PLATE B: AITKIN COUNTY AGGREGATE RESOURCES, CRUSHED-STONE POTENTIAL

Produced by the Aggregate Resource Mapping Program,
Division of Lands and Minerals, Minnesota
Department of Natural Resources
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Carrie E. Jennings and Steven J. Kostka

Printed Map Scale 1:100,000

Based on a 1:100,000 scale resource assessment

Miles 0 1 2 3 4 5 6

0 1 2 3 4 5 6 7 8 9 Kilometers

SUMMARY

Where suitable bedrock crops out or is within 50 feet of the surface as indicated from logs of borings or well records, it has the potential to serve as a crushed-stone resource. The general suitability of the bedrock involves its lithology and durability. Geologic maps and associated reports from the Minnesota Geological Survey (MGS) are a reliable source of bedrock information and were the primary source of information used (Southwick and others, 1988; Boerboom and others, 1999). Various metamorphic, plutonic and volcanic bedrock types of the Little Falls Formation (Paleoproterozoic), Mille Lacs Group (Paleoproterozoic), and McGrath Gneiss (Neoarchean) are near the surface in the southern third of Aitkin County. Bedrock is deeply buried in the rest of the county.

PURPOSE

The purpose of this project is to map crushed-stone bedrock potential and is part of a larger project to identify construction aggregate resources in Aitkin County, Minnesota. The Minnesota Department of Natural Resources (DNR), directed by Minnesota Statutes, section 84.94 "Aggregate Planning and Protection," provides counties with needed information to plan for the future availability of aggregate resources. Crushed-stone is produced by mechanically crushing durable bedrock into desired-sized, angular particles that can meet the specifications for construction aggregate used in building roads, bridges, airport runways and railroad beds, for example. Crushed-stone resources are not evenly distributed across the state of Minnesota or within a single county. Therefore, determining the location of the bedrock with crushed-stone potential within a county is for planning and land-use decisions.

This plate displays the distribution of crushed-stone bedrock potential within 50 feet of the land surface. The crushed-stone potential of any location within the county depends on the physical and compositional characteristics of the bedrock along with how deeply the bedrock is buried. For example, some of the gneissic rocks exposed in Aitkin County provide durable, high-quality, crushed-stone that meets Minnesota Department of Transportation (MnDOT) specifications for a Class A aggregate source. Other rock types, like metamorphosed sedimentary rocks, can be soft, flaky, and not durable enough to be used for aggregate. Also, the crushed-stone potential decreases the more deeply the rock is buried by sediment, sedimentary rock, and/or highly weathered bedrock.

This reconnaissance-level assessment shows the distribution of crushed-stone potential within Aitkin County. Geologic data, such as exposed bedrock locations, subsurface water well data, available drill core samples, geophysics, previous geologic studies, and verbal communication with other geologists, and local aggregate producers, provided the basis for the criteria that were used to define crushed-stone potential. Mapped crushed-stone potential defines an area where the geologic evidence was interpreted to support a particular map designation. This map is not intended to provide the kind of site-specific information that would be required to determine the value or suitability of a potential crushed-stone quarry at individual sites. The mineralogy of the rock was not explicitly considered, that is, which minerals may be present and susceptible to weathering or freeze-thaw failure after crushing. Other site-specific factors can include land ownership, the owner's preferences, biodiversity significance, royalty rates, distance to market, permitting requirements, and/or the cultural and historical significance of the location. Factors such as the economic feasibility of mining a given crushed-stone resource may depend on transportation distances to a potential end user as well as the proximity of a permitted mining operation to existing transportation modes or corridors.

GEOLOGIC OVERVIEW

Aitkin County bedrock is located within the Paleoproterozoic Penokean Orogen (see figure 1), a belt of deformed and metamorphosed bedrock related to crustal collision dating to 2,100 Ma (million years from present) to 1,800 Ma. In southcentral Aitkin County there are bedrock exposures of McGrath Gneiss which was formed from an older event dating to between 2,700 Ma to 2,500 Ma within the Neoarchean period. These two areas are interrupted by rocks associated with the later, Mesoproterozoic Keewenawan Supergroup of the Midcontinent Rift System, which originated as a continent-splitting rift filled with lava flows and overlying sand (1,100 Ma) (Boerboom, 2009). The bedrock geology is comprised of four major terranes that represent these three early events:

1) **Superior Province - Neoarchean McGrath Gneiss bedrock** is a granitic to granodiorite orthogneiss from the Superior Province period formed between 2,700 Ma to 2,500 Ma.

