1209 LITHOLOGICAL SUMMARY

1209.1 GENERAL

This test procedure is used with 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.

NOTE 1: Always add acid to water when mixing and use proper precautions.

B. "Brass Pencil" - Supplied by Central Lab. (See Section 1218.2 for description.)

C. Balances - Shall conform to AASHTO M 231 (Classes G2 & G20). Readability & sensitivity 0.1 grams, accuracy 0.1 grams or 0.1%. Balances shall be appropriate for the specific use.

D. Desk Lamp.

E. Small Hammer, Steel Plate and Safety Glasses.

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

G. Magnifying Hand Lens (10 to 15 power).

H. 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 identify each rock piece individually. Some rock types may need to be cracked open to identify or determine the quality of rock. (Always wear safety glasses).

After each rock piece has been identified, it should be placed in a container labeled as to rock type. When all the pieces in a particular sample have been identified and grouped as to type, each group should be weighed to the nearest 0.1 gram and this value recorded on the Quality Test Work Sheet. (See Section 1209.10) Everything not identified 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 **not** be double classified.

Section 1209.4 (Table 1) shows five types of "lithos" picked in the laboratory and the corresponding rock types. When other special "litho" information is required (such as percent crushing) it will be indicated on the work sheet.

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, mineralogist or petrographer.

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. It should be noted that 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.

CA Standard Litho	CA Complete Litho	BA & GS Standard Litho	BA & GS Complete Litho	PS (Pit Run) Litho
"Spalling" Rock Types	"Spalling" Rock Types	"Spalling" Rock Types	"Spalling" Rock Types	"Spalling" Rock Types
Shale	Shale	Shale	Shale	Shale
Iron Oxides	Iron Oxides	Iron Oxides	Iron Oxides	Iron Oxides
Ochre	Ochre	Ochre	Ochre	Ochre
Unsound Chert	Unsound Chert	Unsound Chert	Unsound Chert	Unsound Chert
Pyrite	Pyrite	Pyrite	Pyrite	Pyrite
Spalling Argillite/Phyllite	Spalling Argillite/Phyllite	Spalling Argillite/Phyllite	Spalling Argillite/Phyllite	Spalling Argillite/Phyllite
Other Material of Similar Characteristics	Other Material of Similar Characteristics	Other Material of Similar Characteristics	Other Material of Similar Characteristics	
Other Identified Rock Types	**Other Identified Rock Types**	**Other Identified Rock Types**	**Other Identified Rock Types**	**Other Identified Rock Types**
Slate	Slate	Slate	Slate	Carbonate[6]
Soft Rock[2]	Soft Rock[2]	Clay Balls[3]	Soft Rock[2]	Other Rock
Clay Balls[3]	Clay Balls[3]	Other Rock	Clay Balls[3]	
Thin or Elongated Pieces[4]	Thin or Elongated Pieces[4]		Disintegrating Rock[2]	
Carbonate[5]	Carbonate[5]		Sandstone	
Other Rock	Disintegrating Rock[2]		Argillite	
	Sandstone		Schist	
	Argillite		Other Rock	
	Schist			
	Other Rock			

[1]Spall Materials is a term used by the Minnesota Department of Transportation 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. This term includes those listed under "Spalling" and also other materials of similar characteristics, such as highly weathered (often pinkish) phyllite (a.k.a. Paint rock) and other locally identifiable types that are likely to spall.

[2] The terms "Soft Rock" and "Disintegrated Rock" describe weathering characteristics (condition) of fine-grained rocks (carbonate, rhyolite, basalt, schist, etc.) and coarse-grained rocks (gabbro, gneiss, granite, etc.) respectively. Coarse-grained rocks are defined as those in which the individual grains can be seen with the unaided eye (no magnification). Also see Section 1209.5.

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

[4]Thin 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.

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

[6] Pick only if requested by submitter.

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

Igneous Rock - Rocks, which have formed or crystallized from magma originating beneath the earth's surface. Some examples of igneous rocks are granite, gabbro, and basalt.

Sedimentary Rock - Stratified rocks that have been laid down for the most part under water, although wind action occasionally is important. They may be composed of pre-existing rocks or they may be of chemical or organic origin. Some examples of sedimentary rocks are limestone, dolostone, shale and sandstone.

