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GEOLOGY

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HEADQUARTERS, DEPARTMENT OF THE ARMY

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Technical Manual
No. 3-34.61

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GEOLOGY

Contents

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Chapter 1

Introduction

PURPOSE AND SCOPE

1-1. The purpose of this manual is to relate the science of geology to military engineering. It is to be used for both reference and training. The manual is not intended to make geologists out of military engineers, but rather to present some of the geologic principles required for the correct solutions of many military engineering problems. It includes a survey of basic geologic materials, features, and processes. It further describes the geologic factors that affect the properties and occurrence of natural construction materials, the construction of dams, tunnels, roads, airfields, and bridges, the location of water supplies, and terrain evaluation.

CHANGES AND COMMENTS

1-2. Users of this manual are encouraged to submit recommended changes or comments to improve the manual. Comments should be keyed to the specific page, paragraph, and line of the text in which change is recommended. Reasons should be provided for each comment to insure understanding and complete evaluation. Comments should be forwarded directly to Commandant, U.S. Army Engineer School, Fort Belvoir, Va. 22060.

DEFINITION OF GEOLOGY

1-3. Geology is the science which deals with the substance, structure, and origin of the earth. It is the application of chemistry, physics, and biology* with their related sciences, to the study of the earth. The formation and alteration of rocks are the result of chemical, physical, and biological phenomena; the behavior of gases, water, and molten and solid rock on and below the surface of the earth is principally a physical phenomenon; the occurrence of animal and plant remains in rocks is a biological phenomenon. Geology also overlaps such other sciences as astronomy, climatology, geography, hydrology, oceanography, and pedology. The relationship is especially close between pedology (soil science or soil mechanics) and geology since soil is the product of the mechanical breakdown and chemical alteration of rocks and rock particles.

GEOLOGY AND MILITARY OPERATIONS

1-4. In military operations, the geologist can translate geologic information into concepts which can be used readily and effectively in conjunction with combat and engineering needs. Combat units, for example, benefit from geologic information in the evaluation of the trafficability of soils, the estimation of the fordability of streams, and the availability of concealment and cover. Engineering units would use geologic information in the location and use of construction materials, the location of ground-water supplies, the siting of roads and airfields, the evaluation of the suitability of foundations, the proper location of excavations, and the evaluation of possible sites for under-ground installations.

GEOLOGY AND MILITARY PLANNING

1-5. Military commanders should incorporate geologic information with other pertinent data when planning military operations. Since it is impossible to predict its ultimate military value, available geologic information should be included as standing operating procedure. During operations, the actual geologic conditions encountered should be continuously observed to verify or modify the preliminary estimate. Information so obtained may have an important bearing on adjacent or future projects.

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Chapter 2

Materials of the Earth's Crust

SECTION I - MINERALS

INTRODUCTION

2-1. The crust of the earth is made up of a variety of materials, but most of the earth's outer mass consists of rock composed of minerals. Without at least an elementary knowledge of the minerals and the rocks they form, it is impossible to understand and interpret the portion of the earth's crust with which the engineer must work.

DEFINITION OF A MINERAL

2-2. A mineral is a naturally occurring, homogeneous solid, inorganically formed, with a definite chemical composition and an ordered atomic arrangement. All possible artificial substances are excluded from consideration. The physical state of a mineral is necessarily solid. Liquids or gases are not considered when speaking of a mineral. A mineral cannot be formed from an organic source, it must be inorganically formed. For example, the mineral calcite and a pearl have the same composition, $CaCO_3$, yet because the pearl is formed by an organic source, an oyster, it is not a mineral. The chemical composition of a mineral is such that within certain limits, it remains the same each time the mineral occurs in nature. An ordered atomic arrangement means that the atoms of the substance are arranged in a geometric pattern which is repeated over and over again, thereby building up the structure of the mineral.

METHODS OF IDENTIFICATION

GENERAL

2-3. Many methods of mineral identification are recognized. The most positive are those which are made in the laboratory. For the purposes of the field engineer, however, sufficient information can be obtained by megascopic (visual) analysis. For military engineers, it is the most important and is widely used.

MEGASCOPIC ANALYSIS

2-4. In the coarser grained minerals and rocks, those in which the grains are 1mm (1/25 inch) or more in diameter, the component mineral or minerals can generally be identified by the unaided eye. Even if finer than 1mm, some mineral grains can be recognized by certain properties described in the following paragraph. When doing a megascopic analysis of a mineral or rock, certain pieces of equipment will aid in rapid and positive identification. While none of these are absolutely essential, the military engineer who uses these aids will find his job simplified. Most of these items can readily be obtained in the theater of operations and are easily carried by the individual. The recommended items of equipment are—

- Geologic hammer (any hammer will do).
- Hand lens or magnifying glass (10 power preferred).
- Pocket knife.
- Dilute acids (preferably hydrochloric acid mixed in the ratio of 1 part acid to 4 parts water).
- A piece of window glass.
- Streak plate (white unglazed porcelain tile—used to determine color of rock powder).

PHYSICAL PROPERTIES OF MINERALS

HARDNESS

2-5. Hardness is a measure of the ability of a mineral to resist abrasion or scratching. A simple scale, based on empirical tests and known as Moh's Scale of Hardness, has been universally accepted. The 10 minerals selected to form the standard of comparison are listed in table 2-1 in order of decreasing hardness. In the absence of the scale minerals, the hardness may be approximated by the expedients given in table 2-1. Care must be taken when testing the hardness of a mineral to select a fresh fragment, and not to confuse a scratch with a mark left by a soft mineral on the surface of a hard one. Moh's Scale does not indicate an exact hardness, i.e., the number 9 is not three times as hard as the number 3. It only means that any mineral can scratch all those beneath it in the scale and can be scratched by all those above it. Two minerals of the same number will scratch each other.

Table 2-1. Scale of hardness Moh's scale

Mineral	*Hardness*
Diamond	10
Corundum	9
Topax or beryl	l8
Quartz	7
Feldspar	6
Apatite	5
Fluorite	4
Calcite	3
Gypsum	2
Talc	1
Expedients	
Porcelain	7.0
Steel file	6.5
Window glass	5.5
Knife blade	5.0
Copper coin	3.0
Fingernail	2.0

CLEAVAGE

2-6. Minerals are composed of atoms held together by electrical attraction. In many minerals this attraction is conspicuously weaker in certain directions than in others, and pressure or a blow will cause the mineral to break along smooth, flat surfaces, or cleavage faces. The terms "perfect", "imperfect", "good", "distinct", and "indistinct" are used to indicate the manner and ease with which cleavage is obtained. The number of cleavage faces and the angles between them are helpful in identifying minerals.

FRACTURE

2-7. When a mineral breaks irregularly instead of cleaving along smooth planes, it illustrates fracture. The appearance of a fracture surface can be characteristic and is commonly designated by the following terms:

- Conchoidal —The surface presents a concave appearance.
- Fibrous or splintery—The surface shows fibers or splinters.
- Hackly—The surface is irregular with sharp edges.
- Uneven—The surface is rough and irregular.

LUSTER

2-8. The luster of a mineral (the manner in which the surface reflects light) is an important aid in the identification of minerals. Two kinds of luster are recognized:

Metallic Luster

2-9. The luster of metals, most sulfides, and some oxides, all of which are opaque or nearly so, very closely resembles that of brass, silver, or steel.

Nonmetallic Luster

2-10. The nonmetallic lusters may be subdivided as follows:

- Adamantine—Brilliant appearance of diamond.
- Vitreous—The luster of glass.
- Pearly—The appearance of mother of-pearl.
- Greasy—The appearance of oil.
- Resinous—The appearance of resin.
- Earthy—The appearance of soil.

COLOR

2-11. The color of a mineral, as an aid in its identification, must be used with caution, since some minerals can show a wide range of color without perceptible change in composition. Color in a mineral may be due to its chemical composition or it may be due to some foreign substance distributed throughout the mineral and acting as a pigment.

STREAK

2-12. The streak of a mineral is the color of its powder. It is frequently the most important test used to identify certain minerals, especially ones with a metallic luster, for it is the true color of the mineral. The color of a mineral in mass may differ greatly from the color of its streak, which is fairly constant and much lighter. The streak may be determined by crushing, filing, or scratching the sample. The most satisfactory means, however, is to run a point of the mineral over a piece of white unglazed porcelain. Small porcelain plates, known as streak plates, are made especially for this purpose. Streak is of the most value in distinguishing among dark colored minerals such as the metallic oxides and sulfides. It is of less value in discriminating among the light colored silicate and carbonate minerals, most of which have a white streak.

