Report for Project 380

Assessment of Sand and Gravel and Clay Deposits in Parts of Northern St. Louis and Lake Counties

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Minnesota Department of Natural Resources

Division of Lands and Minerals

Assessment of Sand and Gravel Potential and Silt and Clay Potential Resources in Parts of Northern St. Louis and Lake Counties

Produced by the Minnesota Department of Natural Resource's Aggregate Resource Mapping Program, Division of Lands and Minerals.

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TABLE OF CONTENTS

Cover photograph: An exposure of boulder-rich outwash deposited sediment in Section 30-T61N-R13W, near Arthur Lake, St. Louis County, MN. This exposure is approximately 20 feet in height, see shovel for scale.

LIST OF FIGURES AND TABLES

ACKNOWLEDGEMENTS

The Department of Natural Resources, Division of Lands and Minerals gratefully acknowledges funding for this project from the Minerals Coordinating Committee. The successful completion of this project was the result of contributions from many people. Concrete Aggregate Lithological Exam quality testing of samples was made possible by a cooperative agreement with the Minnesota Department of Transportation sponsored by Glenn Engstrom. The Tower, MN office of the Department of Natural Resources provided radios, ATVs, and trail condition information. Carrie Jennings of the Minnesota Geological Survey shared pertinent information in addition to reviewing the final plate. Phil Larson provided insight and shared ideas regarding the regional depositional environment. J.D. Lehr offered his perspective on the genesis and distribution of local Rogen moraines in addition to sharing field observations regarding the regional glacial geology. The Hibbing, MN office of the Department of Natural Resources provided field support and conducted sieve analyses on samples. The author wishes to express her gratitude for the technical support and assistance received from the Department of Natural Resources Mineral Potential Section work group, especially Heather Arends, during all phases of this project.

SUMMARY

This report, and the associated plate, summarizes the results of a reconnaissance-level sand and gravel resource evaluation conducted in all or parts of 20 townships encompassing the Duluth Complex copper+nickel deposits in northern St. Louis County and Lake County, MN. Sand and gravel deposits and silt and clay deposits were mapped at a 1:50,000 scale, while the resulting plate is displayed at a scale of 1:63,360.

Beginning in August 2009, the author examined existing geologic records and information such as drill logs, well logs, gravel pit records, relevant maps, theses, and aerial photographs. Field work in Fall 2009 and Spring 2010 documented the following:

- 805 field observations
- 36 test holes
- 207 gravel pits
- 10 sand pits
- 6 borrow pits
- 4 quarries

Sand and gravel potential was assessed using seven characteristics: surficial geology features, predominant sediment description, probability, sand and gravel thickness, overburden thickness, areal extent of deposit, textural characteristics, and quality. Mapped units were assigned one of four potential classifications, high, moderate, low or limited. Units with high and moderate classifications have significant sand and gravel potential. For this project, mapped units with significant sand and gravel potential are typically associated with proglacial outwash and ice contact features.

The quality of sand and gravel varies throughout the project area. Predominant lithologies in the sand and gravel are influenced by the type of underlying bedrock, glacial sediment thickness, and glacial lobe provenance. During field work, 73 samples were collected and processed for sediment size distribution. Quality tests were performed on 12 samples by the Minnesota Department of Transportation (Mn/DOT). Generalized assumptions were made based on test results, field observations and correlations with the final sand and gravel assessment:

- Deposits of the Superior lobe generally are higher in quality
- Near surface bedrock is more likely to be represented and incorporated into sand and gravel, therefore the greater the depth to bedrock, the less it is represented in the sediment
- Disintegrating clasts are a quality issue within this area

This project was funded by the Minerals Coordinating Committee and the assessment was conducted by the Minnesota Department of Natural Resources, Division of Lands and Minerals (MN DNR). The potential for aggregate made from crushed stone was not done for this project because of anticipated availability of crushed stone from future mines and the variability from site to site of the many bedrock lithologies in the area.

<u>**INTRODUCTION**</u>

The purpose of this project is to identify and classify potential sand and gravel construction aggregate resources within a region of copper+nickel deposits in northern Minnesota. Construction materials will be needed to develop infrastructure of potential mines and to support development in the surrounding communities. Clay has also been identified as a needed resource, for the purpose of geotechnical applications such as liners for stockpiles. This report summarizes the project's field observations, geologic relationships, and mapping results related to sand and gravel distribution and quality.

Extensive planning and design processes are required to obtain permits for metallic mineral mines, which include many land easements or considerations for roads, trails, power lines, pipelines, mine portals, facilities and tailings impoundments. The associated map (Attachment A: Plate) provides sand and gravel resource information to land owners, local governments, and all parties to facilitate the wise use of these important local resources.

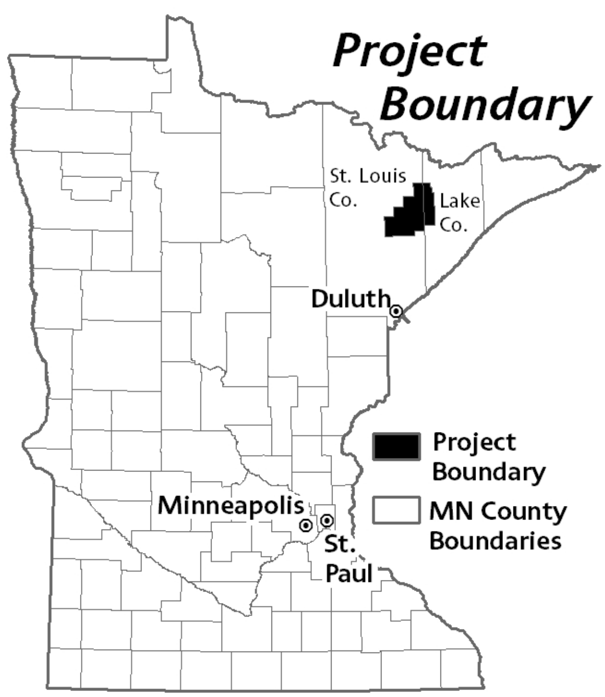

Figure 1: Location of project area.

The project area is located in portions of northern St. Louis and Lake Counties (Figures 1 and 2) and spans all or part of 20 townships. Locally available, low-cost construction aggregate is fundamental to building and maintaining public infrastructure as well as private sector development. This region was identified as a probable zone of rapid growth where additional aggregate resources will likely be required. The results of this project will support regional planning and zoning decisions, aid in infrastructure development, and minimize transportation distances between pits and end-users. In order to accomplish these goals, a comprehensive dataset and report has been prepared, including a plate (Attachment A) showing potential sand and gravel deposits.

Factors related to aggregate resource availability, usability, and supply include but are not limited to: transportation costs, quality of the material, and land-use conflicts. Aggregate materials are high-bulk, low-value commodities, so transportation costs can account for a considerable amount of the delivered price. A local supply of aggregate translates to lower costs for publicly and privately funded projects. Aggregate products, such as concrete and asphalt, have specific quality requirements depending on the end use.

This project represents a reconnaissance-level survey of sand and gravel resources. Site-specific evaluations are still necessary prior to any development of a particular site. Factors such as ownership, zoning, protected waters and wetlands, environmental permitting, and other individual site characteristics are not part of the geological resource data summarized here.

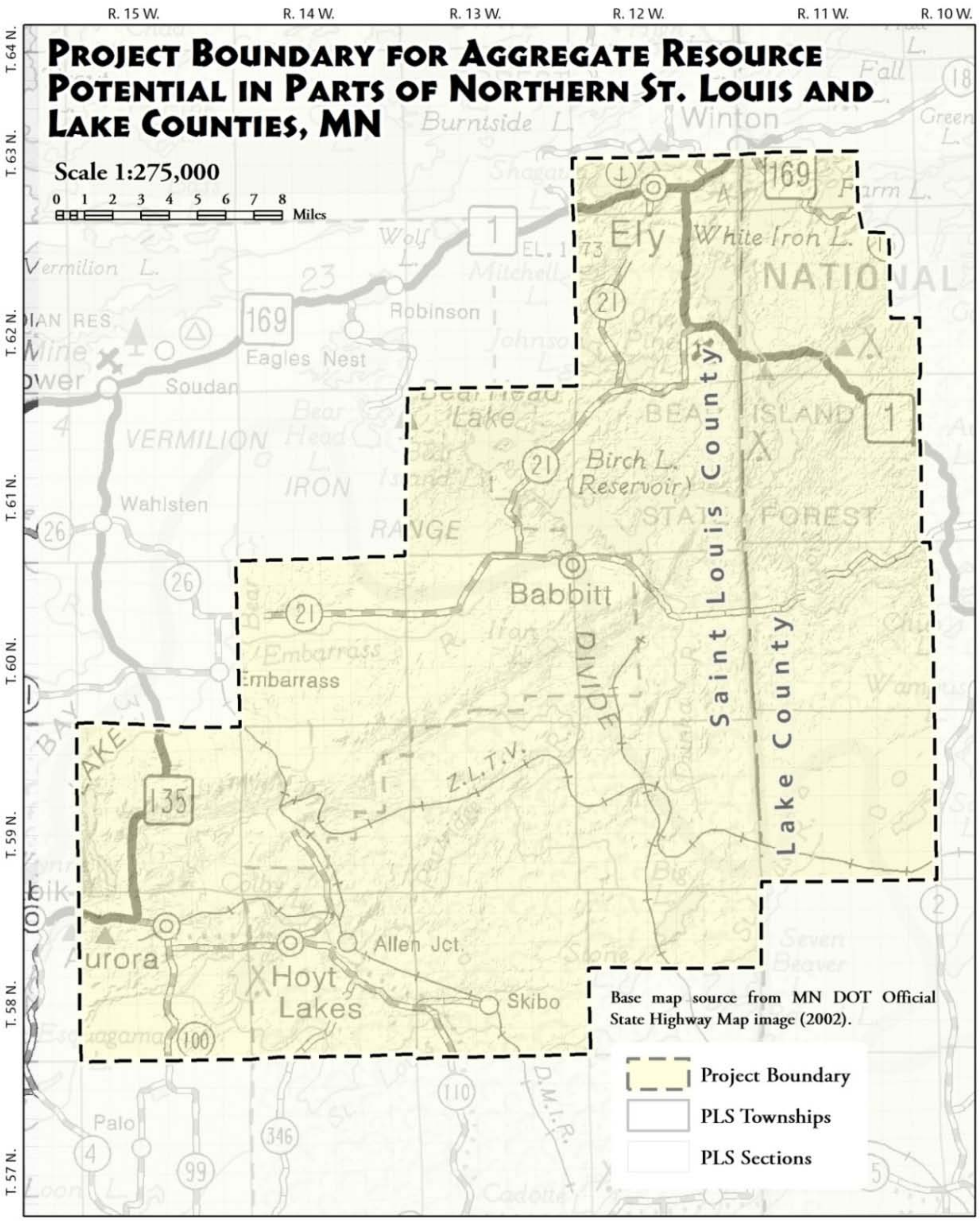

Figure 2: Project area at a scale of 1:275,000.

REGIONAL GEOLOGICAL SETTING

Bedrock Geology

As summarized by Jirsa (2005) and Miller *et. al.,* (2001 and 2002), this region of northern Minnesota is underlain by Mesoproterozoic (Keweenawan) rocks (ca. 1100 Ma) of the Duluth Complex in the southeast and Archean (>2500 Ma) Giants Range Batholith of the Wawa subprovince of the Superior Province to the north and west. In the southwest, Paleoproterozoic sedimentary rocks from the Animikie Group, including the Biwabik Iron Formation, were originally deposited unconformably on Archean Giants Range granitic rocks. Archean rocks of the Superior Province consist mainly of belts of metavolcanic and metasedimentary rocks (greenstone belts) and granitic rocks. The Duluth Complex is a multiply-intruded igneous suite of rocks associated with the Midcontinent Rift. The sedimentary Animikie Group was deposited during the Penokean Orogeny and is variably metamorphosed. The Biwabik Iron Formation (1900 Ma.) was metamorphosed at its eastern extent by the intrusions of the Duluth Complex (1100 Ma.).

The distribution of the generalized bedrock types used in this reconnaissance-level project are shown in Figure 3. This project focuses on the major bedrock contact dividing the project area (marked by dashed line) between the Duluth Complex ("gabbroic" bedrock) and the Giants Range Batholith ("granitic" bedrock).

The north-south border of the southwest edge of the project area (black line) delineates the boundary between R15W-R16W. The boundary is significant because taconite tailings obtained from ore deposits east of that line (the entire project area) cannot be used as crushed stone in aggregate products or Type 61 Aggregate (Mn/DOT specification 3139.3a2).

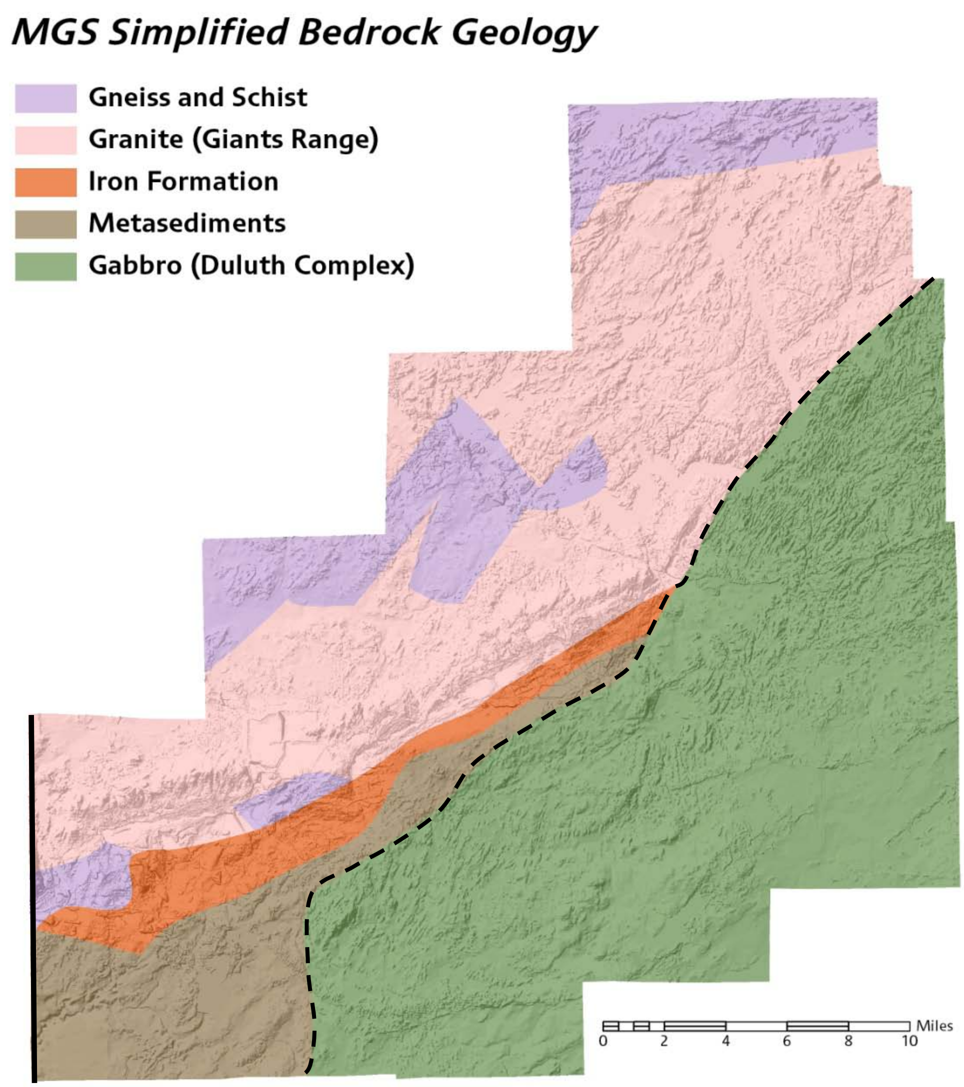

Figure 3: Bedrock geology modified from MGS M-119 "Geologic Map of the Duluth Complex and Related Rocks" (2001).

Glacial Geology

Large continental glaciers covered the project area during much of the Pleistocene Epoch (2.5Ma-12000). These glaciations left behind two general categories of materials: ice-deposited sediment and meltwater deposited sediment. One of the main project goals was to identify and classify the materials deposited by meltwater. The project area consists of mostly near surface bedrock mantled by sandy till with zones of outwash and low lands that were occupied by glacial lakes.

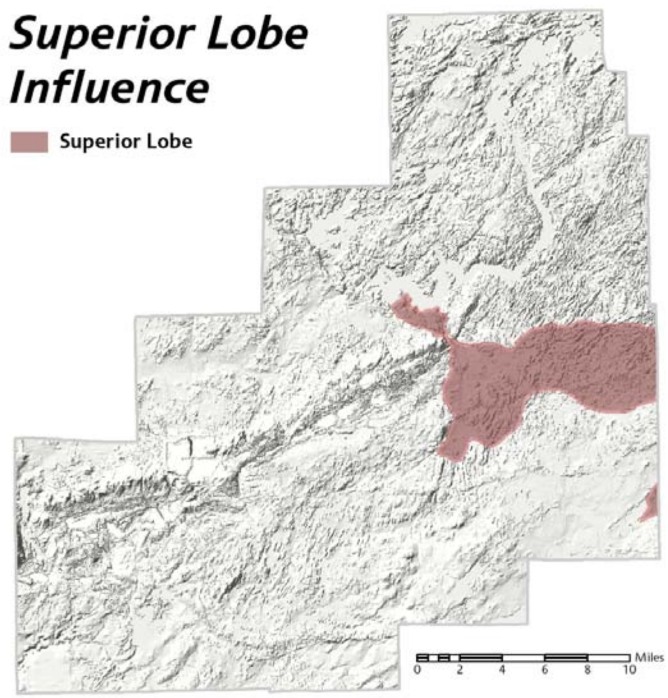

Figure 4: Approximate distribution of Superior lobe outwash.

