1209.0 LITHOLOGICAL SUMMARY

1209.1 GENERAL

This test procedure is performed on aggregates to determine the percentage of various rock types (especially the deleterious varieties) regulated in the Standard Specifications for Construction.

1209.2 APPARATUS

A. Dilute Hydrochloric Acid (10% ±) - One part concentrated HCL with 9 parts water and eyedropper applicator

B. "Brass Pencil" - (See Section 1218.2 for description)

C. Balances - Shall conform to AASHTO M 231 (Classes G2 & G5). Readability & sensitivity 0.1 grams, accuracy 0.1 grams or 0.1%. Balances shall be appropriate for the specific use.

D. Small Hammer, Steel Plate and Safety Glasses

E. Paper Containers - Approximately 75mm (3") in diameter

F. Magnifying Hand Lens (10 to 15 power)

G. Unglazed Porcelain Tile (streak plate)

1209.3 TEST SAMPLE

The test sample, prepared in accordance with Section 1201.4G, shall be washed (Observe washing restrictions in Section 1201.4G1c) and then dried to a constant weight at a temperature of 110 ± 5 °C (230 ± 9 °F). (See Section 1201, Table 1, for sample weights.)

1209.4 PROCEDURE

Examine and classify each rock piece individually. Some rock types may need to be cracked open to identify or determine the identifying properties of the rock. (Always wear safety glasses). The following general guidelines are for informational purposes:

- Always break open pieces of soft rock or any others of which you are unsure as the outside is often weathered.
- Pick the easy particles first

- Don't be overly concerned about questionable particles unless they will fail the sample.
- Give the aggregate supplier the benefit of the doubt. Generally, one questionable rock should not fail a sample.
- Don't expect to find "everything" in the aggregate sample; geology varies greatly across the state.
- Seek help on questionable rocks; contact the Maplewood Materials Lab or Geology Unit for help.

After each rock piece has been classified, it should be placed in a container with the rock type clearly labeled. When all the pieces in a particular sample have been classified and grouped weigh each group to the nearest 0.1 gram and record the value on the Quality Test Work Sheet. (See Section 1209.10) Everything not classified and grouped by type, should be listed as "Other Rock".

Some rock pieces can be identified as belonging to more than one group. For example: a piece of carbonate can also be a soft rock (CA Standard); schist can also be a disintegrated rock (CA Complete). For these and other similar situations, the weight of such piece(s) should be included in **both** groups. (This means it is possible for percentages to add-up to be greater than 100.) Spall pieces (as defined in footnote[1] in Table 1) should only be counted as spall and **not be double classified**.

Section 1209.4 (Table 1) shows four types of "lithos" picked in the laboratory and the corresponding rock types. When other special "litho" information is required, such as percent of non-compliant material in Sioux Quartzite (Note 1), it will be indicated on the work sheet.

TABLE 1 – Rock Types for Lithological Summary

CA[1] Standard Litho	CA[1] Complete Litho	BA & GS[1] Standard Litho	BA & GS[1] Complete Litho
"Spalling" Rock Types[2]	"Spalling" Rock Types[2]	"Spalling" Rock Types[2]	"Spalling" Rock Types[2]
Shale(A1)			
Soft Iron Oxides (Ochre & Paint Rock)(A2)			
Other Iron Oxides(A3)			
Unsound Chert(A4a)			
Pyrite(A5)			
Spalling Argillite(A6)			
Spalling Phyllite(A7)			
Miscellaneous Spall (Other Materials with Similar Characteristics)			
Other Specified Rocks	Other Specified Rocks	Other Specified Rocks	Other Specified Rocks
Carbonate[3](B1)	Carbonate[3](B1)		
Soft Particles[4](B2)	Soft Particles[4](B2)		Soft Particles[4](B2)
Flat or Elongated Pieces[5](B3)	Flat or Elongated Pieces[5](B3)		
Slate(B4)	Slate(B4)		
Clay Balls & Lumps[6](B5)	Clay Balls & Lumps[6](B5)	Clay Balls & Lumps[6](B5)	Clay Balls & Lumps[6](B5)
Class A(B6)	Class A(B6)		
Potential Problem Rocks	Potential Problem Rocks	Potential Problem Rocks	Potential Problem Rocks
	Sandstone		Sandstone
	Schist		Schist
	Non-Spalling Argillite[7]		Non-Spalling Argillite[7]
	Non-Spalling Phyllite[7]		Non-Spalling Phyllite[7]

[1] Per Lab Procedure 1001.1B, CA stands for Concrete Aggregate, BA for Bituminous Aggregate & GS for Gravel Surfacing.

[2] "Spalling Rock Types" is a term used by MnDOT to denote materials that have detrimental qualities such that they will cause a pop-out or spall in the pavement. Such materials are also said to be deleterious

[3] Include percent carbonate only when aggregate is to be used for concrete paving or bridge superstructure.

[4] The term "Soft Particles" includes the sum of "Soft Rock" and "Disintegrated Rock"

[5] Flat pieces are defined as having a maximum thickness less than ¼ the maximum width. Elongated pieces are defined as having a maximum length more than 3 times the maximum width.

[6] "Clay Balls", also referred to as "Lumps", are defined as "loosely bonded aggregations and clayey masses".

[7] Harder, Non-Spalling variety.

1209.5 DEFINITION of MATERIAL and TERMS

Because no amount of printed description can describe a rock in such a manner that an untrained person could make an immediate identification, the definitions included in this section have purposely been made brief and quite general. Therefore, by themselves, these descriptions will usually not enable a person to accurately identify every rock variety. This information is intended to provide a framework for identifying rock types important to pavement performance. The exact identification of some rocks and minerals can, in many cases, be made only by a qualified geologist. When exact identification is required or questions arise as to how a particle will perform in a field environment, a person with extensive experience and/or professional training should be consulted.