TENACITY

2-13. Tenacity refers to the behavior of a mineral when an attempt is made to break, bend, cut, or crush it. A mineral is "brittle" if it breaks or powders easily, "malleable" if it flattens when struck with a hammer, and "tough" if its resistance to being torn apart is great. A mineral is "flexible" if it bends under pressure and remains bent when the pressure is released, and "elastic" if when bent it returns to its original position upon release of pressure.

ACID REACTION

2-14. This test is used most effectively to identify the carbonates. Any acid plus a carbonate will produce an effervescent reaction. Hydrochloric acid is most commonly used.

SPECIFIC GRAVITY

2-15. The specific gravity of a mineral is its weight compared with the weight of an equal volume of water. In a pure mineral of a given composition it is a constant factor and is an important aid in identification. Impurities are responsible for the variations of specific gravity. In the field, the relative specific gravity is obtained by comparing specimens of equal size. Since quartz is relatively abundant and has a specific gravity of about 2.65, other minerals may be compared with quartz for a rough approximation ; this is done by hefting the various minerals and comparing their relative weights.

TASTE

2-16. Most minerals that are readily soluble in water have a distinctive taste. Halite, for example, can be identified quite easily by its salty taste.

ROCK-FORMING MINERALS

GENERAL

2-17. Although approximately 2,000 varieties of minerals are known, only about 200 have definite geologic and economic importance. Of these 200, only about a dozen or so are found in most common rocks. Following are the descriptions of the most important of these rock-forming minerals. Paragraph 2-42 lists identifying characteristics of the common minerals.

QUARTZ

2-18. Quartz, one of the most common minerals on earth, is found in many types of rocks. It is an important constituent of granite, sandstones, quartzite, schists, and gneisses, and often is associated with feldspar. Quartz is very resistant to weathering and is altered chiefly by physical disintegration rather than chemical agents. The chemical composition of all quartz is silicon dioxide. The impurities that are present are responsible for the variety of colors. Quartz may be transparent, translucent, or opaque. Crystalline quartz minerals have a definite arrangement of molecules, that, under proper conditions, produce six-sided crystals, but such conditions are not often present and a really good crystal of quartz is hard to find.

FELDSPAR GROUP

2-19. Chemically, this group is made up of potassium-calcium-sodium-aluminum silicates. Feldspars are probably more widely distributed than any other group of rock-forming minerals. They occur in most of the ingenous rocks, such as granites, felsites and lavas; in certain sandstones and conglomerates of the sedimentary rock types; and in gneisses and other metamorphic rocks. Of the feldspars, orthoclase and plagioclase are among the most important. Orthoclase, which is abundant in granites and gneisses, is white, gray, or pink, and exhibits the striking cleavage common to all feldspars. Plagioclase, which is the predominant light-colored mineral in diorite and gabbro, is distinguished from orthoclase by the fact that the two good cleavages are not at right angles and by its distinctive darker color.

MICA GROUP

2-20. The mica group consists of complex potassium-aluminum silicates with magnesium, iron, and sodium. These minerals are transparent with varying shades of yellow, brown, green, red, and black in thicker specimens. The chief characteristic of this group is that its minerals are capable of being split very easily into extremely thin and flexible sheets. Biotite (black) and muscovite (white) are two representative varieties. Biotite and muscovite have wide distribution in most rocks. Biotite, the black variety, occurs in many granites, gabbros, and their fine-grained equivalents. Muscovite, the light variety, is an abundant mineral in metamorphic rocks such as crystalline schists and gneisses. It is especially useful in the identification of schist.

CALCITE

2-21. Calcite consists of calcium carbonate occurring in a large variety of crystal forms. It is found as a vein mineral in many igneous rocks, but its greatest occurrence is as the primary constituent of limestone. It may also occur as a cementing mineral in other sedimentary rocks.

DOLOMITE

2-22. Dolomite is a calcium-magnesium carbonate. It is the primary constituent of the rock dolomite (dolostone). It is also widespread as a constituent of limestones or marbles.

AMPHIBOLE GROUP

2-23. Amphiboles are complex calcium-magnesium silicates. Hornblende is a common variety that is usually distinguishable from the other amphiboles by its dark color and splintery appearance. Amphiboles are important rock-forming minerals that occur in a variety of igneous and metamorphic rocks.

PYROXENE GROUP

2-24. Pyroxenes are complex calcium-magnesium-iron silicates. The pyroxenes are found chiefly in igneous rocks such as basalts, gabbros, and diorites. It is usually quite difficult to distinguish between the amphiboles and the pyroxenes. They resemble each other in all respect except cleavage angles.

MAGNETITE

2-25. Magnetite is a ferric oxide. It is commonly a minor constituent of igneous rocks. Where it occurs in masses large enough to mine, it is a profitable source of iron.

HEMATITE

2-26. Hematite is also a ferric oxide. Hematite is found as an accessory mineral in igneous rocks and primarily as a sedimentary rock is ore deposits. It is the most important source of iron. It commonly weathers to limonite.

LIMONITE

2-27. Limonite is the name for a group of widespread hydrous ferric oxides, the most common of which is goethite. Limonite is widespread, as it results from the weathering of other iron minerals. In some areas it occurs in sufficient quantities to be mined as one ore of iron. The residual limonite cappings occuring over rocks containing iron-bearing sulfides are called gossans. Where weathering has proceeded for a long time over rocks containing ferrous minerals, the resultant material is called laterite. The yellowish or reddish staining commonly observed on weathered rocks is usually limonite.

IRON PYRITE

2-28. Iron pyrite, commonly known as "fool's gold", is an iron sulfide. It is common as an accessory mineral in all types of rocks.

GALENA

2-29. Galena is a lead sulfide. It occurs in many different types of rocks and is the primary ore of lead.

OLIVINE

2-30. Olivine is a magnesium-iron silicate, with a color olive to grayish-green to brown. An important characteristic of this mineral, due to its granular texture, is its friability or tendency to crumble into small grains. Olivine is a characteristic mineral of the less silicious igneous rocks such as gabbros, peridotites, and basaltic lavas, but it also occurs in metamorphosed magnesium limestone and some schists.

Gypsum

2-31. Gypsum is a calcium sulfate hydrated with water. It is found extensively in sedimentary deposits, often interbedded with limestone, rock salt and clay. Gypsum is normally the first salt precipitated during the evaporation of sea water.

GENERAL IDENTIFICATION CHARACTERISTICS

Introduction

2-32. The following is a list of common rock-forming minerals which gives characteristics that may be used for identification. The most helpful identifying characteristics are emphasized. General uses of each mineral are also presented.

Quartz-Silicon Dioxide

- *Hardness:* 7
- *Cleavage:* None
- *Fracture*: Conchoidal
- *Color*: White, colorless, ink, violet, gray
- *Streak*: White
- *Luster*: Vitreous
- *Sp.Gr*: 2.65
- Primary identifying characteristics: Luster, fracture, hardness
- *Uses*: Rock aggregate, gems, glass

Feldspar Group

2-33. Potassium Aluminum Silicates (orthoclase) to Sodium and Calcium Aluminum Silicates (plagioclase).

- *Hardness: 6*
- *Cleavage*: Two directions at right angles
- *Fracture*: Uneven
- *Color*: Colorless, white, pink, red, gray, green
- *Streak*: White
- *Luster*: Vitreous
- *Sp.Gr*: 2.5—2.7
- *Primary identifying characteristics*: Hardness, cleavage, striations (plagioclase)
- *Uses*: Porcelain, glazes

Mica Group

2-34. Potassium Aluminum Silicates with Magnesium, Iron, Sodium, and Hydroxyl Group.

