SUBCOURSE EN5462

EDITION A

US ARMY ENGINEER CENTER AND SCHOOL

GEOLOGY

"LET US TRY"

THE ARMY INSTITUTE FOR PROFESSIONAL DEVELOPMENT

ARMY CORRESPONDENCE COURSE PROGRAM

GEOLOGY

Subcourse EN 5462

EDITION A

United States Army Engineer School
Fort Leonard Wood, Missouri 65473

7 Credit Hours

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SUBCOURSE OVERVIEW

This subcourse, Geology is designed to help you identify specific rock types from written descriptions and line drawings and to determine engineering properties of rocks in terms of their suitability for construction use. Information is provided on rock types and properties, geological structures, slope failure, surficial features, and construction material. Appendix C contains conversion factors for any metrics introduced in the subcourse. This course is taught in four lessons.

There are no prerequisites for this subcourse.

The lessons in this subcourse reflect the doctrine which was current at the time it was prepared. In your own work situation, always refer to the latest official publications.

Unless otherwise stated, the masculine gender of singular pronouns is used to refer to both men and women.

TERMINAL LEARNING OBJECTIVE:

ACTION: You will identify geological processes and products.

CONDITION: You will be given the material contained in this subcourse and an Army Correspondence Course Program (ACCP) examination response sheet.

STANDARD: To demonstrate proficiency of this task, you must achieve a minimum of 70 percent on the subcourse examination.

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LESSON 1

ROCK TYPES AND PROPERTIES

Critical Task: 051-243-3027

OVERVIEW

LESSON DESCRIPTION:

In this lesson you will learn about different rock types, simple methods for identifying and describing them, and about the properties of rocks in terms of suitability for construction needs. Appendix C contains conversion factors for any metrics introduced in this lesson.

TERMINAL LEARNING OBJECTIVE:

ACTION: You will identify and describe rock types and define the properties of rocks in terms of suitability for construction.

CONDITION: You will be given the material contained in this lesson.

STANDARDS: You must complete the lesson and the practice exercise.

REFERENCES: The material contained in this lesson was derived from FM 5-410.

INTRODUCTION

Geology is not the study of rocks: it is the study of the earth. It is a science that is broken down into many subfields. For example: *volcanology* is the study of volcanoes, *seismology* the study of earthquakes, the study of minerals (the building blocks of rocks) is called *mineralogy*, and the study of rocks is called *petrology*. On a small scale, the study of the grains which make up certain rocks is called *stratigraphy*. On a larger scale, the study of the orientation of large bodies of rock is called *structural geology*. The sciences of groundwater *geology* and *hydrology* are important not only as means of finding water supplies but also as ways to get rid of unwanted water on construction sites. When *geology* (the study of the earth) is combined with *biology* (the study of life) the science is called *paleontology*, (the study of ancient life on earth).

You, as an engineer, may not be as interested in the earth's history and composition as you are in practical applications of geology. For most people, geology is a nice-to-know subject, but for an engineer, a knowledge of geologic processes and products is absolutely essential. History is filled with accounts of engineering projects that failed because the engineer did not have a thorough understanding of geologic processes at work.

PART A: IDENTIFY THE MAJOR ROCK TYPES

You, as the military engineer, must frequently select the best rock for use in different types of construction and evaluate foundation or excavation conditions. This suggests that you have a need for a simple method of identification of rock types that can be applied in the field. The method presented in this subcourse will help you identify most rocks that you are likely to encounter in general practice. The information is presented in simple terms for your benefit because you may not be familiar with the expressions normally used in technical rock descriptions.

1-1. General Classification of Rocks. Rocks are separated into three broad classes based on their mode of origin igneous, sedimentary, and metamorphic. Each class is then subdivided according to its physical characteristics or composition. The rock cycle depicted in Figure 1-1 shows the complex interrelationships of the three rock classes. How a rock was formed will determine many of its characteristics. Table 1-1, page 1-4 shows a general classification of the major types and their characteristics. An understanding of this classification scheme can help you identify and evaluate any rock.

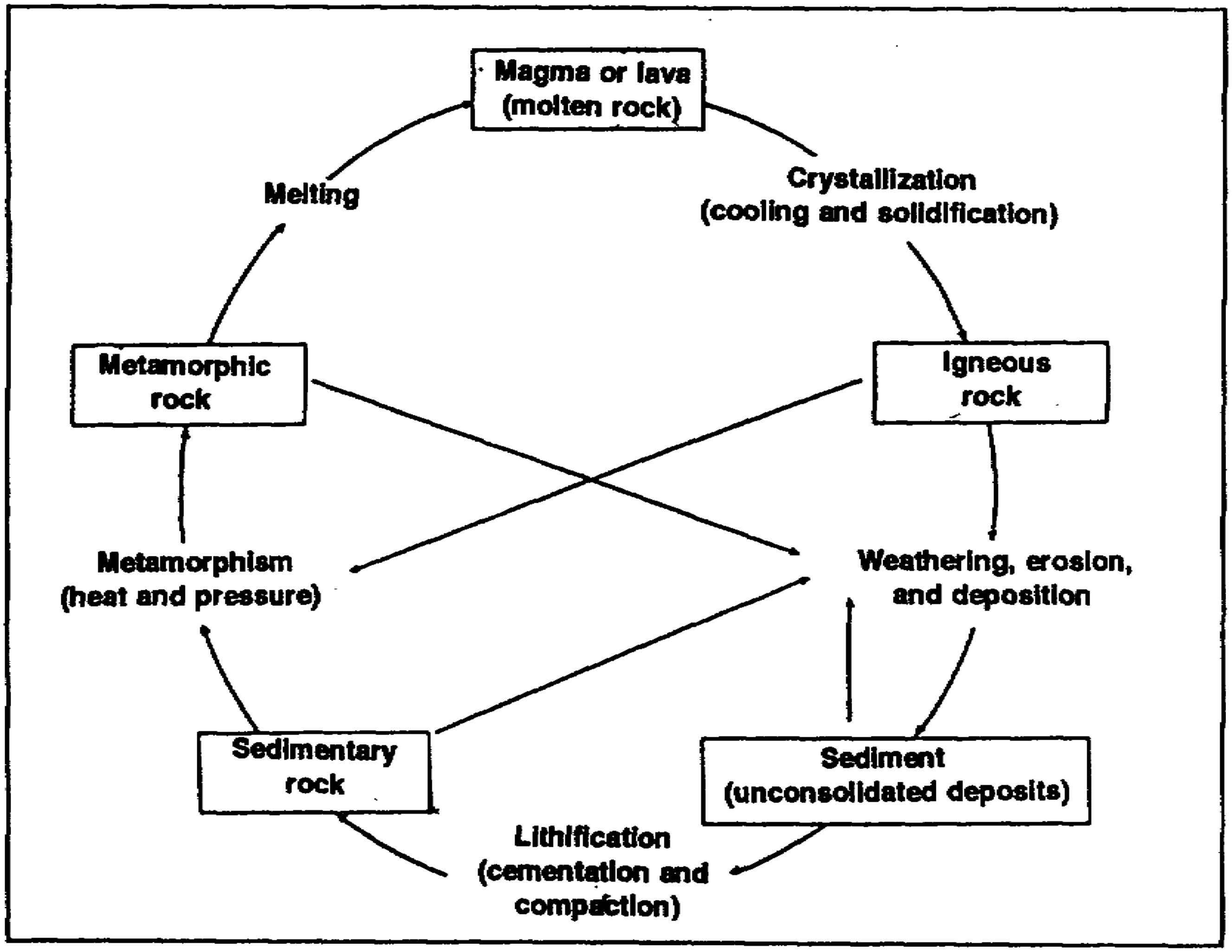
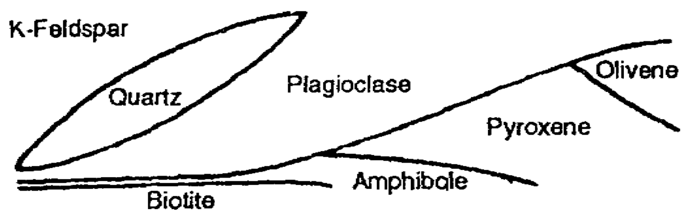


Figure 1-1. The rock cycle

Table 1-1. General classification of rocks

Igneous
(Solidified from a molten state)

Typical mineral composition



Origin	Dominant texture[1]	Light color	Dark color
Intrusive	Coarse (distinguishable grains)	Granite	Gabbro-diorite
	Very fine (indistinguishable grains)	Felsite	Basalt
Extrusive	Glassy	Obsidian	
	Scoriaceous (frothy)	Pumice	Scoria
	Fragmental	Volcanic ash, bombs, and blocks	

[1] Rocks containing many scattered larger crystals are called porphyritic, for example, porphyritic graphite, porphyritic basalt.

Sedimentary
(Consolidated rock fragments, precipitates, or organic debris)

Group	Dominant composition		Rock type
Clastic (Fragmental)	Rock fragments larger than 2 mm	Rounded	Conglomerate
		Angular	Breccia
	Mineral grains (chiefly quartz) sized 1/16 mm to 2 mm		Sandstone
	Clay and silt particles smaller than 1/16 mm		Shale
Pyroclastic	Fine volcanic ash and debris		Tuff
Chemical	Calcite		Limestone
	Dolomite		Dolomite
	Microcrystalline silica		Chert
Organic	Slightly compacted		Peat
	Moderately compacted		Lignite
	Highly compacted		Anthracite

Metamorphic
(Rocks altered by heat, pressure, and chemically active fluids)

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

a. Igneous Rocks. *Igneous rocks* solidify from masses of hot molten rock material (magma or lava) that have forced their way up from depths within the earth. *Extrusive*, or volcanic, types form from magma or lava that has cooled on or near the earth's surface, while *intrusive* types crystallize from magmas within the earth's crust (see Figure 1-2). Intrusions show great variations in form and size, ranging from dikes that are a few centimeters wide to batholiths that are hundreds of kilometers across. Whatever their origin, igneous rocks are classified by mineral *texture* and *composition*.

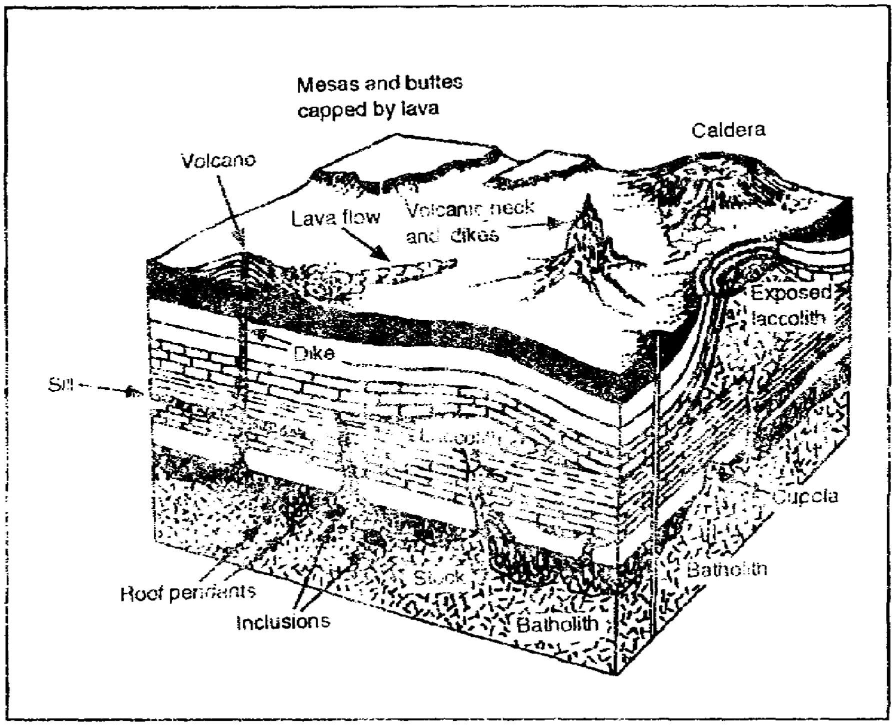


Figure 1-2. Intrusive and extrusive rock bodies

(1) Texture. *Texture* refers to the size, shape, and arrangement of the mineral grains or particles which compose a rock. In most igneous rocks, the texture has an overall aspect of a network of interlocking mixed crystals. This is especially obvious in the coarsely crystalline varieties. Igneous textures develop primarily in response to the conditions under which the parent magma cooled. Magma material that cools slowly, usually deep underground, produces rocks in which the crystals are large enough to be readily distinguished. Molten material that cools more rapidly produces very fine-grained, usually extrusive, rocks in which the crystals are too small to be clearly distinguished by the naked eye. If cooling is very rapid, a natural glass without crystals will result. When masses of gas bubbles are trapped in a rapidly cooling magma, they cause the resulting rock to have an overall *scoriaceous* (spongy or frothy) texture. Changes in conditions during cooling give rise to the *porphyritic* or mixed-grain rocks.

(2) Composition. *Composition* refers to the color of the igneous rocks. The color depends on the chemical composition of the parent magma. *Sialic* magmas, rich in silicon and aluminum, form light-colored rocks that are composed mainly of colorless, white, blue, pink or reddish minerals. *Mafic* magmas, rich in iron and magnesium, form dark-colored rocks that are composed mainly of gray, green, black, or brown materials.

b. Sedimentary Rocks. *Sedimentary rocks* are consolidated from accumulations of solid rock debris, chemical precipitate, or organic material by compaction, cementation, or crystallization. Most form in distinct parallel layers separated by abrupt fairly even contact surfaces called *bedding planes*. Each layer represents a successive deposit of material. Fossils, mud cracks, dunes, buried stream channels, and other features are often preserved as these deposits build up. As a class, sedimentary rocks cover about 75 percent of the earth's surface. Over 95 percent of the total volume of sediments is composed of varieties of shale, sandstone, and limestone. Sedimentary rocks are described as either clastic or nonclastic.

(1) Clastic. *Clastic* sedimentary rocks consist mainly of individual fragments of preexisting rocks cemented together by silica, iron oxides, or calcite deposited around the particles by groundwater. *Pyroclastic* types, sometimes considered to be igneous rocks, form from violently-erupted volcanic particles which have been fused or cemented after settling in air or water. The clastic (or fragmental) rocks are classified by grain size with subsequent subdivisions based on composition.

(2) Nonclastic. *Nonclastic* sedimentary rocks are composed of interlocking crystals or are in earthy masses. They are generally grouped as inorganic (or chemical) or organic:

(a) *Chemical* sedimentary rocks consist mainly of chemical or biochemical precipitates. Most form in shallow seas rich in dissolved minerals. Classification of chemical rocks is based on composition. Further subdivisions are based on texture or other features.

(b) *Organic* sedimentary rocks consist mainly of compacted organic material. These types of rocks are classified based on degree of compaction.

c. Metamorphic Rocks. *Metamorphic* (or changed) rocks form from preexisting rocks by the action of heat pressure, and chemically active fluids deep underground. Like the intrusive rocks with which they are often associated, metamorphic rocks are initially classified into two groups based on structure. They are foliated and massive (or nonfoliated). Further subdivisions of these two groups are based on composition or physical characteristics.

(1) Foliated. *Foliated* metamorphic rocks are characterized by a distinctive planar arrangement of their various mineral components. This foliation may be expressed by closely-spaced fractures (*slaty cleavage*), by parallel arrangement of platy minerals in thin layers (*schistosity*), or by alternating streaks or bands of differing mineralogic composition (*gneissic layering*). Common foliated or banded metamorphic rocks include slate, schist, and gneiss.

(2) Massive. *Massive* (or nonfoliated) metamorphic rocks are essentially structureless and commonly contain only one mineral. They are crystalline or composed of a mass of fused grains. Common massive metamorphic rocks include quartzite and marble.

1-2. Rock-Forming Minerals. Minerals are natural inorganic chemical substances with distinctive physical and chemical properties. Most rocks are named scientifically according to their mineral content. The more important rock-forming minerals are listed in Table 1-2. The *primary minerals* originate in igneous rocks. The *secondary minerals* are formed by the alteration or decomposition of the primary minerals, usually by their reaction to both air and water during weathering at or near the earth's surface.

Table 1-2. Common rock-forming minerals

Level	Name	Composition
Primary Minerals	Quartz (silica)	Silicon dioxide
	Feldspar group:	
	Potassium Feldspar (orthoclase)	Silicate of potassium aluminum
	Plagioclase	Silicate of sodium, calcium, and aluminum
	Mica group:	
	Muscovite	Hydrous silicate of potassium and aluminum
	Biotite	Hydrous silicate of potassium, magnesium, iron, and aluminum
	Amphibole group:	
	Hornblende	Complex silicate principally of calcium, magnesium, iron, and aluminum
	Pyroxene group:	
	Augite	Silicate of calcium, iron, magnesium, and aluminum
	Olivine	Silicate of iron and magnesium
Secondary Minerals	Chlorite	Hydrous silicate of iron, magnesium, and aluminum
	Calcite	Calcium carbonate
	Dolomite	Calcium-magnesium carbonate
	Limonite	Assorted iron oxides.
	Clay	Complex hydrous silicates involving many metals.

Each rock-forming mineral and rock type has special characteristics, limitations, and variations of properties.

a. Primary Rock-Forming Minerals. Common primary rock-forming minerals are--

(1) Quartz. *Quartz* (silica) 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 inter-grown with other minerals in igneous and metamorphic rocks, as rounded or angular grains in sedimentary rocks (particularly sandstone), 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.

(2) Feldspars. *Feldspars* form very hard, blocky, opaque crystals with a pearly or porcelain like luster and nearly rectangular in 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. Potassium varieties (orthoclase) are usually pink, reddish, ivory, or pale gray, while plagioclase crystals are usually white to greenish gray. Crystalline feldspars are major components of most igneous rocks, gneisses, and schists. Where more than one variety is present color differences are normally distinct. In the presence of air and water, the feldspars weather into clay minerals, soluble salts, and colloidal silica.

(3) Micas. *Micas* form soft, extremely thin, transparent to translucent, elastic sheets and flakes with a bright glassy or pearly luster. Layers (books) of easily-separated sheets frequently occur. The biotite variety of mica is usually brown or black while muscovite is yellowish, white, or silvery gray. Micas are very common in granite rocks, gneisses, and schists. They slowly weather to clay minerals.

(4) Amphiboles. *Amphiboles* (chiefly hornblende) are hard, dense, glassy to silky minerals found chiefly in intermediate to dark igneous rocks and in gneisses and schists. They generally occur as well-formed, slender, often needlelike, 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. The amphiboles weather rapidly to form chlorite and, ultimately, clay minerals, iron oxides, and soluble carbonates.

(5) Pyroxenes. *Pyroxenes* (chiefly augite) are hard, very 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. Colors of green to black or brown are most common, but, pale green or gray varieties sometimes occur in marbles or schists. Masses of nearly pure pyroxene form a rock called *pyroxenite*. Pyroxenes weather much like the amphiboles.

(6) 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 into iron oxides and soluble silica.

b. Secondary Rock-Forming Minerals. Common secondary rock-forming minerals are--

(1) 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 (an altered form of gabbro or basalt). Chlorite forms from amphiboles and pyroxenes by weathering or metamorphism and, in turn, weathers to clay minerals and iron oxides.

(2) Calcite. *Calcite* (lime) 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. Calcite often occurs as well-formed, glassy to dull, blocky crystals. As a rock-forming mineral, calcite is fine to coarsely crystalline in marble and loose to compactly granular in ordinary limestone. In addition, calcite is the major component of sea shells and coral skeletons. As a secondary mineral, calcite occurs as a cementing agent in many sedimentary rocks and as veins, or crack-fillings, in igneous and other types of rocks. Calcite weathers chiefly by solution in acidic waters or water containing dissolved carbon dioxide.

(3) Dolomite. *Dolomite* is similar to calcite in appearance and occurrence but is slightly harder and more resistant to dissolving in a solution. It is distinguished by a slow bubbling or fizzing reaction when it comes in contact with dilute hydrochloric acid. 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.

(4) Limonite. *Limonite* most often occurs 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 it is also the major component of laterite. Most weathered rocks contain some limonite as a result of the decomposition of ion-bearing minerals.

(5) Clay. *Clay* minerals form soft microscopic flakes that are usually mixed with impurities of various types (particularly silica, limonite, and calcite). 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. When barely moistened, as by the breath or tongue, clays give off a characteristic musty odor.

c. Rocks. The following rock types listed are composed of one or more of the primary and secondary rock-forming minerals previously discussed.

(1) Granite. *Granite* 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 larger intrusive masses 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. However, very coarse-grained and quartz-rich granites often bond poorly with cementing materials, particularly asphaltic cements. For this reason, antistripping agents should be used when granite is used in bituminous pavements. Finer-grained varieties are normally much tougher and more durable than more coarse-grained types, many of which disintegrate rather rapidly under temperature extremes or frost action. Virtually quartz-free granite, called *syenite*, generally provides better bonds and is somewhat denser and tougher than ordinary granite of equal grain size.

(2) Felsite. *Felsite* 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 streak like flow structures are also common in felsites. 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 (particularly if extremely fine-grained). Many 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.

(3) Gabbro and diorite. *Gabbro* and *diorite* form a series of dense, coarsely crystalline, hard, dark-colored intrusive rocks that are composed mainly of one or more dark minerals and plagioclase feldspar. Gabbro is composed mainly of augite, olivine, or hornblende with plagioclase. Its color is generally dark green to black or brown. Diorite is an intermediate silicate formed mainly of plagioclase with hornblende, biotite, or augite and virtually no potassium, feldspar, or quartz. The color is generally gray to greenish gray. Since both rocks are similar in properties and may be difficult to distinguish in the field, they are often grouped under the name *gabbro-diorite*. The 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. Their great toughness and high density; however, make excavation and crushing costs very high, particularly when using finer-grained varieties.

(4) Basalt. *Basalt* 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 isolated gas bubbles, which may be mineral filled or open. With increasing grain size, basalt often grades into diabase, an extremely tough variety intermediate to gabbro. Despite a tendency to crush into chips or flakes in sizes smaller than 2 to 3 centimeters, both basalt and diabase make aggregates of the highest quality.

(5) Obsidian. *Obsidian* 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.

(6) Pumice. *Pumice* 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 it light enough to float on water and also give pumice good insulating qualities. Although highly abrasive, pumice is very weak and can usually be excavated with hand tools. You may use it in the manufacture of low-strength, lightweight concrete and concrete blocks. Most varieties are chemically unstable and you will need the use of special low-alkali portland cements.

(7) Scoria. *Scoria* looks very much like a coarse, somewhat cindery slag. It may be stony or glassy, or a mixture of both textures, having colors that range from reddish brown to dark gray or black. The gas bubbles (vesicles) that give scoria 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. Compared to pumice, scoria is somewhat denser and tougher; consequently, it is widely used as a lightweight aggregate in concrete and concrete blocks. As with pumice, you may need the use of special low-alkali cements.

(8) Conglomerate and breccia. *Conglomerate* and *breccia* resemble man-made concrete in that they consist of gravel-sized or larger rock fragments in a finer grained matrix. Different varieties such as limestone breccia, boulder conglomerate, or quart pebble conglomerate are generally distinguished by the composition or size of the rock fragments. Wide variations in composition, degree of cementation, and unpredictable degree of weathering of their component particles make these rocks highly unpredictable, even within the same deposit. Generally they exhibit poor engineering properties and are avoided in construction. You may use some very weakly cemented types by crushing them for use as fill or subbase material in road or airfield construction.

(9) Sandstone. *Sandstone* is a medium-to-coarse grained, hard, gritty clastic rock that is composed mainly of sand-size (1/16 to 2 millimeters), 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, you may use some clay-free types by finely crushing them to provide sand.

(10) Shale. *Shale* is a soft to moderately hard sedimentary rock composed of very fine-grained (silt-sized) particles and clay materials. 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 clay odor when barely moistened. Occasionally it will form into massive shales (mudstones), which may 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. You can excavate most shales without the need for blasting. Because of their weakness and lack of durability, shales make very poor construction material.

(11) Tuff. *Tuff* 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 and is often used as an extender for portland cement and as a pozzolana to improve workability and neutralize alkali-aggregate reactions. You can also use it as fills and base course materials.

(12) Limestones. *Limestones* are soft to moderately hard rocks 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 diluted hydrochloric acid. Colors normally range from white through various shades of gray to black, while other colors may result from impurities. Ordinary limestone is a compact moderately tough, very fine-grained or coarsely crystalline rock that serves as a quality material for all construction needs. Hardness, toughness, and durability normally increase with increasing 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. Therefore, they are widely used as fills and base course materials. In mild climates, some may even prove suitable for your use in low-strength portland cement concrete.

(13) Dolomites. *Dolomites* are soft to moderately hard rocks composed mainly of calcium-magnesium carbonates. They are distinguished by a slow bubbling or fizzing reaction when they comes in contact with diluted hydrochloric acid. Usually, the reaction can be observed only if the rock is first powdered (as by scraping it with a knife) before testing. Colors are normally grayish, yellowish, or pinkish. The characteristics of dolomite are similar to those of limestone, although dolomites are more resistant to weathering.

(14) Chert. *Chert* 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 red and 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 disintegrate when exposed to frost action. Despite these problems, cherts are acceptable for road construction in many areas where better materials are not available.

(15) Gneiss. *Gneiss* is a roughly-foliated, medium-to-coarse grained rock that consists of alternating streaks or bands of differing mineralogic composition. These may be straight wavy, or crumpled and of uniform or 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.

(16) Coal. *Coal* is an organic sedimentary rock composed mainly of carbonaceous plant material. *Peat* is a low-grade variety of coal formed from the accumulation of partially-decomposed organic matter at the bottom of a stagnant body of water. With increased pressure due to the weight of overlying sediments, peat is transformed through the intermediate-grade varieties of coal such as *lignite* and *bituminous* coal, to a high-grade variety of coal known as *anthracite*. Mid-to-high grade varieties of coal are used extensively as fossil fuels.

(17) Schist. *Schist* is a fine-to-coarse grained, well-foliated rock composed of discontinuous thin layers of parallel mica, chlorite, hornblende, or other minerals. As a rule, adjacent layers in schist consist of the same minerals. Schists split readily along these mineral layers into thin slabs or flakes. This characteristic makes schists undesirable for construction use and hazardous to excavate. Varieties intermediate to gneiss may prove suitable, however, for you to use as fills, base course materials, or portland cement concrete.

(18) Quartzite. *Quartzite* is an extremely hard, fine-to-coarsely grained, massive rock that forms from the metamorphism of sandstone. Unlike sandstone quartzite fractures through its component grains rather than around them because the cement and sand grains have been fused or welded together during metamorphism. Broken surfaces are, therefore, 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.

(19) Marble. *Marble* is a soft, fine-to-coarse crystalline, massive metamorphic rock that forms from limestone or dolomite. It is distinguished by its softness, acid reaction, lack of fossils, and sugary appearance of freshly broken surfaces. Marble is similar to ordinary compact or crystalline limestones in its engineering properties and uses. However, because of its softness, marble is usually avoided as an aggregate for pavements of 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, whatever its actual color may be.

1-3. System for Rock Identification. The military system of field identification of rock types is given in flow chart form in Table 1-3. In this method, all considerations are based on the appearance or character of a clean, freshly-broken, unweathered rock surface. When you are determining the identification of gravel or weathered samples, you may find pieces to be stained or partially altered, and you may expect some modifications of their characteristics.