2) **Paleoproterozoic sedimentary bedrock** dominated by graywacke-slate of the Thomson Formation that comprise the southern portion of the Animikie Basin and unconformably overlie the metamorphosed sedimentary and igneous rocks of the Paleoproterozoic Mille Lacs Group;

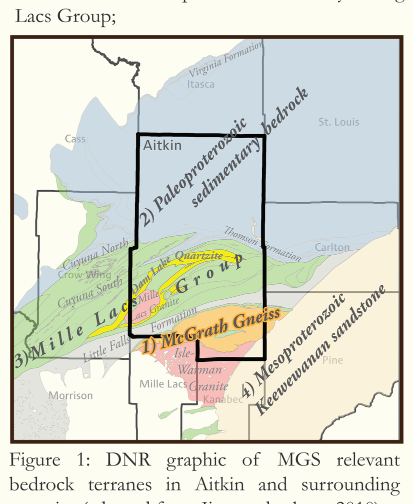


Figure 1: DNR graphic of MGS relevant bedrock terranes in Aitkin and surrounding counties (adapted from Jirsa and others, 2010).

3) **The Mille Lacs Group**, a complex of deformed fold and thrust belts involving sedimentary and volcanic bedrock of Paleoproterozoic age associated with collision and subduction that are separated by major structural discontinuities that include increasingly metamorphosed and plutonic terranes to the SE: North Range, Cuyuna District; South Range Cuyuna District, Moose Lake-Glen Township Structural panel; and McGrath-Little Falls structural panel (Southwick and others, 1988);

4) **Mesoproterozoic Keewenawan sandstone**, a rift-filling, quartzose sandstone, siltstone and conglomerate that is jointed and reversely faulted in places.

METHODS

Since aggregate resources are mined from the earth, geologic methods are required to determine the location, distribution, and quality of a potential aggregate source. At this reconnaissance level (1:100,000) assessment, three geologic criteria were used to determine crushed-stone potential: bedrock type from existing bedrock mapping, depth of burial, and probability of occurrence based on the availability of data. Different bedrock types have different physical properties (e.g. hardness, durability, and chemical composition). To be suitable for use as a construction aggregate, a rock must be hard, durable, not fracture in a predominant direction or react chemically.

The quantity, quality, and distribution of the data available to us determined the confidence level or probability of the crushed-stone potential designation. General trends in the suitability, or quality, of bedrock as a source for crushed-stone resources were interpreted from existing geologic information and MnDOT specifications.

An existing depth to bedrock model (Jirsa and others, 2010) predicted where crystalline bedrock was within 50 feet of the land surface. Much of the subsurface information used for the model came from the County Well Index (CWI), an online database developed and maintained by the Minnesota Department of Health (MDH) and MGS. CWI contains basic geologic and stratigraphic information for over 300,000 domestic and municipal water wells drilled throughout Minnesota. The CWI identifies wells as being either located or unlocated. Located CWI wells are field-verified under the supervision of the MGS. Unlocated CWI wells have not been field-verified, but their records may contain information that can be used to associate a well with a given address or parcel of land. For this project, unlocated wells were integrated into the existing depth-to-bedrock model (Jirsa and others, 2010) if the location of a well record could be reasonably verified using parcel data from county tax records, address information, plat maps, air photographs, and road maps. When correlation was established, the well was placed near a residential dwelling within the parcel. This method of locating wells is not as accurate as field checking using 7.5 Minute USGS Quadrangle maps and/or Global Positioning System (GPS). However, the level of accuracy is within an acceptable range for this reconnaissance-level assessment.

Of the bedrock units mapped within the county, only 5 bedrock types were shallowly buried or exposed; McGrath Gneiss, Little Falls Formation, Glen Township Metabasalt, Dam Lake Quartzite, and Paleoproterzoic Iron-formation. They can be classified using MnDOT's system wherein Class A crushed-stone ranks as the highest quality aggregate (MnDOT 3139.2 A2a) and is defined as crushed-stone derived from listed rock types like basalt, diabase, gabbro, quartzite and granite. Class A aggregates are highly valued because they meet rigorous specifications for high performance pavement mix designs required for Superpave and other applications. All other rock types, (e.g. schist, carbonate, and rhyolite) are classified as Class B aggregates. However, for a bedrock source at any given location to be qualified as a certified aggregate source for concrete, the material must undergo testing and meet MnDOT specifications (MnDOT Standard Specifications for Construction, 2005). This type of testing was not performed as part of this project. Therefore, the final determination of crushed-stone quality was assessed on a relative scale from "low" to "high" within the crushed-stone potential classification system.

