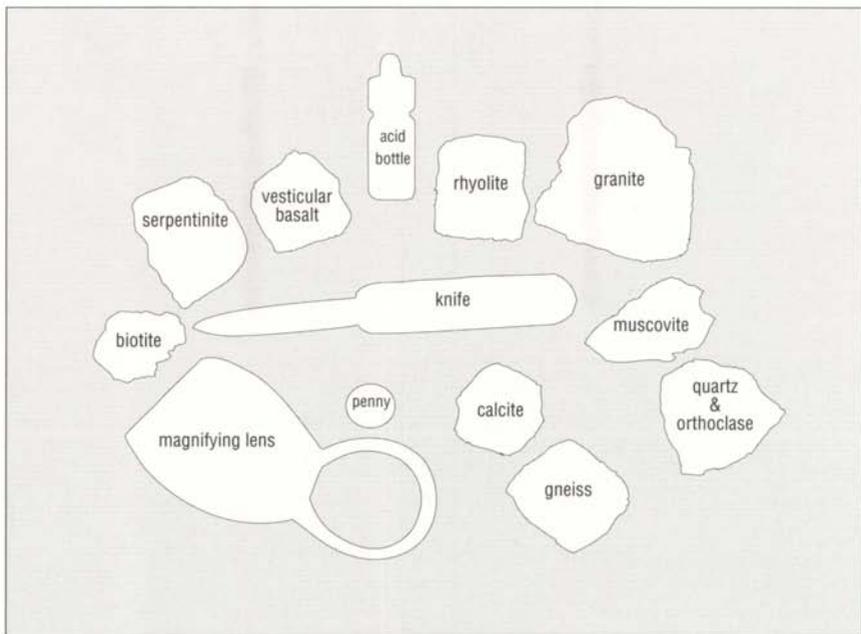

Rock and Mineral Identification for Engineers



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U.S. Department
of Transportation
**Federal Highway
Administration**



Some common rocks, minerals, and identification aids (see text).

Rock And Mineral Identification for Engineers

TABLE OF CONTENTS

Introduction	1
Minerals	2
Rocks	6
Mineral Identification Procedure	8
Rock Identification Procedure	22
Engineering Properties of Rock Types	42
Summary	49
Appendix: References	50

FIGURES

1. Moh's Hardness Scale	10
2. The Mineral Chert	16
3. The Mineral Quartz	16
4. The Mineral Plagioclase	17
5. The Minerals Orthoclase	17
6. The Mineral Hornblende	18
7. The Mineral Calcite	18
8. The Mineral Muscovite	19
9. The Mineral Biotite	19
10. Mineral Identification Flowchart	20
11. The Rock Limestone	27
12. The Rock Marble	27
13. The Rock Dolomite	28
14. The Rock Serpentine	28
15. The Rock Gneiss	29
16. The Rock Schist	29
17. The Rock Granite	30

FIGURES (cont.)

18. The Rock Syenite	30
19. The Rock Granodiorite	31
20. The Rock Gabbro	31
21. The Rock Diabase	32
22. The Rock Pyroenite	32
23. The Rock Peridotite	33
24. The Rock Sandstone	33
25. The Rock Quartzite	34
26. The Rock Conglomerate	34
27. The Rock Limestone (fine grain)	35
28. The Rock Dolomite (fine grain)	35
29. The Rock Shale	36
30. The Rock Slate	36
31. The Rock Rhyolite	37
32. The Rock Andesite	37
33. The Rock Basalt	38
34. The Rock Basalt (vesicular)	38
35. Rock Identification Flowchart, Part A	39
36. Rock Identification Flowchart, Part B	40

TABLES

1. Mineral Groups and Their Common Minerals	3
2. Rock Classes and the Common Rock Types	7
3. Selected Properties of the Common Minerals	11
4. Mineral Identification Procedure	14
5. Rock Identification Procedure	19

Introduction

Civil engineers routinely use rocks as aggregate material in their construction projects. However, many engineers do not have extensive training in rock and mineral identification. This guide, which expands on an article and subsequent publications (Woolf, 1950, 1951, 1960) written for the Bureau of Public Roads, can help practicing civil engineers to identify rocks and minerals and to better understand their characteristics and performances in certain applications.

This guide will not turn engineers into geologists or petrographers, but it can help engineers to make basic distinctions among various natural rock and mineral types. The guide can also help engineers better understand why certain types of rocks and minerals have desirable or undesirable characteristics as potential aggregates.

The equipment needed for the procedures in this guide is inexpensive and easily obtained. The samples that are to be identified are assumed, for our purposes, to be large-sized coarse aggregate pieces or hand samples coming directly from the quarry or gravel pit. To judge the hardness of various minerals, the user will need a pocket knife with a good steel blade and a copper penny. Other useful items are a small bottle (with eyedropper) of dilute (0.1N) hydrochloric acid (HCl), a magnifying glass, and a magnet.

To keep the identification process simple, this guide outlines procedures that rely as much as possible on the visual appearance of rocks and minerals. Basic tests for hardness and reactivity with dilute hydrochloric acid are included for help in classifying a sample.

Those interested in further information may consult the list of references at the back of this manual.

For questions or comments on this manual or the procedures discussed, please contact Dr. Stephen W. Forster, Pavements Division, (703) 285-2073.

Minerals

Minerals are strictly defined as naturally occurring chemical elements or compounds formed as a product of inorganic processes (Hurlbut, 1963). Rocks are composed of an assemblage of one or more distinct minerals. This definition of minerals excludes shells, coral, and other organically formed matter which nonetheless are important constituents of some limestones. For the purposes of this guide, these components are also considered to be minerals.

Mineral Types. Minerals can be separated into groups on the basis of chemical composition. Although incomplete, the following list of groups includes those minerals which would normally be encountered by a practicing engineer. These groups, including their common minerals, are shown in table 1.

Elements. This group consists of chemical elements that occur in nature in an uncombined state. Examples are sulfur, graphite, and gold.

Sulfides. Included in this group are combinations of various metallic elements with sulfur. An example is pyrite.

Oxides. The minerals in this group contain a metal element in combination with oxygen. The iron mineral hematite is an example. A subgroup within the oxides is the hydroxides, which include oxygen in the form of the hydroxyl radical or water. Limonite is an example of a hydroxide.

Halides. Halides are naturally occurring chlorides, fluorides, bromides, and iodides. Examples are halite (rock salt) and fluorite.

Carbonates. The carbonate group of minerals contains the carbonate radical. The common minerals calcite and dolomite are included here.

Phosphates. Minerals whose composition includes the phosphate radical are included in this group. One example is apatite.

Sulfates. These minerals include the sulfate radical. Gypsum is an example of a common sulfate mineral.

Silicates. Silicates form the largest group of minerals. They contain various elements in combination with silicon and oxygen. Examples are quartz and feldspar.

Although there are literally hundreds of minerals, a practicing engineer really only needs to be familiar with and be able to identify about twenty. To classify an aggregate sample as a given rock type, it is usually necessary to identify only its two to three main mineral components.

Table 1. Mineral Groups and their Common Minerals

Group	Minerals	Comments
Elements	sulfur graphite gold silver copper iron	May be seen as trace minerals in some rocks.
Sulfides	PYRITE, iron disulfide galena, lead sulfide sphalerite, zinc sulfide	Common accessory mineral in all 3 rock classes. Source of lead. Source of zinc.
Oxides	HEMATITE, ferric oxide MAGNETITE, ferrous oxide LIMONITE, hydrous iron oxide	Common mineral in all 3 rock types; source of rust-red color in many rocks. Magnetic; common accessory mineral in all 3 rock classes. Yellow-brown; formed by altering of other iron minerals.
Halides	halite, sodium chloride FLOURITE, calcium flouride	Common rock salt. Common accessory mineral.
Carbonates	CALCITE, calcium carbonate DOLOMITE, calcium magnesium carbonate	One of the common minerals; major component of limestone. Common mineral; main mineral in the rock dolomite (also called dolostone.)
Phosphates	APATITE, calcium (fluoro-, chloro-) phosphate	Widely distributed accessory mineral in the 3 rock classes.
Sulfates	GYPSUM, hydrous calcium sulfate barite, barium sulfate	Common mineral, especially in limestone and shale. Common accessory mineral, especially in sedimentary rocks.

Note: Those minerals listed in capital letters are most likely to be encountered.

Table 1. Mineral Groups and their Common Minerals

Group	Minerals	Comments
Silicates	QUARTZ, silicon dioxide	One of the common minerals; hard and very resistant to chemical and physical breakdown.
	CHERT, silicon dioxide	Cryptocrystalline (microscopic crystal size) variety of quartz.
	FELDSPARS:	Family of minerals common in all 3 rock classes.
	ORTHOCLASE, potassium aluminum silicate	Very common mineral.
	PLAGIOCLASE, sodium/calcium aluminum silicate	Includes a series with compositions ranging from the sodium end-member (albite) to the calcium end-member (anorthite); these minerals are very common.
	OLIVINE, magnesium/iron silicate	Fairly common; most often in darker igneous rocks.
	GARNET, calcium, iron, magnesium, manganese/aluminum, titanium, iron, chromium silicate	Common accessory mineral in many igneous rocks; may also occur in the 2 other rock classes.
	zircon, zirconium silicate	Common accessory mineral.
	PYROXENES, magnesium, iron, calcium, sodium, lithium/magnesium, iron, aluminum silicate	Common in many igneous rocks; a family of minerals.
AMPHIBOLES, magnesium, iron, calcium, sodium/magnesium, iron, aluminum silicate	Common in many igneous rocks; a family of minerals that includes HORN- BLENDE.	

Note: Those minerals listed in capital letters are most likely to be encountered.

Table 1. Mineral Groups and their Common Minerals

Group	Minerals	Comments
Silicates (cont.)	CLAY MINERALS:	A group of usually fine-grained soft minerals.
	KAOLINITE, hydrous aluminum silicate	Common clay mineral in soil and sedimentary rocks that includes montmorillonite.
	talc, hydrous magnesium silicate	Common in metamorphic rocks.
	SERPENTINE, hydrous magnesium silicate	Common mineral in metamorphic rocks.
	MICA MINERALS:	
	MUSCOVITE, hydrous potassium aluminum silicate	Very common mineral in metamorphic and igneous rocks.
BIOTITE, hydrous potassium, magnesium/iron, aluminum silicate	Very common mineral in metamorphic and igneous rocks.	
CHLORITE, hydrous magnesium/iron aluminum silicate	Common mineral in metamorphic rocks.	

Note: Those minerals listed in capital letters are most likely to be encountered.

Rocks

Rocks consist of an assemblage of minerals. They are classified according to this assemblage, the mineral proportions, and the conditions under which the rock was formed. Rocks are formed in three basic ways resulting in the following classes:

- **Igneous rocks:** Formed by hardening or crystallization of high-temperature, molten material (magma).
- **Sedimentary rocks:** Formed by solidification of material deposited by wind, water, glaciers, or direct chemical precipitation.
- **Metamorphic rocks:** Formed by modification of previously existing rocks by the application of heat and/or pressure within the earth.