- *Hardness:* 2—4
- *Cleavage*: Perfect basal—one direction
- *Fracture*: Uneven
- *Color*: Transparent with varying shades of yellow, brown, black, red, or green
- *Streak*: White
- *Luster*: Vitreous to pearly
- *Sp. Gr*: 2.8—3.2

- *Primary identifying characteristics*: Cleavage, color
- *Uses*: Insulator, lubricant

CALCITE

2-35. Calcium Carbonate

- *Hardness:* 3
- *Cleavage*: Perfect in three directions (rhombohedral)
- *Color*: Usually white or colorless
- *Streak*: White
- *Luster*: Vitreous to pearly
- *Reaction to acid*: Effervesces readily in cold dilute hydrochloric acid
- *Sp.Gr*: 2.72
- *Primary identifying characteristics*: Acid reaction, cleavage, hardness
- *Uses*: Cements, lime, fertilizer

DOLOMITE

2-36. Calcium, Magnesium Carbonate

- *Hardness:* 3.5-4
- *Cleavage*: Three directions (rhombohedral)
- *Fracture*: Uneven
- *Color*: Variable, but commonly white
- *Streak*: White
- *Luster*: Glassy to dull
- *Sp.Gr*: 2.9
- *Reaction to acid*: Powder will effervesce slowly in cold dilute hydrochloric acid, but coarse crystals will not
- *Primary identifying characteristic*: Acid reaction
- *Use*: Building stone

AMPHIBOLE GROUP

2-37. Complex Calcium, Magnesium Iron, Aluminum Silicate

- *Hardness:* 5—6
- *Cleavage*: Two directions making angles of 56° and 124°
- *Color*: Dark green, brown, black
- *Streak*: Dark green, brown
- *Luster*: Glassy
- *Sp. Gr*: 2.9—3.45
- *Primary identifying characteristics*: Long, prismatic, six-sided crystals; cleavage
- *Uses*: Gems, poor grades of asbestos

PYROXENE GROUP

2-38. Complex Calcium, Magnesium, Iron, Aluminum Silicate

- *Hardness:* 5—7
- *Cleavage*: Two directions making angles of 87° and 93°
- *Color*: Dark green, brown, black

- *Streak*: Grayish-green
- *Luster*: Glassy
- *Sp. Gr*: 3.2—3.7
- *Primary identifying characteristics*: Short, stubby crystals; cleavage
- *Use*: Gems

MAGNETITE

2-39. Ferric Oxide (Fe_3O_4)

- *Hardness:* 6
- *Cleavage*: None
- *Fracture*: Uneven
- *Color*: Black
- *Streak*: Black
- *Luster*: Metallic
- *Sp.Gr*: 5.2
- *Primary identifying characteristic*: Strongly magnetic
- *Use*: Iron ore

HEMATITE

2-40. Ferric Oxide (Fe_2O_3)

- *Hardness*: 5.5—6.5
- *Cleavage:* None
- *Fracture*: Uneven
- *Color*: Iron gray to red
- *Streak*: Red to brownish red
- *Luster*: Submetallic to dull
- *Sp.Gr*: 5.3
- *Primary identifying characteristic*: Streak
- *Uses*: Iron ore, paint pigment

LIMONITE (GOETHITE)

2-41. Hydrous Ferric Oxide

- *Hardness:* 5—5.5
- *Cleavage*: None
- *Fracture*: Uneven
- *Color*: Blackish brown to yellowish or reddish brown
- *Streak*: Brownish yellow, orange yellow
- *Luster*: Dull to earthy
- *Sp.Gr*: 3.3—4.3
- *Primary identifying characteristic*: Streak
- *Uses*: Iron ore, paint pigment

IRON PYRITE (FOOL'S GOLD)

2-42. Iron Sulfide

- *Hardness*: 6—6.5
- Cleavage; None

- *Fracture*: Uneven
- *Color*: Brass yellow
- *Streak*: Greenish black
- *Luster*: Metallic
- *Sp. Gr*: 4.9—5.2
- *Primary identifying characteristics*: Well-formed cubic crystals with striated faces, color
- *Use*: Manufacture of sulfuric acid

GALENA

2-43. Lead Sulfide

- *Hardness:* 2.5
- *Cleavage*: Perfect in three directions (cubic)
- *Fracture*: Uneven
- *Color*: Lead gray
- *Streak*: Lead gray
- *Luster*: Metallic
- *Sp. Gr*: 7.4—7.6
- *Primary identifying characteristics*: Cleavage, specific gravity
- *Use*: Chief ore of lead

OLIVINE

2-44. Iron, Magnesium Silicate

- *Hardness*: 6.5—7
- *Cleavage*: Poor
- *Fracture*: Conchoidal
- *Color*: Olive to grayish-green to brown
- *Streak*: White to colorless
- *Luster*: Glassy
- *Sp. Gr*: 3.2—4.4
- *Primary identifying characteristic*: Small, glassy grains
- *Uses*: Gems, fertilizer

GYPSUM

2-45. Hydrous Calcium Sulfate

- *Hardness*: 2
- *Cleavage*: One direction
- *Fracture*: Uneven
- *Color*: White, gray, pink
- *Streak*: White
- *Luster*: Pearly, silky
- *Sp. Gr*: 2.2—2.4
- *Primary identifying characteristic*: Hardness
- *Uses*: Plaster, fertilizer

Apatite

2-46. Calcium, Fluoride Phosphate

- *Hardness:* 5
- *Cleavage*: One direction
- *Fracture*: Uneven
- *Color*: Red, brown, black, green, yellow, white
- *Streak*: White
- *Luster*: Vitreous, resinous
- *Sp. Gr*: 3.15—3.20
- *Primary identifying characteristic*: Well-formed, rounded crystals
- *Uses*: Gems, abrasives

Serpentine

2-47. Hydrous Magnesium Silicate

- *Hardness*: 2—5
- *Cleavage*: Commonly one direction, but may be in prisms
- *Fracture*: Conchoidal or splintery
- *Color*: Green to yellow
- *Streak*: White
- *Luster*: Waxy to dull
- *Sp. Gr*: 2.2—2.6
- *Primary identifying characteristics*: Foliated or fibrous, usually massive crystals; smooth, greasy feel
- *Use*: Principal source of asbestos

Talc

2-48. Hydrous Magnesium Silicate

- *Hardness:* 1
- *Cleavage*: One direction
- *Fracture*: Splintery and uneven
- *Color*: White, pale green
- *Streak*: White
- *Luster*: Pearly to greasy
- Sp. Gr: 2.8
- *Primary identifying characteristic*: Hardness
- *Uses*: Talcum powder, insulators, paint, paper, rubber

Fluorite

2-49. Calcium Fluoride

- *Hardness*: 4
- *Cleavage*: Four directions (octahedral)
- *Fracture*: Uneven
- *Color*: White, green, purple, black, brown, yellow, blue
- *Streak*: White
- *Luster*: Glassy to pearly

- *Sp.Gr:* 3.2
- *Primary identifying characteristics*: Cleavage, hardness
- *Use*: Flux in steel making

SECTION II - ROCKS

DEFINITION

2-50. A rock is generally defined as a mineral or an aggregate of minerals forming an essential part of the earth's crust. This definition applies to the majority of rocks; however, a few rocks are entirely biochemical in origin, such as coral, or are formed by a combination of biochemical and inorganic processes, such as coal.

MAJOR ROCK TYPES

2-51. Based on the principal mode of origin, rocks are grouped into three large classes—*igneous, sedimentary,* and *metamorphic*. Igneous rocks are of primary origin. They are the rocks which have solidified from molten material called magma. Sedimentary rocks are of secondary origin. They are made up of other rocks and minerals which have been laid down chiefly under water by mechanical, chemical, or organic agents or by wind or ice (glacier) action. Metamorphic rocks are formed from original igneous or sedimentary rocks by alteration through the application of heat, pressure, or chemically active fluids and gases upon the rocks.

IGNEOUS ROCKS

MODE OF OCCURRENCE

2-52. (Figure 2-1, page 2-12). Igneous rocks, formed by the consolidation of molten material, have their source within the earth at some unknown depth. This molten material when forced upward towards the surface of the earth invades other kinds of rocks. If its upward movement is stopped at some depth below the surface, where it cools and solidifies, it is called intrusive rock. If the molten material reaches the surface before it solidifies, it is called extrusive or volcanic rock or lava.

Intrusive Igneous Rocks

2-53. The intrusive rock masses are further classified according to their shape or form and their relationship to the structure of the intruded rock as follows:

Dikes and Sills

2-54. Dikes are tabular igneous bodies that are intruded at an angle to the bedding of the surrounding formations. Sills are similar bodies which are intruded parallel to the bedding planes of the rocks which enclose them. The thickness of a dike or sill may vary from a few inches to many yards, but this dimension is usually quite small in relation to the length and width of the intrusive body. As an example, the Palisades sill of New York has a thickness of 1,000 feet and a length of over 100 miles.

