Minnesota Department of Natural Resources
Division of Lands and Minerals
Director, Jess Richards

PLATE A: AITKIN COUNTY AGGREGATE RESOURCES, SAND & GRAVEL POTENTIAL

Produced by the Aggregate Resource Mapping Program,
Division of Lands and Minerals, Minnesota
Department of Natural Resources
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Printed Map Scale 1:100,000
Based on a 1:50,000 scale resource assessment

ABOUT THIS MAPPING PROJECT

PURPOSE

The purpose of this project is to identify and classify potential construction-aggregate resources in Aitkin County, Minnesota. This mapping is being done in accordance with the 1984, Minnesota Statue 84.94, Aggregate Planning and Protection law directing the Minnesota Department of Natural Resources (DNR), in cooperation with the Minnesota Geological Survey (MGS), and the Minnesota Department of Transportation (MnDOT) to identify and classify potential aggregate resources.

This map, **Sand and Gravel Potential** along with its accompanying database is an interpretative map product intended to be used for planning purposes. For example, a community may want to differentiate and protect resources by their quality; they may want to separate resource extraction from other uses to minimize land-use conflict; or they may want to reduce haulage cost by identifying sources in proximity to a project because aggregate is a high bulk, low price commodity and transportation costs can significantly affect price.

The most up-to-date topographic, soil, and test-hole data were used in the construction of this map. New data were also gathered during the mapping effort, at a scale appropriate for the final map scale of 1:50,000. However this is a regional reconaissance-scale map and it is still necessary to conduct a detailed investigation to verify the information before investing in a deposit or making site-specific decisions. Factors that were not included in the preparation of this map include ownership, zoning, environmental considerations and protection or easement status.

PRIOR WORK

A hand-colored, draft, surficial geology map of Aitkin County, commissioned by the DNR and completed in 1981 by H. Hobbs, MGS, along with review comments by M. Eng, DNR Lands and Minerals, and H.E. Wright, Univ. of Minn., Dept. of Geology and Geophysics were helpful in the construction of this map (Hobbs, 1981). Surrounding maps of surficial geology and aggregate potential of Carlton, (Friedrich, 2009; Knaeble and Hobbs, 2009), Itasca (Meyer, Jennings and Jirsa, 2005; Meyer and Jirsa, 2005), Kanabec (Friedrich, 2012), Mille Lacs (Arends, 2008), and Pine (Patterson and Knaeble, 2001 and 2002) counties, the Mesabi Range (Jennings and Reynolds, 2005), Kathio State Park (Anderson, 1998) and the Chippewa National Forest (Jennings, unpublished, MGS open file data), helped with the regional context of this map. Observations represented on a large scale map of Savanna State Park by M. Oberhelman, DNR (1996) were also considered.

Interpreted records of drillers' logs of water wells, compiled and made available electronically (County Well Index or CWI) by the Minnesota Department of Health (MDH) and the MGS were used where available. An aggregate dataset compiled and maintained by MnDOT (Aggregate Source Information System, ASIS) that is comprised of data pertaining to aggregate quality, including pit sheets and shallow test-hole logs, was valuable where available.

METHODS

The distribution, abundance and quality of aggregate (sand and gravel) resources depends mainly on glacial processes. This resource map is derived from—and therefore emphasizes—glacial landforms, the processes that formed them, and the interpreted distribution of near-surface sediment associated with those landforms. Reconnaissance field work was conducted by Kostka in October, 2008 and the fall of 2009 and drilling and a gravel pit inventory were completed by him between June through October of 2010. Jennings reviewed these data and added new field observations over the spring and summer of 2012.

Exposures were located by driving the study area on section-line and forest roads and consisted mainly of artificial excavations including short-lived road cuts or construction sites and longer-exposed gravel pits. Exposed sediment type and sedimentary structures were used to verify the inferred processes responsible for creating the landforms and to predict the unexposed distribution of sediment within the landform. If no natural exposures were found, a shovel, auger, truck-mounted soil probe or back-hoe were used in places to sample the near-surface geologic material (up to 24 feet). Jennings completed 107 test holes and Kostka, 138 during their respective field seasons.

A portion of the samples collected were analyzed by MnDOT for grain size and quality (n=48) and by the DNR, Hibbing for grain size (n=78). This is, however, a large and complex county and even with this number of samples and observations, the mapping must be considered reconnaissance-level field work requiring further testing to define and develop a gravel pit.

MAP CONSTRUCTION

The map was compiled digitally (ArcMap 10.1) using a 10-m digital elevation model (DEM) as a basemap and then was refined in the areas covered by a higher resolution, 2-m LiDAR elevation model when those data became available late in the compilation process. Map units were created based on field observations, sample test data, air-photo interpretations, U.S.G.S. 1:24,000 topographic map interpretations and digital soil information from National Resource and Conservation Service (NRCS) soil survey for Aitkin County (Soil Survey Geographic Database, SSURGO).

The characteristics used to determine the final aggregate categories are listed in bold and defined where necessary and are:

- ***landform;***
- ***major sediment;***
- ***minor sediment;***
- ***sand and gravel probability,*** the likelihood that sand and gravel occurs within that landform;
- ***unit certainty,*** a relative measure of how easily delineated a certain map unit is based on its geomorphic expression;
- ***texture*** of the sediment in the landform which in some cases is based on a grain-size analysis and in other cases on the interpreted texture associated with a landform;
- ***quality*** of the sand and gravel which in some cases is determined from the presence or absence of deleterious material and in other cases is inferred based on the path of the ice that deposited it (see provenance, below);
- ***depositional variability*** within a landform type, or how varied the processes are in a given depositional setting;
- ***provenance*** or source of the material carried by a given ice lobe;
- ***observed sand and gravel thickness*** associated with that landform as gleaned from well records, borings or surface exposures;
- ***overburden thickness*** if sand and gravel are present, as gleaned from well records, borings or surface exposures.

Landforms that may be comprised of sand and gravel and therefore result in a higher class ranking are *glacial stream valley, terrace or bar; spillway terrace; collapsed stream sediment; collapsed channels*, and *interlobate complex* (see glossary for geologic landform definitions). All of these landforms were created by flowing water that had the potential to sort sediment and concentrate sand and gravel. However, some of these landforms had greater ***depositional variability*** than others (*interlobate complex, collapsed stream sediment*, and *collapsed channels*). Processes that did not sort sediment as well may have also been operative in these landforms therefore, unsorted layers may be complexly interlayered with, or bury the sorted sediment. Landforms with poor ***texture***, that is, sediment too fine or too poorly sorted to be considered aggregate include *lake plain, channelized lake plain, delta or shallow lake, dune or eolian features, streamlined till, scoured lake floor, low-relief washed till plain, alluvial valley, beach, hummocky moraine* and *hummocky till.*

The ***major sediment*** in a landform is based on direct observation where available or inferred from the geologist's understanding of how the landform was created where no data were available. ***Minor sediment*** was also either observed or inferred from the typical variation within the landform or the facies changes (normal progression of depositional environments over time or space) that are normally associated with that depositional setting. Sediment type is defined by the distribution of, in order of size: clay, silt, sand, gravel, cobbles and boulders. Glacial sediment is of mixed grain size—a diamict—meaning a bimodal mixture comprised of a matrix of fines that contains coarse clasts. Standard geologic description methods are followed for ***major and minor sediment*** wherein the word order indicates relative abundance (e.g. sand and gravel). The conjunction and means equal amounts. The preposition "with" in "sand with gravel" means more sand than gravel; "sand with a trace gravel" means even less gravel. Modifiers come before the main sediment type (e.g. silty sand) and are used in accordance with position on the NRCS texture triangle.

