sand, gravelly sand, and cobble gravel***—Moderately to poorly sorted; cross-bedded to horizontally-bedded. Contains sediment predominantly from the north–northeast Rainy provenance including abundant crystalline rocks (basalt and granite). Carbonate, predominantly dolostone attributed to the Winnipeg source area (Gowan and Thorleifson, 2011), is also common in the Hewitt Formation. Either the carbonate has been incorporated from the underlying Winnipeg-sourced tills, or the glacier that deposited the Hewitt Formation had a broad source area including elements of both the Winnipeg and Rainy regions. May also include some red sandstone (Table 1). *Outwash.*

Qhi ***Sandy loam to cobble gravel***—A complex mix of glacial till and ice contact sediment belonging predominantly to the Hewitt Formation, but may include sediments of the South Long Lake Member of the Independence Formation and the unnamed member of the Cromwell Formation. Includes areas of sandy loam till, capped by or interbedded with sand and gravel; areas of thick sand and gravel occur in places. Glacial, fluvial, and lacustrine sediments are too intricately associated to map separately. Generally mapped along ice marginal features where ice-contact sand, gravel, and till were deposited in close proximity. *Glacial till and ice contact sediments.*

Paleoproterozoic

Ƥu **Bedrock undifferentiated**—Predominantly intrusive igneous (granite, granodiorite, and tonalite) and metamorphic rocks (schist, argillite, and slate) relating to the Penokean and Yavapai Orogens (approximately 2,200 to 1,800 Ma; refer to Plate 2, *Bedrock Geology*, for details).

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Numbers in parentheses correspond with those shown on the Index to Previous Mapping

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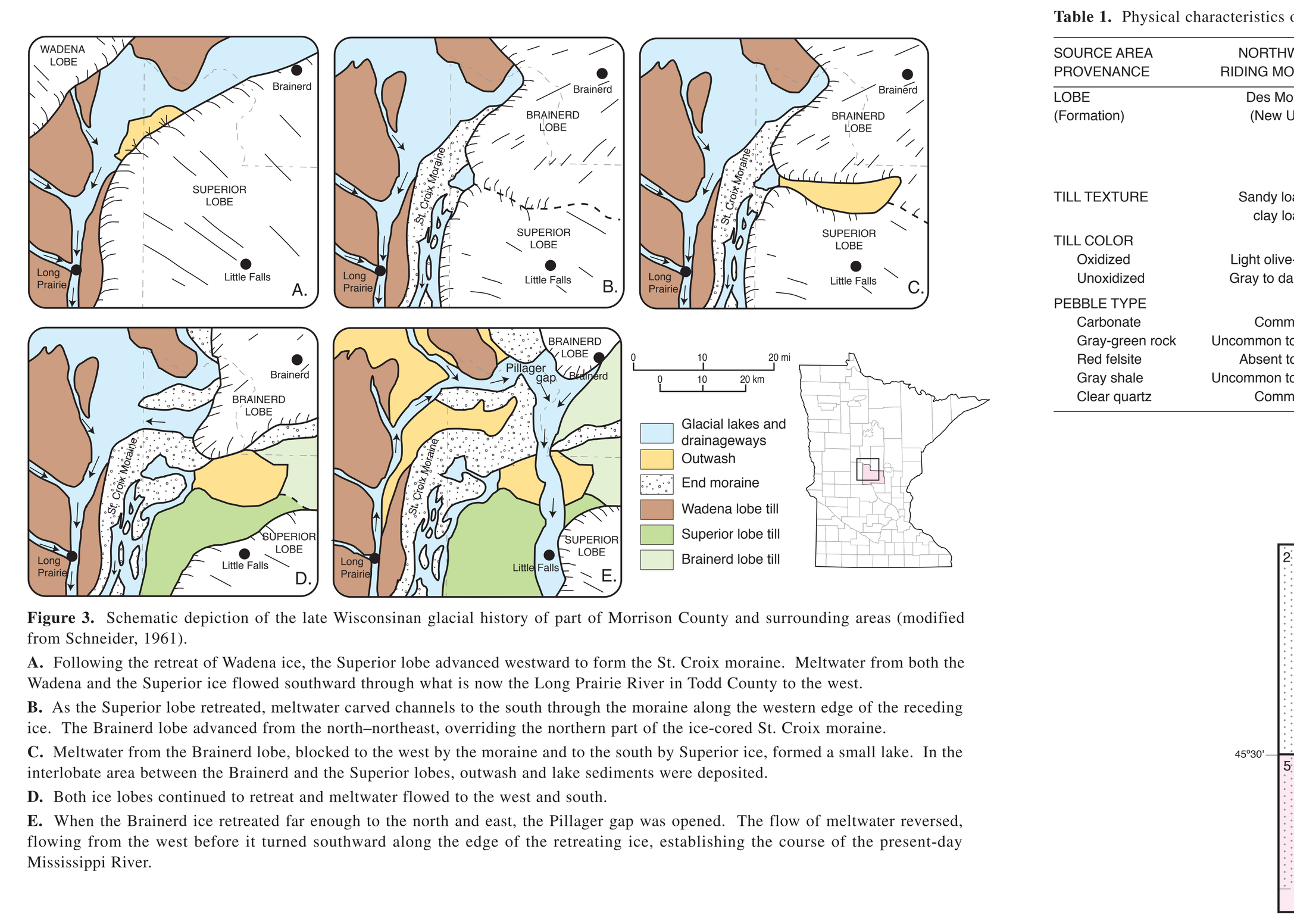