Metamorphic Rock - Pre-existing rocks which have been changed by temperature, pressure, and/or chemical fluids into new forms. Some examples of metamorphic rocks are argillite, slate, phyllite, schist, gneiss and quartzite.
The following descriptions are for rock types most frequently picked for the lithological summary. The lithographer may refer to other published identification techniques as an aid to the proper rock type identification. These rock types are listed in alphabetical order.

Argillite - A slightly metamorphosed, fine-grained rock displaying minor, sub-parallel foliation. Usually, dark gray to black in color and can be scratched with a knife, but not a brass pencil. They will appear to have some layering, but it is not well developed. These "hard" argillites do not typically exhibit spalling characteristics. Some weathered argillites 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. These "soft" or "weathered" argillites often have a dull gray color and have rounded edges in comparison to the more durable "hard" argillites.

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). Occasionally, very dark gray to almost black limestone will be found and care should be taken not to confuse these with other rock types.

When a drop of dilute hydrochloric acid is applied to dry limestone, it will effervesce (bubble) violently. Pure dolostone will not react with the acid, but when scratched with a knife blade, the resulting powder will effervesce. Chemical mixtures of limestone and dolostone will react to varying degrees depending on proportions of each in the particle.

When either limestone or dolostone contain an appreciable percentage of clay-size material (determined by the Insoluble Residue Test, Section 1221) they may be termed clayey or argillaceous. When the silt and clay-size fines make up a significant percentage of the rock, these varieties of rock make particularly poor aggregates. Because of the included fines and the ease with which they weather, these rocks may fail the soft rock test and should be so classified.

Chert - A sedimentary rock composed mainly of very fine- grained silica. Chert will not react with dilute, hydrochloric acid. On the basis of quality, chert can be divided into two groups: sound or unsound.

> **Sound Chert** - A hard, dark gray to gray brown, or off-white in color, has a waxy texture and breaks with a conchoidal (dish-shaped) fracture. Sound chert scratches glass and cannot be scratched with a knife.
>
> **Unsound Chert** - Typically has a dull, white, chalk-like appearance and is quite absorptive. Unsound chert can usually be scratched with a knife.

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 "unsound" if the unsound portion is at least 4.75mm (3/16 inch [0.2 in.]) thick and this thickness covers at least 1/3 of the particle.

Disintegrated Rock - Highly weathered, coarse-grained rocks (such as: granite, gneiss, gabbro, schist, sandstone, etc.) that are poorly cemented and crumble between the fingers. (Highly weathered, fine-grained rocks (such as: rhyolite, basalt, phyllite, carbonate, very fine schist, etc.) should be checked for hardness with a brass pencil and if scratched, classified as "Soft Rock". See footnote[2] in Section 1209.4.)

Iron Oxides - A generic term applied to rocks that are impregnated, coated, or composed of iron oxides in various forms. Although not a true mineral, the most common form of iron oxide is "limonite", which is a highly weathered, impure, soft clayey alteration product of iron-rich minerals such as goethite or hematite. Limonite is typically soft and rusty to yellowish-gold in color. (Black oxides of manganese are common and also contribute coloring to aggregates and are included under the generic term "iron oxide".)

True iron minerals such as magnetite (magnetic), hematite and goethite have somewhat similar chemical compositions to limonite; but, because they are hard and crystalline, should not be considered to be deleterious or spalling. These minerals are easily identified as having much higher specific gravities and greater hardness than spalling iron oxides.

Iron Oxides - Continued

Streaks on unglazed porcelain are useful in identification of these minerals:

Magnetite = black, Hematite = reddish, Goethite = yellowish-brown. Most spalling "iron oxides" ("Limonites") give rusty to yellowish - brown streaks.

"Iron Oxides" can be extremely variable in color, texture and composition. A general classification of the most common types would be as follows:

Oxides of Siderite - The mineral siderite ($FeCO_3$) oxidizes rapidly when exposed to the elements, yielding "iron oxides" of various appearances. (Like shales, these spalling aggregates are very absorptive and usually cling to the wetted lip.)