The three main rock properties you will use in the field identification of rocks are appearance, hardness, and reaction to acid:

- Appearance includes *color* (light or dark) and *texture* (size, shape, and arrangement of grains)

- Hardness includes *hard* (difficult or unable to scratch) and *soft* (nail scratches rock)

- Reaction to acid includes *none* (shale and tuff), *unstable* (pumice and scoria), and *rapid* (limestone or marble). An acid test performed on powdered dolomite (a form of limestone) will produce a rapid acid reaction. The reaction to acid test is performed on samples identified as soft. Your samples should have good fresh surfaces.

Your first determination when using the system is to place the sample, based on its outward appearance, into one of three general groups:

- Foliated.
- Very fine-grained (frothy, glassy, and stony).
- Course-grained.

Simple physical and chemical determinations then permit your further progression through the flow chart until a final identification is made. For most rocks, the identification process will be direct and uncomplicated. If you cannot make a positive identification, you should consult the more detailed rock descriptions given previously in this lesson. However, you should use the flow chart first to eliminate all clearly inappropriate rock types. By using adjectives, you can modify a basic rock classification to compose a "word picture" of the rock such as *"a pale brown, fine-gained, thin-bedded, compact, clayey, silica-cemented sandstone."* Table 1-4, page 1-16, lists the key terms used to modify rock descriptions; these terms should offer further help with identification of samples.

Table 1-3. Field identification of rock types

Rock Type	Appearance (color/texture)	Hardness (hard/soft)	Acid Reaction
Foliated Group			
Slate	Slaty cleavage, very fine grained	Splits along thin planes	NA
Schist	Metallic reflection	Splits into slabs and fragments	NA
Gneiss	Contains streaks or bands of light and dark minerals	Breaks to bulky, angular fragments	NA
Very Fine-Grained Group			
Frothy			
Pumice	Light colored, lightweight	Easily crushed	Unstable
Scoria	Dark colored	Cindery	Unstable
Glassy			
Quartz	Light colored, massive	Extremely hard	NA
Obsidian	Dark colored, may have some gas bubbles		NA
Stony			
Shale	Any color, platy structure Earthy, clay odor	Soft	None
Tuff	May have many small pieces of glass, low density	Soft	None
Marble	Sugary	Soft	Rapid
Limestone	Dull, massive	Soft	Rapid
Chert	Waxy, weathers to soft white	Very hard	NA
Felsite	Dull, light color, may contain some gas bubbles or visible crystals	Hard	NA
Basalt	Dull, dark color, may contain some gas bubbles or visible crystals	Hard	NA
Sandstone	Sandy, mostly one mineral (quartz) Gritty sandpaper feel	Hard	NA
Quartzite	Sandy, mostly one mineral (quartz) Sugary, not gritty texture	Hard	NA
Coarse-Gained Group			
Sandstone	Sandy, mostly one mineral (quartz) Gritty sandpaper feel	Hard	NA
Quartzite	Sandy, mostly one mineral (quartz) Sugary, not gritty texture	Hard	NA
Granite	Light colored, mixed minerals Salt-and-pepper look	Hard	NA
Gabbro-diorite	Dark colored, mixed minerals Salt-and-pepper look	Hard	NA
Conglomerate	Appearance of broken concrete Fragmental	Hard	NA
Tuff	Fragmental, low density May contain small pieces of glass	Soft	NA
Marble	Sugary	Soft	Rapid
Limestone	Shell fragments	Soft	Rapid

Table 1-4. Key terms used in rock descriptions

Grain sizes

Crystals

Term	Size
Very coarse	Over 25 mm
Coarse	5 to 25 mm
Medium	1 to 5 mm
Fine	Below 1 mm
Very fine	Indistinguishable

Rock or mineral fragments

Term	Size
Boulder	Over 256 mm
Cobble	64 to 256 mm
Pebble	4 to 64 mm
Granule	2 to 4 mm
Sand	1/16 to 2 mm
Silt	1/256 to 1/16 mm
Clay	Below 1/256 mm

Bedding thickness

Term	Size
Very thick	Over 3 m
Thick	1 to 3 m
Medium	25 to 100 cm
Thin	5 to 25 cm
Very thin	1 to 5 cm
Laminated	Below 1 cm

Joint (fracture) spacing

Term	Size
Very wide	Over 3 m
Wide	1 to 3 m
Moderately close	25 to 100 cm
Close	5 to 25 cm
Very close	Below 5 cm

Mechanical strength (unconfined compressive strength, in psi)

Term	Size
Very strong	Over 32,000
Strong	16,000 to 32,000
Intermediate	8,000 to 16,000
Weak	4,000 to 8,000
Very weak	Below 4,000

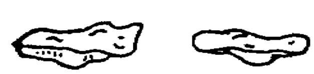
Hardness

Term	Scratch test
Very hard	Can not be scratched by a steel file
Hard	Can be scratched by steel file but difficult or impossible to scratch with steel knife blade
Moderately Hard	Can be scratched by knife but not by a copper coin
Soft	Can be scratched by copper coin
Very soft	Can be scratched by fingernail

Density (bulk density, in gm/cc)

Term	Size
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

Crushed Shape

Term	
Irregular, bulky	
Blocky	
Elongated	
Slab	
Plate	
Flake	
Chip	

PART B: IDENTIFYING THE KEY ENGINEERING PROPERTIES OF ROCKS

A generalized summary of the engineering properties of fresh, unweathered rocks is given in Table 1-5, page 1-18. The key engineering properties are toughness, hardness, durability, chemical stability, surface character, crushed shape, and density.

1-4. Toughness. Toughness (mechanical strength) is a measure of resistance to crushing or breaking. In the field, you may be able to estimate this property by attempting to break the rock with a hammer or by measuring its resistance to penetration by impact drills.

1-5. Hardness. Hardness is a measure of resistance to scratching or abrasion. In the field, you may estimate this by attempting to scratch the rock with a steel knife blade. Soft materials may be readily scratched with a knife, while hard materials are difficult or impossible to scratch with a knife.

1-6. Durability. Durability is a measure of resistance to slaking or disintegration due to alternating cycles of wetting and drying or freezing and thawing. You can estimate this property in the field by observing the effects of weathering on natural exposures of the rock. A durable rock is preferable for use as a construction material.

1-7. Chemical stability. Chemical stability is a measure of the 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 which absorbs water and expands, causing hardened concrete to crack. In the field, you can estimate potential alkali-aggregate reactions by two methods: by identifying the rock and comparing it to known reactive types or by investigating structures in which the aggregate has previously been used.

1-8. Surface character. Surface character 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 also undesirable for construction use because they resist compaction or placement and require excessive amounts of cementing material.

1-9. Crushed shape. Crushed-shape rocks are irregular, bulky fragments of broken rock. They provide the best aggregates for construction needs because the component particles compact well. They also interlock to resist displacement and to 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 narrow dimensions and do not compact, interlock or distribute loads effectively.

1-10. Density. Density is equal to the weight per unit volume. You may estimate this property in the field by hefting a rock sample. Density influences excavation and hauling costs and may affect the selection of rocks for special requirement, such as riprap, jetty stone, or lightweight aggregate. Among rocks of the same type, high density often indicates increased toughness and durability. Table 1-6 shows average rock densities and the value of aggregates for military construction missions.

Table 1-5. Rock characteristics

Class	Rock Type	Toughness	Hardness	Durability	Chemical Stability	Surface Character	Crushed Shape
Igneous	Granite Syenite	Good	Good	Good	Excellent	Fair to good	Good
	Gabbro-diorite	Excellent	Excellent	Excellent	Excellent	Excellent	Good
	Diabase Basalt	Excellent	Excellent	Excellent	Excellent	Excellent	Good
	Felsite	Excellent	Good	Good	Questionable	Fair	Fair
Sedimentary	Conglomerate Breccia	Poor	Poor	Poor	Variable	Good	Fair
	Sandstone	Variable	Variable	Variable	Good	Good	Good
	Shale	Poor	Poor	Poor	Questionable	Fair to good	Poor
	Limestone Dolomite	Good	Good	Fair to good	Good	Good	Good
	Chert	Good	Excellent	Poor	Poor	Fair	Poor
Metamorphic	Gneiss	Good	Good	Good	Excellent	Good	Good to fair
	Schist	Good	Good	Fair	Excellent	Poor to fair	Poor to fair
	Slate	Good	Good	Fair to good	Excellent	Good	Poor
	Quartzite	Excellent	Excellent	Excellent	Excellent	Good to fair	Fair
	Marble	Good	Fair	Good	Good	Good	Good

Table 1-6. Rock density and use of aggregates for military construction missions

Class	Rock Type	Average Rock Densities		Average Crusher Production Factors	Use as Aggregates		Use as Base Course or Subcourse
		Pounds per cubic feet	Tons per cubic yard		Concrete	Asphalt	
Igneous	Granite Syenite	165 165	2.31 2.31	0.90 0.90	Fair to poor Good	Fair to good Good	Good
	Gabbro Diorite	181 181	2.53 2.53	0.80 0.80	Excellent	Excellent	Excellent
	Diabase Basalt	170 170	2.38 2.38	0.75 0.75	Excellent	Excellent	Excellent
	Felsite	148	2.07	0.80	Poor[1]	Fair	Fair to good
Sedimentary	Conglomerate Breccia	159 159	2.23 2.23	1.0	Poor	Poor	Poor
	Sandstone	137	1.92	1.0	Poor to fair	Poor to fair	Fair to good
	Shale	162	2.27	1,0	Poor	Poor	Poor
	Limestone Dolomite	154 154	2.16 2.16	1.0 1.0	Fair to good Good	Good Good	Good
Metamorphic	Chert	162	2.27	0.80	Poor[1]	Poor[2]	Poor to fair
	Gneiss	172	2.41	0.95	Good	Good	Good
	Schist	167	2.34		Poor to fair	Poor to fair	Poor to fair
	Slate	183	2.56	0.90	Poor	Poor	Poor to fair
	Quartzite	165	2.31	0.80	Good	Fair to good	Fair to good
	Marble	165	2.37	0.80	Good	Fair to good[2]	
	[1]Reacts (alkali-aggregate) [2]Antistripping agents should be used						

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PRACTICE EXERCISE

The following items will test your grasp of the material covered in this lesson. When you have completed the exercise, check your answers with the key that follows. If you answer any item incorrectly, study again that part which contains the portion involved.

1. What are the three major classes of rocks?

____

____

____

2. Which class of rock solidifies from magma?

____

3. Which class of rock represents material that consolidates from accumulations of solid rock debris, chemical precipitate, or organic material by compaction, cementation or crystallization?

____

4. What percent of the earth's surface does the class of sedimentary rocks cover?

____

5. Sedimentary rocks are predominately composed of varieties of shale, sandstone, and limestone sediments. What percent of sedimentary rocks do these sediments represent?

____

6. How are extrusive-type rocks formed?

____
____
____

7. How are intrusive-type rocks formed?

____
____
____

8. What particles make up the main composition of chemical sedimentary rocks?

____

9. Metamorphic rocks are initially classified into two groups on the basis of structure. What are the two groups?

____

____

10. What mineral type is extremely hard, transparent to translucent has a glassy or waxy luster, and is virtually unaffected by chemical weathering?

____

11. What three main rock properties are used in the field identification of rocks?

____

Some of the key engineering properties of rock are toughness and density.

12. Define the term toughness.

____

____

13. Define the term density.

____

____

Lesson 1

PRACTICE EXERCISE

ANSWER KEY AND FEEDBACK

Item	Correct Answer
1.	Igneous, sedimentary and metamorphic. (page 1-2, para 1-1)
2.	Igneous. (page 1-5, para 1-la)
3.	Sedimentary. (page 1-6, para 1-1b)
4.	75 percent. (page 1-6, para l-lb)
5.	95 percent. (page 1-6, para 1-1b)
6.	Extrusive rocks are formed from magma or lava that has cooled on or near the earth's surface. (page 1-5, para 1-la)
7.	Intrusive rocks crystallize from magmas within the earth's crust (page 1-5, para 1-1a)
8.	Chemical sedimentary rocks consist mainly of chemical or biochemical precipitates. (page 1-6, para 1-lb(2)(a))
9.	Foliated and massive. (page 1-6, para 1-1c)
10.	Quartz. (page 1-8, para 1-2a(1))
11.	Appearance, hardness, and reaction to acid. (page 1-14 para 1-3)
12.	Toughness is a measure of resistance to crushing or breaking. (page 1-17, para 1-4)
13.	Density refers to the weight per unit volume. (page 1-17, para 1-10)

LESSON 2

GEOLOGIC STRUCTURES

Critical Tasks: 051-243-2006
051-243-3011
051-243-3012
051-243-3027

OVERVIEW

LESSON DESCRIPTION:

In this lesson you will learn about large bodies of rock and their orientation and distribution within the earth's crust.

TERMINAL LEARNING OBJECTIVE

ACTION: You will identify major geologic structures and their engineering significance.

CONDITION: You will be given the materials contained in this lesson.

STANDARD: You must complete the lesson and the practical exercise.

REFERENCES: The material contained in this lesson was derived from FM 5-410.

INTRODUCTION

In Lesson 1 of this subcourse, you learned about the three major categories of rocks. You also learned about some basic rock properties and how to identify rocks. In this lesson, you will learn about large bodies of rock and their orientation and distribution within the earth's crust.

A knowledge of structural geology is important to you, as a military engineer, because of the effect it has on road construction, rock blasting, quarrying, and many other types of engineering projects.

2-1. Geologic Structures. Geologic structure controls the distribution of rock bodies and features along and beneath the earth's surface. Rocks tend to fracture along existing zones of weakness. The presence and spacing of bedding, foliation, and joint planes can control the size and shape of rock fragments produced in quarries and other excavations.

Operational and production costs may be prohibitive if rock fragments are too large, too small, too slabby, or too irregular for intended uses. You can significantly reduce excavation and aggregate production costs by identifying advantageous joint or bedding spacings.

The *primary structure*, or *original* form and arrangement, of rock bodies in the earth is often altered by *secondary structural* features such as *folds*, *faults*, and *joints*. The features are produced in the rocks by movements in the earth after deposition (and usually after consolidation) of the rocks. Like plastic steel, and other familiar materials, rocks may behave as viscous, plastic, or elastic solids when placed under stress. Depending on the amount and duration of the stress and on their composition, temperature, and degree of confinement rocks may flow, bend, or break. Some of the important causes of stress (and movement) in the earth's interior include slow circulation of heat in the dense, hot rocklike materials found below the earth's thin outer crust and rising bodies of molten rock (magma). Other important causes of stress are loading by accumulation of deposits, unloading due to the erosion of surface rock deposits, and contraction due to the compaction or cooling of rock bodies. During the 4.5 billion years of the earth's existence, weathering, erosion, deposition, magnetic intrusions, crustal movements, and climatic conditions have acted at various times and places to produce the different rock bodies and features that make up the today's earth.

2-2. Outcrops. An outcrop is that part of a rock formation which is exposed at the earth's surface. You may view outcrops in areas where soil cover has not developed or where the developed soil cover has been removed, leaving the underlying rock exposed. A few possible outcrop locations are shown in Figure 2-1. Information you can obtain from outcrops includes the rock type, contacts and attitudes.

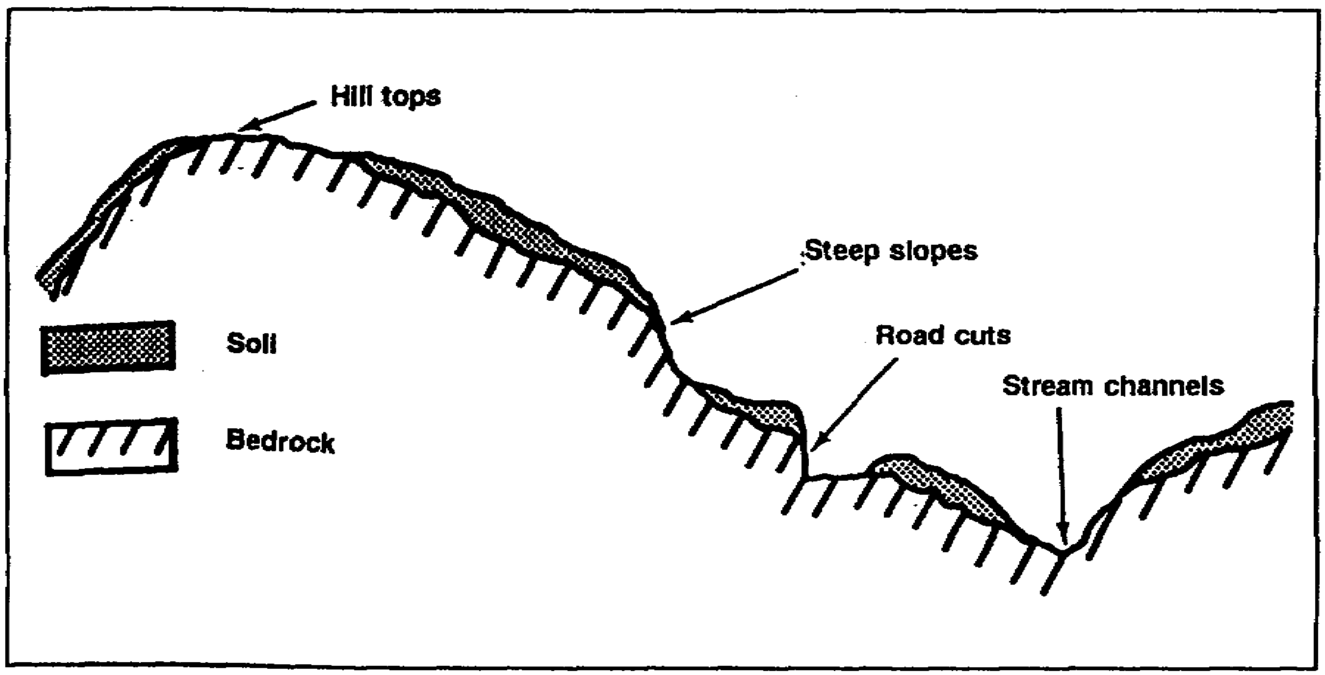


Figure 2-1. Typical locations of outcrops

2-3. Primary Structural Features. Primary structural features are igneous structures, metamorphic foliation, and sedimentary stratification.

a. Igneous Structures. The basic forms and relationships of igneous rock bodies are shown in Figure 2-2. They are formed as intrusive or extrusive rock forms:

(1) Intrusive. *Intrusive* rock bodies form within the earth's crust and may be either concordant or discordant with surrounding rocks. *Concordant* intrusions, such as sills and laccoliths, form tabular or lens-shaped bodies that parallel the structure of the rocks around them. *Discordant* intrusions, such as dikes, solidify in fractures that cut across the structure of the surrounding rocks. Some very large discordant bodies such as batholiths and stocks are up to several kilometers wide. They essentially melt their way into place by forming masses of rock that may contain inclusions of older surrounding rocks.

(2) Extrusive. *Extrusive* igneous rocks form at or near the earth's surface. Most are deposited in thin, broad sheets parallel to the local topography. Older extrusions are often buried under layers of younger extrusive rock or even sedimentary material. In addition, younger intrusive bodies may form around or within older intrusions.

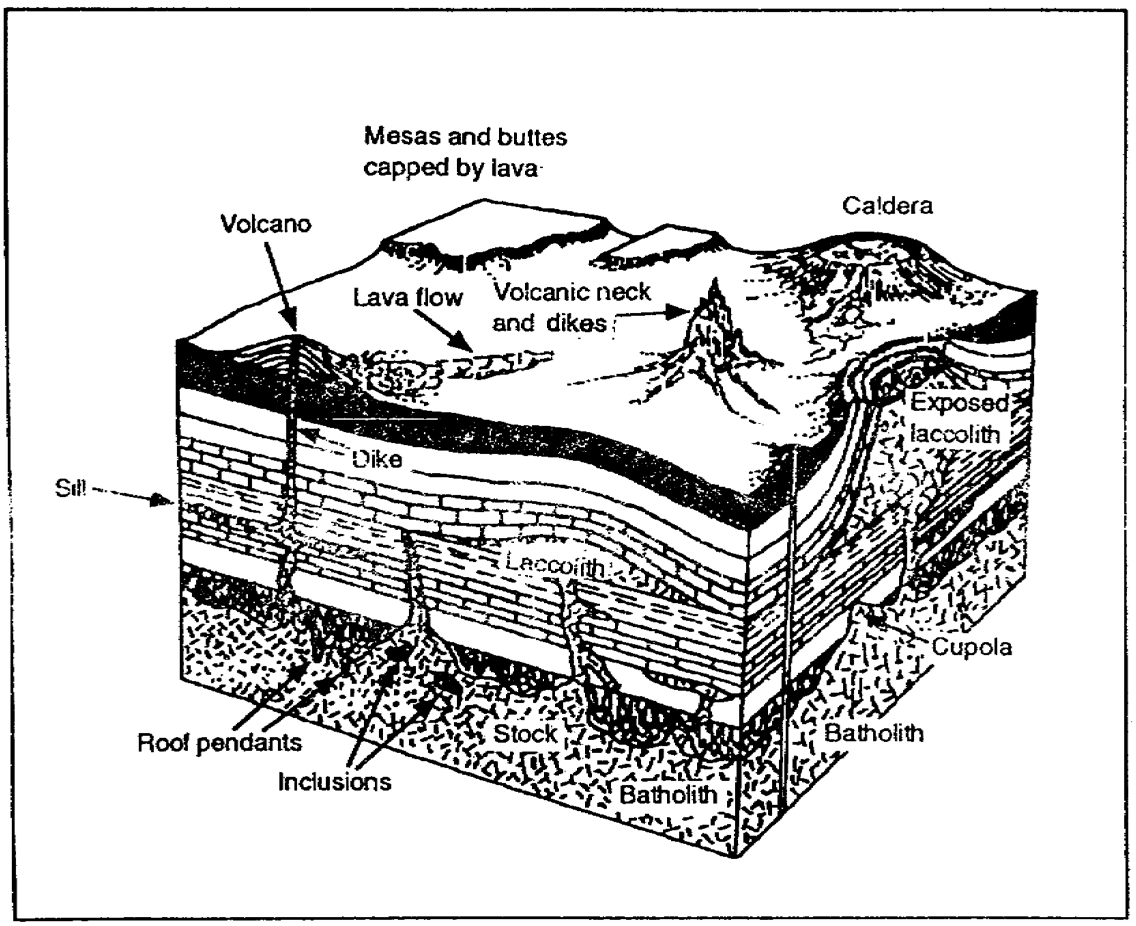


Figure 2-2. Intrusive and extrusive rock forms

b. Metamorphic Foliation. Most metamorphic rocks are distinguished by the segregation and alignment of their component minerals into parallel streaks, bands, layers, or sheets. This arrangement is called *foliation*, and the planes of weakness along which the minerals are aligned are called planes of foliation or, simply, *foliation planes*. Foliation planes develop at right angles to the pressure applied during metamorphism. They frequently form parallel to the original surface of large intrusive bodies and may parallel or cut across older bedding structures in metamorphosed sediments. Often foliation planes are highly distorted by rock flowage associated with the temperatures and pressures of metamorphism.

c. Sedimentary Stratification. Most sedimentary rocks are characterized by an original bedded structure known as *bedding* or *stratification*. The lines of parting between individual beds or strata are called *bedding planes*. The sorting action of water and wind will produce such structures in sedimentary rocks. The sediment is deposited in nearly horizontal layers which may vary in thickness from less than an inch to more than 100 feet.

An important principle on which the study of structural geology is based is called the *Law of Superposition*. It states that in an undisturbed sequence of sediments or sedimentary rocks, the layer on the bottom is older than all the rocks which overlie it. It is clearly obvious that if the bottom bed was not in place first, the others could not have been deposited on top of it.

2-4. Secondary Structural Features. Secondary structural features include folds, joints, and faults.

a. Folds. *Folds* are undulations that exist in the rocks of the earth. They are the most common type of deformation. The size of folds varies considerably. Some folds are miles across; the width of others may be only a few feet, a few inches, or even fractions of an inch. Most folds (Figure 2-3) may be classified as one of three principal types:

- Monocline. Monocline exhibits step-like slopes in otherwise flat or gently inclined rock layers.
- Anticline. Anticline exhibits upfold slopes.
- Syncline. Syncline exhibits downfold slopes.

Upfold and downfold slopes are the most common types of folds. These tend to produce linear valleys and ridges. Since symmetry is a rarity in nature, asymmetrical anticlines and synclines are common.

A *dome fold* is a special case of the anticline in which the beds dip outward in all directions from a central point. A *basin fold* is a special case of the syncline in which the beds dip inward from all sides toward a central point.

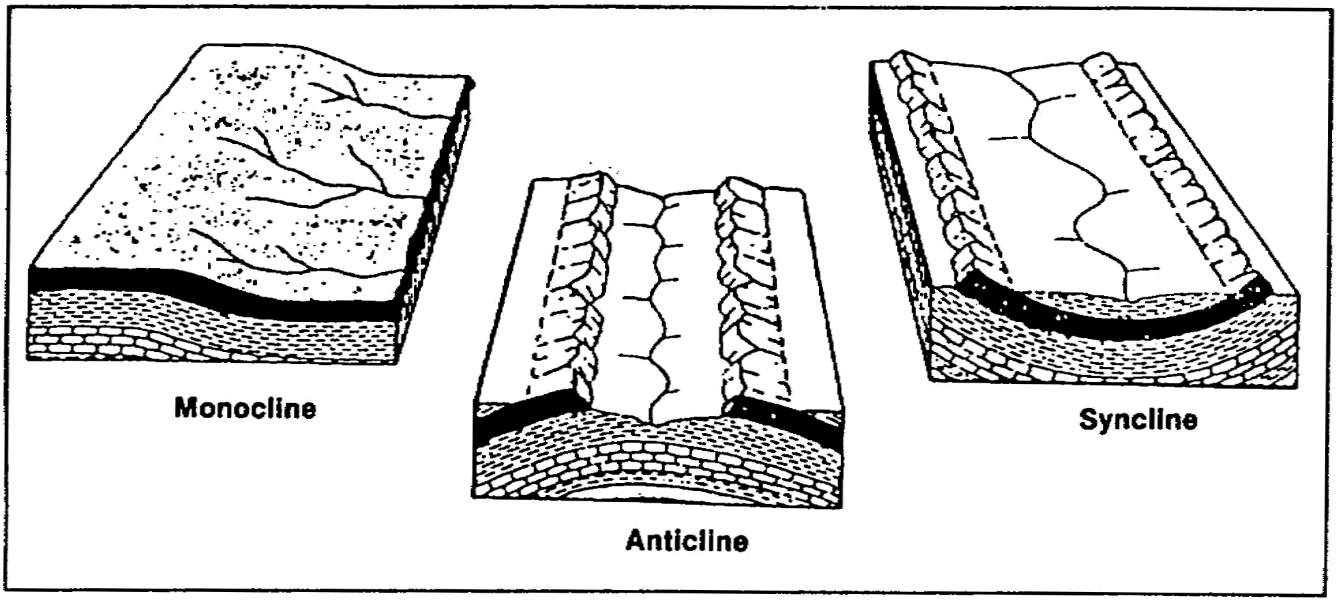


Figure 2-3. Three common folds

(1) Engineering significance of folds. Changes in attitude or position of the bedding planes within rock bodies are significant because they can lead to rock excavation problems and slope instability for such areas as tunneling, quarrying, and dams.