It is important that each person learn by supervised training and practical experience to identify those rock types that must be distinguished for the lithological count. Identification alone does not predict rock quality, but only serves as a method of picking out those aggregates which have not given satisfactory, long-term performance based on field experience.

All rocks may be separated into three main classes on the basis of their origin:

1. **Igneous Rock** - Rocks, which have solidified from magma originating beneath the earth's surface. Magma that cools rapidly at the surface produces fine grained rocks such as basalt and rhyolite. Slower cooling at depth produces coarse grained rocks such as granite and gabbro. Igneous rocks are very strong and typically harder than a knife.

2. **Sedimentary Rock** - Rock formed from consolidation of loose sediment that has accumulated in layers. Clastic sedimentary rocks consist of mechanically formed fragments of older rock or animal fragments. These rocks, such as shale, siltstone, and sandstone are typically weak, and do not make good aggregate. Chemical sedimentary rocks form by precipitation from solution. These rocks include limestone, dolostone and chert, and are moderately strong. Most sedimentary rocks are softer than a knife.

3. **Metamorphic Rock** – Rock formed from pre-existing rocks which have been changed by temperature, pressure, and/or chemical fluids into new forms. Most metamorphic rocks exhibit some type of planar orientation called foliation, such as argillite, phyllite, slate, or schist. In gneiss, the foliation is in the form of banding. Non-foliated metamorphic rocks include quartzite and marble. Metamorphic rocks are typically strong enough for aggregate applications, but their foliation often results in thin and elongated shapes.

Some rocks can be further described as weathered or deleterious.

1. **Weathered Rock** – The term “Weathered” describes rock that has undergone destructive processes on exposure to atmospheric (air, water) or biological agents which have changed the color, texture, composition, or strength of the rock. In many cases the deleterious rocks listed herein are the result of the weathering of originally acceptable rocks.

2. **Deleterious Rock Types** – Rocks that have been shown to have a harmful or damaging effect on pavements or structures. Most spalling rock types are derived from either argillaceous materials (composed of or containing clay and silt-sized particles), or ferruginous materials (composed of or containing iron). Argillaceous rocks include shale and low-grade metamorphic rocks, such as argillite, slate, and phyllite. When weathered, argillite and phyllite take on deleterious qualities and are considered spall. Ferruginous rocks weather to a rusty iron oxide and clay mixture and will spall in pavements and leave an iron oxide stain which is undesirable in architectural applications. <u>Rocks considered by MnDOT to be deleterious are described below in the order in which they appear in the Table 1</u>. These descriptions are intended to give a consistent methodology for picking deleterious material and are not intended to give sufficient training to those without experience with rock identification.

A) SPALLING ROCK TYPES

A1) Shale - A sedimentary rock composed of thinly laminated (fissile) clay and silt-sized particles with a low specific gravity (1.8 or less) and very high absorption. Due to its high absorbency, dry shale will cling when touched to the moistened lip. It is easily scratched with the fingernail and is typically light gray in color. Because of its light weight and tendency to break into flat, platy pieces, shale will cause many more spalls per weight than any other deleterious aggregate. <u>Shale is considered a SPALL Material.</u>

A2) Soft Iron Oxide Particles (ochre and paintrock)

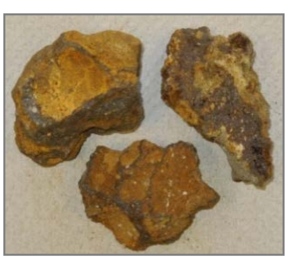
A2a) Ochre - <u>Very</u> soft, loosely-cemented particles of iron oxide, usually red to rusty to yellowish in color, very fine-grained, <u>light weight</u> and highly absorptive. Easily leaves a stain on the fingers. Ochre is picked and classified separately from other "iron oxides" because of its highly deleterious nature. <u>Ochre is considered a SPALL Material.</u>

A2b) Paintrock - Very soft, with a clayey, “greasy” feeling, consisting of particles of iron oxide (red) or manganese oxide (dark gray) and clay minerals. When wetted, it can literally be used to paint a trace on the skin. Paintrock is picked and classified separately from other "iron oxides" because of its highly deleterious nature. Paintrock is considered a SPALL Material.

A3) Other Iron Oxides – A generic term applied to weathered oxides of iron minerals such as hematite, magnetite or siderite. These particles are typically soft, absorptive and rusty to dark gray in appearance. Most iron oxides are the result of severe weathering of local iron formations, or siderite (iron carbonate) beds within carbonate formations. Siderite and other iron minerals often contain clay and readily alter to limonite, which is an impure, soft, clayey product. Iron oxides are perhaps the most easily recognizable deleterious particles. When picking iron oxides, the very soft paintrock and ochre should be separated and placed in their own category of “Soft Iron Oxides”. Once these have been separated, there is no need to further divide the “Other Iron Oxides” into subgroups (as below):

A3a) Shelled Siderite Oxides – Siderite is an iron carbonate ($FeCO_3$) that often occurs as “concretionary ironstone” with a shell consisting of an extremely fine-grained mixture of siderite and clay. The inside is often very soft and will fall apart in your hands. When found intact with a hard core, the whole particle is considered to be spall material if more than 1/3 of it is covered with an oxide shell, which is at least 3/16 in. thick. Pieces of shell by themselves, regardless of thickness, are considered to be Spall Material.

A3b) Sandy Oxides - Fine-grained iron or manganese oxide material in which sand grains (coarse or fine-grained) are "floating" in the oxide matrix; i.e., the individual grains do not generally touch each other. (If the sand grains are touching with iron oxide cement, the rock will be considered sandstone, and NOT a spall.) Sandy Oxides are considered SPALL Material.