Table 2 lists the rock types within each class that are most likely to be encountered by the practicing engineer. Igneous rocks are further divided into two categories:

- **Intrusive:** Cooled slowly **within** the earth and therefore with large crystals.
- **Extrusive:** Cooled rapidly at (or near) the earth's surface (**external** to the earth) with very small or no crystals. Volcanic rocks are included here.

Table 2. Rock Classes and the Common Rock Types

Class	Rock Type	Comments
Igneous subclass Extrusive	felsite	Formed from molten rock. Fine grained. General name which includes the rocks: rhyolite; trachyte; latite; andesite.
	basalt obsidian pumice	Dark color. Glassy. Frothy; lightweight.
subclass Intrusive	granite syenite granodiorite monzonite diorite	Medium to course-grained.
	gabbro diabase	Gabbro and diabase have the same composition; gabbro is course grained, diabase is medium grained.
	pyroxenite peridotite	
Sedimentary	limestone dolostone (dolomite) sandstone shale chert conglomerate	Formed by particle deposition or chemical precipitation.
Metamorphic	slate schist gneiss quartzite marble dolomitic marble serpentinite	Formed by high heat and/or pressure acting on existing rock.

Mineral Identification Procedure

Since minerals are the components of rocks, their identification is an integral part of proper rock identification. For this identification procedure, three characteristics of minerals will be of major importance: hardness, reactivity with dilute hydrochloric acid, and cleavage.

Hardness

Figure 1 is a graph of the Mohs hardness scale applied to minerals. Also shown on the graph is the relative hardness of several common items that can be used to separate the minerals. The knife blade is particularly useful in separating the common harder minerals (quartz and the feldspars) from the common softer minerals (calcite and dolomite). To test for hardness with any of these items, two approaches may be used:

- Use the knife blade (or copper penny, etc.) as a tool to attempt to scratch the mineral
- Use the mineral to attempt to scratch the testing material.

Doing it both ways will often give a clearer indication of the relative hardness of the two materials being compared.

HCl Reactivity

This test serves to differentiate the carbonate minerals (which react with HCl) from other mineral types. The acid used is *dilute* HCl. The dilute acid is obtained by mixing water with full-strength acid. By noting the normality of the acid being diluted, an appropriate volume of water can be used to reach the target of 0.1N. For instance, if the original acid is 1.0N, increasing the volume of water tenfold will result in a 0.1N. When diluting, *always add the acid to the water to avoid splashing full-strength acid*.

Cleavage. If a mineral breaks so it yields definite plane surfaces, the mineral is said to possess cleavage. A mineral can possess one or more directions of cleavage, or none:

- The micas (e.g. muscovite and biotite) are examples of minerals with distinct cleavage in one direction.

- All the feldspars have two cleavage directions, which are at almost right angles.
- Quartz has no cleavage. This fact helps in the distinction between quartz and the feldspars. When quartz and chert are broken, the resulting surfaces often have a typical concave shape called *conchoidal fracture* because of its shell-like appearance. While not a cleavage, this distinctive fracture habit can be useful in identification.

Other Characteristics. Some minerals have a distinct, definitive color. However, because the color of most minerals can vary significantly, color should normally be used as supportive rather than primary evidence. Another useful characteristic is a mineral's ability to transmit light. Depending on the composition, crystallography, and other factors, a mineral may be *transparent*, *translucent*, or *opaque*.

Table 3 lists the hardness, dilute HCl reactivity, cleavage, and other characteristics of common minerals listed in table 1.

See Table 4 for step-by-step mineral identification procedures. The figure references within the table are to photographs of the more common minerals.

**Figure 1 - Relative Hardness of Minerals in Mohs Scale
(numbers in parentheses).**

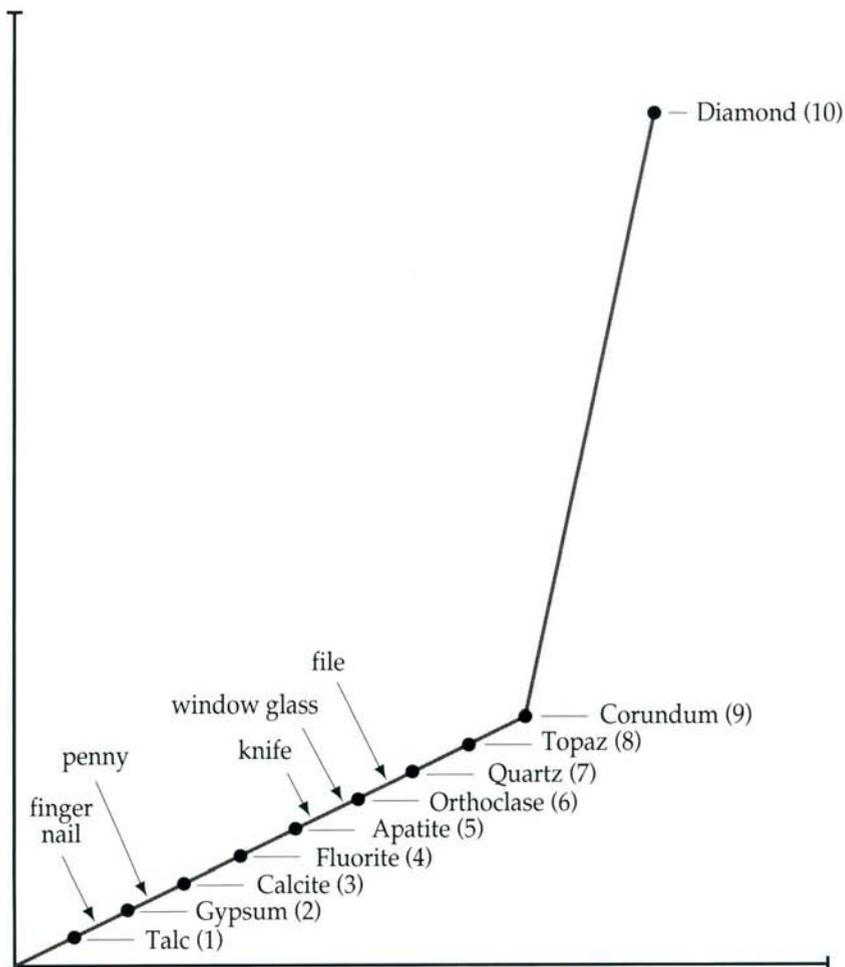


Table 3. Selected Properties of the Common Minerals

Mineral	Hardness	Cleavage	Other
Pyrite	6 - 6 1/2	None	Brassy; fool's gold; weathers easily to give iron stain; common accessory mineral in many rock types.
Hematite	5 1/2 - 6 1/2	None (in massive form)	Red-brown; common accessory in many rocks; cement in many sandstones.
Magnetite	6	None (in granular form)	Black; magnetic; common accessory mineral in many rock types.
Limonite	5 - 5 1/2	None	Yellow-brown; earthy; may appear softer than 5; formed by alteration of other iron minerals.
Fluorite	4	1 plane	Common accessory mineral in limestones and dolostones; translucent to transparent.
Calcite	3	3 planes at 75 °	Very common; occurs in many rock types; chief mineral in limestone; vigorous reaction with dilute HCl.
Dolomite	3 1/2 - 4	3 planes at 74°	Common; with calcite in dolomitic limestone or dolostone (>50% dolomite); vigorous reaction with dilute HCl <i>only</i> when powdered.
Apatite	5	1 plane, poor	Common minor accessory mineral in all rock classes.
Gypsum	2	4 planes; 1 perfect	Common mineral, especially in limestones and shales; may occur in layers.
Quartz	7	None	Very common; may occur in many rock types; glassy; translucent to transparent; may be colored; very resistant to weathering; chief mineral in sandstones.
Chert	7	None	Cryptocrystalline (microscopic crystals) variety of quartz; appears massive to naked eye; common in limestones or in complete layers associated with limestones; light tan to light brown; similar minerals: flint (dark brown to black); jasper (red); chalcedony (waxy look, tan to brown).

Table 3. Selected Properties of the Common Minerals

Mineral	Hardness	Cleavage	Other
Orthoclase	6	2 planes at 90°	A feldspar; very common in many rock types; white to grey to red-pink; translucent to transparent; cleavage separates it from quartz.
Plagioclase	6	2 planes at 94°	A feldspar; very common in many rock types; appears similar to orthoclase - distinguished by the presence of thin, parallel lines on cleavage faces due to crystal structure.
Olivine	6 1/2 - 7	None	Transparent to translucent; olive green; glassy; common accessory mineral in the darker igneous rocks.
Garnet	6 1/2 - 7 1/2	None	Red to red-brown; translucent to transparent; common accessory mineral in metamorphic and some igneous rocks; also in sands and sandstones.
Zircon	7 1/2	None	Usually colorless to brown; usually translucent; common accessory mineral in igneous rocks and some metamorphic rocks; also in sands and sandstones.
Pyroxene (mineral group)	5 - 7	2 planes at 87° and 93°	Most common in the darker igneous rocks; usually green to black; translucent to transparent; most common mineral: augite.
Amphibole (mineral group)	5 - 6	2 planes at 56° and 124°	Most common in metamorphic rocks and the darker igneous rocks; usually dark green to brown to black; translucent to transparent; most common mineral: hornblende; distinguished from pyroxenes by cleavage.
Clay Minerals (a group)	2 - 2 1/2	1 plane	Usually fine grained; earthy; often derived from weathering of feldspars; montmorillonite is the swelling clay that expands with the absorption of water; illite is the common clay mineral in many shales.

Table 3. Selected Properties of the Common Minerals

Mineral	Hardness	Cleavage	Other
Talc	1	1 plane	Very soft, greasy; cleavage may be hard to see because of fineness of particles; commonly white to pale green; usually in metamorphic or altered igneous rocks.
Serpentine	2 - 5 (usually 4)	none	Massive to fibrous; greasy to waxy; various shades of green; found in altered igneous or metamorphic rocks; fibrous variety is the source of asbestos.
Muscovite	2 - 2 1/2	1 plane	A mica; perfect cleavage allows splitting into thin, clear transparent sheets; usually light yellow to light brown; common in light colored igneous rocks and metamorphic rocks.
Biotite	2 1/2 - 3	1 plane	A mica; perfect cleavage allows splitting into thin smoky transparent sheets; usually dark green to brown to black; found in light to medium colored igneous rocks and metamorphic rocks.
Chlorite	2 - 2/12	1 plane	Similar to the micas; usually occurs in small particles so cleavage produces flake; flakes are flexible but not elastic as are the micas; usually some shade of green.

Table 4. Mineral Identification Procedure

Is it harder than a knife?

I. If YES, what is its overall appearance?

A. Dull and earthy, waxy, or metallic.

1. Magnetic (small fragments stick to the knife blade)
— **magnetite**.
2. Nonmagnetic, how does it break (fracture)?
 - a. Sharp edges; conchoidal (concave, like the inside of an oyster shell) surface — **chert** (figure 2).
 - b. Rough, uneven surface
red-brown to black — **hematite**;
brown to dark brown — **limonite**.