METHODS, CONTINUED

The MGS depth to bedrock model (Jirsa and others, 2010) calculates the bedrock-surface elevation and then subtracts it from the ground-surface elevation to produce an approximation of overburden thickness. Crushed-stone potential was delineated where crystalline bedrock was interpreted to be within 0 to 15 feet, 16 to 30 feet, and 31-50 feet. Bedrock that was buried by more than 50 feet was not considered. These intervals were intended to reflect current trends in mining and general water-table elevations.

The accuracy of both the overburden-thickness model and the crushed-stone potential derived from this model rely upon the distribution and density of data points. The more data within an area, the greater the probability that crushed-stone resources exist at the depth described within the map unit. There remains some uncertainty owing to the variability of bedrock topography. In some areas, the bedrock surface is irregular and may have significant relief and be partially buried by glacial sediment. Every effort was made to accurately capture trends in sediment thickness. The probability is a relative assessment that ranges from low to high, based on the quantity, quality, and distribution of information associated with a map unit. The assessment of crushed-stone potential integrates the three criteria of bedrock type, sediment thickness, and probability into a classification system where areas within Aitkin County were classified as having high, moderate, low or limited crushed-stone potential. Areas designated as high or moderate potential were considered to be significant crushed-stone resources, while areas classified as low or limited potential were considered to be nonsignificant crushed-stone resources.

Bedrock Outcrop Areas in Aitkin County

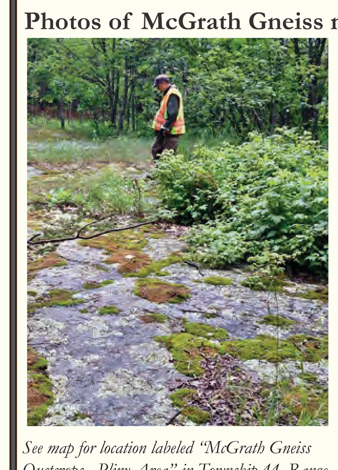
Outcrops of the McGrath Gneiss: Located near the towns of McGrath, Pliny, and Solana

In the south central portion of the county, Neoarchean McGrath gneiss bedrock, a granitic to granodioritic orthogneiss is at or near the surface on the up-ice (north-facing) side of a streamlined upland. This is a Class A rock type and has the highest crushed-stone potential in the county. Jointed and weathered exposures of the McGrath gneiss were found near the towns of McGrath, Pliny, and Solana. The McGrath Gneiss bedrock is less than 50 feet from the surface over much of the rest of the broad highland and a broad valley extending southwest from it. The broad upland in Section 6 of Idun Township along the Aitkin-Mille Lacs border and sections 34-36 of Millward Township along the Aitkin-Pine County border are areas of shallowly buried, pink to gray, medium-to-coarse-grained gneiss that is locally sheared, crushed and recrystallized.

Photos of McGrath Gneiss near the town of McGrath

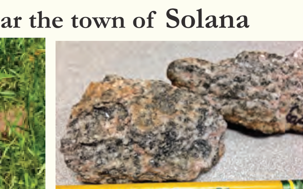
See map for location labeled "McGrath Gneiss Ouctcrops - McGrath Area" in Township 43, Range 24, Section 1. Samples were taken at this site. The small samples collected provide a visual example of the outcrop observed, but are not intended to be representative for testing purposes.

Photos of McGrath Gneiss near the town of Pliny



See map for location labeled "McGrath Gneiss Ouctcrops - Pliny Area" in Township 44, Range 23, Section 6. Samples were taken at this site. The small samples collected provide a visual example of the outcrop observed, but are not intended to be representative for testing purposes.

Photos of McGrath Gneiss near the town of Solana



See map for location labeled "McGrath Gneiss Ouctcrops- Solana Area" in Township 45, Range 22, Section 35. Samples were taken at this site.

Outcrops of the Little Falls Formation

In the central part of the county there is a small outcrop of Paleoproterozoic Little Falls Formation which includes metamorphosed graywacke and mudstone, schist and slate. The exposures are on the up-ice side of an upland in glacially streamlined terrane. The fine-grained, platy and schistose nature of this Formation makes the quality of them less desirable for crushed-stone; it falls within Class B and is of low potential where it outcrops.