Texture is evaluated in the context of how well suited a deposit is for aggregate use (good, poor, moderate). A deposit that is primarily fine sediment (clay and silt) or a mixture (diamict) has a poor distribution of grain sizes for aggregate purposes. Glacial stream sediment is a mixture of gravel and sand with minor amounts of fine-grained sediment (silt and clay) and has a good to moderate texture depending on the ratio of gravel to sand (need some gravel and crushable material) and the presence of fines (need some silt for binder but not too much).

Sand and gravel probability is the geologist's interpretation, based on available data, of how likely a given depositional setting is to have produced sand and gravel (high, moderate, low, very low). In a glacial environment, sand and gravel are secondary deposits created as the glacial sediment is washed and fines winnowed. Original sediment texture, distance of transport and energy of transport are factors that affect sorting. The ***depositional variability*** of a landform and presence of data points affect probability.

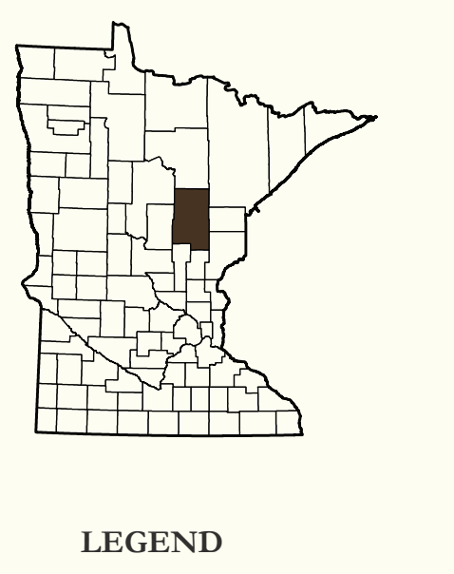
Quality is a measure or estimate of the presence of sound, durable, lithologically suitable and dimensionally favorable clasts in a gravel (high, moderate, low). Clasts that break easily, absorb water, freeze, break, dissolve, expand when wet, have a high length to width ratio or react chemically are considered deleterious. Clast assemblages associated with a given ice-source area and flow path are related to ***lobe provenance***. See the section below, Geologic History as it Pertains to Sand and Gravel Distribution, for images of the clasts typically associated with a given provenance. The lobes that deposited sediment in the area now delineated as Aitkin County, or combinations of deposits that result from the overlapping extent of slightly different-aged lobes and post glacial events are Superior, Itasca, Brainerd sublobe, St. Louis sublobe, and glacial Lake Aitkin-Upham. Recent sediment not directly linked to a glacial lobe is of mixed provenance.

Finally, the ***observed sand and gravel thickness*** and ***overburden thickness*** are single values in the attribute table if only one record was available for a landform; if multiple records were available, a range of thicknesses is given.

RESULTS

Sand and gravel resources are scarce in much of Aitkin County owing to non-deposition, burial by non-aggregate-bearing units or the low-lying nature of the units which places them below the water table and organic deposits. The quality of the aggregate varies greatly because Aitkin County was affected by four different ice lobes, each bearing a lithologically distinct assemblage.

High, discontinuous ridges in the central and southern part of the county that project above the wetland-dominated landscape contain aggregate in places. The courses of former glacial streams commonly followed and reworked by modern streams have discontinuous deposits of sand and gravel. Subglacial tunnels—broad, lake-filled lowlands—in the southeastern part of the county contain narrow ridges of gravel within them. They may have fan complexes bearing sand and gravel where they discharged at the ice margin.



LEGEND

CLASSIFYING SAND AND GRAVEL POTENTIAL

Sand and gravel resources are divided into four categories based on the attributes described in Table 1. The resource has a high probability of containing aggregate when the landform has gravel pits located within its boundaries, sand and gravel is observed at or near the surface, and sand and gravel is encountered in surrounding water wells or other borings. Historical laboratory test results of aggregate quality are compiled, interpreted, and extrapolated from MnDOT pit sheets. In addition to MnDOT quality data, observations of quality characteristics were assessed during field work, where possible. Thickness of overburden and sand and gravel were determined from observations and water well information. For example, if a deposit has areal extent greater than 20 acres, has thickness greater than 15 feet, has overburden thickness of 5 feet or less, has high quality, good texture, and an existing gravel pit, then the resource is classified as having high potential (Table 1). The areas classified as nonsignificant sand and gravel resource potential (low and limited potential) meet the criteria listed in Table 1. Deposits that are too small in areal extent, are too thin, have too thick of overburden, contain significantly more sand than gravel, lack identified resources, or do not meet quality specifications are in these categories.

SIGNIFICANT SAND AND GRAVEL POTENTIAL: These are geologic units that are inferred to contain sand and gravel based on their mode of formation and/or data exhibiting geologic characteristics associated with sand-and-gravel-bearing landforms. Existing gravel pit and MnDOT aggregate sources within these units are considered to be identified, or known resources that increase the level of confidence for that map unit.

Hp **High Sand and Gravel Potential:** Includes landforms such as *glacial stream valley, interlobate complex,* and *collapsed stream sediment.* Predominant sediment typically consists of sand and gravel. The probability that a potential sand and gravel resource exists within any map unit is high. Deposit thickness ranges from 0-80 feet with generally less than 15 feet of overburden. Unit certainty is high as is unit probability. The sand and gravel resources occurring in this unit are large in areal extent and the textural characteristics are moderate to good. The quality is moderate to high relative to other sand and gravel resources within Aitkin County.

Mp **Moderate Sand and Gravel Potential:** Includes landforms listed above and *collapsed channel, spillway terrace, and delta or shallow lake sediment.* The predominant sediment is sand with varying amounts of gravel but fine sediment and diamicton do occur. The probability that a potential sand and gravel resource exists within any map unit is moderate to high. Deposit thickness typically ranges from 0-40 feet but in some landforms can be greater. Burial is typically greater than a high-quality deposit but is not typically over 25 feet. The sand and gravel resources occurring in this unit are moderate to moderately large (5-15+ acres) in areal extent and the textural characteristics are moderate to good. The quality is typically moderate to high relative to other sand and gravel resources within Aitkin County.