Surficially, there is evidence of two glacial lobes in the project area: the Rainy lobe and the Superior lobe. While there were many older glacial advances across the project area, the remnant tills deposited during these previous episodes are either buried or rarely remain as surficial deposits. The Rainy and Superior lobes advanced and retreated repeatedly during the Pleistocene, sometimes contemporaneously. The Rainy lobe traversed the entire project area depositing sediment; the resulting orientation of glacial landforms reflects a general northeast to southwest ice flow direction. The Rainy lobe deposited landforms such as recessional moraines, ground moraine, outwash sediments and ice contact features. Moraine features are primarily composed of till, which is unsorted sediment derived from subglacial erosion and entrainment deposited directly by a glacier. The Superior lobe advanced parallel to the Rainy lobe, but to the southeast of the project area. As a result, no Superior lobe till was observed within the project area. However, Superior lobe meltwater was channelized and drained westward from the eastern edge of the project area, depositing sorted sediments ranging from fine sand to gravel (see Figure 4). Superior lobe sediments generally have characteristic North Shore Volcanic Group provenance clasts. This bedrock type is found to the northeast of the project area.

Several surficial geology and aggregate mapping sources were referenced in the creation of the plate. Jennings and Reynolds (2005) created MGS Miscellaneous M-164, Mesabi Iron Range Surficial Geology (1:100,000) which was used as landform reference in areas of overlap. A review of the Pleistocene Geology of the Embarrass Area, St. Louis County Minnesota, (Lehr, 2000) was used as supplemental documentation of deposits influenced by the Superior lobe. Further documentation of Superior lobe deposits was sourced from MN DNR Report 262 (Bucheit and others, 1989). Another source of regional glacial geologic information was a large-scale glacial geomorphology plate and fieldtrip guidebook created by Lehr and Hobbs (1992). Some esker locations were correlated with a map of esker deposits in northeastern Minnesota (Eng, 1985). The USGS produced "Surficial Geology, Mesabi Vermillion Iron

Range, Northeastern Minnesota" (Winter and others, 1973, 1:125,000) which was used as an overview of the distribution of outwash sediments.

METHODOLOGY

The MN DNR Aggregate Resource Mapping Program (ARMP) integrates traditional geologic mapping techniques (e.g., fieldwork and drilling) with computer software programs like Geographic Information Systems (GIS). This project focused on aggregate resources, specifically sand and gravel, with a lesser emphasis on silt and clay deposits. Crushed stone resources were not included within the project's scope.

Aggregate mapping is accomplished in ARMP through three phases of work. 1) Gathering and compilation of existing data, 2) Fieldwork that ground verifies existing data and obtains new data, and 3) Integration and interpretation of existing and new datasets (including aerial photographic interpretation of landforms).

Data Compilation

The first step in the ARMP mapping process entailed conducting scientific literature and data searches in order to obtain a basic understanding of the regional geology. The data used were: aerial photographs, topographic maps, digital elevation models, shaded relief maps, subsurface logs, gravel pit and quarry locations, surficial and bedrock geology, and soils. The locations of lakes, streams and wetlands were reviewed, as were datasets featuring the distribution of roads as well as PLSS township, range, and section boundaries.

The County Well Index (CWI) database and the Aggregate Source Information System (ASIS) were the most frequently referenced subsurface geologic datasets for constructing a sand and gravel resource map. The CWI is an online database (www.health.state.mn.us/divs/eh/cwi) developed and maintained by MGS (Minnesota Geologic Survey) and the Minnesota Department of Health. These resources contained basic information for over 300,000 wells drilled throughout Minnesota. Approximately 1452 of these wells were located within the project area. The majority of these well logs contain geologic descriptions. Wells were queried for sand and gravel within the upper fifty feet of every well log.

ASIS is a dataset compiled and maintained by Mn/DOT consisting of aggregate quality data, sand and gravel sieve analysis, and pit sheets displaying the descriptions of shallow test-hole logs and diagrams of test-hole locations. This information refers to specific sites that Mn/DOT tested during the approximate period 1930-2000. Subsurface information was important in identifying buried sand and gravel deposits, determining the depth of bedrock, and identifying the type of bedrock encountered.

Before fieldwork began, gravel pit locations were identified and compiled from sources available for the region. Compiled sources of information resulted in multiple records for a single gravel pit. Duplications were reduced to a single point representing a pit by prioritizing gravel pit records into a hierarchy of data sources (listed in order of priority): ASIS data, topographic maps, field work, soil survey data, and aerial photographs. Some ASIS pits were repositioned based on the location information displayed on pit sheets and resolved with respect to pit locations observed on aerial photographs. The following gravel pit attributes were recorded: size of gravel pit (small=0-5 acres, medium=5-15 acres or large=15+ acres), thickness of the deposit, thickness of overburden, depth to water table, dominant lithology, status (active, inactive or reclaimed), gravel pit name (if applicable) and additional comments pertinent to the gravel pit. Not all pits were accessible and many pits were gated prohibiting access. If a pit was not directly observed, but the site was listed as a gravel pit by one or more of the data sources, it was inferred to contain sand and gravel.

After the data was compiled, a preliminary resource assessment was completed by interpreting the geologic landforms observed in aerial photographs. Regional characteristics and other evidence were used to predict the sediment characteristics within these apparent glacial landforms. These predictions were then field verified.

Field Work

Field work was conducted during Fall 2009 and Spring 2010. After preliminary aerial photograph interpretation, several weeks were spent driving every accessible road within the project boundary by auto or ATV. Hiking trails were also used for walk-in access to more remote roadless areas. The objective of this reconnaissance-level field work was to identify sand and gravel-bearing landforms, to examine exposures of glacial sediment, and to locate gravel pits for correlation with meltwater deposits interpreted from aerial photographs. Gravel pits confirmed the presence of gravel in the landform and provided stratigraphic views of a deposit, which helped with interpreting the depositional environment of the sediment. Other types of exposures observed included road cuts, stream cuts, trails, construction projects, and animal burrows. Test holes were drilled to examine subsurface sediment distribution, to understand the depositional environment of the landform, and to further define sand and gravel deposits. Test hole depths varied from 2 to 16 feet.

Sampling Method: Samples were collected for quality testing and sieve analysis using a shovel or a drill auger. Channel samples were collected from exposures using a shovel. Surficial material was first scraped off to reveal a fresh exposure before vertical channels were sampled at regular intervals across the width of the exposure to capture sediment variability. For example, three vertical channel samples were taken at 10 foot intervals across a 30 foot exposure. Samples were also collected using a truck mounted drill with a 6 inch auger. Material was taken from regular depth intervals of the test hole to create a representative sample for a given location. Every effort was made to take a representative sample from the width and depth of an exposure or test hole. However, a single exposure or test hole sample is not necessarily representative of the overall quality or texture of the entire deposit.

Quality Assessment

Clast durability is a key consideration for any potential aggregate resource. Spall material is the terminology used by Mn/DOT to describe undesirable rocks or minerals in sand and gravel. Sand and gravel quality was described through qualitative field observations of the durability of the common pebbles and through quantitative tests on samples collected and submitted to Mn/DOT. The sample and test data provide the beginning of a general framework to identify the range of the quality of materials in this project area.

A total of 73 samples were collected and analyzed. The sample size ranged from 30 to 60 pounds. All collected samples were processed for sediment size distribution by MN DNR. Mn/DOT performed coarse aggregate complete lithological exams for concrete (also referred within this report as quality testing) on 12 of the 73 samples. Samples selected to for quality testing were chosen based on their proximity to copper+nickel deposits and by the lack of existing Mn/DOT quality data.

Sand and Gravel Data Compilation and Interpretation

Field data was combined with existing data and the dataset was used to identify sand and gravel resources using geologic mapping techniques. Aerial photographs and subsurface data were used to map glaciogenic sediments and their constituent landforms. These maps enabled inferences to be made regarding potential sand and gravel resources within the various geologic units. The sand and gravel resources were classified using a glacial mapping technique known as the landsystems approach (Eyles, 1983). This technique relies on the principle that glacial landforms contain a predictable range of sediments, from sorted sand and gravel, to silt, clay, and till. Using the landsystems approach, identifying sand and gravel-bearing landforms becomes the basis for delineating aggregate potential.

Aerial photographs aided with interpreting landform characteristics, such as color, texture, shape, size, size trends, and patterns. These characteristics helped in determining the type of material deposited. For example, a particular type of vegetation might prefer well-drained soils, such as sand and gravel, and have a distinctive texture, tone, or pattern in aerial photographs. Sand and gravel bearing features such as eskers, terraces, outwash channels, as well as other meltwater features can be located using this technique. An important consideration in applying this approach to this project was the presence of near-surface bedrock. Glacial landform interpretation was generalized in areas that had irregular bedrock topography. Where bedrock data did exist, such as the MGS bedrock outcrop dataset, it assisted in differentiating between bedrock dominated landforms and glacially-derived landscapes. MGS outcrop locations were not field verified.

Aerial photographs were supplemented with other datasets and layered using GIS software. Other supplemental datasets include: topographic maps (USGS 1: 24,000), digital elevation models (DEM), shaded relief maps, subsurface data, field observations, location and distribution of existing pits, and soil surveys. From the compiled datasets sand and gravel bearing features were identified and then sand and gravel potential was delineated. Mapping units were delineated at a scale of 1:50,000.

Mine lands associated with iron mining were not assessed in this project due to their inaccessibility. Sand and gravel landforms in areas of iron mining are commonly stripped to access underlying bedrock, modified, or covered with rock and stockpiles.

DEFINITION OF SAND AND GRAVEL POTENTIAL

Sand and gravel potential is defined as an estimation of relative probability that a sand and gravel deposit exists within a given mapping polygon. In this assessment only geologic criteria were used. Economic and environmental criteria vary depending on location and applicable land use restrictions and therefore are not considered in this evaluation of sand and gravel potential. Thus, the emphasis of this investigation was placed upon interpretation of geologic evidence at the reconnaissance level, rather than upon economic or cultural considerations. This assessment does not imply that economic sand and gravel deposits exist everywhere within a map unit designated as "Potential Sand and Gravel Resources." Rather, within such a map unit, known geologic processes could have created sand and gravel deposits at specific sites or as part of the landform within the polygon. While site-specific factors such as ownership, zoning, protected waters and wetlands, sensitive or protected environments, permitting, distance to markets, royalties, and access, all contribute to the feasibility of mining specific parcels, these factors are not considered in this reconnaissance-level project.

MAPPING CLASSIFICATIONS

Sand and Gravel Resource Classification

The classification of sand and gravel deposits is based on seven geologic characteristics (Table 1, Plate): surficial geology features (geologic landform), predominant sediment description, the probability or certainty that sand and gravel exists, the thickness of sand and gravel, the thickness of overburden, areal extent or size of the deposit, the texture of sand and gravel, and finally the quality of sand and gravel. These seven characteristics are described here including definitions, examples, and where applicable, distributions within the project area. The combination of these characteristics classifies the potential of sand and gravel deposits existing within a mapping unit.

Surficial Geology Features: Is a description of different landform types identified in the project area. An important criterion for delineating sand and gravel is identifying and classifying the landscape into a suite of landforms and determining if these landforms contain sand and gravel. Within the project area 11 landform types have been classified: alluvial valley, beach, glaciofluvial feature, ground moraine, ice contact feature, lake plain, linear ridges, outwash channel, outwash feature, outwash terrace, and recessional moraine.

Report 380: Sand and Gravel Potential Classification Table[1]
In Parts of Northern St. Louis & Lake Counties, MN

Characteristics	SIGNIFICANT RESOURCES		NONSIGNIFICANT[2] RESOURCES	
	High Potential	**Moderate Potential**	**Low Potential**	**Limited Potential**
Surficial Geology Features	Glaciofluvial feature; outwash channel; outwash feature; ice contact feature	Ice contact feature; linear ridge; recessional/ ground moraine; outwash terrace, channel, feature	Outwash features; alluvial valley; lake plain; recess-ional/ground moraine; ice contact; linear ridge; beaches	Alluvial valley; bedrock; lake plain; outwash channel feature; recessional/ground moraine; glaciofluvial feature
Predominant Sediment Description	Sand and gravel	Till, sand and gravel	Till, sand, sand with gravel	Till, silt, sand, bedrock
Probability[3]	Moderately high to very high	Moderate to high	Low to moderately low	Very low to low
Sand and Gravel Thickness[4] (in feet)	10-50+	0-45+	0-40+	0-15+
Overburden Thickness (in feet)	0-5	0-15	0-45+	0-35+
Sand and Gravel Deposit Size (areal extext)[5]	Moderately large to very large (10-30+ acres)	Moderate to moderately large (10-20+ acres)	Moderately small to small (1-10 acres)	Very small to small (0-10 acres)
Sand and Gravel Textural Characteristics[6]	Good to very good	Moderate to good	Poor to moderately poor	Very poor to moderately poor
Sand and Gravel Quality[7]	Moderately high to very high	Moderate to high	Moderately low to low	Very low to moderately low

Footnotes associated with sand and gravel resource potential table

[1] Table excludes classification of silt and clay potential.

[2] Nonsignificant: Term representing 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.

[3] Probability: The degree of certainty that aggregate exists within a mapping unit largely defined by the amount of available information.

[4] Thickness Variability: The thickness of a deposit may range from 0 to stated value due to the presence of bedrock outcrops or lateral discontinuation of the deposit.

[5] 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.

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

[7] 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 the historic data.

Table 1. Classification matrix used to determine the potential for sand and gravel deposits relative to this project area.

Predominant Sediment: Is a general assessment of the type of sediment observed at several locations within a single mapping unit. Within the project area, predominant sediments range from unsorted till to sorted sand and gravel. Although a landform can consist of many different sediments, this broad characterization captures the predominant sediment type associated with the landform. Figure 5 shows the predominant sediment, sand and gravel, with a mantle of red-brown clayey till. This illustrates how a landform that mostly consists of one predominant sediment type can also contain minor occurrences of other sediment types. Information about predominant sediment is gathered in the field through documentation of field observations. The relationship between landforms and predominant sediments is a useful tool to extrapolate interpretations into areas with limited data.

Figure 5: Red line delineates the contact between red-brown clayey till mantle above the predominant material, sand and gravel.

Probability: Is a measure of certainty or confidence that sand and gravel exists within a mapping unit. The more characteristics known about a mapping unit (Table 1), the higher the probability assigned to the mapping unit. Probability is one of three characteristics (probability, textural characteristics, and quality) within the sand and gravel classification matrix that uses a relative scale. The degrees of the scale include: very low, low, moderately low, moderate, moderately high, high, and very high.

Areas with gravel pits, field observations, water wells, and other information are designated as high on the probability scale. Whereas areas with no data or comparative information, (e.g., identifiable landforms associated with known sediments), the relative probability will be low. Lack of accessibility, and therefore unknown field observation information, results in lowered probability that sand and gravel exists within a mapping unit.

Sand and Gravel and Overburden Thickness: Is an approximation of the observed thickness or projected thickness of sand and gravel deposits and overburden. Overburden is defined as the sediment that lies above economic sand and gravel. The ratio between sand and gravel thickness and overburden thickness is called the stripping ratio which is an indicator of the feasibility of mining a deposit. For example, a 20 foot thick deposit of sand and gravel with 5 feet of overburden is more likely to be mined than a deposit having 25 feet of overburden. Each mapping unit has an estimated thickness of sand and gravel expressed as a range. A range of 0-20+ feet of sand and gravel within a landform indicates variability where the landform can contain no sand and gravel to greater than 20 feet of sand and gravel. Every effort is made to accurately quantify thickness as observed in the field and in water well information.

Areal Extent: Is an approximation of the size of a sand and gravel deposit within a mapping unit. Areal extent is expressed as a scale:

- Very small= less than 1 acre
- Small=1-5 acres
- Moderately Small= 3-10 acres
- Moderate= 5-10 acres
- Moderately Large= 10-15 acres
- Large= 10-30 acres
- Very Large= 30+ acres

This is an estimation of the size of a sand and gravel deposit within a landform, not the size of the landform itself. This size range is based on sand and gravel deposits observed in the field. Ground moraines tend to have deposit sizes ranging from very small to moderately small whereas outwash features have deposit sizes ranging from small to very large. When describing sand and gravel as isolated pockets this is an indication of a small areal extent.

Sand and Gravel Textural Characteristics: Is a general approximation of the sediment size distribution. Texture is a relative description relating to the amount of gravel within a deposit. Mn/DOT specifications and aggregate industry standards define gravel as anything larger than 4.76mm (#4 sieve) but smaller than 76.1mm (3 inch sieve). The values for textural characteristics are relative from very poor, poor, moderately poor, moderate, moderately good, good, and very good.

An example of poor texture is clayey till with rocks. An example of good texture is sediment consisting of sand and gravel with greater than 30% by weight gravel content. This scale is meant to be a comparative attribute among different deposits, sediment types, and landforms. Sieve analysis was conducted on 73 samples to determine sediment size distribution and percent gravel content.

Sand and Gravel Quality: Is based on both qualitative and quantitative data. Field observations are the primary source of qualitative data and are based upon soft, non-durable clast lithologies and other spall observed within a deposit. Quality is a relative range from very low, low, moderately low, moderate, moderately high, high and very high. Deposits that include clast lithologies from granitic sources and North Shore Volcanic Group sources generally rank higher in quality than bedrock sources from metasedimentary and gabbro units. When available, quantitative data is incorporated into quality rankings. Quantitative data includes sediment size distribution from samples, quality test results from Mn/DOT ASIS pit sheets, and lithological analysis on selected samples (see Figure 10).

Silt and Clay Resource Classification

Silt and clay resources were delineated separately from the sand and gravel assessment. First, landform-sediment associations were used to identify large, probable areas containing silt and clay sediments deposited by large glacial lakes. Secondly, field work further refined resources. Field observations were used to describe thickness of silt and clay-bearing deposits and qualitatively estimate lacustrine deposits with relatively higher clay content. Smaller deposits were not extrapolated from landform-sediment associations due to the variability of clay content in Rainy lobe tills and isolated lacustrine sediments. One smaller deposit was delineated based on the presence of an existing clay pit. Silt and clay potential was mapped independently from sand and gravel potential and is presented as an overlay or another layer of resource data where potential exists.