NOTE: both hematite and limonite can appear softer than a knife if not tested on a fresh, unweathered surface.

- c. Pale to medium brass color, often in cubic crystals
— **pyrite**.

B. Vitreous (glassy), transparent to translucent.

1. No cleavage.
 - a. Colorless to white to pale pink — **quartz** (figure 3).
 - b. Olive green — **olivine**.
 - c. Red-brown — **garnet**.
2. Two cleavage planes, intersecting at approximately a 90-degree angle.
 - a. Good to perfect cleavage surfaces (feldspar group, one surface with parallel striations)
— **plagioclase** (figure 4); no striations present
— **orthoclase** (figure 5).
 - b. Poor to fair cleavage surfaces — **pyroxene**.
 - c. Two cleavage planes, intersecting at 120 and 60 degrees — **amphibole** (includes **hornblende**) (figure 6).

Table 4. Mineral Identification Procedure (cont.)

II. If NO, will it scratch a copper penny?

- A. If yes, will it react with dilute HCl?
1. vigorous reaction — **calcite** (figure 7).
 2. minor reaction when whole, vigorous when powdered — **dolomite**.
 3. no reaction.
 - a. One plane of perfect cleavage — **fluorite**.
 - b. plane of poor cleavage — **apatite**.
 - c. Non-crystalline; waxy to greasy or fibrous appearance — **serpentine**.
- B. If no, does it have perfect cleavage which allows splitting into thin sheets?
1. Yes — **mica group**.
 - a. Pale, light colors, sheets are flexible **and** elastic — **muscovite** (figure 8).
Usually in very small flakes; sheets are flexible but **not** elastic — **chlorite**.
 - b. Dark colors, green to brown to black — **biotite** (figure 9).
 2. No.
 - a. Opaque, very fine grained — **clay minerals**.
 - b. Translucent to transparent — **gypsum**.

NOTE: Color has been used in the latter stages of some decisions despite the caution given on the use of color. In the instances where color is used, its use is judged appropriate for the minerals involved and the low likelihood of encountering examples outside the color ranges given. Figure 10 is a "decision tree" diagram of the outline given above.

Two copies of this diagram are also included on weatherproof cards of pocket size for handy reference in the field.



Figure 2. The Mineral Chert



Figure 3. The Mineral Quartz

Photos



Figure 4. The Mineral Plagioclase (note striations due to crystal structure)

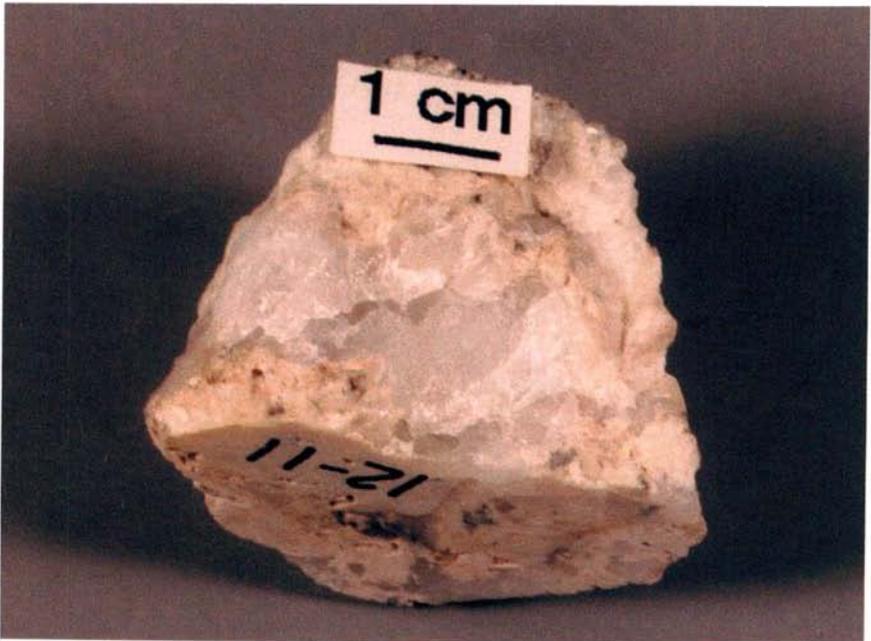


Figure 5. The Mineral Orthoclase (pinkish-tan) and Quartz (white)