NONSIGNIFICANT[1] SAND AND GRAVEL POTENTIAL: These are units that generally have little or no potential for significant aggregate resources based on their geologic interpretation or lack of sufficient data to support a classification as a significant aggregate resource. These units typically contain clay, silt, fine sand, unsorted sediments and only very thin layers of sand and gravel. Units may include aggregate resources that are too small to map or with significant overburden.

Lp **Low Sand and Gravel Potential***:* May include any of the above landforms, but also *lake plain, ice-walled lake plain, low-relief washed till plain, alluvial valley,* or *beach.* Predominant sediment varies but is typically sand with silt and diamicton and only small amounts of gravel. The probability that a potential sand and gravel resource exists within any map unit is moderate to very low. Deposit thickness typically is less than 10 feet but ranges from 0-35 however, overburden thickness ranges from 25-40 feet and may present a barrier to mining. The sand and gravel resources occurring in this unit are moderately small to small in areal extent and the textural characteristics are generally good to very poor.

Ltd **Limited or Unknown Sand and Gravel Potential***:* May include any of the above landforms, but also *channelized lake plain, dune or eolian features, streamlined till, hummocky moraine* and *hummocky till.* The deposits of this unit contain diamict, clay, silt and sand with only limited gravel. The probability that a significant sand and gravel resource exists within this unit is moderate to very low. A limited potential rating includes circumstances where characteristics are unknown; there were insufficient data to give a higher ranking; there was limited access to the area or there were no obvious sand-and-gravel-bearing landform associations at the surface.

IDENTIFIED SAND AND GRAVEL RESOURCES

Several sources of information were used to identify gravel mine locations including: topographic maps, aerial photographs, soil surveys, MnDOT files, fieldwork, gravel operators, and LiDAR relief data. Gravel mines range in size from less than 1 acre to greater than 50 acres and may be active, inactive, depleted, or reclaimed. The sand and gravel quality of the mines varies. Size of symbol indicates the relative areal extent of the pit as of 2010. Sites identified on the map with an "ASIS#" are from MnDOT's Aggregate Source Information System (ASIS). Although identified as a potential resource location, sites have not necessarily been mined or geologically evaluated. Some ASIS locations were modified to better correlate to present gravel pit boundaries.

Small <5 acres	Medium 5-15 acres	Large >15 acres	
□ *n = 249*	□ *n = 66*	□ *n = 19*	**Gravel Pits:** Includes sites that have been or are currently being mined.
△ *n = 50*			**Sand Pits:** Contain significant amount of sand with little to no gravel. Includes sites that have been or are currently being mined. There are no medium or large sand pits.

OTHER FEATURES

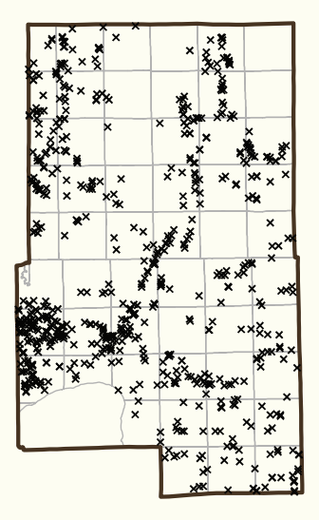
⦶ *n = 11* **Borrow Pits:** Contains other unconsolidated sediment like clay, silt, and clay with boulders and do not contain significant amounts of sand and/or gravel. Includes sites that have been or are currently being mined.

◎ *n = 69* **Prospects:** Indicates a site that has been prospected and/or leased by MnDOT. A prospected classification does not necessarily imply that the source is actually producing or will produce aggregate. In fact, it may only indicate that a parcel was at one time leased by MnDOT.

GEOLOGIC DATA SOURCES FOR MAP UNIT INTERPRETATION

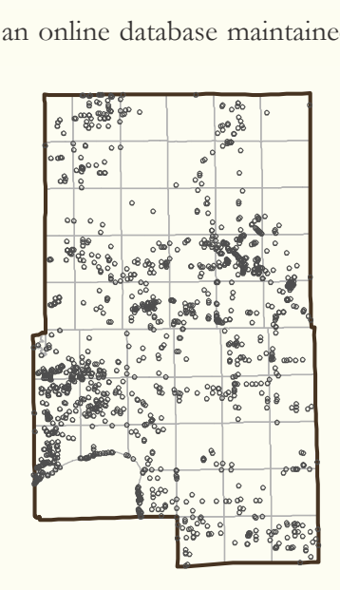
Field observations, **CWI database,** and **test-holes** were data sources used in the interpretation of sand and gravel potential.

Field Observations: A total of 699 field observations were logged throughout the course of the project.



Data Source Map 1. Locations of geologic field observations. Surficial geologic sediment, glacial stratigraphy, and bedrock formations were observed in gravel pits, sand pits, borrow pits, road cuts, stream exposures, excavations, such as basements, artificial drainages, construction projects and animal holes.

County Well Index Database: CWI is an online database maintained by the MGS and the MDH.



Data Source Map 2. County Well Index Database-Located Wells: Displays the 1,364 wells (as of 06/10) located within Aitkin County that were used in the creation of this map.

⊕ **Test Holes:** Test holes were completed to verify the presence or absence of sand and gravel (**see Methods**). A total of 245 samples were taken. Of these 140 were drilled, 76 were grabbed with a shovel, and 29 were taken using a backhoe.

DH-272 — ⊕
LL-490 — ⊕ **Test Holes Sampled for Gradations and Construction Aggregate Quality:** Selected samples from test holes were analyzed for size gradations by the DNR and for construction aggregate quality at a MnDOT material laboratory. Sampled test holes are shown on the map as DH-### if from a drill hole, or LL-### if from a grab/shovel sample. Sample quality has been characterized at the reconnaissance level by 48 MnDOT gradational and aggregate quality samples and 78 DNR gradational samples. The MnDOT concrete lithological exam identifies certain deleterious rock types present within a sample and calculated as a weight percent. Sampled data results are included with the digital data produced for this project.