Economic versus Geologic Factors

The haul distance cost from a deposit to its end-use may be the most important factor in determining the economic feasibility of using a given aggregate resource. Some deposits classified as low potential can be locally significant for reasons such as proximity to road projects, the potential of blending with other materials to meet specifications, or if it can be used in specialty applications. Aggregate potential can change due to variable, site-specific circumstances involving transportation costs. Consequently, the economics relating to transportation can supersede geological factors used to classify sand and gravel deposits. The purpose of the geological classification system used here is to map and qualify the physical characteristics of sediments spanning a relatively large area at a reconnaissance scale.

RESULTS

The results of this project are available as a plate (see Attachment A) as well as GIS datasets (see Attachment B). The GIS datasets include spatial and tabular information about field observations, surveyed pits and quarries, sand and gravel potential, and the silt and clay potential overlay. Tabular datasets include ASIS quality and sieve database.

The plate is displayed at 1:63,360 scale however the data was captured at 1:50,000 scale. Plate elements include the classification matrix (Table 1), a conceptual cross-section depicting various geological depositional settings observed in the project area, and an abbreviated legend.

Both GIS data and PDFs of the plate are available for download on the ARMP website (http://www.dnr.state.mn.us/lands_minerals/aggregate_maps/index.html). GIS data can also be viewed on the website without requiring GIS software. The site features a web-based mapping program, Aggregate Mapper, which allows users to interact with aggregate resource data displayed on digital topographic maps, aerial photographs, and DEMs.

Expanded Legend of Mapping Units

The map legend on the plate has abbreviated descriptions of sand and gravel potential, identified resources, and field observations. The descriptions below further define these mapped features and represent the expanded legend for the plate.

Sand and gravel potential results are divided into two main categories: significant and nonsignificant potential. Significant potential represents mapping units consisting of higher quality sands and gravels that are generally thick and areally extensive with little to no overburden. These mapping units have high or moderate potential for containing sand and gravel. Nonsignificant sand and gravel potential represents mapping units that either consist of little to no sand and gravel of large areal extent, areas dominated by near surface bedrock, have limited data associated to the mapping unit, or sand and gravel is buried at depth. Nonsignificant resources include mapping units with low or limited or unknown potential.

Significant Sand and Gravel Potential		Nonsignificant Sand and Gravel Potential	
High Potential	Moderate Potential	Low Potential	Limited Potential

Significant Potential for Sand and Gravel Resources: Geologic units are inferred to contain sand and gravel resource potential. These units exhibit geological characteristics that typically correlate with sand and gravel resources. Existing gravel pits and Mn/DOT sand and gravel sources (identified or known resources) within these units indicate a high level of confidence for the mapping unit.

> <u>HIGH POTENTIAL FOR SAND AND GRAVEL RESOURCES:</u> Glaciofluvial features, outwash channels, outwash features, and ice contact features. Within these features sand and gravel is the predominant sediment. The probability that a potential sand and gravel resource exists within any mapping unit is moderately high to very high. Thickness of the deposits ranges from 10-50+ feet with less than 5 feet of overburden. These

features are moderately large to very large in areal extent and the textural characteristics are good to very good. The quality is moderately high to very high.

MODERATE POTENTIAL FOR SAND AND GRAVEL RESOURCES: Outwash channels, outwash features, outwash terraces, recessional and ground moraines, linear ridges, and ice contact features. Predominant sediment ranges from sand and gravel to sand with gravel to sandy till. Cobbles and boulders are common in this classification within the project area. Isolated pockets of sorted sand and gravel exist within ground moraine. The probability that a potential sand and gravel resource exists within this unit is moderate to high. Deposit thickness ranges from 0-45+ feet with less than 15 feet of overburden. Variations in bedrock topography such as bedrock outcrops in moderate potential units create wide ranges in thickness of sand and gravel features. These features are moderate to moderately large in areal extent and the textural characteristics are moderate to good. The quality is moderate to high.

Nonsignificant Potential for Sand and Gravel Resources: Geologic units that generally have little or no potential for significant sand and gravel resources or lack sufficient data to support a classification of significant sand and gravel resources. These units typically contain clay, silt, fine sand, unsorted sediments (till), very thin layers of sand and gravel, or buried sand and gravel (+20 feet of overburden). Such units may include sand and gravel resources that are too small to map (<10 acres).

LOW POTENTIAL FOR SAND AND GRAVEL RESOURCES: Outwash channels, outwash features, outwash terraces, recessional and ground moraines, linear ridges, alluvial valleys, lake plains, beaches, and ice contact features. Predominant sediment varies and can include sand, sand with gravel, or sandy till. The probability that a potential resource exists within this unit is low to moderately low. Buried deposits, where identified, are assigned Low Potential, rather than Limited Potential, because a resource exists. The inclusion of buried deposits increases the overburden thickness range of Low Potential category within Table 1 as compared to Limited Potential. Thickness of the deposits ranges from 0-40+ feet with overburden thickness ranging from 0-45+ feet. These features are small to moderately small in areal extent and the textural characteristics are poor to moderately poor. The quality ranges from low to moderately low.

LIMITED POTENTIAL FOR SAND AND GRAVEL RESOURCES: Outwash channels, outwash features, recessional and ground moraines, lake plains, alluvial valleys, and glaciofluvial feature. Deposits of this unit contain one or more of the following, clay, bedrock outcrops, sand, silt and/or organics. The probability that a significant sand and gravel resource exists within this unit is very low to low. The thickness of these deposits is typically less than 10 feet but can range from 0 to 15+ feet with overburden thickness ranging from 0 to 35+ feet. Since mapped units can include near surface bedrock and bedrock outcrops, the range of overburden thickness can be less than higher potential classes. The sand and gravel resources occurring in this unit are very small to small in areal extent. The textural characteristics are very poor to moderately poor with the quality ranging from very low to moderately low. A Limited Potential rating includes the circumstance where characteristics are unknown and there was insufficient data, such as no access and no obvious landform-sediment association.

Silt and Clay Resource Potential: Geologic units that are inferred to contain silty clay sediment. These units exhibit geologic characteristics that may generate clayey sediment resources or are modified from silt and clay bearing landforms. Units typically contain clayey till or silty clay lacustrine sediments with possible thin beds of fine sand.

SILT AND CLAY POTENTIAL RESOURCES: Lake plains, ground moraines, beaches, and low areas within outwash features. Predominant sediment varies and can include clayey till or silty clay. Potential is quantified as being near or at the surface with less than 10 feet of overburden and a thickness of greater than 5 feet.

Identified Sand and Gravel Resources: Locations where sand and gravel have been or are currently being mined. Several sources of information identify gravel mine locations: topographic maps, aerial photographs, soil surveys, MGS field mapping sites, Mn/DOT files, fieldwork, gravel operators, and other miscellaneous sources. Gravel mines range in size from less than 1 acre to greater than 30 acres and may be active, inactive, or reclaimed. The sand and gravel quality of the mines varies. A limited number of quarries exist in the project area. A report by Oberhelman (1991) was sourced for the location and description of an active dimension stone quarry. Topographic maps were used for determining the locations of the historic quarries. The distribution of all identified resources is illustrated in Figure 9.

PITS AND QUARRIES: (n=227) Gravel pits (207), sand pits (10), borrow pits (6), and quarries (4) were documented in the project area. In the field, 150 pits and quarries were directly observed. The remainder were verified by historical records and cross referenced with aerial photographs. Pit and quarry attributes include: source, type, size, thickness of material, overburden, water table depth, status, dominant lithology, dominant texture, and description. Sources of pits include ASIS, soil survey, field work, and topographic maps. Types of the pits include: gravel, sand, or borrow. Types of the quarries were dimension stone and unknown. The areal extent of the pit, size and thickness of material and estimated thickness of overburden are attributes necessary to define potential. Status refers to the activity of the pit; is it currently being mined or has it been reclaimed, and if so to what degree. ARMP documents dominant lithology as which glacial lobe influenced the landform rather than dominant clast type. This project area was either influenced primarily by the Rainy lobe or by both the Rainy lobe and Superior lobe (in the form of outwash). Dominant texture and the description lend more information that aids in assessing potential.

Field Observations: (n=841, includes test holes) Surficial geologic sediment, glacial stratigraphy, and bedrock formations were logged as 841 field observations during Fall 2009 and Spring 2010. Test holes accounted for 36 of the field observations. Field observation attributes include: site type, material observed, field description, thickness of material, overburden, and if the material is sampled. Examples of site types include: road cuts, stream exposures, trails, construction excavation, and animal holes. Primary material and, if applicable, secondary material observed are documented. Field observations were taken within some gravel pits and sand pits where additional data needed to be collected, such as variability of texture and quality. These field observations are not shown on the map because of their proximity to the Gravel Pits and Sand Pits symbols at the scale of 1:63,360.

Test Holes: (n=36) Test holes were drilled to verify the presence or absence of sand and gravel. A Giddings probe with a 6 inch auger was used. The frequency of boulders and coarse sediment made drilling difficult within this region. Although 36 sites were drilled, the average depth of a test hole was 5.5 feet and the range of depths varied from 1 foot to 16 feet. Field observations documented test hole and attributes were recorded.

Landform-Sediment Associations and Resource Potential

As previously mentioned, eleven landform types were observed and condensed into five major categories. The distribution of landforms containing resource potential depends on glacial processes. Major features that affected ice-marginal processes include the Giants Range which is an Archean granitic ridge that rises up to 500 feet higher than surrounding elevation, and large glacial meltwater channels. Major geomorphic features referenced in this section are illustrated in Figure 6.

The five major landforms observed in the project area include: outwash features, ice contact features, moraines, lacustrine sediments, and alluvial valleys. All five features contain varying potential for containing a sand and gravel resource. These landforms are described in terms of how the landforms were deposited, the range of sediments associated with the landforms, the distribution within the project area, and how the landforms relate to sand and gravel resource potential. Landforms are listed from significant to nonsignificant potential highlighting specific sand and gravel deposits. Deposits of silt and clay are associated with lacustrine features as well as isolated deposit of clay within an outwash feature.

Outwash Features: Includes channels, terraces, and glaciofluvial features. These landforms consist of sediment sorted and deposited by glacial meltwater. Sediments within outwash features range from stratified to massive beds of sands, gravels, cobbles, and boulders. Sand and gravel deposits within outwash features have the largest variability in size and thickness from small pockets of sorted material to broad proglacial outwash valleys. Outwash features are distributed throughout the project area from small isolated pockets to large well-formed features.

Sand and gravel deposits are abundant within this suite of landforms. In the region where bedrock is near surface (see Plate: Figure 1, Setting 3), sediment is generally coarser; and interpreted as an ice proximal depositional environment. Large volumes of meltwater generated enough transport energy to move cobbles and boulders. The photograph on the cover of this report depicts boulder-rich sediment deposited by outwash immediately in front of the Vermilion Moraine, near Arthur Lake (Figure 6, A).

The glacial history of the area indicates that the present-day Kawishiwi River and Birch Lake occupy large subglacial meltwater channels which funneled meltwater away from the Rainy lobe. The meltwater flowed to the southwest and deposited sediment that ranged from silt to cobbles. One such sand and gravel deposit is located on the south shore of the South Kawishiwi River (Figure 6, B). The Embarrass Gap, a breach within the Giants Range, channelized meltwater flow as a glaciofluvial outlet depositing large amounts of outwash in the Aurora area. The level of Glacial Lake Norwood was regulated by the downcutting of the Embarrass Gap but varied between 1475 and 1450 feet (Lehr and Hobbs 1992).

The Dunka River outlet also channelized meltwater. Stark (1977) speculated that the outlet of the Dunka River acted as a probable proglacial tributary to the Embarrass River valley, draining through the narrow gap in the Giants Range (near Babbitt, south of Birch Lake). Water draining through both the Embarrass and Dunka River outlets resulted in thick and areally extensive sand and gravel deposits. Some of these areas are capped with bedded silts and clays deposited from subsequent glacial lake formation.

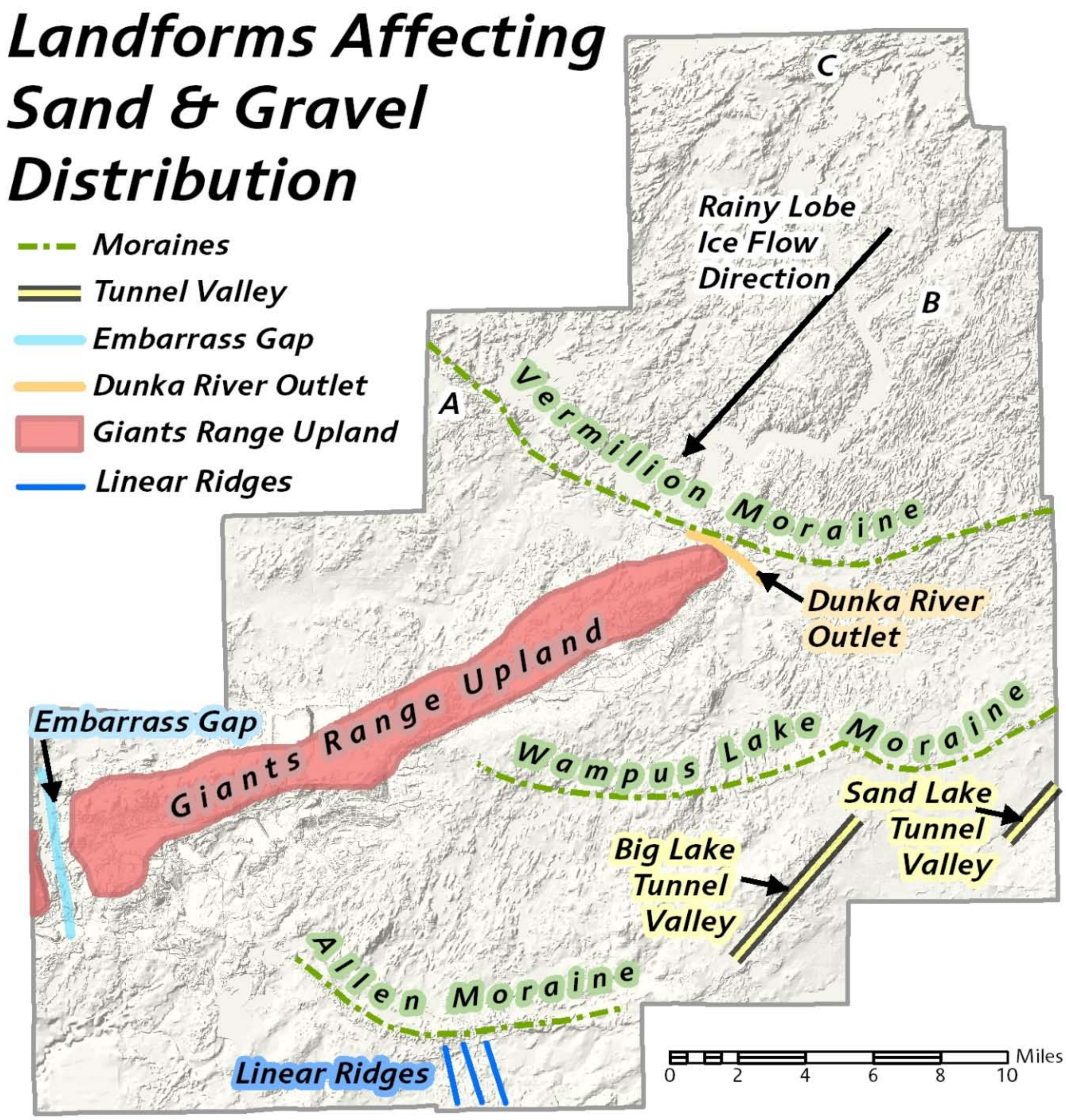

Figure 6: Landforms affecting sediment deposition. See the text explanation for the connection between these features and the sand and gravel deposits, such as A, B and C.

Sand and gravel with thick overburden is delineated and noted as buried deposits within the correlating GIS dataset (CD-ROM). Other sources for outwash include proglacial outwash aprons near glacial margins and related to recessional moraines. These landforms contain both significant and nonsignificant resources; however, they yield some of the largest sand and gravel deposits observed in the project area.

One identified deposit of clay has been mined southwest of Ely in Section 36-T63N-R12W, adjacent to a large sand and gravel deposit. Verbal communication with an area forester confirmed the existence of a clay pit that was used for a geotechnical purpose. The deposit is within a region dominated by outwash sediment. Other areas of silt and clay could exist but were not observed in this reconnaissance-level survey.

Ice Contact Features: Includes eskers, kames, and ice-walled lake plains. Ice contact features form in or adjacent to active and stagnant ice. Eskers and kames are glacial meltwater streams that flow either on top of, within, or below glacial ice. When the ice melts the resulting landforms are ridges or mounds of sorted sediment, respectively. Ice walled lake plains form as lakes bounded by glacial ice, resulting in flat topped hills that can contain sand and gravel. Proximity to glacial ice and variable velocity of meltwater creates a range of possible sediment sizes from silty fine sands to cobbles with some boulders. Ice contact features occur as continuous deposits to isolated pockets of sand and gravel. Ice contact features are distributed throughout the project area.

Sand and gravel deposits are abundant within this suite of landforms. The texture of ice contact features is usually stratified sands and gravels with cobbles. Ice contact features are chiefly associated with recessional moraine depositional environments and are generally moderate in size. However, two exceptions are located in the northern half of the project area. A kame-esker complex (see Figure 6, C) is one of the thickest and areally extensive sand and gravel features within the project area. This complex covers approximately 650 acres and ranges in thickness from 10 to 60+ feet. Another areally extensive ice contact feature is located underneath the Ely Municipal Airport and extends north and south from the airport. Conversely, this deposit is bedrock cored and yields significantly less gravel because the thickness is less consistent and ranges from 0 to 50+ feet. Sand and gravel is actively being mined from both of these large deposits.