(a) Tunneling. Folded rock sometimes shows considerable fracturing along the axis of the fold. With anticlines, these fractures diverge upward; with synclines they diverge downward. If you are driving a tunnel along the crest of a fold, the shattered rock may present a problem that you can solve by lining. Synclines give rise t more trouble because even moderate fracturing may cause the blocks bounded by the fracture planes to drop out. Fractures located along the crest of a fold may also cause problems by acting as channels for surface water.

(b) Quarrying. The position of folded rocks greatly influences quarrying operations. Often the dip creates a serious safety problem for your soldiers. The dip also creates a drainage problem for the operation. In steeply dipping strata, the flooring operation becomes difficult as it is harder to obtain a level working surface.

(c) Dams. Folding can cause dangerous fracturing that may allow leakage or slipping of the beds under a dam.

(2) Measuring and defining local bedrock. To be able to discuss or describe the structure of local bedrock, you must have some means by which you can measure and define the trend of the rock on the earth's surface.

(a) Attitude of beds. The trend of the rock is known as the *attitude* of the rock. If the rock is sedimentary, as approximately 75 percent of those on the earth's surface are, the attitude is described in terms of the *strike* and the *dip* of the bedding plane (Figure 2-4).

- Strike is the compass direction of the horizontal line formed by the intersection of horizontal plane and the bedding plane.
- Dip is the acute angle between the bedding plane and the horizontal plane, measured at right angles to the strike direction.

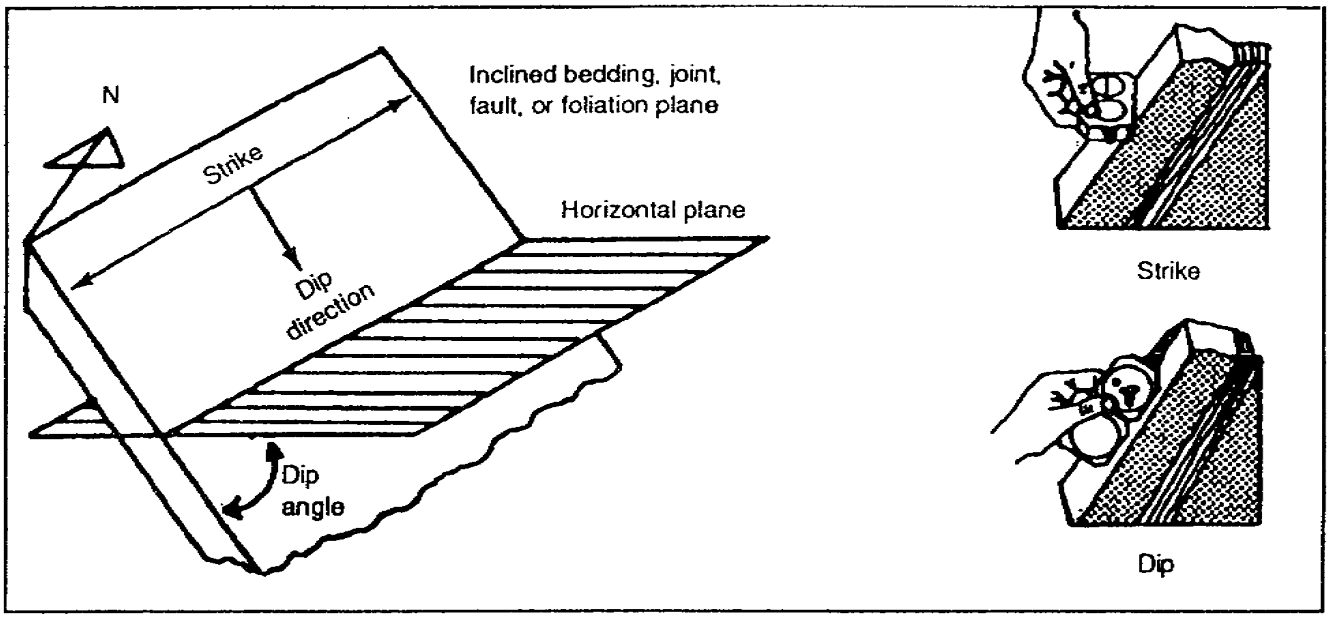


Figure 2-4. Strike and dip

(b) Measurement. You may measure the strike and dip of a plane with a standard Brunton compass. This compass is graduated in degrees and has a bull's eye level for you to determine the horizontal plane when you are measuring the strike direction. A bubble level and a clinometer are provided for you to measure the dip angle. Read the *strike direction* directly from the compass. It is referenced to the North, such as North 30° East or North 20° West. You determine the *dip angle* by placing the compass at right angles to the strike direction and reading the acute angle indicated by the clinometer. You use both the dip direction and the dip angle to describe the dip of the plane, such as South-West 10°.

(c) Symbols. Strike and dip are shown on a map by strike and dip symbols. The symbol is drawn at the point representing the exact spot where the strike and dip were measured in the field. By convention, there is a special symbol to represent the strike and dip of inclined beds, vertical beds, and horizontal beds.

Inclined beds strike and dip symbols are shown in Figure 2-5. The strike and dip symbols used for inclined beds are defined below:

- The long line represents the direction of the strike. The line is oriented with reference to the map grid lines in exactly the same compass direction as it was measured.
- The short line represents the direction of the dip. The line is always drawn perpendicular to the strike line and in the direction the plane is dipping.
- The number written next to the symbol represents the angle of the dip.

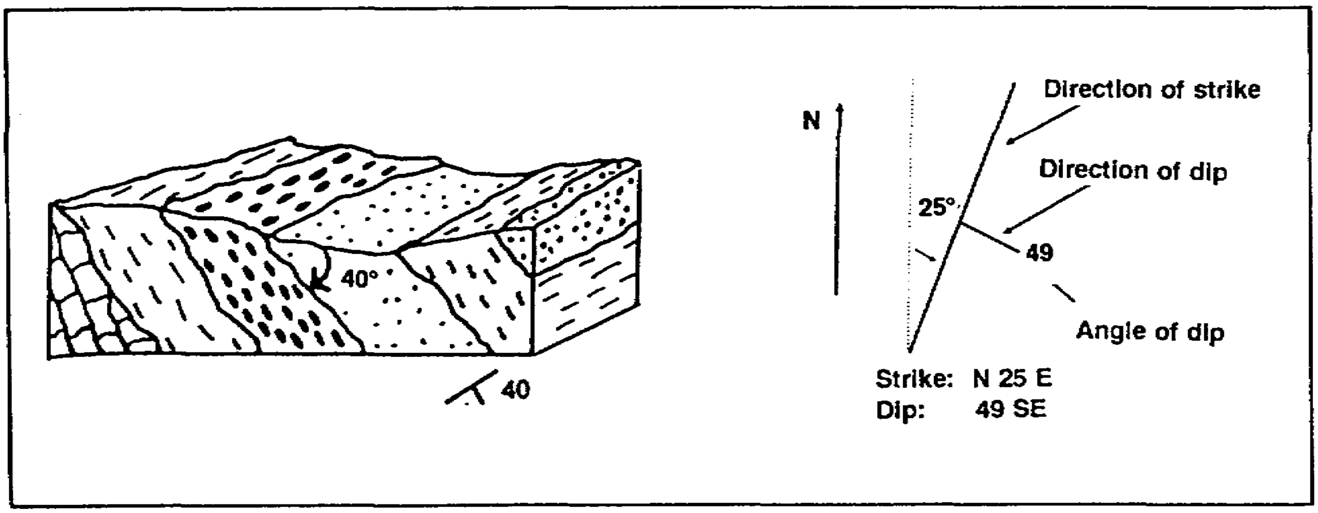


Figure 2-5. Inclined beds

Vertical beds (Figure 2-6). Strike is represented in the same way as it is for inclined beds. The dip symbol differs from inclined beds as defined below:

- A short line crossing the line of strike at right angles represents the direction of the dip. It indicates that vertical beds can be considered to be dipping in either of the two directions at right angles to the strike line.

- The directions of strike and dip are plotted but not written on the map.

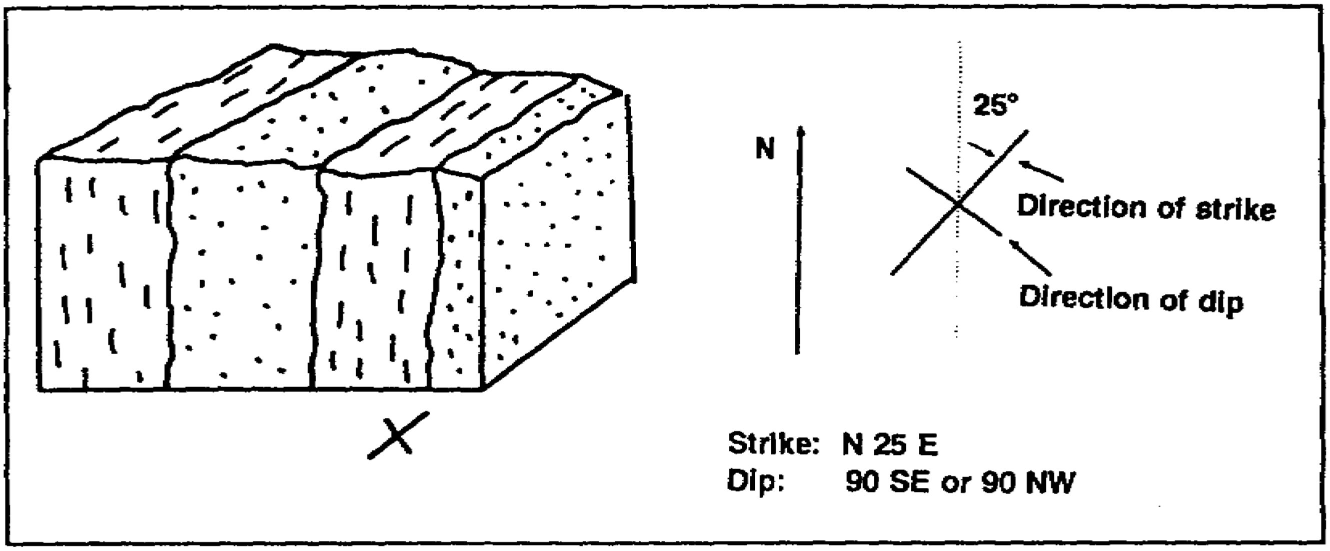


Figure 2-6. Vertical beds

Horizontal beds (Figure 2-7). Horizontal beds strike and dip symbols are defined below:

- The strike s represented by crossed lines. The lines indicate that there is no single line of strike or that it strikes in every direction.

- A circle surrounding the crossed lines represent the dip. The circle implies that there is no direction of dip and that there is no angle of dip, or zero degree dip.

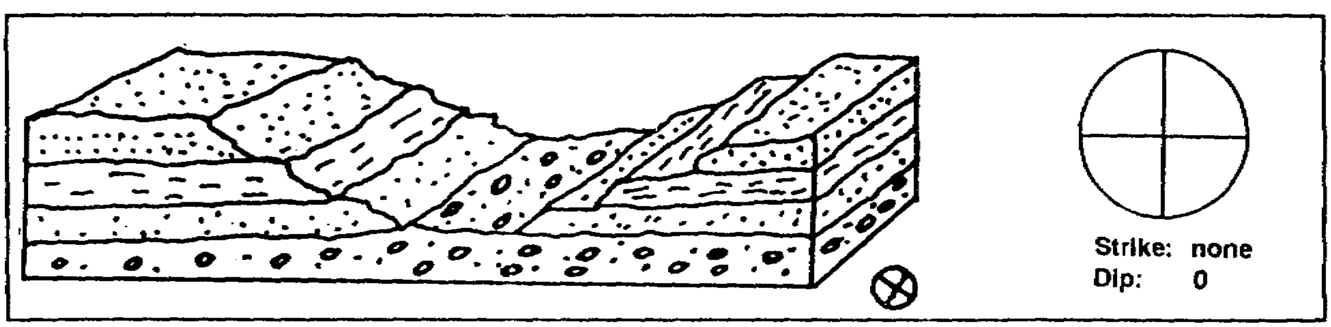


Figure 2-7. Horizontal beds

b. Joints. *Joints* are fractures along which there has been no visible movement. Although joints characteristically produce planar surfaces, some may produce curved surfaces. Joints may have any attitude; some joints are vertical, others are horizontal, and many are inclined at various angles (Figure 2-8). You measure the strike and dip of joints in the same manner as the strike and dip of bedding planes. The *strike* is the direction of a horizontal line on the surface of the joint. The *dip*, measured in a vertical plane at right angles to the strike of the joint, is the angle between a horizontal plane and the joint. Joints vary greatly in magnitude. Some joints are only a few feet long while others are hundreds or even thousands of feet long. Joints are formed as freshly emplaced igneous rocks that contract and cool. This occurs during lithification as sedimentary rocks are compacted, during metamorphism as rocks are stressed, and when rock masses expand as overlying rock is removed by erosion. A special type of jointing known as *exfoliation* occurs when alternating heating and cooling periods cause rocks to expand and contract. In dense and compact extrusive igneous rock such as basalt, a form of prismatic fracturing known as *columnar jointing* (as shown in Figure 2-8) often develops as the rock cools rapidly and shrinks.

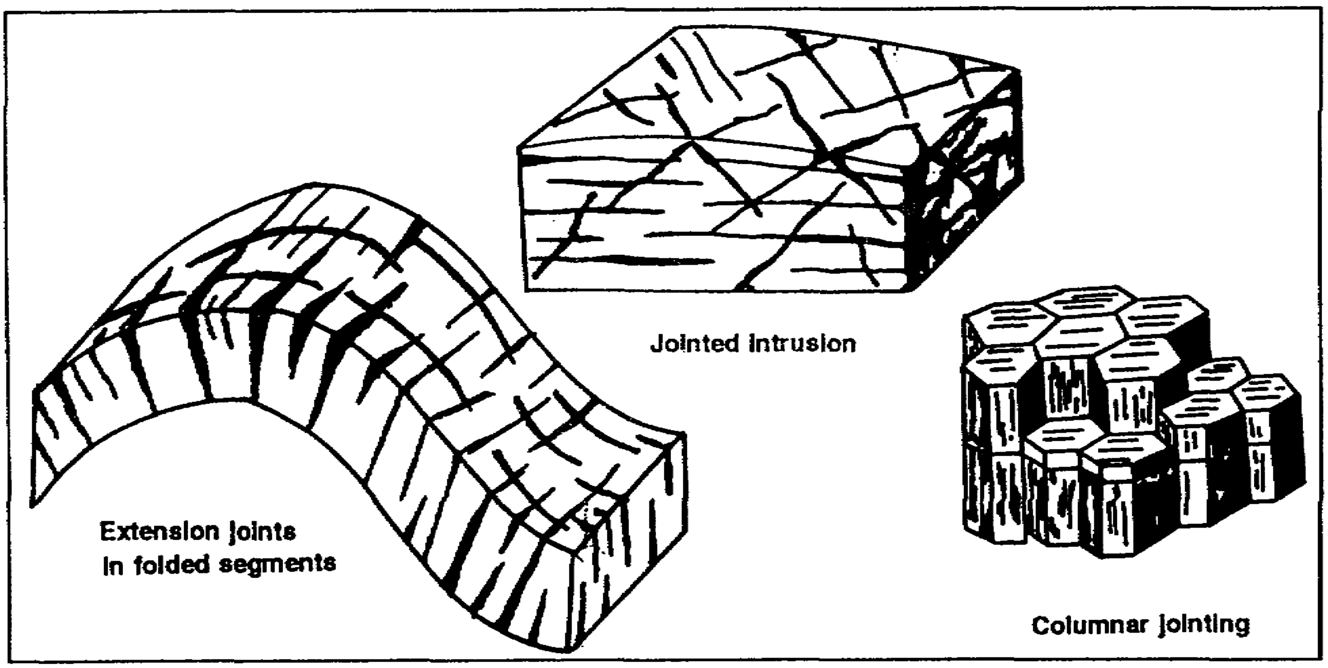


Figure 2-8. Block diagrams illustrating common joint patterns

(1) Classification of joints. Joints are classified as strike and dip joints, oblique joints, joint sets, and joint systems:

- Strike and dip joints. In folded rocks, joints are grouped into strike and dip joints to indicate their attitudes. *Strike joints* are parallel or essentially parallel to the strike of the bedding of a rock. *Dip joints* are parallel or essentially parallel to the direction in which the beds dip.

- Oblique joints. *Oblique* or *diagonal joints* extend in a direction that lies between the strike and dip directions of the associated rocks.

- Joint sets. A *joint set* is a group of nearly parallel joints.

- Joint systems. A *joint system* consists of two or more joint sets of any group of joints with a characteristic pattern.

(2) Engineering significance of joints. Joints are frequently encountered during construction projects. They are of considerable engineering importance to you, especially in excavation operations. It is desirable for joints to be spaced closely enough to reduce secondary plugging and blasting requirements to a minimum, but not so closely as to impair stability of excavation slopes or increase overbreakage in tunnels.

Quarry operations involve the drilling and blasting of rock material. Jointing can lead to several problems in these operations as shown in the following examples:

(a) Drill bits will tend to follow the inclined planes where joints or bedding planes incline across the axis of the drill hole. This tendency causes the drill holes to be misaligned or, more often, results in drills binding, sticking, or breaking off in the holes. Open fractures and layers of weak rock may greatly reduce blasting effectiveness by allowing the force of the blast to escape before the surrounding rock has been properly fragmented. In these instances, you will generally be required to use special drilling and blasting techniques.

(b) The efficiency of your operations is influenced by the orientation of joints with respect to quarry development. Joints oriented approximately at right angles to the working face present the most unfavorable condition, while joints oriented approximately parallel to the working face greatly facilitate blasting operations and ensure a fairly even and smooth break, parallel to the face.

(c) Joints offer channels for groundwater circulation. They may increase water problems, especially in areas of underground excavation. Where permeable rocks or fractures dip toward a tunnel, road cut, or other excavation, groundwater movement can cause drainage problems and promote rock slides by weakening or lubricating the rocks. Permeable rock zones can also permit water to escape from canals and reservoirs.

(d) Joints may exert an important influence on weathering of rocks.

c. Faults. *Faults* are fractures along which adjacent rock masses have moved with respect to one another. Their essential feature is differential movement parallel to the surface of the fracture. Some faults are only a few inches long and the total displacement is measured in fractions of an inch. At the other extreme are faults that are hundreds of miles long with a displacement measured in miles or tens of miles. A fault is classified as either a *normal fault* or a *reverse fault*.

(1) In a normal fault (sometimes called a *gravity fault*), the *hanging wall* (the mass of rock above the fault plane) has been displaced downward relative to the *footwall* (the mass of rock below the fault plane) as shown in Figure 2-9.

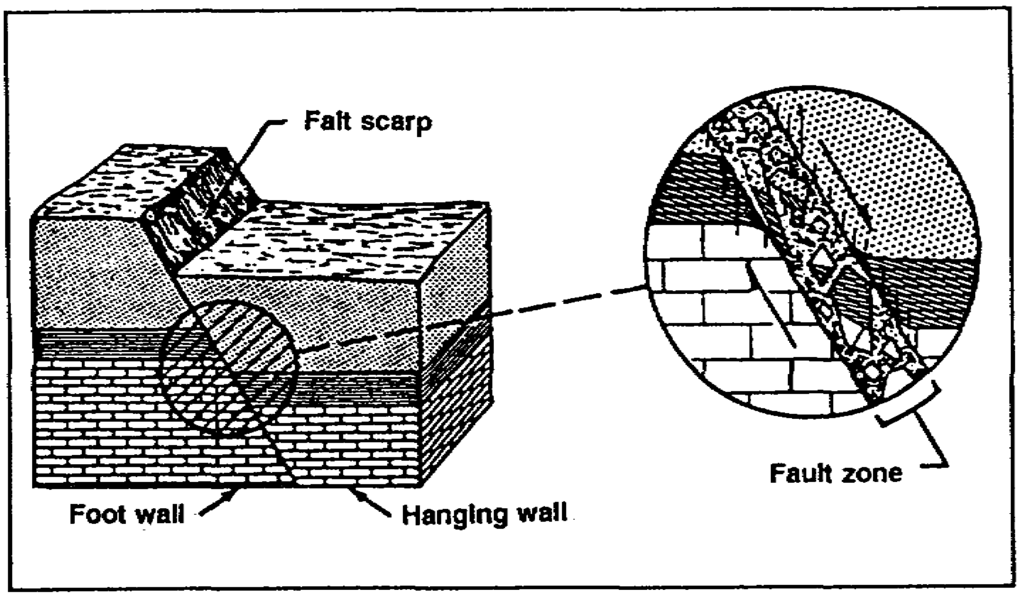


Figure 2-9. Normal Fault

(2) In a reverse fault, as shown in Figure 2-10, the hanging wall has been displaced upward relative to the footwall.

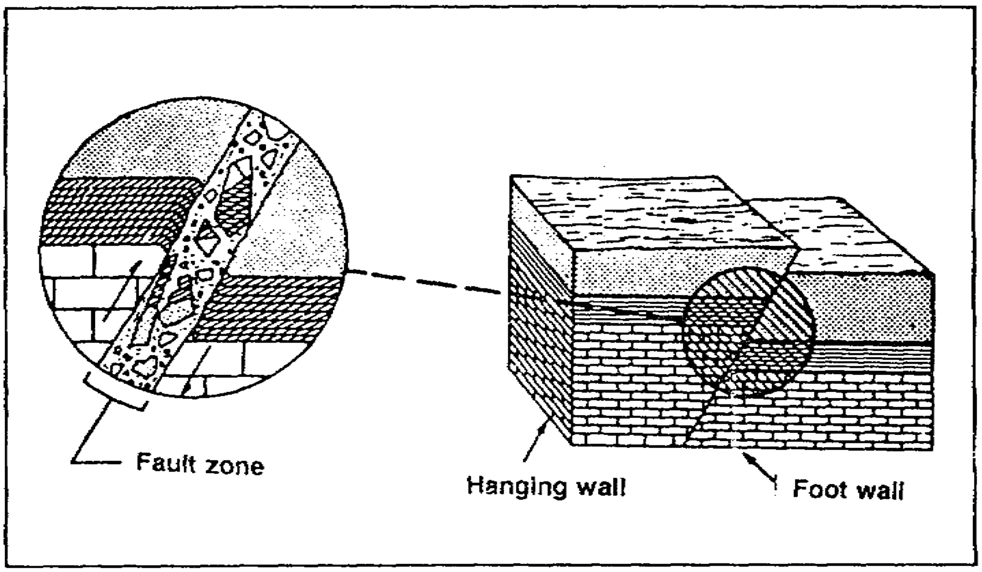


Figure 2-10. Reverse fault

d. Fault Terminology. Terms associated with faults are fault plane, attitude, fault zone, fault line, hade, slickensides, gouge, drag, thrust fault, and fault scarp:

(1) Fault plane. A *fault plane* is the planar surface along which movement has taken place.

(2) Attitude. The *attitude* is described in terms of the strike and dip of the planar feature. The strike and dip of a fault are measured in the same manner as they are for a layer of rock. The strike is the bearing of a horizontal line in the plane of the fault. The dip is the angle between a horizontal plane and the plane of the fault.

(3) Fault zone. A *fault zone* is an area in which there are several closely spaced faults. Although many faults are clean, in some instances, the displacement is not confined to a single fracture but is distributed through a fault zone that may be hundreds or thousands of feet wide. It may consist of numerous small faults, or it may be a zone of broken or crushed-rock material.

(4) Fault line. A *fault line* is the intersection of the fault plane with the surface of the earth. It is known as the fault line, fault trace, or fault outcrop (Figure 2-11).

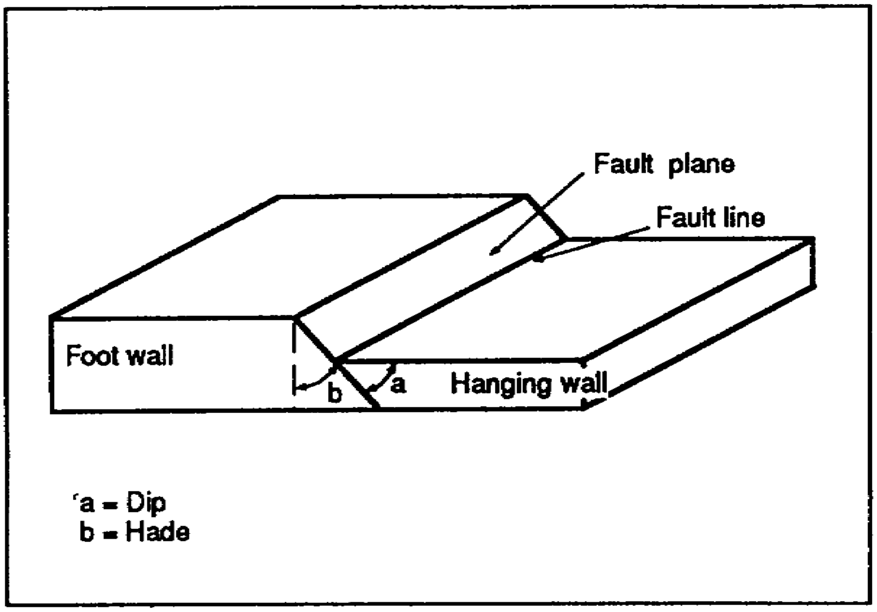


Figure 2-11. Fault terminology

(5) Hade. A *hade* is the inclination of a vein or fault measured from the vertical.

(6) Slickensides. *Slickensides* are polished and striated surfaces that result from grinding along the fault plane. These scratches or striations are parallel to the direction of movement of the fault. However, you should use caution in determining the direction of movement from the slickensides. The reason for caution is that although several series of movements may have occurred, only the trend of the last period of movement is evident.

(7) Gouge. A *gouge* is very finely pulverized rock material that has the appearance and feel of clay. It is found along the fault zone.

(8) Drag. A *drag*, which is the folding of the rock beds adjacent to the fault, is an indication of movement along the fault plane (Figure 2-12, page 2-14).

(9) Thrust fault. A *thrust fault* (Figure 2-12) is a fault along which the hanging wall appears to have been raised relative to the foot wall. It is generally characterized by a low angle of inclination, with reference to the horizontal. The fault is commonly called a reverse fault.

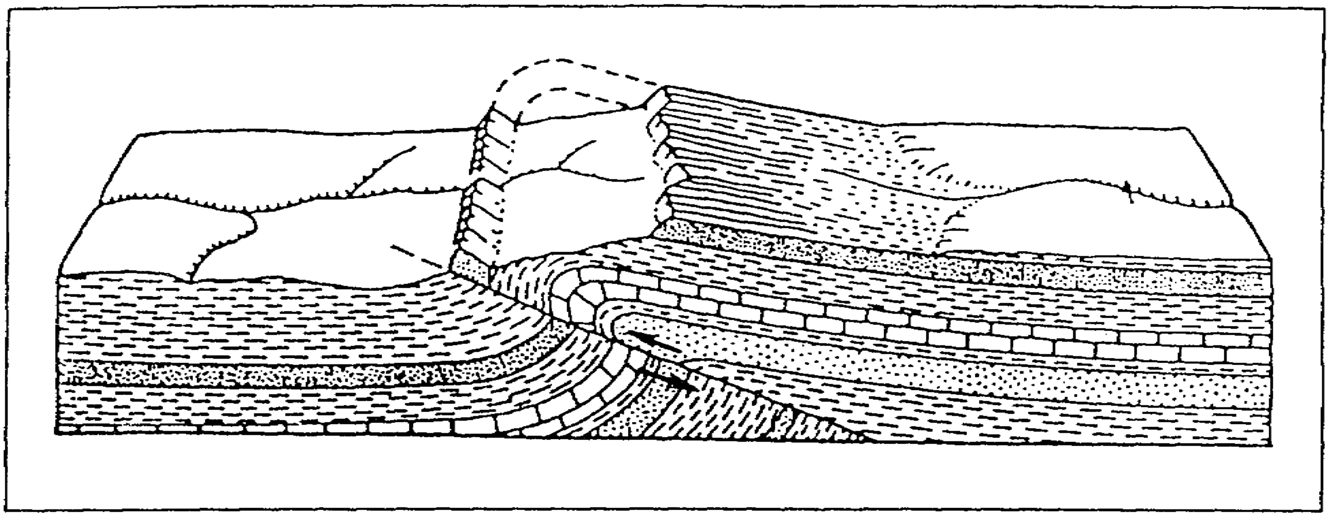


Figure 2-12. Thrust fault with drag folds

(10) Fault scarp. A *fault scarp* is a relatively steep, straight slope of any height caused by the movement of fault blocks. It is the visible portion of the fault plane. It may vary in height from a few feet to thousands of feet or it may be completely eroded away (Figure 2-13). As erosion attacks a scarp, its slope may become irregular.