BASE MAP SYMBOLS

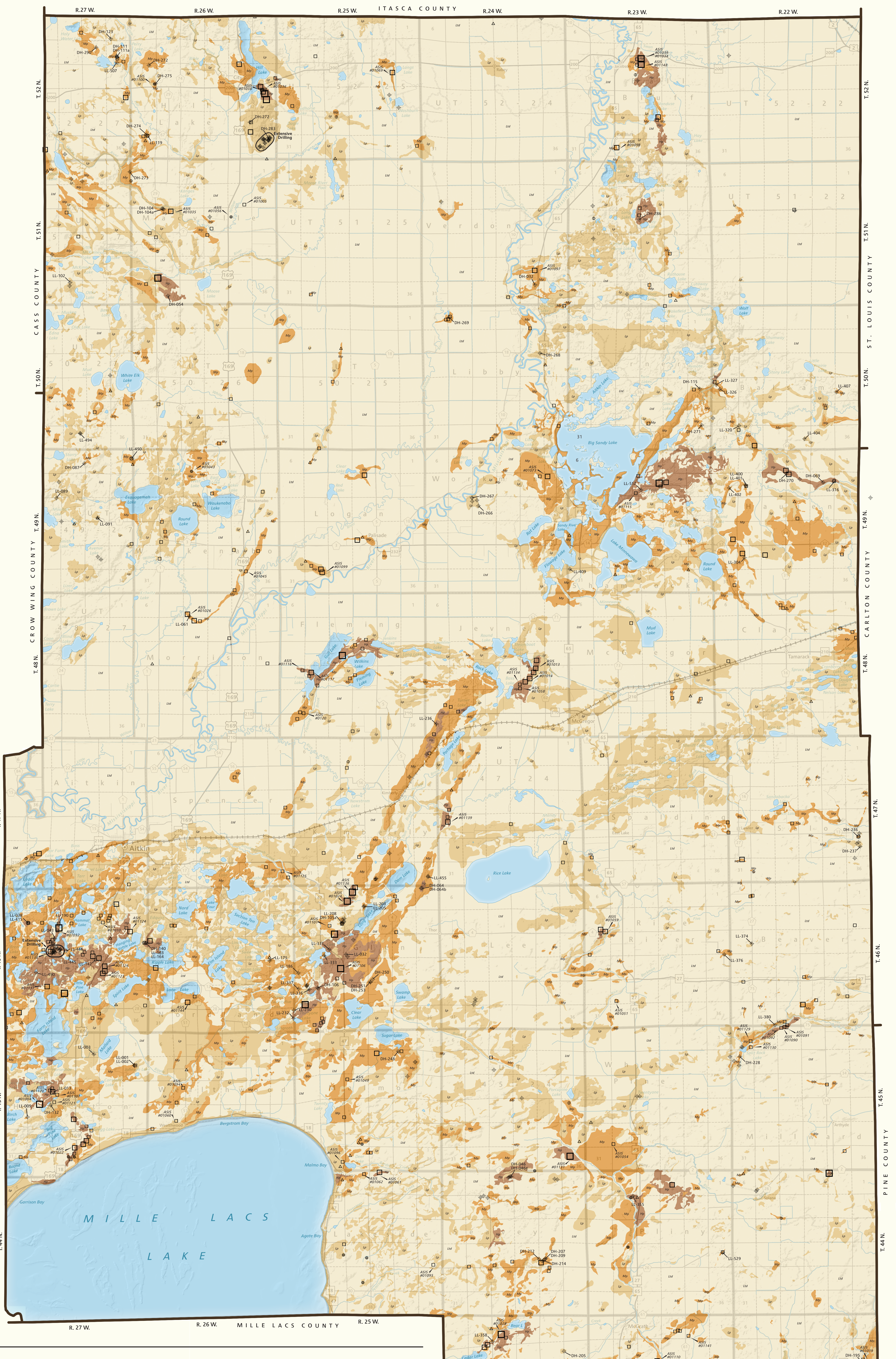
Symbols may appear in different shades due to the overlaid layers of sand and gravel resource potential (limited, low, moderate, or high).

Transportation Features
94 Interstate Highway
71 US Highway
238 MN Highway
17 County Highways and Roads
Township and Other Roads
Municipal Roads
┼┼┼ Railroad Tracks

Bounding Features
Counties (KANABEC COUNTY)
PLS Townships (Idun)
PLS Sections (1,6,31,36)

County Seat & Cities
⦿ County Seat **(Aitkin)**
⊙ Cities (McGrath)

Physical Features
Lakes *(Cedar Lake)*
Rivers & Streams *(Stony Creek)*
Topographic Relief



GEOLOGIC HISTORY AS IT PERTAINS TO SAND & GRAVEL DISTRIBUTION

Introduction

The surface sediment of Aitkin County was deposited primarily by ice lobes that extended south from the Laurentide ice sheet during the most recent glaciation (see **figure 1**) and their associated meltwater streams and lakes. The lobes advanced from different ice-sheet-source areas and as a result of the paths they followed, carried distinct rock assemblages (see **figure 2**). The Superior lobe provides fairly high quality aggregate because it incorporated late Precambrian extrusive and intrusive igneous rocks (basalt and gabbro). It also incorporated sedimentary rock (primarily salmon to pink quartzose sandstone) associated with the mid-continent rift system (see **figure 3A)** and in places this might lower quality slightly. In Carlton County the Superior lobe has locally incorporated metasediments, also lowering its quality (G. Melchert, 2013, written comm). However, for the most part, deleterious material is not present in these deposits. The Brainerd sublobe of the Rainy lobe advanced from the north-northeast through the Animikie basin (see **figure 3B**). It also incorporated continental granitic and metamorphosed oceanic crustal rocks (greenstone belts) from the Superior Province of the Canadian Shield and is of high quality. However, Rainy provenance material may contain schistose or metasedimentary rock fragments, which are less desireable. The Itasca lobe reached the extreme northwest corner of Aitkin County and has Rainy provenance material similar to the Brainerd sublobe but may contain carbonate. The St. Louis sublobe of the Koochiching lobe advanced from the northwest conveying shale- and carbonate-bearing glacigenic sediment of both Winnipeg and Riding Mountain provenance so its deposits are the least valued aggregate resource (see **figure 3C & 3D)**, as they contain shale and carbonate.

