CHAPTER 1

Rocks and Minerals

The crust of the earth is made up of rock; rock, in turn, is composed of minerals. The geologist classifies rocks by determining their modes of formation and their mineral content in addition to examining certain chemical and physical properties. Military engineers use a simpler diagnostic method that is discussed below. Rock classification is necessary because particular rock types have been recognized as having certain properties or as behaving in somewhat predictable ways. The rock type implies information on many properties that serves as a guide in determining the geological and engineering characteristics of a site. This implied information includes—

- A range of rock strength.
- Possible or expected fracture systems.
- The probability of encountering bedding planes.
- Weak zones.
- Other discontinuities.
- Ease or difficulty of rock excavation.
- Permeability.
- Value as a construction material.
- Trafficability.

This chapter describes procedures for field identification and classification of rocks and minerals. It also explains some of the processes by which rocks are formed. The primary objective of identifying rock materials and evaluating their physical properties is to be able to recommend the most appropriate aggregate type for a given military construction mission.

Section I. Minerals

PHYSICAL PROPERTIES

Rocks are aggregates of minerals. To understand the physical properties of rocks, it is necessary to understand what minerals are. A mineral is a naturally occurring, inorganically formed substance having an ordered internal arrangement of atoms. It is a compound and can be expressed by a chemical formula. If the mineral's internal framework of atoms is expressed externally, it forms a crystal. A mineral's characteristic physical properties are controlled by its composition and atomic structure, and these properties are valuable aids in rapid field identification. Properties that can be determined by simple field tests are introduced here to aid in the identification of minerals and indirectly in the identification of rocks. These properties are—

- Hardness.
- Crystal form.
- Cleavage.
- Fracture.
- Luster and color.
- Streak.
- Specific gravity.

Hardness

The hardness of a mineral is a measure of its ability to resist abrasion or scratching by other minerals or by an object of known hardness. A simple scale based on empirical tests has been developed and is called the Mohs

Hardness Scale. The scale consists of 10 minerals arranged in increasing hardness with 1 being the softest. The 10 minerals selected to form the scale of comparison are listed in *Table 1-1.* Hardness kits containing most of the reference minerals are available, but equivalent objects can be substituted for expediency. Objects with higher values on Mobs' scale are capable of scratching objects with lower values. For example, a rock specimen that can be scratched by a copper coin but not by the fingernail is said to have a hardness of about 3. Military engineers describe a rock as either hard or soft. A rock specimen with a hardness of 5 or more is considered hard. The hardness test should be performed on a fresh (unweathered) surface of the specimen.

Table 1-1. The Mohs Hardness Scale.

Mineral	Relative Hardness	Equivalent Objects
Diamond	10	
Corundum	9	
Topaz	8	
Quartz	7	Porcelain (7)
Feldspar	6	Steel file (6.5)
Apatite	5	Window glass (5.5) Knife blade or nail (5)
Fluorite	4	
Calcite	3	Copper coin (3.5)
Gypsum	2	Fingernail (2)
Talc	1	

Crystal Form

Most, but not all, minerals form crystals. The form, or habit, of the crystals can be diagnostic of the mineral and can help to identify it. The minerals galena (a lead ore) and halite (rock salt) commonly crystallize as cubes. Crystals of garnet (a silicate mineral) commonly have 12 or 24 equidimensional faces. Some minerals typically display long needle-like crystals. Minerals showing no crystal form are said to be amorphous. *Figure 1-1* illustrates two of the many crystal forms.

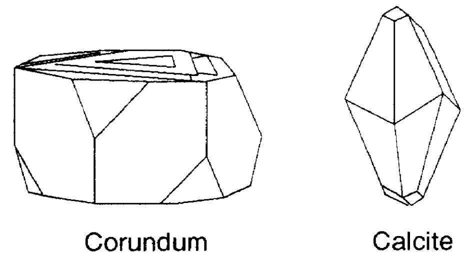


Figure 1-1. Crystal forms.

Cleavage

Cleavage is the tendency of a mineral to split or separate along preferred planes when broken. It is fairly consistent from sample to sample for a given mineral and is a valuable aid in the mineral's identification. Cleavage is described by noting the direction, the degree of perfection, and (for two or more cleavage directions) the angle of intersection of cleavage planes. Some minerals have one cleavage direction; others have two or more directions with varying degrees of perfection. *Figure 1-2* illustrates a mineral with one cleavage direction (mica) and one with three directions (calcite). Some minerals, such as quartz, form crystals but do not cleave.

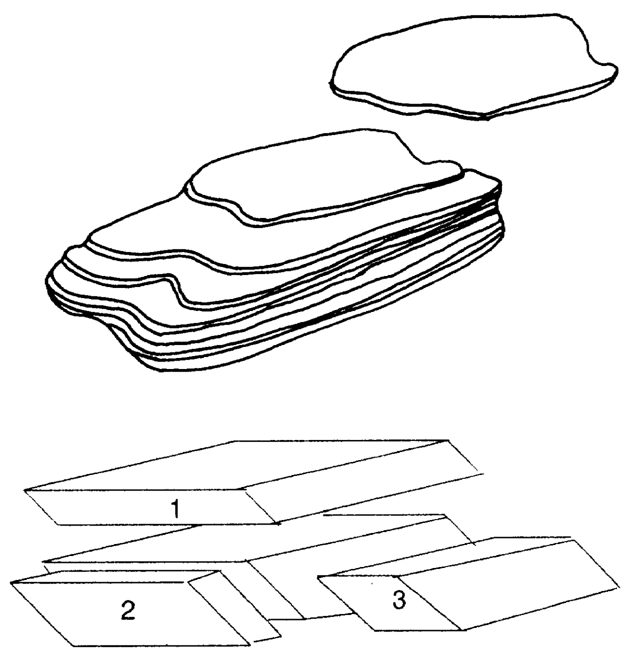


Figure 1-2. Cleavage.

Fracture

Fracture is the way in which a mineral breaks when it does not cleave along cleavage planes. It can be helpful in field identification. *Figure 1-3* illustrates the common kinds of fracture. They are—

- Conchoidal. This fracture surface exhibits concentric, bowl-shaped structures like the inside of a clam shell (for example, chert or obsidian).
- Fibrous or splintery. This fracture surface shows fibers or splinters (for example, some serpentine).
- Hackly. This fracture surface has sharp, jagged edges (for example, shist).
- Uneven. This fracture surface is rough and irregular (for example, basalt).

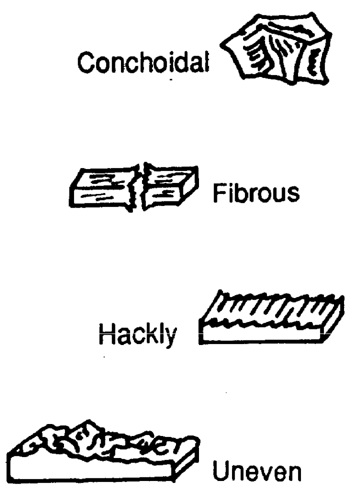


Figure 1-3. Fractures.

Luster and Color

The appearance of a mineral specimen in reflected light is called its luster. Luster is either metallic or nonmetallic. Common nonmetallic lusters are—

- Vitreous (having the appearance of glass).
- Adamantine (having the brilliant appearance of diamonds).
- Pearly (having the iridescence of pearls).
- Silky (having a fibrous, silklike luster).
- Resinous (having the appearance of resin).

For some minerals, especially the metallic minerals, color is diagnostic. Galena (lead sulphide) is steel gray, pyrite (iron sulphide) is brass yellow, and magnetite (an iron ore) is black. However, many nonmetallic minerals display a variety of colors. The use of color in mineral identification must be made cautiously since it is a subjective determination.

Streak

The color of a powdered or a crushed mineral is called the streak. The streak is obtained by rubbing the rnineral on a piece of unglazed porcelain, called a streak plate. The streak is much more consistent in a mineral than the color of the intact specimen. For example, an intact specimen of the mineral hematite (an iron ore) may appear black, brown, or red, but the streak will always be dark red. The streak is most useful for the identification of dark-colored minerals such as metallic sulfides and oxides. Minerals with hardness 6.5 will not exhibit a streak, because they are harder than a piece of unglazed porcelain.

Specific Gravity

The specific gravity of a substance is the ratio of its weight (or mass) to the weight (or mass) of an equal volume of water. In field identification of minerals, the heft, or apparent weight, of the specimen is an aid to its identification. Specific gravity and heft are controlled by the kinds of atoms making up the mineral and the packing density of the atoms. For example, ores of lead always have relatively high specific gravity and feel heavy.

COMMON ROCK-FORMING MINERALS

There are approximately 2,000 known varieties of minerals. Only about 200 are common enough to be of geologic and economic importance. Some of the more important minerals to military engineers are—

- Quartz.
- Feldspars.
- Micas.

- Amphiboles.
- Pyroxenes.
- Olivine.
- Chlorite.
- Calcite.
- Dolomite.
- Limonite.
- Clay.

Quartz

Quartz (silicon dioxide) is an extremely hard, transparent to translucent mineral with a glassy or waxy luster. Colorless to white or smoky-gray varieties are most common, but impurities may produce many other colors. Like man-made glass, quartz has a conchoidal (shell-like) fracture, often imperfectly developed. It forms pointed, six-sided prismatic crystals on occasion but occurs most often as irregular grains intergrown with other minerals in igneous and metamorphic rocks; as rounded or angular g-rains in sedimentary rocks (particularly sandstones); and as a microcrystalline sedimentary rock or cementing agent. Veins of milky white quartz, often quite large, fill cracks in many igneous and metamorphic rocks. Unlike nearly all other minerals, quartz is virtually unaffected by chemical weathering.

