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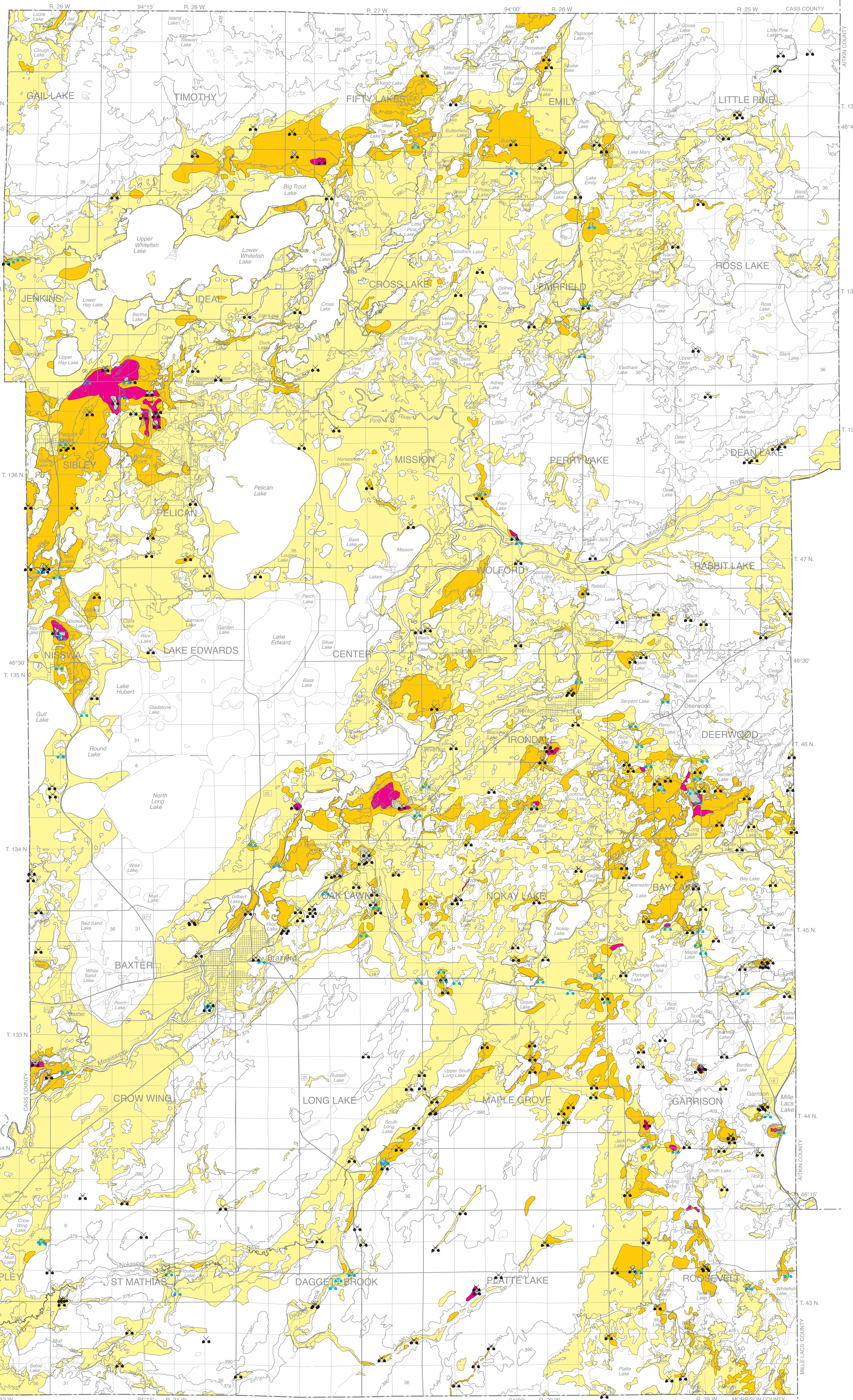

Digital base modified from the Minnesota Department of Transportation BaseMap data; digital base annotation by the Minnesota Geological Survey.