Batholiths

2-55. Very large, irregular masses of intrusive igneous rock covering an area of over 40 square miles are called batholiths. Though originally deeply buried beneath the earth's surface, they have become exposed through processes of uplift and erosion. A good example of a batholith is one in central Idaho which has an estimated area of over 80,000 square miles. Smaller bodies of similar origin are called stocks.

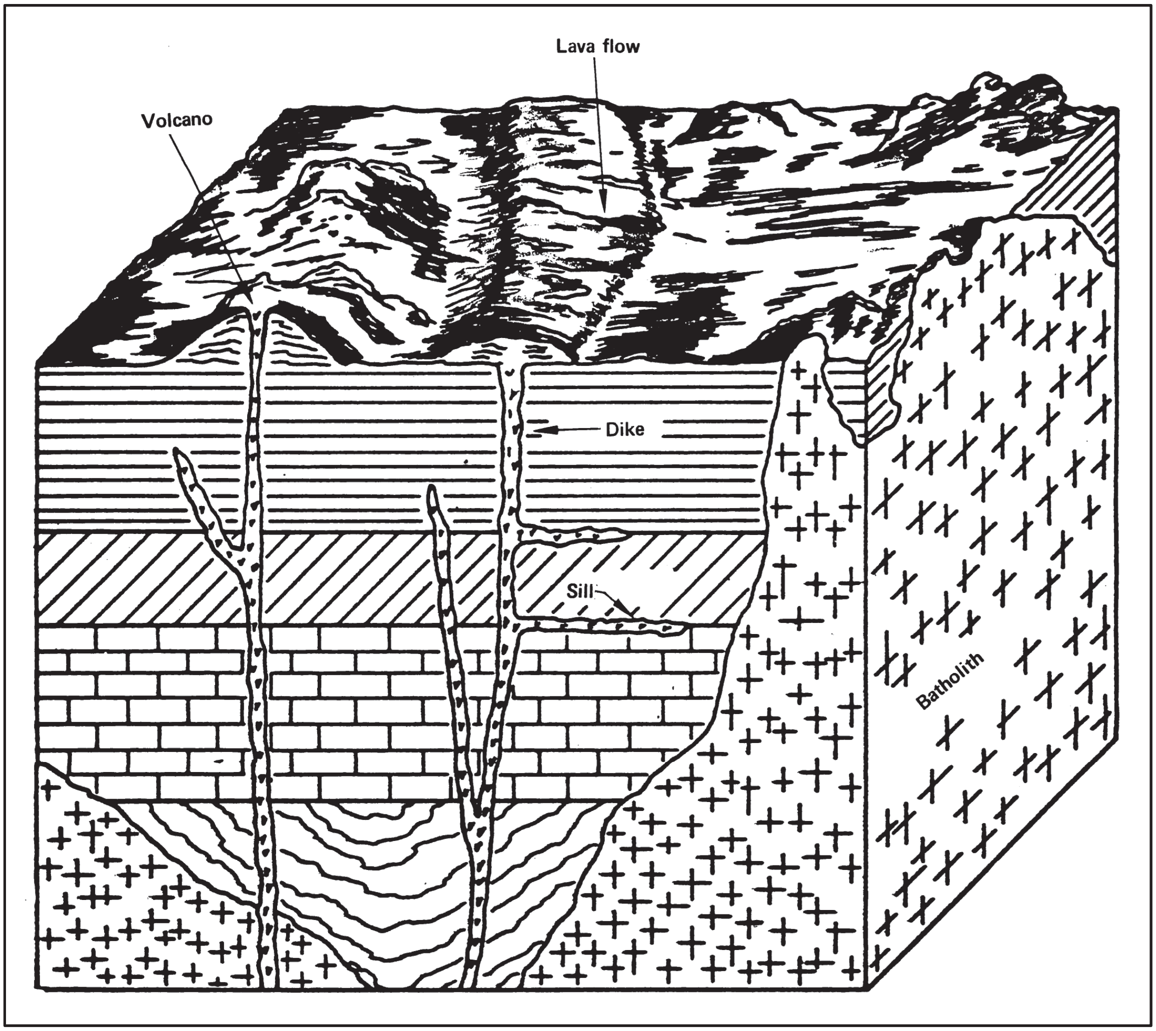

Figure 2-1. Environment of igneous rock formation

Extrusive Igneous Rocks

2-56. Extrusive igneous rocks are classified according to whether they reach the earth's surface as a flow or as an ejection of fragments of varying size.

Lava Flows

2-57. Lava flows are the results of the solidification of lava which has poured out of fissures in the earth's crust or poured out of volcanoes. These flows are the most common modes of occurrence of extrusive rocks.

Pyroclastics

2-58. Explosive volcanoes frequently eject great quantities of broken and pulverized rock material and blobs of molten lava which solidify before striking the ground. These volcanic ejections are termed pyroclastic materials and vary in size from great blocks weighing many tons through small cinders or lapilli to fine dust size particles referred to as ash.

Chemical Composition

2-59. A mass of molten rock known as magma may be regarded as a complex solution containing many minerals, one of which behaves as an acid (silicon dioxide) and others which behave as bases (iron oxides, aluminum oxides, etc.). As the magma gradually solidifies, minerals separate out of solution. If more silica is available than is necessary to satisfy the bases in the magma, the surplus will show itself as free silicon dioxide (quartz) and the resulting rock is acidic. If the bases are excessive, the mineral composition will reveal this condition by the presence of iron-magnesium minerals (hornblendes, olivine, etc.), and the rock is said to be basic. As a rule, acidic rocks are lightcolored; basic rocks are dark to black. The one apparent exception to this rule is obsidian, an acid glassy rock which normally looks dark colored. (Note. The color of its powder is white). Any tone of red or pink will fall into the light colored grouping, whereas any tone of green will be classified with the dark colored minerals.

Texture

2-60. The texture of an igneous rock is determined by the size, shape, and manner of aggregation of its component minerals. Texture is controlled primarily by the rate of cooling of the molten magma, and the cooling rate in turn is directly controlled by the size, shape and position of the molten magma at the time of solidification. In general, the slower the molten magma cools, the larger the size of the mineral grains.

Coarse-Grained

2-61. When solidification of the molten magma takes place slowly under a thick cover of rock (e.g., batholith), large crystals are formed that are visible to the unaided eye. This texture is usually referred to as coarsegrained.

Fine-Grained

2-62. When molten magma is injected into the upper layers of the crust, as in sills and dikes, solidification takes place much more rapidly. Under these conditions small crystals of equal size tend to form a fine-grained texture which can only be seen with a hand lens or microscope.

Glassy (Noncrystalline)

2-63. When the molten magma is forced to the earth's surface, as in volcanic eruptions and along fissure flows, solidification is rapid and the resultant rock may have a noncrystalline or glassy texture around the edges, grading into fine or medium-grained in the center.

Scoriaceous (Frothy or Foamy)

2-64. When the molten magma has a great deal of volatiles (gases and liquids) present and is forced onto the surface, a very frothy texture develops. The frothy appearance can range from a uniformly porous material to a jagged, angular mass.

Fragmental

2-65. Angular fragments ejected from a volcano form a fragmental texture.

Classification and Uses of Igneous Rocks (Table 2-2)

2-66. Table 2-2, page 2-14, is a breakdown of rock types based upon color rather than chemical composition and upon texture, which is merely the appearance of the material. Assuming for the present that the rock is igneous, the texture is first determined and then the color. The rock name can then be determined by use of the table. For instance, if the rock has a fine texture and a dark color, the rock name is basalt. The various rocks are:

Table 2-2. Igneous rock classification

Texture \ Color	Light colored (white, red, pink, blue)	Dark colored (black, green, grey)	Use
Coarse	Granite	Gabbro-diorite	Construction material.
Fine	Felsite	Basalt	Good aggregate.
Glassy	Obsidian		Poor construction material.
Scoriaceous (bubbly)	Pumice	Scoria	Use as lightweight aggregate or as insulating material. Do not use for load-bearing structures.
Fragmental	Ash	Ash	If fused, might be useful as aggregate. Otherwise useless.

