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PRELIMINARY SURFICIAL GEOLOGIC MAP OF THE CENTRAL ARROWHEAD AREA, LAKE AND ST. LOUIS COUNTIES, NORTHEASTERN MINNESOTA

By

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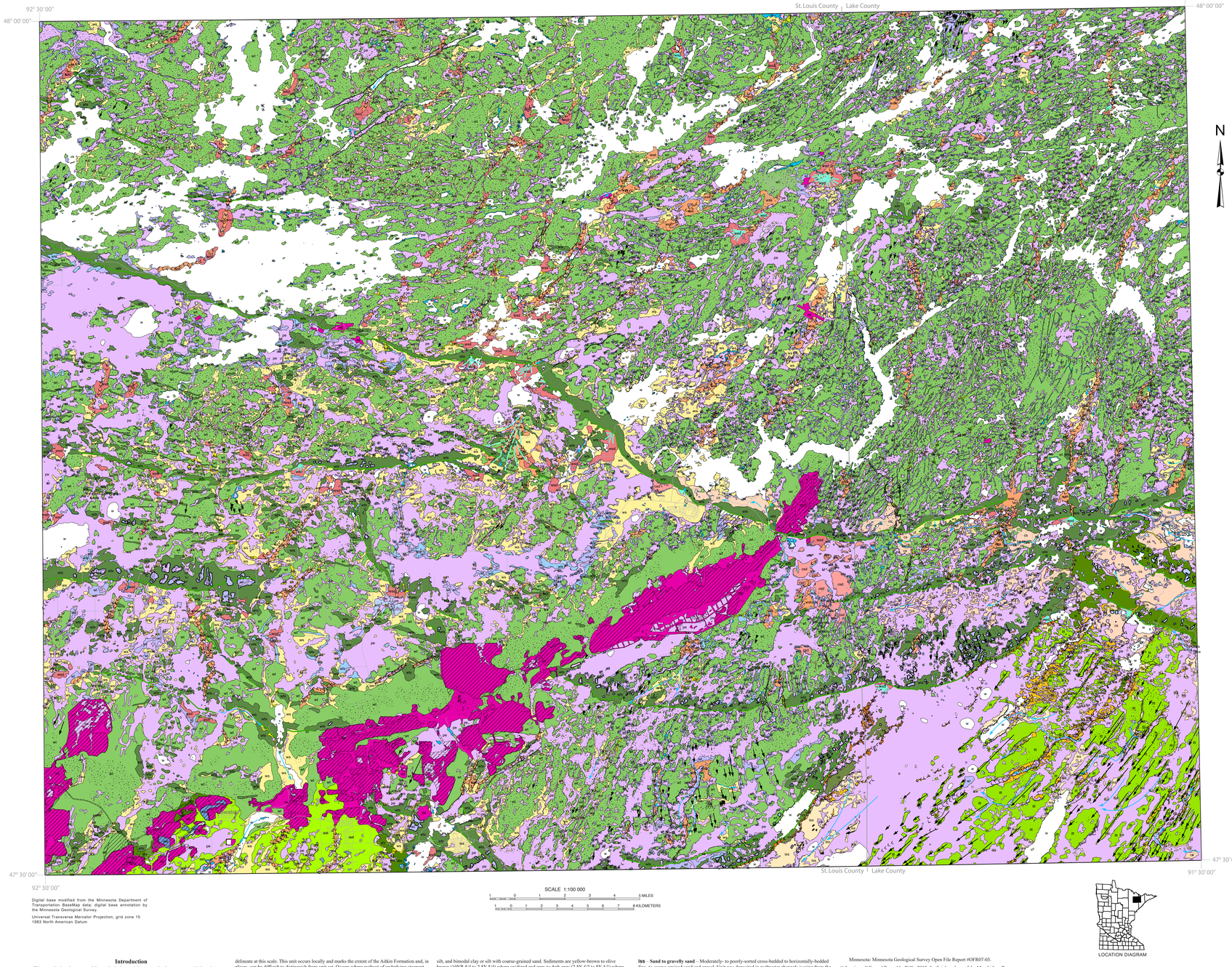
Minnesota Geological Survey
University of Minnesota
2016