Photos



Figure 6. The Mineral Hornblende

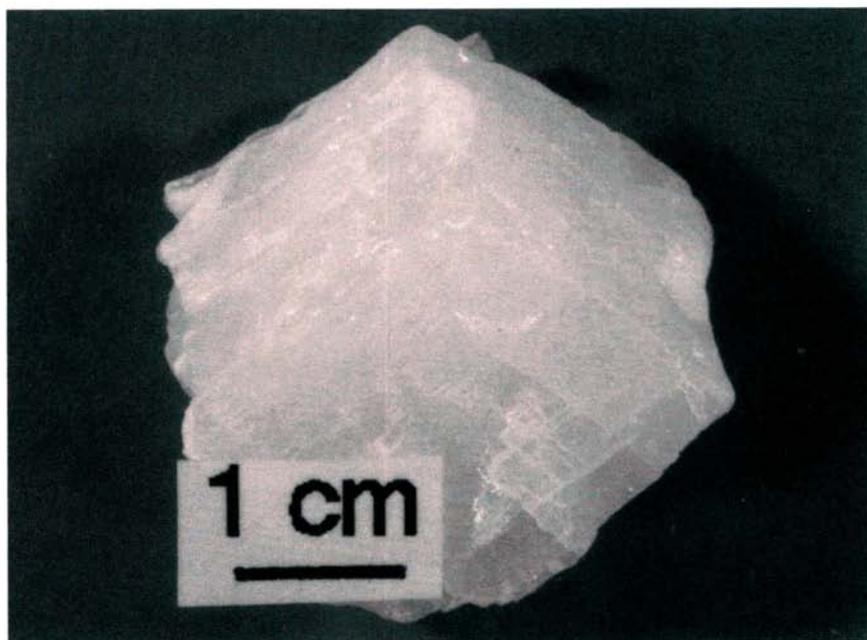


Figure 7. The Mineral Calcite

Photos



Figure 8. The Mineral Muscovite

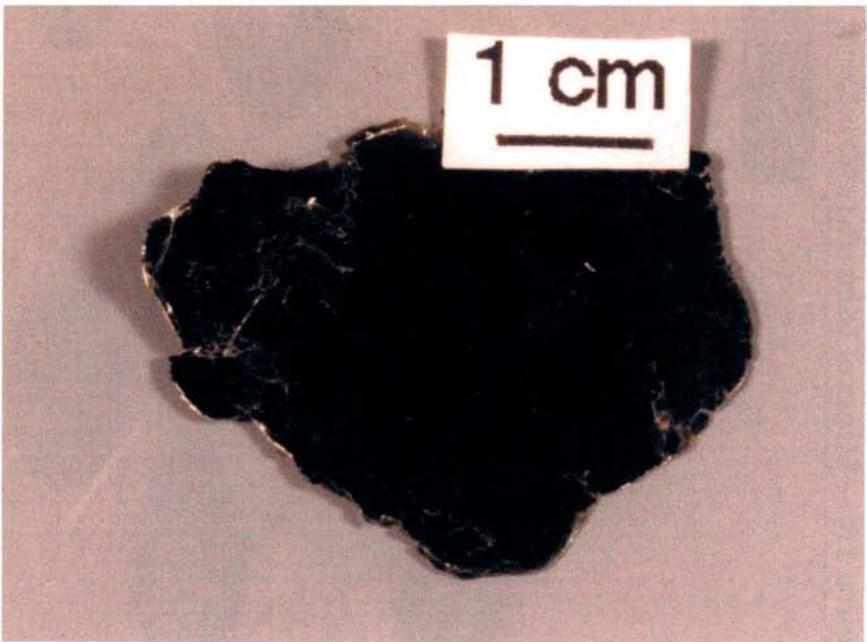


Figure 9. The Mineral Biotite

Figure 10 — Mineral Identification Flowchart **Part A - Scratched by a Knife**

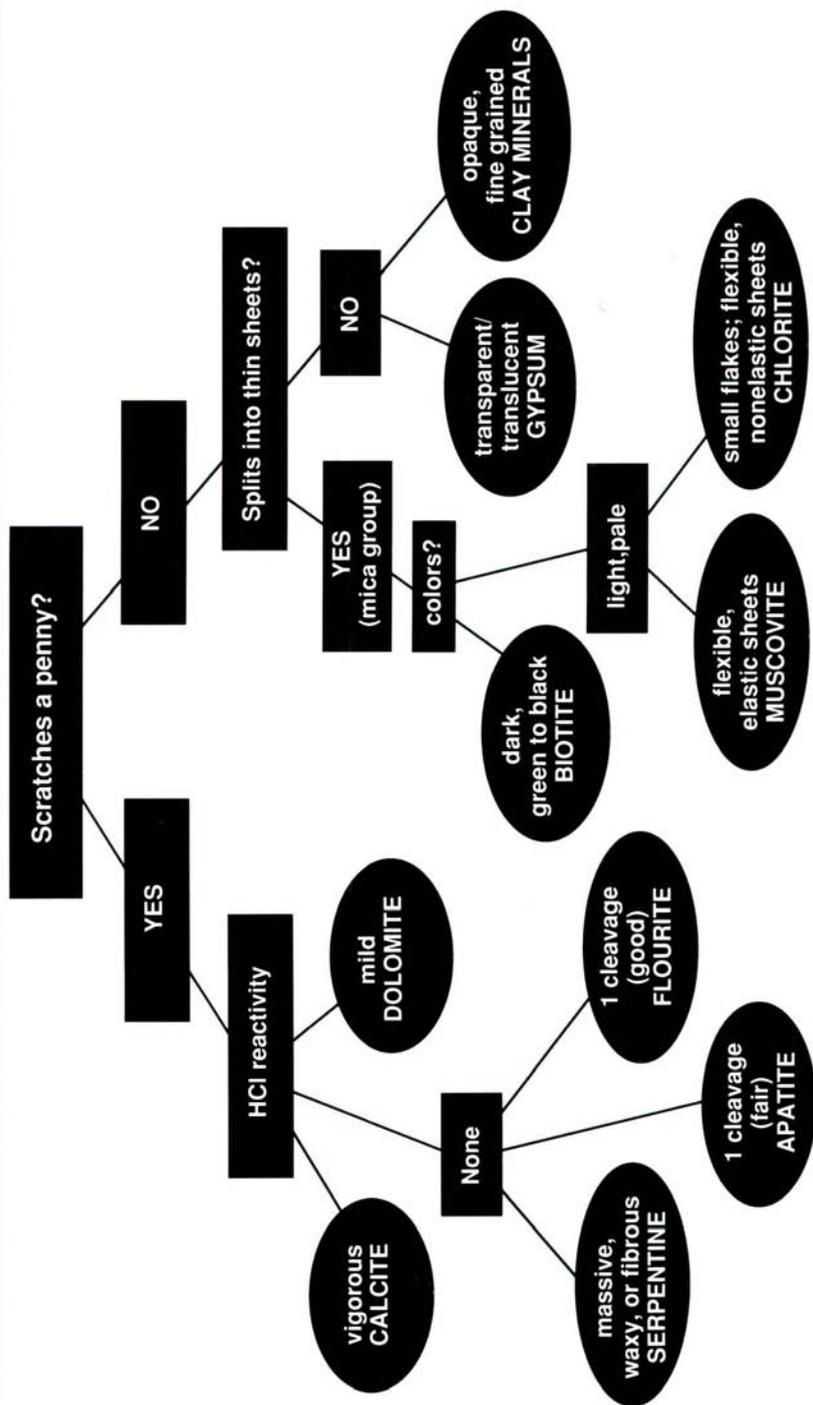
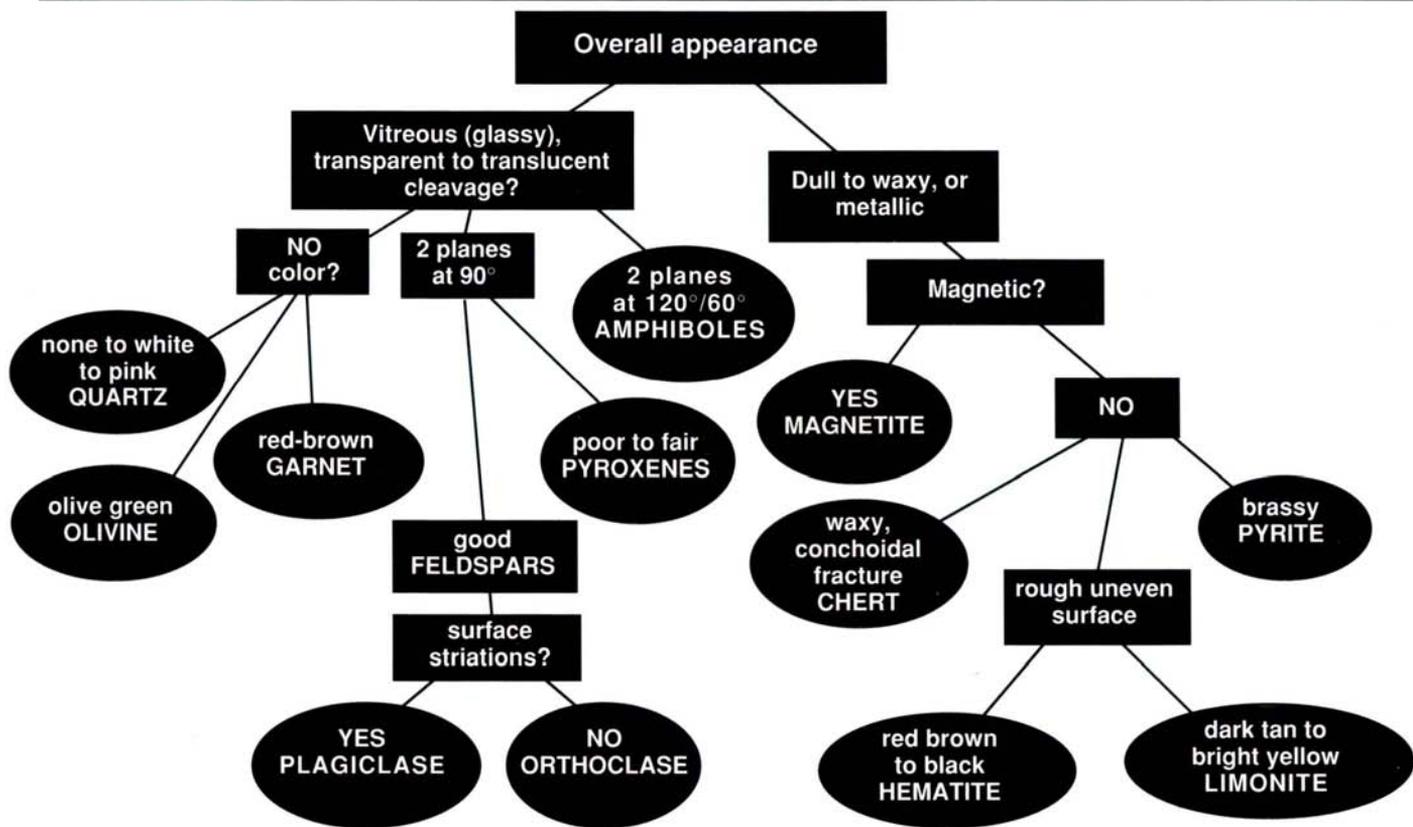


Figure 10 — Mineral Identification Flowchart

Part B -Not Scratched by a Knife



Rock Identification Procedure

Identification of rock types involves not only identifying their mineral constituents and their relative amounts, but also a series of characteristics of the rock. The three classes of rocks, igneous, sedimentary, and metamorphic, were defined earlier. Because rocks from different classes can appear quite similar, and rocks within the same class can often appear quite different, separation by class will not be a specific part of the identification process.

See table 5 for step-by-step rock identification procedures. Refer to the mineral identification procedure in table 3 as necessary to support some portions of this procedure.

The rock identification procedure in table 5 results in the distinction of 26 rock types. This degree of separation is possible under most circumstances. However, if a sample is not very big, or small to medium mineral grain size makes definite identification difficult, identification to the next-to-last level of the outline will often suffice for preliminary engineering purposes. This level of identification is often adequate, because the engineering properties of the rock types within one category at this level are usually very similar.

One example of such a category is given in the procedure: the felsites. This term includes all the fine-grained, light-colored igneous rocks. These are all composed predominantly of feldspar, either orthoclase or plagioclase, with or without lesser amounts of quartz plus some accessory minerals.

Because of the similarity of composition and texture within the felsite group, the behavior when used as a construction material of all the rock types in the group is very similar.

The coarse-grained equivalents of the felsites may be treated similarly. This category includes granite, granodiorite, syenite, monzonite, and diorite. Since quartz is a mineral that is easily recognized with a little practice, separating those that have quartz (granite and granodiorite) from those that don't (syenite, monzonite, and diorite) is relatively easy. Further categorization of these two groups depends on the relative amounts of the two feldspar minerals, orthoclase and plagioclase.

Table 5. Rock Identification Procedure

- I. Distinct mineral grains, easily seen by the naked eye.
- A. Entire rock surface easily scratched by a knife. (Make sure that the mineral surfaces are being scratched, and not simply that poorly cemented grains are being dislodged.)
1. Reactivity with dilute HCl.
 - a. Vigorously, with much effervescence — **limestone** or **marble** (figures 11 and 12).

NOTE: *If visibly crystalline with interlocking grains, the rock in question may be a marble or a limestone. Without larger samples to reveal the presence or absence of characteristic irregular banding (“marbled” appearance) and other textural features, distinction between the two may not be possible. The presence of noninterlocking mineral grains and undistorted fossils confirm the rock is a limestone (figure 11).*
 - b. Slowly on the rock surface, vigorously if the rock is powdered — **dolomite (dolostone)** or **dolomitic marble** (figure 13).

NOTE: *the note given for 1.a., above, applies here also.*
 - c. No reaction, greasy or waxy appearance — **serpentinite** (figure 14).
 - B. Entire rock surface cannot be scratched by a knife, (that is, some or all of the minerals present are harder than the knife blade).
 1. The minerals are intergrown (contact surfaces between minerals are irregular and interlocking).
 - a. Minerals arranged in layers or bands (foliated).
 - (1) Irregular, coarse foliation if poorly developed (or lineation), with zones of light minerals (often quartz or feldspar, or both) alternating with zones of dark minerals (often biotite or hornblende). The foliation is not developed to the extent that planes of weakness are present in the rock — **gneiss** (figure 15).
 - (2) Minerals arranged in thinner, more distinct layers which create planes of weakness along which the rock may be split. Mica minerals are plentiful — **schist** (figure 16).

NOTE: *Some sandstones are color banded. However, examination of the mineral grains will show a lack of intergrowth.*

Table 5. Rock Identification Procedure (cont.)

- b. Minerals not in distinct layers (massive).
 - (1) Chief minerals are the feldspars, with orthoclase >plagioclase; five percent or more quartz; mica minerals or hornblende, or both in small amounts are common — **granite** (figure 17).
 - (2) Like granite, except little or no quartz — **syenite** (figure 18).
 - (3) Chief minerals are the feldspars, with plagioclase >orthoclase; five percent or more quartz; mica minerals and/or hornblende in small amounts are common — **granodiorite** (figure 19).
 - (4) Like granodiorite, except little or no quartz — **monzonite**.
 - (5) Mainly plagioclase, with hornblende and some biotite; no quartz; medium to dark color — **diorite**.
 - (6) Like diorite, except pyroxene and possibly olivine present instead of hornblende and biotite; color is usually dark — **gabbro** (figure 20).

NOTE: *Finer grained gabbros are often referred to as diabase (figure 21). The rather ambiguous term traprock is also used for this rock type.*
 - (7) Chief minerals are pyroxenes and olivine; pyroxenes >olivine; dark color — **pyroxenite** (figure 22).
 - (8) Chief minerals are pyroxenes and olivine; olivine >pyroxenes; dark color — **peridotite** (figure 23).
- 2. Minerals are in distinct grains that are cemented together rather than intergrown.
 - a. Sand-sized particles, cemented by silica, clay, calcite, or hematite; chief minerals are usually quartz and feldspar; breaks around rather than through the sand grains — **sandstone** (figure 24).
 - b. Similar to sandstone in general appearance; quartz is the chief mineral; grain boundaries range from partial to total intergrowth due to secondary quartz crystallization during metamorphism; due to this intergrowth, the rock breaks through rather than around the mineral grains — **quartzite** (figure 25).

NOTE: *Under higher levels of metamorphism, quartzite would fall under category B.1.b., above, due to nearly complete mineral intergrowth. It can*

Table 5. Rock Identification Procedure (cont.)

easily be separated from the other rocks listed under B.1.b. because the only mineral present in significant amounts is quartz.

- c. Gravel-sized particles of rocks and minerals, cemented by silica, clay, calcite or hematite — **conglomerate** (figure 26).
- II. Very fine mineral grains, not visible to the naked eye.
- A. Glassy.
 1. Looks like glass; may have a few inclusions or bubbles; dark brown to black — **obsidian**.
 2. Contains many bubbles, frothy — **pumice**.
 - B. Dull, earthy or stony.
 1. Can be scratched with a knife.
 - a. Reacts vigorously with dilute HCl — **limestone** (figure 27).
 - b. Reacts slowly when whole or vigorously when powdered with dilute HCl — **dolomite** (figure 28).
 - c. Reacts slowly or not at all with dilute HCl, whether whole or powdered.
 - (1) Tends to break into flaky pieces — **shale** (figure 29).
 - (2) Layered; breaks into thin, flat sheets — **slate** (figure 30).
 2. Can't be scratched with a knife.
 - a. Very hard; fractured surface is smooth (may be conchoidal) with sharp edges; surface may appear waxy; tan to black color — **chert**.
 - b. Massive; dull-appearing fractured surface; may have small inclusions of glass or crystals.
 - (1) Light to medium colors — **felsite**.
- NOTE: *Felsite includes the extrusive igneous rock types: **rhyolite** (figure 31), **trachyte**, **latite**, and **andesite** (figure 32) which usually can't be distinguished by the naked eye. They differ basically only in the relative amounts of the two feldspars (their primary constituents) and the presence or absence of quartz.*
- (2) Dark to black color — **basalt** (figures 33 and 34).