A3c) Rusty, Banded, or Mottled Oxides - Rusty oxides are fine-grained, soft, highly absorptive and are usually a uniform light to dark brown in color. Banded oxides have similar properties, but show roughly concentric rings or bands of darker and lighter oxide when fractured. Mottled oxides exhibit a mixture of black and yellow to rust oxidation products. The entire group of Iron Oxides are considered SPALL Material.

A4) Chert - A sedimentary rock composed of cryptocrystalline quartz (chalcedony). It is typically hard (can't be scratched with a knife), dark gray to gray brown, has a waxy texture and breaks with a conchoidal (dish-shaped) fracture. Chert, because of its fine-grained silica content, will cause alkali-silica reactions in concrete, but it is NOT considered a spall material.

A4a) Unsound Chert - Chert readily weathers to an absorptive, white, chalk-like appearance and is considered deleterious. Frequently, both sound and unsound chert are found in the same pieces; often with the unsound variety forming a shell around a sound core. In this case, the particle shall be classed as spall if the unsound portion is at least 3/16 inch thick and this thickness covers at least 1/3 of the particle. Unsound Chert is considered a spall material.

A5) Pyrite – A mineral composed of iron sulfide (FeS_2) which is a golden metallic color in its more stable crystal form (fool's gold). It often exists as a very fine-grained, grayish-silver, globular concretion that weathers to a greenish-black color. Because of its high specific gravity, particles may feel heavier than other rocks. When near the surface, pyrite in any form will weather and severely stain the pavement surface. Both the crystalline and the concretionary form of Pyrite are considered spall materials.

A6) Argillite - A slightly metamorphosed, fine-grained, argillaceous rock displaying minor, sub-parallel foliation. Argillites will appear to have some layering, but it is not well developed. They are typically dark gray to black in color and can be scratched with a knife, but not a brass pencil. Hard, non-weathered, argillites do not typically exhibit spalling characteristics. When not weathered, Argillite is NOT considered a spall material, but it should be identified on the "Quality Test Work Sheet."

A6a) Spalling Argillite – Soft, weathered argillites that have had some of their minerals altered to softer clay minerals. These weathered argillites are soft enough to be scratched by a brass pencil, are often absorptive, and will spall when near the pavement surface. Spalling argillites often have a dull gray color and have rounded edges in comparison to the more durable, non-weathered argillites. Spalling Argillites are considered a SPALL Material.

A7) Phyllite - A foliated metamorphic rock primarily composed of quartz, mica and chlorite. It is metamorphosed a degree between slate and schist. Phyllite is typically silver to gray in color and is easy to pick out due to its satiny sheen. Some phyllites will display crenulation folds (small rippled appearance) which are the result of secondary stresses. When not weathered, Phyllite is typically harder than a brass pencil and is NOT considered a spall material, but it should be identified on the "Quality Test Work Sheet".

A7a) Spalling Phyllite – Weathered phyllites become softer as their minerals are altered to clays. These weathered phyllites are soft enough to be scratched by a brass pencil, are often absorptive, and will spall when near the pavement surface. In some areas near the Cuyuna Range, phyllites have weathered to a dull pinkish color. Spalling Phyllites are considered SPALL Materials.

A8) Miscellaneous Spall (Other Materials with Similar Characteristics) - This category includes all other materials that are not listed specifically as spalling rock types, but exhibit characteristics that make it probable that they will spall, and have a documented history of bad performance in the field. Rocks that are added to this category should be done so on a regional or state-wide basis with approval of the Geology Unit, District Materials Lab and the Material & Testing Section.

A highly weathered troctolite, which is found commonly in pits along the TH1 corridor in Lake County, has been shown to be deleterious and has been added to the category of Miscellaneous Spall. This rock type should be considered spall material if it fits the criteria identified in **NOTE 1 for Special Method for Identifying Spalling Potential of Weathered Troctolite/Gabbro from the Isabella, MN area.**

B) OTHER SPECIFIED ROCKS

These are rock types that have specified limits which have been established by one or more of the Pavement Units (Concrete of Bituminous). Exceeding the specified limits will cause a test failure of the aggregate sample. These ARE NOT SPALL Materials and should not be included under the spall total.

B1) Carbonates - Limestone $CaCO_3$, and dolostone $CaMg(CO_3)_2$, dominate the rock group called carbonates. Because of their similarity, they are grouped as one rock type for the litho count. The two may also be found chemically mixed together in almost any proportion. Carbonates

vary widely in color, ranging from off-white, through light gray, dark gray, tan/buff, and pinkish to yellowish orange (rusty). The diagnostic test for carbonates is to apply of a drop of dilute hydrochloric acid (HCl) to the rock; if it effervesces, it should be counted as a carbonate. Because pure dolostone does not react with HCl unless it is powered, all rocks that look like carbonates should be scratched with a knife blade and HCl applied to the powder – effervescence indicates a dolostone which should be counted as a carbonate.

B2) Soft Particles – Rocks that fit into this category have been substantially weakened by weathering. The term "Soft Particles", as used in Concrete specifications, includes the total of both **soft rock** and **disintegrating rock** (described below):

B2a) Soft Rock- Highly weathered, fine-grained rocks (such as: limestone, rhyolite, basalt, etc.), which can be scratched with a brass pencil. Since rocks typically weather from the outside to the inside, soft rocks should be verified by breaking and testing the inside. If the inside can be scratched, then it should be counted as "Soft Rock".

B2b) Disintegrated Rock - Highly weathered, coarse-grained rocks (such as: granite, gneiss, gabbro, schist, etc.) that have been weakened by weathering to the extent that they can be broken by finger pressure. These rocks should be counted as "Disintegrated Rock".