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

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

MAP UNITS

- ml
- peat (pe)
- sa
- la
- aat
- atx
- aal
- csd
- cs
- wlc
- wls
- wl
- wsd
- ws
- wsk
- wt
- wtx
- il
- isd
- iss
- isk
- itt
- ix
- vsk
- vx
- water

CORRELATION OF MAP UNITS

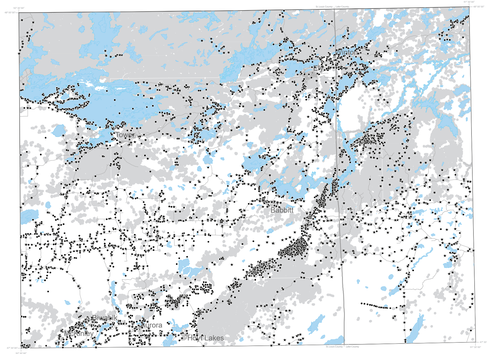


Figure 1. Location of water wells (circles), Quaternary data points (stars), near surface bedrock (gray) and lakes (blue).

MAP SYMBOLS

Geologic contact – Approximately located.

Glacial lineation – Arrow shows the direction of ice flow. Most commonly these features are drumlins (subglacially molded, streamlined, or elongate hills that parallel ice-flow direction and are composed of glacial till), which are primarily located in the southern and southeastern regions of the mapping area. However, in places, these features are rock-cored, or extend down-ice from points of bedrock outcrop (crag-and-tails). Line symbol lengths reflect scaled lengths of actual landforms. The most prominent glacial lineations in this mapping area are primarily oriented northeast-southwest and occupy the northeastern extent of the Toimi drumlin field (Fig. 2). In places, drumlins may be masked by supraglacial sediment or glaciofluvial sand and gravel. Not all glacial lineations are marked with a symbol.

Esker – A narrow, sinuous ridge of sand, gravel, and cobbles interpreted to have been deposited in a subglacial, englacial, or subaerial ice-walled channel by flowing water. On this map, the symbol is correlative with units isk, vsk, and wsk, but also occurs where features are draped by more than eight feet (2.4 meters) of diamicton, or are locally overlain by thin glaciolacustrine or proglacial outwash sediments. Arrows point in the direction of flow.

Ice margin – Approximate location of recessional ice margins of the Rainy lobe.

Fan deposit – Sand and gravel deposits, interpreted to be alluvial fans where associated with glacial outwash, and deltas where associated with deltaic sediments. Fan deposits are present at the mouths of ekers, and commonly along the distal margins of moraines, indicating these features are the result of meltwater drainage systems of the retreating ice. In places abutting the ice margin, fans may be draped by till or complex deposits generated by mudflows off the ice as it retreated, or fluctuating ice margins readvancing over the deposit.

Ice-walled lake plain – Elliptical to quasi-circular plateaus of fine-grained bedded sediment interpreted to be the deposits of former water-filled hollows bound by ice or ice-cored terrain. Features formed supraglacially upon melt-out of underlying and surrounding stagnant ice and permafrost, resulting in topographic inversion. Generally small (less than one mile [1.6 km] in diameter), and dished to flat-topped, with relief of up to 35 feet (10.7 meters). Often feature encompassing narrow rim ridges composed of coarser-grained, poorly sorted to unsorted sediment.

Meltwater flow direction – Arrow points downstream in the general direction of glacial meltwater flow.

Tunnel channel – Elongate valleys and re-entrants interpreted to be subglacial meltwater drainage channels of the Rainy lobe that were partially filled with sediment. Commonly encompass ekers and ice-contact glaciofluvial deposits. Other sediments within tunnel channels are variable. In the Toimi drumlin field region, mounds of poorly sorted sand, gravel, cobbles and diamicton occupying tunnel channels are interpreted as collapsed wall and roof deposits. Commonly, the valleys are now occupied by modern lakes or rivers. Hachures point down-slope.