Granite

2-67. If the rock is light colored and coarse-grained, the rock is granite. Granite is the most common light colored igneous rock with abundant supplies occurring in most areas of the world. It is composed largely of quartz and feldspar, and as a rule contains mica (the biotite variety). Granite is gray, pink, or red and its color is dependent chiefly upon the color of the feldspar and the proportion of feldspar to dark minerals. Specific gravity ranges from 2.63 to 2.75. The crushing strength ranges on the average from 15,000 to 30,000 pounds per square inch, and the percentage of absorption is less than one percent. Unweathered granite is a strong and durable rock and is used in bridge piers, sea walls, and foundations of buildings. Its chief defect is that when alternately heated and chilled, the rock surface may crumble or peel. Granites are intrusive rocks that have cooled at some depth beneath the surface in batholiths and other forms.

Gabbro-Diorite Group

2-68. If the rock is dark colored and coarse textured, it is either gabbro or diorite. However, the major difference between these rocks is the percentage of amphibole or pyroxene present. Since it is difficult to distinguish between amphiboles and pyroxenes in the field, it is generally impossible to distinguish between diorite and gabbro in the field. Fortunately, occurrence and construction properties of these rocks are so similar that it does not matter if they are not distinguished. Thus, any dark colored, coarse-grained, igneous rock can be called a diorite, a gabbro, or a gabbro-diorite. Gabbrodiorite is only about 1/20 as common as granite, but it is a durable construction material for all purposes. Diorite is composed of feldspar, and one or more dark minerals such as biotite, hornblende, or pyroxene. Diorite is a dark-colored rock but not as dark as the gabbros. It has a specific gravity of 2.85 to 3.0. Diorities are widely distributed rocks occurring as stocks and dikes, and they are frequently found associated with granite and gabbro into which they may grade. Gabbro differs from diorite in that the dark minerals such as hornblende, pyroxene, and olivine predominate. Gabbros have specific gravity between 2.9 and 3.2. Gabbros, with a high degree of compressive strength and low absorbability, are used chiefly for road material. Diorite has a compressive strength of 960—2600 kg/cm^2, averaging 1960 kg/cm2. Gabbro has values of 460— 4700 kg/cm2, averaging 1800 kg/cm^2.

Basalt

2-69. Basalt is a dark colored, fine grained rock and is the most common and widespread of the basic rock types. Basalt has a specific gravity between 2.9 and 3.1, commonly has columnar jointing, and occurs chiefly as lava flows, sheets, and dikes. Its principal uses at present are for macadam, paving aggregate, and concrete aggregate. Its compressive strength ranges from 2000—3500 kg/cm^2, averaging 2750 kg/cm^2, making it the strongest rock under compression. Because of its dark color, basalt is little used as a building stone.

Felsite

2-70. Felsite is the light-colored equivalent of basalt. It is, however, not nearly as common. When found, it will make an excellent construction material for nearly all purposes. Its compressive strength ranges from 2000—2900 kg/cm^2, averaging 2450 kg/cm^2.

Obsidian

2-71. Obsidian, the common form of volcanic glass, is identified by its glassy texture and vitreous luster. For purposes of this manual, all glassy textured igneous rocks, regardless of color, can be classified as obsidian because it is virtually impossible to distinguish basaltic glass from obsidian in the field. Obsidian has a light-colored streak and appears light colored when viewed on a thin edge. This rock has no value as a construction material, as it is easily crushed into a powder of glass fragments.

Pumice

2-72. Pumice is light colored volcanic rock composed of tiny glass bubbles. Pumice has a very low specific gravity due to the volume of gas trapped within the bubbles. This rock has been successfully used as a lightweight aggregate in prefabricated concrete construction. Pumice may also have value as an insulating material.

Scoria

2-73. Scoria, the dark colored equivalent of pumice, is usually composed of larger glass bubbles or "vesicles". Scoria has much the same construction characteristics as pumice.

Ash

2-74. Ash is the unconsolidated fine sand, silt, and clay size particles which are emitted from the mouth of an active volcano. As the material settles, a blanket of sediment is formed. This sediment may fuse when it is deposited, if the material is still in a molten state, or it may form layers of unconsolidated dust. Ash has been successfully used as pozzolan material to mix with Portland cement. Its other construction usability depends upon the degree to which it has fused. When consolidated, ash is termed tuff.

SEDIMENTARY ROCKS

Mode of Occurrence

2-75. Sedimentary rocks, or stratified rocks, are of secondary origin, since they are formed chiefly from pre-existent materials. A few sedimentary rocks are formed from the remains of plants and animals. The material from which sedimentary rocks are composed may have been pre-existing igneous, metamorphic, or sedimentary rocks. The material is transported by some medium to a place of final deposition. The most common agency of transportation is water, but many sediments are deposited on land by wind and ice. Sedimentary rocks are formed of layerlike masses through cementation, compaction, or recrystallization.

Classification of Sediment

2-76. The products of rock decay vary greatly in size and shape, but when subjected to the action of running water they sometimes grade into particles of approximately equal size. The Corps of Engineers Unified Soils Classification System defines unconsoliidiated fragmental material as follows:

- Cobbles are rock and mineral fragments that are too large to pass through the 3-inch sieve (diameter greater than 76 mm) and smaller than 6 inch.

- Gravel is defined as rock grains or fragments with a diameter of from 76 mm (3 inches) to 4.76 mm (retention on a No. 4 sieve). Gravel varies in character and strength according to the type of rock from which it was derived, and the method of derivation.
- Sand consists of grains with a diameter range of 4.76 mm (passing No. 4 sieve) to 0.074 mm (retention on a No. 200 sieve). Sedimentary sands may vary greatly in size, shape, and mineral composition.
- Fines are the particles that pass the No. 200 sieve (.074 mm). They are subdivided into two groups.
  - Silt particles are the bulky shaped, nonplastic particles that pass the No. 200 sieve (0.074 mm).
  - Clay is defined as those particles that pass the No. 200 sieve and exhibit plasticity when mixed with water.

TEXTURE

2-77. The texture of sedimentary rocks is the size, shape, and arrangement of the individual grains composing the rocks. The shape of the grains is dependent on the weathering they have suffered. They vary from smooth and well rounded to angular. Clay particles possess flaky to needlelike shapes.

CONSOLIDATION OF SEDIMENTS INTO SOLID ROCKS

2-78. The conversion of sediment into rock, called lithification, is brought about by compaction, cementation, or recrystallization, and is rarely the work of any one single process. This lithification process is primarily responsible for whatever strength a sedimentary rock may have. Considerable time is generally required for conversion of loose sediments into solid rock.

Compaction

2-79. Ultimate consolidation of sediments can be accomplished as a result of long periods of pressure due largely to the weight of overlying materials. The pressure expels the water in the sediment and brings the rock or mineral particles closer together. This type of consolidation operates most effectively on fine-grained sediments like silts and clay (conversion of clay to shale) and on organic sediments (conversion of peat to coal).

Cementation

2-80. In porous material through which water can circulate, minerals in solution may be precipitated. Cementation occurs when these minerals eventually fill the voids between particles and bind the fragments together. The most common cementing materials are silica, iron oxide, and calcium carbonate.

Silica

2-81. Silica is the most durable kind of cement in rocks exposed to the chemical action of the atmosphere.

Iron Oxide

2-82. Iron oxide is the second most durable cement in rocks, and gives the rock a yellow, red, or brown color.

Calcium Carbonate

2-83. Calcium carbonate, the least durable of the cements, gives a white to grayish color to the rocks.

Recrystallization

2-84. Chemical recombination of dissolved minerals in permeating water may bring about the continued growth of the mineral grains in a sediment or the development of new minerals. This growth or development gives some coherence to the mass and develops a rock with an interlocking, crystalline fabric or grain. Lime sediment, for example, is readily converted into crystalline limestone or even dolomite by this process.

Structure of Sedimentary Rocks

2-85. Most sedimentary rocks are characterized by original bedded structure known as bedding or stratification. The lines of parting between individual beds or strata are called bedding planes. Such structure in sedimentary rocks results from the sorting action of water and wind. The sediment is deposited in nearly horizontal layers, which may vary in thickness from less than an inch to more than 100 feet.

Classification of Sedimentary Rocks

2-86. Sedimentary rocks are classified as (1) clastic, (2) chemical, or (3) organic, based on the mode of origin of the sediment from which they are derived. The clastic rocks commonly show separate grains. The chemical precipitates either have interlocking crystals or are earthy masses. The organic rocks commonly contain easily recognizable animal and plant remains, such as shells, bones, stems, leaves, ferns, or tree trunks. Table 2-3 lists the common sedimentary rocks and the classification characteristics which will aid in their identification.