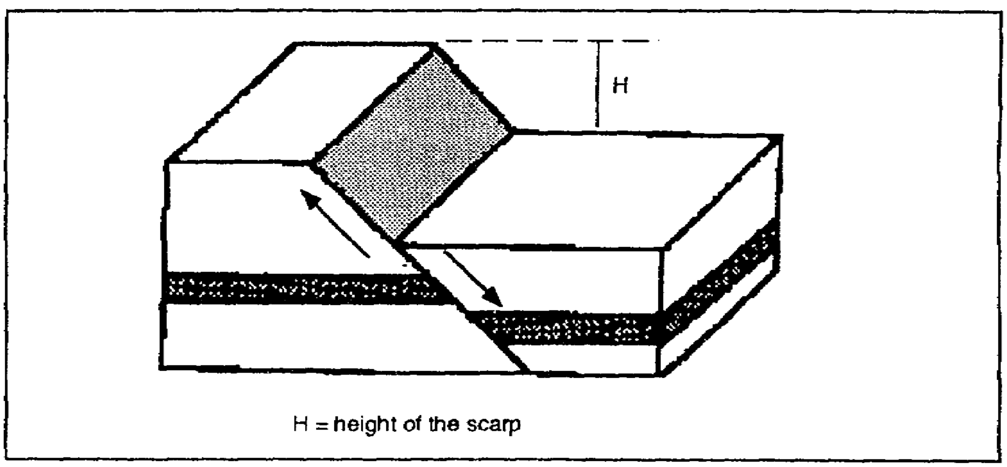


Figure 2-13. Fault scarp (the fault scarp is shaded)

e. Recognition of Fault. You may recognize faults in various ways. They are direct observation, discontinuity of structures, and repetition and omission of strata.

(1) Direct observation. You can readily observe faults that are exposed in a cliff, a road cut or a mine working. In such cases, you may obtain precise data concerning its attitude and the displacement of the disrupted strata. In other instances your observations may not be so direct, but your careful field work may bring to light data that will permit a complete analysis of the fault.

(2) Discontinuity of structures. If a layer of rock, in a cross-sectional view, suddenly ends against a completely different layer, a fault may be present (Figure 2-12, page 2-14). This might occur on a cliff face, a road cut, or a streambed. Discontinuity of beds (layers), though it often indicates the presence of a fault could be caused by other means. Examples of discontinuity of beds caused by other means are--

- Intrusive contacts. This discontinuity is caused by the upward movement of molten rock material that is later cooled in place.

- Unconformities. This discontinuity is caused by the omission of beds of rock due to erosion or nondeposition.

- Cross-bedding of deposits. This example of discontinuity is found on a small scale.

(3) Repetition and omission of strata. In many cases you may recognize faults by the repetition or omission of beds or rock. In Figure 2-14, the manner by which beds may repeat themselves is illustrated. When you are walking from X to X^1, you will encounter the sequence of beds from A to E. They will repeat themselves after you cross the fault at point F.

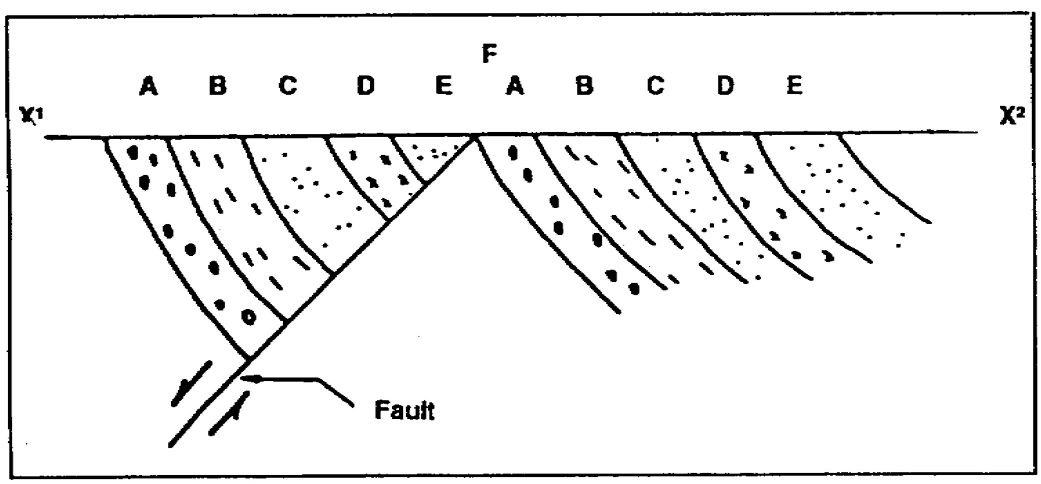


Figure 2-14. Repetition of beds

Figure 2-15 shows the *omission of beds* due to faulting. Again, when you are walking from X to X^1, you will encounter the series of beds A to E, but after you cross point F, beds C, D, and E are encountered. Beds A and B are cut off against the fault and are not exposed on the surface. This method of fault is usually not visible.

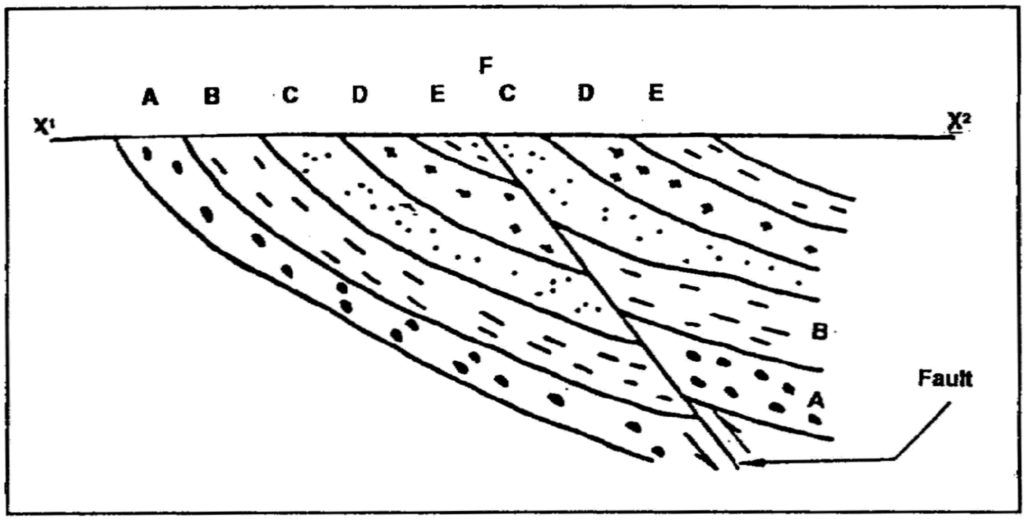


Figure 2-15. Omission of beds

f. Engineering Significance of Faults. Recognition of faults is extremely important to you, as a military engineer, as faults represent potential weakness in the rock mass. Potential problem areas you might encounter are--

(1) Tunneling. If the surrounding rock has been deformed by faulting, you will need to line the tunnel in the crushed region to prevent caving of the crushed material. Also, if the fault extends to the surface, it will often act as a channel for surface water.

(2) Dams. If you are constructing a dam in a valley floor containing a fault, as is the case in many valley floors, you must determine whether the fault, is active or inactive.

(3) Quarries. Before you open a quarry in a faulted area, you should make a careful reconnaissance to ensure that the desired rock is not displaced to an unreachable depth near the quarry site.

g. Map Symbols. Symbols are used to identify various features on a geological map. Some of the features are--

(1) Formations. *Formations* are letters, colors, or symbolic patterns used to distinguish formations or rock units on a geologic map. Symbolic patterns for various rock types are shown in Figure 2-16.

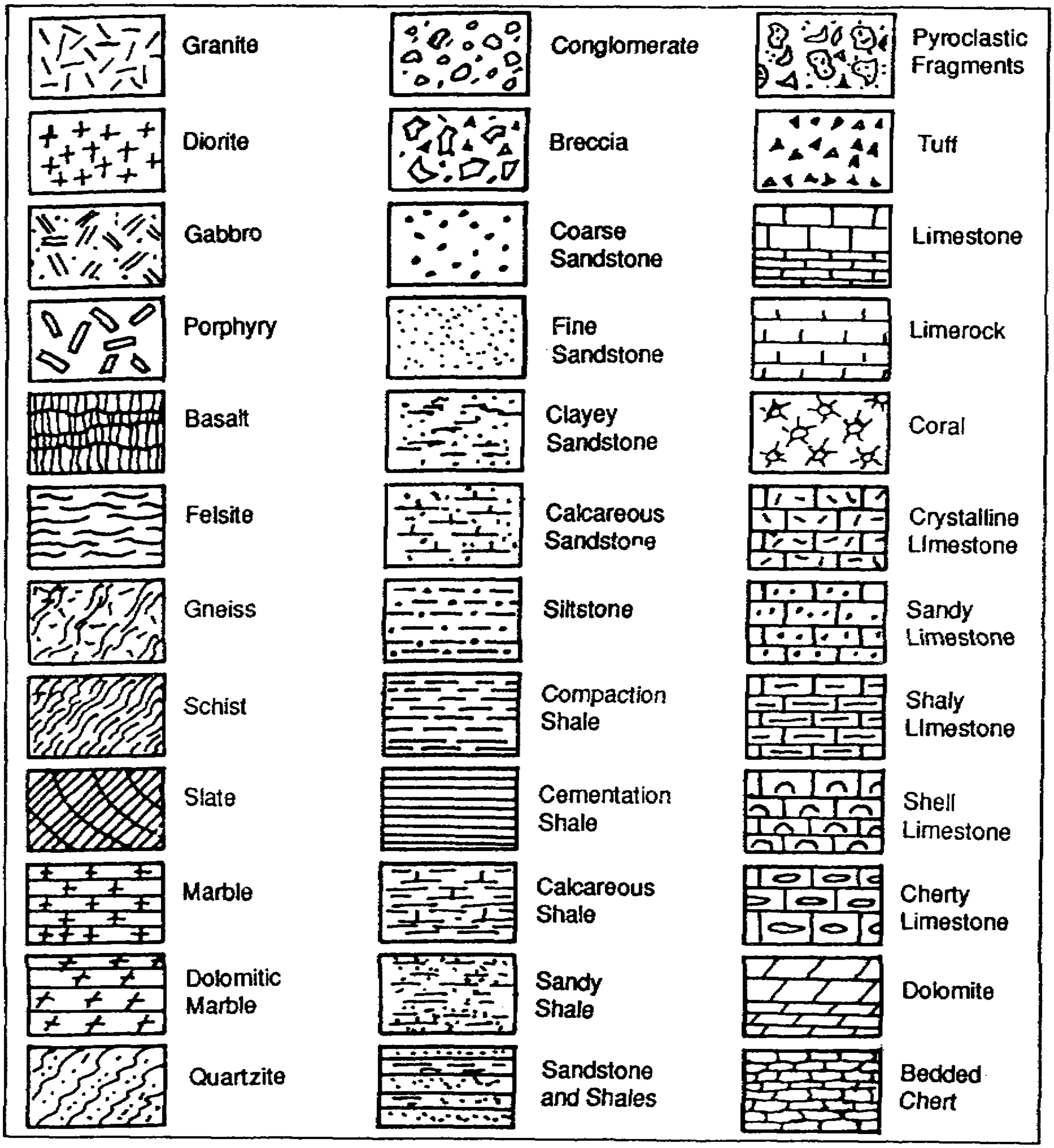
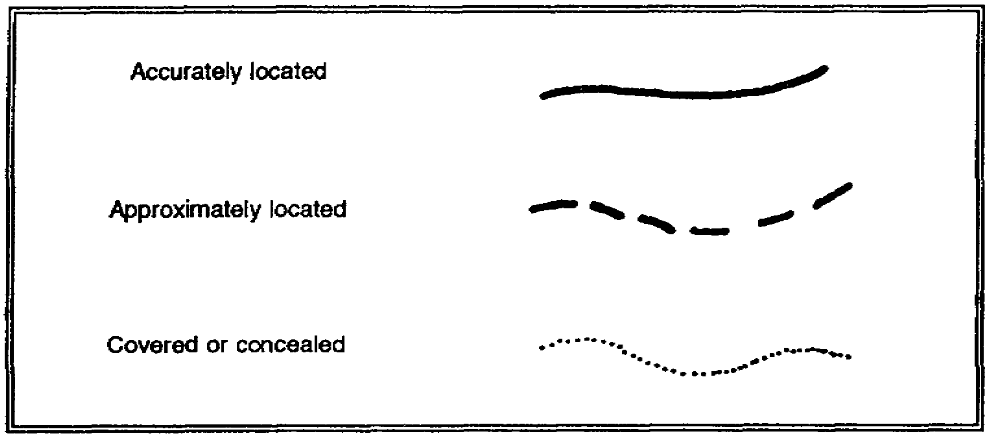


Figure 2-16. Symbolic pattern for rock types

Structural details can be added to basic maps using the symbols as shown in Figure 2-17, and Tables 2-1 and 2-2.

(2) Contacts. A *contact* is a thin solid line that shows contacts or boundaries between rock units if the boundaries are *accurately located*. A dashed line is used for an *approximate location*, and a dotted line if the contact is *covered or concealed*. Questionable or gradation contacts are shown by a dashed or dotted line with question marks. See Figure 2-17 for examples of contact symbols.

Figure 2-17. Contact map symbols



(3) Attitudes. *Attitudes* are strike and dip symbols that describe planes of stratification, jointing, and faulting. Table 2-1 shows examples of some of the attitude symbols covered earlier; however, other symbols might be encountered on maps and are included here.

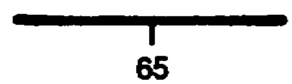
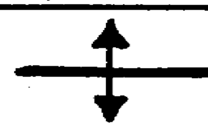
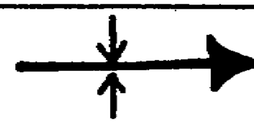
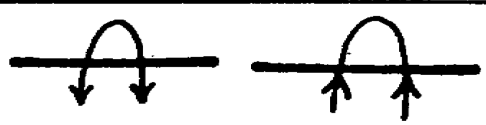
Table 2-1. Attitude map symbols for strike and dip

Attitude Types	Types of Symbols			
	Inclined	Vertical	Horizontal	Overturned
For strata: (folds)	40	or		40
For joints:	40			None
For foliation : (faults)	40			None

Attitude symbols, as shown in Table 2-1, consist of a *strike line* which is long enough so that its bearing can be determined from the map, a *dip mark* to indicate the dip direction of the plane being represented, and a *number* to show the value (in degrees) of the dip angle. The number is omitted on representations of both vertical and horizontal beds, because the values of the dips are automatically acknowledged to be 0 and 90 degrees, respectively.

(4) Fault lines and fold axes. *Fault lines* and *fold axes* are heavy black lines, which may be solid, dashed, or dotted (as described for contacts). The direction of movement along faults is shown by arrows or by the use of symbols to indicate upthrown and downthrown sides. The arrows accompanying fold axes indicate the dip direction of the limbs and/or the plunge direction of the fold. Table 2-2 shows examples.

Table 2-2. Fault line and fold axes map symbols

	Description	Symbol
Fault traces	Fault showing dip of fault plane	
	Fault showing relative movement (U, upthrown side, D, downthrown side	
	Thrust fault (Ts or hachuers on upper plate)	
Axes of folds	Anticline	
	Syncline showing plunge of axes	
	Overturned anticline and syncline showing dip of limbs	

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LESSON 2

PRACTICE EXERCISE

The following items will test your grasp of the material covered in this lesson. When you have completed the exercise, check your answers with the key that follows. If you answer any item incorrectly, study again that part which contains the portion involved.

1. Define outcrop.

2. Define fold.

3. List the three common folds.

4. Define strike.

5. Define dip.

6. Define joint.

7. Define fault.

Lesson 2

PRACTICE EXERCISE

ANSWER KEY AND FEEDBACK

Item	Correct Answer and Feedback
1.	An outcrop is that part of a rock formation which is exposed at the earth's surface. (page 2-2, para 2-2)
2.	Folds are undulations that exist in the rocks of the earth. They are the most common type of deformation. (page 2-4, para 2-4a)
3.	Monocline, anticline, and syncline. (page 2-4, para 2-4a)
4.	Strike is the compass direction of the horizontal line formed by the intersections of horizontal plane and the bedding plane. (page 2-6, para (2)(a))
5.	Dip is the acute angle between the bedding plane and the horizontal plane, measured at right angles to the strike direction. (page 2-6, para (2)(a))
6.	Joints are fractures along which there has been no visible movement. (page 2-9, para b)
7.	Faults are fractures along which adjacent masses of rock masses have moved with respect to one another. (page 2-11, para c)

LESSON 3

SLOPE FAILURE

Critical Tasks: 051-243-2006
051-243-3011
051-243-3012
051-243-3027

OVERVIEW

LESSON DESCRIPTION:

In this lesson, you will learn to identify slope failure problems and significant risks involved with construction on slopes.

TERMINAL LEARNING OBJECTIVES:

ACTION:	You will identify causes of slope failure and the actions to be taken to prevent slope failure.
CONDITIONS:	You will be given the materials contained in this lesson.
STANDARD:	You must complete the lesson and the practical exercise.
REFERENCES:	The material contained in this lesson was derived from FM 5-410.

INTRODUCTION

In areas of moderate to high relief, there is a significant risk of major damage to roads and other construction from unstable slopes. As a military engineer, you must be able to anticipate slope-failure problems and modify construction in the presence of unstable slopes.

3-1. Identification of Mass Movement. Mass movement is the downslope movement of earth materials in response to the forces of gravity. For the most part, the movement is slow, but it may be locally rapid or even catastrophic. You must consider the possibilities of this movement occurring before you undertake any construction project.

The reason engineers are concerned about gravity as an erosional agent is because of the effect that slope failure has on engineer projects. A slope failure occurs when the downslope component of forces acting on a soil or rock mass exceeds the strength of shearing resistance of the material. Force is equal to mass times acceleration, so there are two ways to increase the force acting on a slope: by increasing the component of acceleration due to gravity (such as making a steeper slope) or by increasing the mass of the slope. Another way to cause a slope failure is to reduce the resistance to it.

3-2. Causes and Types of Slope Failures. In simple terms, a slope will fail when the strength of the slope material is not sufficient to withstand the pull of gravity. A slope may be weakened to failure in one or more of the following four ways:

- Overloading. This is caused by an increase of weight on the slope.

- Loss of internal strength. This loss is the result of deterioration of the internal strength of the bedrock and/or soil.

- Loss of external friction. This is caused by loss of friction between the soil and bedrock or between individual planes within the bedrock.

- Loss of physical support. This loss is caused by removal of material located at the toe of a slope.

Man's construction efforts sometimes contribute to overloading or loss of physical support. Rainfall, though, can directly or indirectly weaken a slope in all of the above-mentioned ways.

Slopes are made up of combinations of different rock and/or soil types; consequently, they may be weakened in different ways. As a result, several types of a slope failure may be produced, some of which are distinctive. Although slope failures may closely model one of the following major types other failures may be a combination of failure types.

a. Slow Movement. Forms of slow movement consist of creep, solifluction, and rock creep:

(1) Creep. *Creep* (Figure 3-1) is the slow downslope migration of materials consisting of soil and loose rocks. The material on even the gentlest surface moves slowly down the slope. You may detect the actual movement only by such things as tilted and dislocated telephone poles, trees, fences, roadbeds, and railroad grades. This process occurs primarily in the weathered soil above bedrock. The motivating force is gravity acting on material partially saturated with groundwater. Creep is particularly evident in regions having a cold winter, where each freezing of the water in the soil lifts the soil in a direction perpendicular to the slope and each thawing drops the material downward vertically. Hence, as a result of repeated freezing and thawing, the soil moves a considerable distance down the slope. In any event creeping soil indicates a slope that is slightly but clearly unstable. Additional weakening of the slope may cause a more rapid form of slope failure. Debris slide or debris flow are examples of slope weakening.

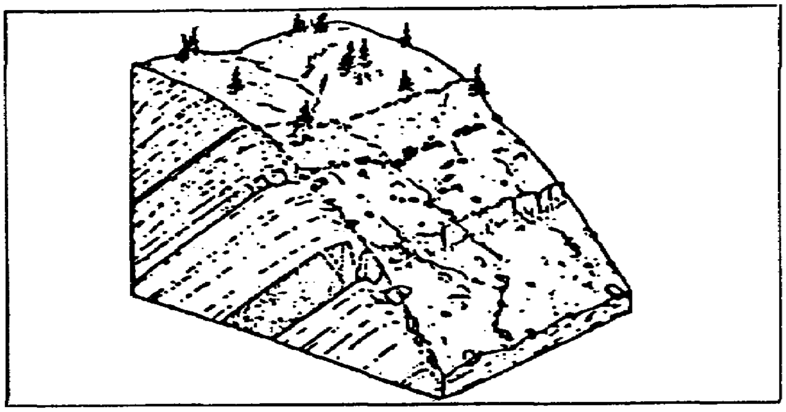

Figure 3-1. Creep

(2) Solifluction. *Solifluction* is common in permafrost regions, or regions in which the subsoils remain permanently froze. Meltwater has no opportunity to drain, and the excess water saturates the soil. On slopes, this saturated soil moves as a semifluid downhill over the frozen subsoil.

(3) Rock creep. *Rock creep* is the slow movement of massive material recently detached from bedrock outcroppings along a slope.

b. Rapid Movement. Forms of rapid movement consist of rock falls, rock slides, debris flows, debris slides, block slides, and slumps.

(1) Rock falls. A *rock fall* (Figure 3-2) refers to rocks free-falling to the earth from a steep cliff. A rock fall involves very few rocks and is caused by the weakening of the rocks exposed at the cliff face. Most rock falls occur during the spring of the year, due to the repeated freezing and thawing cycles.

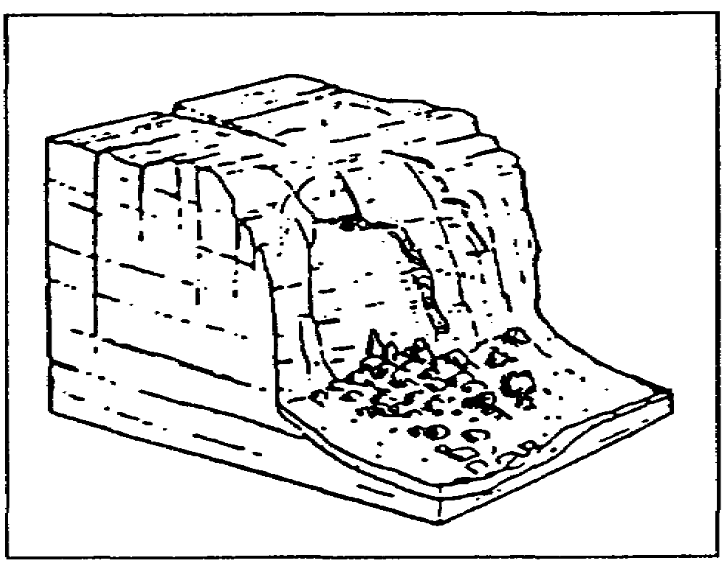

Figure 3-2. Rock fall

(2) Rock slides. *Rock slides* (Figure 3-3) are masses of rock that slide down bedding, joint, or fault planes. When the structural planes are weakened by the freezing/thawing process (usually in the spring) there may be rapid and massive movements of this type.

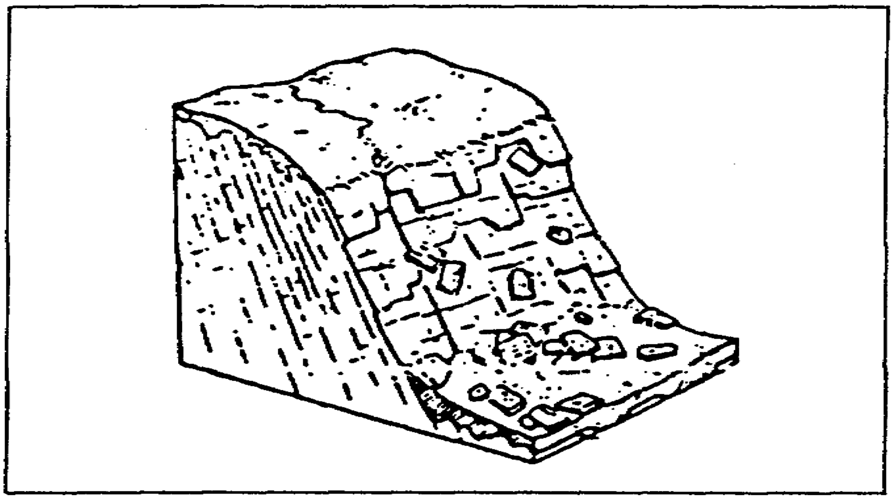

Figure 3-3. Rock slide

(3) Debris flows. *Debris flows* (Figure 3-4) may be subdivided into mud flows and soil/rock flows. Conditions associated with the occurrence of debris flows include unconsolidated materials that become slippery when wet, steep slopes, an abundant but intermittent water supply, and little vegetation. These conditions describe many of the drier regions of the earth.

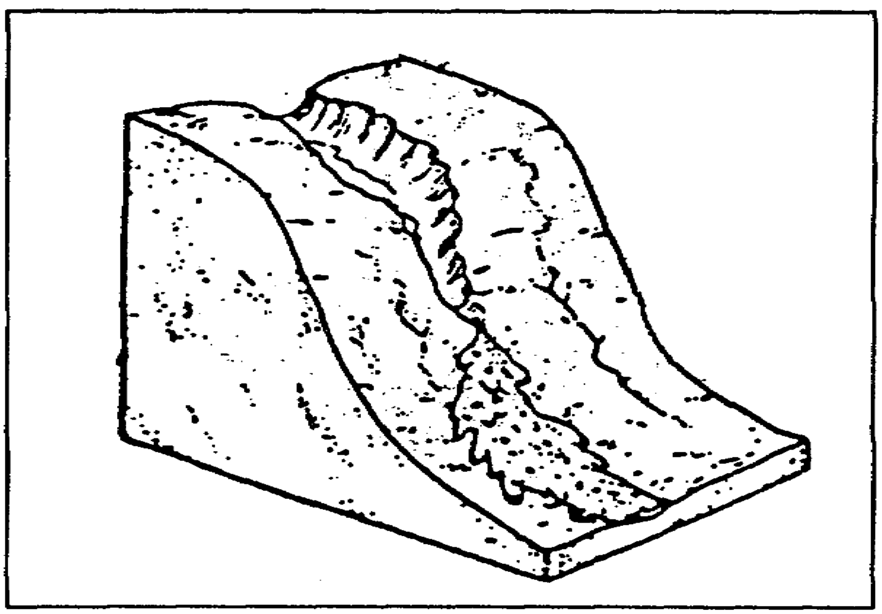

Figure 3-4. Debris flow

(4) Debris slides. *Debris slides* (Figure 3-5) are sometimes referred to as *earth slides* or *landslides*. The movement involves a sliding or rolling motion with no backward rotation. The amount of water present in debris slides is less than that present in a debris flow. Conditions favoring landslides exist in rugged regions of steeply dipping beds where groundwater has the opportunity to percolate along the joint and bedding planes. This process weakens the rock to the extent that it finally breaks away from the parent material. Movement is rapid, and any type of material might be involved.