Figure 3. Schematic depiction of the late Wisconsinan glacial history of part of Morrison County and surrounding areas (modified from Schneider, 1961).

A. Following the retreat of Wadena ice, the Superior lobe advanced westward to form the St. Croix moraine. Meltwater from both the Wadena and the Superior ice flowed southward through what is now the Long Prairie River in Todd County to the west.

B. As the Superior lobe retreated, meltwater carved channels to the south through the moraine along the western edge of the receding ice. The Brainerd lobe advanced from the north–northeast, overriding the northern part of the ice-cored St. Croix moraine.

C. Meltwater from the Brainerd lobe, blocked to the west by the moraine and to the south by Superior ice, formed a small lake. In the interlobate area between the Brainerd and the Superior lobes, outwash and lake sediments were deposited.

D. Both ice lobes continued to retreat and meltwater flowed to the west and south.

E. When the Brainerd ice retreated far enough to the north and east, the Pillager gap was opened. The flow of meltwater reversed, flowing from the west before it turned southward along the edge of the retreating ice, establishing the course of the present-day Mississippi River.

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

SOURCE AREA PROVENANCE	NORTHWEST RIDING MOUNTAIN	NORTH–NORTHWEST WINNIPEG	NORTH–NORTHEAST RAINY	NORTHEAST SUPERIOR
LOBE (Formation)	Des Moines (New Ulm)	Pre-Wisconsinan (Browerville) (Lake Henry) (Eagle Bend) (Elmdale)	Wadena (Hewitt) Rainy Brainerd (Independence)	Superior (Cromwell) Pre-Wisconsinan (St. Francis)
TILL TEXTURE	Sandy loam to clay loam	Loam to silt loam to clay loam	Sandy loam to loamy sand	Sandy loam to loamy sand
TILL COLOR				
Oxidized	Light olive-brown	Light olive-brown	Yellow-brown to 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	Rare to common	Rare to uncommon
Gray-green rock	Uncommon to common	Uncommon to common	Uncommon to common	Common to abundant
Red felsite	Absent to rare	Absent to uncommon	Rare to uncommon	Common to abundant
Gray shale	Uncommon to common	Absent to uncommon	Absent	Absent
Clear quartz	Common	Common to abundant	Abundant to common	Uncommon to common