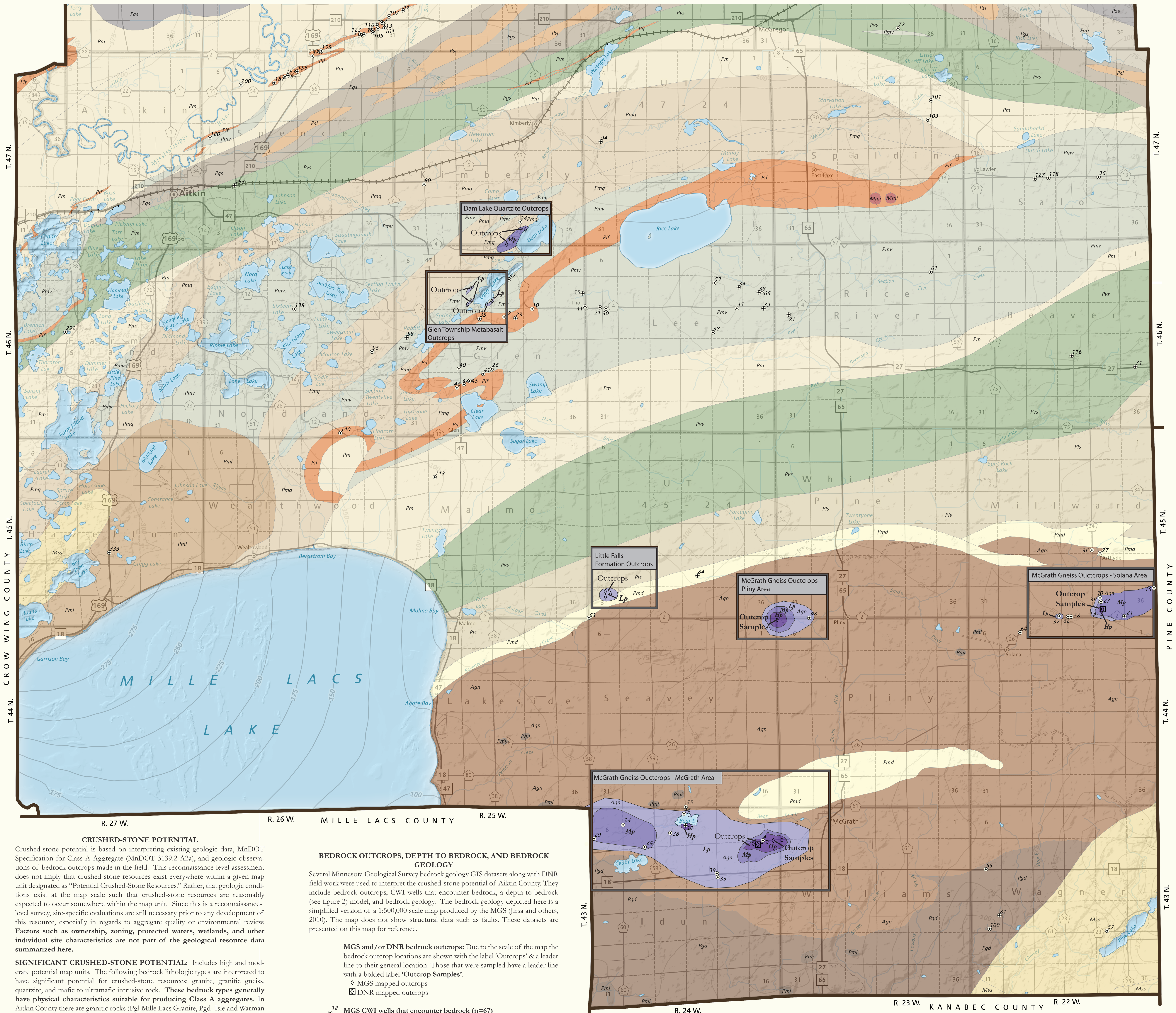
Outcrops of the Glen Township Metabasalts

Southwest of Rice Lake and along the shores of Long Lake there are shallow bedrock areas where Glen Township metabasalt and associated metasedimentary rocks and Paleoproterozoic Iron-formation in the Penokean fold and thrust belt subcrop. The DNR was unable to view and sample these outcrops due to them being located on private land. According to Terry Boerboom at the MGS, who mapped the bedrock geology here, these bedrock outcrops are all mafic hypabyssal intrusive rocks and their schistose nature makes the quality of them less desirable for crushed-stone resources.