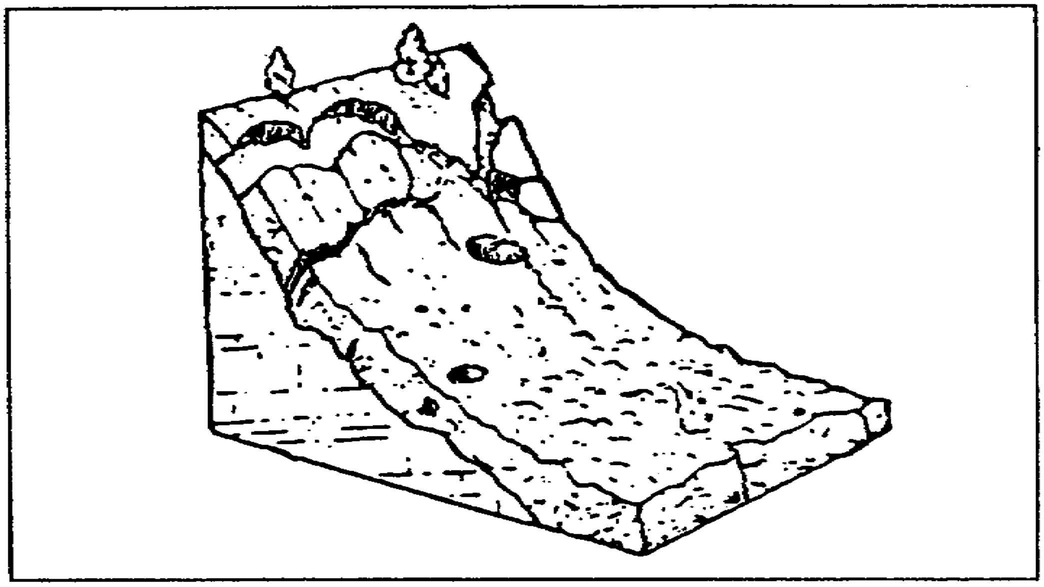

Figure 3-5. Debris slide

(5) Block slides. *Block slides* (Figure 3-6) involve large blocks of material that slide along layers of weak, plastic materials (like clay or shale). The movement is relatively slow.

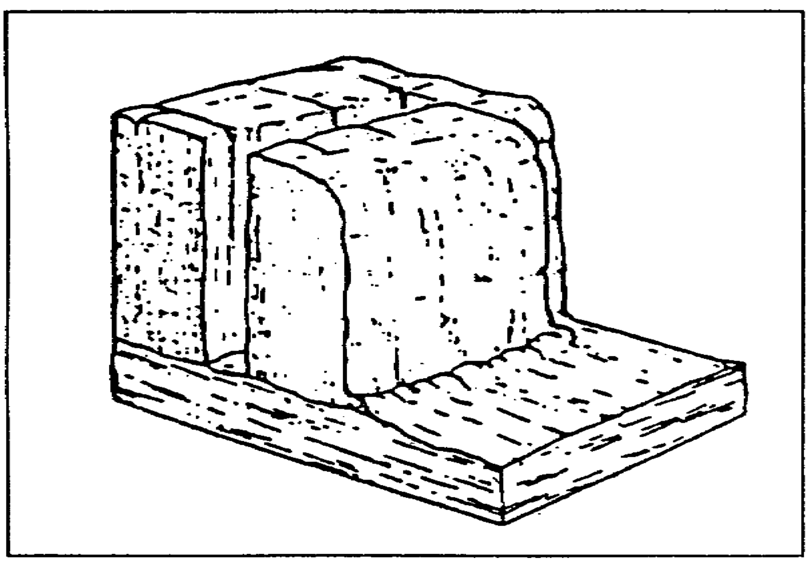

Figure 3-6. Block slides

(6) Slumps. *Slumps* (Figure 3-7) often resemble the motion of a fault block. Movement is abrupt often of a relatively small magnitude and typically involves a backward rotation. This causes the failed surface to arch upwards. Often, small terraces are formed along the slump. Slumps occur where the strength of the slope material is essentially homogenous.

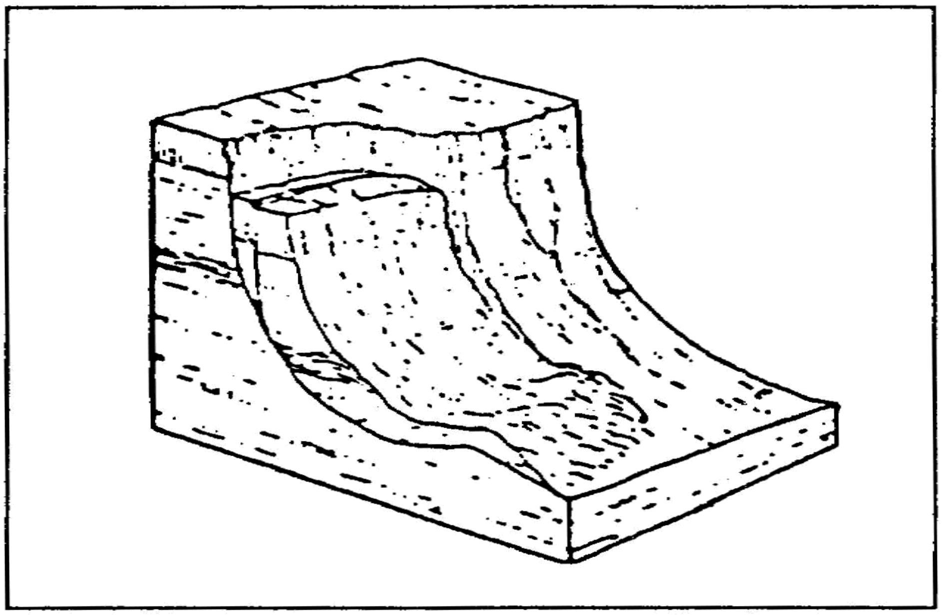

Figure 3-7. Slump

3-3. Indications of Unstable Slopes. For you to treat unstable slope areas with the respect that they are due, you must first be able to recognize the indications for them. Unfortunately, recognizing areas of unstable slopes is moderately difficult. Indications of unstable slopes for you to look for are--

- Old slope failures.
- Bent tree trunks.
- Displaced fence posts or telephone/power poles.
- Ground cracks.
- Cat steps (step-like structures caused by fissures in the ground).

3-4. Preventative and Protective Actions Where Unstable Slopes Are Detected. If you suspect that a problem exists, you may need to take preventive measures. If these measures fail or you do not detect unstable slopes until a slope failure has taken place, corrective actions are in order. Preventive and corrective measures that you can take include--

- Avoiding the suspect area.
- Improving the drainage of external and internal suspect areas.
- Decreasing the slope angle.
- Using artificial supports.
- Using protective structures.

The preventive or corrective measures that you use must be carefully selected based on the type of failure you encountered or suspected. Planting vegetation, for example, is not a technique of slope stabilization.

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LESSON 3

PRACTICE EXERCISE

The following items will test your grasp of the material covered in this lesson. When you have completed the exercise, check your answers with the key that follows. If you answer any item incorrectly, study again that part which contains the portion involved.

1. Define land mass movement.

____
____
____

2. A slope may be weakened to failure in one or more of four major ways. What are the four major causes of a slope failure?

____
____
____
____

3. What type of slope failure is shown in Figure 3-8?

____

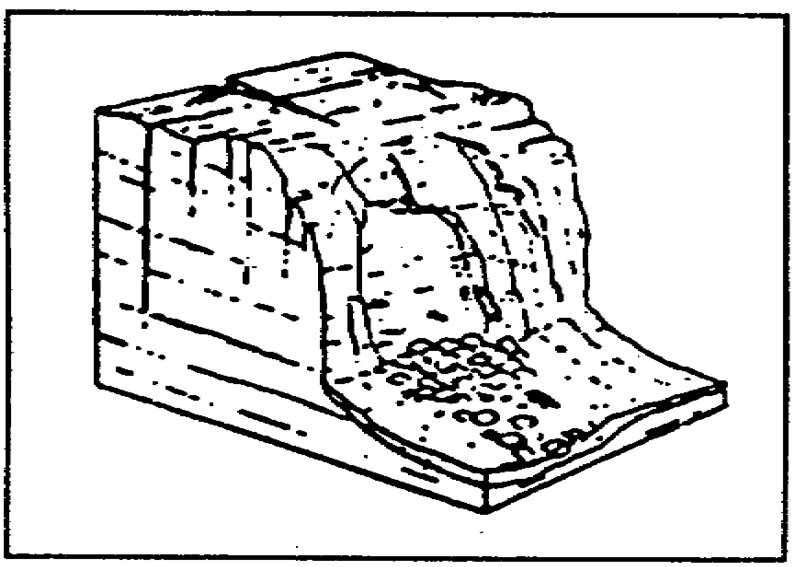

Figure 3-8. Slope failure

4. What type of slope failure is shown in Figure 3-9?

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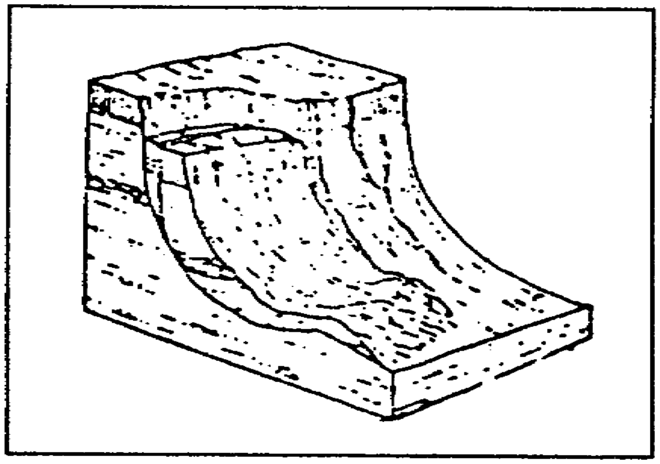

Figure 3-9. Slope failure

5. What type of slope failure is shown in Figure 3-10?

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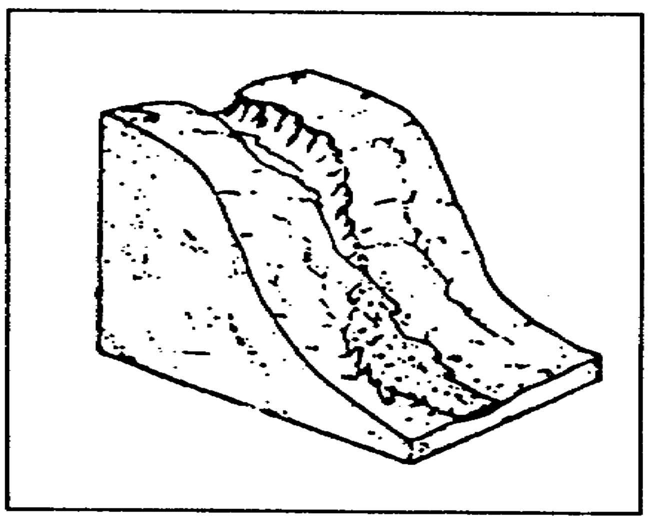


Figure 3-10. Slope failure

6. Cat steps, bent tree trunks, and ground cracks are examples of what failure process?

____

7. List five preventive and corrective measures taken when unstable slopes are detected.

8. Why is planting vegetation not recommended for slope stabilization?

Lesson 3

PRACTICE EXERCISE

ANSWER KEY AND FEEDBACK

Item	Correct Answer and Feedback
1.	Mass movement is the downslope movement of earth materials in response to the force of gravity. (page 3-1, para 3-1)
2.	Overloading loss of internal strength, loss of external friction, and loss of physical support. (page 3-2, para 3-2)
3.	Rock fall. (page 3-3, Figure 3-2)
4.	Slump. (page 3-6, Figure 3-7).
5.	Debris flow. (page 3-4, Figure 3-4)
6.	Indications of unstable slopes. (page 3-6, para 3-3)
7.	Avoiding the suspect area, improving drainage of suspect area, decreasing slope angle, using artificial supports, and using protective structures. (page 3-7, para 3-4)
8.	Preventive or corrective measures that you use must be carefully selected based upon the type of failure you encountered or suspected. Planting vegetation is not a technique of slope stabilization. (page 3-7, para 3-4)

LESSON 4

SURFICIAL FEATURES AND CONSTRUCTION MATERIALS

Critical Tasks: 051-243-2006
051-243-3011
051-243-3012
051-243-3027

OVERVIEW

In this lesson you will learn about surficial features which may provide construction materials and assess the trafficability, foundation, and excavation conditions of the material.

TERMINAL LEARNING OBJECTIVE

ACTION: You will identify surficial features which may provide construction materials and assess the trafficability, foundation, and excavation conditions of the material.

CONDITION: You will be given the materials contained in this lesson.

STANDARD: You must complete the lesson and the practical exercise.

REFERENCES: The material contained in this lesson was derived from FM 5-410.

INTRODUCTION

In this lesson you will learn about the most important geologic agent at work on the earth today--water. Fluvial processes, products, and their engineering significance will be discussed. The term *fluvial* refers to the action of running water. This lesson also covers coastal processes and some methods of coastal erosion control. A knowledge of fluvial and coastal geology is important to you, as a military engineer, because of the effect it has on location of construction materials, site location for construction projects, and trafficability.

This lesson has three parts: Fluvial and coastal features, glacial and eolian landforms, and residual landforms.

PART A: FLUVIAL AND COASTAL FEATURES

4-1. Fluvial Features. As mentioned in the introduction, *fluvial processes* are the processes of running water. Sediment erosion, transportation, and deposition are all fluvial processes. Running water (rivers, streams) is the dominant agent shaping the surface of the continents today. Streams are estimated to carry 8,000 cubic miles of water to the sea each year (250,000,000 gallons per second). In places, nature has created *stockpiles* of construction materials. If recognized, these natural deposits can be used for almost all military construction. Fluvial processes are often responsible for sorting sediment thereby concentrating certain particle sizes into certain types of stockpiles.

a. Stream Terminology. From an engineering view-point no two streams are alike, and each one requires complete investigation. General principles and terms related to all streams will be covered.

(1) Competence and capacity determine the size and amount of material (load) a stream can move from one point to another:

(a) Load. *Load* is the material actually transported by a stream. There are three components of load: material which is bounced or dragged along the stream bottom (the *bed load*); material carried by swirling flowing water (the *suspended load*); and material carried in solution by the water (the *dissolved load*).

(b) Competence. *Competence* refers to the maximum size of particle a stream is capable of moving. The power of running water to transport the loose mantle of the earth depends on its flow velocity. Velocity depends on the degree of slope, or gradient over which it flows and on the depth of the water. Water friction along the stream channel causes shallow water to move relatively slowly, whereas deeper water in the same channel (as during a flood) flows much more rapidly. The transporting stream power can be measured in terms of the largest piece of rock that the current can move. If a flood doubles the velocity of a stream, the current is then theoretically, strong enough to move a block of rock 64 times as large as it could move at normal velocity. This relationship between velocity and competence is sometimes referred to as the *sixth-power law*, as 64 is the sixth power of two. If the velocity increases to three times the original, then the theoretical increase in competence is three to the *sixth power law*, or 729 times the original competence. This maximum theoretical value in increased transporting power may not be possible to reach due to natural conditions, but this phenomenal increase helps to explain how floodwaters can cause such extensive destruction.

(c) Capacity. *Capacity* refers to the maximum quantity of material a stream can carry past a given point in a unit of time. Capacity is often measured in tons per hour on larger streams and rivers. Capacity is distinct from competence, and it is almost impossible to compute for natural streams. The smaller particles (clay and silt) are kept in suspension more easily than sand. As a result of suspension a stream might move a large amount of the finer sizes if small particles were available, whereas it would move no clastic sediment at all if these sizes were not available. Some clay and silt particles may be carried from their place of origin to the sea without temporary deposition en route. Sand and pebbles originating from the same source, however, might be deposited temporarily many times over before reaching the sea.

(2) Competence versus capacity. It should be noted that a small, rapid stream can move a relatively large particle. Its competence is great but its capacity may be very small. Conversely, a large, slow-moving stream may have a relatively low competence, but, because of its volume of flow, it may have great capacity as shown in Figure 4-1. The *competence* of a current to carry particles is a measure of the largest sizes it can carry.

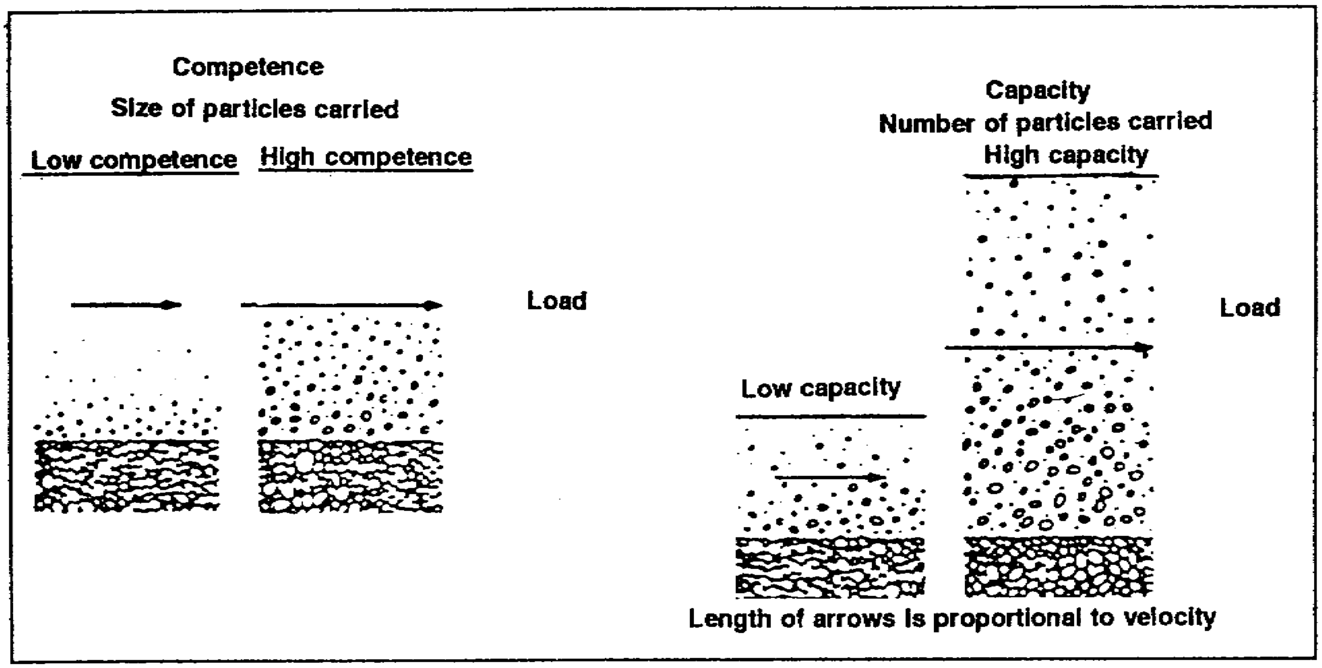


Figure 4-1. Competency versus capacity

The *capacity* of a current is a measure of the number of particles it can carry. Although both depend on velocity t some extent competence depends much more directly on velocity and capacity depends largely upon discharge. Discharge is the volume of water flowing past a point in a given time. Figure 4-2, page 4-4 shows several factors influencing stream processes and their energy relationships.

(3) Base level. *Base level* is an important principle which governs the actions of flowing water as it shapes the land surface. Base level (Figure 4-3, page 4-4) is the level below which a land surface cannot be lowered by running water. *Sea level* is the principal base level, and, as such, a stream continues the downcutting of its valley only until its bed reaches sea level. The sea level of a stream, when projected inland, is the base level. However, temporary base levels are often created. For example, lake surfaces limit downward erosion by the inflowing streams, but since (in a geologic sense) lakes are only

temporary features, they are regarded as temporary base levels. In a similar way, a main stream at any tributary junction limits the depth of the valley of that particular tributary. Therefore, major streams are also considered the temporary base level for their tributaries. Obstructions to downcutting (such as resistant rocks or dams) also serve as temporary base levels. In rare instances in arid climates, such as in Death Valley, California, local base levels actually exist below sea level. If there were sufficient water, such basins would be freshwater lakes with outlets to the sea.

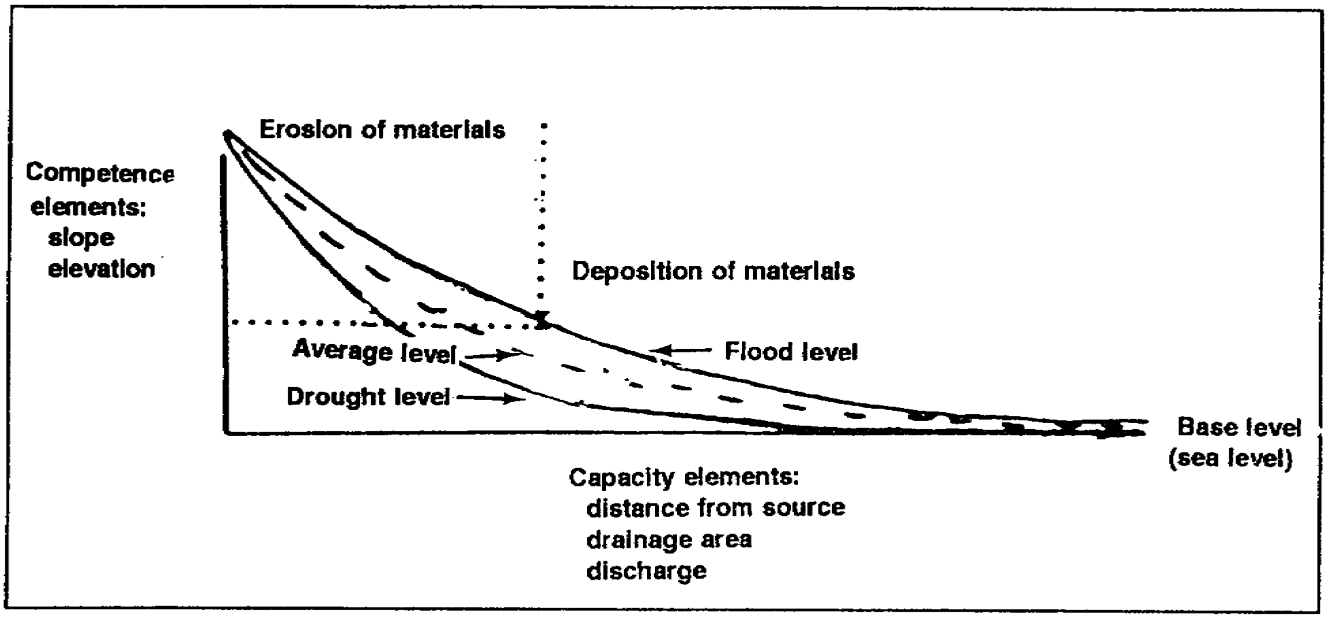


Figure 4-2. Energy relationships and processes along an ideal (graded) stream

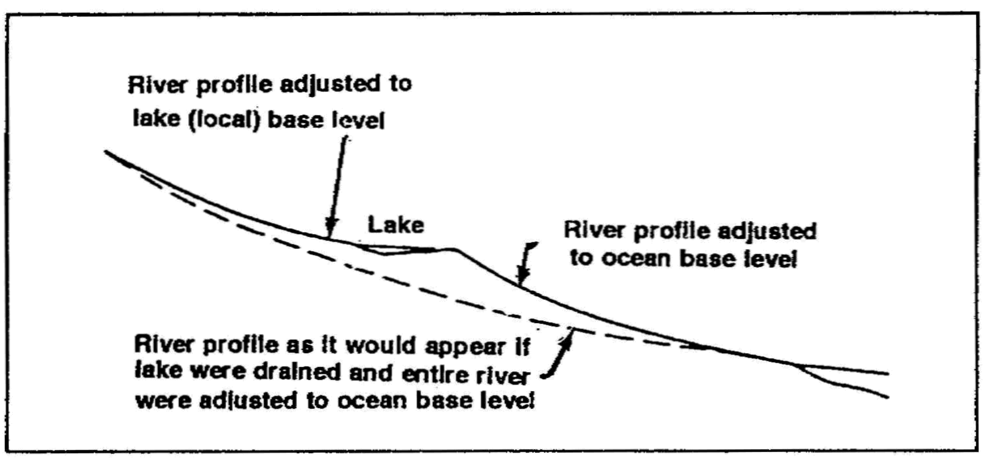


Figure 4-3. Base levels

(4) Profile of equilibrium (grade). A graded stream is one with a profile in which the slope at every point is just sufficient to enable the stream to carry its load of sediments. The grade neither erodes nor deposits sediments in the riverbed. That is, the slope and velocity of the river are such that neither erosion of the riverbed nor deposition of sediments takes place.

b. Evolution of a Stream Valley. The likelihood of finding construction materials in a particular stream valley can be characterized by the evolution of that valley and the cycles of the stream. The evolution of a stream valley development is described in terms of youth, maturity, and old age (Figure 4-4), however, the terms are not referring to age in years. Each stage is a grouping of features or characteristics commonly associated in the course of normal stream evolution and development Table 4-1, page 4-6, summarizes this.

(1) Youth. During the early life of a stream, the gradient is high and the stream expends most of its energy in downcutting, forming a V-shaped valley. The earth's surface is then cut by canyons and sharp divides. The Grand Canyon's Colorado River is an example of a youthful stream. During the youthful stage of a stream, the stream features high, V-shaped valleys, rapids, and falls, with relatively straight channels and few tributaries.

(2) Maturity. In maturity, the stream valley widens at the expense of the divides and canyons. At this stage, the stream's meandering begins and a flood plain starts to develop. The *floodplain* is that portion of the valley floor subject to inundation during over-bank floods. During this stage, the stream is distinguished by wider and deeper valleys, a floodplain, and numerous tributaries.

(3) Old age. In old age, the flood plain widens extensively forming a peneplain. Meandering is marked by frequent *oxbow lakes*, which are formed when a stream cuts off a meandering and the abandoned part of the channel remains as a crescent shaped lake. The oxbows indicate that the stream changes course many times and has a sluggish flow. During this stage, the stream has few tributaries and a very gentle gradient.