Because this ratio between orthoclase and plagioclase is a continuum, rocks may be found on the borderline between the two groups. If in doubt, classifying a rock as a granite/granodiorite or syenite/monzonite is sufficient because of their similar performance in construction. As the percentage of plagioclase in this family of rocks increases, the percentage of so-called dark minerals (mainly amphiboles and pyroxenes) also increases, giving the rock a darker overall appearance. This often allows the distinction of diorite from the other members of the group.

The two dark igneous rocks — pyroxenite and peridotite — may be indistinguishable in hand specimen if the mineral crystal size is too small to distinguish cleavage. As was the case above, identifying a rock as being one of the members of this continuum is helpful since they behave similarly in construction uses.

Although often even-textured (mineral grains are all about the same size), all igneous rocks may exhibit what is called porphyritic texture. A porphyritic texture is defined as one in which one or more minerals occur in crystals much larger than the surrounding minerals in the rock. It is the size difference rather than absolute size which defines the texture. Therefore it can exist as 1 mm crystals dispersed through a basalt or 10 mm crystals in a granite. **The presence of this texture does not affect the rock's classification, although it may affect some of its engineering properties, which will be discussed here.**

Figures 35 and 36 are two decision tree diagrams of the outline given above. They are also included on the weather-proof card for use in the field.

Photos



Figure 11. The Rock Limestone (coarse grained example)

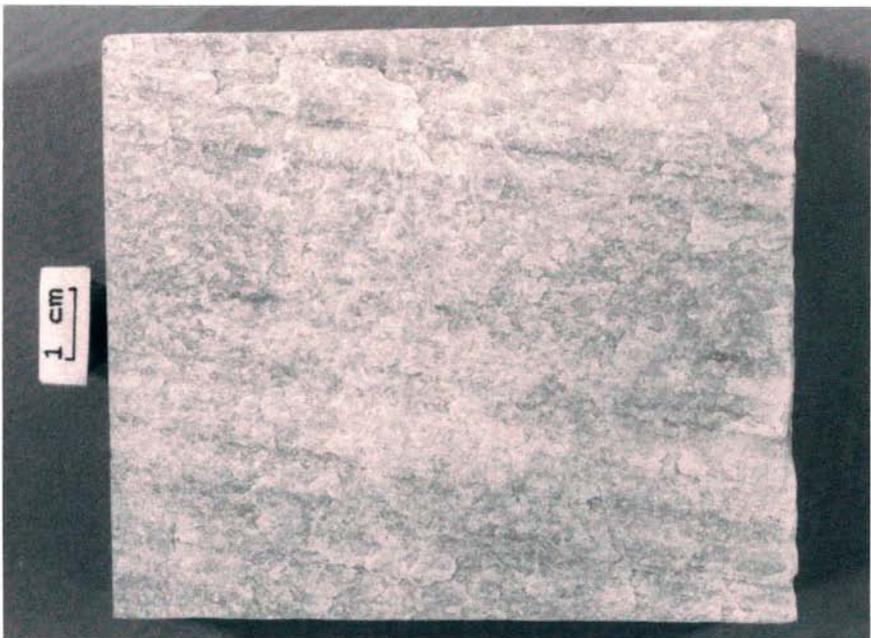


Figure 12. The Rock Marble (note banding)

Photos



Figure 13. The Rock Dolomite (dolostone)



Figure 14. The Rock Serpentinite

Photos



Figure 15. The Rock Gneiss (note foliation of minerals)

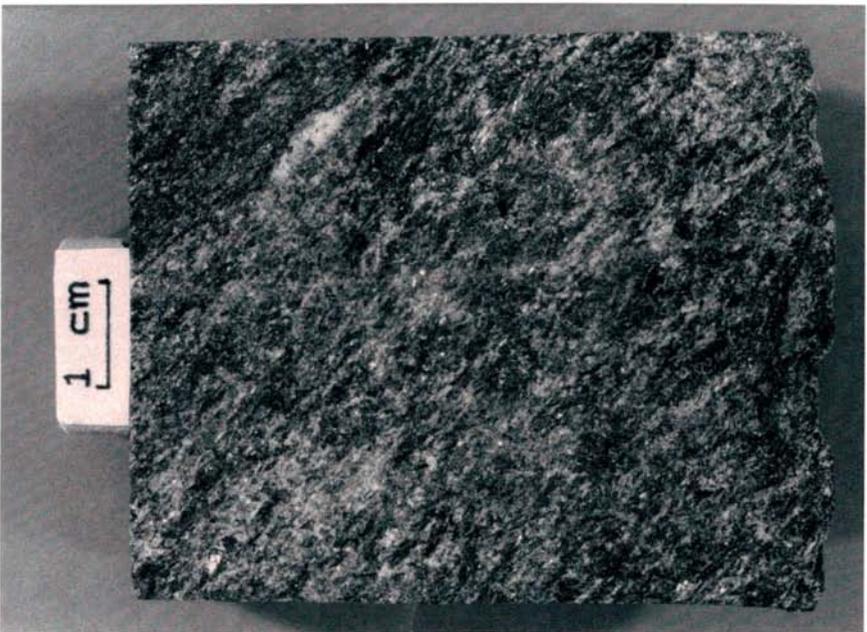


Figure 16. The Rock Schist (note distinct foliation of minerals)