Feldspars

Feldspars form very hard, blocky, opaque crystals with a pearly or porcelainlike luster and a nearly rectangular cross section. Crystals tend to cleave in two directions along flat, shiny, nearly perpendicular surfaces. Plagioclase varieties often have fine parallel grooves (striations) on one cleavage surface. Orthoclase varieties are usually pink, reddish, ivory, or pale gray. Where more than one variety is present, color differences are normally distinct. Crystalline feldspars are major components of most igneous rocks, gneisses, and schists. In the presence of air and water, the feldspars weather to clay minerals, soluble salts, and colloidal silica.

Micas

Micas form soft, extremely thin, transparent to translucent, elastic sheets and flakes with a bright glassy or pearly luster. “Books” of easily separated sheets frequently occur. The biotite variety is usually brown or black, while muscovite is yellowish, white, or silvery gray. Micas are very common in granitic rocks, gneisses, and schists. Micas weather slowly to clay minerals.

Amphiboles

Amphiboles (chiefly hornblende) are hard, dense, glassy to silky minerals found chiefly in intermediate to dark igneous rocks and gneisses and schists. They generally occur as short to long prismatic crystals with a nearly diamond-shaped cross section. Dark green to black varieties are most common, although light gray or greenish types occur in some marbles and schists. Amphiboles weather rapidly to form chlorite and, ultimately, clay minerals, iron oxides, and soluble carbonates.

Pyroxenes

Pyroxenes (chiefly augite) are hard, dense, glassy to resinous minerals found chiefly in dark igneous rocks and, less often, in dark gneisses and schists. They usually occur as well- formed, short, stout, columnar crystals that appear almost square in cross section. Granular crystals are common in some very dark gabbroic rocks. Masses of nearly pure pyroxene form a rock called pyroxenite. Colors of green to black or brown are most common, but pale green or gray varieties sometimes occur in marbles or schists. Pyroxenes weather much like the amphiboles.

Olivine

Olivine is a very hard, dense mineral that forms yellowish-green to dark olive-green or brown, glassy grains or granular masses in very dark, iron-rich rocks, particularly gabbro and basalt. Masses of almost pure olivine form a rare rock called peridotite. Olivine weathers rapidly to iron oxides and soluble silica.

Chlorite

Chlorite is a very soft, grayish-green to dark green mineral with a pearly luster. It occurs most often as crusts, masses, or thin sheets or flakes in metamorphic rocks, particularly schists and greenstone. Chlorite forms from amphiboles and pyroxenes by weathering or metamorphism and, in turn, weathers to clay minerals and iron oxides.

Calcite

Calcite is a soft, usually colorless to white mineral distinguished by a rapid bubbling or fizzing reaction when it comes in contact with dilute hydrochloric acid (HC1). Calcite is the major component of sea shells and coral skeletons and often occurs as well-formed, glassy to dull, blocky crystals. As a rock-forming mineral, it usually occurs as fine to coarse crystals in marble, loose to compacted granules in ordinary limestone, and as a cementing agent in many sedimentary rocks.

Calcite veins, or crack fillings, are common in igneous and other rocks. Calcite weathers chiefly by solution in acidic waters or water containing dissolved carbon dioxide.

Dolomite

Dolomite is similar to calcite in appearance and occurrence but is slightly harder and more resistant to solutioning. It is distinguished by a slow bubbling or fizzing reaction when it comes in contact with dilute HC1. Usually the reaction can be observed only if the mineral is first powdered (as by scraping it with a knife). Coarse dolomite crystals often have curved sides and a pinkish color. Calcite and dolomite frequently occur together, often in intimate mixtures.

Limonite

Limonite occurs most often as soft, yellowish-brown to reddish-brown, fine-grained, earthy masses or compact lumps or pellets. It is a common and durable cementing agent in sedimentary rocks and them major component of laterite. Most weathered rocks contain some limonite as a result of the decomposition of iron-bearing minerals.

Clay

Clay minerals form soft microscopic flakes that are usually mixed with impurities of various types (particularly quartz, limonite, and calcite). When barely moistened, as by the breath or tongue, clays give off a characteristic somewhat musty "clay" odor. Clays form a major part of most soils and of such rocks as shale and slate. They are a common impurity in all types of sedimentary rocks.

Section II. Rocks

FORMATION PROCESSES

A rock may be made of many kinds of minerals (for example, granite contains quartz, mica, feldspar, and usually hornblende) or may consist essentially of one mineral (such as a limestone, which is composed of the mineral calcite). To the engineer, rock is a firm, hardened substance that, in contrast to soil, cannot be excavated by standard earthmoving equipment. In reality, there is a transitional zone separating rock and soil so that not all "rock" deposits require blasting. Some "rock" can be broken using powerful and properly designed ripping equipment. The geologist places less restriction on the definition of rock.

Rocks can be grouped into three broad classes, depending on their origin. They are—

- Igneous.
- Sedimentary.
- Metamorphic.

Igneous rocks are solidified products of molten material from within the earth's mantle. The term igneous is from a word meaning "formed by fire. " Igneous rocks underlie all other types of rock in the earth's crust and may be said to form the basement of the continents on which sedimentary rocks are laid down. Most sedimentary rocks are formed by the deposition of particles of older rocks that have been broken down and transported from their original positions by the agents of wind, water, ice, or gravity. Metamorphic rocks are rocks that have been altered in appearance and physical properties by heat, pressure, or permeation by gases or fluids. All classes of rocks (sedimentary, igneous, and metamorphic) can be metamorphosed. Igneous, sedimentary, and metamorphic rocks often occur in close association in mountainous areas, in areas once occupied by mountains but which have since eroded, and in broad, flat continental regions known as shields. Flat-lying sedimentary rocks form much of the plains of the continents and may occupy broad valleys overlain by recent or active deposits of sediments. The sediments being deposited in today's oceans, lakes, streams, floodplains, and deserts will be the sedimentary rocks of tomorrow. The rock-forming processes continually interact in a scheme called the rock cycle, illustrated in *Figure 1-4.*

Igneous

Igneous rocks are solidified from hot molten rock material that originated deep within the earth. This occurred either from magma in the subsurface or from lava extruded onto the earth's surface during volcanic eruptions. Igneous rocks owe their variations in physical and chemical characteristics to differences in chemical composition of the original magma and to the physical conditions under which the lava solidified.

The groups forming the subdivisions from which all igneous rocks are classified are—

- Intrusive igneous rocks (cooled from magma beneath the earth's surface).
- Extrusive igneous rocks (cooled from magma on the earth's surface).

Figure 1-5 is a block diagram illustrating the major kinds of intrusive and extrusive rock bodies formed from the crystallization of igneous rocks. Dikes and sills are tabular igneous intrusions that are thin relative to their lengths and widths. Dikes are discordant; they cut across the bedding of the strata penetrated. Sills are concordant; they intrude parallel to and usually along bedding planes or contacts of the surrounding strata. Dikes and sills may be of any geologic age and may intrude young and old sediments. Batholiths are large, irregular masses of intrusive igneous rock of at least 40 square miles in area. A stock is similar to a batholith but covers less than 40 square miles in outcrop. Stocks and batholiths generally increase in volume (spread out) with depth and originate so deep that their base usually cannot be detected. Magma that reaches the earth's surface while still molten is ejected onto the ground or into the air (or sea) to form extrusive igneous rock. The molten rock may be ejected as a viscous liquid that flows out of a volcanic vent or from fissures along the flanks of the volcano. The flowing viscous mass is called lava and the lava flow may extend many miles from the crater vent. Lava that is charged with gases and ejected violently into the air forms pyroclastic debris consisting of broken and pulverized rock and molten material. The pyroclastics solidify and settle to the ground where they form deposits of ash and larger-sized material that harden into layered rock (tuff). Igneous rocks are usually durable and resistant and form ridges, caps, hills, and mountains while surrounding rock material is worn away.

The chemical composition and thus the mineral content of intrusive and extrusive igneous rocks can be similar. The differences in appearance between intrusive and extrusive rocks are largely due to the size and arrangement of the mineral grains or crystals. As molten material cools, minerals crystallize and separate from solution. Silica-rich magma or lava solidifies into rocks high in silicon dioxide (quartz) and forms the generally light-colored igneous rocks. Molten material rich in ferromagnesian (iron-magnesium) compounds form the darker-colored igneous rocks, which are deficient in the mineral quartz. If the magma cools slowly, large crystals have time to grow. If the magma (or lava) cools quickly, large crystals do not have the chance to develop. Intrusive rocks are normally coarse-grained and extrusive igneous rocks are fine-grained for this reason. If lava cools too quickly for crystals to grow at all, then natural glass forms. *Figure 1-6, page 1-8,* illustrates the difference between intrusive and extrusive igneous rock crystals.