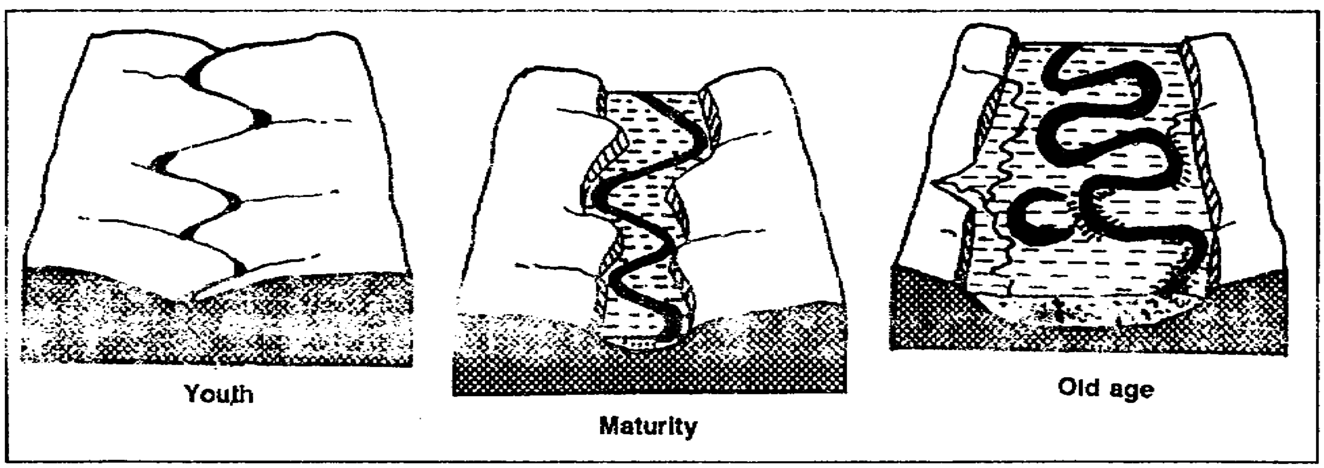


Figure 4-4. Stream evolution and valley development

Table 4-1. Stream evolution process

Characteristic	Youth	Maturity	Old age
Gradient	Steep, irregular	Moderate, smooth	Low, smooth
Valley profile	Narrow, V-shaped	Bold, moderately U-shaped	Very broad
Valley depth	Deep	Deep, moderate, shallow	Shallow
Meanders	Absent	Common	Extremely common
Floodplain	Absent or small	Equals width of meander belt	Wider than width of meander belt
Natural levees	Absent	May be present	Abundant
Tributaries	Few, small	Many	Few, large
Velocity	High	Moderate	Sluggish
Waterfalls	Many	Few	None
Erosion	Downward cutting	Downward and lateral cutting equal	Lateral cutting
Deposition	Absent or transitory	Present, but partly transitory	Much and fairly permanent
Culture	Steep-walled valleys are barriers to roads and railroads	Flat valley floors are good transportation routes	Large rivers and nearby swamps are barriers
Summary of regional erosion cycle			
Dissection	Partial	Complete	None
Divides	Broad, flat ,high	Knife-edged	Low, broad, rounded
Stage of stream and valley development	Youthful to mature	Mostly mature	Old age
Number of streams	Few	Maximum	Few
Relief	Great	Maximum	Minimum

c. Fluvial Deposits and Features. The factors of volume and velocity influence the deposition of sediments in the same way that they influence their erosion and transportation, since deposition merely marks the end of transportation (Figure 4-5). When the velocity of transportation decreases, the heavier and coarser materials are dropped first and the lighter and finer particles are carried farther. This size-sorting process is seldom as perfect, however, in fluvial sediments as it is in marine sediments. The velocity of a stream may decrease for one of several reasons:

- As local obstructions are encountered, the gradient lessens.

- The discharge decreases as floods subside, the water soaks into underlying pervious materials.

- Or, in arid regions, the water evaporates.

As the velocity decreases, the sediment that the stream has been carrying begins to accumulate in the channel. Over time, numerous bars may be formed. This accumulation results in the river, at low water stages, consisting merely of a series of branching and reuniting streams flowing among these deposits. When this happens, the river is said to have a braided channel.

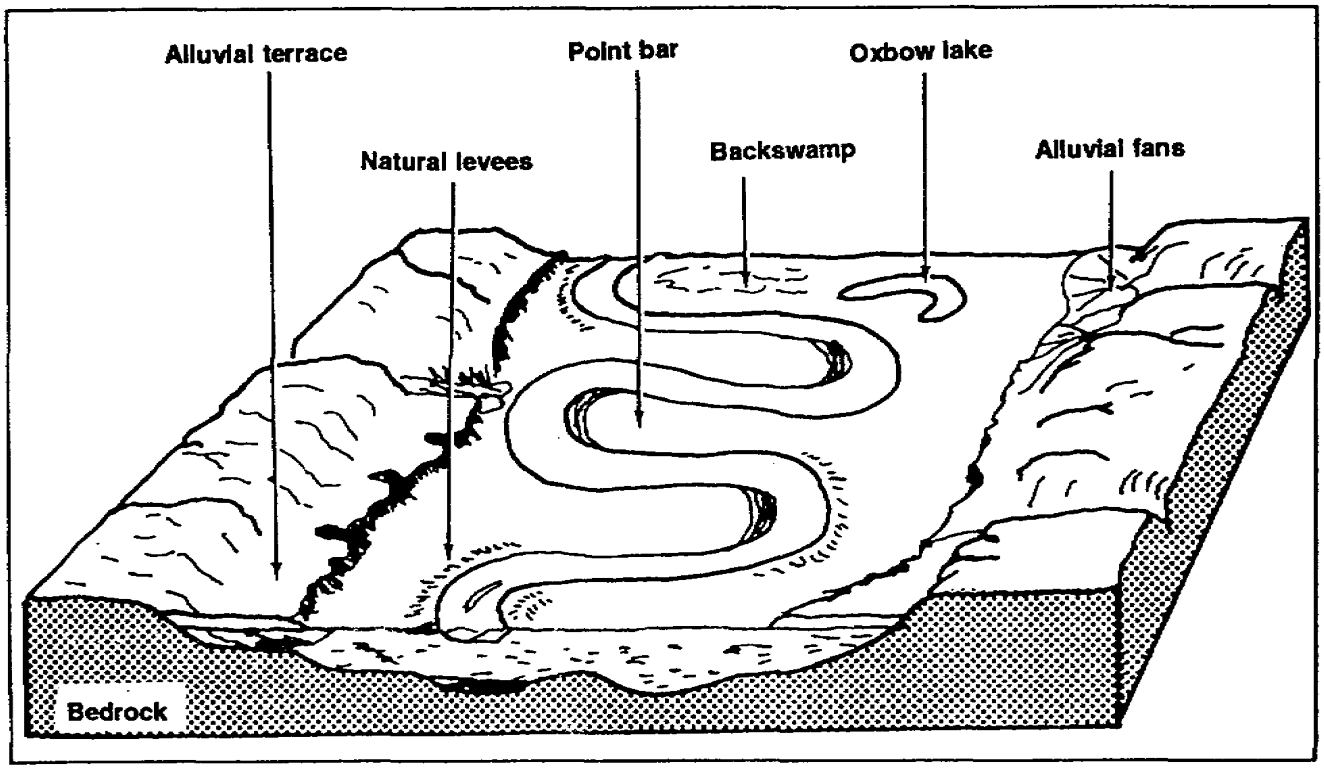


Figure 4-5. Major floodplain features

Terms commonly associated with fluvial deposits and features are--

- Meanders. *Meanders* are a series of turns or looplike bends in the stream.

- Point bars. *Point bars* are the material deposits that exist inside of the curves of meanders and oxbow lakes.

- Channel bars. *Channel bars* are embankments of deposited material occurring on stream beds.

- Braided channels. *Braided channels* are streams choked with sandbars so that they are divided into intricate networks of interlacing channels.

- Floodplain. A *floodplain* is that expanse of land that is inundated during flood stages of the river.

- Natural levees. *Natural levees* are embankments built up along the river by sand deposition during flood stages.

- Backswamp deposits. A *backswamp deposit* is a marsh or wetlands area that was caused by an impermeable layer of fines (deposits) in the lower lying areas of the floodplain.

- Oxbow lake. An *oxbow lake* is a crescent or U-shaped body of water formed by a meander-neck cutoff

- Filled oxbow lake. A *filled oxbow lake* is a thick deposit of fine-grained material in an old oxbow lake.

- Alluvial terraces. *Alluvial terraces* are extensive, flat-topped river deposits of ancient floodplains that generally parallel the river or stream.

- Alluvial fans. *Alluvial fans* are dryland counterparts of deltas. Where streams flow from steep slopes onto a bordering lowland, the abrupt drop in gradient results in the channel filling with sediment, causing the water to overflow to the lowest available point. With time, the process is repeated. As a result, a fan-shaped deposit called an alluvial fan is built up. Its apex is at the point where the stream emerged from the canyon at the base of the steep slope. Fans of enormous dimensions have developed at the margins of fault-block mountains in the Western and Southwestern U. S. Adjacent fans may grow and overlap each other to form a continuous alluvial plain.

- Delta. A *delta* is the alluvial deposit at the mouth of a river. The loss of stream velocity when a river enters the sea or other body of standing water causes deposition of clastic sediments. Wave and current action may exert a minor influence on final deposition of sediments. Because of the abrupt decrease in velocity, the coarser sediments, such as gravel and sand, settle out first at the mouth of the stream. The finer materials, such as silt and clay, are carried farther out into the standing body of water. The entire process results in the formation of a delta. There are many large and famous deltas such as the Nile Delta and the Mississippi Delta. However, in the Northern U. S. and Southern Canada, many small deltas were deposited in the temporary lakes that existed along the margin of the last continental glacier during its final stages. These deltas consist mostly of sand and gravel and are important sources of supply for concrete construction and for road materials. As with the larger deltas, the coarser materials overlie the finer, a condition not always realized by pit operators. A common error is to suppose that the coarsest materials are to be found at the base of the entire deposit

- Alluvium. *Alluvium* is a broad category that includes all the deposits made by streams. The term is not, however, generally used for delta deposits in seas or lakes, nor does it refer to glaciofluvial deposits, which generally are referred to as outwash. The considerable variations, within short distances, of the conditions of stream deposition preclude good size sorting. In this respect, alluvium contrasts strongly with the broad uniformity of stratification and good size sorting that characterize most marine and lake sediment.

4-2. Coastal Features. Over 70 percent of the earth's surface is covered by water. The interface between land and oceans is important to you, as an engineer. Coastal areas give rise to a variety of engineering problems, including mobility, location of construction materials, and excessive shoreline erosion.

Most coastlines are continually changing. Some sandy beaches are being eroded while others are being built up by the deposition of sand. Other coastal areas are composed of rocky shores and bluffs, but, even these may yield to the onslaught of coastal processes.

a. Coastal Processes. Present-day shore changes are primarily due to water in motion. Waves, wave action, and currents are types of water movement that erode and deposit materials along coastlines.

(1) Waves. Every body of standing water is affected to some extent by waves. The size and power of the waves depend upon the surface area and the depth of the body of water and also on the force generating the waves. Most waves are caused by winds, tides, seismic activity, or gravity (displacement of water by ice, soil, or rock). The erosive power of a wave is enhanced by any rock fragments the wave may carry.

(2) Wave action. The wind passing over water sets up waves by alternately raising and depressing the water surface. These types of waves are called *waves of oscillation*. No forward movement of the water actually occurs, but there is a circular motion of water particles at the surface, the diameter of which is determined by the height of the wave crest above the adjacent wave trough. The effect of this movement is a progression of the wave shape in the direction of the wind. In shallow water, this oscillating motion is retarded by friction along the bottom. Friction causes the wave crests to become more closely spaced, each wave becoming higher and narrower. The top eventually pitches forward, resulting in a translation of the water that sweeps up sediment. The return flow washes much of the sediment back with it, leaving only the coarser particles behind.

(3) Currents. A *current* is a large-scale form of water movement. The different types of current include longshore, rip, or tidal:

- Longshore currents. *Longshore currents* form when waves hit a shoreline at some angle rather than head-on. The waves and the backwash both have a tendency to move particles with the same sideways motion to the beach. The net effect of the waves and backwash is a current that travels parallel to the coastline in a downstream direction from the waves.

- Rip currents. *Rip currents* are often called *undertows*. They are formed when waves break onto the shore and excess water is pushed up on land, creating a hydrostatic head. The water must escape, but on shallow shores, the water trying to move seaward is pushed back by advancing waves. In such cases, a current flows parallel to the shore until it finds a depression that will allow it to move seaward. On steeper shores, a hydrostatic head may be great enough to allow an undertow to flow beneath the advancing waves.

- Tidal current. Tides can give rise to another significant form of current, the *tidal current* (not tidal wave). In *bays* and large *sounds* (necks of ocean bodies that extend well inland), the changing of a tidal stage sets an enormous amount of water in motion. The temporary lowering or raising of the ocean level can be accomplished only by moving vast quantities of ocean water either into or out of the sound or bay. Tidal currents are cyclic and often very rapid.

b. Landforms Produced by Coastal Processes. Beach and shoreline landforms produced by coastal processes consist of a variety of patterns and types.

(1) Beaches. Beaches are the most common coastal landform. They are relatively permanent features on low coastlines. The beaches along the low coastlines of Florida and the Gulf states are examples. Shorelines that are largely rocky and cliffed have few, if any, beaches, except at the heads of bays or near stream mouths. Terminology used to describe beach slopes and associated features is shown in Figure 4-6.

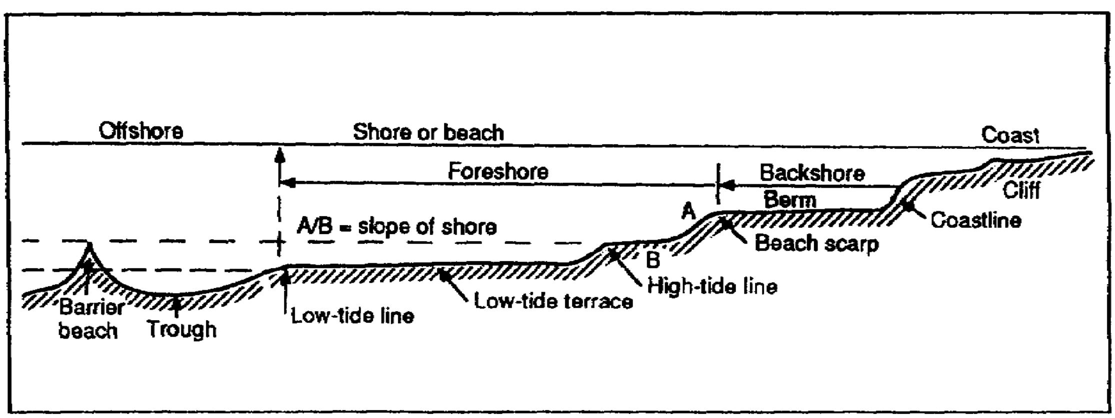


Figure 4-6. Beach slopes and features

Three common patterns of beach profiles exist:

- Narrow beaches with regular seaward slopes and no backshore area.

- Beaches with foreshore and backshore areas separated by a berm that is seldom wave washed.

- Beaches with or without berms, but having a bar (terrace) separated from the beach by a trough. The bar is exposed at low tide.

In general, you may locate construction materials on shorelines by measuring the beach slope. The steeper the beach slope, in both the foreshore and the nearshore areas, the coarser the material in the beach.

Beach characteristics may change seasonally. During the stormy seasons, a beach may be eroded and steepened. During the quieter seasons the beach may be built up and flattened by the addition of finer materials. Finally, the inland area behind a beach may be composed of any of a variety of terrain types, such as steep cliffs, dunes, hills, or lagoons. Of special importance to you, as the engineer, are roads or natural breaks in otherwise difficult terrain. When conducting movement from the beach to road or rail networks, parallel movement along the coast may be required until a break in the terrain is located.

(2) Shorelines. Five common types of shorelines may be recognized from contour maps. These shorelines may be the result of *emergence* (uplift of the land or fall in sea level), *submergence* (rise of sea level or lowering of the land), or a combination of both.

- Low-plain coast. A *low-plain coast* is one in which the land slopes very gently toward the sea. Usually, the shoreline is quite regular, however, an offshore bar will frequently develop parallel to it

- Embayed coast. An *embayed coast* is one along which there are numerous bays. These bays are usually the results of the submergence of the mouths of streams. A *ria coast* is an embayed coast that has been developed by the submergence of a shoreline in which the streams approached the sea in parallel courses.

- Fjord coast. Fjords are submerged glacial troughs. A *fjord coast* is one in which a region of mature dissection has been glaciated so that the valleys are glacial troughs and are submerged following glacial melt.

- Deltaic coast. A *deltaic coast* is one produced by the convergence of several deltas along the shoreline.

- Coral coast. A *coral coast* is one in which the development of coral reefs has been a dominant feature in the development of the shoreline.

Seven common kinds of coastlines are shown in Figure 4-7. The examples have been selected to illustrate a wide range in coastal features. Landforms of sea cliffs are also depicted.

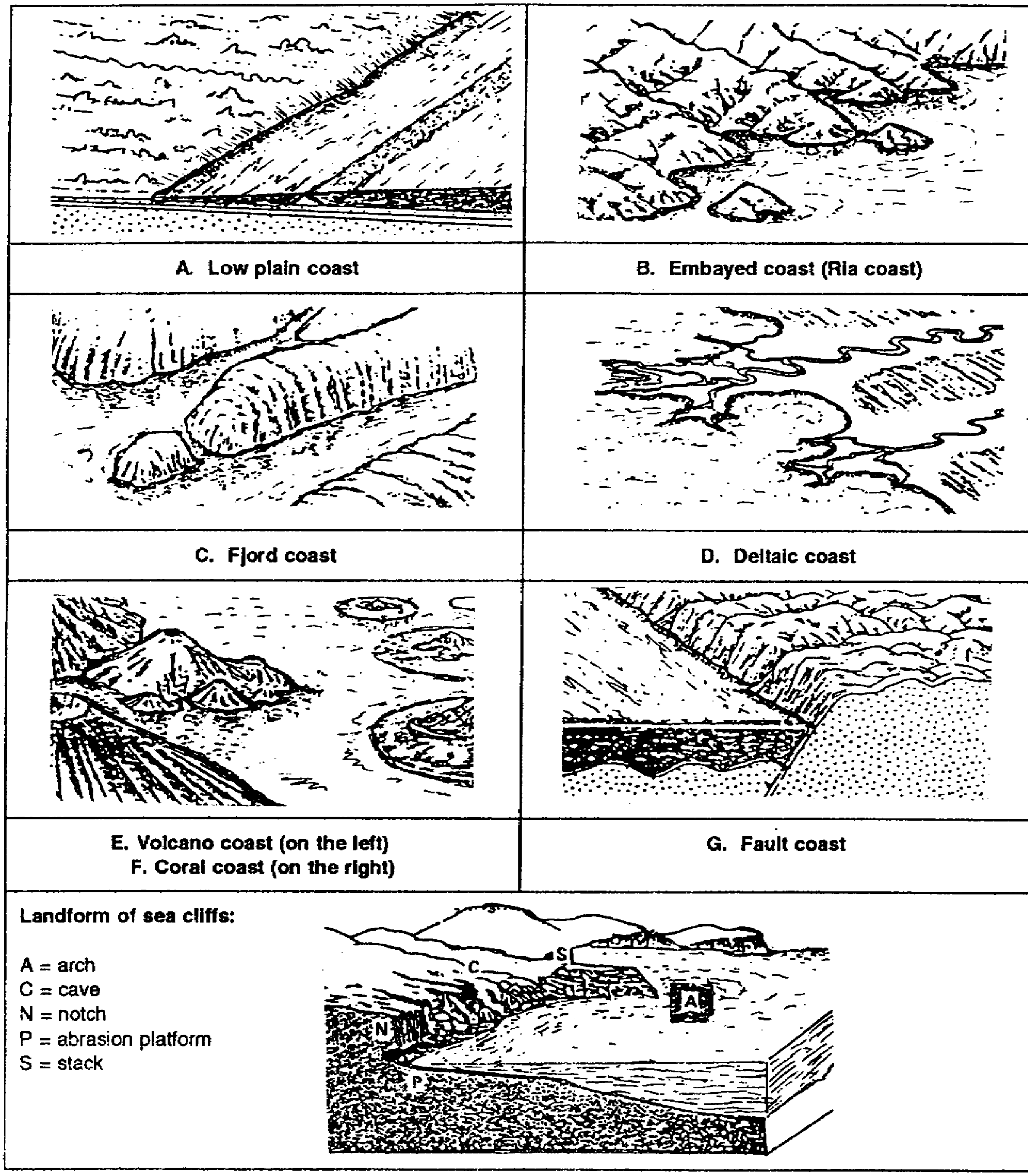


Figure 4-7. Coastlines and landfalls

c. Depositional Features of Shorelines. Beach deposits (Figure 4-8) that have collected along the shorelines form into distinctive features:

(1) Spit. A *spit* is a bar of sand and gravel that projects from a point of land into the water. It is formed beach drift.

(2) Hook. A *hook*, or recurved spit, is similar to a spit but is curved at the end. This curvature is the result of a change in the direction of beach drift.

(3) Bar. A *bar* is an elongated body of sand and gravel deposited by beach drift. A bar is further described in terms of its position, as a bayhead bar, mid-bay bar, bay-mouth bar, offshore bar, and so forth.

(4) Crescent (bar) beach. A *crescent beach* is a beach formed between two headlands (any projection of the land into the sea). It is crescentic in outline and is formed by the movement of beach drift from the headlands inland toward the center of the inlet or bay.

(5) Offshore bar or barrier (island) beach. An *offshore bar* is formed in shallow water where the line of breakers lies distinctly away from the shore. Sediment washed from the beach tends to accumulate on the sea bottom at the point where the breakers occur. This material may reach such a thickness that, at low tide, it is exposed above the sea. Wind may then build dunes up on this ridge, and storms may throw additional material from the seaward side upon it. A semipermanent island (*barrier island*) may *thus* be formed.

(6) Cuspate (bar) foreland. A *cuspate foreland* is a projecting deposit of material deposited by beach drift of conflicting shore currents.

(7) Tombolo. A *tombolo* is a deposit of sand and gravel deposited by beach drift in such a way that it connects one island to the mainland.

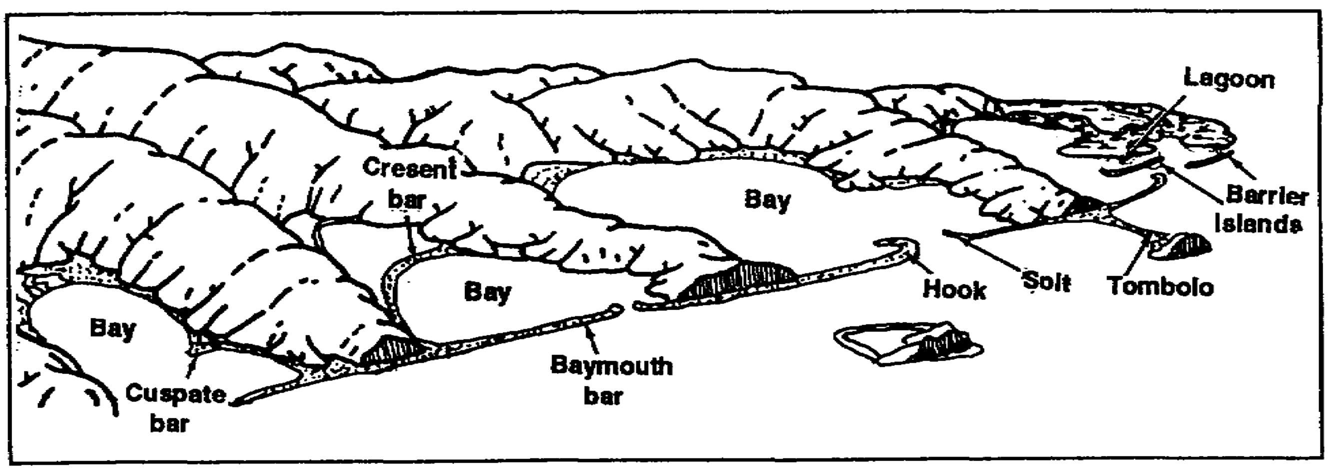


Figure 4-8. Depositional features of shorelines

d. Erosional Features of Shorelines. The major erosional features of shorelines are the wave-cut cliff, wave-cut bench, and the stack. Of these, the wave-cut cliff and the stack may be identified from topographic maps.

(1) Wave-cut cliff. A *wave-cut cliff* is a cliff formed by wave erosion. The cliff, therefore, is a seaward-facing cliff whose base represents the elevation of sea level at the time the cliff was cut out.

(2) Wave-cut bench. A *wave-cut bench* or *terrace* is created at the base of the cliff and widens as wave erosion proceeds landward against the cliff.

(3) Stack. A *stack* is a remnant of rock left standing on a wave-cut bench as the result of erosion by waves on all sides.

e. Shoreline Protection. Few coastal protection projects are undertaken without careful study. Your study should include an evaluation of past as well as present conditions, the rate of movement, and source of shore deposits. Most shoreline structures are built to aid navigation or prevent damage resulting from wave attack. There are a number of forms of shoreline protection, but, in all cases, the construction materials that you use should be of high density and durability to resist the forces of water. Common forms of shoreline protection for consideration are--

(1) Seawalls and bulkheads. *Seawalls and bulkheads* are structures built on the shoreline parallel to the beach. They may be vertical walls and pilings, stepped or curved. The design is to protect the shore from wave erosion.

(2) Groins. *Groins* are built perpendicular to the shoreline. They may be of permeable (porous) or impermeable (nonporous) material. The purpose is to induce deposition of sand on the beach.

(3) Jetties. *Jetties* are built perpendicular to the shore at harbor entrances, river mouths, or bay inlets. They are usually made of porous material. The design is to induce erosion to keep the entrance free of material. As with all of these structures, the construction material is of high density and durability to resist the forces of water.

PART B: GLACIAL AND EOLIAN LANDFORMS

4-3. Glaciers. During the last million years (geologic time) large continental ice sheets have encroached upon and retreated from the continents on four separate occasions. At times, these glaciers have covered up to 30 percent of the earth's land surface. The last retreat of these ice sheets was approximately ten thousand years ago.

A *glacier* is a mass of snow and ice that moves under the influence of gravity out over the land from an area of perennial snow which is its source or head. Glaciers may be classified as one of three main types: alpine, piedmont, or continental. An *alpine glacier* (also called mountain or valley glacier) is an ice stream that flows from a snowfield down a steep-walled mountain valley (Figure 4-9, page 4-16). The merging of several alpine glaciers at the foot of a mountain forms a *piedmont glacier*. *Continental glacier* (also called ice sheet) is found only in high latitudes, and covers vast areas (Figure 4-10, page 4-17). For example, Greenland is covered by such a glacier.

a. Factors Influencing Glacial Erosion. Glaciers are important agents of erosion and transportation. Glacial action has shaped much of the present topography of the northern hemisphere. Glacial erosion is accomplished by plucking, plowing, and abrasion.