Shelled Siderite Oxides - They have a shell of iron oxide over a sound gray to buff siderite core. (These rocks may frequently seem relatively heavy, as siderite has a specific gravity of about 3.9.) Frequently, the center core may also be weathered to a soft, porous, highly absorptive condition and, at times, the core may be completely missing. 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 4.75mm (3/16 in. [0.2 in.]) thick. The shell may be either black or rusty. (If hard and dense, the core in itself is not deleterious). Pieces of shell by themselves, regardless of thickness, are considered to be spall.

Rusty, Banded, or Mottled Siderite Oxides - Oxides in which the siderite core has been completely oxidized or weathered and a shell-core relationship is not evident. These materials are always classified as spall. Rusty oxides (or "Chocolate bars" as they have sometimes been called) are fine-grained, soft, highly absorptive and usually are 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.

Sandy Siderite 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. These rock types will behave similarly to those listed above and should be considered spall. (See Section 1209.5, Sandstone.)

Iron Oxides - Continued

Other Iron Oxides - "Iron Oxides" also form in connection with the severe weathering of other rocks, such as goethite, hematite, limestones, or dolostones. These oxides are frequently difficult to distinguish from siderite oxides; but, if they are soft, rusty to black and absorptive, they will also likely spall and should be included as "iron oxides" in the litho.

Ochre - Very soft, loosely-cemented particles of iron oxide, usually red to rusty to yellowish in color, very fine-grained, light weight 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.

Phyllite (weathered) - A metamorphic rock intermediate between slate and schist in metamorphism and usually gray to green- gray in color. Typically breaks in flat slabby pieces with flat surfaces exhibiting a sparkly/shiny, wavy sheen. Some phyllites (and slates) from the Iron Ranges are highly weathered and altered. These weathered particles (often pinkish in color and locally called "paint rock") will spall when near the pavement surface and should be considered to be "other material having similar characteristics". Such particles are easily scratched with the fingernail and when moistened typically leave a reddish "paint" smear on the fingers.

Pyrite - FeS_2, is a mineral with a sparkly, metallic, bright yellow-gold color when not weathered, and is commonly known as "Fool's Gold". When very finely divided and weathered, pyrite may have a dull greenish-gray to greenish-black color. Because of its high specific gravity, particles may feel heavier than other rocks. Pyrite is sometimes found as a cementing agent in sandstones. When near the surface, pyrite in any form, will weather and severely stain the pavement surface.

Quartzite - A metamorphosed sandstone, which is so hard and cemented, that when broken the fracture goes through the sand grains rather than around the grains as in a sandstone. Quarried quartzite may include some sandstone, which has not been totally metamorphosed. When specifications limit the percentage of sandstone, "sandstone" should be identified as those particles, which exhibit obviously rounded corners/edges in contrast to the sharp, angular corners/edges for quartzite. (See NOTE 1 below for special methods for determining non-compliant material in Sioux Quartzite)

NOTE 1: 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

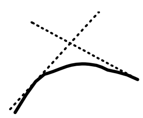
To determine the amount of non-compliant sandstone in a crushed sample of Sioux Quartzite, it is recommended that you follow these steps:

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).

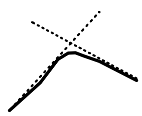
2) Separate all granular (grainy appearance), pink to brown particles from the glassy, angular particles (quartzite). If in doubt, throw the particle into the granular pile. These particles should be predominantly sandstone, and often appear to have larger grains than the glassy quartzite particles.

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.

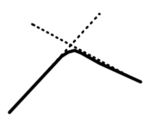
4) The remaining particles should be [2]sub-rounded to [3]sub-angular. If the particles have edges or corners that are considerably rounded off to smooth curves, then consider them sub-rounded and place them in the non-compliant pile. Particles that are somewhat abraded or worn, yet keep their general 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.