Sedimentary

Sedimentary rocks, also called stratified rocks, are composed of chemical precipitates, biological accumulations, or elastic particles. Chemical precipitates are derived from the

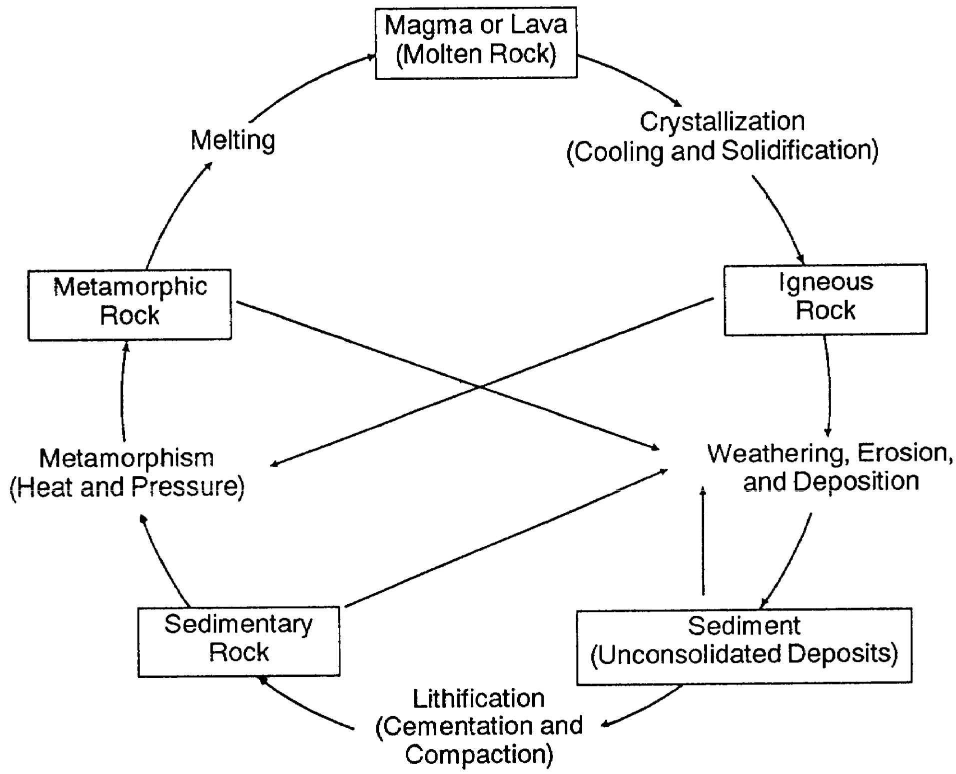


Figure 1-4. The rock cycle.

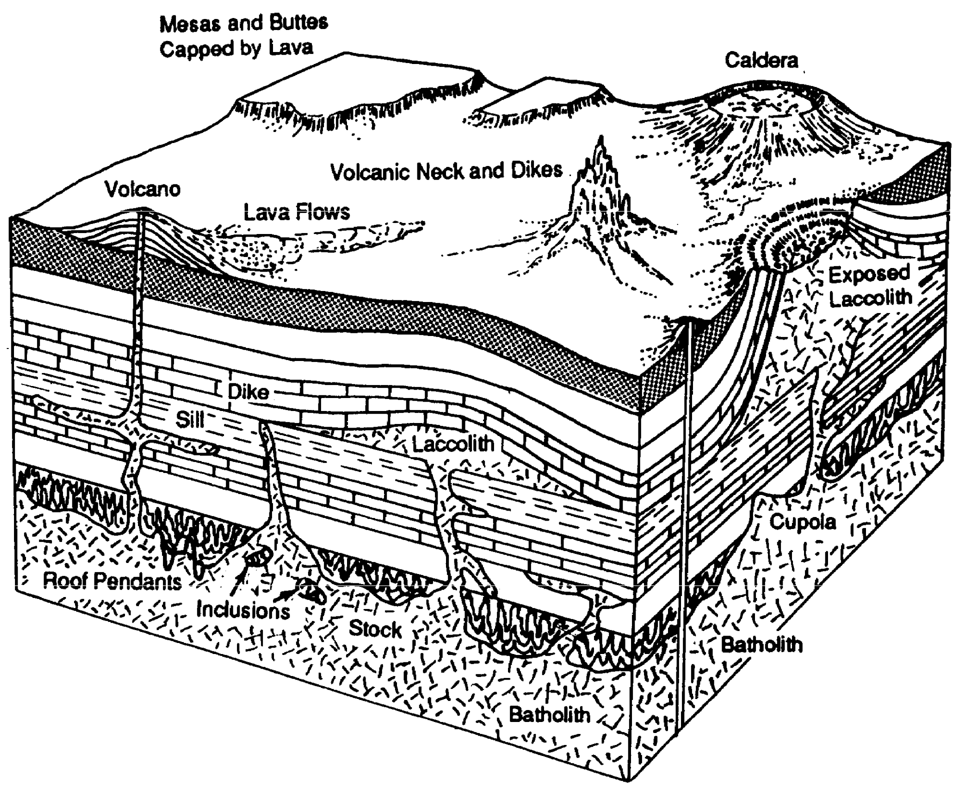


Figure 1-5. Intrusive and extrusive rock bodies.

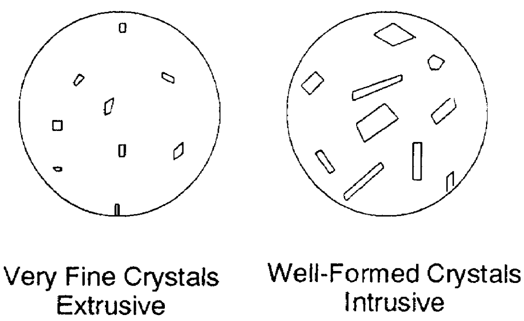


Figure 1-6. Cross section of igneous rock.

decomposition of existing igneous, sedimentary, and metamorphic rock masses. Dissolved salts are then transported from the original position and eventually become insoluble, forming "precipitates"; or, through evaporation of the water medium, they become deposits of "evaporites." A relatively small proportion of the sedimentary rock mass is organic sediment contributed by the activities of plants and animals. Clastic sediments are derived from the disintegration of existing rock masses. The disintegrated rock is transported from its original position as solid particles. Rock particles dropped from suspension in air, water, or ice produce deposits of "elastic" sediments. Volcanically ejected material that is transported by wind or water and then deposited forms another class of layered rocks called "pyroclastics." Most pyroclastic deposits occur in the vicinity of a volcanic region, but fine particles can be transported by the wind and deposited thousands of miles from the source. Inorganic elastic sediments constitute about three-fourths of the sedimentary rocks of the earth's crust. Loose sediments are converted to rock by several processes collectively known as lithification. These are—

- Compaction.
- Cementation.
- Recrystallization.

The weight of overlying sediments that have accumulated over a longtime produces great pressure in the underlying sediments. The pressure expels the water in the sediments by the process of compaction and forces the rock particles closer together. Compaction by the weight of overlying sediments is most effective in fine-grained sediments like clay and silt and in organic sediments like peat. Cementation occurs when precipitates of mineral-rich waters, circulating through the pores of sediments, fill the pores and bind the grains together. The most common cementing materials are quartz, calcite (calcium carbonate), and iron oxides (limonite and hematite). Recrystallization and crystal growth of calcium carbonate dissolved in saturated lime sediments develop rocks (crystalline limestone and dolomite) with interlocking, crystalline fabrics.

Sedimentary rocks are normally deposited in distinct parallel layers separated by abrupt, fairly even contact surfaces called bedding planes. Each layer represents a successive deposit of material. Bedding planes are of great significance as they are planes of structural weakness. Masses of sedimentary rock can move along bedding planes during rock slides. *Figure 1-7* represents the layer-cake appearance of sedimentary rock beds. Sedimentary rocks cover about 75 percent of the earth's surface. Over 95 percent of the total volume of sediments consists of a variety of shales, sandstones, and limestones.

Metamorphic

The alteration of existing rocks to metamorphic rocks may involve the formation within the rock of new structures, textures, and minerals. The major agents in metamorphism are—

- Temperature.
- Pressure.
- Chemically active fluids and gases.

Heat increases the solvent action of fluids and helps to dissociate and alter chemical compounds. Temperatures high enough to alter rocks commonly result from the intrusion of magma into the parent rock in the form of dikes, sills, and stocks. The zone of altered rock formed near the intrusion is called the contact metamorphism zone (see *Figure 1-8)*. The alteration zone may be inches to miles in width or length and may grade

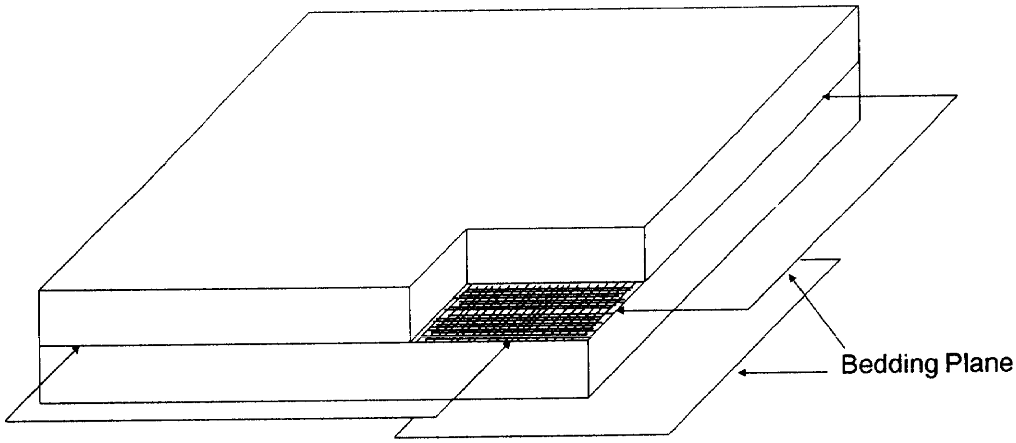


Figure 1-7. Bedding planes.