B3) Flat or Elongated Pieces – Flat or elongated particles can interfere with good compaction or paving practices, and are limited by specification in both concrete and bituminous applications. The procedure for determining these particles is outlined in 1208, "Flat and Elongated Particles in Coarse Aggregate." These rocks should be counted as "Flat or Elongated Pieces".

B4) Slate - A very fine-grained, metamorphosed argillaceous rock. It commonly breaks into thin plates or sheets and is typically a dark gray to black color. Usually harder than a brass pencil. Thin pieces may "ring" when dropped on a solid surface. Broken edges exhibit layering and parallel breaks (slaty cleavage).
These rocks should be counted as "Slate"

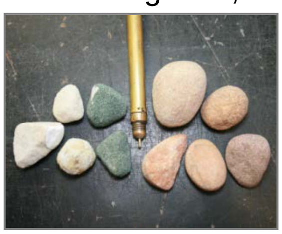
B5) Clay Balls & Lumps – Agglomerated pieces of clay that have hardened to the degree that they survive handling and treatment like regular aggregates, but will break apart on wetting and/or freezing. They can typically be broken with a light hammer blow. The particles are not counted as spall but should be reported under "Clay Ball & Lumps."

B6) Class A – When pavement applications require higher quality rock for certain applications, they specify "Class A" aggregates, which typically includes crushed igneous rocks (basalt, granite, gabbro, etc.) as well as quartzite and gneiss. Since aggregates are a natural product, they may contain impurities, such as sandstone or argillite in quartzite, or schist in gneiss. Class A specifications often include a maximum limit of "Non-Class A" material. When conducting this litho test, pick out all of the non-Class A material and report it as such. There is a special procedure included in this section to describe the method for identifying the sandstone content in Sioux Quartzite **(Note 2: Special Method for Identifying Non-Compliant Material Quarried from the Sioux Quartzite).**

C) POTENTIAL PROBLEM ROCKS

These are rocks that have suspect quality and MnDOT has chosen to track them on projects in the event that pavement durability problems arise. None of these rocks are currently regulated and should not be counted as Spall Material.

C1) Sandstone - A rock composed of sand-sized, predominately quartz grains, which are compacted or cemented together. Three of the most common cements are calcite, silica, and iron oxide. Colors vary widely depending on the cementing agent. Individual grains usually can be seen with the unaided eye, although some of the very fine-grained varieties may require the use of a hand lens for identification. Individual grains can range from rounded to angular. Sandstone should not be counted as Spall material.



C2) Schist - A metamorphic rock which is usually medium or coarse-grained and characterized by parallel orientation of plate-like or needle-like mineral grains (foliation). This orientation causes the rock to have a thinly banded or layered appearance. Frequently, rocks of this type fracture along the parallel layers and often disintegrate quite rapidly upon weathering. Schist should not be counted as Spall material.

C3) Non-Spalling Phyllite & Argillite – When they are sufficiently weathered, both phyllite and argillite can be considered spall material. The harder varieties (cannot be scratched with a brass pencil) are not considered spall material, but they are tracked by MnDOT should future problems arise. Non-spalling argillites and phyllites should not be counted as Spall material.

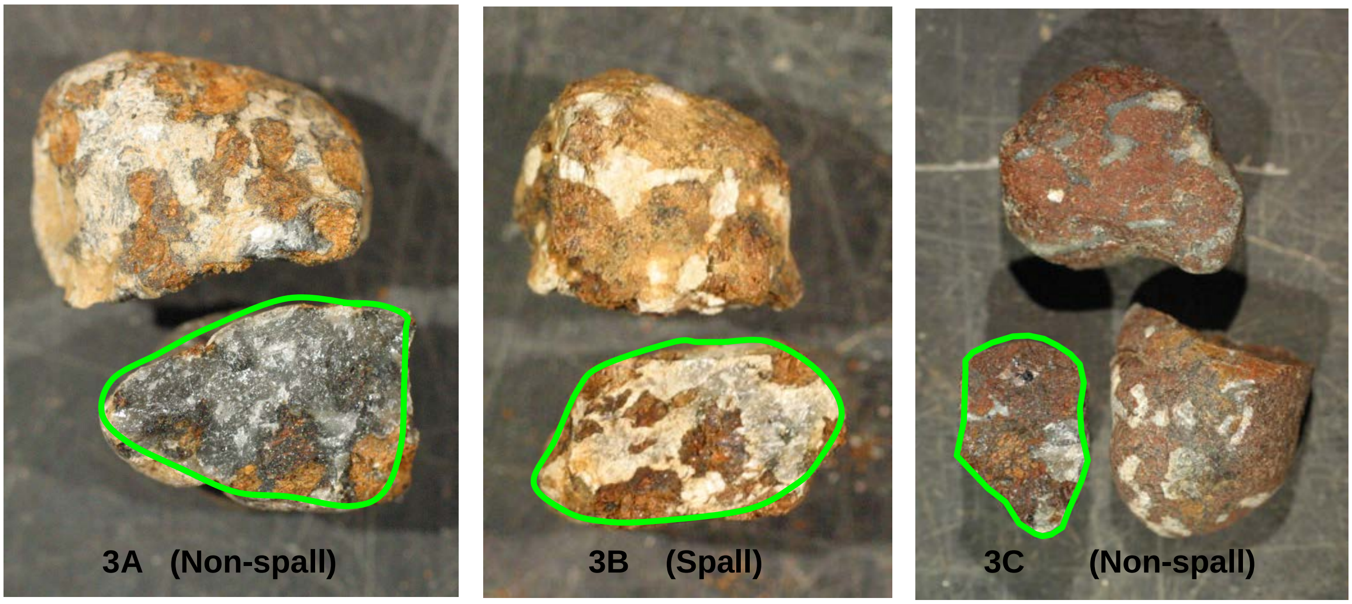
NOTE 1: SPECIAL METHOD FOR IDENTIFYING SPALLING POTENTIAL OF WEATHERED TROCTOLITE/GABBRO FROM THE ISABELLA, MN AREA.