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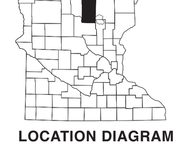
Universal Transverse Mercator Projection, grid zone 15
1983 North American Datum



LOCATION DIAGRAM

SCALE 1:100 000

1 0 1 2 3 4 5 MILES

1 0 1 2 3 4 5 6 7 8 KILOMETERS

CONTOUR INTERVAL 15 METERS

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.

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

MINERAL ENDOWMENT

By

Gary N. Meyer and Terrence J. Boerboom

2004

INTRODUCTION

The terms *mineral* or *geologic endowment* and *mineral resource* refer to geologic materials that have intrinsic economic value and thus potentially could be mined and marketed. The geologic endowment of a mineral commodity can be defined and quantified on observable physical and compositional attributes of the deposit, such as deposit thickness and horizontal dimensions, overburden thickness, measure of crushing strength, and particle-size distribution. A mineral resource is a narrower subset of a geologic endowment; it is an occurrence of geologic material of economic interest in such form and quantity that reasonable prospects for eventual economic extraction exist. If a part of the deposit does not have reasonable prospects for eventual economic extraction, it cannot be included in a mineral resource (Resources and Reserves Committee, 1999). Factors that may remove some portion of an endowment from consideration as a resource are zoning restrictions, land ownership considerations, prohibitive taxation, competing surface uses, and environmental considerations, in addition to the supply–demand–price fluctuations of the commodity marketplace. Therefore a mineral resource must possess favorable geologic attributes and also be relatively unencumbered by socioeconomic factors that would remove it from consideration as the basis of a business enterprise. The authors of this plate did not take into account these socioeconomic factors, and therefore the maps portray the mineral endowment of Crow Wing County, not the mineral resource.

AGGREGATE ENDOWMENT

By

Gary N. Meyer

2004

INTRODUCTION

The principal Quaternary mineral endowments in Crow Wing County are sand and gravel, potential sources for construction aggregate. Principal uses for aggregate are in concrete for buildings, bridges, and road pavement; in road base and fill; in bituminous road pavement; and lesser uses, including riprap and landscaping. Sand and gravel deposits in Crow Wing County are subdivided into three categories of aggregate potential on the basis of geologic attributes and physical properties of the mapped materials. Bedrock formations in the area are too deeply buried to be mined for aggregate. However, waste rock in iron mine dumps may be suitable for some construction applications.

The judgement of potential deposit quality is based predominantly on reconnaissance-level geologic information and interpretation. This study does not identify specific aggregate resources, which are defined in part on economic and societal criteria and concerns. Furthermore, this assessment does not mean that economic aggregate deposits exist everywhere within a given map unit; rather, the materials in each map unit were created by geologic processes that could have produced aggregate deposits at specific sites within the unit as mapped. Geologic endowment, although imprecisely measured, is fixed, whereas economic criteria and environmental regulations vary across time and place. Important site-specific factors such as land ownership, zoning, protected waters and wetland designations, environmental impact, required permits, distance to markets, royalties, and site access all contribute to the final "potential" of a specific parcel. These factors are outside the scope of this study.

DESCRIPTION OF MAP UNITS

POTENTIAL SAND AND GRAVEL SOURCES—These units typically exhibit geologic characteristics that indicate sand and gravel deposits may be present. Existing gravel pits and aggregate sources used by the Minnesota Department of Transportation within these units are identified or known resources. Geologic units that have the best potential for sand and gravel include outwash and ice-contact sediments (eskers, kames, and fans); they typically contain sorted sand and gravel with little silt and clay. The map units are classified by the thickness of sand and gravel, thickness of overlying deposits, percentage of material retained on the number 4 sieve (4.76-millimeter pore space), depth to the water table, and percentage of spall materials[1] (Table 1). Very good to good quality deposits generally contain less than 1.5 percent total spall materials. Good to moderate quality deposits generally contain less than 5 percent total spall materials. Gravel in moderate to poor quality deposits generally contain more than 5 percent total spall materials.

Primary sand and gravel deposits—Defined as having a sand and gravel thickness of 20 to more than 50 feet (6 to more than 15 meters); generally less than 5 feet (1.5 meters) of overburden; on average more than 20 percent of material retained on the number 4 sieve; depth to water table greater than 20 feet (6 meters); and are of very good to good quality. The probability that a sand and gravel deposit exists within this unit is very high to high.