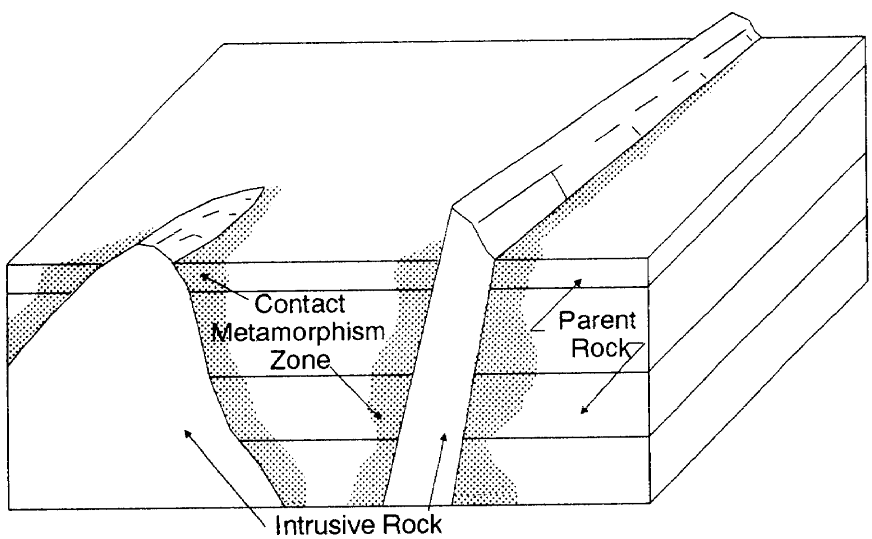


Figure 1-8. Contact metamorphism zone.

laterally from the unaltered parent rock to the highly metamorphosed derivative rock. Pressures accompanying the compressive forces responsible for mountain building in the upper earth's crust produce regional metamorphic rocks characterized by flattened, elongated, and aligned grains or crystals that give the rock a distinctive texture or appearance called foliation (see *Figure 1-9, page 1-10)*. Hot fluids, especially water and gases, are powerful metamorphic agents. Water under heat and pressure acts as a solvent, promotes recrystallization, and enters into the chemical composition of some of the altered minerals.

CLASSIFICATION

Igneous, metamorphic, and sedimentary rocks require different identification and classification procedures. The fabric, texture, and bonding strength imparted to a rock by its formation process determine the procedures that must be used to classify it.

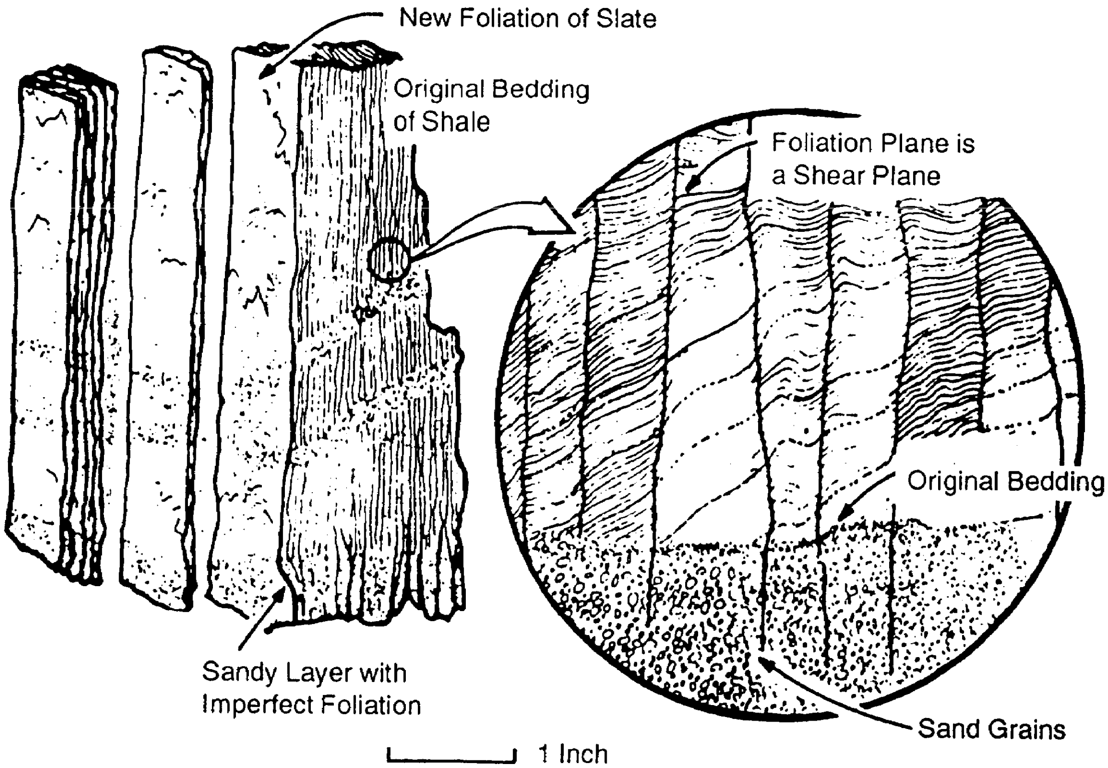


Figure 1-9. Metamorphic foliation.

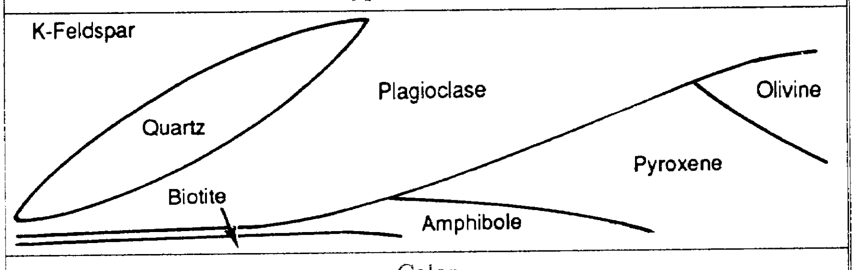
Igneous

Igneous rocks are classified primarily on the basis of—

- Texture.
- Color (or mineral content).

Texture is the relative size and arrangement of the mineral grains making up the rock. It is influenced by the rate of cooling of the molten material as it solidifies into rock. Intruded magmas cool relatively slowly and form large crystals if the intrusion is deep and smaller crystals if the intrusion is shallow. Extrusive lava is exposed abruptly to the air or to water and cools quickly, forming small crystals or no crystals at all. Therefore, referring to *Table 1-2,* igneous rocks may have textures that are coarse-grained (mineral grains and crystals that can be differentiated by the unaided eye), very fine-grained (mineral crystals too small to be differentiated by the unaided eye), or of contrasting grain sizes (large crystals, or "phenocrysts," in a fine-grained "ground mass"). The intrusive igneous rocks generally have a distinctive texture of coarse interlocking crystals of different minerals. Under certain conditions, deep-seated intrusions form "pegmatites" (rocks with very large crystals). The extrusive (volcanic) igneous rocks, however, show great variation in texture. Very fine-grained rocks maybe classified as having stony, glassy, scoriaceous, or fragmental texture. A rock with a stony texture consists of granular particles. Fine-grained rocks with a shiny smooth texture showing a conchoidal fracture are said to be "glassy." An example is obsidian, a black volcanic glass. Gases trapped in the extrusive lava may escape upon cooling, forming bubble cavities, or vesicles, in the rock. The result is a rock with scoriaceous texture. Fragmental rocks are those compsed of lithified, pyroclastic material. The pyroclastic (volcanoclastic) deposits are made up of volcanic rock particles of various sizes that have drifted and accumulated by the action of wind and water after ejection

Table 1-2. Classification of igneous rocks.



Origin	Dominant Texture*		Typical Mineral	
			Color	
			Light	Dark
Intrusive	Coarse-grained (distinguishable grains)		Granite	Gabbro-diorite
Extrusive	Very fine (indistinguishable)	Stony	Felsite	Basalt
		Glassy	Obsidian	
		Scoriaceous	Pumice	Scoria
		Fragmental	Volcanic ash, cinder, bombs, and blocks	
Intrusive/ extrusive	Contrasting grain size		Porphyritic rocks	

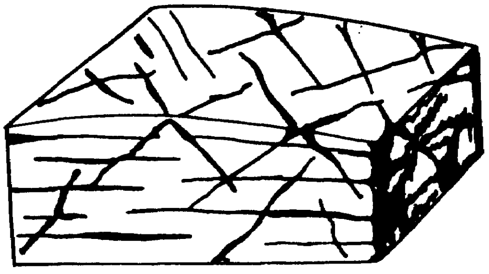
*Rocks containing many scattered larger crystals are called "porphyritic," such as porphyritic granite and porphyritic basalt.

from the volcanic vent. Fine-grained (smaller than 32 millimeters (mm)) ejects (called lapilli, or ash) form deposits that become volcanic tuff. Lava flowing out of the volcanic vent or fissure forms a flow with a ropelike texture if the lava is very fluid. More viscous lava forms a blocky flow. Upon cooling, basaltic lava flows, sills, and volcanic necks sometimes crack. They often acquire columnar jointing characterized by near-vertical columns with hexagonal cross sections (see *Figure 1-10, page 1-12).*

Igneous rocks are further grouped by their overall color, which is generally a result of their mineral content (see *Table 1-2).* The light-colored igneous rocks are silica-rich, and the dark-colored igneous rocks are silica-poor, with high ferromagnesian content. The intermediate rocks show gradations from light to dark, reflecting their mixed or gradational mineral content. An example illustrating the use of *Table 1-2* is as follows: lava and other ejects charged with gases may form scoria, a dark-colored, highly vesicular basaltic lava or pumice, a frothy, light-colored felsite lava so porous that it floats on water.

The common igneous rocks are—

- Granite.
- Felsite.
- Gabbro and diorite.



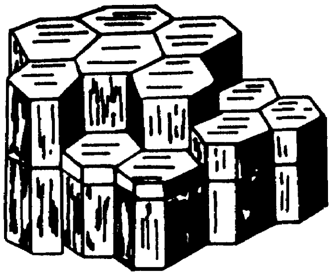


Figure 1-10. Jointing in igneous rocks.

- Basalt.
- Obsidian.
- Pumice.
- Scoria.