Two tunnel valleys associated with Big Lake and Sand Lake in the southeast corner of the project area were labeled low potential because they were inaccessible. Since probability was low, the potential rating for these landforms remains low. Ice contact features are generally moderately sized and probable sources for significant sand and gravel potential.

Moraines: Includes ground moraine, bedrock outcrops within ground moraines, recessional moraines, and linear ridges. Ground moraine is a term used to identify plains of till deposited by glacial ice. This includes areas dominated by bedrock topography with a thin discontinuous mantle of till. Recessional moraines form at the margin of a glacier and are often identified by linear arcuate ridges of unsorted and sorted sediment. In the south central region of the project area, linear ridges were observed. These landforms have been previously described as Rogen moraines (Lehr, 2000). Sediments associated with moraines range from silty clay to large boulders. Moraines are the most abundant landform, have the largest areal extent, and are distributed throughout the project area.

Sand and gravel deposits can exist within these landforms as either pockets of sorted sand and gravel within till or as very sandy till that may be suitable for use as Class 5 sand and gravel. In the east central project area significant sand and gravel deposits exists in both the Vermillion and Allen recessional moraines and are classified as moderate aggregate potential. Figure 7 shows a gravel pit in the Vermillion Moraine. Also, some ground moraines have been modified by glacial meltwater which

Figure 7: Gravel pit in recessional moraine. Shovel circled in red for scale.

reworked the till and redeposited it as sorted sediment. Therefore these landforms consist of the largest variability of sediments within the project area. Since texture can be dependent on localized sorting, the size of deposits is variable from very small to medium (<1-15 acres) and generally occurs as discontinuous pockets. These landforms contain both significant and nonsignificant sand and gravel potential.

Lacustrine Features: Includes lake plains and beaches. Ponding of water creates lacustrine features, lake plains are generally laterally extensive landforms with little relief while beaches (or strandlines) are smaller features with gradual relief around the perimeter of lake plains. Lake plains consist mostly of sorted clay, silt, fine sand, gravel, till and organic material. Till occurs within this landform as isolated, resistant highlands. Beaches consist of silty clay to well sorted fine sands to coarse gravel and cobbles. Although the most predominant beach sediment is fine sand, an exception exists in the southwestern corner of the project area where a wave-washed delta redeposited pre-existing sands and gravels. This area represents the only significant sand and gravel deposit associated with lacustrine features.

The same major topographic features that directed and prevented the flow of meltwater also affected the deposition of clay. Former glacial lake plains are the region's largest source for silt and clay materials (Figure 8). In the extreme southwest corner of the project area, glacial lake levels fluctuated and a modified beach contains silt, clay, and sand. Two large lake plains were delineated; one north of the Giants Range and one south of the Giants Range. To a lesser extent, minor lake plains exist in front of and behind recessional moraines. As the regional topographic high, the Giants Range influenced ice flow and constrained movement of meltwater resulting in glacial lakes (Lehr and Hobbs, 1992). Within the project boundary, Glacial Lake Norwood is an example of ponded meltwater north of the Giants Range. The lake level ranged between 1450-1475 feet and was bounded to the north and east by ice, to the south by the Giants Range, and to the west by ice and high land (Lehr and Hobbs, 1992). Much of the area between the Vermillion Moraine and the Giants Range is mantled by glaciolacustrine sediment due to the persistence of a proglacial lake documented in field observations and further substantiated by Larson and Mooers (2009). South of the Giants Range, meltwater drained to the south. Despite predominant meltwater drainage away from the Rainy lobe in this region, there is evidence of meltwater ponding south of the Giants Range. These ponded regions are smaller in areal extent compared to Glacial Lake Norwood. An example of a smaller ice marginal lake basin south of the Giants Range is Glacial Lake Dunka. Sediments deposited in the Dunka River basin are generally stratified glacial outwash sand with zones of gravel deposited on top of glaciolacustrine silts and clays. Glacial Lake Dunka drained north through a gap in the Giants Range near Babbitt and into Glacial Lake Norwood (Stark 1977).

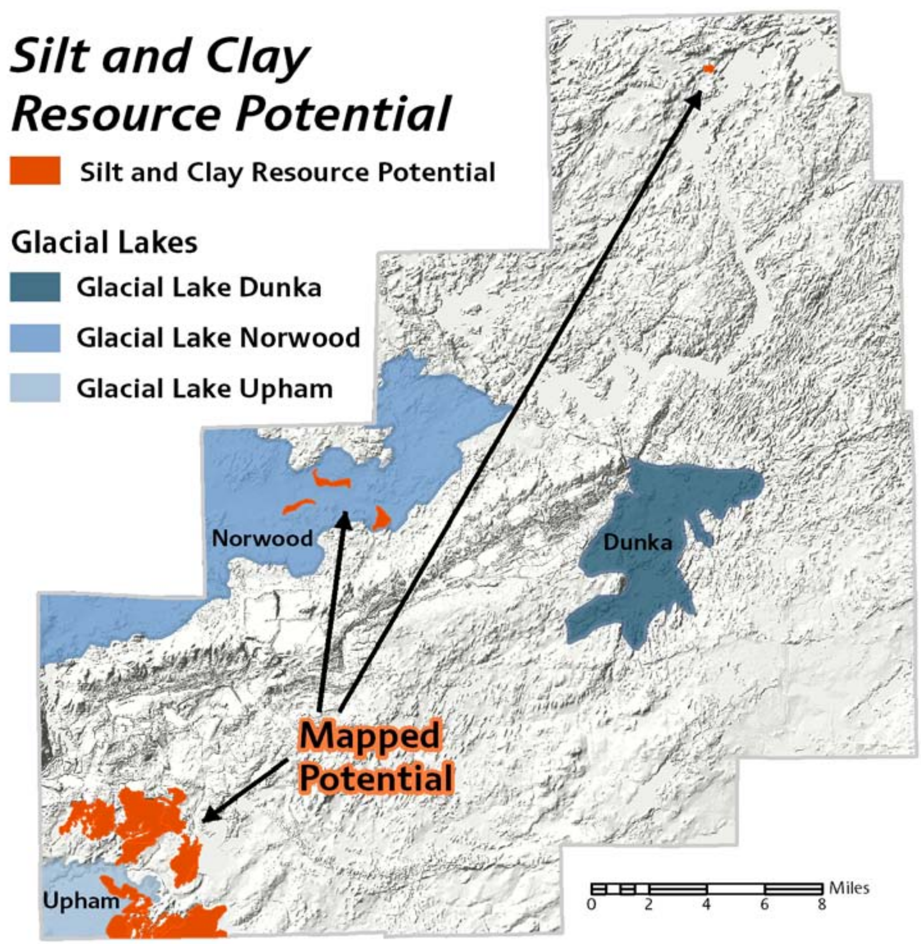

Figure 8: Mapped silt and clay resource potential overlaps some areas identified as former glacial lakes. Modified marginal glacial lake areas were also sources of potential.

Alluvial Features: Occurs as modern streams and rivers. They tend to form in pre-existing glacial meltwater channels or are controlled by bedrock topography. Sediments consist of very well sorted silts and sands as well as organic debris. Boulders were also observed within alluvial streams and rivers and were interpreted as proximal to a bedrock source or from winnowing of glacial till and outwash. Alluvial features were captured and delineated in areas where recent erosion and deposition were observed at the mapping scale. These features are distributed throughout the project area.

Sand and gravel deposits associated with alluvial features tend to be small, finely textured, and contain organic sediment. With exception of alluvial valleys flowing over outwash deposits, no significant sand and gravel deposits were observed in association with alluvial streams and rivers.

Accessibility and Distribution of Data

Portions of the project area were remote with limited access by roads or trails. Other areas were inaccessible due to active mining. Consequently, the lack of accessibility made it difficult to field-verify possible deposits (Figure 9) and resulted in diminished confidence in some areas. This resulted in a lower potential classification. Several examples within the project area demonstrate how access affects potential classification. The Big Lake and Sand Lake tunnel valleys in the southeast quadrant have diminished potential due to inaccessibility. Portions of these landforms possibly contain sand and gravel. Since they are located in inaccessible areas, the probability of sand and gravel was mapped as low, which decreased the overall potential classification. Another inaccessible landform in the southeast corner of the project area is a recessional moraine west of Fools Lake and north of Lake Culkin (the Wampus Lake Moraine). Outside of the project area, gravel pits are located within the eastern extension of the Wampus Lake Moraine. Within the project area, sand and gravel was not observed where this landform was accessible, instead several observation points established till as the predominant sediment within the moraine. Although this landform contains pockets of sand and gravel probability was lowered due to the presence of till. Finally, near-surface bedrock, common throughout the project area is irregular and the thickness of glacial sediments is unpredictable. Where supporting data is lacking, (e.g., field observations or CWI wells), and aerial photographs and topographic signatures are inconclusive, sand and gravel potential is diminished and generally relegated to limited potential where extensive near-surface bedrock occurs. While sand and gravel deposits could exist in these areas, there were no indications or evidence of their existence. In areas where field observations could not be collected, interpretations of aerial photographs, topographic signatures, and regional soil surveys were relied upon to assess sand and gravel potential.

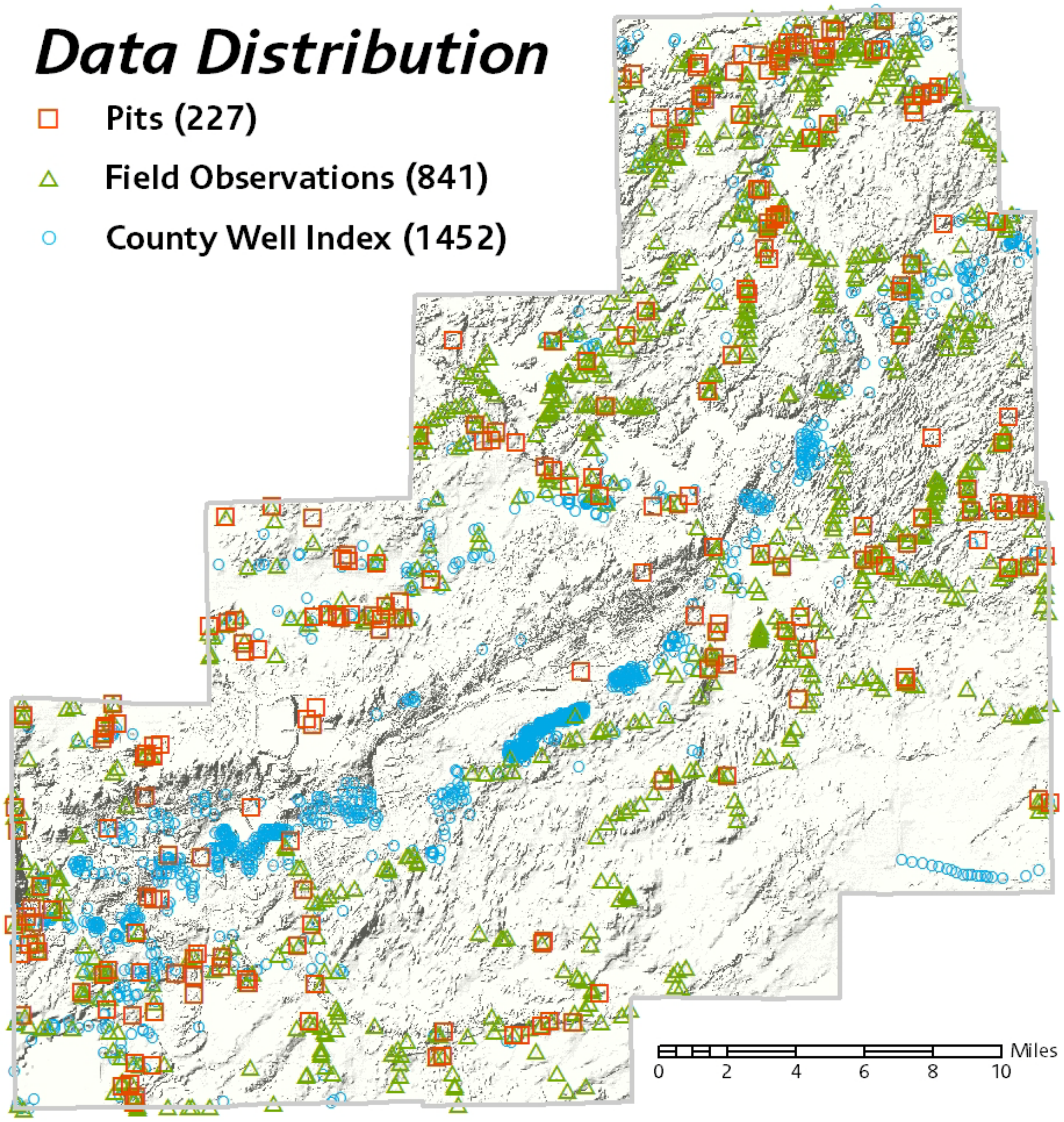

Figure 9: Distribution of pits, field observations, and CWI well logs.

Sample Test Results

All 73 samples were processed for sediment size distribution and 12 samples were selected for additional quality testing. Sediment size distribution analysis was conducted by the MN DNR and recorded in the sieve database (which is included in the CD/ROM as report380_sieve.dbf). Mn/DOT conducted Concrete Aggregate Lithological Exams on 12 samples (see Figure 10 for distribution of samples). Results are summarized in Table 2. The Mn/DOT lab test reports are in Appendix A.

For illustrative purposes the sediment size distribution data of 12 samples are plotted against Mn/DOT's typical requirements for Class 5 material (see Appendix B). These are only general guidelines that are useful for planning. Specific testing, if necessary, should be done for each deposit. After crushing the values will be slightly different because larger rock particles (>1 inch) will be incorporated into the smaller sizes. Also note that particles larger than 4 inches are not included.

Sample Number	Bituminous Specifications		Class 5 Specifications		Geological Attributes		
	% Total Spall (<5%)	**% Disintegrating Rock (<5%)**	**% Gravel (20-65%)**	**% Silt (3-10%)**	**Glacial Lobe Influence**	**Landform**	**Underlying Bedrock Type**
38	0.7	25.8	44	3.0	Rainy/Superior	Outwash Feature	Duluth Complex
198	0.4	4.0	38	12.4	Rainy	Ice Contact Feature	Granitic
244	1.4	19.1	43	12.9	Rainy	Recessional Moraine	Duluth Complex
262	3.3	14.2	26	11.9	Rainy	Ground Moraine	Duluth Complex
287	0.3	0.0	26	3.3	Rainy/Superior	Ice Contact Feature	Duluth Complex
324	0.2	3.1	41	8.0	Rainy	Outwash Feature	Duluth Complex
347	0.9	1.0	29	4.9	Rainy/Superior	Ice Contact Feature	Duluth Complex
573	3.1	0.7	28	5.3	Rainy	Outwash Feature	Duluth Complex
594	0.0	0.9	7	7.3	Rainy/Superior	Ice Contact Feature	Duluth Complex
822	0.4	8.5	17	7.2	Rainy	Ice Contact Feature	Duluth Complex
824	0.4	49.3	21	28.8	Rainy	Recessional Moraine	Duluth Complex
853	1.0	11.3	44	5.6	Rainy	Ice Contact Feature	Duluth Complex

Table 2. Results for 12 quality tested samples including: weight percent spall and weight percent disintegrating rock from Mn/DOT Concrete Aggregate Lithological Exam with bituminous specifications listed in parentheses (Mn/DOT 3139.2), sediment size distribution results from gradation analyses with Class 5 specifications listed in parentheses (Mn/DOT 3138-1), and correlating geological attributes. Grey highlighted values do not meet Mn/DOT standards for corresponding bituminous specifications or Class 5 specifications (Mn/DOT Standard Specifications for Construction, 2005). Mn/DOT concrete standards for both spall and disintegrating rock are 1.5% (3137.2).