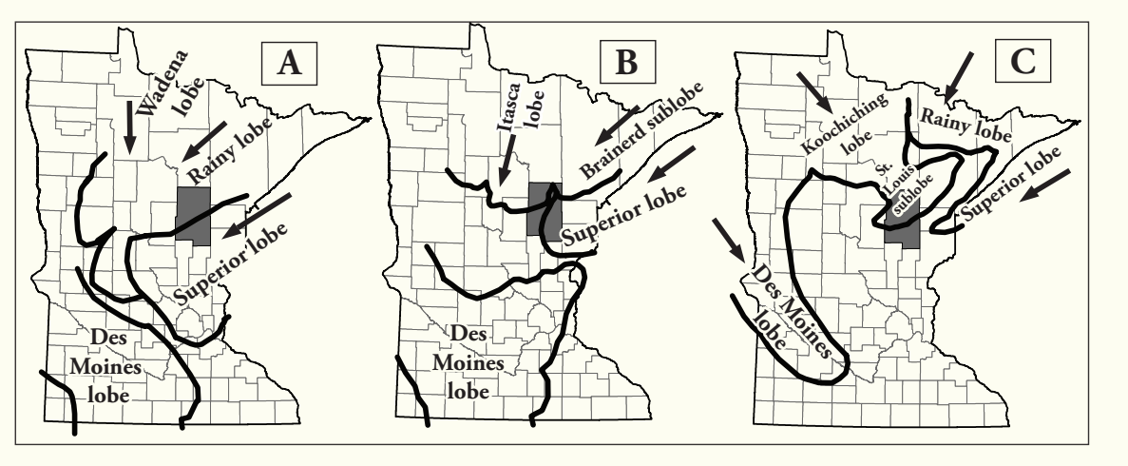


Figure 1: *These diagrams are not meant to represent the paleogeography of the glacial lobes at precise times, but rather show the change in names as the geometry of the lobes evolved during the Late Wisconsinan glaciation. (A) Lobes during the Last Glacial Maximum (LGM). (B) Lobes following retreat from the last glacial maximum. (C) Lobes of the latest glacial phases. From Johnson et al., (in press) and Knaeble and Hobbes, 2009.*

Superior lobe

Superior lobe sediment is exposed at the surface in southern Aitkin County. As it advanced, it streamlined its subglacial till plain (drumlins are exposed at the surface and also beneath Lake Mille Lacs) and also streamlined pre-existing minor moraines. A moraine of this lobe impounds Lake Mille Lacs on the west, (Anderson, 1998; Knaeble and Hobbs, 2009 and references therein). It also created a more subtle moraine on the east side of the lake and one more near the eastern border of the county before retreating northeastward from the county. The still-stands of the ice during retreat are important to demarcate because it is along stationary ice margins that coarse fans may potentially form at the discharge points of subglacial streams. While in Aitkin County, the Superior lobe blocked meltwater from more northerly sources, creating the conditions for the formation of glacial lakes Aitkin and Upham I.

Brainerd sublobe of the Rainy lobe

The Rainy lobe first advanced to the west, beyond the borders of Aitkin county, then the Brainerd sublobe of the Rainy lobe developed a narrower and less extensive flow path that covered part of Aitkin County. The Superior lobe and the Brainerd sublobe of the Rainy lobe were at times confluent so their materials are complexly mixed along their common boundary in the center of the county. The lobes were not necessarily in sync with one another; in fact it is clear that as one lobe retreated, the other invaded that space.

Itasca lobe

The Wadena lobe advanced from a more northerly source and was confluent with the Rainy lobe. It retreated and ice that formed a stable margin at the Itasca moraine is referred to as the Itasca lobe. The Itasca lobe created some very large, ice-marginal landforms in the northwestern part of the county. Although this highland was overtopped by a narrow portion of the St. Louis sublobe, discussed below, and later scoured by flood water from the drainage of glacial Lake Koochiching, which lay to the northwest (Jennings and Reynolds, 2005), the constructional landforms of the Itasca lobe are the most prominent features in this part of the county and include thrust moraines and moraine elements large enough to be used as ski hills. This area also hosts some of the largest commercial gravel pits in the County.

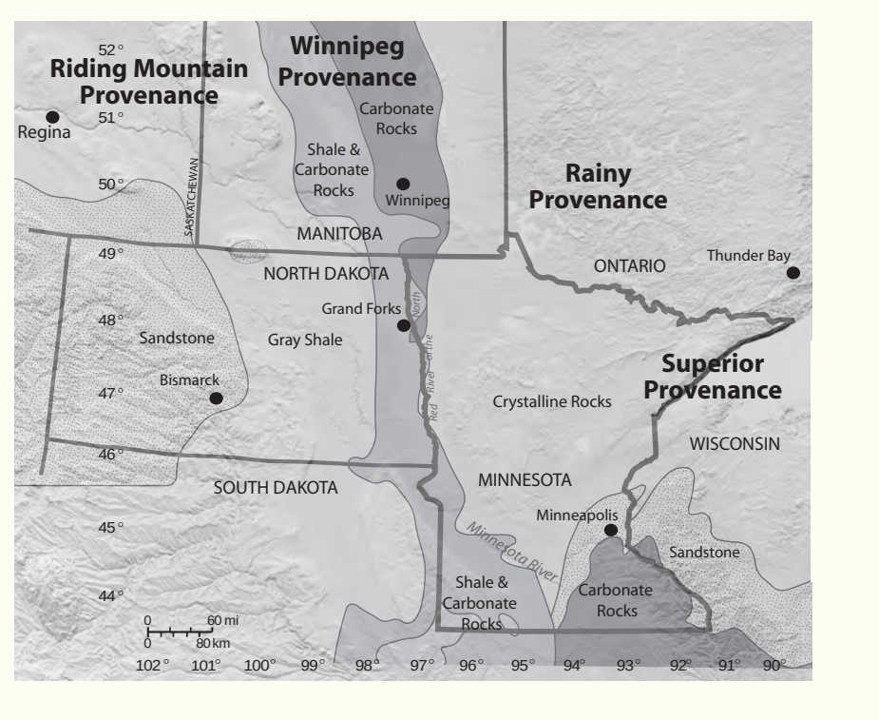


Figure 2: *A simplified geologic map of the region around Minnesota showing provenance zones. Glaciers came into Minnesota from the north, northwest, and northeast, and incorporated bedrock as well as sediment overlying the bedrock from these regions (from Meyer and Knaeble, 1996 as reported in Johnson et al., in press).*

St. Louis sublobe of the Koochiching lobe

After the retreat of the Superior lobe, Brainerd sublobe and Itasca lobe, the Koochiching lobe and its offshoot, the St. Louis sublobe initially carried predominantly yellow-brown to gray, loamy to clayey debris into Aitkin County from the northwest. The debris content changed dramatically as the sublobe entered the basin of glacial Lake Aitkin-Upham, in central Aitkin County, where the ice incorporated clayey, red, lake sediment. The St. Louis sublobe advanced after the Brainerd and Superior lobes had stagnated and/or retreated. Stagnant ice that was buried by insulating debris in their interlobate area affected the course and deposits of the St. Louis sublobe as well as Glacial Lake Aitkin-Upham. The latter sediments can drape, incompletely cover or be in fault contact with the formerly ice-supported deposits. This adds even more complexity to the interlobate deposits. The St. Louis sublobe advanced to a subtly demarcated, essentially east-west position in the southern part of the county north of Mille Lacs Lake.

Glacial lakes

As the St. Louis sublobe retreated, two, coalescing, proglacial lakes formed and are called glacial lakes Aitkin and Upham II (Hobbs, 1981) because they occupy nearly the same basin as the first lakes. At some point this lake water drained through the southern part of the county and deposits along its spillway, which is now occupied by the Snake River, are locally coarse enough to be a significant aggregate resource. Otherwise, this lobe mainly buried or obscured existing aggregate deposits.