Granite. This is a coarsely crystalline, hard, massive, light-colored rock composed mainly of potassium feldspar and quartz, usually with mica and/or hornblende. Common colors include white, gray, and shades of pink to brownish red. Granite makes up most of the large intrusive masses of igneous rock and is frequently associated with (and may grade into) gneisses and schists. In general, it is a reasonably hard, tough, and durable rock that provides good foundations, building stones, and aggregates for all types of construction. Relatively fine-grained varieties are normally much tougher and more durable than coarse-grained types, many of which disintegrate rather rapidly under temperature extremes or frost action. Very coarse-grained and quartz-rich granites often bond poorly with cementing materials, particularly asphaltic cements. Antistripping agents should be employed when granite is used in bituminous pavements.

Felsite. This is a very fine-grained, usually extrusive equivalent of granite. Colors commonly range from light or medium gray to pink, red, buff, purplish, or light brownish gray. Felsites often contain scattered large crystals of quartz or feldspar, Isolated gas bubbles and streaklike flow structures are common in felsitic lavas. As a rule, felsites are about as hard and dense as granites, but they are generally tougher and tend to splinter and flake when crushed. Most felsites contain a form of silica, which produces alkali-aggregate reactions with portland cements. Barring these considerations, felsites can provide good general-purpose aggregates for construction.

Gabbro and Diorite. They form a series of dense, coarsely crystalline, hard, dark-colored intrusive rocks composed mainly of one or more dark minerals along with plagioclase feldspar. Since gabbro and diorite have similar properties and maybe difficult to distinguish in the field, they are often grouped under the name gabbro-diorite. They are gray, green, brown, or black. Gabbro-diorites are common in smaller intrusive masses, particularly dikes and sills. As a group, they make strong foundations and excellent aggregates for all types of construction. However, their great toughness and high density make excavation and crushing costs very high, particularly in finer-grained varieties.

Basalt. This is a very fine-grained, hard, dense, dark-colored extrusive rock that occurs widely in lava flows around the world. Colors are usually dark gray to black, greenish black, or brown. Scattered coarse crystals of olivine, augite, or plagioclase are common, as are gas bubbles that may or may not be mineral-filled. With increasing grain size, basalt often grades into diabase, an extremely tough variety of gabbro. Both basalt and diabase make aggregates of the highest quality despite a tendency to crush into chips or flakes in sizes smaller than 2 to 4 centimeters.

Obsidian. This is a hard, shiny, usually black, brown, or reddish volcanic glass that may contain scattered gas bubbles or visible crystals. Like man-made glass, it breaks readily into sharp-edged flakes. Obsidian is chemically unstable, weak, and valueless as a construction material of any type.

Pumice. This is a very frothy or foamy, light-colored rock that forms over glassy or felsitic lava flows and in blocks blown from erupting volcanoes. Innumerable closely spaced gas bubbles make pumice light enough to float on water and also impart good insulating properties. Although highly abrasive, pumice is very weak and can usually be excavated with ordinary hand tools. It is used in the manufacture of low-strength, lightweight concrete and concrete blocks. Most varieties are chemically unstable and require the use of low-alkali portland cements.

Scoria. It looks very much like a coarse, somewhat cindery slag. In addition to its frothy texture, scoria may also exhibit stony or glassy textures or a combination of both. The color of scoria ranges from reddish brown to dark gray or black. Scoria is somewhat denser and tougher than pumice, and the gas bubbles that give it its spongy or frothy appearance are generally larger and more widely spaced than those in pumice. Scoria is very common in volcanic regions and generally forms over basaltic lava flows. It is widely used as a lightweight aggregate in concrete and concrete blocks. Like pumice, it may require the use of special low-alkali cements.

Sedimentary

Sedimentary rocks are classified primarily by—

- Grain size.
- Composition.

They can be described as either elastic or nonelastic (see *Table 1-3, page 1-14).* The elastic rocks are composed of discrete particles, or grains. The nonclastic rocks are composed of interlocking crystals or are in earthy masses.

Clastic sedimentary rocks are further classified as coarse-grained or fine-grained. The coarse-grained rocks have individual grains visible to the naked eye and include sandstones, conglomerates (rounded grains), and breccias (angular grains). These are the rock equivalents of sands and gravels. The fine-grained rocks have individual grains that can only be seen with the aid of a hand lens or microscope and include silts tones, shales, clays tones, and mudstones.

Shales, claystones, and mudstones are composed of similar minerals and may be similar in overall appearance; however, a shale is visibly laminated (composed of thin tabular layers) and often exhibits “fissility,” that is, it can be split easily into thin sheets. Claystone and mudstone are not fissile. Mudstone is primarily a field term used to temporarily identify fine-grained sedimentary rocks of unknown mineral content.

The nonelastic sedimentary rocks can be further described as inorganic (or chemical) or organic. Dolomite is an inorganic calcium-magnesium carbonate. Chert, a widespread, hard, durable sedimentary rock, composed of microcrystalline quartz, precipitates from silica-rich waters and is often found in or with limestones. Limestone is a calcium carbonate that can be precipitated both organically and inorganically. A diagnostic feature of limestone is its effervescence in dilute HC1. Coal is an accumulation and conversion of the organic remains of plants and animals under certain environments.

Important features of the exposed or sampled portion of a deposit include stratification, the thickness of strata, the uniformity or nonuniformity of strata laterally, and the attitude (strike and dip) of the bedding planes. Special sedimentary bedding features are—

- Cross bedding (individual layers within a bed lie at an angle to the layers of adjacent beds (see *Figure 1-11, page 1-14),* typical of sand dune and delta front deposits).

- Mud cracks (polygonal cracks in the surface of dried-out mud flats).
- Ripple marks (parallel ridges in some sediments that indicate the direction of wind or water movement during deposition).

Some typical sedimentary rocks are—

- Conglomerate and breccia.
- Sandstone.
- Shale.
- Tuff.
- Limestone.
- Dolomite.
- Chert.

Conglomerate and Breccia. They resemble man-made concrete in that they consist of gravel-sized or larger rock fragments in a finer-grained matrix. Different varieties are generally distinguished by the size or composition of the rock fragments (such as limestone breccia, boulder conglomerate, or quartz pebble conglomerate). Wide variations in composition, degree of cementation, and degree of weathering of component partitles make these rocks highly unpredictable, even within the same deposit. Generally,

Table 1-3. Classification of sedimentary rocks.

Group		Dominant Composition		Rock Type
Clastic	Coarse-grained	Rock fragments larger than 2 mm	Rounded	Conglomerate
			Angular	Breccia
		Mineral grains (chiefly quartz) $\frac{1}{16}$ mm to 2 mm)		Sandstone
	Fine-grained	Clay and silt-sized particles (smaller than $\frac{1}{16}$ mm)		Shale
Nonclastic	Inorganic	Dolomite Microcrystalline silica		Dolomite Chert
	Organic/inorganic	Calcite		Limestone
	Organic	Carbonaceous plant debris		Coal

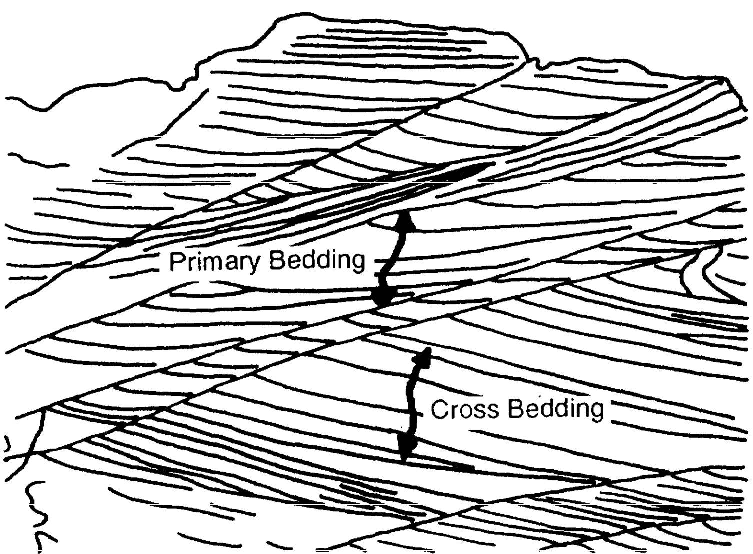


Figure 1-11. Cross bedding in sandstone.

they exhibit poor engineering properties and are avoided in construction. Some very weakly cemented types may be crushed for use as fill or subbase material in road or airfield construction.

Sandstone. This is a medium- to coarse-grained, hard, gritty, elastic rock composed mainly of sand-sized (1/16 mm to 2 mm) quartz grains, often with feldspar, calcite, or clay. Sandstone varies widely in properties according to composition and cementation. Clean, compact, quartz-rich varieties, well-cemented by silica or iron oxides, generally provide good material for construction of all types. Low-density, poorly cemented, and clayey varieties lack toughness and durability and should be avoided as sources of construction material; however, some clay-free types may be finely crushed to provide sand.

Shale. This is a soft to moderately hard sedimentary rock composed of very fine-grained silt and clay-sized particles as well as clay minerals. Silica, iron oxide, or calcite cements may be present, but many shales lack cement and readily disintegrate *or* slake when soaked in water. Characteristically, shales form in very thin layers, break into thin platy pieces or flakes, and give off a musty odor when barely moistened. Occasionally, massive shales (called mudstones) occur, which break into bulky fragments. Shales are frequently interbedded with sandstones and limestones and, with increasing amounts of sand or calcite, may grade into these rock types. Most shales can be excavated without the need for blasting. Because of their weakness and lack of durability, shales make very poor construction material.