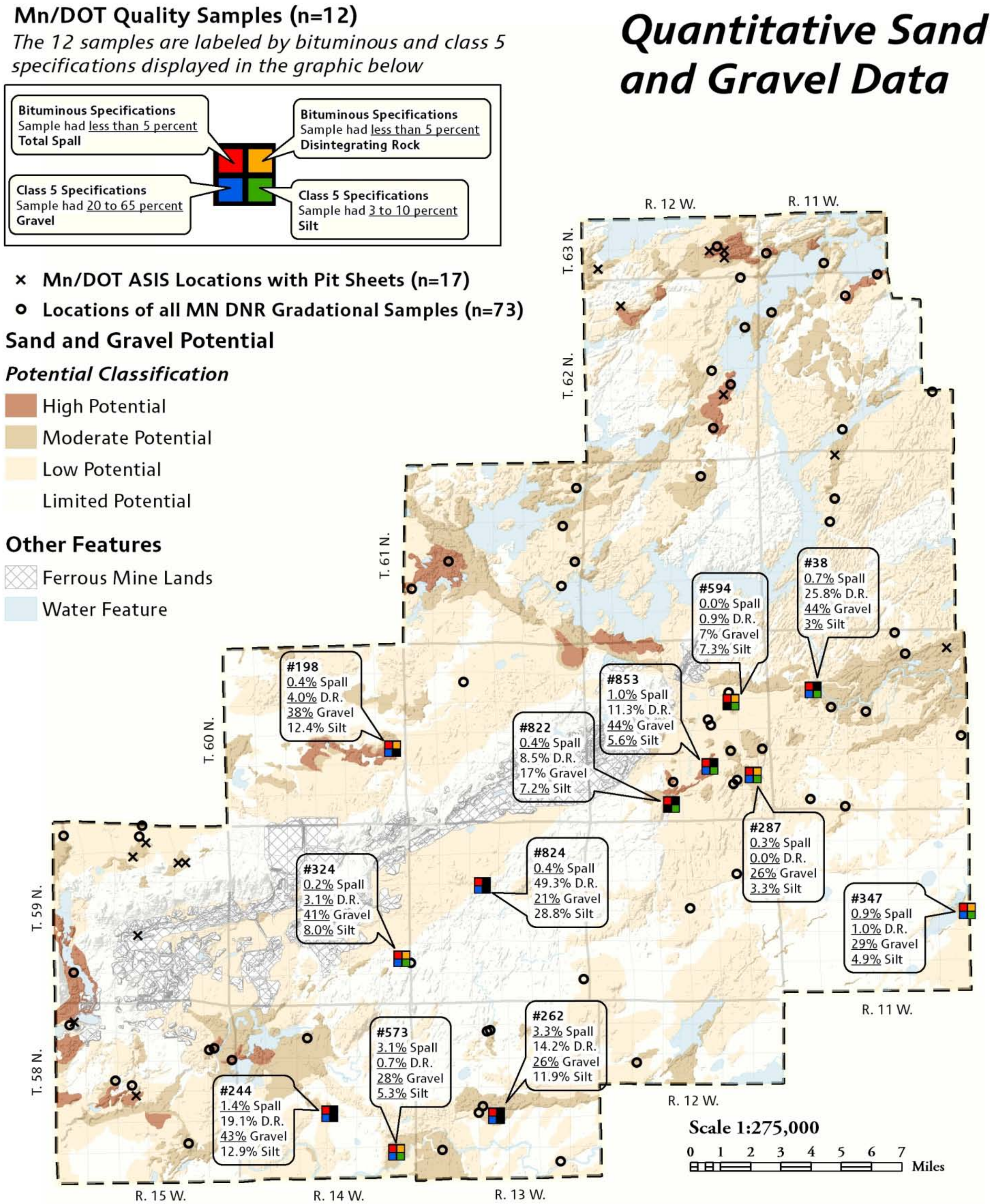

Figure 108: Quantitative sand and gravel data including locations of: Mn/DOT ASIS pit sheets, MN DNR sediment size analysis samples, and quality tested samples with associated results. Block diagram represents number of Mn/DOT standards met; bituminous specifications were used for spall and disintegrating rock amounts and Class 5 specifications were used for gravel and silt amounts. Mn/DOT concrete standards for both spall and disintegrating rock are 1.5% (3137.2).

DISCUSSION

The quality of a sand and gravel deposit is dependent on many attributes including: sediment size distribution, spall, disintegrating rock, and dominant clast lithologies. The dominant clast lithology of a deposit can be dependent on bedrock type, glacial sediment thickness or depth to bedrock, and glacial lobe influence. Samples were evaluated on the following characteristics to determine trends: relative degree of bedrock influence and glacial sediment thickness, glacial lobe influence, and landform type. Since silt and gravel content can vary throughout a deposit and are dependent on geological processes, sediment size distribution was evaluated based on landforms rather than correlations with bedrock influence, glacial sediment thickness, and glacial lobe influence.

Bedrock Influence: As mapped by MGS (Figure 3) a major bedrock contact divides the project area; granitic bedrock in the west and the Duluth Complex in the east. One of the samples (198) overlies the granitic bedrock and the remaining eleven overly the Duluth Complex (Table 2). The sample taken in the granitic bedrock region has relatively high but still acceptable amounts of disintegrating rock. However six of the eleven samples taken from the Duluth Complex region (38, 244, 262, 822, 824, and 853) exceeded the allowable amount of disintegrating rock. Bedrock type could have a direct correlation to percent disintegrating rock. All of the samples had acceptable amounts of total spall; the two highest values (Samples 262 and 573) were taken from the Duluth Complex bedrock region. Field observations indicate that samples from the granitic bedrock region tend to be more durable than samples taken from the Duluth Complex region and the one test sample verifies this assumption.

Glacial Sediment Thickness (Depth to Bedrock): North of the Vermillion Moraine, bedrock is at or near the surface. Surficial sediment thickness ranges from 0-25 feet thick. South of the Vermilion Moraine bedrock outcrops are still fairly common but surficial thicknesses can reach 100+ feet in the Embarrass River Basin and 40+ feet in the Dunka River basin. Thickness of sediment is also 40+ feet thick in the area of former Glacial Lake Upham. The depth to bedrock for the most southerly samples (Samples 244, 262, and 573) ranged between approximately 60 feet to 100 feet. Disintegrating rock results for these samples are 19.1, 14.2 and 0.7, respectively. Total spall results for these samples are 1.4, 3.3, and 3.1, respectively. This southerly sample set includes the two samples with the highest spall amounts.

Generalized clast lithologies observed in the sand and gravel were noted in *Field Observations: Comments* (which is included in the CD/ROM). Based on this visual assessment samples were less reflective of local bedrock in areas with thicker deposits of glacial sediment. This observation is further substantiated by a project which correlated bedrock type to dominant drift pebble lithology (Green, G. and Venzke, E., 1990). They also found that the correlation between dominant clast lithology and glacial sediment thickness was not as strong where glacial sediments were thicker. Thicker sequences of sediment provide less access to local bedrock. The correlation was also diminished with the influence of subsequent glacial outwash events (such as the Superior lobe within this project area) or supraglacial till deposition. In both of these cases sediment represented is distally sourced.

Glacial Lobe Influence: Superior lobe-influenced samples account for four of the twelve quality tested samples (Samples 38, 287, 347, and 594). Respective disintegrating rock percentages are: 25.8, 0.0, 1.0, and 0.9. Respective spall percentages are 0.7, 0.3, 0.9, and 0.0. Three of the four samples fall within accepted disintegrating rock amounts. All Superior lobe influenced samples fall within Mn/DOT specifications for spall. Sediments derived from the Superior lobe generally contain characteristic North

Shore Volcanic Group rocks. These are generally competent rocks according to aggregate standards and their presence could increase sand and gravel quality. Superior lobe deposits generally have lower amounts of disintegrating rock and spall elsewhere in the state.

Landform: Samples were taken from multiple glacial landforms including: ice contact features, outwash features, recessional moraines and ground moraine. Moraine deposits (Samples 244, 262, 824), both recessional and ground, tend to have a wide range in sediment sizes and high silt content, generalizing from the three samples taken from moraine associated landforms. The silt content for all three samples is relatively high. Disintegrating rock percentages for these samples (19.1, 14.2, and 49.3 respectively) are very high. Spall percentages are more variable (1.4, 3.3, and 0.4 respectively).

Six samples were from ice contact features (Samples 198, 287, 347, 594,822, and 853). These varied from the lowest to the highest gravel content (12%-44%), relative to the sample set. Silt content varied between 3.3% and 12.4%. Samples 287, 347, and 594 met Mn/DOT specifications for disintegrating rock. All of the ice contact feature samples had acceptable amounts of spall.

The remaining three samples corresponded with outwash deposits (Samples 38, 324, 573) and averaged higher gravel content (44%, 41%, and 28%) with low to moderate silt values (3.0%, 7.9%, and 5.3%). Sample 38 exceeded Mn/DOT standards for disintegrating rock, 25.8%. Sample 573 (3.1%) had an acceptable but relatively high allowable spall amount compared to the sample set.

The quality (spall and disintegrating rock) of the landforms represented varied widely. The strongest correlation is between moraine features and remarkably high amounts of disintegrating rock. The other landforms were less conclusive with three of the six ice contact features exceeding specifications for disintegrating rock and one of the three outwash feature samples exceeding specifications for disintegrating rock. Although correlations between landform and quality are relatively inconclusive, correlations between texture and landform were more significant. Moraine features represent the three siltiest samples (16.0%, 14.4%, and 12.9%). Outwash features were generally coarse whereas ice contact features were generally less coarse.

CONCLUSIONS

Identification of potential sand and gravel resources in the region of known copper+nickel deposits in northern St. Louis County and western Lake County was accomplished by mapping geologic landforms. Sand and gravel potential was classified in this region based on seven characteristics listed in Table 1. The methodology used in mapping landforms consisted of interpreting aerial photographs and topographic maps, evaluating subsurface data including well logs and Mn/DOT ASIS pit sheet data. Next these interpretations were combined with extensive field observations and test holes of surficial sediments. The map was prepared using the tools available in GIS. The geologic units were digitized with ArcMap and integrated with base map data resulting in the sand and gravel resource potential map. The final map and data were created by relying on experience mapping sand and gravel in other counties.

The potential sand and gravel resources are dispersed throughout the project area, with the exception of lowlands in the southeastern corner which were largely inaccessible. However, some potential was identified in this corner near the Sand Lake and Big Lake tunnel valleys. North of the Vermilion Moraine, significant potential occurs as ice contact features located both adjacent to and south of Ely. Potential resources are otherwise found within thin outwash features, or as small pockets in lows of bedrock-cored landscape. South of the Vermilion Moraine, where the glacial sediment is thicker, large deposits of outwash are associated with proglacial meltwater in front of recessional moraines. A large glaciofluvial channel is the source of significant sand and gravel potential in the southwestern region. The recessional moraines are sources of variably textured material throughout the region.

The texture and quality of sand and gravel within the potential aggregate resource unit were assessed using field observations, MN DNR sieve analysis, and Mn/DOT quality testing. With a small sample set (n=12) it is difficult to generalize. Sand and gravel quality was evaluated by comparing dominant sand and gravel lithologies, glacial lobe influence, and depth to bedrock. Field observations indicate that samples from the granitic bedrock region tend to be more durable and the one test sample verifies this assumption. Samples influenced by Superior lobe outwash generally have lower disintegrating rock and spall amounts. Samples taken in areas with greater depth to bedrock had higher disintegrating rock and spall amounts. Overall, disintegrating rocks are more of a quality issue in the Duluth Complex region.

Glacial landforms including moraines, ice contact features, and outwash features were evaluated on correlations between percent gravel, percent silt, disintegrating rock, and spall. Coarse-textured material or deposits with high percent gravel are distributed throughout the region. Siltier samples generally correlate with moraine features or sandy rocky till that classifies as aggregate. Moraine features also had greatest amounts of disintegrating rock. Otherwise quality and texture varied across landform type designations.

REFERENCES

Buchheit, R.L., Malmquist, K.L., and Niebuhr, J.R., 1989, Glacial drift geochemistry for strategic minerals; Duluth Complex, Lake County, Minnesota: Minnesota Department of Natural Resources Division of Minerals Report 262, Part II, p.15.

Eng, M. 1985, Sample Sites in Eskers in Northeastern Minnesota *in* Martin, D., and Eng, M, 1986, Esker Prospecting Over the Duluth Complex in Northeastern Minnesota: Minnesota Department of Natural Resources Division of Minerals Report 246, 27p.

Eyles, N. 1983, Glacial Geology: A Landscape Approach, Glacial Geology: An Introduction for Engineers and Earth Scientists, Pergamon Press, Oxford p.1-18.

Jennings, C. and Reynolds, W., 2005, Mesabi Iron Range Surficial Geology: Minnesota Geological Survey, St. Paul, Minnesota, Miscellaneous Map Series M-164.

Jirsa, M., Chandler, V., and Lively, R., 2005, Bedrock Geology of the Mesabi Iron Range: Minnesota Geological Survey, St. Paul, Minnesota, Miscellaneous Map Series M-163.

Larson, P., and Mooers, H., 2009, Glacial Geology of the Vermilion Moraine: Institute on Lake Superior Geology Proceedings Vol. 55, Part 2–Field Trip Guidebook, pp. 81-99.

Lehr, J. 2000, Pleistocene Geology of the Embarrass Area St. Louis County, Minnesota: [Unpublished M.S. thesis]: University of Minnesota, 157 p.

Lehr, J., and Hobbs, H.C., 1992, Field trip guidebook for the glacial geology of the Laurentian Divide area, St. Louis and Lake Counties, Minnesota: Minnesota Geological Survey, St. Paul, Minnesota, Guidebook Series No. 18, 73 p.

Miller, J., Green, J., Severson, M., Chandler, V., and Peterson, D., 2001, Geologic map of the Duluth Complex and related rocks, northeastern Minnesota, Minnesota Geological Survey, St. Paul, Minnesota, Miscellaneous Map Series M-119.

Miller, J, Green, J., Severson, M., Chandler, V., Hauck, S., Peterson, D., and Wahl, T., 2002, Geology and mineral potential of the Duluth Complex and related rocks of northeastern Minnesota: Minnesota Geological Survey Report of Investigations 58, 207p.

Mn/DOT Standard Specifications for Construction, 2005, Minnesota Department of Transportation, 1074p.

Oberhelman, M., 1991, Dimension stone inventory of northern Minnesota: Minnesota Department of Natural Resources, Report 289, 34 p.

Stark, J. R., 1977, Surficial geology and ground-water geology of the Babbitt-Kawishiwi area, northeastern Minnesota with planning implications: [Unpublished MS thesis] University of Wisconsin-Madison, 113 p.

Green, J., and Venzke, E., 1990, Drift Pebble Lithology of the Tomahawk Road Area, Lake County, Minnesota: Can it be used to infer local bedrock? Appendix 290-F *in* Aeromagnetic Interpretation Pseudo-Geologic Maps, with Evaluation, in Lake of the Woods and Lake Counties, Minnesota, Report 290, 1991, Minnesota Department of Natural Resources Division of Minerals 48p.

Winter, T.C., Cotter, R.D., and Young, H.L., 1973, Petrography and stratigraphy of glacial drift, Mesabi-Vermillion Iron Range area, northeastern Minnesota: U.S. Geological Survey Bulletin 1331 – C, pp 36-40.

APPENDIX A

Concrete Aggregate Lithology Exam lab test reports from Mn/DOT

State of Minnesota Department of Transportation
Aggregates Test Report
Office of Materials and Road Research
1400 Gervais Avenue
Maplewood, MN 55109

Sample ID Number: CO-PS10-0012 **Project Number: For Info Only**

Field ID:	38	Billing Agency:	
Date Sampled:		Project Engineer:	DENNIS MARTIN
Date Received	09/14/2010	Submitter:	H. FRIEDRICH
Approved:	10/6/2010 12:39	IAS Name:	
TH Number:		Legal:	NE1/4 NE1/4 Sec 18 - 060 - 11
Depth:		Pit Name:	
Grade Spec:		Pit Owner:	
Spec Class:		Sampled From:	
Quality Spec:		Usage:	DNR PROSPECTING
Plant Name:			
Comment:			

Test Procedures: AASHTO T-19, T-21, T-27(M), T-30(M), T-84(M), T-85(M), T-96(M), T-104(M), T-113(M), T-176(M), T-248(M), T-304 Method A, ASTM C123, ASTM C535, ASTM D3042, ASTM D4791(M), Micro Deval(MP), Percent Crushing(MP) M = MN/DOT Modified MP = MN/DOT Procedures

% Passing Sieve:	Lab Test	Field Test	Spec. Limits Low	Spec. Limits High
200mm (8")	100			
75mm (3")	90			
63mm (2 1/2")	90			
50mm (2")	85			
37.5mm (1 1/2")	82			
31.5mm (1 1/4")	80			
25.0mm (1")	77			
19.0mm (3/4")	72			
12.5mm (1/2")	66			
9.5mm (3/8")	62			
4.75mm (#4)	48			
2.36mm (#8)	33			
2.00mm (#10)	30			
1.18mm (#16)	20			
600um (#30)	10			
425um (#40)	7			
300um (#50)	4			
150um (#100)	2			
75um (#200)	1.2			
% Shale In Sand	0.0			
% Disint. Rock	25.8			
% Iron Oxide	0.20			
% Misc. Spall	1.25			
%TotalSamplSpall	0.7			
% BA Spall +4	1.4			

* Value does not meet Spec
~ Value out of Field Lab Tolerance
*** Trace (0.00 - 0.05) Detected
% Shale in Sand N.C. = Trace

- ☐ Meets Requirements
- ☐ Does Not Meet Requirements
- ☒ For Info Only
- ☐ Incentive/Disincentive
- ☐ Unable to Verify
- ☐ Unable to Verify, Not Enough Material Supplied
- ☐ Within Lab-Field Tolerance
- ☐ Out of Lab-Field Tolerance

Comments:
NON-REPRESENTATIVE SAMPLE

Copies To
DNR - H. FRIEDRICH

Charge: 1 - 1012
1 - 1013
1 - 1014
1 - 1029

Report Approved By:
David B. Bak[signature]

CO-PS10-0012 Ver. 1 Page 1 of 1 10/6/2010 12:39

State of Minnesota Department of Transportation
Aggregates Test Report
Office of Materials and Road Research
1400 Gervais Avenue
Maplewood, MN 55109

Sample ID Number: CO-PS10-0008 | **Project Number: For Info Only**

Field ID:	198	Billing Agency:	
Date Sampled:		Project Engineer:	DENNIS MARTIN
Date Received	09/14/2010	Submitter:	H. FRIEDRICH
Approved:	10/6/2010 9:23	IAS Name:	
TH Number:		Legal:	NW1/4 SE1/4 Sec 24 - 060 - 14
Depth:		Pit Name:	
Grade Spec:		Pit Owner:	
Spec Class:		Sampled From:	
Quality Spec:		Usage:	DNR PROSPECTING
Plant Name:			
Comment:			

Test Procedures: AASHTO T-19, T-21, T-27(M), T-30(M), T-84(M), T-85(M), T-96(M), T-104(M), T-113(M), T-176(M), T-248(M), T-304 Method A, ASTM C123, ASTM C535, ASTM D3042, ASTM D4791(M), Micro Deval(MP), Percent Crushing(MP) M = MN/DOT Modified MP = MN/DOT Procedures

% Passing Sieve:	Lab Test	Field Test	Spec. Limits Low	Spec. Limits High
63mm (2 1/2")	100			
50mm (2")	98			
37.5mm (1 1/2")	90			
31.5mm (1 1/4")	89			
25.0mm (1")	81			
19.0mm (3/4")	73			
12.5mm (1/2")	65			
9.5mm (3/8")	60			
4.75mm (#4)	49			
2.36mm (#8)	39			
2.00mm (#10)	37			
1.18mm (#16)	31			
600um (#30)	23			
425um (#40)	18			
300um (#50)	15			
150um (#100)	10			
75um (#200)	7.6			
% Shale in Sand	0.0			
% Disint. Rock	4.0			
% Misc. Spall	0.88			
%TotalSamplSpall	0.4			
% BA Spall +4	0.9			