This to bedrock – Pattern delineates both regions where bedrock occurs at the surface, as well as where the overlying units are thin (less than ten feet) to bedrock. This was created by using the outcrop database and setting a buffer of 656 feet (200 meters) around each outcrop. Though this buffer is fairly accurate, the actual bedrock topography is extremely variable in this region. There will likely be areas covered by the shading that are greater than ten feet to bedrock, and locations that are less than ten feet to bedrock not covered by the shading. The majority of the Superior Hiking Trail, Boundary Waters Canoe Area Wilderness has bedrock at or very near the surface, yet little outcrop data exists for the region due to accessibility issues. Therefore, the buffer was extended to cover this region.

DNR Mine Land Coverage – Pattern delineates the extent of coverage by the MN DNR mine features shapefile (DNR-Mine-Features, 2015). Distinct units were not delineated on this iteration of the map. DNR-Mine-Features (2015) splits the coverage region into units, including, but not limited to, stockpiles, pits, and tailings basins.

Figure 2. Location of major provenances and the distribution of ice-lobe materials at the land surface. Glacial sediments derive their distinct material content from bedrock and sediment found in the region of these source areas. The extent of Des Moine-lobe (Riding Mountain and Winnipeg provenances) deposits is shown in green. The surface extent of the Rainy lobe (Rainy provenance) deposits are shown in brown, and Superior lobe (Superior provenance) deposits are in pink. Moraines (labeled) are indicated by the dashed black lines.

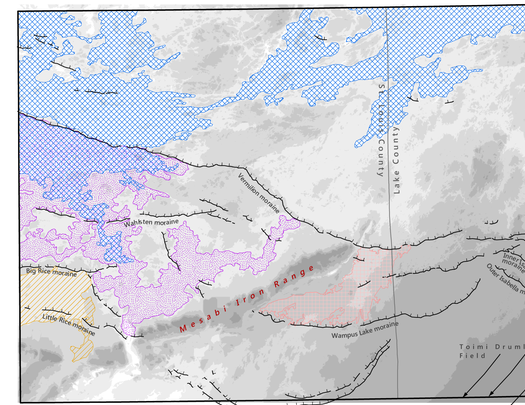


Figure 3. Schematic map showing prominent geomorphic features and former glacial lake levels within the Central Arrowhead. Areas of high elevation are depicted in dark shades on the basemap, lower elevations in lighter shades. The Toimi drumlin field is shown in the southeast corner of the study area. The most prominent recessional moraines are displayed and labeled. Four former glacial lake levels are shown, 1) Orange: early level glacial Lake Nemadji at an elevation of 1475 feet (about 550 meters), 2) Purple: later level of glacial Lake Nemadji at an elevation of 1450 feet (442 meters), 3) Blue: early Mizpah stage of glacial Lake Koochiching at an elevation of 1410 feet (about 430 meters), 4) Pink: glacial lake Duntka at an elevation of 1560 feet (about 475 meters).

Introduction

This map depicts the nature of the geological materials expected to be encountered below the topsoil in the Central Arrowhead region of St. Louis and Lake Counties. Sediment-landform associations were inferred from digital aerial photographs, satellite imagery, and 1-meter spatial resolution LiDAR data, which provided the most significant constraints on the placement of unit boundaries across many remote and inaccessible regions of the mapping area. LiDAR data in the Central Arrowhead was procured by the Minnesota Department of Natural Resources from data collected in the spring of 2011 and is freely available from the Minnesota Geospatial Information Office through the Minnesota Geospatial Commons (ftp://ftp.lmic.state.mn.us/pub/data/elevation/lidar/projects/arrowhead/). Geological interpretations in the form of unit boundaries and landform traces were drawn within a geographic information system (GIS). Previous work in and adjacent to the study area aided in the mapping and interpretation of sediments and landforms (see numbered references). These resources, along with National Wetlands Inventory maps (U.S. Fish and Wildlife Service, 2015), water-well construction records stored in the Minnesota Well Index (MWI), and sediment descriptions and textural analyses housed in the Minnesota Geological Survey Quaternary Data Index (QDI), were used to interpret the distribution of surficial geological units and their boundaries (Figure 1). MWI is publicly available online through the Minnesota Department of Health (http://www.health.state.mn.us/divs/eh/cwi/). QDI is an internal working database of the MGS. Fieldwork, conducted from 2014 to 2016 to verify and enhance interpretations, consisted of analyzing and collecting samples from road cuts, stream bank exposures, and gravel pit excavations. This work was supplemented with auger borings drilled to an average depth of ten feet (three meters), and shallow pit excavations dug by backhoe to an average depth of six feet (1.8 meters).