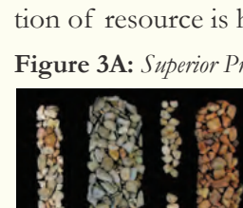
Interlobate complex

Although the deposits of each lobe are distinct, their interlobate or confluence areas are a complex mixture of source material and of dynamic depositional processes. The landforms that were created in the confluence area are a series of prominent, chevron-shaped ridges in the center of Aitkin County. These were modified as the ice of the St. Louis sublobe surrounded and/or overtopped them and subsequently stagnated. The hummocky terrain surrounding Big Sandy Lake and extending north is the result of the stagnation of the St. Louis sublobe. The relief of this sedimentologically complex central highland is accentuated by the low-lying, flat, glacial lake plain covering most of northern Aitkin County.

In the narrow slot between confluent ice lobes, unsorted sediment may be pushed by, or slip off the ice with little to no sorting. Meltwater streams on or in front of the ice may sort the fines, leaving behind a clean sand and gravel that varies greatly in coarseness depending on the energy available to do the sorting. Water may pond temporarily, allowing fines to settle out in a lake bottom or as a drape on other features. Or, all of the above may occur in rapid succession in time and space making the sedimentology of the landform difficult to predict.

This ice-marginal confluence area was also a location where the debris that accumulated was likely to bury and insulate ice, sometimes for hundreds of years. The subsequent slow melting of the buried ice eventually disrupted bedding as the surface collapsed. This makes the depositional processes hard to interpret and the layers of sediment hard to project into unexposed or unexplored areas because the slopes that originally affected sediment sorting are no longer present and the sediment layers that were present may be faulted and offset. So, although this is the setting for many of the largest aggregate pits in the county, the distribution of resource is highly variable and the predictability, low.

Figure 3A: *Superior Provenance*



End-member example of Superior provenance; 8-16 millimeter fraction from site O11 of Thorleifson et al. (2007).

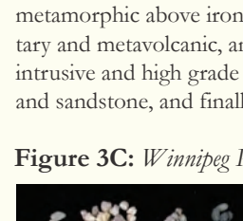
From left to right, felsic intrusive and high grade metamorphic above ironstone, dark metasedimentary and metavolcanic, and from top down, mafic intrusive and high grade metamorphic, quartzite, and sandstone, and finally, reddish volcanic rocks.

Figure 3B: *Rainy Provenance*

End-member example of Rainy provenance; 8-16 millimeter fraction from site S10 of Thorleifson et al. (2007).

From left to right, felsic intrusive and high grade metamorphic, dark metasedimentary and metavolcanic, and from top down, sandstone and quartz; elsewhere, felsic may dominate.

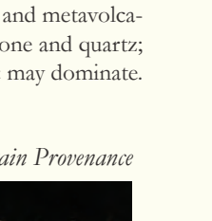
Figure 3C: *Winnipeg Provenance*



End-member example of Winnipeg provenance; 8-16 millimeter fraction from site U3 of Thorleifson et al. (2007).

From left to right, Cretaceous shale, Paleozoic carbonate, felsic intrusive and high grade metamorphic above mafic intrusive and high grade metamorphic, and from top down, dark metasedimentary and metavolcanic, quartzite, reddish volcanic, and ironstone.

Figure 3D: *Riding Mountain Provenance*



End-member example of Riding Mountain provenance; 8-16 millimeter fraction from site N4 of Thorleifson et al. (2007)

From left to right, Cretaceous shale, Paleozoic carbonate, felsic intrusive and high grade metamorphic, dark metasedimentary and metavolcanic, and from top down, reddish volcanic, ironstone, and quartzite.

Glacial stream sediment

All of the lobes generated meltwater. Drainage usually flowed away from or around an ice lobe. Glacial-age drainage may have been controlled or impeded by slopes that are no longer present owing to the subsequent retreat of active ice or downwasting of exposed or buried stagnant ice. Collapsed stream sediment was initially deposited in an ice-supported channel; it typically has positive relief but does not form a recognizable alluvial feature. From a aggregate-prospecting point of view, the meltwater stream deposits of the Superior lobe, Itasca lobe, and Brainerd sublobes are more desirable than their other deposits—which are less well sorted—and more desirable than the lower quality St. Louis sublobe meltwater deposits. However, these more desirable deposits are buried by the St. Louis sublobe glacial, lake, and wind deposits in the northern two-thirds of the county. The deposits of the Superior lobe are at the surface only in the southern third of the county and in much of that area are covered with organic material.

Dunes and eolian features

A few thousand years after deglaciation, dry conditions developed across much of Minnesota (Dean, 1997). In Aitkin County, west-northwesterly winds blew sand across dried-up wetlands and lake beds, depositing an extensive windblown sand sheet. There are some areas of well-formed dunes. A return to wetter conditions stabilized the dunes but they are easily recognized as they project above the accumulated organic deposits, especially in the north-central and northeastern part of the county. Eolian sand is the first sediment encountered in a large area of northern Aitkin County and the associated, finer-grained, windblown silt (loess), typically deposited downwind of areas where sand dropped out of the wind column, covers much of the county. It occurs as a thin layer that is commonly in the upper portion of the soil horizon. In places the silt has sieved into the upper one to two feet or so of coarse-grained deposits such as collapsed stream sediment and provides fines for an otherwise coarse aggregate deposit.

Figure 4: *Interlobate landform with large gravel pit in northern Aitkin County near Jacobson, Ball Bluff Twp. T 52 R 23 S 10.*