Tuff. This is a low-density, soft to moderately hard pyroclastic rock composed mainly of fine-grained volcanic ash. Colors range from white through yellow, gray, pink, and light brown to a rather dark grayish brown. When barely moistened, some tuffs give off a weak “clay” odor. Very compact varieties often resemble felsite but can usually be distinguished by their softness and the presence of glass or pumice fragments. Loose, chalky types usually feel rough and produce a gritty dust, unlike the smooth particles of a true chalk or clay. Tuff is a weak, easily excavated rock of low durability. When finely ground, it has weak cementing properties. It is often used as an “extender” for portland cement and as a pozzolan to improve workability and neutralize alkali-aggregate reactions. It can also be used as a fill and base course material.

Limestone. This is a soft to moderately hard rock composed mainly of calcite in the form of shells, crystals, grains, or cementing material. All varieties are distinguished by a rapid bubbling or fizzing reaction when they come in contact with dilute HC1. Colors normally range from white through various shades of gray to black; other colors may result from impurities. Ordinary limestone is a compact, moderately tough, very fine-grained or coarsely crystalline rock that makes a quality material for all construction needs. Hardness, toughness, and durability will normally increase with greater amounts of silica cement. However, more than about 30 percent silica may produce bonding problems or alkali-aggregate reactions. Clayey varieties usually lack durability and toughness and should be avoided. Weak, low-density limestones (including limerock and coral) are weakly recemented when crushed, wetted, and compacted. They are widely used as fill and base course material. In mild climates, some may prove suitable for use in low-strength portland cement concrete.

Dolomite. It is similar to limestone except that the mineral dolomite occurs in lieu of calcite. It is distinguished by a slow bubbling or fizzing reaction when it comes into contact with dilute HC1. Often the reaction cannot be seen unless the rock is first powdered (as by scraping with a knife). Limestone and dolomite exhibit similar properties, and often one grades into the other within a single deposit.

Chert. This is a very hard, very fine-grained rock composed of microcrystalline silica precipitated from seawater or groundwater. It occurs mainly as irregular layers or nodules in limestones and dolomites and as pebbles in gravel deposits or conglomerates. Most cherts are white to shades of gray. Very dark, often black, cherts are called flint, while reddish-brown varieties are called jasper. Pure, unweathered cherts break along smooth, conchoidal (shell-like) surfaces with a waxy luster; weathered or impure forms may seem dull and chalky-looking. Although cherts are very hard and tough, they vary widely in chemical stability and durability. Many produce alkali-aggregate reactions with portland cement, and most require the use of antistripping agents with bituminous cements. Low-density cherts may swell slightly when soaked and break up readily under frost action. Despite these problems, cherts are used in road construction in many areas where better materials are not available.

Metamorphic

Metamorphic rocks are classified primarily by—

- Mineral content.
- Fabric imparted by the agents of metamorphism.

They are readily divided into two descriptive groups (see *Table 1-4)* known as—

- Foliated.
- Nonfoliated.

Foliated metamorphic rocks display a pronounced banded structure as a result of the reformational pressures to which they have been subjected. The nonfoliated, or massive, metamorphic rocks exhibit no directional structural features.

The common foliated or banded metamorphic rocks include—

- Slate.
- Schist.
- Gneiss.

Slate. This is a very fine-grained, compact metamorphic rock that forms from shale. Unlike shale, slates have no "clay" odor. They split into thin, parallel, sharp-edged sheets (or plates) usually at some angle to any observable bedding. Colors are normally dark red, green, purple, or gray to black. Slates are widely used as tiles and flagstones, but their poor crushed shape and low resistance to splitting makes them unsuitable for aggregates or building stones.

Schist. This is a fine- to coarse-grained, well-foliated rock composed of discontinuous, thin layers of parallel mica, chlorite, hornblende, *or* other crystals. Schists split readily along the structural layers into thin slabs or flakes. This characteristic makes schists undesirable for construction use and hazardous to excavate. However, varieties intermediate to gneiss maybe suitable for fills, base courses, or portland cement concrete.

Gneiss (pronounced "nice"). This is a roughly foliated, medium- to coarse-grained rock that consists of alternating streaks or bands. The banding is caused by segregation of light-colored layers of quartz and feldspar alternating with dark layers of ferromagnesian minerals. These streaks may be straight, wavy, or crumpled and of uniform or

Table 1-4. Classification of metamorphic rocks.

Structure	Characteristics	Rock Type
Foliated	Very fine-grained; cleaves readily into thin sheets or plates	Slate
	Fine- to coarse-grained; thin semiparallel layers of platy minerals; splits into flakes between layers	Schist
	Fine- to coarse-grained; streaks or bands of differing mineralogic composition; breaks into bulky pieces	Gneiss
Nonfoliated	Mostly fused quartz grains	Quartzite
	Mostly calcite or dolomite	Marble

variable thickness. Gneisses normally break into irregular, bulky pieces and resemble the granitic rocks in properties and uses. With increasing amounts of mica or more perfect layering, gneisses grade into schists.

The common nonfoliated metamorphic rocks include—

- Quartzite.
- Marble.

Quartzite. This is an extremely hard, fine- to coarse-grained, massive rock that forms from sandstone. It is distinguished from sandstone by differences in fracture. Quartzite fractures through its component grains rather than around them as in sandstone, because the cement and sand grains of quartzite have been fused or welded together during metamorphism. Therefore, broken surfaces are not gritty and often have a splintery or sugary appearance like that of a broken sugar cube or hard candy. Quartzite is one of the hardest, toughest, and most durable rocks known. It makes excellent construction material, but excavation and crushing costs are usually very high. Because of its high quartz content, antistripping agents are normally required with bituminous cements, Even so, bonds may be poor with very fine-grained types.

Marble. This is a soft, fine- to coarsely crystalline, massive metamorphic rock that forms from limestone or dolomite. It is distinguished by its softness, acid reaction, lack of fossils, and sugary appearance on freshly broken surfaces. Marble is similar to ordinary compact or crystalline limestones in its engineering properties and uses. However, because of its softness, it is usually avoided as an aggregate for pavements on highways and airfields. White calcite or pinkish dolomite veins and subtle swirls or blotches of trace impurities give marble its typical veined or "marbled" appearance.

Metamorphic rocks have been derived from existing sedimentary, igneous, or metamorphic rocks as depicted in *Figure 1-4, page 1-7* and *Figure 1-12, page 1-18.*

IDENTIFICATION

Military engineers must frequently select the best rock for use in different types of construction and evaluate foundation or excavation conditions.

Field Identification

A simple method of identification of rock types that can be applied in the field will assist in identifying most rocks likely to be encountered during military construction. This method is presented in simple terms for the benefit of the field engineer who is not familiar with expressions normally used in technical rock descriptions.

The identification method is based on a combination of simple physical and chemical determinations. In some cases, the grains composing a rock may be seen, and the rock may be identified from a knowledge of its components. In other cases, the rock maybe *so* fine-grained that the identification must be based on its general appearance and the results of a few easy tests.

The equipment required consists only of a good steel knife blade or a nail and a bottle of dilute (10 percent solution) HC1, preferably with a dropper. A small 6- to 10-power magnifying glass may also be helpful. HC1 (muriatic acid) is available at most hardware stores and through the military supply system. Military hospitals are a typical source for HC1.

Samples for identification should be clean, freshly broken, and large enough to clearly show the structure of the rock. In a small sample, key characteristics (such as any alignment of the minerals composing the rock) may not be observed as readily as in a larger one. Pieces about 3 inches by 4 inches by 2 inches thick are usually suitable.

General Categories

The identification system of geologic materials is given in flow chart form (see *Table 1-5, page 1-19).* In this method, all considerations are based on the appearance or

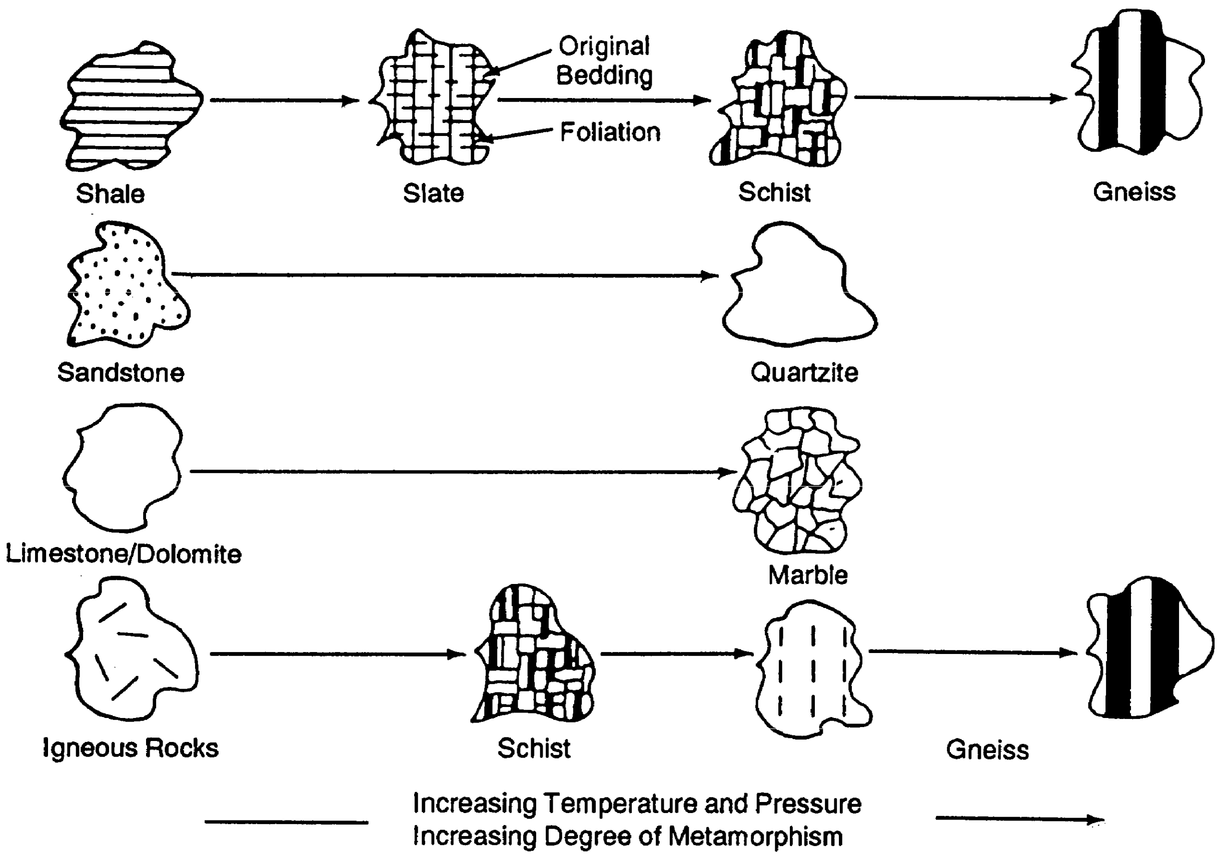


Figure 1-12. Metamorphism of existing rocks.

character of a clean, freshly broken, unweathered rock surface. Weathered surfaces may exhibit properties that may not be true indicators of the actual rock type.