Outcrops of the Dam Lake Quartzite

West of Dam Lake are isolated exposures of the Dam Lake Quartzite, a Paleoproterozoic metasedimentary rock. It is also part of the Penokean fold and thrust belt. MnDOT defines Quartzite as a Class A rock type. One of the outcrops is on the lake shore, the other outcrop is just off the road in the woods. Geologists of the DNR were unable to view and sample these outcrops. Terry Boerboom at the MGS who viewed and mapped the outcrops stated that they are fairly course-grained and pretty well annealed. Based on this correspondence, and MnDOT's Class A rock type determination, the DNR interprets the Dam Lake Quartzite here as having moderate potential for crushed-stone resources where it is near the surface (0-15 feet).

North-half of Aitkin County not shown due to limited potential for crushed-stone resources



CRUSHED-STONE POTENTIAL

Crushed-stone potential is based on interpreting existing geologic data, MnDOT Specification for Class A Aggregate (MnDOT 3139.2 A2a), and geologic observations of bedrock outcrops made in the field. This reconnaissance-level assessment does not imply that crushed-stone resources exist everywhere within a given map unit designated as "Potential Crushed-Stone Resources." Rather, that geologic conditions exist at the map scale such that crushed-stone resources are reasonably expected to occur somewhere within the map unit. Since this is a reconnaissance-level survey, site-specific evaluations are still necessary prior to any development of this resource, especially in regards to aggregate quality or environmental review. **Factors such as ownership, zoning, protected waters, wetlands, and other individual site characteristics are not part of the geological resource data summarized here.**

SIGNIFICANT CRUSHED-STONE POTENTIAL: Includes high and moderate potential map units. The following bedrock lithologic types are interpreted to have significant potential for crushed-stone resources: granite, granitic gneiss, quartzite, and mafic to ultramafic intrusive rock. **These bedrock types generally have physical characteristics suitable for producing Class A aggregates.** In Aitkin County there are granitic rocks (Pgl-Mille Lacs Granite, Pgd- Isle and Warman Granite), granitic gneiss rocks (Agn- McGrath Gneiss), quartzite (Pmq- Dam Lake Quartzite), and mafic intrusive rocks (Pmi). High or moderate crushed-stone potential map units also need to be either exposed at the surface or be covered by less than 30 feet of overburden. Only the McGrath Gniess and Dam Lake Quartzite are exposed at the surface or interpreted to be covered by less than 30 feet of overburden in Aitkin County.

DNR geologists viewed and sampled McGrath Gneiss in three areas of the county. They were not able to view the Dam Lake Quartzite outcrops displayed on the map but did correspond with Terry Boerboom at the MGS who mapped those outcrops. **None of the McGrath Gneiss outcrop samples were tested for construction aggregate quality specifications according to MnDOT and therefore should be considered Class A aggregate candidates.**

Hp **High Crushed-Stone Potential:** Includes McGrath Gneiss exposed at the land surface or buried by less than 15 feet of overburden. The interpreted quality of this bedrock type is moderate. The probability of crushed-stone existing within a map unit ranges from moderate to high.

Mp **Moderate Crushed-Stone Potential:** Can include either of the following criteria:

- McGrath Gneiss buried beneath 15 to 30 feet of overburden or,
- Dam Lake Quartzite exposed at the land surface or,
- Dam Lake Quartzite buried by less than 15 feet of overburden.

The interpreted quality of these two bedrock types are moderate. The probability of crushed-stone resource existing within a map unit ranges from moderate to high.

NONSIGNIFICANT CRUSHED-STONE POTENTIAL: Includes low and limited potential map units. Nonsignificant is a term used in this assessment to define mapped areas that contain any of the following conditions: poor quality bedrock units, moderate quality bedrock units with thick overburden (>30 feet), or areas where higher potential may exist but cannot be verified due to a lack of substantiating data which facilitate a lower probability rating. Poor quality bedrock units exposed at the surface, or are buried by less than 15 feet of overburden, include metasedimentary and metavolcanic rocks in the Little Falls Formation.

Lp **Low Crushed-Stone Potential:** Can include either of the following criteria:

- McGrath Gneiss buried by 30 to 50 feet of overburden or,
- Little Falls Formation bedrock exposed at the land surface or,
- Little Falls Formation buried by less than 15 feet of overburden.

Low potential also includes areas with little supporting data to substantiate a higher potential classification. The interpreted rock quality ranges from poor to moderate. The probability that these rock types occur within the map unit ranges from low to high.