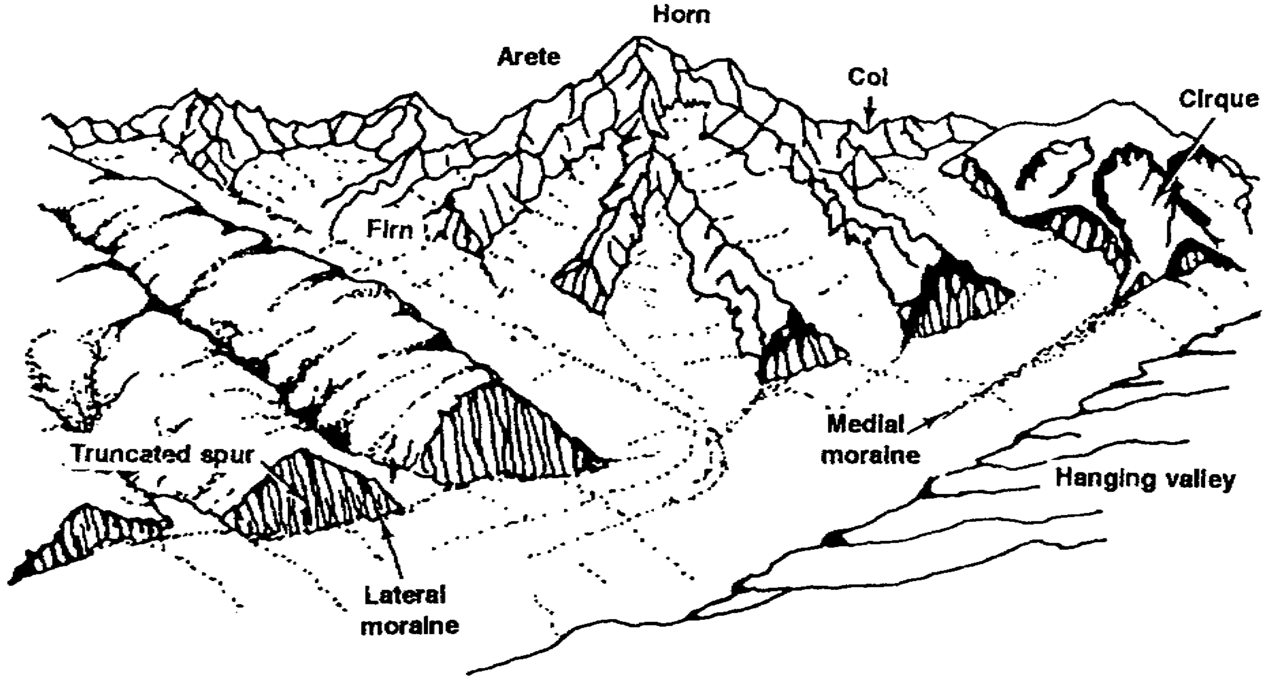
(1) Plucking. *Plucking* is when a glacier dislodges and picks up protruding fragments of bedrock.

(2) Plowing. *Plowing* is when loose material is pushed ahead of the glacier. Material is often loosed by *frost wedging*. This is the process of breaking down by which water freezes in the cracks and pores of rock and expands in all directions.

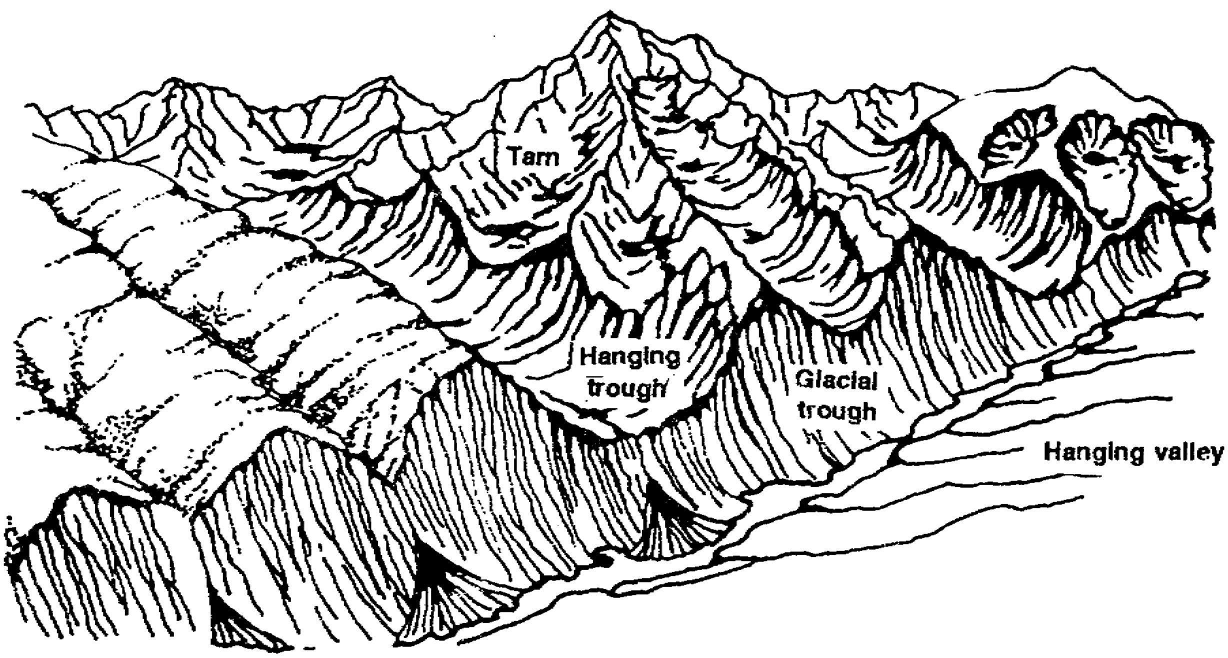
(3) Abrasion. *Abrasion* occurs when ice-plucked blocks and other rock debris grind (scratch and polish) the bedrock over which the glacier passes.

Abrasion is the primary erosional process of glaciers. Speed of abrasion depends on the resistance of the local bedrock, the abundance of cutting debris, the speed of glacial flow, and the weight or thickness of the ice. The effects of abrasion are more pronounced under the thick continental glaciers (Figure 4-10). Figure 4-9 shows a number of erosional and depositional features formed by alpine glaciers. Common terms found in alpine glacial feature are--

- Cirque. A *cirque* is the head of mountain glacier valley (semicircular in shape).
- Tarn. A *tarn* is a water-filled cirque that forms a lake.
- Horn. A *horn* is an angular peak formed by intersecting walls of several cirques.
- Arete. An *arete* is a knife-edged ridge.
- Hanging valley. A *hanging valley* is a truncated glacial valley.
- Moraine. *Moraine* is a linear deposit of glacial debris.
- Outwash. *Outwash* is water-sorted glacial sediment.
- Firn. *Firn* is compacted, granular snow that is also called *neve*.



Area of alpine glaciation showing erosional features and placement of ice



Same area of alpine glaciation with ice removed

Figure 4-9. Evolution of alpine (valley) glaciation features

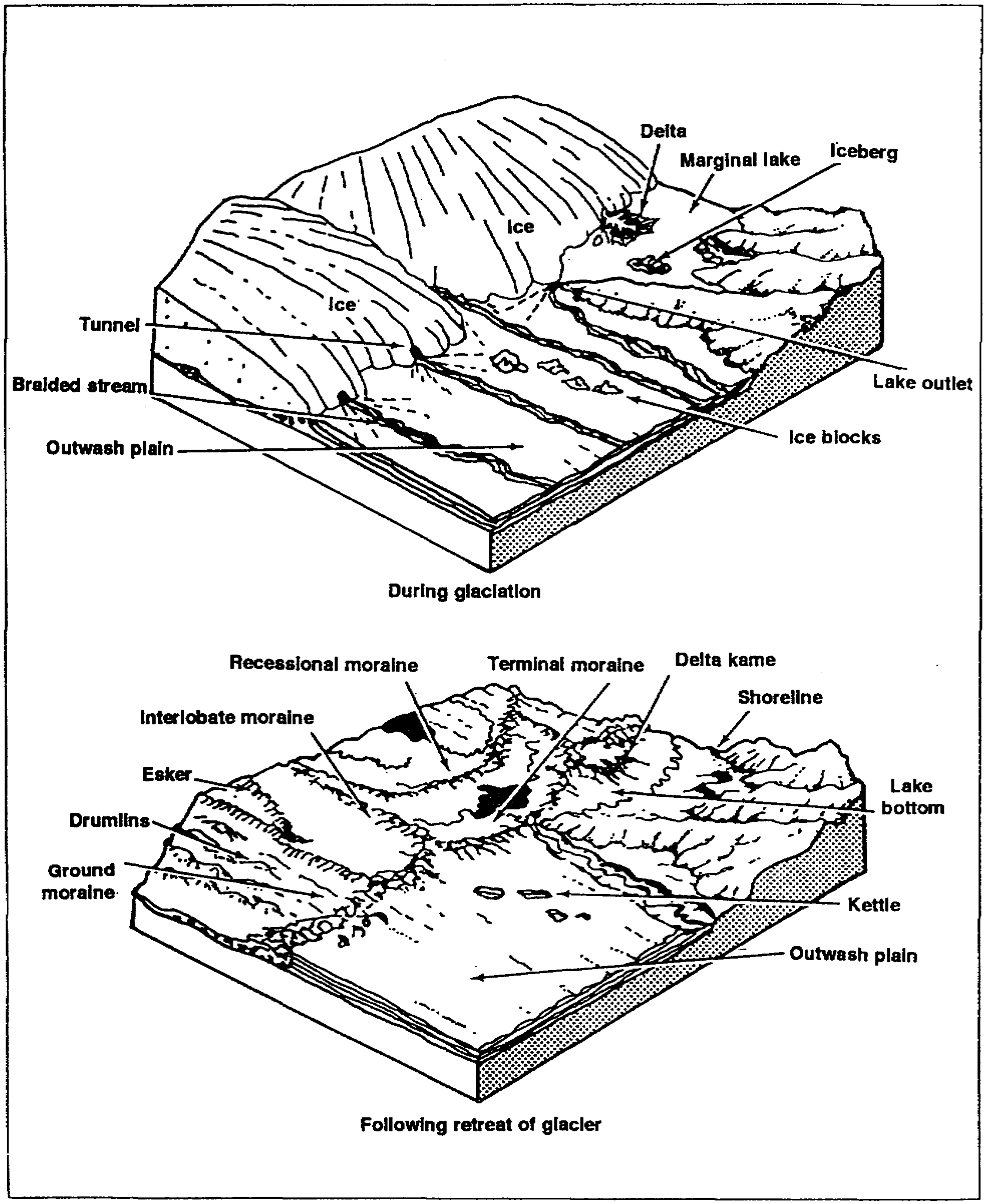


Figure 4-10. Evolution of continental glaciation features

- Cirques. *Cirques* are bowl-shaped hollows with steep sides found at the head of a glacier. A *horn* is formed when three or more cirques come together, creating a high pyramidal peak with steep sides. The famous Matterhorn of the Swiss Alps is a typical example of a horn. Cirques are formed by the plucking and abrading action of the glacier as it moves out of the mountain peaks. Lakes occupying these depressions (after the extinction of the glacier) are called *tarn* lakes or, when in a series, *paternoster* lakes.

- Col. A *col* is a low pass in a mountain ridge formed by the intersection or meeting of the cirques of two glaciers. This feature is also known as a *saddle*.

- U-shaped valley. A U-shaped valley is a valley formed by glacial erosion and is so called because of its broad U-shape bottom (as opposed to the narrow V-shaped valley produced by stream erosion).

- Fjord. A *fjord* is a glacial trough eroded by ice either below sea level or above sea level, in which case it is subsequently submerged due to a rise in sea level. Fjords comprise much of the Scandinavian coastline.

b. Depositional Features. Terms commonly associated with depositional features caused by glaciation process are kettle, till, moraines, drumlin, kame, esker, rock flour, and glacial milk. Refer to Figures 4-9 and 4-10 for examples.

- Kettle. As a glacier recedes, it sometimes leaves behind large masses of ice embedded in the valley floor. Depressions (*kettles*) remain after the ice melts, when water collects in them kettle lakes are formed.

- Till. Glacial *till* is the unsorted material deposited by a glacier. The sorted and stratified materials deposited by streams flowing from glaciers are called *glacio-fluvial deposits*.

- Moraines. *Moraines* (Figure 4-11) are the glacial drift or till deposited chiefly by direct glacial action. Rock debris deposited by a glacier form ridges of loosely consolidated materials. The deposited materials are called--

  Outwash plains when melting ice at the edge of the glacier crates a great volume of water that flows through the end moraine as a number of streams rather than a continuous sheet of water.

  Terminal moraines when they are found at the end or toes of the glaciers.

Ground moraines when laid down on the valley floor of a glacier.

Lateral moraines when formed by the deposition of material along the sides of a glacier.

Medial moraine, when formed as a common moraine by the merger of two glaciers.

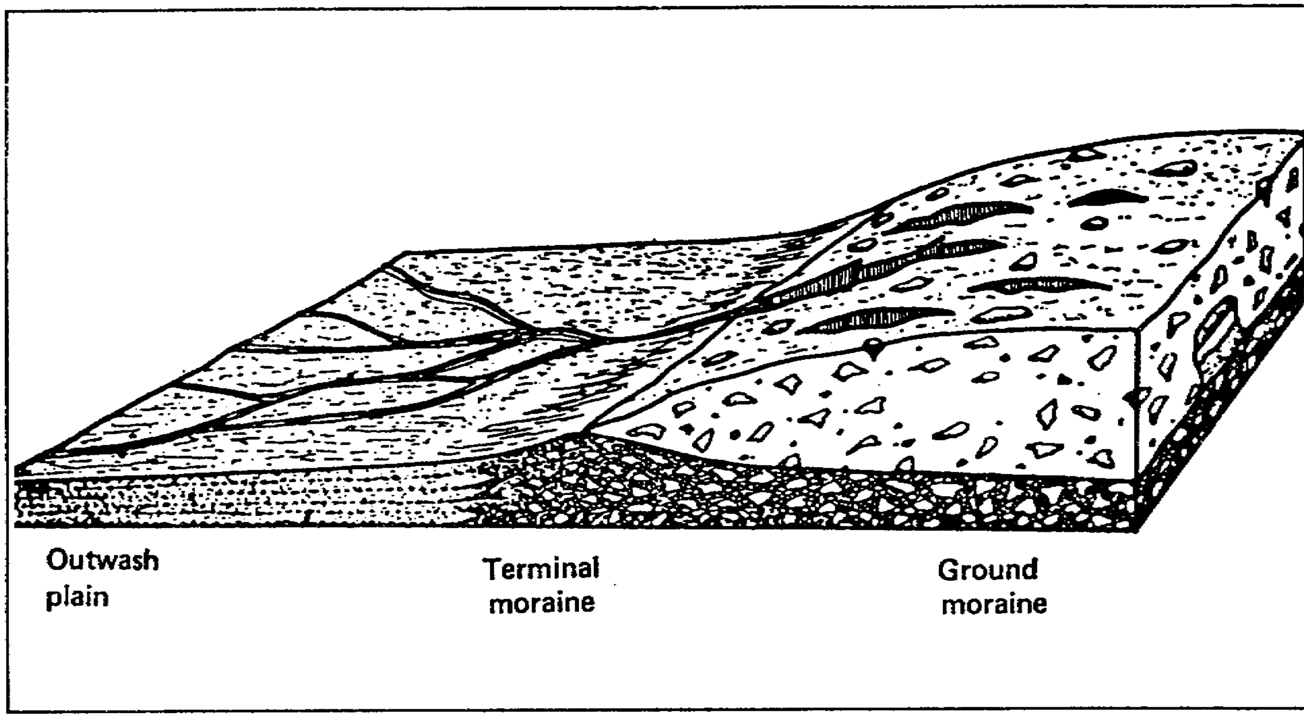


Figure 4-11. A block of a valley glacier showing the relationship and nature of the deposits

- Drumlin. A *drumlin* is a streamlined, lens-shaped deposit of glacial till with its longer axis parallel to the direction of the glacial movement (Figure 4-12).

- Kame. A *kame* is a terrace or flat-topped hill created by the deposition of material carried by streams flowing along the margin of the glacier.

- Esker. An *esker* is a winding ridge of stream-built stratified glacial gravel and sand formed between walls of ice or in ice tunnels.

- Rock Flour. *Rock flour* is the finely powdered rock material produced by glacial erosion

- Glacial milk. *Glacial milk* is the milk-white water (charged with rock flour) that flows from beneath glaciers.

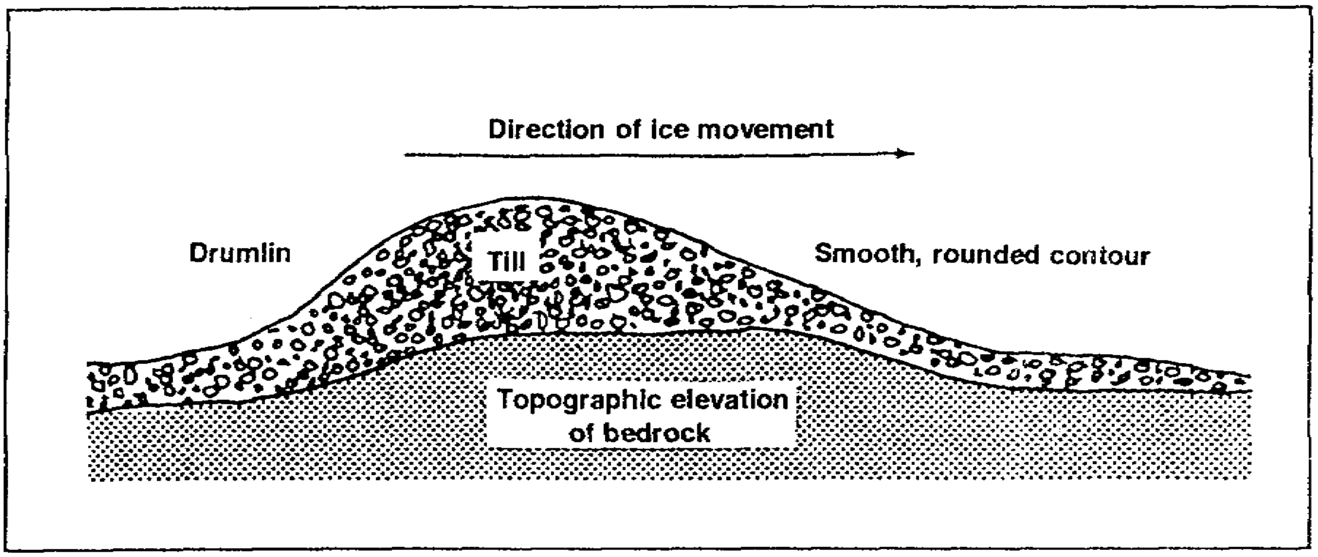


Figure 4-12. Idealized cross section of a drumlin

c. Other Effects of Glaciation. Base changes, depressions of the earth's crust and the effects of marginal weather conditions are some of the other effects of glaciation:

- Base changes. Base change occurs when a worldwide glacial melt raises the sea level 200 feet

- Depression of the earth's crust. The weight of ice depresses the earth's crust. When this weight is removed, the earth's crust rebounds. The north side of Lake Superior is an example of an area that has rebounded following the retreat of glaciers.

- Margin weather conditions. The cold and windy climate, in conjunction with massive deposition, prevents the establishment of vegetation.

4-4. Eolian Geology. Eolian geology is the study of geologic processes associated with the actions of wind.

Arid and semiarid regions (deserts, steppes, high plains, and plateaus) comprise nearly one-fourth of the earth's land surface. In these areas of diminished surficial water supply, mechanical weathering dominates the forces that break up rock. The resultant loose, dry material allows the wind to become a powerful erosional agent. It is the unique and varied landforms and sediment deposits formed by the wind in and around these dry environments that concern the Army. Your knowledge of these processes and products will help provide the flexibility you will need for a successful military operation.

a. Types of Eolian Erosion. The eolian erosion process consists of two types: deflation and abrasion.

(1) Deflation. *Deflation* occurs when loose particles are lifted and removed by the wind. Wind picks up finer material and lets heavier particles or pebbles to settle and compact themselves. Deflation lowers the land surface and is not limited by base level. It can continue as long as it has loose material to carry away; however, moisture stops deflation and leads to vegetation. Death Valley, California is an example of deflation.

(2) Abrasion. *Abrasion* is a weathering process by which particles carried by the wind scratch exposed rock surfaces. It occurs when hard particles are blown against a rock, causing it to break down. As they are broken off, the resulting fragments are carried away by wind. These abraded rocks are called *ventifacts*. Abrasion also occurs due to water and glacial actions.

Ventifacts (Figure 4-13) are pebbles or boulders shaped by abrasive action of windblown sand. In windswept arid areas, pebbles may develop smoothly polished facets on the side facing the blast of sand. Over time, the process eventually produces many facets on the stones. **NOTE: The pebbles shown in Figure 4-13 become a ventifact between stage A and stage B.**

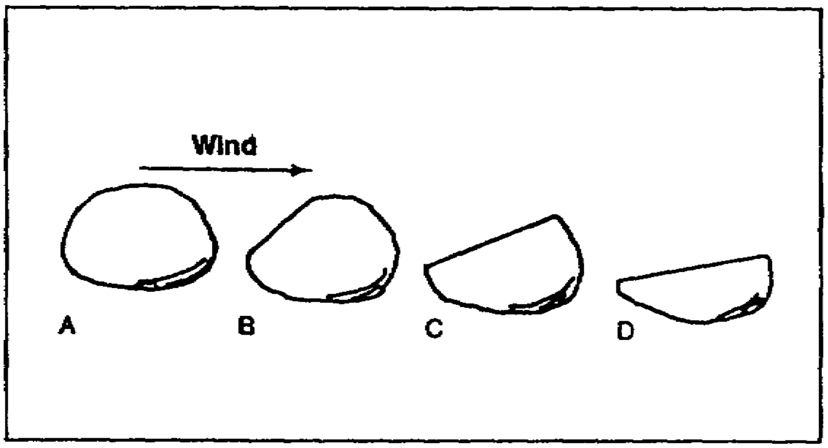


Figure 4-13. Four stages in cutting of a ventifact

b. Modes of Transport. The two transportation modes of eolian erosion are *saltation* and *suspension*.

(1) Saltation. *Saltation* is a process whereby unconsolidated material is bounced from one location to another.

(2) Suspension. *Suspension* is a process whereby material is transported in an airborne fashion. Suspended loads consist of fines carried at least two feet off the ground.

4-5. Eolian Features. Eolian features are desert pavement, dunes, and loess.

a. Desert Pavement. *Desert pavement* is a layered deposit of gravelboulders created by the removal of fines during the deflation process. Desert pavement is also known as *deflation armor*. This deflation armor is too thin to constitute a viable source for your construction material needs, and it is also too thin to serve as a foundation for a construction site. Trafficability is good, but rough. You can use desert pavement as an expedient surface for roads or airfields.

b. Dunes. *Dunes* are hillocks of windblown sand. They are temporary, migratory, and predictable and form into numerous types. Common dune types as shown in Figure 4-14 are--

- Transverse. *Transverse dunes* are dunes that form perpendicular to a constant wind direction in areas where there are abundant sand supplies.

- Longitudinal. *Longitudinal dunes* are dunes that form parallel to the prevailing winds in areas where wind direction is variable.

- Barchan. *Barchan dunes* are formed where there is a limited sand supply and constant wind direction.

- Parabolic. *Parabolic dunes* are hairpin-shaped forms whose ends are anchored. They are composed of limited amounts of sand.

- Complex dunes and sand sheets. Neither *complex dunes* nor *sand sheets* have a distinctive shape; however, both are stationary forms created in areas where wind blows from all directions.

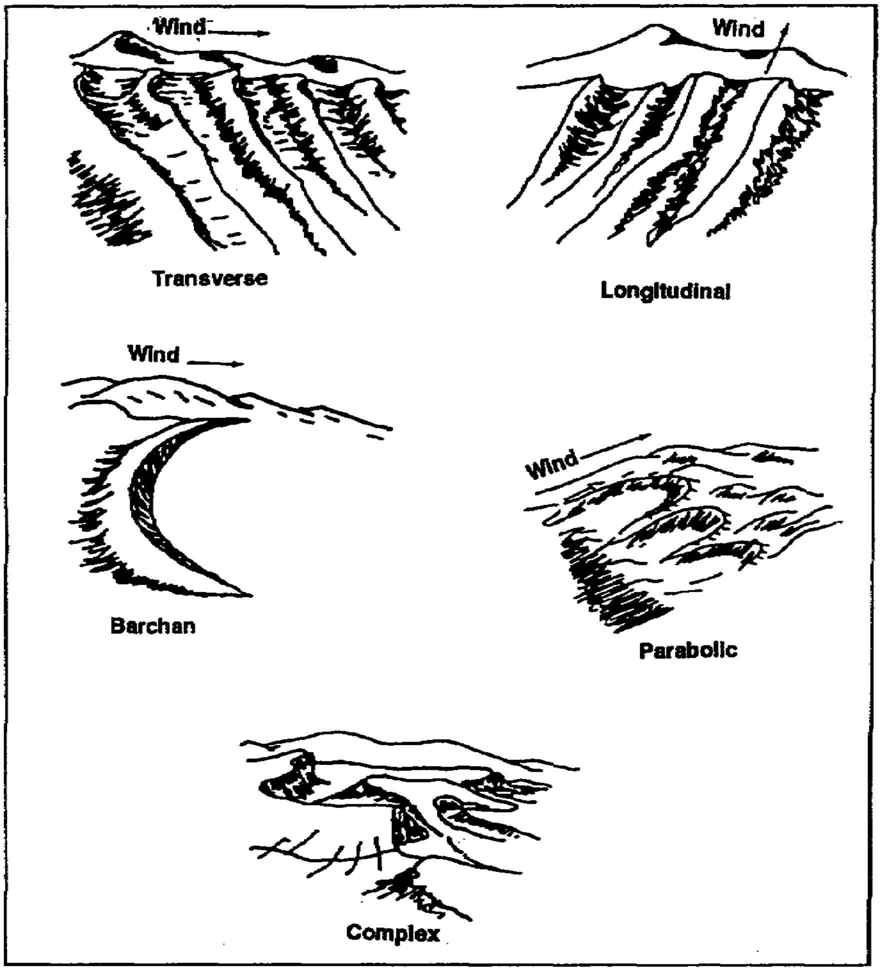


Figure 4-14. Sand dune types

(1) Control of dunes. From a construction standpoint, migrating sand poses a significant engineering problem--how to prevent dune formations on facilities. As an engineer, your objectives for dune and drift-sand control are to--

- Destroy or stabilize wind-borne sand accumulations-in order to prevent further migrating and encroachment
- Divert windblown sand around works requiring protection.

- Stop sand movement short of the works to be protected.

- Avoid sand deposits over a specific location by encouraging its movement. This is accomplished primarily by surface smoothing and obstacle removal.

There are many ways for you to control dune and drift sand, each with certain advantages and disadvantages. The following methods for the stabilization are listed with the most attractive methods first:

(a) Aligning. You achieve this method by aligning the route upwind of the sand source to avoid major dune fields.

(b) Oiling. Cover the windblown materials with a suitable oil product, such as high-gravity penetrating oil. The oil will stabilize the treated surface and may destroy dune formation. This is often a quick, cheap, and effective method for you to perform.

(c) Fencing. Use relatively porous barriers to stop or divert the sand movement or to destroy or stabilize dunes. Cheap, portable, and expendable structures are suitable barriers. For example: palm fronds, chicken wire, or snow fencing.

(d) Planting. Plant appropriate vegetation that is designed to stop or reduce sand movement, bind surface sand, and provide surface protection. You may be required during early stages of control to use planting or sand-stilling plants through mulching, seeding, and the systematic creation of surface organic matter. Planting is permanent and attractive, but it is expensive to initiate and maintain.