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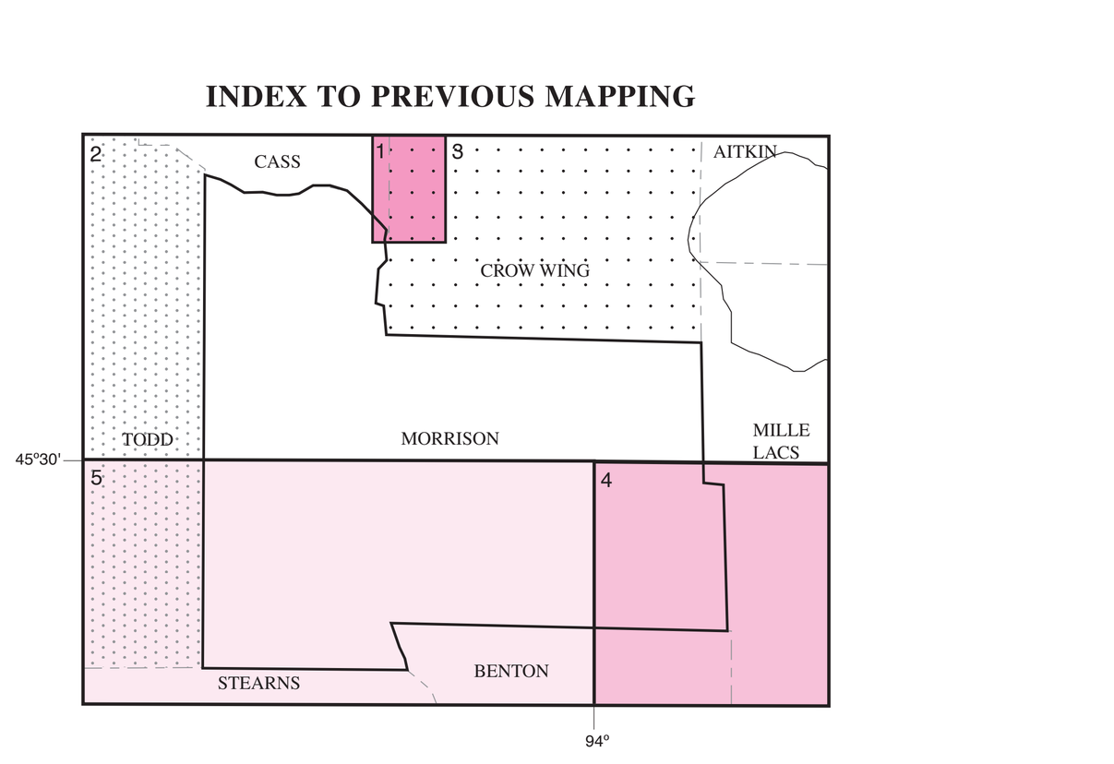