Unit Descriptions

Holocene

ml – Disturbed lands – Includes land that has been reformed, dump mounds, mines, and tailings basins. Lands primarily occur in the mining region of the Mesabi Iron Range, where pre-development surficial materials were dominated by boulder-rich sandy loam diamicton (unit wt) and more sparsely distributed sand and gravel deposits. Bluish pattern depicts the areal extent as shown by the MN DNR Mine Features shapefile (DNR-Mine-Features, 2015). *Mine lands and fill.*

pe – Organic debris, clay, silt and fine sand – Partially to highly decomposed plant matter and fine grained mineral sediment deposited in bogs, swamps, and marshes. Organic matter is greater than 50 percent. Includes minor alluvial deposits along streams and narrow beach deposits. Unit commonly occurs around modern lakes, former lake plains, and in buried inter-drumlin swales. Distribution of this unit has been modified from the National Wetlands Inventory (2015). *Peat and wetland sediment.*

sa – Sand and gravel, sandy loam to silt loam – Generally, coarse grained sediment (sand and gravel) occurs in channels, and fine-grained sediment (fine-grained sand and silt) occurs on floodplains. Locally capped or interbedded with organic-rich sediment and/or peat (unit pe). *Floodplain and channelized fluvial deposits.*

la – Silt, sand, and clay – Locally includes organic layers and regularly underlies fine-grained organic matter or peat (unit pe). Commonly coarser-grained at the shoreline where waves erode the sediment and concentrate sand; includes human made beaches. The extent of exposure depends on the water level in a given lake. Deposited in post-glacial lakes. *Lacustrine sediment.*

Pleistocene

AITKIN FORMATION – Includes all deposits associated with the northwest-sourced (mixed Riding Mountain, Winnipeg, and Superior provenance) St. Louis sublobe of the Koochiching Lobe (Figure 2). The Aitkin Formation on this map occurs in the southwestern corner, south of the Mesabi Iron Range. In this region the Aitkin Formation includes till of the Alborn member as well as select exposures of glaciolacustrine sediment of glacial Lake Upham I in places where overlying deposits have been removed by mining activities.

aat – Clay loam to loam – Silty clay to silty clay loam, with scattered very coarse-grained sand and very fine-grained gravel, ranging rarely up to medium-grained gravel. When oxidized, unit is brown to reddish-brown (7.5YR 4/4 to 5YR 4/4); unoxidized, it is reddish-grey to grey (5YR 4/2 to 7.5YR 4/1). Carbonate leaching is generally less than six feet (1.8 meters). The average sand, silt, and clay texture percentage is 22, 30, and 48, respectively, and the average light, dark, and red assemblage is 73, 25, and 2 percent, respectively (Table 1). The lower portion of this unit commonly grades into underlying glacial Lake Upham I sediments (unit aal). The sediments that comprise unit aat were deposited by the St. Louis sublobe, after it overrode and incorporated material from the underlying glacial Lake Upham I, including fine-grained red sediment from the Cromwell Formation (Autonba phase). *Glacial till, Alborn member.*

atx – Diamicton, silt and clay, sand, and gravel – Primarily clay loam to loam diamicton with folds of silt and clay, and sand and gravel; these sediments are too complexly commingled to delineate at this scale. This unit occurs locally and marks the extent of the Aitkin Formation and, in places, can be difficult to distinguish from unit aat. Occurs where meltout of underlying stagnant ice produced collapse of the sediment. Unit locally incorporates the overridden sandier sediments of the Boundary Waters Formation. *Sand and gravel till/lacustrine complex.*