For most rocks the identification process is direct and uncomplicated. If a positive identification cannot be made, the more detailed rock descriptions (in the preceding paragraphs) should be consulted after first using the flow chart to eliminate all clearly inappropriate rock types. By the use of descriptive adjectives, a basic rock classification can be modified to buildup a "word picture" of the rock (for example, "a pale brown, fine-grained, thin-bedded, compact, clayey, silica-cemented sandstone").

To use the flow chart, the sample must be placed into one of three generalized groups based on physical appearance. These groups are—

- Foliated.
- Very fine-grained.
- Coarse-grained.

Foliated. Foliated rocks are those metamorphic rocks that exhibit planar orientation of their mineral components. They may exhibit slaty cleavage (like slate) expressed by closely spaced fractures that cause the sample to split along thin plates. If the sample exhibits a parallel arrangement of platy minerals in thin layers and has a silky or metallic reflection, the sample has schistosity and is called a schist. If the sample exhibits alternating streaks or bands of light and dark minerals of differing composition, then the sample has gneissic layering and is called a gneiss.

Table 1-5. Identification of geologic materials.

Foliated			Very fine-grained; splits along thin planes		Slate
Foliated			Metallic reflection; splits into slabs and flakes or thin semitransparent sheets		Schist
Foliated			Contains streaks or bands of light and dark minerals; breaks to bulky, angular fragments		Gneiss
Very Fine-Grained	Frothy		Light colored; lightweight; easily crushed		Pumice
Very Fine-Grained	Frothy		Dark colored; cindery		Scoria
Very Fine-Grained	Glassy		Light colored; massive; extremely hard		Quartz
Very Fine-Grained	Glassy		Dark colored; may have some gas bubbles		Obsidian
Very Fine-Grained	Stony	Soft	No acid reaction	Earthy; clay odor; platy	Shale
Very Fine-Grained	Stony	Soft	No acid reaction	May have small pieces of glass; low density	Tuff
Very Fine-Grained	Stony	Soft	Acid reaction	Sugary appearance	Marble
Very Fine-Grained	Stony	Soft	Acid reaction	Dull and massive	Limestone
Very Fine-Grained	Stony	Hard	Waxy; very hard; weathers to soft white		Chert
Very Fine-Grained	Stony	Hard	Dull; may contain some gas bubbles or visible crystals	Light colored	Felsite
Very Fine-Grained	Stony	Hard	Dull; may contain some gas bubbles or visible crystals	Dark colored	Basalt
Very Fine-Grained	Stony	Hard	Sandy; mostly one mineral (quartz)	Gritty sandpaper feel	Sandstone
Very Fine-Grained	Stony	Hard	Sandy; mostly one mineral (quartz)	Sugary; not gritty	Quartzite
Coarse-Grained	Hard		Sandy; mostly one mineral (quartz)	Gritty sandpaper feel	Sandstone
Coarse-Grained	Hard		Sandy; mostly one mineral (quartz)	Sugary; not gritty	Quartzite
Coarse-Grained	Hard		Mixed minerals; salt-and-pepper appearance	Light colored	Granite
Coarse-Grained	Hard		Mixed minerals; salt-and-pepper appearance	Dark colored	Gabbro-diorite
Coarse-Grained	Hard		Fragmental; appearance of broken concrete		Conglomerate
Coarse-Grained	Soft		Fragmental; may contain small pieces of glass	Low density	Tuff
Coarse-Grained	Soft		Acid reaction	Sugary appearance	Marble
Coarse-Grained	Soft		Acid reaction	Shell fragments	Limestone

Very Fine-Grained. If the sample appears pitted or spongy, it is called frothy. The pits are called vesicles and are the result of hot gases escaping from magma at the top of a lava pool. If the sample is light enough to float on water and is light-colored, it is called pumice. If the frothy rock sample is dark-colored and appears cindery, it is called scoria.

If the sample has the appearance of broken glass, it is called either obsidian or quartz. Obsidian is a dark-colored natural volcanic glass that cooled too fast for any crystals to develop. Quartz is not a glass but is identified on the flow chart as light-colored and glassy. Quartz is a mineral and not one of the aggregates classifed for use in military construction. It is often found in its crystalline form with six-sided crystals. It is common as veins in both igneous and metamorphic rock bodies.

A hardness test is conducted to determine whether a stony sample is hard or soft. If the sample can be scratched with a knife or nail, then it is said to be soft. If it cannot be scratched, then it is said to be hard.

Fine-grained rocks maybe glassy, frothy, or stony. The term “stony” is used to differentiate them from “glassy” and “frothy” rocks.

If the sample is soft, a chemical determination must be made using dilute HC1, HC1 tests determine the presence or absence of calcite (calcium carbonate) which comprises limestone / dolomite and marble. Very fine-grained rocks that are soft and stony in appearance and have an acid reaction are composed of calcium carbonate. If the sample is dull and massive, it is called a limestone. Dolomites are also dull and massive and are not separated from limestones on this chart, but they do not readily react to acid. Their surface must be powdered first by scratching the sample with a nail. The dolomite powder then readily reacts to the acid. If the sample exhibits a sugary appearance, then it is the metamorphic rock, marble. The sugary appearance is due to the partial melting or fusing of calcite crystals by heat and pressure. It is similar to the appearance of the sugar coating on a breakfast cereal. These rocks are susceptible to chem ical attack by acidic solutions that form when carbon dioxide (CO_2) is absorbed in groundwater. This produces a mild carbonic acid that dissolves the calcite in the rock. This is the process that produces caves and sinkholes. If there is not an acid reaction (no effervescence) and the sample has a platy structure, it is a shale. A shale may be any color. It is normally dull and separates into soft, thin plates. When freshly broken, it may have a musty odor similar to clay. Shales are derived from lithification of clay particles and fine muds. Shale is a sedimentary rock and should not be confused with its metamorphic equivalent, slate. Shales often occur interbedded within layers of limestone and dolomite. Because they are often found with carbonate rocks, they may exhibit an acid reaction due to contamination by calcium carbonate.

If the sample has no acid reaction and has a relatively low density, with small pieces of glass in its fine-grained matrix, the rock is called a tuff. Tuff is a volcanic sedimentary rock comprised mostly of ash particles that have been solidified. By the flow chart, it is characterized as soft; however, it may be hard if it has been welded by hot gases during the eruption. If it is hard, tuff may exhibit physical properties that make it suitable for some construct ion applications.

Fine-grained, stony samples that are hard may be waxy, dull, or sandy. Waxy samples resemble candle wax and have a conchoidal fracture and sharp edges. These rocks are called chert. They often weather into soft, white materials. Dull samples are either light- or dark-colored igneous extrusive rocks. If the sample is light-colored, it is a felsite. Felsites are normally massive but may appear banded or layered. Unlike gneiss, the layers are not made up of alternating light and dark minerals. Felsites may also have cavities filled with other lighter-colored minerals. They represent a variety of lava rocks that are high in silica. Because of their great variety, they may be hard to identify properly. The dark counterpart to the felsites is basalt. Basalt is normally black and very tough. It is also a lava rock and often exhibits columnar jointing. It often occurs as dikes or sills in other rock bodies.

Hard, sandy, very fine-grained samples composed mostly of quartz may be either sandstone or quartzite. If the sample feels gritty like sandpaper, it is called sandstone. Sandstones are sedimentary rocks composed of sand grains that have been cemented together. If the sample appears sugary and does not feel like sandpaper, the rock is called quartzite. Quartzite is the metamorphic equivalent of sandstone. Like marble, it has a sugary appearance, which is due to the partial melting and fusing of the crystal grains.

Coarse-Grained. Coarse-grained rocks refer to those that have either crystals or cemented particles that are large enough to be readily seen with the unaided eye. Samples may be hard or soft. Hard samples may appear sandy, mixed, or fragmental. A sandy sample would be a sandstone or a quartzite. Because coarse sands grade into fine sands, there are coarse sandstones and fine sandstones. The sugary-appearing metamorphic version of a coarse sandstone is called a quartzite.

Hard, coarse-grained rocks that are comprised of mixed interlocking crystals have a salt-and-pepper appearance due to their light and dark minerals. If the rock is predominantly light in color, it is a granite. If it is predominantly dark in color, it is called a gabbro-diorite. Both of these rocks are igneous intrusive rocks that cooled slowly, allowing the growth of large interlocking crystals. If the sample appears to be made of round, cemented rock fragments similar to the appearance of concrete, it is called a conglomerate. If the rock fragments are angular instead of round, the rock is called a breccia.