Table 2-3. Sedimentary rock classification

Type	*Characteristics*		*Rock*	*Use*
Clastic (rock particles)	50 % of grains larger than 2 mm.	rounded	Conglomerate	Highly variable quality, usually poor
		angular	Breccia	
	Sand-sized grains Rock breaks around grains		Sandstone	For fine or coarse aggregate, depending upon cementation
	Clay-and silt-sized particles Breaks into plates		Shale	Poor construction material
Pyroclastic*	Light weight Often shows layering		Tuff	Poor construction material
Chemical or biochemical	Reacts with 10% HC1 Dense texture		Limestone	Excellent construction material
	Reacts with 10% HC1 Loosely packed shell fragments		Coquina	Usually poor construction material. Sometimes used for aggregate
	Reacts with 10% HC1 only when, powdered Dense texture		Dolomite	Excellent construction material
	Very hard, brittle Cuts glass		Chert	Poor as road aggregate. DO NOT use in concrete
Chemical residues	Black or dark reddish, brown hydrated oxides of iron and aluminum		Laterite	Good for road aggregate Hardens with alternate wetting and drying
'Also included in many igneous rock classifications.				

DESCRIPTION AND USES OF SEDIMENTARY ROCKS

Conglomerate

2-87. Conglomerates are composed of rounded and water-worn material of different sizes cemented together into solid rock. The pebbles are rounded from water action and usually made up of the more resistant minerals and rocks that may have travelled some distance from their original source. Among the commonest cements binding the pebbles together are silica, calcium carbonate, and iron oxide. Conglomerates and gravels are usually deposited in shallow water close to shore, or in streams. Gravels (unconsolidated conglomerates) are used for concrete, gravel roads, and railroad ballast. The mineral composition of the pebbles should be studied because it affects their durability. Quartz conglomerate would be more durable than a limestone conglomerate, and so on. Because of the wide variability which exists in the composition of the pebbles, however, conglomerates are usually poor for construction use.

Breccias

2-88. Breccias, angular masses of rock fragments, may be cemented into solid masses. Many types of breccias are recognized according to origin. The breccia may be the product of volcanism, formed from the coarse and fine angular material erupted by volcanic action and afterwards consolidated into solid rock. It may also result along a fault zone where the existing rock is heavily fractured. Breccias are usually very porous and permeable, and should be avoided in dam and reservoir construction. Zones of brecciated rock are often treacherous ground. Tunnels through such material must usually be strongly timbered and usually an inflow of water from the surface above complicates the construction effort. Breccia may be used for road material if properly graded or crushed to size. Its mode of formation usually makes it susceptible to rapid weathering and consequent weakness.

Sandstone

2-89. Sandstones are grains of sand (chiefly quartz) cemented together, the amount of cement reflecting the strength. Medium and fine-grained well-cemented sandstones are best suited for building purposes. Sandstones exhibit a color for each cementing material. Porous sandstones under favorable structural conditions may be reservoirs for water, gas, or oil. Nonporous sandstone is quite frequently used as railroad ballast and road construction when crushed to proper size. Sandstones of low absorption and superior hardness may be very durable, but some of the more friable ones disintegrate easily. Sandstone used in construction must be carefully selected.

Shale

2-90. Shales are compacted clays, or silts that have been deposited in water. Shales can be split into very thin leaves, exhibit a variety of color, are usually soft brittle rocks which crumble readily under the hammer when dry, and are impermeable. Shales are not as strong as sandstones and are not good construction material. Shales sometimes grade into sandstones and vice versa. The possibility of variation in sedimentary rock from shale to sandstone is an important point for engineers to bear in mind when searching for a quarry site for road material or dimension stone.

Tuff

2-91. Fine ash materials when consolidated are called volcanic tuff. Tuffs are usually soft and easily worked, but their porosity may prove troublesome to the military engineer. Tuff has been used in the manufacture of pozzolan cement. It is generally not recommended as a road or construction material.

Limestone

2-92. Limestone is the most important and widely distributed of the carbonate rocks. It is essentially calcium carbonate, white when pure. The various shades of gray to black are the most common colors. Variations in texture, strength, porosity, and durability require that each proposed limestone quarry site be carefully analyzed. Limestones vary from very fine-grained and compact rocks to coarse fragments of shells or coral (coquina). Most limestones have crushing strengths of from 9,000 to 12,000 pounds per square inch. Limestones are often found in beds of thickness up to 100 feet or more. They weather chiefly through solution. The soluble calcium carbonate is removed and the insoluble material left in place to form residual clayey soils and karst topography. Limestone is extensively used for construction material. As a building stone it is used in both inner and outer walls and in floors and foundations. Bridges and a variety of other structures are made from it. When crushed, limestone is used for the manufacture of portland cement and is mixed with crushed rock to make concrete or with asphalt to make pavement.

Dolomite

2-93. Dolomite (dolostone) is similar to limestone, except that it is slightly harder and somewhat more resistant to weathering because it is less soluble. Dolomite (Ca Mg) $(C0_3)_2$ contains magnesium in place of some of the calcium, whereas limestone ($CaC0_3$) is predominantly calcium carbonate. Dolomite is extensively used for construction material. It has much the same uses as limestone.

Chert

2-94. Chert (or flint, a variety of chert) is hard, dark-gray to black, and is formed by deposition from evaporating aqueous solutions and by the action of organic life. These deposits do not have the widespread occurrence and importance of some of the other sediments; however, they are found in some massive limestones. Chert is extensively used as a road material in the Southern United States. Chert should not generally be used as a concrete aggregate. An alkali aggregate chemical reaction takes place between the alkali in the cement of the concrete and the chert which weakens the bond between the two. Chert is usable only with a special cement not normally available in the field.

Coquina, Coral, and Chalk

Coquina

2-95. Coquina is loosely cemented seashell aggregates and is neither strong nor durable.

Coral

2-96. Coral is composed of deposits of coral reefs, coral fragments, and shells, all cemented by calcium carbonate. When hard coral is to be used as a construction material it may require quarrying, but because of fissures and veins of clay and soft coral it may be difficult to blast. It usually requires crushing. Hard coral is excellent for fills, subgrades, and base courses and when properly graded makes a good aggregate for concrete. It is also a good stabilizing material. White or nearly white soft coral, with properly proportioned granular sizes compacted at optimum moisture content, creates a concrete like surface; however, it requires considerable maintenance. Unlike hard coral, soft coral cannot be used as an aggregate.

Chalk

2-97. Chalk—minute disks of planktonic algae mixed with tiny shells of foraminifera—is pure calcium carbonate. It has no importance as a construction material.

Laterite

2-98. Laterite is a porous indurated concretionary material which is usually red to reddish-brown in color. There are three types of laterite commonly encountered in a tropical or subtropical climate. The names of these types describe their physical appearance. Wormhole lateriate (vermicular) is a massive concretionary formation with an iron rich matrix and a slaggy or wormhole-like appearance. Pellet laterite (oolitic) consists of fine soil grains which are cemented by iron oxide into pellet shaped particles. These pellets may be loosely consolidated or unconsolidated. The third type of laterite is a "soft, doughy" material which hardens irreversibly upon exposure to alternate wetting and drying. This type of laterite was first described in southern India and large deposits have been found in Africa. Wormhole and pellet laterite will also become irreversibly harder and more stable upon exposure to alternate wetting and drying. This unique property supplements the physical properties to make these two types of laterite desirable construction materials. Wormhole and pellet laterite is found in the soil profiles of sparsely vegetated and rolling to roughly dissected terrain. It is formed through the action of solutions which remove silica and other elements and thus concentrate iron and aluminum. Laterite is often confused with lateritic soil simply because the physical appearances are so similar. Lateritic soils vary in type from poorly graded sands (SP) to highly plastic clays (CH) and vary in color from a red to a reddish-brown. These soils characteristically exhibit some secondary iron cementation between mineral grains; however, there is a wide variation in the degree of cementation. Although lateritic soils also harden upon drying, they soften readily upon wetting. The lateritic soils are finer grained materials than laterite and behave accordingly. An important physical difference between a laterite and a lateritic soil is that the soil contains a higher percentage of silica. The type of laterite formed depends upon the type of rock being weathered and the amount of iron available. For example, laterite derived from a basaltic rock is usually thick, hard, and dense. Laterite is formed from iron rich rocks such as basalt, granite, and granite-gneiss. Laterite is formed as a residual soil (in place). Although some authorities have shown that laterite can be derived from sandstone, extensive areas of pellet laterite in Thailand above sandstone appear to have been transported from the place where it was formed and redeposited. Chemical weathering including the hydration of basic rock minerals such as the ferro-magnesium silicates (biotite, hornblende, pyroxene) and plagioclase and orthoclase feldspars yields the necessary iron and aluminum for laterization. The weathered rocks below the layer undergoing laterization and from adjacent higher areas are two principal sources of these minerals. It is often very difficult to determine whether a sample is a laterite, a lateritic soil, or a tropical red gravel. However, the differences in behavior of these kinds of soil material are significant and erroneous classification could lead to serious construction failures and/or hazardous consequences. For example, decomposed red granites are often mistaken for laterite and used as a base course for a road. Unfortunately, the first rainfall will turn such a roadway to mud and make it useless if traffic is allowed on it before it dries sufficiently.