aal – Clay, silt, and very fine-grained sand – Where exposed, unit occurs as rhythmically-bedded red clay and grey silt overlying variable layers of grey clay and grey very fine-grained sand. This upper section commonly overlies rhythmites of grey clay, and grey fine- and medium-grained sand. Unit stratigraphically underlies the Alborn till (unit aat) and is interpreted to have been deposited in glacial Lake Upham I. Unit is reddish grey (5YR 4/1) to brown (10YR 4/4 to 7.5YR 4/4) to greyish-brown (10YR 4/2 to 2.5Y 4/3). *Glacial lacustrine sediment.*

CROMWELL FORMATION – Includes all deposits associated with the northeast-sourced (Superior provenance) Superior lobe (Figure 2). Within the map area, the Cromwell Formation exclusively represents materials related to the Automba Phase of the Superior lobe. The maximum northwestern extent of this ice advance is marked by the position of the Highland Moraine (Figure 2). This formation primarily contains dark metasedimentary (slate, greywacke, trace rod sandstone) and red igneous rock types (basalt, porphyritic rhyolite, and felsite) attributable to the North Shore Volcanic Group.

csd – Sand and gravel – Consists of interbedded fine-to very fine-grained sand and silt in bottomset beds, prograded to former lake levels, and grading up to coarse gravel in foresets. Overlain by silt and very fine- to fine-grained sand from suspension fallout, and by ponded lacustrine sediments (units wl and wls) fronting the Rainy lobe. Deposited by Superior lobe meltwater flowing west into glacial Lake Dunka (Figure 3) prior to drainage. *Deltaic sand and gravel.*

cs – Cobbly gravel, sandy gravel and gravelly sand – Predominantly medium- to very coarse-grained, poorly- to well-sorted sand with very fine- to very coarse-grained gravel and cobbles. In the vicinity of Slate, Gander and Wadop Lakes (T. 60N, R. 10W), unit is primarily planar bedded, clast-supported, subrounded to rounded gravel and cobbles. Longitudinally grades to fining upward medium to coarse sand and gravel, and is increasingly diluted by Rainy provenance lithologies to the west. Primarily includes sediments deposited by meltwater of the Superior lobe while it was at the Highland moraine (Figure 2). Unit is geomorphically expressed as smooth plains with channel scars, or as irregular topography with closed depressions. In areas featuring the latter, unit was deposited over Rainy lobe stagnant ice, causing surface collapse and stratigraphic reversal upon meltout, hence, in places, Rainy lobe material (unit wtx) may occur at the surface. *Outwash.*

BOUNDARY WATERS FORMATION (redefined from extent and composition published in Johnson and others, 2016) – Sediment deposited by the northeast-sourced (Rainy provenance) Rainy lobe (Figure 2). Previously identified primarily by its relative location north of the Vermilion moraine (Figure 2 and 3), extending to the Canadian border. The interpreted distribution of this formation has now been extended south of the Vermilion moraine, though the southern and western limits have not yet been determined. To the east and southeast, the unit abuts the Independence Formation and, at the surface, extends to the northern edge of the Toimi drumlin field (Figure 3). The unit north of the Vermilion moraine can be very thin and patchy and is locally influenced by bedrock. This local influence heavily impacts the composition of the 1-2 mm grain size fraction (Table 1), which tends to strongly reflect bedrock lithologies immediately underlying and up-ice (generally north, or northeast) of a given location. In this region, sand and gravel deposits tend to be thicker than corresponding diamicton, and are primarily contained in positive-relief subglacial ice contact features, often which directly overly bedrock. A thicker Boundary Waters package is generally found south of the Vermilion moraine, though it may locally occur as a thin drape over bedrock.