Photos

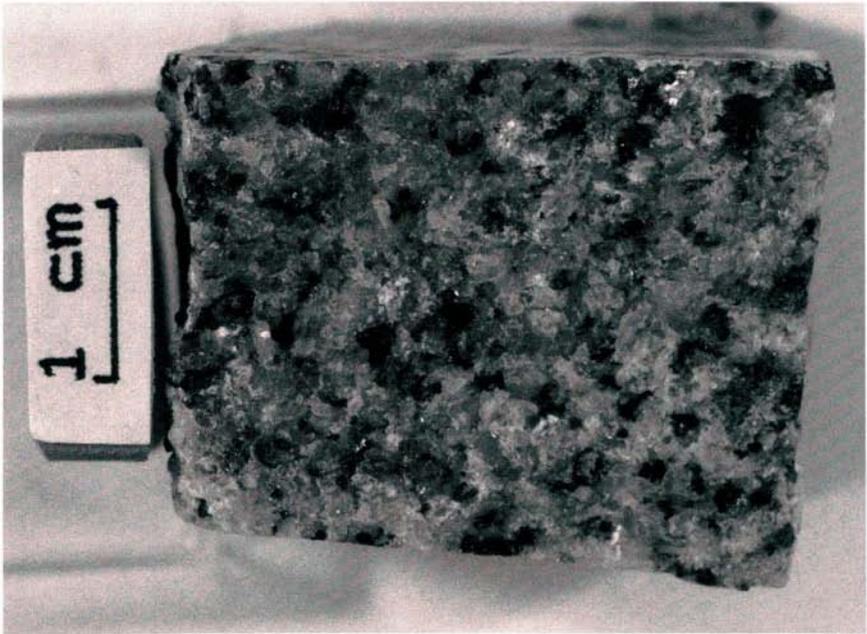


Figure 17. The Rock Granite



Figure 18. The Rock Syenite

Photos

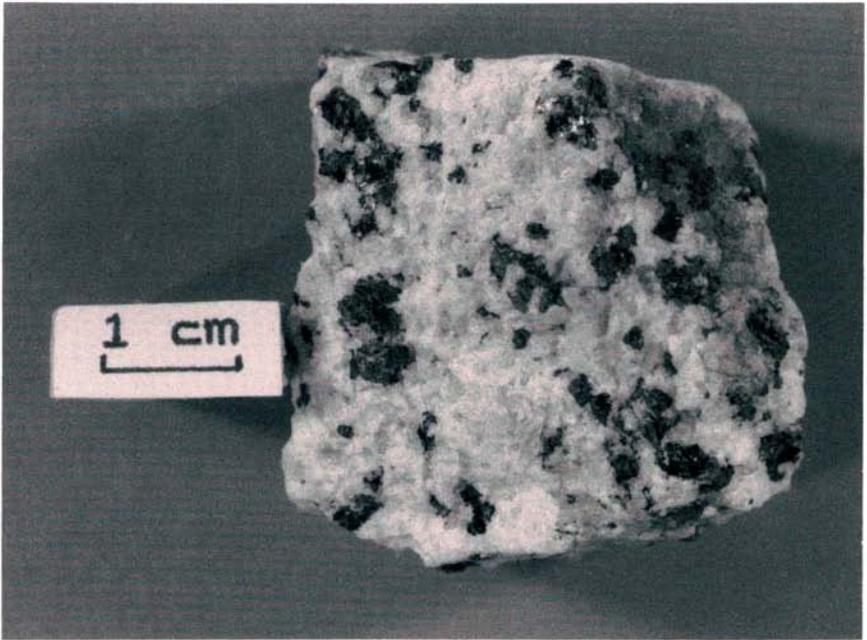


Figure 19. The Rock Granodiorite



Figure 20. The Rock Gabbro

Photos



Figure 21. The Rock Diabase

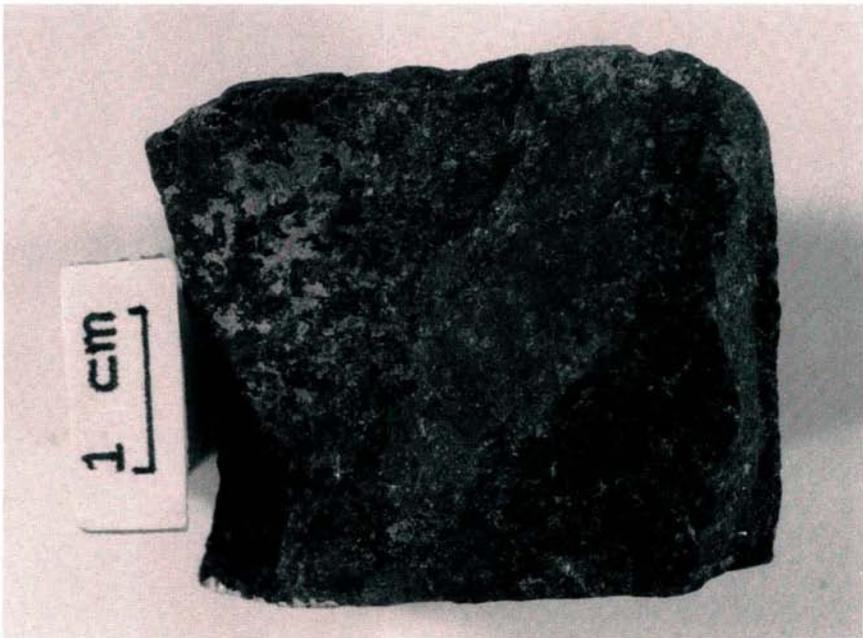


Figure 22. The Rock Pyroxenite

Photos

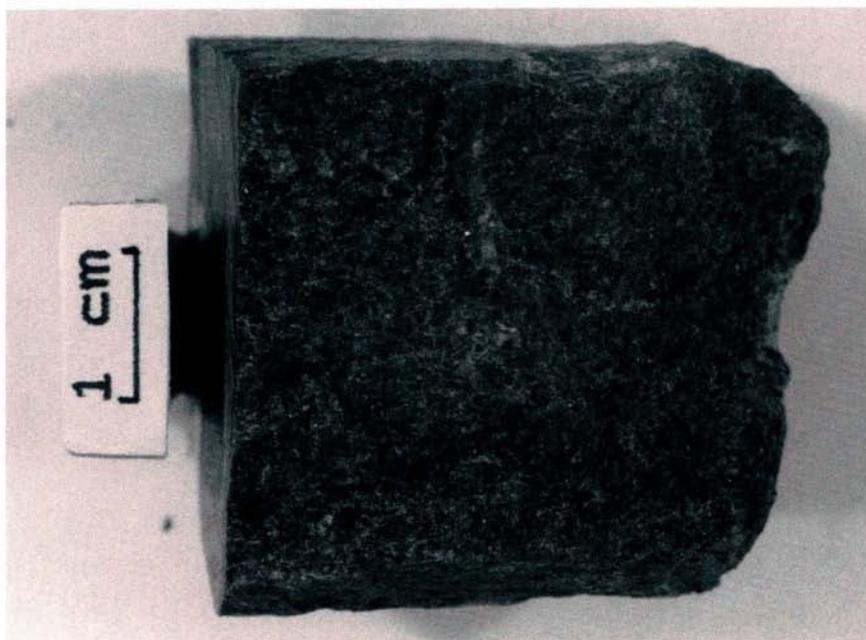


Figure 23. The Rock Peridotite



Figure 24. The Rock Sandstone (note sandy, grainy appearance)

Photos



Figure 25. The Rock Quartzite (note more glassy, sharper surface than sandstone)

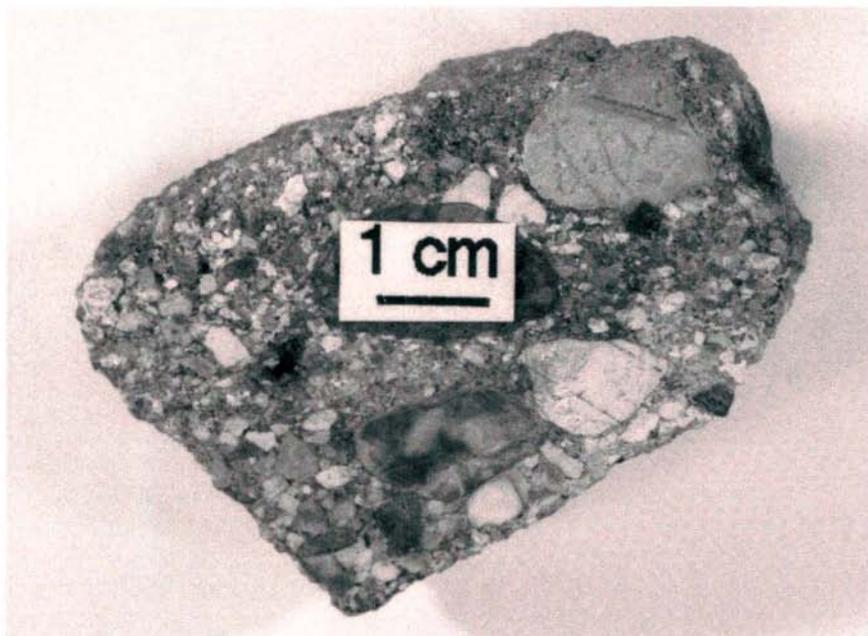


Figure 26. The Rock Conglomerate

Photos



Figure 27. The Rock Limestone (fine grained example)

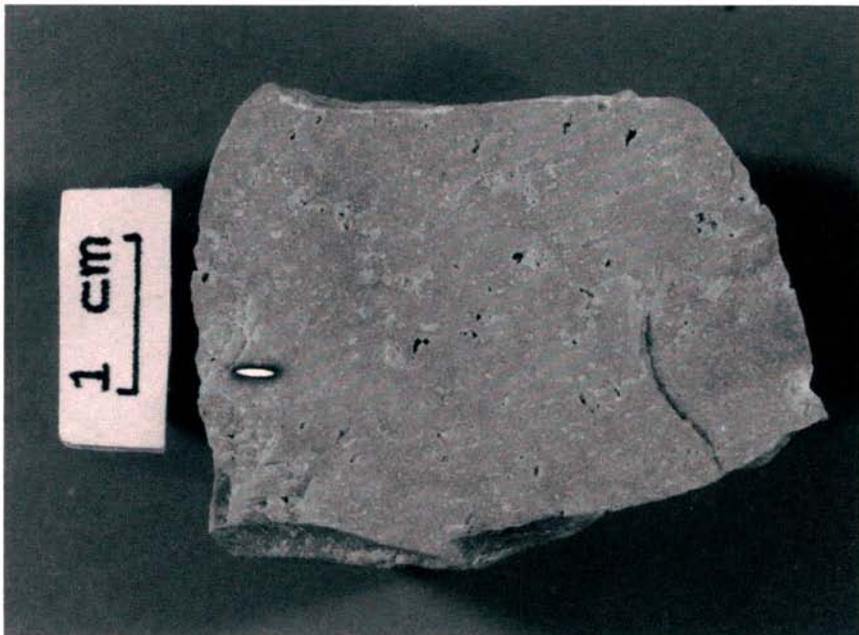


Figure 28. The Rock Dolomite (dolostone) (very fine grained example)

Photos



Figure 29. The Rock Shale

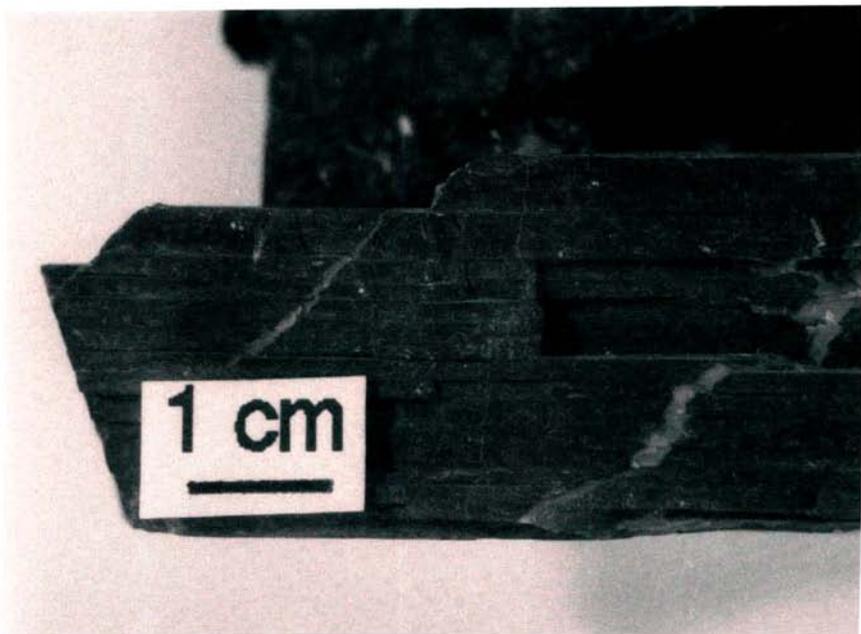


Figure 30. The Rock Slate (note thin layers that can be split apart)