* Value does not meet Spec
~ Value out of Field Lab Tolerance
*** Trace (0.00 - 0.05) Detected
% Shale in Sand N.C. = Trace

- [ ] Meets Requirements
- [ ] Does Not Meet Requirements
- [x] For Info Only
- [ ] Incentive/Disincentive
- [ ] Unable to Verify
- [ ] Unable to Verify, Not Enough Material Supplied
- [ ] Within Lab-Field Tolerance
- [ ] Out of Lab-Field Tolerance

Comments:
NON-REPRESENTATIVE SAMPLE

Copies To
DNR - H. FRIEDRICH

Charge: 1 - 1012, 1 - 1013, 1 - 1014, 1 - 1029

Report Approved By: [signature]

CO-PS10-0008 Ver. 1 Page 1 of 1 10/6/2010 9:23

State of Minnesota Department of Transportation
Aggregates Test Report

Office of Materials and Road Research
1400 Gervais Avenue
Maplewood, MN 55109

Sample ID Number: CO-PS10-0002 | **Project Number: For Info Only**

Field ID:	244	Billing Agency:	
Date Sampled:		Project Engineer:	DENNIS MARTIN
Date Received	09/14/2010	Submitter:	H. FRIEDRICH
Approved:	10/7/2010 15:24	IAS Name:	
TH Number:		Legal:	SW1/4 SW1/4 Sec 22 - 058 - 14
Depth:	0.00 to 5.00	Pit Name:	
Grade Spec:		Pit Owner:	
Spec Class:		Sampled From:	0-5 FT.
Quality Spec:		Usage:	DNR PROSPECTING
Plant Name:			
Comment:			

Test Procedures: AASHTO T-19, T-21, T-27(M), T-30(M), T-84(M), T-85(M), T-96(M), T-104(M), T-113(M), T-176(M), T-248(M), T-304 Method A, ASTM C123, ASTM C535, ASTM D3042, ASTM D4791(M), Micro Deval(MP), Percent Crushing(MP) M = MN/DOT Modified MP = MN/DOT Procedures

% Passing Sieve:	Lab Test	Field Test	Spec. Limits Low	High
50mm (2")	100			
37.5mm (1 1/2")	100			
31.5mm (1 1/4")	97			
25.0mm (1")	97			
19.0mm (3/4")	94			
12.5mm (1/2")	89			
9.5mm (3/8")	86			
4.75mm (#4)	77			
2.36mm (#8)	69			
2.00mm (#10)	66			
1.18mm (#16)	59			
600um (#30)	47			
425um (#40)	39			
300um (#50)	32			
150um (#100)	21			
75um (#200)	14.7			
% Shale in Sand	0.0			
% Disint. Rock	19.1			
% Iron Oxide	0.10			
% Unsound Chert	0.05			
% Misc. Spall	5.88			
%TotalSamplSpall	1.4			
% BA Spall +4	6.0			

* Value does not meet Spec
~ Value out of Field Lab Tolerance
*** Trace (0.00 - 0.05) Detected
% Shale in Sand N.C. = Trace

☐ Meets Requirements
☐ Does Not Meet Requirements
☒ For Info Only
☐ Incentive/Disincentive

☐ Unable to Verify
☐ Unable to Verify, Not Enough Material Supplied
☐ Within Lab-Field Tolerance
☐ Out of Lab-Field Tolerance

Comments:
NON-REPRESENTATIVE SAMPLE

Copies To

Charge: 1 - 1012
1 - 1013
1 - 1014
1 - 1029

Report Approved By: [signature]

CO-PS10-0002 Ver. 1 Page 1 of 1 10/7/2010 15:24

State of Minnesota Department of Transportation
Aggregates Test Report
Office of Materials and Road Research
1400 Gervais Avenue
Maplewood, MN 55109

Sample ID Number: CO-PS10-0003 | **Project Number: For Info Only**

Field ID:	262	Billing Agency:	
Date Sampled:		Project Engineer:	DENNIS MARTIN
Date Received	09/14/2010	Submitter:	H. FRIEDRICH
Approved:	10/6/2010 9:28	IAS Name:	
TH Number:		Legal:	SW1/4 SE1/4 Sec 21 - 058 - 13
Depth:	10.00 to 15.00	Pit Name:	
Grade Spec:		Pit Owner:	
Spec Class:		Sampled From:	10-15 FT.
Quality Spec:		Usage:	DNR PROSPECTING
Plant Name:			
Comment:			

Test Procedures: AASHTO T-19, T-21, T-27(M), T-30(M), T-84(M), T-85(M), T-96(M), T-104(M), T-113(M), T-176(M), T-248(M), T-304 Method A, ASTM C123, ASTM C535, ASTM D3042, ASTM D4791(M), Micro Deval(MP), Percent Crushing(MP) M = MN/DOT Modified MP = MN/DOT Procedures

% Passing Sieve:	Lab Test	Field Test	Spec. Limits Low	High
63mm (2 1/2")	100			
50mm (2")	95			
37.5mm (1 1/2")	90			
31.5mm (1 1/4")	85			
25.0mm (1")	81			
19.0mm (3/4")	76			
12.5mm (1/2")	67			
9.5mm (3/8")	62			
4.75mm (#4)	51			
2.36mm (#8)	41			
2.00mm (#10)	38			
1.18mm (#16)	31			
600um (#30)	21			
425um (#40)	16			
300um (#50)	13			
150um (#100)	8			
75um (#200)	5.4			
% Shale in Sand	0.0			
% Disint. Rock	14.2			
% Misc. Spall	6.68			
%TotalSamplSpall	3.3			
% BA Spall +4	6.7			

* Value does not meet Spec
~ Value out of Field Lab Tolerance
*** Trace (0.00 - 0.05) Detected
% Shale in Sand N.C. = Trace

- ☐ Meets Requirements
- ☐ Does Not Meet Requirements
- ☒ For Info Only
- ☐ Incentive/Disincentive
- ☐ Unable to Verify
- ☐ Unable to Verify, Not Enough Material Supplied
- ☐ Within Lab-Field Tolerance
- ☐ Out of Lab-Field Tolerance

Comments:
NON-REPRESENTATIVE SAMPLE

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CO-PS10-0003 Ver. 1   Page 1 of 1   10/6/2010 9:28

State of Minnesota Department of Transportation
Aggregates Test Report

Office of Materials and Road Research
1400 Gervais Avenue
Maplewood, MN 55109

Sample ID Number: CO-PS10-0007 **Project Number: For Info Only**

Field ID:	287	Billing Agency:	
Date Sampled:		Project Engineer:	DENNIS MARTIN
Date Received	09/14/2010	Submitter:	H. FRIEDRICH
Approved:	10/6/2010 9:26	IAS Name:	
TH Number:		Legal:	SW1/4 NE1/4 Sec 25 - 060 - 12
Depth:	5.00 to 10.00	Pit Name:	
Grade Spec:		Pit Owner:	
Spec Class:		Sampled From:	
Quality Spec:		Usage:	DNR PROSPECTING
Plant Name:			
Comment:			

Test Procedures: AASHTO T-19, T-21, T-27(M), T-30(M), T-84(M), T-85(M), T-96(M), T-104(M), T-113(M), T-176(M), T-248(M), T-304 Method A, ASTM C123, ASTM C535, ASTM D3042, ASTM D4791(M), Micro Deval(MP), Percent Crushing(MP) M = MN/DOT Modified MP = MN/DOT Procedures

% Passing Sieve:	Lab Test	Field Test	Spec. Limits Low	High
50mm (2")	100			
37.5mm (1 1/2")	100			
31.5mm (1 1/4")	99			
25.0mm (1")	98			
19.0mm (3/4")	94			
12.5mm (1/2")	85			
9.5mm (3/8")	80			
4.75mm (#4)	66			
2.36mm (#8)	54			
2.00mm (#10)	51			
1.18mm (#16)	40			
600um (#30)	23			
425um (#40)	14			
300um (#50)	7			
150um (#100)	2			
75um (#200)	1.5			
% Shale in Sand	0.0			
% Misc. Spall	0.99			
%TotalSamplSpall	0.3			
% BA Spall +4	1.0			

* Value does not meet Spec
~ Value out of Field Lab Tolerance
*** Trace (0.00 - 0.05) Detected
% Shale in Sand N.C. = Trace

- [ ] Meets Requirements
- [ ] Does Not Meet Requirements
- [x] For Info Only
- [ ] Incentive/Disincentive
- [ ] Unable to Verify
- [ ] Unable to Verify, Not Enough Material Supplied
- [ ] Within Lab-Field Tolerance
- [ ] Out of Lab-Field Tolerance

Comments:
NON-REPRESENTATIVE SAMPLE

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DNR - H. FRIEDRICH

Charge: 1 - 1012
1 - 1013
1 - 1014
1 - 1029

Report Approved By: David B. Bak[signature]

CO-PS10-0007 Ver. 1 Page 1 of 1 10/6/2010 9:26

State of Minnesota Department of Transportation
Aggregates Test Report
Office of Materials and Road Research
1400 Gervais Avenue
Maplewood, MN 55109

Sample ID Number: CO-PS10-0005 | **Project Number: For Info Only**

Field ID:	324	Billing Agency:	
Date Sampled:		Project Engineer:	DENNIS MARTIN
Date Received	09/14/2010	Submitter:	H. FRIEDRICH
Approved:	10/7/2010 15:22	IAS Name:	
TH Number:		Legal:	NE1/4 SW1/4 Sec 25 - 059 - 14
Depth:	0.00 to 10.00	Pit Name:	
Grade Spec:		Pit Owner:	
Spec Class:		Sampled From:	
Quality Spec:		Usage:	DNR PROSPECTING
Plant Name:			
Comment:			

Test Procedures: AASHTO T-19, T-21, T-27(M), T-30(M), T-84(M), T-85(M), T-96(M), T-104(M), T-113(M), T-176(M), T-248(M), T-304 Method A, ASTM C123, ASTM C535, ASTM D3042, ASTM D4791(M), Micro Deval(MP), Percent Crushing(MP) M = MN/DOT Modified MP = MN/DOT Procedures

% Passing Sieve:	Lab Test	Field Test	Spec. Limits Low	Spec. Limits High
63mm (2 1/2")	100			
50mm (2")	96			
37.5mm (1 1/2")	95			
31.5mm (1 1/4")	90			
25.0mm (1")	87			
19.0mm (3/4")	82			
12.5mm (1/2")	74			
9.5mm (3/8")	69			
4.75mm (#4)	55			
2.36mm (#8)	42			
2.00mm (#10)	39			
1.18mm (#16)	31			
600um (#30)	20			
425um (#40)	14			
300um (#50)	10			
150um (#100)	6			
75um (#200)	3.9			
% Shale in Sand	0.0			
% Disint. Rock	3.1			
% Iron Oxide	0.40			
%TotalSamplSpall	0.2			
% BA Spall +4	0.4			

* Value does not meet Spec
~ Value out of Field Lab Tolerance
*** Trace (0.00 - 0.05) Detected
% Shale in Sand N.C. = Trace

- [ ] Meets Requirements
- [ ] Does Not Meet Requirements
- [x] For Info Only
- [ ] Incentive/Disincentive
- [ ] Unable to Verify
- [ ] Unable to Verify, Not Enough Material Supplied
- [ ] Within Lab-Field Tolerance
- [ ] Out of Lab-Field Tolerance

Comments:
NON-REPRESENTATIVE SAMPLE - FOR INFORMATION ONLY

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DNR - H. FRIEDRICH

Charge: 1 - 1012
1 - 1013
1 - 1014
1 - 1029

Report Approved By: [signature]

CO-PS10-0005 Ver. 1 Page 1 of 1 10/7/2010 15:22

State of Minnesota Department of Transportation
Aggregates Test Report
Office of Materials and Road Research
1400 Gervais Avenue
Maplewood, MN 55109

Sample ID Number: CO-PS10-0011 | **Project Number: For Info Only**

Field ID:	347	Billing Agency:	
Date Sampled:		Project Engineer:	DENNIS MARTIN
Date Received	09/14/2010	Submitter:	H. FRIEDRICH
Approved:	10/6/2010 12:41	IAS Name:	
TH Number:		Legal:	NE1/4 SE1/4 Sec 24 - 059 - 11
Depth:		Pit Name:	
Grade Spec:		Pit Owner:	
Spec Class:		Sampled From:	
Quality Spec:		Usage:	DNR PROSPECTING
Plant Name:			
Comment:			

Test Procedures: AASHTO T-19, T-21, T-27(M), T-30(M), T-84(M), T-85(M), T-96(M), T-104(M), T-113(M), T-176(M), T-248(M), T-304 Method A, ASTM C123, ASTM C535, ASTM D3042, ASTM D4791(M), Micro Deval(MP), Percent Crushing(MP) M = MN/DOT Modified MP = MN/DOT Procedures

% Passing Sieve:	Lab Test	Field Test	Spec. Limits Low	Spec. Limits High
63mm (2 1/2")	100			
50mm (2")	97			
37.5mm (1 1/2")	95			
31.5mm (1 1/4")	95			
25.0mm (1")	90			
19.0mm (3/4")	87			
12.5mm (1/2")	78			
9.5mm (3/8")	72			
4.75mm (#4)	58			
2.36mm (#8)	48			
2.00mm (#10)	46			
1.18mm (#16)	39			
600um (#30)	28			
425um (#40)	23			
300um (#50)	19			
150um (#100)	14			
75um (#200)	10.2			
% Shale in Sand	0.0			
% Disint. Rock	1.0			
% Iron Oxide	0.30			
% Misc. Spall	1.90			
%TotalSamplSpall	0.9			
% BA Spall +4	2.2			

* Value does not meet Spec
~ Value out of Field Lab Tolerance
*** Trace (0.00 - 0.05) Detected
% Shale in Sand N.C. = Trace

- ☐ Meets Requirements
- ☐ Does Not Meet Requirements
- ☒ For Info Only
- ☐ Incentive/Disincentive
- ☐ Unable to Verify
- ☐ Unable to Verify, Not Enough Material Supplied
- ☐ Within Lab-Field Tolerance
- ☐ Out of Lab-Field Tolerance

Comments:
NON-REPRESENTATIVE SAMPLE

Copies To
DNR- H. FRIEDRICH

Charge: 1 - 1012
1 - 1013
1 - 1014
1 - 1029

Report Approved By:
[signature]

CO-PS10-0011 Ver. 1 Page 1 of 1 10/6/2010 12:41

State of Minnesota Department of Transportation
Aggregates Test Report

Office of Materials and Road Research
1400 Gervais Avenue
Maplewood, MN 55109

Sample ID Number: CO-PS10-0001 **Project Number: For Info Only**

Field ID:	573	Billing Agency:	
Date Sampled:		Project Engineer:	DENNIS MARTIN
Date Received	09/14/2010	Submitter:	H. FRIEDRICH
Approved:	10/7/2010 15:29	IAS Name:	
TH Number:		Legal:	NW1/4 NE1/4 Sec 36 - 058 - 14
Depth:	2.00	Pit Name:	
Grade Spec:		Pit Owner:	
Spec Class:		Sampled From:	2-7 FT.
Quality Spec:		Usage:	DNR PROSPECTING
Plant Name:			
Comment:			

Test Procedures: AASHTO T-19, T-21, T-27(M), T-30(M), T-84(M), T-85(M), T-96(M), T-104(M), T-113(M), T-176(M), T-248(M), T-304 Method A, ASTM C123, ASTM C535, ASTM D3042, ASTM D4791(M), Micro Deval(MP), Percent Crushing(MP) M = MN/DOT Modified MP = MN/DOT Procedures

% Passing Sieve:	Lab Test	Field Test	Spec. Limits Low	Spec. Limits High
50mm (2")	100			
37.5mm (1 1/2")	95			
31.5mm (1 1/4")	92			
25.0mm (1")	88			
19.0mm (3/4")	85			
12.5mm (1/2")	80			
9.5mm (3/8")	78			
4.75mm (#4)	68			
2.36mm (#8)	57			
2.00mm (#10)	54			
1.18mm (#16)	43			
600um (#30)	26			
425um (#40)	17			
300um (#50)	13			
150um (#100)	8			
75um (#200)	5.4			
% Shale in Sand	0.0			
% Disint. Rock	0.7			
% Misc. Spall	9.84			
%TotalSamplSpall	3.1			
% BA Spall +4	9.8			

* Value does not meet Spec
~ Value out of Field Lab Tolerance
*** Trace (0.00 - 0.05) Detected
% Shale in Sand N.C. = Trace

- [ ] Meets Requirements
- [ ] Does Not Meet Requirements
- [x] For Info Only
- [ ] Incentive/Disincentive
- [ ] Unable to Verify
- [ ] Unable to Verify, Not Enough Material Supplied
- [ ] Within Lab-Field Tolerance
- [ ] Out of Lab-Field Tolerance

Comments:
NON REPRESENTATIVE SAMPLE

Copies To
DNR- H. FRIEDRICH

Charge: 1 - 1012
1 - 1013
1 - 1014
1 - 1029

Report Approved By:
[signature]

CO-PS10-0001 Ver. 1 Page 1 of 1 10/7/2010 15:29

State of Minnesota Department of Transportation
Aggregates Test Report
Office of Materials and Road Research
1400 Gervais Avenue
Maplewood, MN 55109

Sample ID Number: CO-PS10-0006 **Project Number: For Info Only**

Field ID:	594	Billing Agency:	
Date Sampled:		Project Engineer:	DENNIS MARTIN
Date Received	09/14/2010	Submitter:	H. FRIEDRICH
Approved:	10/7/2010 15:12	IAS Name:	
TH Number:		Legal:	NW1/4 NW1/4 Sec 14 - 060 - 12
Depth:	10.00 to 20.00	Pit Name:	
Grade Spec:		Pit Owner:	
Spec Class:		Sampled From:	
Quality Spec:		Usage:	DNR PROSPECTING
Plant Name:			
Comment:			

Test Procedures: AASHTO T-19, T-21, T-27(M), T-30(M), T-84(M), T-85(M), T-96(M), T-104(M), T-113(M), T-176(M), T-248(M), T-304 Method A, ASTM C123, ASTM C535, ASTM D3042, ASTM D4791(M), Micro Deval(MP), Percent Crushing(MP) M = MN/DOT Modified MP = MN/DOT Procedures

% Passing Sieve:	Lab Test	Field Test	Spec. Limits Low	High
50mm (2")	100			
37.5mm (1 1/2")	100			
31.5mm (1 1/4")	100			
25.0mm (1")	98			
19.0mm (3/4")	96			
12.5mm (1/2")	94			
9.5mm (3/8")	92			
4.75mm (#4)	88			
2.36mm (#8)	77			
2.00mm (#10)	73			
1.18mm (#16)	57			
600um (#30)	34			
425um (#40)	25			
300um (#50)	18			
150um (#100)	8			
75um (#200)	3.7			
% Shale in Sand	0.0			
% Disint. Rock	0.9			
%TotalSamplSpall	0.0			

* Value does not meet Spec
~ Value out of Field Lab Tolerance
*** Trace (0.00 - 0.05) Detected
% Shale in Sand N.C. = Trace

- ☐ Meets Requirements
- ☐ Does Not Meet Requirements
- ☒ For Info Only
- ☐ Incentive/Disincentive
- ☐ Unable to Verify
- ☐ Unable to Verify, Not Enough Material Supplied
- ☐ Within Lab-Field Tolerance
- ☐ Out of Lab-Field Tolerance

Comments:
NON-REPRESENTATIVE SAMPLE. ALL TEST RESULTS FOR INFO ONLY.