Secondary sand and gravel deposits—Have a sand and gravel thickness ranging from near zero to more than 40 feet (12 meters); less than 10 feet (3 meters) of overburden; generally more than 15 percent material retained on the number 4 sieve; depth to water table greater than 10 feet (3 meters); and are of very good to moderate quality. The probability that a sand and gravel deposit exists within this unit is high to moderate.

Tertiary sand and gravel deposits—Consist primarily of sand and gravelly sand ranging from near zero to greater than 20 feet thick (6 meters); overburden no more than 20 feet thick (6 meters); generally less than 15 percent material retained on the number 4 sieve; water table from 0 to greater than 20 feet (6 meters) below the surface, and are of very good to moderate quality. The probability that a sand and gravel deposit exists within this unit is high to moderately low. Iron mine dumps are included in this unit.

LIMITED POTENTIAL FOR AGGREGATE SOURCES—The map shows that the remainder of Crow Wing County is underlain by geologic units that have little or no potential for significant aggregate resources. The units may, however, include local aggregate deposits that are too small to map or are unknown.

IDENTIFIED AGGREGATE RESOURCES—Areas where aggregate resources have been mined or are currently being mined. Pit locations have been gathered from aerial photographs, topographic maps, the county soil survey (Arneman and others, 1965), and fieldwork for this study.

Large gravel pit, or an area of more than one gravel pit or gravel-pit operation—The areas of larger pits shown on the map were primarily determined using aerial photographs from 1992; therefore some pit areas may be more extensive than portrayed. Aggregate resources may remain within some pits. Smaller pits are indicated only by the pit symbol. Inactive, depleted, and reclaimed pits are shown by a line through the pit symbol.

Gravel pit listed in the Aggregate Source Information System data base of the Minnesota Department of Transportation—Ancillary data may include test-hole logs, sieve data, test data on aggregate quality, and information drawn from U.S. Geological Survey 7.5-minute topographic quadrangles (Minnesota Department of Transportation, 2004). Inactive, depleted, and reclaimed pits are shown by a line through the pit symbol.

OTHER QUATERNARY MINERAL ENDOWMENTS

Clay—Clay deposited in Glacial Lake Brainerd (see Plate 3) was used in the past in Brainerd for the manufacture of brick (Nelson and others, 1990). However, due to undesirable carbonate content in the clay, texture variability, and accessibility issues, brick-making is not likely to resume in Crow Wing County.

Marl—Marl is composed largely of calcium carbonate dissolved from sediments and transported mostly by ground water to nearby lakes and bogs, where it is deposited through chemical and/or biochemical precipitation. In general, the lighter the color, the higher the calcium content of a marl deposit. Marl is used for improving soil for agriculture, and in the past was used in road construction. Crow Wing County has more than four times as many marl deposits as any other county in the state (Schwartz, 1959). Although not mapped in this atlas because they are generally concealed below peat, numerous marl deposits in the county are delineated in Schwartz (1959).

Peat—Mapped on Plate 3 (unit pe), peat deposits are widespread across the county. Peat is mined elsewhere in Minnesota primarily for horticultural purposes.