Gravel Pits in the Isabella area contain sand and gravel deposits of the Superior/Rainey Lobe. The rock fragments are principally igneous in nature with a large fraction derived from troctolitic bedrock (gabbro with olivine as the predominant ferromagnesium mineral). The rock fragments (boulders down to gravel size) have a spotted appearance due to weathering of their main constituents – plagioclase and olivine. The plagioclase weathers to the light colored mica mineral, *sericite*; and the olivine weathers to a rusty-colored mixture of clay minerals, iron oxides and ferrihydrides, known as *iddingsite*. Iddingsite can be loosely described of as an "iron oxide", particularly when it has undergone extreme weathering to the extent where it has a rusty, pulverulent (easily pulverized) appearance.

Figure 1 – 3/8-inch pile of marginal quality aggregate (right), close-up of aggregate (left)

Figure 2 – Full range weathered troctolitic aggregate found in area pits from highly weathered/altered (left) to fresh (right). Also found in the pits is a metallic looking, "high iron" variety which is not considered spall (far right).

Mn/DOT testing has revealed that the highly weathered portion of this aggregate is deleterious and will not perform well in freeze/thaw conditions. The line between marginal (non-spall) and spalling aggregate will be based on the degree of weathering of the particle. To be considered a spall particle, at least 50% of the aggregate must contain highly weathered minerals (rusty iron oxide and soft, light-colored clayey silts).



Green outline indicates split (broken) face.

Figure 3A - "Marginal" aggregate (left) with mostly fresh core,
Figure 3B - "Spall" aggregate (center) with mostly weathered/altered core,
Figure 3C - "High Iron" aggregate (right).
Green outline indicates split (broken) face.

TEST PROCEDURE

To determine the amount of spalling rock that should be reported under "Other materials with similar characteristics", it is recommended that you follow these steps:

1. Pick out all of the marginal, spotted material
2. Split or break all of the marginal material.
3. Place in the spall category, any sample where the split face has at least 50% highly weathered minerals (rusty iron oxide and soft light-colored clayey silts), such as Figure 3B.
4. Do not include material designated as "high iron" (Figure 3C), which has a more reddish color and often, a metallic luster. This is likely a similar product of alteration, where the olivine has been altered to iron oxide products (such as magnetite or hematite), but has not been weathered to an earthy, rusty, iron oxide as the other categories have.

NOTE 2: SPECIAL METHOD FOR IDENTIFYING NON-COMPLIANT MATERIAL QUARRIED FROM THE SIOUX QUARTZITE

DEFINITION of MATERIAL and TERMS

Sioux Quartzite is quarried at locations in southwestern Minnesota and eastern South Dakota for use in Mn/DOT projects. The formation is primarily quartzite but also contains minor amounts of sandstone, mudstone and conglomerate. The geological characteristics identifying these rock types are given in the *Geotechnical & Pavement Manual.* Quarried quartzite is considered Class A material but sandstone, mudstone and conglomerate are not. Mudstone and conglomerate are not commonly found in the quarried aggregate material from these quartzite sources, however, sandstone is frequently present.

Sandstone may be separated from quartzite by observing the crushing characteristics of a sample, where quartzite will fracture through the grains, giving it a glassy or vitreous appearance and sandstone will fracture around the grains giving it a granular appearance. Using this criterion would be unnecessarily restrictive since many of the sandstone particles possess engineering characteristics similar to the quartzite, such as low absorption, high resistance to abrasion, high resistance to degradation, high strength, superior hardness and angularity. Sandstone that possesses engineering characteristics similar to quartzite will be considered substantially compliant to Class A requirements. Sandstone that does not possess these characteristics will be considered non-compliant material.

Shape is a valuable characteristic that can be used to help separate these materials. When quartzite is crushed, it tends to break in very angular shapes, and because the quartzite is hard and resistant to abrasion, the crushed particles keep their angular shape through the production and handling operations. On the other extreme is poorly cemented, "brown" sandstone that will often crumble under finger pressure. These particles are weak and not abrasion resistant, and consequently end up as rounded particles. There is of course, a continuum between these two extremes, and a line must be drawn between the less resistant sandstone particles and the more resistant sandstone particles that exhibit near-quartzite qualities.

The natural place to make the break between the more angular, "substantially compliant" sandstone and the less angular "non-compliant" sandstone is at the division between the roundness classification of sub-angular and sub-rounded particles (Roundness Classification of sedimentary particles - M.C. Powers, 1953). In practice this line between sub-angular and sub-rounded may be very subtle. Since the distinction is based on visual qualities that are difficult to measure, the results may not be consistent between all viewers. In light of this, all questionable decisions should be made in favor of the producer.

TEST PROCEDURE

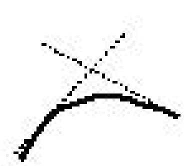
To determine the amount of non-compliant sandstone in a crushed sample of Sioux Quartzite, it is recommended that you follow these steps:

1) Pick out all the brown to rusty, rounded sandstone particles, and any particles that are soft and friable (will break under finger pressure). These are the lowest quality, and are generally the easiest to pick. This pile will be the beginning of the non-compliant sandstone. (You may occasionally come across a rusty particle that is very hard and angular. You can put it in the granular pile described in Step 2, for further identification).

2) Separate all granular (grainy appearance), pink to brown particles from the glassy, angular particles (quartzite). If in doubt, throw the particle into the granular pile. These particles should be predominantly sandstone, and often appear to have larger grains than the glassy quartzite particles.

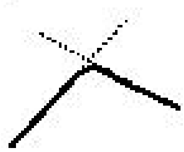
3) Pick through the granular pile. Any particle that has a [1]rounded or well-rounded shape (Figure 1) should be added to the non-compliant pile.