Copies To
Aggregate Office
DNR - H. FRIEDRICH

Charge: 1 - 1012, 1 - 1013, 1 - 1014, 1 - 1029

Report Approved By: [signature]

CO-PS10-0006 Ver. 1 Page 1 of 1 10/7/2010 15:12

State of Minnesota Department of Transportation
Aggregates Test Report
Office of Materials and Road Research
1400 Gervais Avenue
Maplewood, MN 55109

Sample ID Number: CO-PS10-0009 | **Project Number: For Info Only**

Field ID:	822	Billing Agency:	
Date Sampled:		Project Engineer:	DENNIS MARTIN
Date Received	09/14/2010	Submitter:	H. FRIEDRICH
Approved:	10/6/2010 9:22	IAS Name:	
TH Number:		Legal:	NE1/4 SW1/4 Sec 33 - 060 - 12
Depth:		Pit Name:	
Grade Spec:		Pit Owner:	
Spec Class:		Sampled From:	
Quality Spec:		Usage:	DNR PROSPECTING
Plant Name:			
Comment:			

Test Procedures: AASHTO T-19, T-21, T-27(M), T-30(M), T-84(M), T-85(M), T-96(M), T-104(M), T-113(M), T-176(M), T-248(M), T-304 Method A, ASTM C123, ASTM C535, ASTM D3042, ASTM D4791(M), Micro Deval(MP), Percent Crushing(MP) M = MN/DOT Modified MP = MN/DOT Procedures

% Passing Sieve:	Lab Test	Field Test	Spec. Limits Low	Spec. Limits High
50mm (2")	100			
37.5mm (1 1/2")	96			
31.5mm (1 1/4")	96			
25.0mm (1")	93			
19.0mm (3/4")	92			
12.5mm (1/2")	90			
9.5mm (3/8")	88			
4.75mm (#4)	83			
2.36mm (#8)	76			
2.00mm (#10)	74			
1.18mm (#16)	68			
600um (#30)	55			
425um (#40)	45			
300um (#50)	36			
150um (#100)	17			
75um (#200)	7.2			
% Shale in Sand	0.0			
% Disint. Rock	8.5			
% Misc. Spall	2.40			
%TotalSamplSpall	0.4			
% BA Spall +4	2.4			

* Value does not meet Spec
~ Value out of Field Lab Tolerance
*** Trace (0.00 - 0.05) Detected
% Shale in Sand N.C. = Trace

☐ Meets Requirements
☐ Does Not Meet Requirements
☒ For Info Only
☐ Incentive/Disincentive

☐ Unable to Verify
☐ Unable to Verify, Not Enough Material Supplied
☐ Within Lab-Field Tolerance
☐ Out of Lab-Field Tolerance

Comments:
NON-REPRESENTATIVE SAMPLE

Copies To
DNR - H. FRIEDRICH

Charge: 1 - 1012
1 - 1013
1 - 1014
1 - 1029

Report Approved By: [signature]

CO-PS10-0009 Ver. 1 — Page 1 of 1 — 10/6/2010 9:22

State of Minnesota Department of Transportation
Aggregates Test Report
Office of Materials and Road Research
1400 Gervais Avenue
Maplewood, MN 55109

Sample ID Number: CO-PS10-0004 | **Project Number: For Info Only**

Field ID:	824	Billing Agency:	
Date Sampled:		Project Engineer:	DENNIS MARTIN
Date Received	09/14/2010	Submitter:	H. FRIEDRICH
Approved:	10/5/2010 13:33	IAS Name:	
TH Number:		Legal:	NW1/4 NE1/4 Sec 16 - 059 - 13
Depth:		Pit Name:	
Grade Spec:		Pit Owner:	
Spec Class:		Sampled From:	
Quality Spec:		Usage:	DNR PROSPECTING
Plant Name:			
Comment:			

Test Procedures: AASHTO T-19, T-21, T-27(M), T-30(M), T-84(M), T-85(M), T-96(M), T-104(M), T-113(M), T-176(M), T-248(M), T-304 Method A, ASTM C123, ASTM C535, ASTM D3042, ASTM D4791(M), Micro Deval(MP), Percent Crushing(MP) M = MN/DOT Modified MP = MN/DOT Procedures

% Passing Sieve:	Lab Test	Field Test	Spec. Limits Low	High
50mm (2")	100			
37.5mm (1 1/2")	95			
31.5mm (1 1/4")	93			
25.0mm (1")	90			
19.0mm (3/4")	85			
12.5mm (1/2")	81			
9.5mm (3/8")	79			
4.75mm (#4)	72			
2.36mm (#8)	65			
2.00mm (#10)	63			
1.18mm (#16)	58			
600um (#30)	51			
425um (#40)	47			
300um (#50)	42			
150um (#100)	30			
75um (#200)	19.7			
% Shale in Sand	0.0			
% Disint. Rock	49.3			
% Misc. Spall	1.28			
%TotalSamplSpall	0.4			
% BA Spall +4	1.3			

* Value does not meet Spec
~ Value out of Field Lab Tolerance
*** Trace (0.00 - 0.05) Detected
% Shale in Sand N.C. = Trace

- [ ] Meets Requirements
- [ ] Does Not Meet Requirements
- [x] For Info Only
- [ ] Incentive/Disincentive
- [ ] Unable to Verify
- [ ] Unable to Verify, Not Enough Material Supplied
- [ ] Within Lab-Field Tolerance
- [ ] Out of Lab-Field Tolerance

Comments:
NOT ENOUGH MATERIAL SUBMITTED FOR REPRESENTATIVE TESTING

Copies To
DNR - H. FRIEDRICH
AGGREGATE ENGINEER - T. BEAUDRY

Charge: 1 - 1012
1 - 1013
1 - 1014
1 - 1029

Report Approved By: David B. Bak[signature]

CO-PS10-0004 Ver. 1 Page 1 of 1 10/5/2010 13:33

State of Minnesota Department of Transportation
Aggregates Test Report
Office of Materials and Road Research
1400 Gervais Avenue
Maplewood, MN 55109

Sample ID Number: CO-PS10-0010 **Project Number: For Info Only**

Field ID:	853	Billing Agency:	
Date Sampled:		Project Engineer:	DENNIS MARTIN
Date Received	09/14/2010	Submitter:	H. FRIEDRICH
Approved:	10/6/2010 12:38	IAS Name:	
TH Number:		Legal:	NE1/4 NE1/4 Sec 27 - 060 - 12
Depth:		Pit Name:	
Grade Spec:		Pit Owner:	
Spec Class:		Sampled From:	
Quality Spec:		Usage:	DNR PROSPECTING
Plant Name:			
Comment:			

Test Procedures: AASHTO T-19, T-21, T-27(M), T-30(M), T-84(M), T-85(M), T-96(M), T-104(M), T-113(M), T-176(M), T-248(M), T-304 Method A, ASTM C123, ASTM C535, ASTM D3042, ASTM D4791(M), Micro Deval(MP), Percent Crushing(MP) M = MN/DOT Modified MP = MN/DOT Procedures

% Passing Sieve:	Lab Test	Field Test	Spec. Limits Low	Spec. Limits High
50mm (2")	100			
37.5mm (1 1/2")	89			
31.5mm (1 1/4")	88			
25.0mm (1")	83			
19.0mm (3/4")	80			
12.5mm (1/2")	74			
9.5mm (3/8")	71			
4.75mm (#4)	60			
2.36mm (#8)	46			
2.00mm (#10)	42			
1.18mm (#16)	28			
600um (#30)	13			
425um (#40)	9			
300um (#50)	6			
150um (#100)	4			
75um (#200)	2.6			
% Shale in Sand	0.0			
% Disint. Rock	11.3			
% Misc. Spall	2.59			
%TotalSamplSpall	1.0			
% BA Spall +4	2.6			

* Value does not meet Spec
~ Value out of Field Lab Tolerance
*** Trace (0.00 - 0.05) Detected
% Shale in Sand N.C. = Trace

- ☐ Meets Requirements
- ☐ Does Not Meet Requirements
- ☒ For Info Only
- ☐ Incentive/Disincentive
- ☐ Unable to Verify
- ☐ Unable to Verify, Not Enough Material Supplied
- ☐ Within Lab-Field Tolerance
- ☐ Out of Lab-Field Tolerance

Comments:
NON REPRESENTATIVE SAMPLE

Copies To
DNR - H. FRIEDRICH

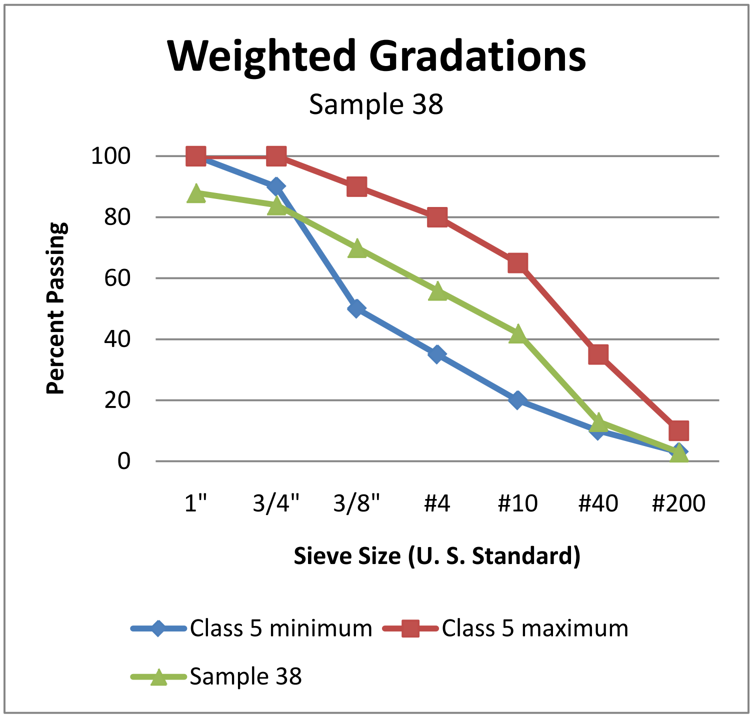
Charge: 1 - 1012
1 - 1013
1 - 1014
1 - 1029

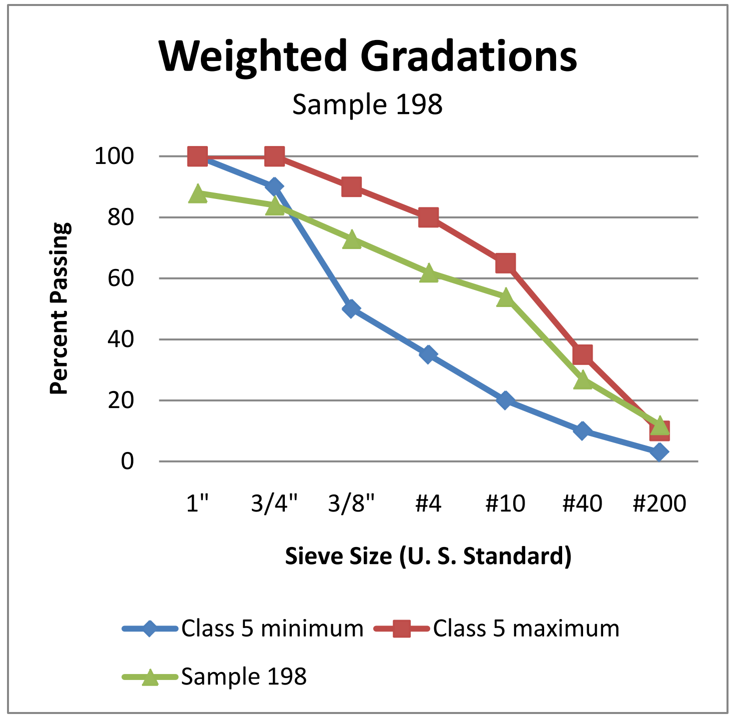
Report Approved By: David B. Bak[signature]

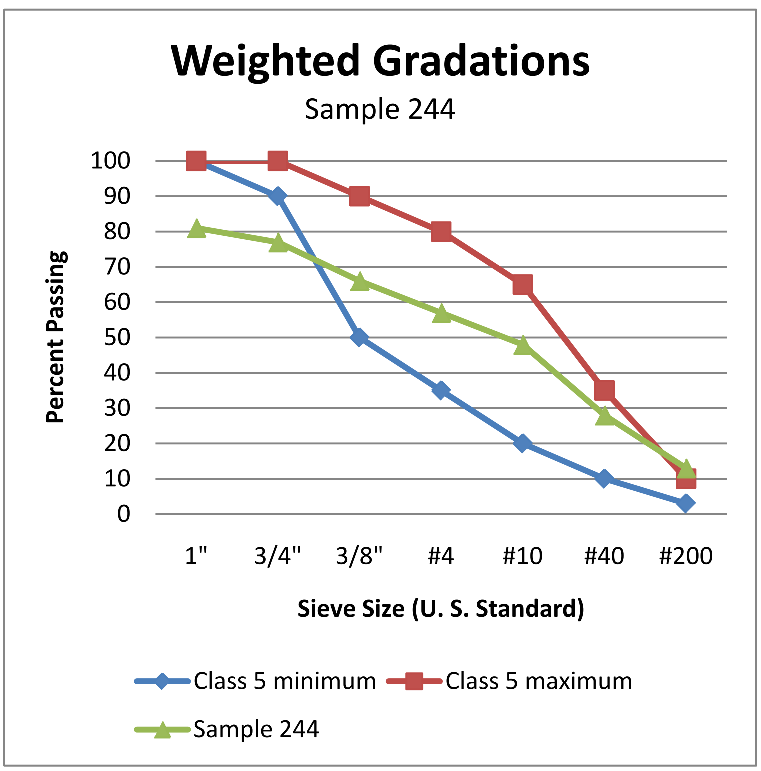
CO-PS10-0010 Ver. 1 Page 1 of 1 10/6/2010 12:38

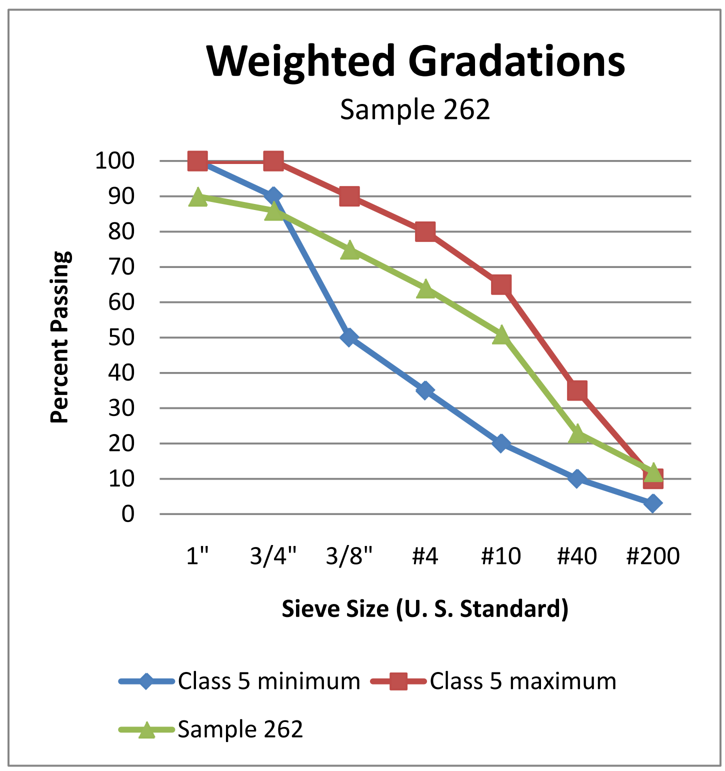
APPENDIX B

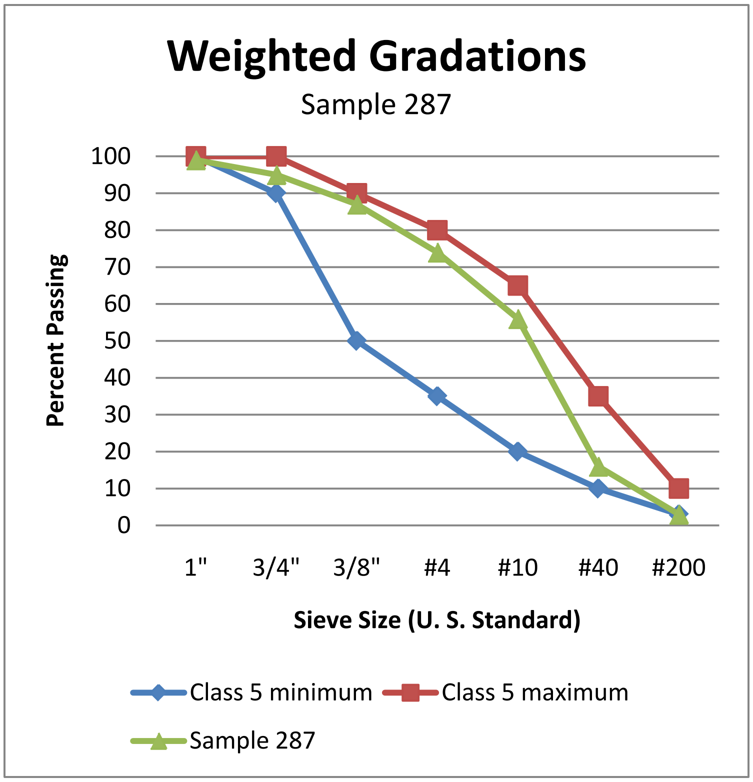
The following graphs compare the weighted gradations (or sediment size distribution) of the gravel sampled for quality testing to Mn/DOT's gradation requirements for Class 5 aggregate (Table 3138-1). These graphs are intended to provide a point of reference to a familiar gravel product (Class 5). A project may require material meeting a different gradation specification. Percent passing refers to the proportion of the sample that passes through a particular sieve size.