Limited Crushed-Stone Potential: *Not symbolized on the map.* Includes all other rock types seen in bedrock geology legend with varying thickness of overburden (15 to >50 feet). The interpreted quality ranges from poor to moderate. The probability of crushed-stone existing within a mapping unit ranges from low to moderately low.

BEDROCK OUTCROPS, DEPTH TO BEDROCK, AND BEDROCK GEOLOGY

Several Minnesota Geological Survey bedrock geology GIS datasets along with DNR field work were used to interpret the crushed-stone potential of Aiktin County. They include bedrock outcrops, CWI wells that encounter bedrock, a depth-to-bedrock (see figure 2) model, and bedrock geology. The bedrock geology depicted here is a simplified version of a 1:500,000 scale map produced by the MGS (Jirsa and others, 2010). The map does not show structural data such as faults. These datasets are presented on this map for reference.

MGS and/or DNR bedrock outcrops: Due to the scale of the map the bedrock outcrop locations are shown with the label 'Outcrops' & a leader line to their general location. Those that were sampled have a leader line with a bolded label **'Outcrop Samples'**.

◊ MGS mapped outcrops

DNR mapped outcrops

12 **MGS CWI wells that encounter bedrock (n=67)** Labeled by depth to bedrock in feet (see figure 2)

25 **Depth to bedrock contours generalized:** 25 foot intervals

BEDROCK GEOLOGY LEGEND
MESOPROTEROZOIC AND PALEOPROTEROZOIC ROCKS

Highlighted in Bold are bedrock types that generally have physical characteristics suitable for producing Class A aggregates

MESOPROTEROZOIC

- Mss Sandstone, siltstone, and local conglomerate. Includes the Hinckley Sandstone and Fond du Lac Formations
- Mmi Mafic intrusive stock; diabase, diorite, pyroxenite, gabbro

PALEOPROTEROZOIC

- Pmi **Mafic intrusion; pyroxenite, peridotite, gabbro, and lamprophyre. Defined largely by magnetic signature**

East-central Minnesota batholith

- Pgd Gray granodioritic to dioritic intrusion; Isle and Warman granite

Animikie Group

- Pas Virginia, and Thomson formations, mudstone and graywacke
- Pag Slate, graywacke twice deformed metasedimentary rocks
- Psi Sulfidic iron-formation, graphitic argillite, slate
- Pgs Graywacke, slate with graphitic and sulfidic zones

Little Falls Formation

- Pls Of graywacke, mudstone, and schist and slate protolith
- Pmd Denham Formation; sandstone, marble, schist

Mille Lacs and North Range Groups in the fold and thrust belt of the Penokean Orogen

- Pm Mudstone, quartzite, graywacke, phyllite, graphitic argillite
- Pif Iron-formation, interbedded with mafic volcanic and hypabyssal intrusive rocks
- Pmv Mafic metavolcanic and hypabyssal intrusive rocks, argillite, slate, graywacke
- Pmq **Dam Lake Quartzite**
- Pvs Interlayered metasedimentary and metavolcanic rocks
- Pml **Mille Lacs Granite**

NEOARCHEAN ROCKS

- Agn **McGrath Gneiss - Granitic to granodioritic orthogneiss**

BASE MAP SYMBOLS

Symbols may appear in different shades due to the overlaid layers of bedrock geology and/ or crushed stone potential.

Transportation Features

- Interstate Highway
- US Highway
- MN Highway
- 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)

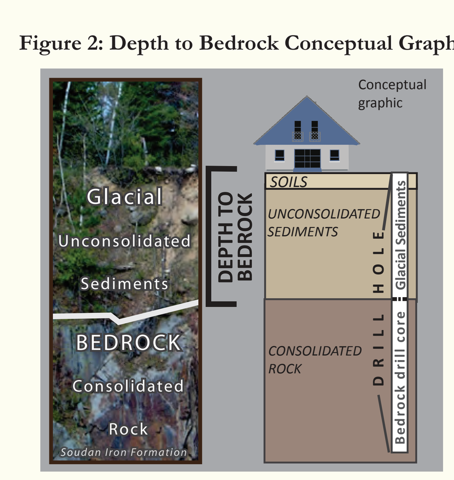
County Seat & Cities

- County Seat (Aitkin)
- Cities (McGrath)

Physical Features

- Lakes (Cedar Lake)
- Rivers & Streams (Stony Creek)
- Topographic Relief

Figure 2: Depth to Bedrock Conceptual Graphic



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 MnDOT 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.

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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*