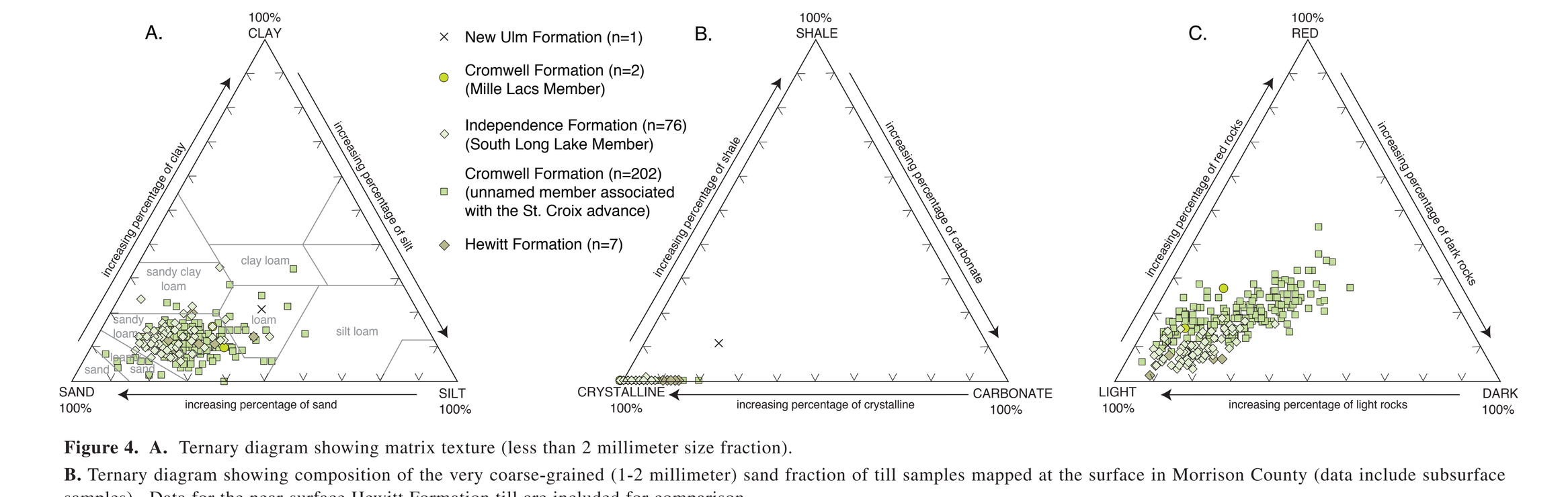

Figure 4. A. Ternary diagram showing matrix texture (less than 2 millimeter size fraction).

B. Ternary diagram showing composition of the very coarse-grained (1-2 millimeter) sand fraction of till samples mapped at the surface in Morrison County (data include subsurface samples). Data for the near-surface Hewitt Formation till are included for comparison.

C. Ternary diagram showing the amount of light, or felsic grains (granite, gneiss, quartzite, and quartz); dark, or mafic grains (basalt, graywacke, and other metamorphic rocks); and red grains (volcanic and sandstone) within the crystalline category shown in B.

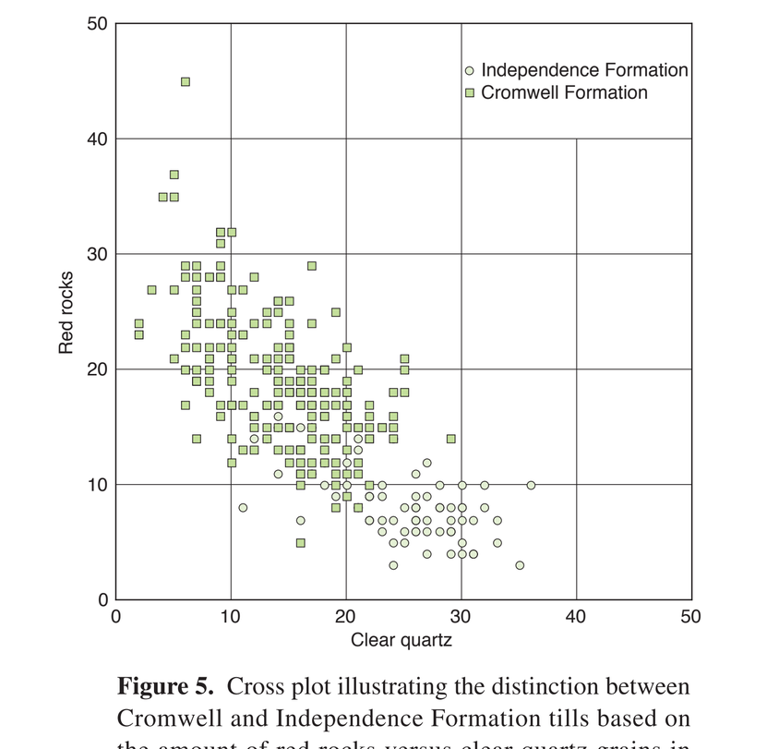

Figure 5. Cross plot illustrating the distinction between Cromwell and Independence Formation tills based on the amount of red rocks versus clear quartz grains in the crystalline rock category of the 1-2 millimeter very coarse-grained sand fraction. Although the texture and overall grain composition of both units are similar, the Cromwell Formation tills contain fewer clear quartz grains and more red rocks than does till of the South Long Lake Member of the Independence Formation. Data include subsurface samples.