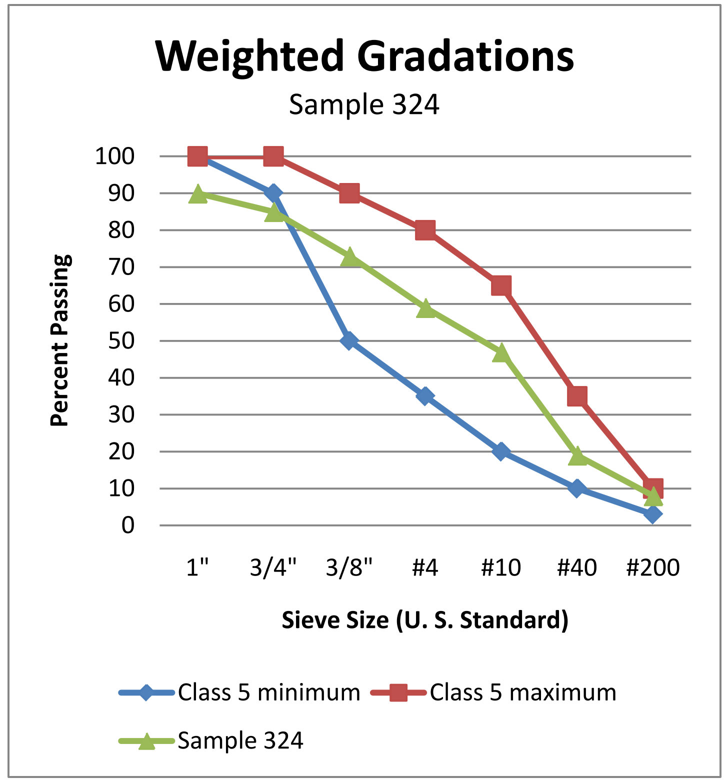

Weighted Gradations
Sample 38
100
80
60
40
20
0
Percent Passing
1"
3/4"
3/8"
#4
#10
#40
#200
Sieve Size (U. S. Standard)
Class 5 minimum
Class 5 maximum
Sample 38

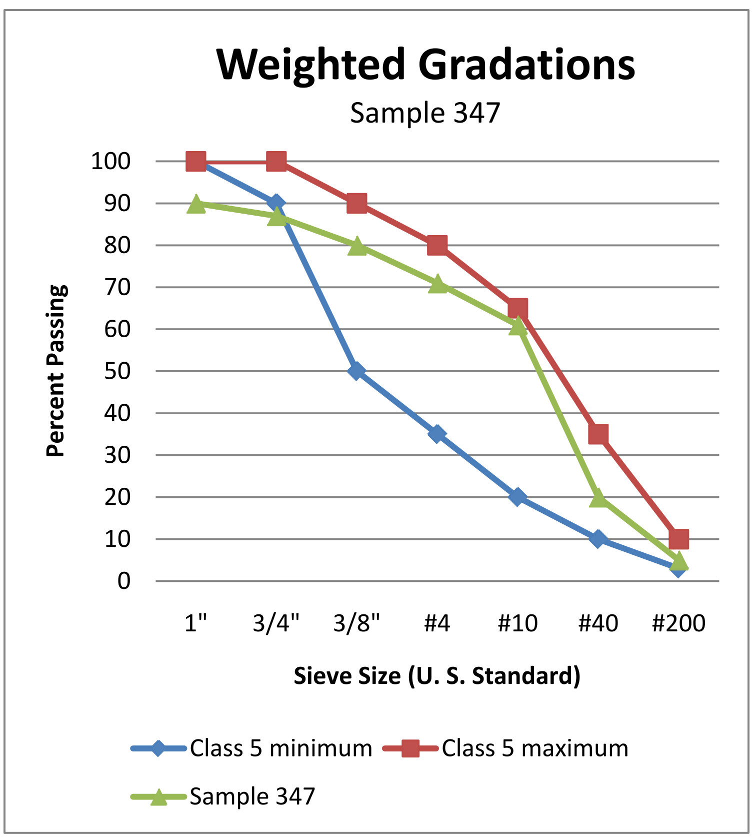

Weighted Gradations
Sample 198
100
80
60
40
20
0
Percent Passing
1"
3/4"
3/8"
#4
#10
#40
#200
Sieve Size (U. S. Standard)
Class 5 minimum
Class 5 maximum
Sample 198

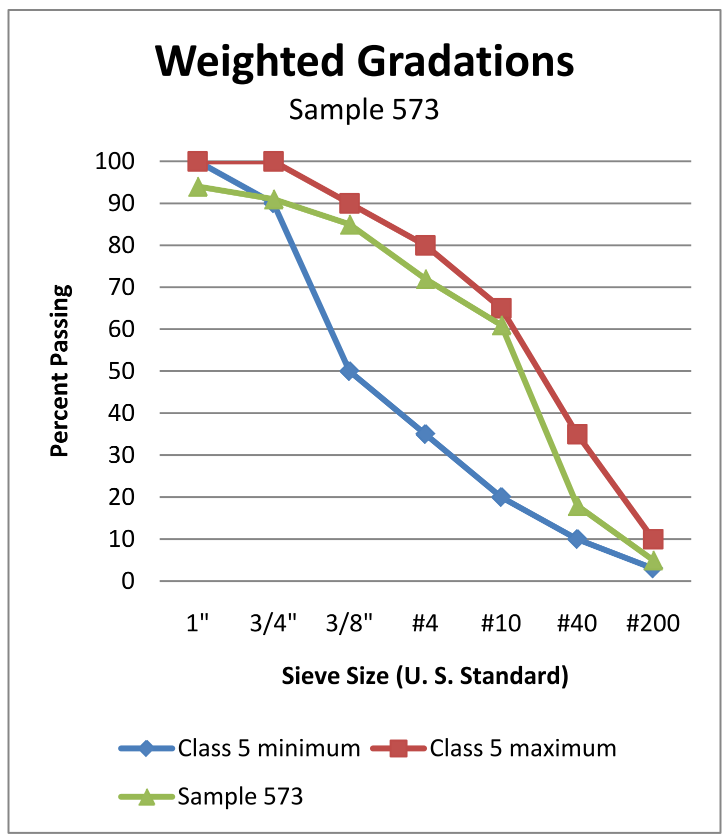

Weighted Gradations
Sample 244
100
90
80
70
60
50
40
30
20
10
0
Percent Passing
1"
3/4"
3/8"
#4
#10
#40
#200
Sieve Size (U. S. Standard)
Class 5 minimum
Class 5 maximum
Sample 244

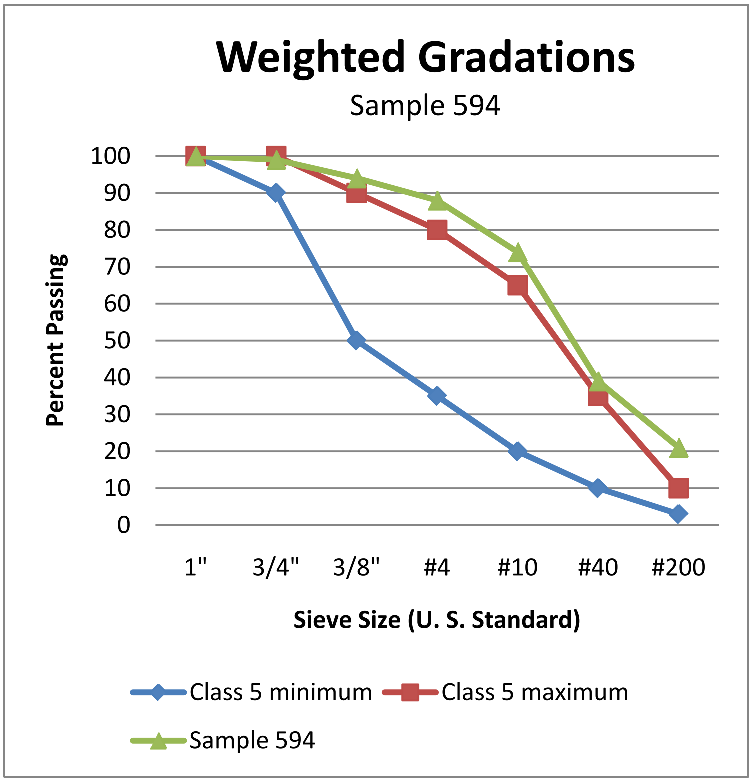

Weighted Gradations
Sample 262
100
90
80
70
60
50
40
30
20
10
0
Percent Passing
1"
3/4"
3/8"
#4
#10
#40
#200
Sieve Size (U. S. Standard)
Class 5 minimum
Class 5 maximum
Sample 262

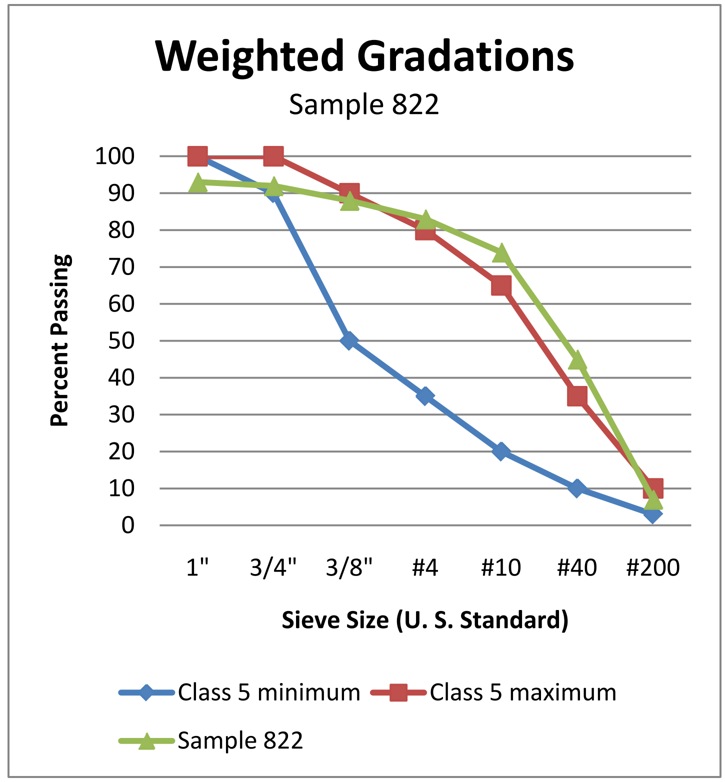

Weighted Gradations
Sample 287
Percent Passing
100
90
80
70
60
50
40
30
20
10
0
1"
3/4"
3/8"
#4
#10
#40
#200
Sieve Size (U. S. Standard)
Class 5 minimum
Class 5 maximum
Sample 287

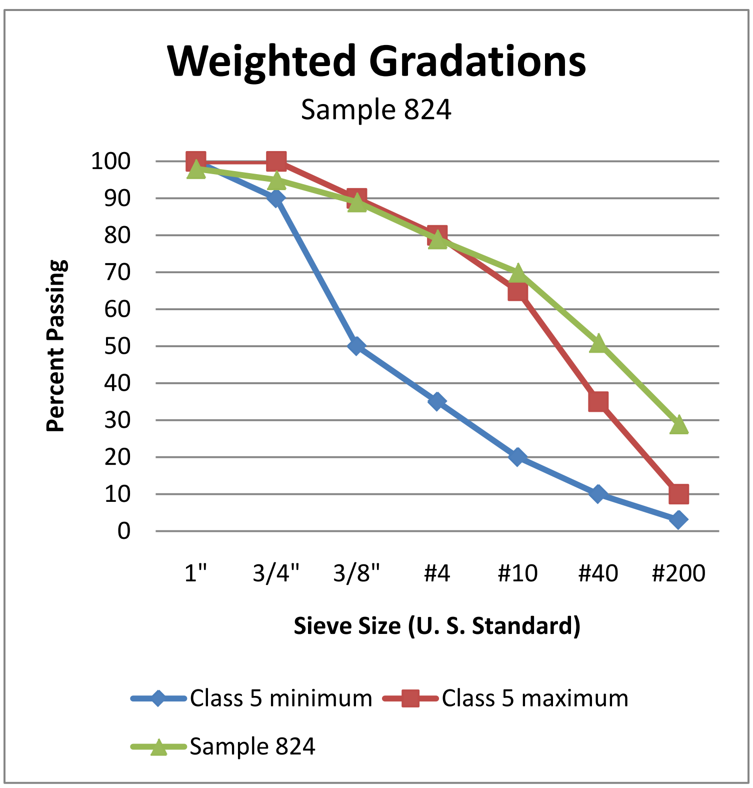

Weighted Gradations
Sample 324
Percent Passing
100
90
80
70
60
50
40
30
20
10
0
1"
3/4"
3/8"
#4
#10
#40
#200
Sieve Size (U. S. Standard)
Class 5 minimum
Class 5 maximum
Sample 324

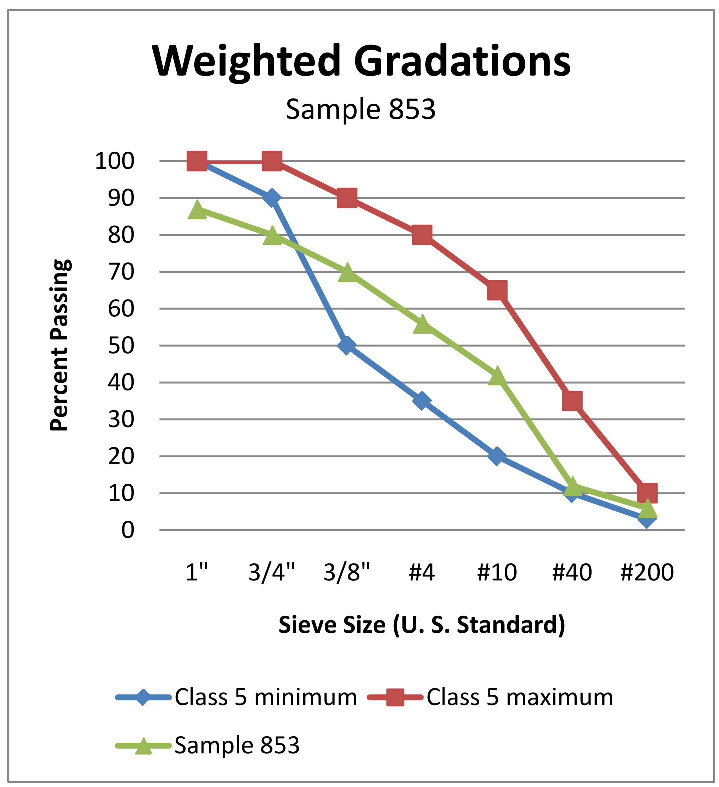

Weighted Gradations
Sample 347
Percent Passing
100
90
80
70
60
50
40
30
20
10
0
1"
3/4"
3/8"
#4
#10
#40
#200
Sieve Size (U. S. Standard)
Class 5 minimum
Class 5 maximum
Sample 347


Weighted Gradations
Sample 573
Percent Passing
100
90
80
70
60
50
40
30
20
10
0
1"
3/4"
3/8"
#4
#10
#40
#200
Sieve Size (U. S. Standard)
Class 5 minimum
Class 5 maximum
Sample 573


Weighted Gradations
Sample 594
Percent Passing
100
90
80
70
60
50
40
30
20
10
0
1"
3/4"
3/8"
#4
#10
#40
#200
Sieve Size (U. S. Standard)
Class 5 minimum
Class 5 maximum
Sample 594


Weighted Gradations
Sample 822
Percent Passing
100
90
80
70
60
50
40
30
20
10
0
1"
3/4"
3/8"
#4
#10
#40
#200
Sieve Size (U. S. Standard)
Class 5 minimum
Class 5 maximum
Sample 822


Weighted Gradations
Sample 824
Percent Passing
100
90
80
70
60
50
40
30
20
10
0
1"
3/4"
3/8"
#4
#10
#40
#200
Sieve Size (U. S. Standard)
Class 5 minimum
Class 5 maximum
Sample 824


Weighted Gradations
Sample 853
Percent Passing
100
90
80
70
60
50
40
30
20
10
0
1"
3/4"
3/8"
#4
#10
#40
#200
Sieve Size (U. S. Standard)
Class 5 minimum
Class 5 maximum
Sample 853