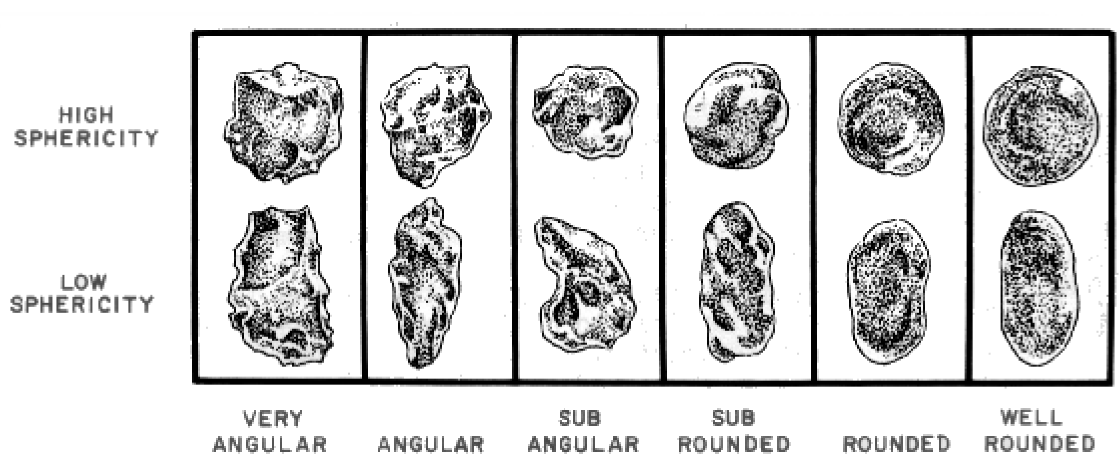


[2]**Sub-rounded -** A particle showing considerable but incomplete abrasion and an original general form that is still discernible, and having many of its edges and corners noticeably rounded off to smooth curves



[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 1 **-** 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 2 – Particle roundness from left to right: angular, sub-angular, sub-rounded and rounded (in natural light)

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 with rusty to black iron oxide filling the pore spaces should **not** be classified as a spalling iron oxide, i.e., the individual grains are touching each other and **not** "floating". See Section 1209.5, Sandy Siderite Oxide.)

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.

Shale - A sedimentary rock composed of thinly laminated (fissile) clay and silt-sized particles with a low specific gravity and very high absorption. Due to its high absorbency, dry shale will cling when touched to the moistened lip. Usually, easily scratched with the fingernail and typically light gray in color.

Slate - A very fine-grained, metamorphosed shale/argillite. It commonly breaks into thin plates or sheets and is usually 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).

Soft Rock - Highly weathered, fine-grained rocks (such as: rhyolite, argillite, carbonate, very fine-grained schist, etc.), which can be scratched with a brass pencil. (See Section 1209.4, footnotes; Section 1209.5, Disintegrated Rock; and Section 1218.)

Other Materials with Similar Characteristics – This category includes all other materials that are not listed specifically as spalling rock types yet exhibit characteristics that make it probable that these rocks will spall. Most spalling rock types are derived from fine-grained argillaceous materials (composed of or containing clay and silt-sized particles), or materials with a high iron oxide content. Often, the argillaceous, low-grade metamorphic rocks, such as argillite, slate, and phyllite will weather to clayey minerals that will behave as spall materials. In these cases, the identifiable characteristics are that they are soft (can be scratched with a brass pencil), and are slightly absorptive. Materials that have been included in this category, that have shown a history of spalling are:

1. Weathered argillite, typically found in Districts 1 and 3, and
2. Weathered phyllite, typically found in Districts 1 and 3 near the Mesabi and Cuyuna Iron Ranges.

Another rock type, which has been shown to be deleterious, has been added to this category. The rock is a highly weathered troctolite, which is a gabbro with olivine as the predominant ferromagnesium mineral. In the deleterious form, most of the olivine has been weathered to a rusty iron oxide mineral that will cause spalling. This coarse-grained, “spotted” rock type is found in sources in the Isabella area (District 1) and should be considered spall material if it fits the criteria identified in NOTE 2 for Special Method for Identifying Spalling Potential of Weathered Troctolite/Gabbro From the Isabella, MN area.

Other rock types may be added to the category of *“Other Materials with Similar Characteristics”* when sufficient evidence suggests that they will cause spalling in pavements. Such evidence should include field experience, testing, and/or designation by the Mn/DOT Geologist.

NOTE 2: Special Method for Identifying Spalling Potential of Weathered Troctolite/Gabbro From the Isabella, MN area.