Photos

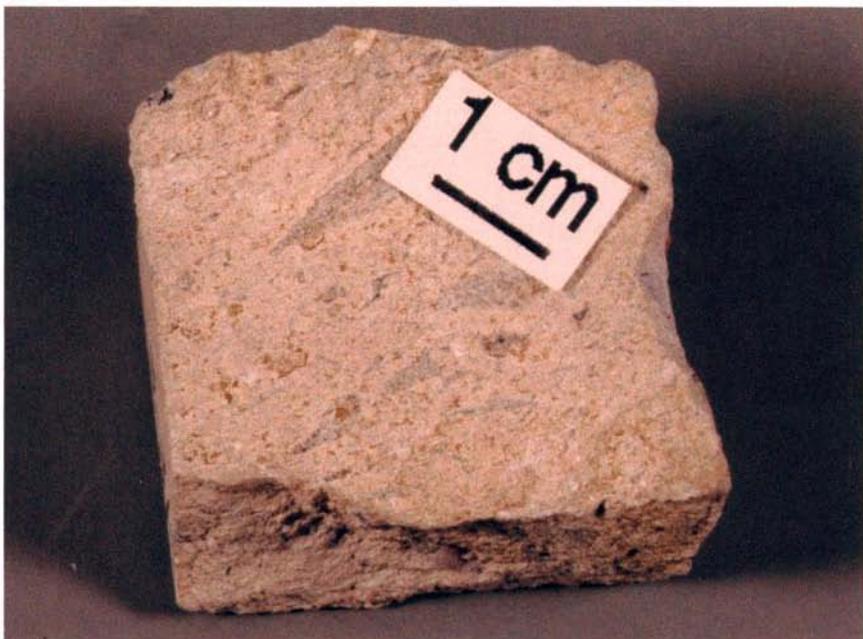


Figure 31. The Rock Rhyolite



Figure 32. The Rock Andesite

Photos



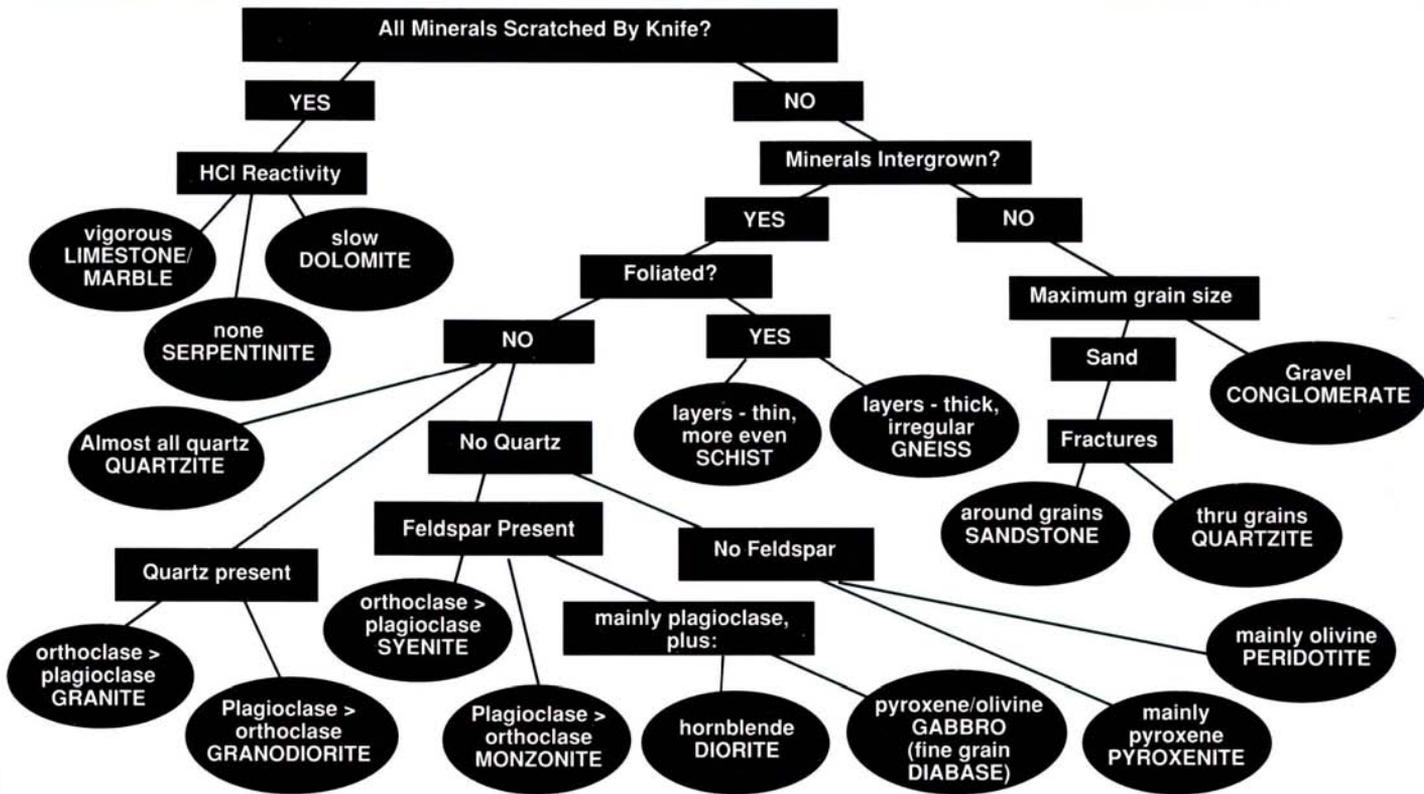
Figure 33. The Rock Basalt



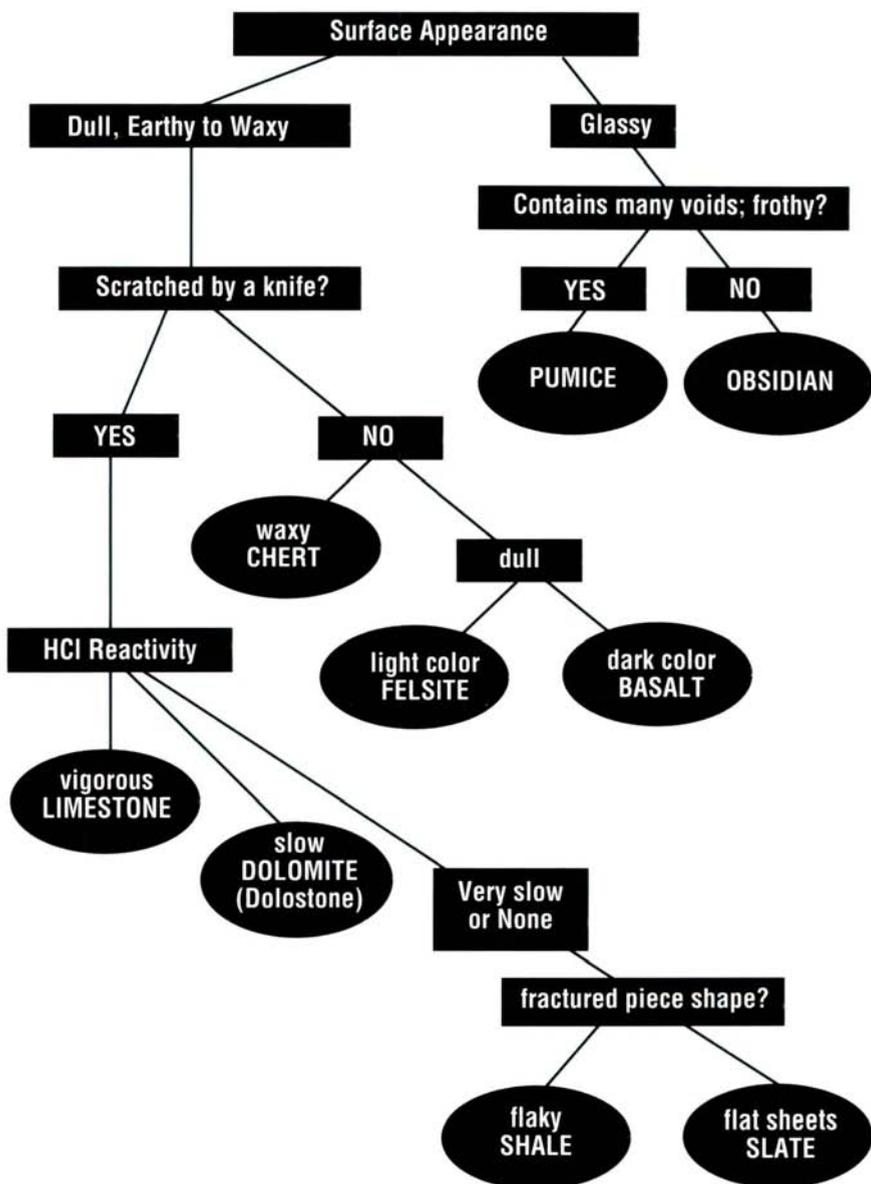
Figure 34. The Rock Basalt (vesicular)

Figure 35 — Rock Identification Flowchart
Rocks with Mineral Grains/Crystals Easily Visible to the Naked Eye

Part-A



**Figure 36 — Rock Identification Flowchart Part-B
Rocks With Very Fine Mineral Grains/Crystals
Not Easily Visible to the Naked Eye**



Role of Aggregate Source in Identification. A natural aggregate may come from a sand and gravel deposit or from a quarry in the form of crushed stone. For two important reasons, identifying the rock type(s) in a crushed stone is usually easier than identifying those in a gravel source. First, a crushed stone is normally composed of only one or two closely related rock types, even though some changes in mineralogy and texture may occur with vertical or horizontal separation, or both, in the quarry. Second, since it is a crushed material, sample surfaces are freshly broken and clean, which is the ideal condition for identifying minerals and determining texture.

A sand and gravel source, on the other hand, has several potential difficulties for rock and mineral identification. Since sand and gravel are water transported and deposited, rock fragments contained therein can have many different original bedrock sources. As a result, a single gravel deposit can contain many, often unrelated, rock types. Samples must therefore be taken especially carefully to ensure that they are representative of the whole deposit. In addition, particles in a sand and gravel deposit are often worn or coated with secondary minerals or both, making identification of the minerals more difficult. This can often be remedied by wetting the particles before examination or by breaking the particles to expose a fresh surface.

Engineering Properties of Rock Types

Although there can be some variation in engineering properties within a given rock type, knowing rock type or even rock class for the aggregate will often provide insight about its physical, mechanical, and/or chemical properties. These general relationships between rock type and properties can help in selecting a proper aggregate material for a given application. ASTM C-294 "Standard Descriptive Nomenclature for Constituents of Natural Mineral Aggregates" and *STP 169B* on tests and properties of concrete making materials (ASTM, 1986a, 1978) provide additional information on this subject. Various engineering properties are discussed below.

Absorption. Absorption is closely related to the porosity (pore space) in the rock and its permeability (ability to transmit water). Sedimentary rocks (which in general are composed of individual rock fragments or mineral grains, or both, packed to varying degrees) tend to have more space between grains and therefore higher absorption than igneous and metamorphic rocks. The pore space in igneous and metamorphic rocks is generally less due to an interlocking grain structure created by the mineral crystallization (or recrystallization) in place.

Based on tests conducted on thousands of aggregate samples from across the country by the FHWA's forerunner, the Bureau of Public Roads, absorption of sedimentary rocks was found to be in the 1 to 2 percent range, while igneous and metamorphic rocks were usually well below 1 percent (Woolf, 1953). Of the sedimentary rocks, sandstone and chert tended to be on the high end of the range, and limestone and dolomite at the lower end. Keep in mind that while these trends are useful, these values are average results, and a specific rock source can be significantly above or below these levels.

Freeze/Thaw Durability and D-Cracking. The ability of an aggregate to withstand the rigors of freeze/thaw (F/T) cycling in the presence of moisture often has a complex relationship with its porosity and permeability. Rocks can have fairly high absorption and still be durable under F/T conditions if their permeability is such that any water

present within the rock can migrate as freezing takes place to accommodate the volume change. Many sedimentary rocks fit this description. Igneous and metamorphic rocks, on the other hand, are durable under F/T conditions because their absorption is typically low.

F/T durability tends to be lower for rocks having certain combinations of porosity, pore size distribution, and permeability. These rocks can absorb critical amounts of water over long periods. However, the water cannot escape rapidly enough during freezing, and the pressure buildup due to the water migration and expansion fractures the aggregate. Certain carbonate rocks found in the Central United States are particularly susceptible to this phenomenon.

When an aggregate is used in concrete, its effect on the F/T durability of the paste must also be considered. The nondurable rock described above, when used in concrete, not only cracks itself but may form cracks in the surrounding concrete. In slabs on grade, these cracks are typically seen at the surface as a series of cracks parallel to each other and a free edge or joint in the concrete. This is the phenomenon known as D-cracking.

As noted above, rocks with high absorption are durable in an unbound condition, because their permeability allows internal pressures to be relieved to their outside as water freezing takes place. When these same rocks are enclosed in concrete, water in the aggregate may develop disruptive forces when the aggregate is frozen in a critically saturated condition. This is because the lower permeability of the concrete paste may not be able to accommodate (at a rate sufficient to prevent pressure buildup) the water being forced from the aggregate due to expansion during freezing. The resulting pressure may be sufficient to cause tensile cracking in the concrete paste (or "popouts" if the aggregate particle is near the surface). For these F/T related distresses to occur, it is assumed that the aggregate is either

- (1) critically saturated (that is, there is enough water in the pores so the remaining pore space will not accommodate the expansion due to freezing) or

- (2) it has a pore system that will not allow a rapid enough migration of water during freezing to prevent the buildup of destructive tensile stresses.

Wear and Polish Resistance : The wear and polish resistance of an aggregate exposed to traffic at the pavement surface is highly related to the absolute and relative hardness of the minerals making up the aggregate. These characteristics are especially critical for the coarse aggregate when it is to be used in an asphalt pavement. Aggregates composed of soft minerals (common ones are calcite and dolomite) or aggregates whose mineral grains are weakly cemented together will quickly wear away (low-wear resistance), leaving little or no aggregate protruding above the general surface of the pavement. Without this protruding aggregate, the pavement has no drainage channels for water to escape from beneath vehicle tires during rain, and therefore high-speed skid resistance tends to be low.