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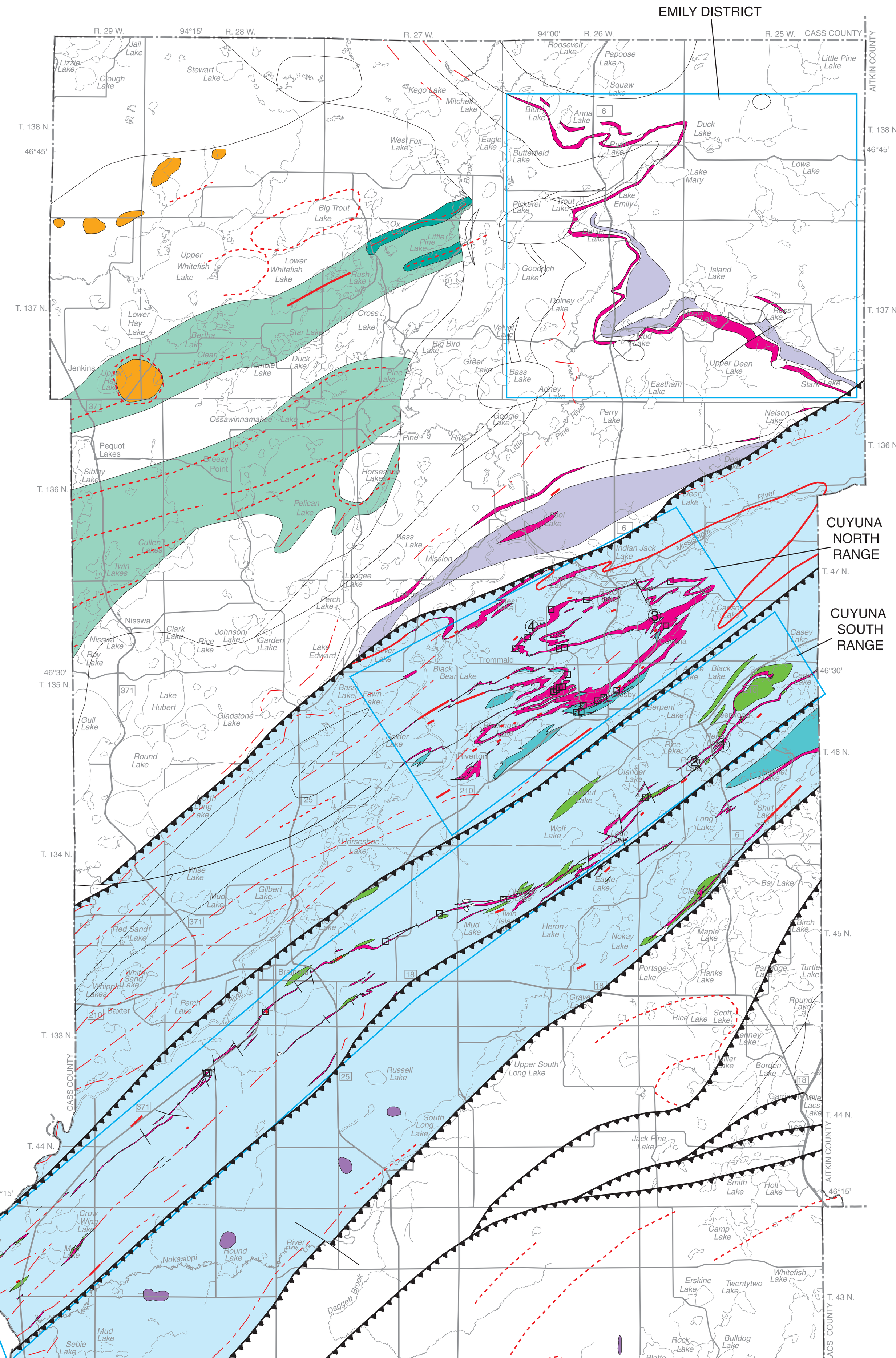
[1]Spall materials are rock particles that will cause a pop-out in hardened concrete or bituminous pavement. Maximum permissible spall materials allowed by the Minnesota Department of Transportation in coarse-grained aggregate for concrete used in highway construction, by weight percent of total sample, are: 0.7 percent shale, 0.3 percent soft iron oxide particles, and total spall materials (shale and iron oxide, plus unsound chert, coal, and clayey limestone) no more than 1.5 percent. Maximum permissible total spall materials in bituminous pavement is 5.0 percent.

Table 1. The potential for sand and gravel resources in Crow Wing County.

	Primary	Secondary		Tertiary	
sand and gravel thickness (feet)	20–50 or greater	0–40 or greater		0–20 or greater	
overburden thickness (feet)	less than 5	less than 10		less than 20	
retained on #4 sieve	greater than 20%	greater than 15%		less than 15%	
depth to water table (feet)	greater than 20	greater than 10		0–20 or greater	
probability	very high to high	high to moderate		high to moderately low	
total spall[1]	<1.5%	<1.5%	<5%	<1.5%	<5%
quality	very good to good	very good to good	good to moderate	very good to good	good to moderate



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

SCALE 1:200 000

5 0 5 10 MILES

5 0 5 10 15 KILOMETERS

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

BEDROCK ENDOWMENT

By

Terrence J. Boerboom

2004

INTRODUCTION

The bedrock endowment map highlights bedrock units that may host mineralization or attract the interest of explorationists, and the locations of the three main districts of the Cuyuna iron range. The map includes outlines of the bedrock geologic units from Plate 2, *Bedrock Geology*; see that plate for a complete description of the bedrock map units. The map also shows the locations of old mine shafts.