wlc – Clay and silt – Fine-grained sediments settled into paleobathymetric lows after the retreat of the Rainy lobe. The sediments are yellowish-brown (10YR 4/4) when oxidized, and dark grey (2.5Y 4/1 to 5Y 5/1) when unoxidized. Commonly massive, but locally includes thin (less than 1 cm) calcareous laminae below about eight feet (2.4 meters). This primarily occurs in the western portion of the study area, where there was meltwater influx from the mixed Riding Mountain/Winnipeg provenance Koochiching lobe (Figure 2) into the glacial Lake Norwood and early glacial Lake Koochiching basins (Figure 3). *Clayey lacustrine sediment.*

wls – Silt and very fine- to medium-grained sand – Very fine- to medium-grained sand to silt settled into paleobathymetric lows after the retreat of the Rainy lobe. The coarsest fractions occur primarily along the margins of unit wl as beach deposits. Stratigraphically bounds units cs and csd within the glacial Lake Dunka basin (Figure 3). In this region, unit is not calcareous. In the western portion of the study area, where there was meltwater influx from the mixed Riding Mountain/Winnipeg provenance Koochiching lobe (Figure 2) into the glacial Lake Norwood and early glacial Lake Koochiching basins (Figure 3), the lack of calcareous sediments at the surface is likely due to leaching. *Sandy lacustrine sediment.*

wl – Clay, silt, and fine- to medium-grained sand – Undifferentiated sediment settled into paleobathymetric lows during the retreat of the Rainy lobe. Unit includes sandy clay, clay and silt, and bimodal clay or silt with coarse-grained sand. Sediments are yellow-brown to olive brown (10YR 5/4 to 2.5Y 5/4) where oxidized and grey to dark grey (2.5Y 4/2 to 5Y 4/1) where unoxidized. Includes sediments of glacial lakes, ice marginal ponds, and ice-walled lake plains. Unit includes calcareous clay laminae locally below about eight feet (2.4 meters). This primarily occurs in the western portion of the study area, where there was meltwater influx from the mixed Riding Mountain/Winnipeg provenance Koochiching lobe into the glacial Lake Norwood and early glacial Lake Koochiching basins (Figure 3). *Undifferentiated lacustrine sediment.*

wsd – Fine- to coarse-grained sand and gravel – Well-sorted fine- to coarse-grained bedded sand and gravel with localized beds of silt and very fine-grained sand. In places where this unit occurs along or adjacent to ekers, it is interpreted to be a fan deposit formed proximal to the ice margin as meltwater discharged from the ice. The sediment may also have formed in subglacial meltwater cavities during localized de-pressurization. Where the deposits occur in former lake or ice marginal basins, they are interpreted to be deltaic. *Bedded sand and gravel.*

ws – Sand to gravelly sand – Fine to coarse-grained sand and gravel; moderately- to well-sorted in fining upward layers. Unit was deposited in channels draining meltwater from Rainy lobe ice. *Outwash.*

wsk – Cobbles and gravel, sandy gravel, and gravelly sand – Unit can be massive, planar bedded, or cross-stratified. Gravels and cobbles are generally subangular to rounded. Massive to (occasionally deformed) planar-parallel bedded well-sorted fine- to coarse-grained sand occurs locally as interbeds within coarse- to very coarse-grained sand, gravel and cobble sequences. Commonly mantled by up to six feet (1.8 meters) of loose diamicton. Deposited by water flowing within, on top of, beneath, or alongside the ice. Commonly mapped as ice marginal ridges and eskers. *Ice contact glaciofluvial deposit.*

wt – Sandy loam diamicton – Unsorted sandy loam (matrix can range from sand to loam but appears sandy loam) with abundant subangular to subrounded fine-grained gravel and cobbles. In grained cobbles throughout. Unit commonly contains boulders, many of which are perched at the surface. This unit varies in thickness from one foot (0.3 meters) to 40 feet (12.2 meters). Oxidized, the matrix is yellowish-brown (10YR 5/6) to brown (10YR 4/3) and unoxidized is olive-brown (2.5Y 5/4) to grey-brown (2.5Y 4/2). Average sand, silt, and clay percentages are 65, 26, and 9, respectively. The average light, dark, and red composition for this unit is 81, 18, and 1 (Table 1). In places where bedrock is near the surface, (i.e. north of the Vermilion Moraine), the local bedrock has a greater influence on the composition of the unit. *Glacial till.*