If a coarse-grained sample is soft, it may either be fragmental or have an acid reaction. If it appears fragmental and has a low density and small pieces of glass, it is a tuff. Tuff has already been described as a very fine-g-rained, stony, soft rock material. This entry on the chart is for the coarse-grained version of the same material. The coarse-grained rock samples that are soft and have an acid reaction are coarse-grained limestones and marbles, as already described.

The system of identification of rock types used by military engineers serves to identify most common rock types. This method requires the user to approach rock identification in a mnsistent and systematic manner; otherwise, important rock characteristics may go unnoticed. Many important rock features may not appear in small hand specimens. To enable better identification and evaluation, personnel who are in charge of geologic exploration should maintain careful notes on such rock features as bedding, foliation, gradational changes in composition or properties, and on the associations of rocks in the field. During preliminary reconnaissance work, geologic maps or map substitutes should be used to make preliminary engineering estimates based on the typical rock properties.

Engineering Properties

The following engineering properties and tests are provided to help make engineering judgments concerning the use of rock materials as construction aggregate:

- Toughness.
- Hardness.
- Durability.
- Crushed shape.
- Chemical stability.
- Surface character.
- Density.

Preliminary engineering estimates can be made based on the typical rock properties ascertained from these tests. If a rock sample cannot be identified using the flow chart, a decision can be made as to its suitability for use as a construction material by these tests.

Toughness. This is mechanical strength, or resistance to crushing or breaking. In the field, this property may be estimated by attempting to break the rock with a hammer or by measuring its resistance to penetration by impact drills.

Hardness. This is resistance to scratching or abrasion. In the field, this may be estimated by attempting to scratch the rock with a steel knife blade. Soft materials are readily scratched with a knife, while hard materials are difficult or impossible to scratch (see *Table 1-6).*

Table 1-6. Field-estimating rock hardness.

Hardness	Charcteristics
Very hard	Not scratched by a steel file
Hard	Scratched by a steel file but difficult or impossible to scratch with a steel knife blade (or nail)
Moderately hard	Scratched by a knife but not by a copper coin
Soft	Scratched by a copper coin
Very soft	Scratched by a fingernail

Durability. This is resistance to slaking or disintegration due to alternating cycles of wetting and drying or freezing and thawing. Generally, this may be estimated in the field by observing the effects of weathering on natural exposures of the rock.

Crushed Shape. Rocks that break into irregular, bulky fragments provide the best aggregates for construction because the particles compact well, interlock to resist displacement and distribute loads, and are of nearly equal strength in all directions. Rocks that break into elongated pieces or thin slabs, sheets, or flakes are weak in their thin dimensions and do not compact, interlock, or distribute loads as effectively (see *Figure 1-13).*

Chemical Stability. This is resistance to reaction with alkali materials in portland cements. Several rock types contain impure forms of silica that react with alkalies in cement to form a gel. The gel absorbs water and

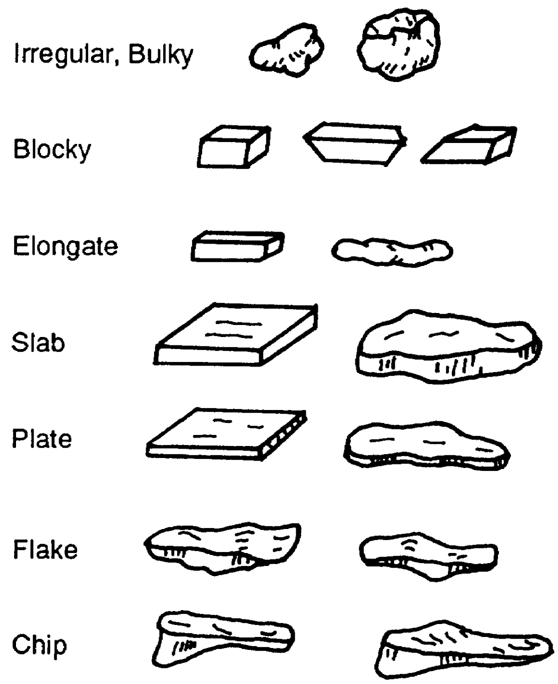


Figure 1-13. Crushed shape.

expands to crack or disintegrate the hardened concrete. This potential alkali-aggregate reaction may be estimated in the field only by identifying the rock and comparing it to known reactive types or by investigating structures in which the aggregate has previously been used.

Surface Character. This refers to the bonding characteristics of the broken rock surface. Excessively smooth, slick, nonabsorbent aggregate surfaces bond poorly with cementing materials and shift readily under loads. Excessively rough, jagged, or absorbent surfaces are likewise undisturbed because they resist compaction or placement and require excessive amounts of cementing material.

Density. This is weight per unit volume. In the field, this may be estimated by "hefting" a rock sample (see *Table 1-7).* Density reflects on excavation and hauling costs and may influence the selection of rocks for special requirements (such as riprap, jetty stone, or lightweight aggregate). Among rocks of the same type, density is often a good indicator of the toughness and durability to be expected, *Table 1-8, page 1-24,* lists the general ratings of rock properties for each of the 18 typical military construction aggregates. These

Table 1-7. Field-estimating rock density.

Description	Density (g/cm^3)
Very dense	Over 3.0
Dense	2.8 to 3.0
Moderately dense	2.6 to 2.8
Low density	2.4 to 2.6
Very low density	Below 2.4

ratings serve only as a guide; each individual rock body must be sampled and evaluated separately. *Table 1-9, page 1-24,* provides general guidance to determine the suitability of an unidentified rock sample for general military construction missions based on the evaluation of its physical properties.

Table 1-10, page 1-25, provides a rating for selected geologic materials concerning their suitability as an aggregate for concrete or asphalt or for their use as a base course material. Rock materials that typically exhibit chemical instability in concrete are marked with an asterisk. These materials may cause a concrete-alkali reaction due to their high silica content. In general, felsites, chert, and obsidian should not be used as concrete aggregate. The end result of these reactions is the weakening, and in extreme cases the failure, of the concrete design. Apparently, silica is drawn out of the aggregate to make a gel that creates weaknesses within the mix. The gel may expand with temperature changes and prevent the proper bonding of the cement and aggregate.

Rock types with two asterisks may not bond readily to bituminous materials. They require special antistripping agents to ensure that they do not “strip,” or separate, from the pavement mix. Stripping severely reduces pavement performance.

Table 1-8. Engineering properties of rocks.

	Rock Type	Toughness	Hardness	Durability	Chemical Stability	Crushed Shape	Surface Character	Density (g/cm^3)
Igneous	Granite	Good - very good	Good	Good	Excellent	Excellent	Good	2.65
	Gabbro-Diorite	Excellent	Excellent	Excellent	Excellent	Good	Good	2.96
	Basalt	Excellent	Excellent	Excellent	Excellent	Fair - good	Good	2.86
	Felsite	Good	Good	Good	Questionable	Fair - good	Fair - good	2.66
	Obsidian	Poor	Good	Good	Questionable	Very poor	Very poor	2.3 - 2.4
	Pumice	Very poor	Very poor	Poor	Questionable	Good	Poor	<1.0
	Scoria	Poor	Poor	Poor	Good	Good	Poor	Variable
Sedimentary	Tuff	Poor	Poor	Poor	Questionable	Good	Good	Variable
	Conglomerate (Breccia)	Poor - fair	Poor - fair	Poor - fair	Good	Fair	Good	2.68
	Sandstone	Variable	Variable	Variable	Excellent	Good	Excellent	2.54
	Shale	Poor	Poor	Poor	Questionable	Poor	Good	1.8 - 2.5
	Limestone or Dolomite	Good	Fair - good	Good	Good	Good	Good	2.66 - 2.70
	Chert	Poor	Excellent	Variable	Questionable	Poor - fair	Fair	2.50
Metamorphic	Gneiss	Good	Good	Good	Excellent	Good - fair	Good	2.74
	Schist	Good	Good	Good	Excellent	Poor - fair	Poor - fair	2.85
	Slate	Poor	Poor	Poor	Excellent	Poor	Good	2.72
	Quartzite	Excellent	Excellent	Excellent	Excellent	Fair	Good - fair	2.69
	Marble	Good	Poor	Good	Good	Excellent	Excellent	2.63

Table 1-9. Aggregate suitability based on physical properties.

Aggregate Used In	Toughness	Hardness	Durability	Chemical Stability	Crushed Shape	Surface Character
Portland Cement	Good	Fair	Good	Good	Good*	Good
Bituminous Surfaces	Good	Good	Good	Any/All	Good	Good
Base Coarse	Good	Good	Good	Any/All	Good	Good

*The preferred shape for portland cement aggregate is an irregular, bulky shape.

Table 1-10. Use of aggregates for military construction missions.

	Rock Type	Use as Aggregates		Use as a Base Course or Subbase
		Concrete	Asphalt	
Igneous	Granite	Fair - good	Fair - good**	Good
	Gabbro-Diorite	Excellent	Excellent	Excellent
	Basalt	Excellent	Excellent	Excellent
	Felsite	Poor*	Fair	Fair - good
Sedimentary	Conglomerate (Breccia)	Poor	Poor	Poor
	Sandstone	Poor - fair	Poor - fair	Fair - good
	Shale	Poor	Poor	Poor
	Limestone Dolomite	Fair - good Good	Good	Good
	Chert	Poor*	Poor**	Poor - fair
Metamorphic	Gneiss	Good	Good	Good
	Schist	Poor - fair	Poor - fair	Poor - fair
	Slate	Poor	Poor	Poor
	Quartzite	Good	Fair - good**	Fair - good
	Marble	Fair	Fair	Fair

*Reacts (alkali-aggregate).
**Antistripping agents should be used.