Figure 5: *Landform Map Simplified*

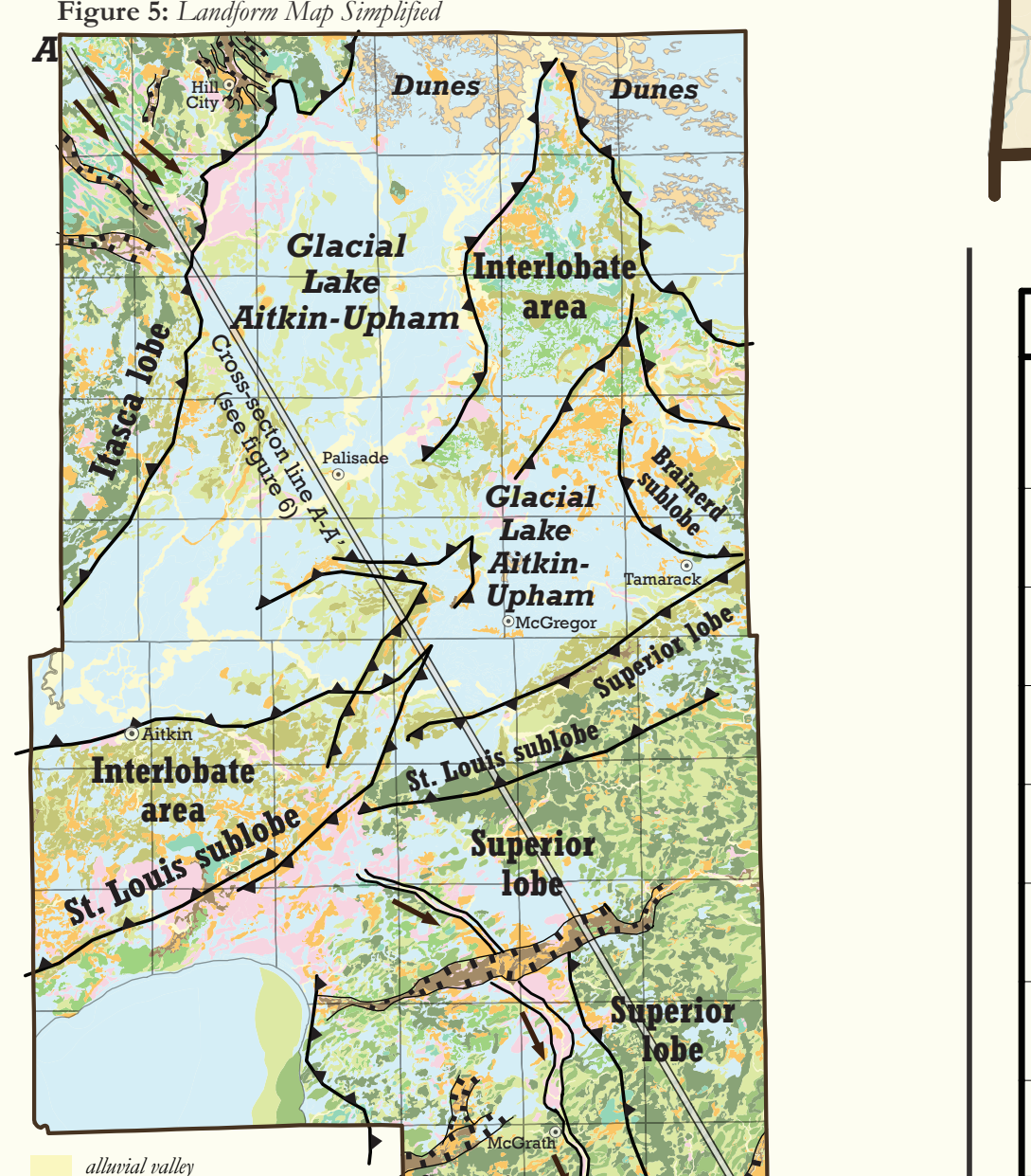


TABLE 1: CLASSIFICATION OF SAND AND GRAVEL POTENTIAL

Characteristics	SIGNIFICANT RESOURCES		NONSIGNIFICANT[1] RESOURCES	
	High Potential	Moderate Potential	Low Potential	Limited Potential
Surficial Geology Landforms	Glacial stream valley; collapsed stream sediment; interlobate complex	Glacial stream valley; collapsed stream sediment; interlobate complex; collapsed channel; spillway terrace; delta or shallow lake	Add: alluvial valley; beach; ice-walled lake plain; lake plain; low-relief washed till plain	Add: channelized lake plain; dune or eolian feature; hummocky moraine; hummocky till; streamlined till
Predominant Sediment Description	Gravel, sand, with minor diamicton	Sand, gravel, diamicton with minor fine sediment (silt and clay)	Sand, fine sediment (silt and clay), gravel and diamicton	Diamicton, fine sediment (silt and clay), sand and
Probability[2]	High	Moderate to high	Very low to moderate	Very low to moderate
Sand and Gravel Thickness (in feet)	0-80+	0-40+	0-35+	0-15+
Overburden[3] Thickness (in feet)	0-15	15-25	25-40	>40
Sand and Gravel Deposit Size (areal extent[4])	Large (10-30+ acres)	Moderate to large (5-15+ acres)	Moderately small to small (3-10+ acres)	Very small to small (<1-5+ acres)
Sand and Gravel Textural Characteristics[5]	Moderate to good	Moderate to good	Very poor to good	Very poor to moderate
Sand and Gravel Quality[6]	Moderate to high	Moderate to high	Low to high	Low to high

FOOTNOTES ASSOCIATED WITH SAND AND GRAVEL POTENTIAL

[1] Nonsignificant: Aggregate resources that do not meet the criteria for high or moderate aggregate potential according to the characteristics listed in Table 1. This is a relative classification that changes from one mapping region to another.

[2] Probability: The degree of certainty that aggregate exists within a mapping unit largely defined by the amount of available information. Many gravel pits verify the certainty for many map units classified as high potential.

[3] Overburden: The material that lies above the sand and gravel that must be removed to access a deposit.

[4] Areal Extent: The size, horizontal extent, or distribution of a unit (e.g., area in acres). This attribute does not necessarily reflect the size of an individual polygon but the size of a deposit found within that polygon.

[5] Textural Characteristics: Particle size distribution, defined as the percentage of gravel or sand vs. silt or clay (e.g., sieve analysis).

[6] Quality: The physical characteristics of the material, such as soundness (e.g., magnesium sulfate test), durability (Los Angeles Rattler test), and percent of deleterious rock types such as iron oxide, disintegrating rock, or unsound chert. Field observations supplement historic data.

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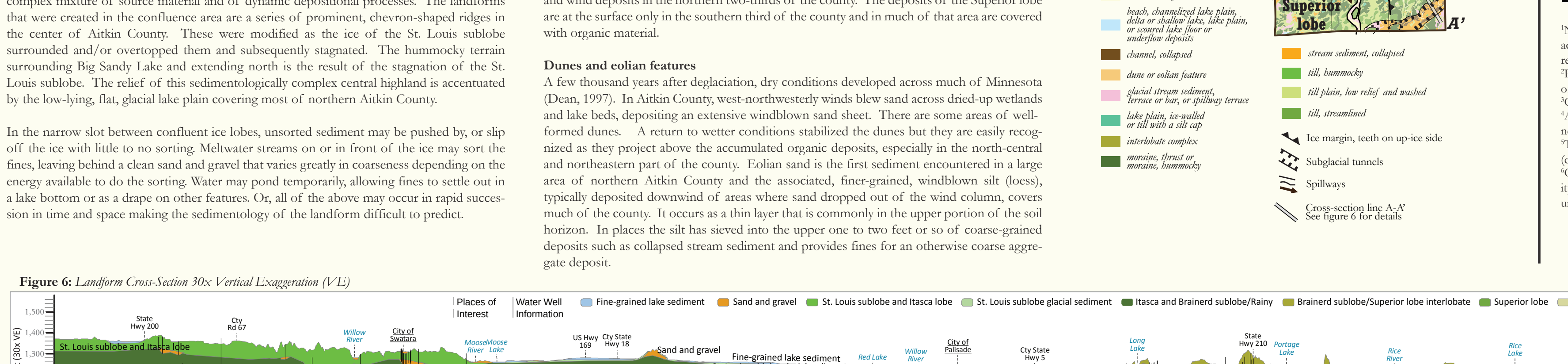
BASE MAP DATA SOURCES