The mining shafts shown on this map are ones that could be located with some degree of confidence using historical maps and published reports. Not all shafts are shown, and the shafts that are shown are located with varying degrees of confidence. In particular, the location of the former Brainerd–Cuyuna underground mine, located at the southern edge of the city of Brainerd, is poorly constrained. The other shaft locations shown on the South range were located with the aid of historic maps on file at the Minnesota Geological Survey, and are mapped with more certainty. The locations of mine shafts on the Cuyuna North range were taken directly from those shown on maps by Schmidt (1963); these shafts may have been overrun by open-pit mines. The extent of the open-pit mines is mapped on Plate 2.

The Cuyuna iron range has long been subdivided into three separate areas—the Emily district, the North range, and the South range—based on contrasting lithologic and structural attributes of the iron-formation and associated rocks (Schmidt, 1963). The South range has been extensively explored, and ore has been extracted from a few underground mines from this area within Crow Wing County. The North range has been the focus of intense exploration activity, and several underground and open-pit mines operated there for a period of years. The Emily district has been thoroughly explored, but never mined.

HISTORY OF MINING ON THE CUYUNA IRON RANGE

The Cuyuna iron range is contained almost entirely within Crow Wing County. The range extends from west-central Aitkin County southwest through Crow Wing County into Morrison County, a distance of 65 miles (105 kilometers). The Cuyuna range produced iron ore for almost 80 years, during which time more than 106 million tons of iron ore were shipped (Skillings Minnesota Mining Directory, 2001). Production peaked in 1953, when the annual production was 3.9 million gross tons of ore (Schmidt, 1963).

The following history of the Cuyuna range is summarized from Schmidt (1963). The name Cuyuna is said to have come from a combination of the name Cuyler Adams, a pioneer of iron exploration on the Cuyuna range, and his dog named Una. The first indications of buried iron ore in the Cuyuna range were noted in 1859 by the deflection of survey lines recorded by land surveyors. The first systematic attempt to trace the lines of magnetic attraction produced by iron-formation was during the years 1875 and 1876, and again in 1882; a hole was drilled near Brainerd in 1893 without finding iron ore. In 1895, Cuyler Adams conducted extensive dip-needle surveys, and in 1903 iron was discovered by drilling in sec. 16, T. 46 N., R. 28 W. (number 1 on map). The first discovery of ore-quality iron was in 1904 in sec. 20, T. 46 N., R. 28 W. (2), in what is now referred to as the Cuyuna South range. That same year, drilling started on the North range in sec. 30, T. 47 N., R. 28 W. (3) near the Kennedy mine, and the first mine shaft to reach bedrock was constructed there in 1908. The first ore from the Cuyuna range was shipped by railroad from stockpiles at the Kennedy mine in 1911. The last ore was shipped in 1984, from the Zeno mine (sec. 28, T. 47 N., R. 29 W. [4]; Skillings Minnesota Mining Directory, 2001). Mining activity peaked between the years 1912 and 1914 when 32 mines were in operation, mostly in the North range, due to demand for manganiferous iron ore. In 1924, 41 miners were killed when mud and water flooded the Milford mine.

MANGANESE RESOURCES OF THE CUYUNA RANGE

Manganiferous iron-formation occurs in the Cuyuna North range, mainly in the Trommald Formation, in small lenses of iron-formation in the underlying Rabbit Lake Formation, and in the iron-formation of the Emily district. Beltrame and others (1981) estimated a minimum resource of 170 million metric tons of manganiferous ore with an average grade of approximately 10 weight percent manganese, and a more demonstrated resource of 9.1 million metric tons of manganese metal for the Cuyuna range.