METAMORPHIC ROCKS

2-99. Metamorphic rocks are those formed within the earth from preexisting rocks as a result of an enforced adjustment of these rocks to conditions entirely different from those in which they were originally formed.

MODE OF ORIGIN

2-100. Heat, pressure, and chemically active fluids are the major factors involved in metamorphism. Heat increases the plasticity of minerals, aiding the deformation. Liquids and gases act as reagents, especially when superheated. They also promote recrystallization, and form new minerals. Metamorphism occurs when regional crustal movement takes place or when magmatic intrusions occur.

CLASSIFICATION OF THE COMMON METAMORPHIC ROCKS

2-101. There are two structural or textural groups of metamorphic rocks: foliates and nonfoliates. The foliates have a texture which ranges from fine to coarse and the structure is characterized by distinct layering (foliation), laminations (flaky, tabular, or needle-like mineral particles with their long axes parallel), or banded structures. The nonfoliates are massive and display no structural features. Table 2-4 lists the common metamorphic rocks and their classification characteristics.

Table 2-4. Metamorphic rock classification

FOLIATED				
Degree of folitation	**Texture**	**Characteristics**	**Rock**	**Use**
Poor	Coarse, banded	Streaked or banded	Gneiss	Good aggregate
Medium	Medium-grained	Rich in mica, splits easily	Schist	Poor construction material
Excellent	Fine-grained	Splits easily into smooth sheets	Slate	Poor construction material
NONFOLIATED				
Mineral content		**Characteristics**	**Rock**	**Use**
Chiefly quartz, some others		Hard, breaks across mineral grains	Quartzite	Good construction material, but expensive to quarry
Chiefly calcite or dolomite		Reacts with 10% HC1, granular	Marble	Excellent, as good as limestone

Foliates

Gneiss

2-102. Gneiss is a banded metamorphic rock, the bands being mineralogically unlike. The interlocking mineral particles are generally large enough to be visible to the naked eye. Color may range from nearly white to nearly black. Other physical properties are dependent chiefly on mineral composition and size and shape of grain. The banded structure of gneisses permits the rock to be split into more or less parallel flat surfaces (sometimes called rock cleavage or foliation), and to be used in the construction of rough walls and in street work. Some of the common minerals or mineral groups present in gneisses are: quartz, feldspar, mica, amphibole, and pyroxene.

Schist

2-103. A schist is a foliated metamorphic rock in which the individual layers are mineralogically alike, and the principal minerals are visible to the naked eye. Schist differs from gneisses in mineral composition chiefly in the lack of feldspar. Quartz is the most frequently occurring essential constituent, with one or more minerals of the mica, chlorite, talc, amphibole, or pyroxene group. A schist exhibits a variety of color dependent chiefly on the kind and proportions of the principal mineral. Because of their tendency to split off along the planes of foliation, schists are often treacherous if unsupported on steep or vertical faces where the schistosity is parallel to the surface. Because of the slippery character of the foliation planes, schists sometimes will cause rock slips in quarries, rock cuts, and tunnels.

Slate

2-104. Slate is a thinly cleavable rock, the cleavage pieces mineralogically alike, and the mineral grains too small to be distinguishable by the unaided eye. Slate is dense homogeneous rock of very fine-grained texture and is the metamorphic equivalent of shales, or occasionally volcanic ash and tuffs. They represent the fine particles of mineral matter, being mostly quartz, mica, and other less important minerals. The color is gray to dark or bluish black, and its most important structural feature is its cleavage, making it valuable for roofing. Slate is generally not a good construction material.

Nonfoliates

Quartzite

2-105. Quartzite is a nonfoliated metamorphic rock derived from the recrystallization or cementation of sandstone or siltstone. Quartzite formed by recrystallization bears little resemblance to the parent rock. The cementing material is as hard as the sand or silt grains, and therefore the fractures break right through the grains. In sandstone or siltstone, the fractures pass around the grains. The rough surface is produced by the sand or silt grains which stand above the fractured surface of the weaker cementing material. The most important mineral is quartz, although feldspar minerals, mica, calcite, and others may be present. Quartzites are hard, tough, usually firm and compact, granular rocks. The color may be white, gray, yellowish, greenish, or reddish. Quartzite is excellent as crushed rock for concrete work, railroad ballast, etc., but the expense of excavation and crushing may preclude its economic use.

Marble

2-106. Marbles, when pure, are compact crystalline granular rocks composed of calcite or dolomite, or a mixture of the two, a result of the metamorphism of limestone or dolomite. The texture varies from fine to coarse. Marbles show a wide range in color and like ordinary limestone, are soluble and weather readily. Marble, when crushed, is equivalent to limestone in value as an aggregate.

Chapter 3
Structural Geology

INTRODUCTION

3-1. Structural geology is the study of relative position and orientation of rock units. Features represented in these rock units include folds, faults, and joints. These features are most clearly shown in the disturbance of the bedding planes of sedimentary rocks. Rock structure affects engineering in many ways. Folds and faults influence the choice of dam sites, and even the spacing of joints may affect uplift pressures and the safety of dams. Crushed and chemically altered rock adjoining faults may cause difficulties in tunneling operations, and earthquakes originating along faults may damage or destroy engineering structures. The design of deep cuts in rock is greatly influenced by rock structure, and the suitability of quarry sites is largely a matter of joint spacing. Perhaps the most important of all is the influence of rock structure on the circulation of ground water.

OUTCROPS

3-2. An outcrop is that part of a rock formation that is exposed at the earth's surface. Outcrops are located where there is no existing soil cover or where the soil cover has been removed, leaving the rock beneath it exposed. Figure 3-1 shows a few of the possible outcrop locations. Outcrops may indicate both the type and the structure of the local bedrock.

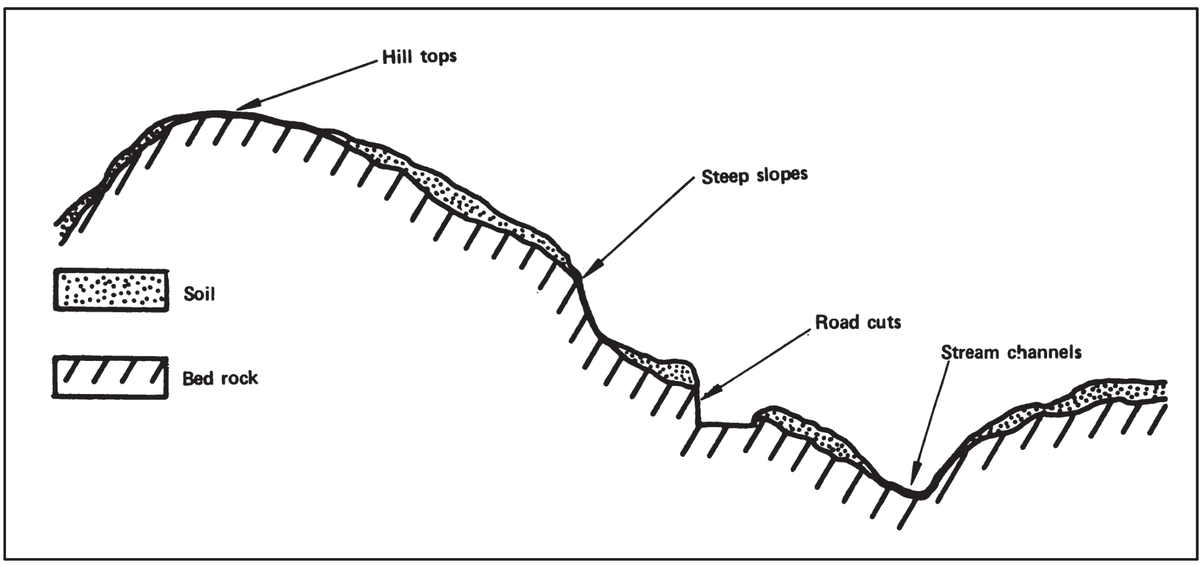

Figure 3-1. Typical locations of outcrops

ATTITUDE OF BEDS

GENERAL

3-3. To be able to discuss or describe the structure of local bedrock, the military engineer must have some means by which he can measure and define the tread of the rock on the earth's surface. This trend is known as the attitude of the rock. If the rock is sedimentary, as approximately 75% of those on the earth's surface are, the attitude is described in terms of the strike and the dip of the bedding plane. The strike is the compass direction of the horizontal line formed by the intersection of a horizontal plane and the bedding plane, and the dip is the acute angle between the bedding plane and the horizontal plane, measured at right angles to the strike direction (figure 3-2). Strike and dip are shown on a map by a strike and dip symbol. 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 each of the following: inclined beds, vertical beds, and horizontal beds. Examples of each type are given in figure 3-3.