4) The remaining particles should be [2]sub-rounded to [3]sub-angular. If the particles have edges or corners that are considerably rounded off to smooth curves, then consider them sub-rounded and place them in the non-compliant pile. Particles that are somewhat abraded or worn, yet keep their general form and have only slightly rounded edges or corners can be placed in the compliant pile. Use the definitions below, as well as the chart (Figure 1) to help you make your determinations.



[1]**Rounded** - A particle whose original edges and corners have been smoothed off to rather broad curves and whose original faces are almost completely removed by abrasion.

[2]**Sub-rounded** - A particle showing considerable but incomplete abrasion and an original general form that is still discernible, and having many of its edges and corners noticeably rounded off to smooth curves



[3]**Sub-angular** - a particle showing definite effects of slight abrasion, retaining its original general form , and having faces that are virtually untouched and edges and corners that are rounded off to some extent.

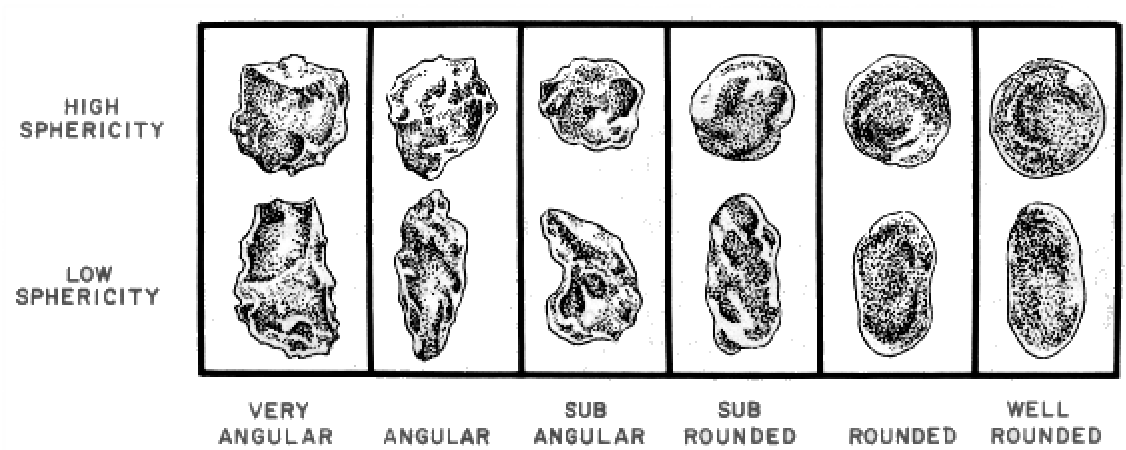


Figure 4 - Particle roundness (or angularity) depicted for both equant and elongate particles. (Modified from Powers, M. C., 1953, A New Roundness Scale for Sedimentary Particles)

If there is any uncertainty of how to pick a group of particles and that group of particles could fail the sample, the sample should be sent to the Geology Unit at the Maplewood Lab. The Chief Geologist or designated assistant will analyze the roundness of the particles using the procedure outlined above, and any other appropriate method.

Figure 5 – Particle roundness from left to right: angular, sub-angular, sub-rounded and rounded (in natural light)

1209.6 CALCULATIONS

1. Calculate the percent retained (rock type) for each size (1”+, 1”- 1/2”, ½”- #4) using the following formula:

$$\textbf{\% (Rock Type)} = \frac{\text{Dry Weight of Rock Type}}{\text{Dry Weight of Sample Size}} \quad \mathbf{X} \ 100$$

   Record to the nearest 0.01 percent.

2. Determine the weighted average (WA) on the rock type using the following formulas:

   WA% (Rock Type) = (Rock Type %[1”+]) x (% Retained [1”+])
   +
   (Rock Type %[1”- 1/2”]) x (% Retained [1”- 1/2”])
   +
   (Rock Type %[1/2”- #4]) x (% Retained [1/2”- #4])

   Report to the nearest 0.1 percent.

NOTES:

1. Add the WA% of all rock types together. The total should equal approximately 100%. If a rock type is placed in more than one category (Example: as a carbonate and as a soft rock) the total of the percentages will exceed 100.

2. On a Spall Litho, where one size is not tested it is assumed to be the same as the fraction above or below, with the exception of the Soft Rock calculation which assumes there is no Soft Rock included in the calculation.

3. Computerized Spreadsheets for calculating aggregate quality are available on the MnDOT Lab Manual Website.

Link to Bituminous GB Qualities Spreadsheet

Link to Concrete Qualities Spreadsheet

1209.7 EXAMPLE CALCULATIONS FOR CONCRETE AGGREGATE

Refer to the Example Calculation Spreadsheet in 1209.10 for sample weights and aggregate gradation information.

Determine the % Carbonate for each size:

For size (1" – 1/2"):

$$\% \text{ Carbonate} = \frac{300.0}{3150.0} \times 100 = 9.52$$

For size (1/2" - #4):

$$\% \text{ Carbonate} = \frac{110.0}{1050} \times 100 = 10.48$$

Determine the weighted average (WA) of the % Carbonate for the total sample:

For size (1" – 1/2"): (9.52 x 0.40) = 3.81

For size (½" - #4): (10.48 x 0.60) = 6.29

WA % (Carbonate) = 3.81 + 6.29 = 10.10

Reported to 0.1 = 10.1%

NOTE: From the sample gradation 37% of the total sample is contained in the (1" - 1/2") size and 92% of the total sample is contained in the (1" - #4) size.

To make calculations on the (+ #4) material only, divide 37% by 92% = 40% of the material on the (1" - 1/2") size.

The remaining 60% of the material is contained on the (1/2" - #4) size.