Lakes, rivers, streams, and drainage ditches from NWI (National Wetland Inventory), MnDOT Base map, DNR 24K Streams, compiled at 1:24,000 from aerial photography (1979-1988) and USGS quadrangle maps (1980-1990); PLS (Public Land Survey) townships and sections layers extracted from PLS Project, 2001, DNR, Division of Lands and Minerals; Cities were derived from the GNIS (Geographic Name Information System) by pulling out the features that were coded as populated places. A selected subset of these was used for this map, 2003; County boundaries from DNR, derived from combination of 1:24,000 scale PLS lines, 1:100,000 scale TIGER, 1:100,000 scale DLG, and 1:24,000 hydrography lines, 1993; Hydrography labels derived from selected Mn/DOT County Highway Maps water feature annotations, 2002; Roads from MnDOT Base map, Fall of 2006; Railroad Tracks from MnDOT Base map, 2001. GIS support and cartography by Kevin J. Hanson, DNR, Division of Lands and Minerals.

MAP AND DATA DISCLAIMER

Figure 6: *Landform Cross-Section 30x Vertical Exaggeration (VE)*



GLOSSARY FOR GEOLOGIC LANDFORMS

Holocene landforms (recent, peat glacial)

alluvial valley; Holocene and modern stream valleys that have been adjusting to precipitation and groundwater flow since the end of the last glaciation. In places stream courses follow the path of former glacial meltwater streams; sediment is primarily sand, silt and muck with gravel where coarser glacial stream sediment is being reworked.

beach; narrow ridge(s) or slope surrounding modern lakes or wetlands; created by wave, wind and ice action; sediment is primarily well sorted sand in laterally continuous horizontal layers, coarser in places owing to reworking of pre-existing glacial sediment. May include finer-grained lake sediment.

channel, collapsed; broad, elongated and irregular lowland; interpreted as stream channels that were formerly supported by ice; may represent former subglacial tunnels or channels with ice walls; although erosional in origin they have the potential to contain depositional ridges of sand and gravel (eskers) but also irregularly infilled by supraglacial, hummocky till, lake sediment and muck (not mapped).

Late Holocene and Quaternary landforms (glacial)

dunes or eolian features; low relief, undulating surface with or without discrete dunes; primarily located in former glacial lake plain and along major stream valleys; sediment is homogeneous, well sorted sand; interpreted as formerly active sand sheet that is now stabilized by higher water table and vegetation.

delta or shallow lake; gently sloping surface found between higher ground and flat lake plain; interpreted as deposited by streams entering lake and by reworking of pre-existing sediment by stream and lake. Varies in texture owing to changing lake levels but primarily silty sand to sandy silt in facies relationship (lateral and vertical changes) with clay and silt (lake sediment) and sand and gravel (stream sediment).

glacial stream valley, plain, terrace or bar; channels, flat surfaces paralleling channels, streamlined forms within channels or lake plains or fans sloping away from former ice margins; sediment is primarily well sorted and bedded sand and gravel with silt. Interpreted as glacial meltwater stream sediment. In the northwest corner and south central map area, includes channels of spillway origin (lake drainage); may include non-glacial stream sediment.

interlobate complex; broad and complex ridges, flat-topped in places; sediment is highly variable and includes sand and gravel layered with diamicton; may fine up to silt; interpreted as having been deposited in low areas on ice, between confluent lobes, or along margins of buried stagnant ice by running water and gravity.

lake plain; level area of bedded to massive silt and clay; includes sand, trace gravel; may be overlain by modern organic material; interpreted as offshore lake deposits of glacial lakes Aitkin and Upham II or smaller post-glacial lakes.

lake plain, channelized; similar to above but appearing in a subtle, broad linear depression. May be a channel that was then infilled by lake sediment, burying coarser material, or a channel cut into the lake sediment.

lake plain, ice-walled; flat-topped hill with steep side slopes and somewhat circular outline; sediment is silt, clay and fine sand, laminated to layered; commonly with diamict layers or flow till; sorted sediment common along the edge of hill; sediment is interpreted to have accumulated in ice-walled depression in stagnant ice and was sorted to some degree by settling through standing water.

lake plain, ice-walled, or till with a silt cap; interfluves of spillway channels in northwest corner of map area; sediment is silt and fine sand over glacial sediment; interpreted as either deposits of a higher stage lake or waning flow deposits of a flood from a glacial lake basin to the northwest or wind deposits that were preferentially deposited and/or preserved on till highlands.

moraine, hummocky; broad linear zone interpreted as demarcating the limit of an ice advance. Generally comprised of till but may be interspersed with collapsed stream sediment.

moraine, thrust; large, irregular hills interpreted to be thrust blocks created by the Itasca lobe based on occurrence of similar features northwest of Aitkin County. Sediment is primarily diamicton but in other occurrences, thrust blocks are documented to have disrupted and include bedrock units.

stream sediment, collapsed; narrow, irregular, low ridges; sediment is poorly sorted gravel and sand intercalated with diamicton; in places fines up to silt; interpreted to have been deposited in crevasses or low areas on the ice surface by running water and gravity or in subglacial tunnels.

terrace, spillway; bars and terraces in sinuous channels oriented down-gradient from former glacial lake basin; sediment is primarily sand and gravel; interpreted as spillway deposits associated with draining of a lake.

till, hummocky; irregular hills of unsorted deposit interspersed with irregular areas of sorted sediment and ice-walled lake plains; interpreted as originating in an unstable layer on unevenly down-wasting ice and may be sorted in places as a result of resedimentation.

till, streamlined; streamlined low hills oriented generally with interpreted ice-flow direction; sediment is dense diamicton; interpreted as having formed beneath active ice.

till plain, low relief and washed; undulating to nearly level surface of subdued and commonly streamlined expression; sediment is primarily diamicton but has the potential to have a coarse lag resulting from the removal of finer particles by water and/or be capped with a drape of fine sediment; interpreted as having been washed by water of a lake or stream.

Products of this project include a CD/ROM with digital maps, GIS data, and metadata
Plate A, Report 381, Aitkin County Aggregate Resources, Sand and Gravel Potential **and Plate B, Report 381, Aitkin County Aggregate Resources, Crushed Stone Potential**