wtx – Diamicton, silt and clay, sand, and gravel – Diamicton, sorted to poorly sorted fine- to very-coarse grained sand to boulders, clay, and silt, all of which are too complexly commingled to delineate at this scale. In places, unit includes gravity-flow deposits. This unit occurs primarily along east-west trending recessional moraines of the Rainy lobe. It is commonly associated with topography, where meltout of underlying stagnant ice produced collapse of the sediment, resulting in partial to complete intermixing of overlying deposits. Local relief is up to 60 feet (18.3 meters). Locally capped by poorly consolidated diamicton and perched boulders, sharp-crested ridges of sand and gravel (unit wsk), or ice-walled lake plain deposits. Where meltwater ponded or adjacent to bounding Glacial Lake Norwood shorelines (Figure 3), deposits are commonly much sandier and have lower relief. *Sand and gravel till/lacustrine complex.*

INDEPENDENCE FORMATION – Includes all deposits associated with the northeast-sourced (mixed Rainy and Superior provenance) Brainerd sublobe of the Rainy Lobe (Figure 2). This unit extends south and west from the Inner Isabella moraine (Figure 3). It is bound to the east by the Highland moraine and to the west by the Boundary Waters Formation. The formation extends as far southwest as the St. Croix moraine (Figure 2). Deposits of the Brainerd assemblage are generally deeply leached, however they contain carbonate clasts and a calcareous matrix at depth (Lehr and Hobbs, 1992). Dark metasedimentary (slate, greywacke) and red igneous lithic fragments attributable to the North Shore Volcanic Group (NSVG; primarily basalt, porphyritic rhyolite, and felsite) may comprise a significant quantity of the very-coarse grained (1-2 millimeter) sand fraction, featuring up to 25% red volcanics. Formation contains sediment of Rainy and Superior provenances, though the proportion of NSVG lithologies generally increases at the surface towards the south and east.

il – Clay, silt, and very fine- to medium-grained sand – Undifferentiated sediment deposited in paleobathymetric lows during the retreat of the Brainerd sublobe. Unit consists of fine- to very fine-grained sand, silt, and clay. Predominantly includes sediments deposited in ice-marginal ponds and ice-walled lake plains. *Undifferentiated lacustrine sediment.*

isd – Sand and gravel – Interbedded fine- to very coarse-grained sand and gravel, deposited by meltwater issuing from the Brainerd sublobe into ice-marginal lakes and ponded water. In places where this unit occurs along or adjacent to ekers, it is interpreted to be a fan deposit formed proximal to the ice margin as meltwater discharged from the ice. The sediment may also have been deposited in subglacial meltwater cavities during localized de-pressurization. Where the deposits occur in former lake or ice marginal basins, they are interpreted to be deltaic. *Bedded sand and gravel.*

iss – Sand to gravelly sand – Moderately- to poorly-sorted cross-bedded to horizontally-bedded fine- to coarse-grained sand and gravel. Unit was deposited in meltwater channels issuing from the receding Brainerd sublobe. Primarily occupies swales between streamlined bedforms of the Toimi drumlin field (Figure 3), and commonly underlies peat/and or organic-rich wetland sediment (unit pe). Near the innermost margins of the Brainerd sublobe, deposits are overlain by fine sand where they experienced intermittent ponding. *Outwash.*

isk – Cobbles and gravel, sandy gravel, and gravelly sand – Variably massive, planar bedded, and cross-stratified gravel and cobbles, regularly bedded in both normal- and reverse-graded sequences with fine to very coarse sand. Massive to (occasionally deformed) planar parallel bedded well-sorted fine- to coarse-grained sand occurs locally as interbeds within coarse- to very coarse-grained sand, gravel and cobble sequences. Commonly mantled by up to six feet (1.8 meters) of loose diamicton. Deposited by water flowing within, on top of, beneath, or alongside the ice. Commonly mapped along ice marginal ridges and eskers. *Ice contact glaciofluvial sediment.*