Determine the weighted average (WA) of the % Soft Rock for the total sample:

WA % (Soft Rock) **=** (1.11 x 0.37) **+** (0 x 0.55) **=** 0.41

Reported to 0.1 = 0.4%

NOTE: It is assumed there is no Soft Rock in the (- #4) size therefore 8% is not included in the weighted average calculation. This is done only for the Soft Rock calculation; all other calculations are done as in the carbonate example above.

1209.8 EXAMPLE - QUALITY TEST WORK SHEET (1 - 1/2" size)

Quality Test Work Sheet Lab. No. *TS-CA12-0014*

Test	Litho	Comp.	Crush	Ing.	Soft R.	Carbonate
	L.A.R.	A.B.C	Str.-Str.	Mag. Sul.	F&T	Sp.G. & Abs
	Shale	-4 +4				
Size	1½+	1 - ¾		½ - ⅜		
	1½ - 1	¾ - ½		⅜ - #3	3 - 4	

L.A.R. TEST

Weight Before		# Balls	
Weight After		Rev. Start	
Weight Loss		Rev. End	
% Loss		Difference	

SHALE TEST		**% CRUSHING COUNT**			
Original Weight		1F		2F	
Shale		Non-Crushed			
% Shale		Total			

SPALLING ROCK TYPES			
		Disintegrating Rock	0.0g
Shale	2.0g	Slate	0.0g
Ochre	0.1g	Clay Balls	
Paint Rock	0.1g	Flat or Elongated	
Other Iron Oxides	7.0g	Class A	
Unsound Chert	0.0g	**POTENTIAL PROBLEM ROCKS**	
Pyrite	0.0g	Sandstone	65.0g
Spalling Argillite	0.0g	Schist	0.0g
Spalling Phyllite	0.0g	Non-Spall Argillite	20.0g
Miscellaneous Spall	5.0g	Non-Spall Phyllite	20.0g
OTHER SPECIFIED ROCKS		Other Rock	2695.8g
Carbonate	300.0g	TOTAL WEIGHT	3150.0g
Soft Rock	35.0g		

PREPARED BY: DW TESTED BY: CR DATE: 8/16/12

1209.9 EXAMPLE - QUALITY TEST WORK SHEET (1/2" - #4 size)

Quality Test Work Sheet Lab. No. *TS-CA12-0014*

Test	Litho	Comp.	Crush	Ing.	Soft R.	Carbonate
	L.A.R.	A.B.C	Str.-Str.	Mag. Sul.	F&T	Sp.G. & Abs
	Shale	-4 +4				
Size	1½+	1 - ¾		½ - ⅜		
	1½ - 1	¾ - ½		⅜ - #3	3 - 4	

L.A.R. TEST

Weight Before		# Balls	
Weight After		Rev. Start	
Weight Loss		Rev. End	
% Loss		Difference	

SHALE TEST		% CRUSHING COUNT	
Original Weight		1F	2F
Shale		Non-Crushed	
% Shale		Total	

SPALLING ROCK TYPES			
		Disintegrating Rock	0.0g
Shale	1.0g	Slate	0.0g
Ochre	0.1g	Clay Balls	
Paint Rock	0.1g	Flat or Elongated	
Other Iron Oxides	3.5g	Class A	
Unsound Chert	0.0g	**POTENTIAL PROBLEM ROCKS**	
Pyrite	0.0g	Sandstone	30.0g
Spalling Argillite	0.0g	Schist	0.0g
Spalling Phyllite	0.0g	Non-Spall Argillite	10.0g
Miscellaneous Spall	2.5g	Non-Spall Phyllite	12.0g
OTHER SPECIFIED ROCKS		Other Rock	880.8g
Carbonate	110.0g	TOTAL WEIGHT	1050.0g
Soft Rock	0.0g		

PREPARED BY: DW TESTED BY: CR DATE: 8/16/12

1209.10 EXAMPLE- CONCRETE AGGREGATE QUALITY SPREADSHEET

Concrete Aggregate Quality Summary (10/11/12)

	Weight Retained Sieve Sizes			Percent Retained Sieve Sizes			Weighted Average	Weighted Average +1/2"
	1" +	1"-1/2"	1/2"- #4	1" +	1"-1/2"	1/2"- #4		
Spalling Rock Types								
Shale		2.0	1.0		0.06	0.10	0.1	0.1
Ochre		0.1	0.1		0.00	0.01	0.0	
Paint Rock		0.1	0.1		0.00	0.01	0.0	
Soft Iron Oxides		0.2	0.2		0.01	0.02	0.0	
Other Iron Oxides		7.0	3.5		0.22	0.33	0.3	
Unsound Chert		0.0	0.0		0.00	0.00	0.0	
Pyrite		0.0	0.0		0.00	0.00	0.0	
Spalling Argillite		0.0	0.0		0.00	0.00	0.0	
Spalling Phyllite		0.0	0.0		0.00	0.00	0.0	
Miscellaneous Spall		5.0	2.5		0.16	0.24	0.2	
Total Spall		14.2	7.2		0.5	0.7	0.6	0.5
Other Specified Rocks								
Carbonate		300.0	110.0		9.52	10.48	10.1	
Soft Rock		35.0			1.11		0.4	
Disintegrating Rock		0.0	0.0		0.00	0.00	0.0	
Soft Particles		35.0	0.0		1.11	0.00	0.4	
Slate		0.0	0.0		0.00	0.00	0.0	
Clay Balls								
Flat or Elongated								
Spall, Soft Particles and Clayball								
		49.2	7.2		1.56	0.69	1.0	
Potential Problem Rocks								
Sandstone		65.0	30.0		2.06	2.86	2.5	
Schist		0.0	0.0		0.00	0.00	0.0	
Non-Spall Argillite		20.0	10.0		0.63	0.95	0.8	
Non-Spall Phyllite		20.0	12.0		0.63	1.14	0.9	
Other Rock		2695.8	880.8		85.58	83.89	84.6	
Wt Total Sample		3150.0	1050.0		100.00	100.00		