The other important aspect of skid resistance to which the aggregate contributes is tire adhesion to the surface. The pavement surface texture necessary for this adhesion is provided by the exposed fine aggregate and the small scale (less than 0.5mm) surface texture of the exposed coarse aggregate. To be effective, a coarse aggregate must not only have this texture initially, but also be of a composition which resists the smoothing or polishing of this texture under traffic. Pure limestone coarse aggregates may have this texture after crushing, but since the soft minerals of which they are composed are easily polished, these aggregates will not maintain this texture very long under traffic (low-polish resistance). Sandstones often have this texture, and will maintain it quite well under traffic because quartz (a hard mineral) is usually a major mineral component.

As noted above, the strength of the cement holding the mineral grains together is also an important factor in the performance of a sandstone. If the grains aren't adequately bound together, the aggregate will be worn away too rapidly to be acceptable (low-wear resistance), even though its surface texture is maintained.

Igneous and metamorphic rocks generally have the potential to provide adequate pavement friction; however, each

aggregate source must be judged on its own merits, since soft minerals can be abundant in some rocks in these classes as well as the sedimentary class. The ideal aggregate would be composed of one very hard mineral and one medium-hard mineral. Having two relatively hard components would keep the rate of wear at low levels. Having one of these components that is harder than the other would maintain the surface texture since the harder mineral would polish slower and therefore remain above the medium hard mineral at the surface of each coarse aggregate piece.

Aggregate surface texture and its resistance to polishing can be judged by using ASTM D-3319, "Standard Test Method for Accelerated Polishing of Aggregates Using the British Wheel" (ASTM, 1989a). "The Insoluble Residue Test", ASTM D-3042, (ASTM, 1986b) is used for evaluating the suitability of carbonate aggregates for surface courses. ASTM E-965, (ASTM, 1987) "Standard Test Method for Measuring Surface Macrotexure Depth Using a Volumetric Technique", can be used to determine the pavement's surface texture, and therefore some indication of its drainage capability. The mix design and construction can greatly affect the pavement surface texture obtained initially on an asphalt pavement.

Impact/Abrasion Resistance. The impact and abrasion resistance of an aggregate is determined by testing using the Los Angeles machine (ASTM C-131 (ASTM, 1989b) for small-size coarse aggregate and C-535 (ASTM, 1989c) for large-size coarse aggregate). The results of these tests are general indicators of aggregate quality and may or may not relate to an aggregate's suitability for use in a pavement surface as discussed in the section above. Aggregates with high losses in these tests degrade easily, and it may be difficult to maintain their gradation during processing. They may create problems by degrading during mixing in asphalt or Portland cement mixes, or during placement and compaction. These aggregates also may disintegrate or degrade rapidly when exposed to traffic and the environment. These tests, then, are good initial screening tests for distinguishing the potential performance of an aggregate. Foliated metamorphic rocks have the potential for high loss, as do poorly cemented sandstones and other sedimentary rocks.

Particle Shape and Roundness: Particle shape may be defined by the ratio of the three principal axes: length, width, and thickness. Where the three axes are nearly equal, the particle may range in appearance between a cube and a sphere. Where length and width are of nearly the same dimension, and also several times the dimension of the thickness, a flat particle is described. Where the length is several times the size of both the width and thickness, an elongate or rod-shaped particle is present.

A cube may be differentiated from a sphere by the characteristic known as roundness (or its antithesis, angularity). Roundness may be defined mathematically by the average radius of curvature of the corners on a particle divided by the radius of the maximum inscribed circle. By this definition a sphere would have a roundness of 1.0, whereas a cube would have a roundness of <1.0 . In practice, roundness of material is generally determined by comparing the particles in question with photographs or drawings of particles representing five levels of roundness: well rounded, rounded, subrounded, subangular, and angular.

Crushed stone, no matter what the rock type, will be in the subangular to angular class. Sand and gravel deposits, on the other hand, may range from angular to well rounded depending on the distance of transport before final sedimentation in the deposit, and the amount of particle impact and abrasion that occurred during this transport. If several rock types are present in a deposit, a range of roundness levels may be present due to potential variation in susceptibility to rounding of various rock types, as well as distance of transport.

Both crushed stone and gravel may have equidimensional, flat, or elongate particles. Particles with shapes other than equidimensional tend to occur when there are planes of weakness in the parent rock. These could include bedding planes in sedimentary rocks, and foliation and lineation in metamorphic rocks. The type of crusher used in crushed stone operations has also been found to influence particle shape.

The characteristics of shape and roundness are important because they influence an aggregate's performance in most uses. In asphalt mixes angular particles result in a more

stable mix due to interlocking of the corners of adjacent pieces. In contrast, round particles have more tendency to roll or slide past each other. This same tendency may affect the stability and load bearing capacity of unbound bases. In Portland cement concrete, this tendency for angular particles to interlock may result in a harsher mix that is difficult to mix and place. To compensate for this difficulty, additional natural fines may need to be included in the mix.

Excessive amounts of flat or elongate particles are not desirable in asphalt or Portland cement mixes. In both mix types these particles make mixing and placement more difficult, and they are subject to breakage, particularly during compaction of asphalt pavements.

Alkali Aggregate Reactivity. All aggregates react, to some degree, when incorporated in Portland cement concrete. This only becomes a problem when the reaction products are of a certain composition and extensive enough so that their uptake of moisture exerts destructive expansion forces within the concrete. This reaction process involves the alkalis present in the concrete (usually derived from the cement), water, and certain siliceous or carbonate aggregates. Deterioration due to this reaction is usually manifested at the surface of the affected structure by a regular system of cracks called map or pattern cracking. This pattern may be influenced by the size and shape of the affected structure.

Siliceous minerals identified as potentially reactive include opal, chalcedony, microcrystalline to cryptocrystalline quartz, crystalline quartz which is intensely fractured or strained, and certain volcanic glasses. This group basically includes most types of very finely divided, highly siliceous minerals. Consequently, the list of rock types which **may** contain these minerals is quite extensive.

Of the carbonate rocks, many are somewhat reactive, but only a very limited range appear to cause deleterious expansion. The known problem aggregates have the following characteristics:

- They are dolomitic, but contain significant amounts of calcite.

- Their mineralogical texture consists of small dolomitic crystals within a matrix of clay or silt and finely divided calcite or both; and
- The matrix is extremely fine-grained.

When dealing with the reactivity problem, the simplest solution is to avoid the use of reactive aggregate. With the shortage of available aggregates in some areas, this is not always possible. Using a low alkali cement (less than 0.6 percent) or certain admixtures has been a common practice when known reactive aggregates are used in concrete. The use of low alkali cement prevents deleterious expansion in most instances. More recently, some aggregates have been found to be deleteriously reactive, even with the low alkali cements. This situation reinforces the need to test aggregate-cement combinations before using them on the job wherever a reactivity problem is suspected. Definitive screening tests may take six months to a year to run, but more rapid test methods are being developed.

Weathering. All of the above discussions about aggregate assume that the material is in a “fresh” unweathered condition. The most durable rock, if exposed for a sufficiently long period to the natural environment, will degrade into a soil. For most aggregates, this time frame is geologic rather than historic, and therefore, for engineering purposes, need not be of concern. That is, it need not be of concern if initially unweathered aggregate is used.

In the case of crushed stone, the production of unweathered aggregate material can usually be assured by stripping sufficient overburden from the site before opening the quarry, and during horizontal expansion of the quarry at the surface. Sand and gravel deposits tend to be more variable than crushed stone quarries in both the horizontal and vertical direction, so variation in the weathering state of the material may need to be more closely monitored during operations than with a crushed stone quarry. In either case, the development and operation of an aggregate source should be carefully monitored by a geologist, materials engineer, or other qualified person.

Summary

This manual provides a brief discussion of the formation, composition and classification of rocks and minerals. Identification procedures are presented for differentiating the most common rock and mineral types the practicing engineer is likely to encounter. The procedures may be carried out in the field or the laboratory using simple tools and the flowcharts provided. The ability to identify the rocks and minerals of which an aggregate is composed will give the engineer additional insight into the potential performance of that aggregate in a particular construction application. This ability will also help the engineer to understand the aggregate's impact on the performance (good or bad) of past construction projects that are being reviewed.

For comprehensive aggregate identification, testing, and analysis, a qualified geologist, petrographer, or materials engineer should be consulted as appropriate.

References

1. Woolf, D.O. 1950. "The Identification of Rock Types." *Public Roads*: vol 26, no. 2, pp. 44-48. Bureau of Public Roads, U.S. Dept. of Commerce, Washington, D.C.
2. Woolf, D.O. 1951. *The Identification of Rock Types*. Reprint by U.S. Government Printing Office, Washington, D.C. 11p.
3. Woolf, D.O. 1960. *The Identification of Rock Types, Revised Edition*. U.S. Government Printing Office, Washington, D.C., November, 1960. 17p.
4. Hurlbut, Cornelius S., Jr. 1963. *Dana's Manual of Mineralogy, 17th edition*. John Wiley and Sons: New York. 609p.
5. Woolf, D.O. 1953. *Results of Physical Tests of Road-Building Aggregate*. U.S. Government Printing Office, Washington, D.C. 227p.
6. ASTM, 1986a C-294, "Standard Descriptive Nomenclature for Constituents of Natural Mineral Aggregates", *ASTM Annual Book of Standards*, Vol. 04.02, Concrete and Concrete Aggregates.
7. ASTM, 1978, "Significance of Tests and Properties of Concrete-Making Materials", Special Technical Publication 169B, ASTM, Philadelphia, PA, 8_p.
8. ASTM, 1989a, D3319, "Standard Test Method for Accelerated Polishing of Aggregates Using British Wheel", *ASTM Annual Book of Standards*, Vol. 04.03, Road and Paving Materials; Traveled Surface Characteristics.
9. ASTM, 1986b, D3042, "Standard Test Method for Insoluble Residue in Carbonate Aggregates", *ASTM Annual Book of Standards*, Vol. 04.03, Road and Paving Materials; Traveled Surface Characteristics.
10. ASTM, 1987, E965, "Standard Test Method for Measuring Surface Macrotecture Depth using a Volumetric Technique", *ASTM Annual Book of Standards*, Vol. 04.03, Road and Paving Materials; Traveled Surface Characteristics.
11. ASTM, 1989b, "Standard Test Method for Resistance to Degradation of Small-size Course Aggregate by Abrasion and Impact in the Los Angeles Machine", *ASTM Annual Book of Standards*, Vol. 04.02, Concrete and Concrete Aggregates.
12. ASTM, 1989c, "Standard Test Method for Resistance to Degradation of Large-size Course Aggregate by Abrasion and Impact in the Los Angeles Machine", *ASTM Annual Book of Standards*, Vol. 04.02, Concrete and Concrete Aggregates.