itt – Sandy-loam to loamy-sand diamicton – Unsorted, clast-rich, matrix-supported sandy loam to loamy-sand, with abundant subangular to subrounded, fine- to coarse-grained gravel, cobbles and boulders. Varies to clast-supported in upper six feet (1.8 meters). Contains occasional stringers and lenses of sand and gravelly sand. Brown (10YR 4/3) to dark yellowish-brown (10YR 4/4) where oxidized, and dark grayish-brown (10YR 4/2 to 2.5Y 4/2) where unoxidized. Geomorphically expressed as elongate, streamlined bedforms of the Toimi drumlin field (Figure 3), where inter-bedform swales locally exhibit ponded water, peat and/or organic-rich wetland sediment (unit pe). The average sand, silt, and clay percentages are 61, 32, and 7, respectively. The light, dark, and red assemblage averages 46, 42, and 12 respectively (Table 1). *Glacial till.*

ix – Diamicton, silt and clay, sand, and gravel – Diamicton, sorted to unsorted fine- to coarse-grained sand to boulders, clay, and silt. This unit occurs locally along northwest-southeast trending recessional moraines of the Brainerd sublobe. It is commonly associated with hummocky topography, where meltout of underlying stagnant ice produced collapse of the sediment, resulting in partial to complete intermixing of overlying deposits. Local relief is up to 60 feet (18.3 meters). Locally capped by poorly consolidated diamicton and perched boulders, sharp-crested ridges of sand and gravel (unit wsk), or ice-walled lake plain deposits. Where meltwater ponded or adjacent to bounding Glacial Lake Norwood shorelines (Figure 3), deposits are commonly much sandier and have lower relief. *Sand and gravel till/lacustrine complex.*

vsk – Cobbles and gravel, sandy gravel, and gravelly sand – Variably massive to bedded coarse-grained sediments, alternating between coarse-grained gravel and cobbles and stratified sand. *Ice contact glaciofluvial sediment.*

vx – Diamicton, sand, and gravel – Sorted to unsorted fine- to coarse-grained sand to boulders, clay, and silt. In places, unit is washed by meltwater issuing from the Brainerd sublobe and/or wave action in ponded Rainy lobe meltwater. *Sand and gravel till/lacustrine complex.*

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Numbered references correspond to previous mapping that is adjacent to, or covers a portion of the project area.

MATRIX TEXTURE — % of the less than 2 mm fraction

CLAST TYPE — % of total grains counted of the 1-2 mm fraction — % of total Precambrian grains

Description	Total # of samples	Sand	Silt	Clay	Total # of samples	Precambrian	Paleozoic	Cretaceous	Light	Dark	Red
Aitkin till-Alborn member (aat)	33	22	30	48	28	99	0.7	0.6	73	25	2
Boundary Waters till (wt)	110	65	26	9	104	100	0	0	81	18	1
Independence till (itt)	36	61	32	7	20	100	0	0	46	42	12

Table 1: Average values for the composition and texture of till units identified in the Central Arrowhead study area. The matrix texture (based on the less than 2 mm grain size fraction) is expressed as the percentage of sand, silt and clay components. The lithologic composition of the units is based off the very coarse-grained sand fraction (1-2 mm). It is divided into relative portions of Precambrian crystalline rock, Paleozoic carbonate rocks and Cretaceous shale fragments. The Precambrian fraction is subdivided by rock type - light (granite, gneiss, clear quartz expressed as a percentage of the light category), dark (mafic-rich igneous and metamorphic rocks), and red (rhyolite, agate and sandstone).

Every reasonable effort has been made to ensure the accuracy of the factual data on which this map interpretation is based; however, the Minnesota Geological Survey does not warrant or guarantee that there are no errors. Users may wish to verify critical information; sources include both the references listed here and information on file at the offices of the Minnesota Geological Survey in St. Paul. In addition, effort has been made to ensure that the interpretation conforms to sound geologic and cartographic principles. No claim is made that the interpretation shown is rigorously correct, however, and it should not be used to guide engineering-scale decisions without site-specific verification.

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