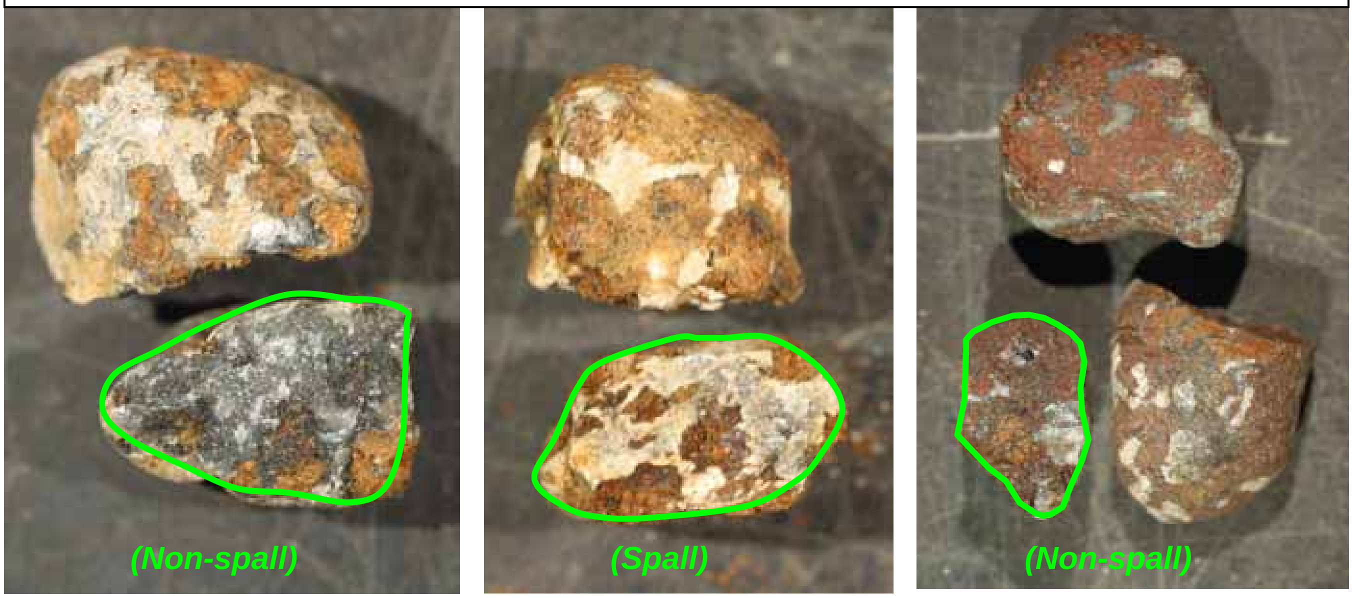
Gravel Pits in the Isabella area contain sand and gravel deposits of the Superior/Rainey Lobe. The rock fragments are principally igneous in nature with a large fraction derived from troctolitic bedrock (gabbro with olivine as the predominant ferromagnesium mineral). The rock fragments (boulders down 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).

Figure 3 – “Marginal” aggregate (left) with mostly fresh core, “Spall” aggregate (center) with mostly weathered/altered core, and “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 3*B*.
4. Do not include material designated as “high iron” (Figure 3*C*), 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.

THE BALANCE OF THIS SECTION 1209.5 IS ADVISORY AND CONTAINS INFORMATION THAT MAY BE USEFUL TO "LITHOGRAPHERS".

A. Rules of the Road for "Lithographers":

1) Always break open pieces of soft rock or any others of which you are unsure as the outside is often weathered.

2) Pick the <u>easy</u> stuff first.

3) Don't sweat a questionable, possible problem-causing rock(s) unless it/they will fail the sample.

4) Give the producer the benefit of the doubt. Generally, one questionable rock should not fail a sample.

5) Don't expect to find "everything" in your litho. Geology across the state is highly variable.

6) Send questionable rocks to the Geology Unit at the Maplewood Lab - particularly if the sample contains quite a few pieces. Questions are always welcome.