(e) Paving. Smoothing or hard-surfacing a relatively level area will increase the saltation coefficient of wind-transporting material. This process promotes sand migration and prevents its accumulation at undesirable sites. You will often use this method downwind of fencing where wind is unladen of sediment and the paving will prevent its recharge. Your paving materials may consist of concrete asphalt or wind-stable aggregates such as crushed rock or gravel.

(f) Panelling. Erect solid barriers to the windward side of areas to be protected. The barriers will either stop or deflect sand movement (depending largely on the angle of the barrier to wind direction). In general, this method is unsatisfactory and expensive, although it may be suitable for short-term emergency action.

(g) Trenching. This method involves cutting trenches across dunes. The process will destroy the symmetry of the dunes and may lead to dune destruction. By excavating pits on the lee of sand mounds or on the windward side of the work to be protected, you will provide temporary local accumulation areas.

(h) Removal of material. This method is rarely successful and is normally not long-term.

(2) Engineering considerations. Your engineering considerations for dunes include construction materials, construction sites, and trafficability.

(a) Construction material considerations for sand:

- Use a *snow* fence to collect sand.
- Use a native brick or stone because timber and steel are often lacking in eolian environments.
- Use matting and membranes.

(b) Construction site considerations for sand:

- Confine and compact sand to provide a good base.
- Orient buildings carefully and add depth to the foundations to deter wind undermining.

(c) Trafficability considerations for sand:

- Avoid dunes, loose sand is often a barrier to wheels.
- Mix asphalt with aggregate (pavement) to improve the trafficability of sand.

(d) Other considerations for sand:

- Avoid concrete construction due to a lack of water and high salt content in aggregates.
- Destroy dunes if they approach within 20 times the height of the structure.

c. Loess. *Loess* is a yellow or beige deposit comprised primarily of windblown silt. It may contain small amounts of clay or fine sand, and it erodes to form nearly vertical walls. The Dauiz Desert in Iran is an example of an area composed of loess.

(1) Origin. Loess becomes airborne on dry, windblown outwash plains at the edges of glacier. It is then transported to distant areas, where it is deposited in layers 10 to 100 feet thick.

(2) Engineering considerations. Your engineering considerations for loess are construction materials, construction sites, and trafficability.

- Construction materials. Loess is a poor construction material. It is weak due to its open structure, and it tends to liquefy when wet

- Construction sites. You should avoid the use of loess if possible. It does not maintain a cut slope. Although some of its properties resemble consolidated rock, it is weak due to its open structure. Furthermore, it erodes quickly.

- Trafficability. Loess has no trafficability if wet, but it will support a load if dry.

PART C: RESIDUAL LANDFORMS

Now it is time for you to get acquainted with the various landforms created by the erosion of igneous, metamorphic, and sedimentary structures in various climates.

4-6. Sedimentary Rocks. The best differentiator of sedimentary rocks is the presence of layers separated by bedding planes. This section discusses the most common types of sedimentary rocks and the characteristics associated with them.

a. Conglomerate and Sandstone. The following characteristics of conglomerate and sandstone include--

(1) Landforms. Conglomerates and sandstones are relatively resistant to erosion and form areas of high relief. In temperate climates, sandstone topography is somewhat rounded. In arid regions, sandstone and conglomerate form the cap rock of plateaus and ridges, and the relief is usually rugged and angular.

(2) Drainage patterns. Flat-lying sandstones and conglomerates usually develop a dendritic drainage pattern. However, a rectangular drainage pattern, which is one characterized by right angle bends of streams, may result from the presence of joints and faults. A trellis pattern develops where sandstones and softer rocks are interbedded and folded. In contrast to shale, sandstone will show a medium-to-coarse drainage network

(3) Vegetation. In humid climates, sandstone and conglomerates will support a heavier growth of vegetation than will limestone and shale.

(4) Photo tone. The tone is generally light-colored because of good drainage and light-colored minerals.

(5) Special keys. Special keys to sandstone are angular relief; bold, massive hills; light tone; and a curved or pincer-like dendritic drainage pattern.

b. Shale. The following characteristics of shale include--

(1) Landforms. Shale is usually very susceptible to erosion in both humid and arid climates, and it often forms areas of low relief. In arid regions where sandstones develop vertical cliffs, shales form slopes below the sandstone, often with parallel drainage of fine density. If sandstone is not present with shale in an arid climate, badlands topography (a region marked by intricate erosional sculpturing, scanty vegetation, and fantastically formed hills) develops. In humid regions, shale forms valleys and low, rounded hills.

(2) Drainage pattern. Shale exhibits fine-textured dendritic and angular drainage patterns that often contain small, rounded projections (crenulations). A trellis pattern develops on shale when it is interbedded with harder rocks and has been folded. Water erosion produces trench patterns such as V-shaped gullies in arid regions and U-shaped gullies in humid regions.

(3) Vegetation. In humid areas, shale may be heavily forested, but in arid regions, it is usually barren.

(4) Photo tone. Tones in humid areas are mottled due to variations in moisture and organic content. In arid climates, tones are uniformly light or dark except for occasional horizontal banding in the rock.

(5) Special keys. Mottled tones, dendritic drainage patterns, and subdued landforms, as well as the definite badlands topography, are indicators of shale.

c. Limestones-Karst Topography. The following characteristics of limestone-karst include--

(1) Landforms. Because of its solubility, limestone is very susceptible to chemical weathering in humid regions. Sinkholes that appear as depressions in the limestone terrain, are very characteristic of this rock type in humid areas and are easily identified on aerial photographs. Underground water flowing through limestone deposits causes cavities to develop. Many limestones are honeycombed with these voids. Limestone also forms lowlands when interbedded with sandstone in humid climates. In arid regions, however, limestones are just as resistant to erosion as sandstones and may also form the cap rock of plateaus or of ridges.

(2) Drainage patterns. Where they are present sinkholes represent the main surface drainage. In many areas, streams are found to disappear into sinkholes. In other areas, dendritic and rectangular drainage patterns are most likely to form on limestone terrain. A trellis pattern is developed on interbedded and tilted rock.

(3) Vegetation. In humid areas, limestone supports much vegetation since it develops a very fertile soil. Orchards are commonly planted in limestone regions. Only a weak soil profile develops in arid regions and, consequently, the vegetation is usually sparse.

(4) Photo tone. The overall tone of limestone is fairly uniform light gray, but it may be interrupted by the occurrence of darker spots, indicating sinkholes. The mottled tone thus created is an excellent guide to ground underlain by limestone.

(5) Special keys. The occurrence of sinkholes and the mottled tones are easy to see and are excellent photo aids. Although basalt also displays mottled tones, there should be no confusion in differentiating limestone and basalt. Mottled tones associated with sinkholes indicate limestone, while mottled tones associated with columnar jointing indicate basalt. Stratification should, of course, be evident on limestone, but a coarse layering sometimes is exhibited by basalt.

d. Interbedded Flat-Lying Sedimentary Rocks. Two or more types of sedimentary rocks often occur together. If these rocks are flat-lying or nearly so, they can be identified by several characteristics. Differences in resistance to weathering between the rocks can cause a stair-stepped or bench-like topography. This topography may be accentuated by a distinct banding due to vegetation color and photo tone. A dendritic drainage pattern will develop on thick interbedded sedimentary rocks, while differences in drainage indicate differences in rock types.

e. Interbedded Tilted Sedimentary Rocks. Tilted sedimentary rocks may be identified by the characteristic topography of each individual rock type. Generally, the different rock types will be accentuated by differences in drainage pattern, topographic expression, tone, and/or vegetation type. Folded sedimentary rocks usually develop a trellis drainage pattern which accentuates alternating valleys and ridges. If all three rock types are present, sandstone will form the highest landforms, limestone the intermediate slopes, and shale the valleys.

4-7. Igneous Rocks. Igneous rocks vary greatly in mineral and chemical composition, texture, and mode of occurrence. Intrusive rocks are emplaced as dikes, sills, batholiths, laccoliths, and stock. Extrusive igneous rocks generally occur as lava flows and volcanoes.

a. Intrusive Igneous Rocks. The following characteristics of intrusive igneous rocks include--

(1) Landforms. Depending upon the climate, intrusive igneous rocks will weather in differing ways. Some intrusive bodies like dikes and laccoliths will form characteristic shapes upon exposure to erosion. A dike will usually appear as a distinct ridge, while laccoliths and batholiths generally appear as dome like masses. Generally, in a humid or temperate climate, granite rocks will produce rounded or knobby topography, while in arid or semiarid climates they will appear more angular. All igneous rocks, regardless of their composition and structure, show jointing or cracking. Upon cooling during and after emplacement, these masses develop both horizontal and vertical cracks. The vertical cracks show up well on aerial photographs and, in most instances, specific directions can be ascertained. They are more resistant to erosion in any type of climate than most sedimentary or metamorphic rocks. Intrusive igneous rocks will form high areas, hills, or

mountains where they occur in association with other kinds of rocks due to their erosion resistance. In regions where granitic rocks alone cover extensive areas, they may be eroded by glaciation or stream action to low rolling plains.

(2) Drainage patterns. Dendritic, rectangular, and radial drainage may all be produced on granitic rocks. Since any one of these three patterns may be developed, other keys must be used in conjunction with this one to identify the rock type more specifically. Furthermore, annular drainage is frequently developed in association with small intrusive bodies.

(3) Vegetation. In humid climates, igneous rocks are affected by chemical weathering to form a deep soil horizon that will support much vegetation. In arid climates, jointing and fracturing in the mass may he evidenced by alignment of vegetation.

(4) Photo tone. Since intrusive igneous rocks are usually primarily composed of light-colored minerals, the photo tone will usually be light, provided the surface of the mass is` not extremely rough.

(5) Special keys. Jointing, rectangular drainage pattern, exfoliation, angular relief, lack of banding, and light photo tone are basic keys in the identification of intrusive igneous rock types.

b. Extrusive Igneous Rocks. Extrusive igneous rocks are typified by lava flows or volcanic cones composed of dark-colored minerals. The following characteristics of extrusive igneous rocks include--

(1) Landforms. Lava flows may be recognized by the rounded projections along their edges or by the vegetation patterns. Lava flows sometimes build up deposits many thousands of feet thick. Layering due to the intermittent outpouring of lava is common. Depending on the age of the flow and the intensity of weathering, the surface may vary from smooth and rolling to very rough. Columnar jointing is a characteristic feature. This jointing is perpendicular to the surface of the flow and is caused by cooling. Cinder cones are identified by their conical shapes.

(2) Drainage pattern. Since lava flows are relatively flat-lying, homogeneous masses, a dendritic pattern may develop. In many cases, however, there is little visible drainage. The joints in basalt render it very porous, so much of the drainage is internal.

(3) Vegetation. In humid areas, abundant vegetation may be present because basalt weathers rapidly and develops a thick soil profile. In more arid areas, very little vegetation is found.

(4) Photo tone. Basalt usually shows dull and dark tones on aerial photos. One feature of the basaltic lava flows is a characteristic mottled tone that is usually easy to identify unless the soil cover is too thick.

(5) Special keys. Columnar jointing, plateau structure, and dark or mottled tone are excellent for identification of basalt. The presence of cinder cones is also a definite clue to areas of extrusive igneous rock.

4-8. Metamorphic Rocks. Generally, massive metamorphic rocks are difficult to identify as such from photographs, especially when metamorphic rocks and igneous rocks occur together. When these rock types are closely associated, it is usually sufficient to describe them as *crystalline rocks*. Additionally, it is usually not possible or necessary to differentiate between lightly metamorphosed sedimentary rocks and the original rocks.

a. Gneiss. *Gneissic rocks* are laminated and have a dark-to-light banded appearance. The composition of gneiss is similar to that of granite. Steep, sharp-crested hills and strong dendritic or angular drainage patterns are characteristic of this rock. Slight banding of tone or vegetation may be apparent on aerial photographs.

b. Schist. *Schistose rocks* are highly altered and thinly laminated. Large areas of schist may parallel features of alternating hard and soft layers. The topography is rough in arid regions, while it may be subdued with a deep soil cover in humid regions. A rectangular or angular drainage pattern will develop where jointing and faulting occur.

c. Slate. *Slate* is hard and dense and forms rugged topography in all climates. A highly developed fine-textured dendritic or rectangular drainage pattern usually develops on this rock. The terrain is deeply dissected. When the rock is well exposed, it exhibits a light gray photo tone.

LESSON 4

PRACTICE EXERCISE

The following items will test your grasp of the material covered in this lesson. When you have completed the exercise, check your answers with the key that follows. If you answer any item incorrectly, study again that part which contains the portion involved.

1. Define fluvial processes.

____

____

____

2. Define competence.

____

____

____

3. Define capacity.

____

____

____

4. Which number in Figure 4-15 is pointing to the river profile as it would appear if the lake were drained and the entire river was adjusted to ocean base level?

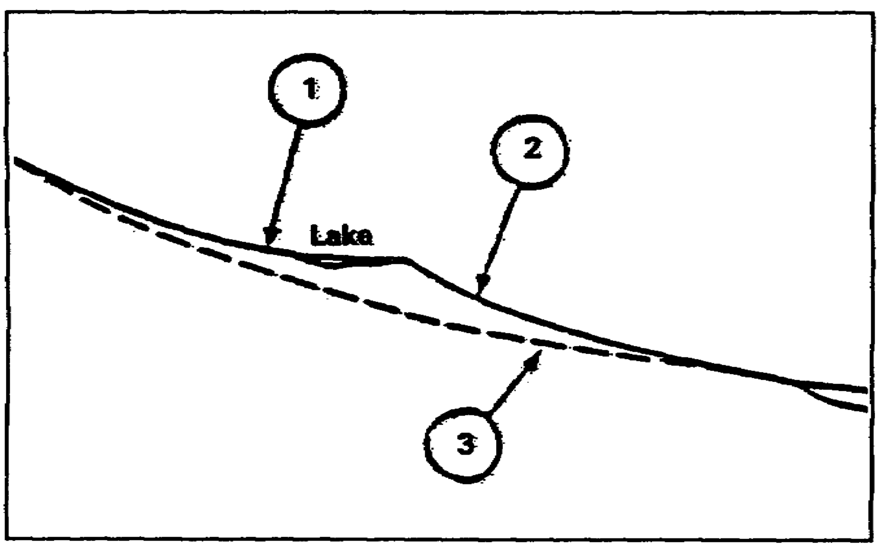


Figure 4-15. River profile

5. What stage of stream development does Figure 4-16 illustrate?

____

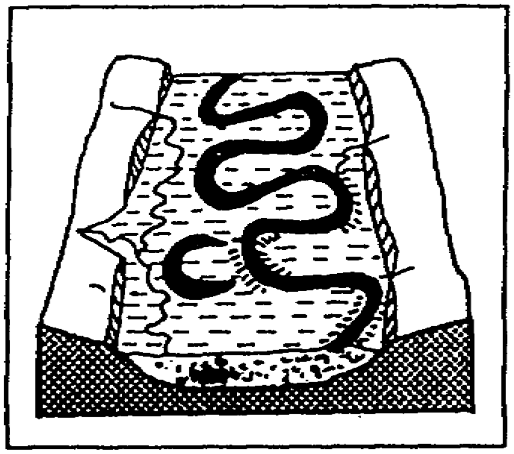


Figure 4-16. Stream stage

6. What stage of stream development does Figure 4-17 illustrate?

____

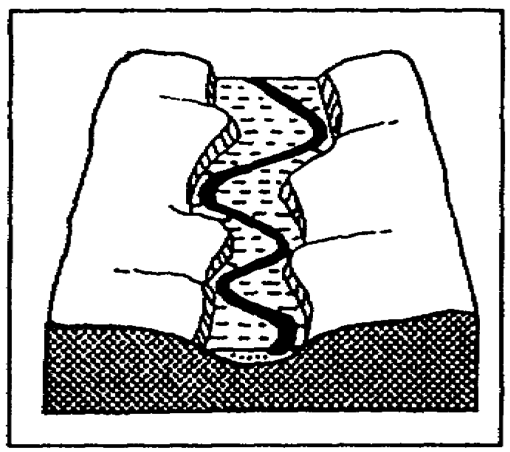


Figure 4-17. Stream stage

Use Figure 4-18 to answer questions 7 through 9.

7. Which number is pointing to the point bar? ______________________________

8. How many meanders are there? ______________________________

9. Which number is pointing to a marsh or wetland caused by impermeable layer of fines in the flood plain? ______________________________

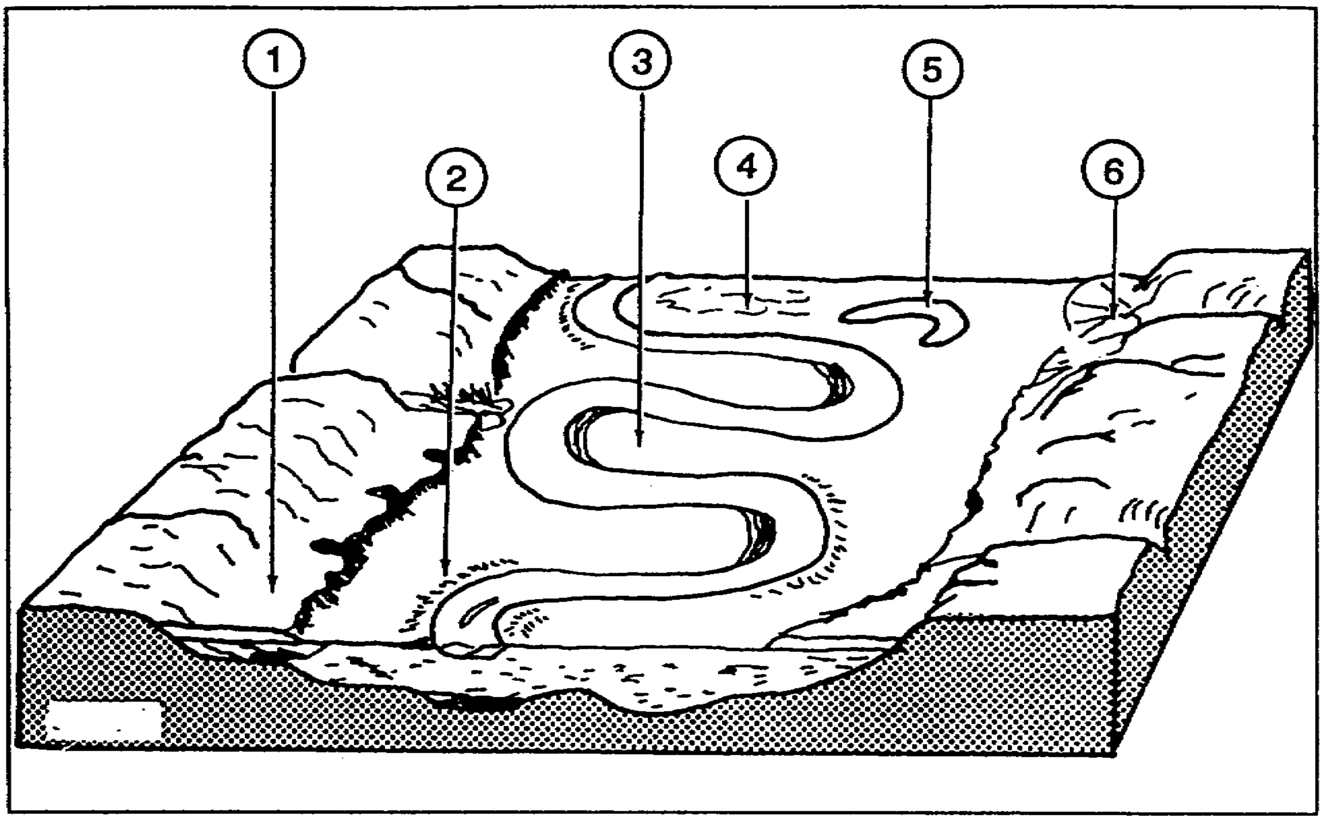


Figure 4-18. Major flood plain features

10. Define shoreline of emergence.

11. Define shoreline of submergence.

12. How is a wave-cut bench created?

13. Define glacier.

14. Broken rocks get carried away by the glacier in which glacial processes?

____

____

15. In which glacial process is there a grinding of bedrock by particles contained within the glacier?

____

____

16. Define deflation.

____

____

17. Figure 4-19 illustrates the four stages in the cutting of a ventifact. The pebble becomes a ventifact between which two stages? ______________________________

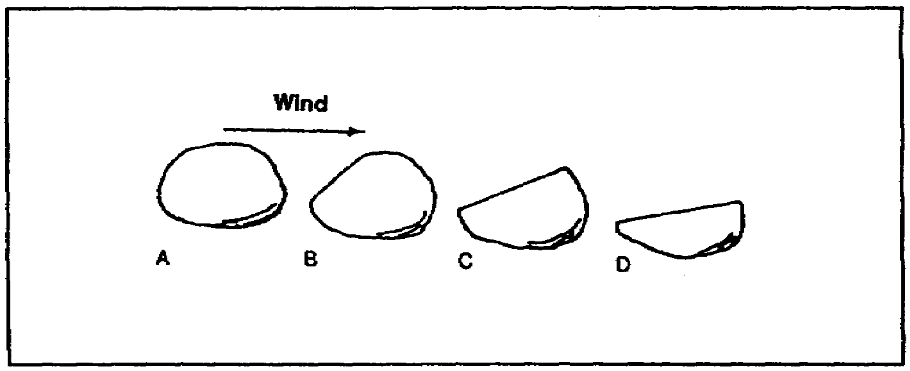


Figure 4-19. Ventifact stages

18. Which type of dune is shown in Figure 4-20? ______________________________

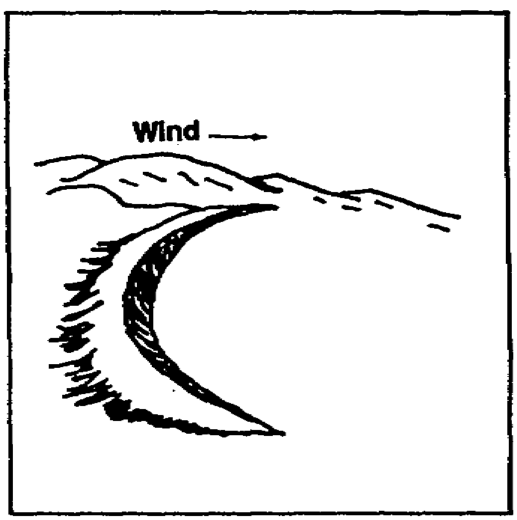


Figure 4-20. Sand dune

19. Which type of dune is shown in Figure 4-21? ____

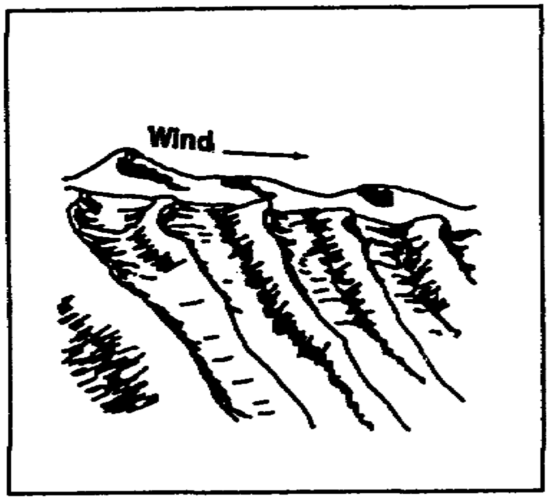


Figure 4-21. Sand dune

20. Define loess.

____

____

21. Which sedimentary rocks are relatively resistant to erosion and form areas of high relief in nearly all climates?

____

22. Which type of sedimentary rock is usually susceptible to erosion in both humid and arid climates and often form areas of low relief?

____

23. Because of its solubility, which rock is very susceptible to chemical weathering in humid regions?

____

24. Which rock is laminated and shows a dark-to-light banded appearance?

____

25. Which type of metamorphic rock is hard and dense and forms rugged topography in all climates?

____

LESSON 4
PRACTICE EXERCISE
ANSWER KEY AND FEEDBACK

<u>Item</u>	<u>Correct Answer</u>
1.	Fluvial processes are processes of running water. (page 4-2, para 4-1)
2.	Competence refers to the maximum size of particle a stream is capable of moving. (page 4-2, para 4-1a(1)(b))
3.	Capacity is the maximum quantity of a material a steam can carry past a given point in a unit of time. (page 4-2, para 4-1a(1)(c))
4.	Three. (page 4-4, Figure 4-3)
5.	Old age. (page 4-5, Figure 4-4)
6.	Mature. (page 4-5, Figure 4-4)
7.	3. (page 4-7, Figure 4-5)
8.	4. (page 4-7, Figure 4-5)
9.	5. (page 4-7, Figure 4-6)
10.	A shoreline of emergence is the result of an uplift of land or fall in sea level. (page 4-11, para b(2))
11.	A shoreline of submergence is the result of a rise in sea level or lowering of land. (page 4-11, para b(2))
12.	A wave-cut bench or terrace is created at the base of a cliff and widens as wave erosion proceeds landward against the cliff. (page 4-14, para d(2))
13.	A glacier is a mass of snow and ice that moves under the influence of gravity out over the land from an area of perennial snow which is its source or head. (page 4-15, para 4-3)
14.	Plucking and plowing. (page 4-15, para 4-3a(1)(2))
15.	Abrasion. (page 4-15, para 4-3a(3))

16. Deflation occurs when loose particles are lifted and removed by the wind. Wind picks up the finer material and lets heavier particles or pebbles to settle and compact themselves. (page 4-21, para 4-4a(1))

17. Stages A and B (page 4-21, para 4-4a(2)).

18. Barchan (page 4-23, Figure 4-14).

19. Transverse (page 4-23, Figure 4-14).

20. Loess is a yellow or beige deposit comprised primarily of wind-blown silt. (page 4-25, para 4-5c)

21. Conglomerate and sandstone (page 4-26, para 4-6a(1)).

22. Shale (page 4-27, para 4-6b(1).

23. Limestone (page 4-27, para 4-6c(1)).

24. Gneiss (page 4-30, para 4-8a).

25. Slate (page 4-30, para 4-8c).

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APPENDIX A

LIST OF COMMON ACRONYMS

ACCP	Army Correspondence Course Program
AV	Automatic voice network
cm	centimeter(s)
D	downthrow
DSN	defense switching network
E	east
EN	engineer
FM	field manual
gm/cc	gram(s) per cubic centimeter(s)
IPD	Institute for Professional Development
m	meter(s)
mm	millimeter(s)
MOS	military occupation speciality
N	north
NW	northwest
para	paragraph
psi	pound(s) per inch(s)
RYE	Retirement Year Ending
SE	southeast
SM	soldier's manual
SSN	social security number
SW	southwest

TM	technical manual
TRADOC	Training and Doctrine Command
Ts	thrust fault
US	United States (of America)
U	upthrow
VA	Virginia

APPENDIX B

RECOMMENDED READING LIST

FM 5-410, *Military Soils Engineering,* 23 December 1992, provides additional information about the material in this subcourse. You do not need this material to complete this subcourse.

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APPENDIX C

CONVERSION FACTORS

Multiply	By	To obtain
Feet	03048	Meters
Inches	2.540	Centimeters
Miles	1.6093	Kilometers
Pounds per cubic foot	16.02	Kilograms per cubic meter
Pounds per cubic inch	27.68	Grams per cubic centimeter
Pounds per square foot	4.882	Kilograms per square meter
Pounds per square inch	703.1	Kilograms per square meter
Tons	1016	Kilograms

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