POTENTIAL EXPLORATION FOR NON-FERROUS METALS

Outside of drilling targeted specifically at magnetic anomalies produced by the linear iron-formation layers in the Cuyuna range, very little exploratory drilling has been conducted in Crow Wing County specifically, and in all of east-central Minnesota in general. Overall, the fold-and-thrust belt area of east-central Minnesota (Plate 2, Fig. 1) has experienced only localized and sporadic exploration for mineral deposits other than iron and manganese. Nevertheless, some mineral potential may exist, as described below.

Paleoproterozoic mafic intrusions

Several small mafic intrusions of Paleoproterozoic age, recognized by distinctive, positive aeromagnetic anomalies, have been drilled by explorationists searching for diamonds in many of the counties surrounding Crow Wing County. To date, none of these sampled intrusions have been known to yield diamonds. They may be potential hosts for other types of mineralization, such as platinum-group elements or base-metal sulfides, and thus may be further explored. A few of these intrusions are inferred from aeromagnetic data to be present in southern Crow Wing County (unit Ꝑp), but none have been verified by drilling.

Archean rocks

The Archean supracrustal rocks in northwest Crow Wing County, with the exception of two or three drill holes along the eastern edge, are completely unexplored. Meager drilling data in and adjacent to the county, and extrapolation of known geology from outside the county by interpretation of aeromagnetic data, imply that a substantial portion of these rocks are comprised of metavolcanic rocks typical of Archean greenstone terranes (units Agm and Amv) that may contain iron-formation. It is known from drill core that, at least locally, the greenstone units contain hypabyssal mafic intrusions (unit Ag). Collectively these inferences imply that the greenstone belts contain a geologic complexity typical of other well-exposed greenstones in Ontario and northern Minnesota, and may at some point be examined by explorationists for indications of potential mineral deposits. Likewise, the aeromagnetically inferred mafic intrusions (unit Ami) may attract exploration interest as analogues to Archean mafic intrusions in Ontario, which are known to host mineralization of platinum-group elements.

CRUSHED ROCK AGGREGATE

With the possible exception of rock contained in waste dumps adjacent to open-pit mines, there is no potential for any bedrock-derived aggregate in Crow Wing County due to the thick cover of glacial deposits.

Waste-rock tailings from the Mesabi Iron Range in northeastern Minnesota have been used on a limited basis for crushed-rock aggregate applications, and testing has shown that they may be suitable for more widespread use (Zanko and others, 2003). However, the Mesabi range tailings are already crushed to a suitable size as part of the ore-concentrating process, are readily available in large quantities, and possess physical properties that meet aggregate test standards. In contrast, waste rock from the Cuyuna range is of mixed composition, consisting dominantly of variably weathered, soft, phyllitic and schistose rocks. A thorough study of the waste dumps on the Cuyuna range was not conducted for this project because of the small chance of encountering suitable material. However, these waste piles cannot be completely dismissed as an aggregate source, and they may present opportunities as a local aggregate source for specialized aggregate needs.

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DESCRIPTION OF MAP UNITS AND SYMBOLS

Plate 2 contains a complete description of the map units.

PALEOPROTEROZOIC

Bedrock unit Ꝑp—Small ultramafic intrusions.

Bedrock unit Ꝑvs—Carbonaceous argillite, locally pyritic.

Iron-formation, undivided.

Sedimentary rocks of the Cuyuna North and South ranges.

Bedrock unit Ꝑdu—Subvolcanic mafic intrusive rocks in the Cuyuna South range. Probably more abundant than indicated on map.

Bedrock units Ꝑvm and Ꝑrv—Mafic volcanic rocks, largely fragmental. Probably more abundant than indicated on map.

ARCHEAN

Bedrock unit Ami—Mafic intrusions.

Bedrock unit Ag—Subvolcanic gabbroic rocks.

Bedrock units Amv and Agm—Mafic volcanic rocks; includes possible iron-formation and subvolcanic mafic intrusive rocks.

Limited potential for bedrock resources—The unshaded portions of the map indicate areas underlain by bedrock units that have little or no potential for significant minerals exploratory activites based on current knowledge and models of mineralization.

Location of mine shaft.

Inferred fault.

Inferred thrust fault.

Iron-formation inferred from linear aeromagnetic anomalies.