B. IRON OXIDE MINERALS

MINERAL		**STREAKS**
Magnetite		**Black**
Hematite	**(Limonite)***	**Red**
Goethite		**Yellowish-brown**

*** Highly weathered and altered hematite or goethite. Not a true mineral. Usually rusty to yellowish-brown in color.**

C. CHARACTERISTICS OF:

NON-SPALLING IRON OXIDE MINERALS	**SPALLING IRON OXIDES**
Heavy (high SpG)	Lighter
Usually hard	Softer
Not absorptive	Absorptive
Usually crystalline	Earthy

D. TYPICAL "SPALL" AGGREGATE CHARACTERISTICS

1. **Absorptive--Always**
2. **Fine-grained---------------------------------------Usually**
3. **Brass pencil soft----------------------------------Frequently**
4. **Platy-- Sometimes**
5. **Very light weight---------------------------------Sometimes**
6. **Characteristic Streak Color------------------- Sometimes**

E. METAMORPHIC ROCKS

SHALE (Sedimentary)	Very fine-grained, platy or fissile, absorptive, slakes in water
ARGILLITE	Very fine-grained, firmly indurated (hardened), conchoidal to saw tooth break
SLATE	Very fine-grained, thin layered, platy cleavage (parallel planes), often "rings" when struck
PHYLLITE	Fine-grained, mica noticeable, wavy satin luster, elongate or tabular
SCHIST	Coarser-grained, visible mica, foliated, segregated mineral (color) layers
GNEISS	Very coarse-grained, pronounced segregated mineral layers (banded)

NOTE: METAMORPHISM INCREASES DOWNWARD (increasing in grain size & hardness).

F. REFERENCES - Some of the following references may prove helpful in clarifying the above definitions and as an aid to rock identification, or for general reading:

Minnesota's Geology;
Ojakanges and Matsch, University of Minnesota Press, 1982.

Minnesota Underfoot;
Sansome, Voyager Press, 1982.

The Lake Superior Agate;
Wolter, Lake Superior Agate Inc., 1986.

Rock and Mineral Identification for Engineers;
Federal Highway Administration, Publication No. FHWA-HI-91-025, 1991. (Probably the best simplified identification guide currently available.)

Classification of Rocks,
Quarterly of the Colorado School of Mines, Vol. 50, No. 1, 1955 (The Geology Unit has a copy.)

Minnesota Rocks - Guide to the Minerals and Rocks of Minnesota;
Schwartz and Thiel, Minnesota Geological Survey, 1960. (Copy form only).

Guide to Mineral Collecting in Minnesota,
Educational Series -2, Minnesota Geological Survey, 1966.

1209.6 EXAMPLE CALCULATIONS (+19.0mm [3/4"] Material)

The percentage of each rock type shall be calculated by the following formula:

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

Report to the nearest 0.1 percent.

Calculations for CO-CA99-0001 (+19.0mm [3/4"+]) - See Sections 1209.8, 1209.9 and 1209.10 for example of forms.

	37.5 – 25.0mm (1½ - 1") size	***25.0 – 12.5mm (1 - ½")size***	***12.5 – 4.75mm (½" - #4) size***	**Weighted *Average***
% Shale	$\frac{4.1}{11294.1}$ = 0.04	$\frac{10.0}{4543.8}$ = 0.22	NO MATERIAL	0.18
% Iron Oxide	0.0	$\frac{40.0}{4543.8}$ = 0.88		0.66
% Carbonate	$\frac{2462.0}{11294.1}$ = 21.80	$\frac{1150.0}{4543.8}$ = 25.31		24.43*
% Sandstone	0.0	$\frac{13.7}{4543.8}$ = 0.32		0.22
% Schist	0.0	$\frac{1.3}{4543.8}$ = 0.03		0.02
% Soft Rock	0.0	$\frac{36.8}{4543.8}$ = 0.81		0.60**
% Other Rock	$\frac{8828.0}{11294.1}$ = 78.16	$\frac{3292.0}{4543.8}$ = 72.45		73.89
Total	100.0	100.0		100.0

Note 3: From the sample gradation, 25% of the total sample is contained in the 37.5 - 25.0mm (1 1/2 - 1") size and 75% is contained in the 25.0 - 12.5mm (1 - 1/2") size.