Lightweight Pieces in Fine Aggregate:	
Original Wt. (Sand Total)	
Wt of Lightweight Pieces	
Percent Shale in Sand	

Percent Passing #200 Sieve (Coarse Aggregate)	
Original Wt.	5000.2
Wt. After Wash	4960.2
Pan Wt.	0
Pct Passing #200 Sieve	0.8

Gradation Coarse Sieve Analysis		
Sieve size	% Passing	% Retained
1 1/2"		100
1 1/4"		100
1"	100	0
3/4"	95	5
5/8"	86	14
1/2"	63	37
3/8"	41	59
#4	8	92

For Wtd. Avg. Calculations		
	Raw Value	Adjusted*
Percent Retained 1" +	0	0
Percent Retained 1"-1/2"	37	37
Percent Retained 1/2"- #4	55	55
Total Retained on #4	92	92

*FOR SMALL QUANTITIES NOT TESTED - If fraction is not tested due to insufficient material, it is assumed to have the same qualities as that fraction above or below that is tested. Mn/DOT assumes amount above 5% will be tested.

Example Calculations:

$$\text{Rock Type \%} = \frac{\text{Dry Weight of Rock Type}}{\text{Dry Weight of Total Sample}} \times 100$$

Weighted Avg = (Rock Type % (1"+))(% Retained 1"+) + (Rock Type % (1" -1/2 "))(% Retained 1" -1/2 ") + (Rock Type % (1/2" - #4))(% Retained 1/2" - #4)

[Link to Bituminous GB Qualities Spreadsheet]

[Link to Concrete Qualities Spreadsheet]

1209.11 EXAMPLE – TEST REPORT FORM

The aggregate test report shown on this page is an example of the current computer generated report and does not reflect any of the examples and values shown elsewhere in this manual section.

State of Minnesota Department of Transportation
Aggregates Test Report
Test District
123 Sesame Street
Lake Wobegon, MN 98765

Sample ID Number: TS-CA12-0014		**Project Number:**	**For Info Only**
Field ID:	#1 3/4-	Billing Agency:	
Date Sampled:	08/15/2012	Project Engineer:	
Date Received	08/15/2012	Submitter:	T. HUNT
Approved:	9/17/2012 10:53	IAS Name:	
TH Number:	I-94	Pit#:	
Bridge #:		Pit Name:	EUREKA
Grade Spec:	3137	Pit Owner:	
Spec Class:	CA-50	Sampled From:	BELT
Quality Spec:	3137.2D3C	Usage:	PAVING
Plant Name:	JOB MIX		
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
25.0mm (1")	100	100	100	100
19.0mm (3/4")	95	95	85	100
16.0mm (5/8")	83	84		
12.5mm (1/2")	63	66		
9.5mm (3/8")	41	43	30	60
4.75mm (#4)	8	9	0	12
% Minus #200	0.8	0.7	0	1.0
%Total Shale +1/2"	0.1			0.4
%Total Shale +4	0.1			0.7
% Ochre	0.0			
% Paint Rock	0.0			
% Soft Iron Oxide	***0.0			0.3
% Iron Oxide	0.30			
% Unsound Chert	0.00			
% Pyrite	0.0			
% Spall Argillite	0.0			
% Spall Phyllite	0.0			
% Misc. Spall	0.21			
% Carbonate	10.1			30
% Soft Rock	0.4			2.5
% Disint. Rock	0.0			
% Slate	0.0			3.0
% Sandstone	2.5			
% Schist	0.00			
% NonSpall Argillite	0.8			
% NonSpall Phyllite	0.9			
% Other Rock	84.6			
%Spall,SRock&Cball	1.0			3.5
%Total Spall +1/2"	0.5			1.0
%Total Spall +4	0.6			1.5
Mag%Lost 3/4-1/2	3.1			
Mag%Lost 1/2-3/8	4.8			
Mag%Lost 3/8-4	5.3			
%Mag Total Loss	4.4			15

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

- [x] 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

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1209.12 BLANK - QUALITY TEST WORK SHEET

Quality Test Work Sheet

Lab. No. ____________

Test	Litho	Comp.	Crush	Ing.	Soft R.	Carbonate
	L.A.R.	A.B.C	Str.-Str.	Mag. Sul.	F&T	Sp.G. & Abs
	Shale	-4 +4				
Size	1½+	1 - ¾		½ - ⅜		
	1½ - 1	¾ - ½		⅜ - #3	3 - 4	

L.A.R. TEST

Weight Before	____	# Balls	____
Weight After	____	Rev. Start	____
Weight Loss	____	Rev. End	____
% Loss	____	Difference	____

SHALE TEST		**% CRUSHING COUNT**	
Original Weight	____	1F ____ 2F	____
Shale	____	Non-Crushed	____
% Shale	____	Total	____

SPALLING ROCK TYPES		Disintegrating Rock	____
Shale	____	Slate	____
Ochre	____	Clay Balls	____
Paint Rock	____	Flat or Elongated	____
Other Iron Oxides	____	Class A	____
Unsound Chert	____	**POTENTIAL PROBLEM ROCKS**	
Pyrite	____	Sandstone	____
Spalling Argillite	____	Schist	____
Spalling Phyllite	____	Non-Spall Argillite	____
Miscellaneous Spall	____	Non-Spall Phyllite	____
OTHER SPECIFIED ROCKS		Other Rock	____
Carbonate	____	TOTAL WEIGHT	____
Soft Rock	____		

PREPARED BY: ____________ TESTED BY: ____________ DATE: ____________