* Example of weighted average (WA) calculation for Spall Litho:

WA % (Limestone) = (21.8)(0.25) + (25.31)(0.75) = 24.43

NOTE 4: On a Spall Litho where one size is not tested (12.5 - 4.75mm [1/2" - #4]) it is assumed to be the same as the fraction above or below. In the example (CO-CA99-0001, +19.0mm [3/4"+]) the one percent passing the 19.0mm (1/2") sieve is included in the 25.0 - 12.5mm (1 - 1/2") size for calculation purposes.

NOTE 5: 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.

** Example of weighted average (WA) calculation for Soft Rock:

WA % (Soft Rock) = (0.0)(25.0%) + (0.81)(74.0%) = 0.60

NOTE 6: From the sample gradation, 25% of the total sample is contained in the 37.5 - 25.0mm (1 1/2 - 1") size, 74% of the total sample is contained in the 25.0 - 12.5mm (1 - 1/2") size, it is assumed there is no Soft Rock in the 12.5 - 4.75mm (1/2" - #4) size therefore that 1% is left out. This is done only for the Soft Rock calculation; all other calculations are done as in the carbonate example above.

1209.7 EXAMPLE CALCULATIONS (-19.0mm [3/4"-] Material)

Calculations for CO-CA99-0002 (-19.0mm [3/4"-]) - See Sections 1209.8, 1209.9 and 1209.10 for examples of forms.

	25.0 – 12.5mm (1 - ½") size	**12.5 – 4.75mm (½ - #4) size**	**Weighted Average***
% Shale	$\frac{6.0}{3312.2} = 0.18$	$\frac{3.5}{1040.7} = 0.34$	0.29
% Iron Oxide	$\frac{15.2}{3312.2} = 0.46$	$\frac{8.9}{1040.7} = 0.88$	0.74
% Carbonate	$\frac{603.4}{3312.2} = 18.22$	$\frac{252.9}{1040.7} = 24.30$	22.54
% Sandstone	$\frac{5.5}{3312.2} = 0.17$	0.0	0.05

	25.0 – 12.5mm (1 - ½”) size	**12.5 – 4.75mm (½ - #4) size**	**Weighted Average***
% Soft Rock	$\frac{18.6}{3312.2}$ = 0.56	NONE	0.16
% Other Rock	$\frac{2663.5}{3312.2}$ = 80.42	$\frac{775.4}{1040.7}$ = 74.51	76.22
TOTAL	100.0	100.0	100.0

From the sample gradation 27% of the total sample is contained in the 25.0 - 12.5mm (1 - 1/2") size and 92% of the total sample is contained 25.0 - 4.75mm (1" - #4) size. To make calculations on the +4.75mm (#4) material only, divide 27% by 92% = 29% of the material on the 25.0 - 12.5mm (1 - 1/2") size and 71% of the material on the 12.5 - 4.75mm (1/2" - #4) size.

*Example of weighted average (WA) calculations:

WA % (Carbonate) = (18.22)(0.29) + (24.30)(0.71) = 22.54

1209.8 EXAMPLE - GRADATION WORK SHEET

GRADATION WORK SHEET

Lab. No. ________ Pan No.
Gross Wt. Bag No. ________
Tare ________ Tested By
Net ________ Date ________

SIEVE	WEIGHT RET.	SIEVE	% (Pass)
8		8	
3		3	
2½		2½	
2		2	
1½		1½	
1¼		1¼	
1		1	
¾		¾	
⅝		⅝	
½		½	
⅜		⅜	
No. 4		No. 4	
Bottom			
Total			
6		6	
8		8	
10		10	
16		16	
20		20	
30		30	
40		40	
50		50	
60		60	
80		80	
100		100	
200		200	
Bottom			
Total		FM	

Pan Wt. ________ Sieved by ________
Gross Wt. ________ Date ________
Pan and Sample Before Washing ________
Pan and Sample After Washing ________

— OTHER TESTS — Loss in Wt. ________

Shale-4,+4	Mag. Sulf.	Sp. G.	Voids	
Litho	F. & T.	Abs.	K. Abs.	Proctor
L.A.R.		Stru. Str.	C.P.	Trial Mix

LITHOLOGICAL SUMMARY

SIZE	1½ - 1		1 - ½		½ - #4		Wdt. Av.
Shale							
Iron Oxide							
Soft R.							
Uns. Chert							
Limestone							
Other							
TOTAL							

Mn/DOT 2429 (12-77)

1209.9 EXAMPLE – TEST REPORT FORM

NOTE 7: 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

Sample ID CO-CA99-0516	IAS Name:	**Sample ID**	IAS Name:
Field ID: 1 1/2-3/4	Project No: **OTH Qualitiy Testing**	Field ID:	Project No:
Date Sampled: 7/20/99	Proj Eng:	Date Sampled	Proj Eng:
Date Received: 8/10/99	County	Date Received	County
Usage: CA & BA mixes	Bridge #:	Usage:	Bridge #:
Submitter: Rob Kuehborn	Sampled From: Pit	Submitter:	Sampled From:
Grad Spec: 3137	Pit #:	Grad Spec:	Pit #:
Spec. Class: CA-50	Pit Name: Eureka	Spec. Class:	Pit Name:
Quality Spec: 3137.2D2	Comment:	Quality Spec:	Comment:

% Passing Sieve:	Lab Test	Field Test	Spec. Limits Low	Spec. Limits High	Lab Test	Field Test	Spec. Limits Low	Spec. Limits High
50mm (2")	100							
37.5mm (1 1/2")	100							
31.5mm (1 1/4")	77							
25.0mm (1")	*34		100	100				
19.0mm (3/4")	*6		85	100				
16.0mm (5/8")	1							
12.5mm (1/2")	1							
9.5mm (3/8")	*1		30	60				
4.75mm (#4)	1		0	12				
%Total Shale +1/2"	***0.0							
%Total Shale +4	***0.0			0.30				
% Sandstone	2.7							
% Slate	0.00			3.00				
% Carbonate	11.9			30.00				
% Iron Oxide	0.20							
% Ochre	0.0							
% Unsound Chert	0.00							
% Thin/Elong.	0.1							
% Clay Balls	0.00			0.30				
% Other Rock	83.2							
% Soft Rock	1.3			2.50				
%Spall,SRock&Cball	1.5			3.00				
%TotalSamplSpall	0.2							
%Total Spall +4	0.2			0.30				
% Soft Iron Oxide	0.00			0.20				
%Absorpt 1 1/2-3/4	1.12							
Bulk SpG 1 1/2-3/4	2.675							
Mag%Lost 1 1/2-1	3.96							
Mag%Lost 1-3/4	6.20							
%Mag Total Loss	5			15				

cc: **Approved By:** ______________________

Charge: 1 - 1012
1 - 1014
1 - 1015
1 - 1016
1 - 1026

* Value does not meet Spec
** Value out of Field-Lab Tolerance
*** Trace (0.0045 - 0.044) Detected
% Shale in Sand N.C. = Trace

☐ Meets Requirements
☐ Does Not Meet Requirement
☑ For Info Only

1209.10 EXAMPLE - QUALITY TEST WORK SHEET

Quality Test Work Sheet

Lab. No. ________________

Test	Litho L.A.R. Shale	Comp. A,B,C -4 +4	Crush Str.-Str.	Ing. Mag. Sul.	Soft R. F&T	Limestone Sp. G. & Abs
Size	1 1/2+	1-3/4		1/2 - 3/8		
	1 1/2-1	3/4-1/2		3/8-#3	3-4	

L.A.R TEST

Wt. Before	________	# Balls	________
Wt. After	________	Rev. Start	________
Wt. Loss	________	Rev. End	________
% Loss	________	Diff.	________

SHALE TEST		**% CRUSHING COUNT**	
Org. Wt	________	Crushed	________
Shale	________	Non crushed	________
% Shale	________	Total	________

LITHOLOGICAL COUNT

Shale	________	Slate	________
Iron Oxide	________	Clay Balls	________
Unsound Chert.	________	Distint. R.	________
Ochre	________	Sandstone	________
Paint rock	________	Igneous	________
Non-spall Argillite	________	Thin or Elong.	________
Spalling Argillite	________	Soft Rock	________
Limestone	________	Other Rock	________
Schist	________	TOTAL	________

PREPARED BY: ________ TESTED BY: ________ DATE ________