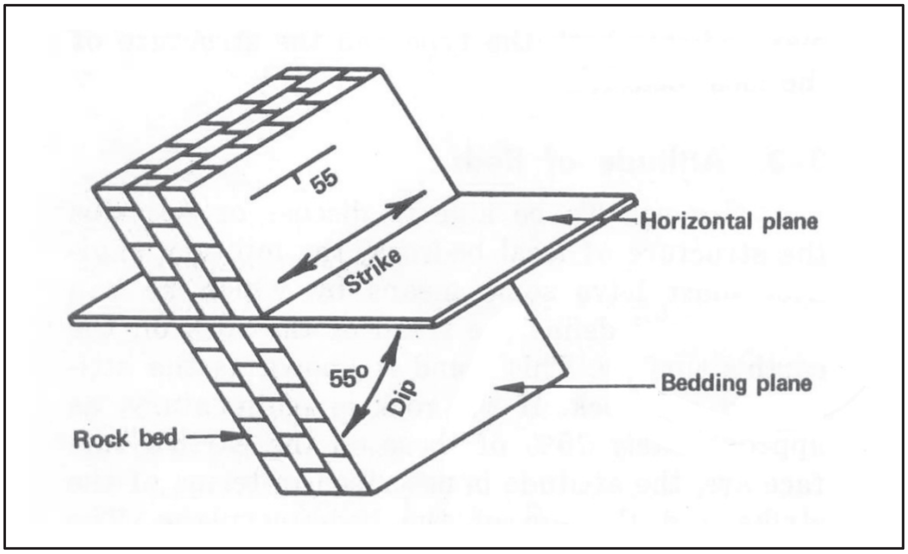

Figure 3-2. Strike and dip

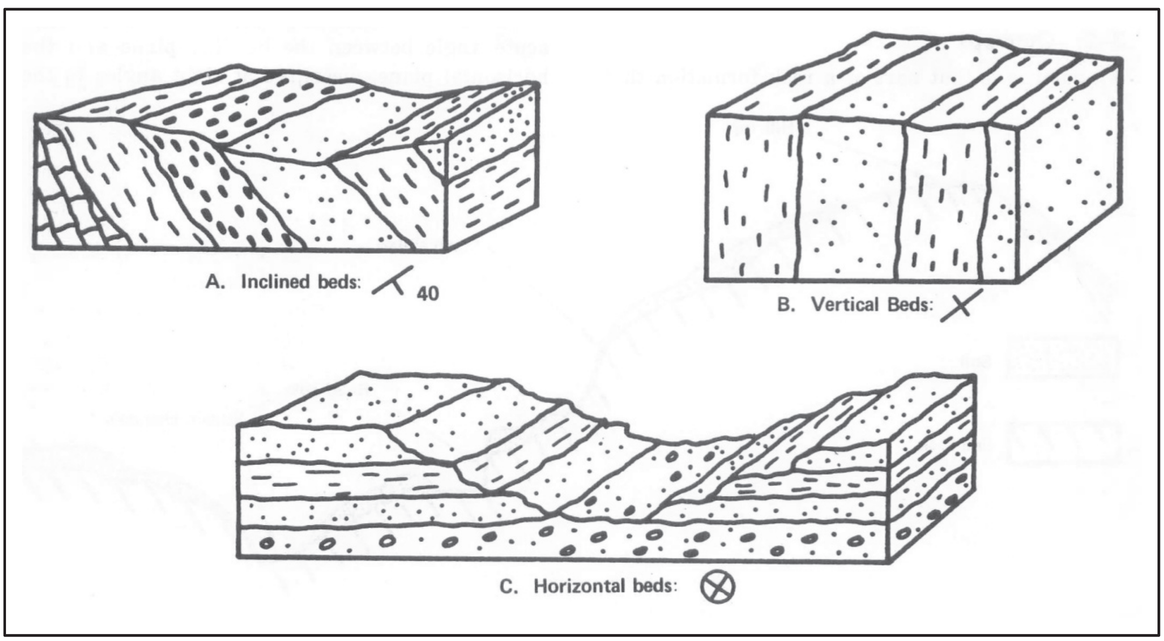

Figure 3-3. Types of beds

MEASUREMENT

3-4. The strike and dip of a rock may be measured with the M2 compass or standard Brunton compass. This compass is graduated in degrees or mils and has a bull's eye level for determining the horizontal plane when measuring the strike direction. A bubble level and a clinometer are provided to measure the dip angle. The strike direction is read directly from the compass and referenced to North, such as North 30° East, or North 20° West. The dip angle is determined by placing the compass at right angles to the strike direction and reading the acute angle indicated by the clinometer, such as South-West 10°.

INCLINED BEDS (FIGURE 3-4)

3-5. Direction of strike is the long line which is oriented in reference to the map grid lines in exactly the same compass direction as it was measured.

3-6. Direction of dip is the short line which is always drawn perpendicular to the strike line and in the direction of the dip.

3-7. Angle of dip is the number written next to the symbol.

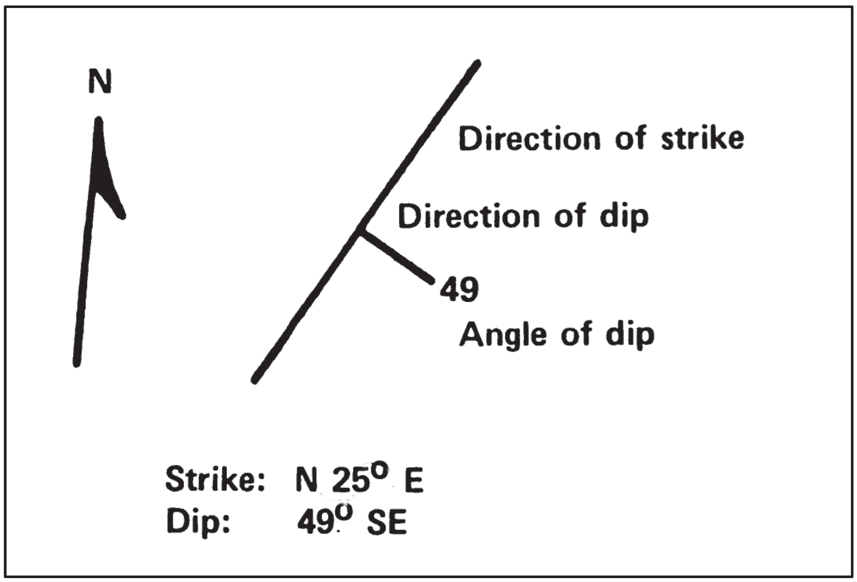

Figure 3-4. Strike and dip symbol for inclined beds

VERTICAL BEDS (FIGURE 3-5, PAGE 3-4)

3-8. The direction of strike is the same as for inclined beds.

3-9. The direction of dip is a short line crossing the line of strike, indicating that vertical beds can be considered to be dipping in either of two directions, or at 90° to either the left or the right of the strike line. The directions of strike and dip are plotted but not written on the map. The dip angle is shown opposite the dip line, providing it is less than 90°.

HORIZONTAL BEDS (FIGURE 3-6, PAGE 3-4)

3-10. The direction of strike is represented by crossed lines which indicate that the rock strikes in every direction, or that there is no single line of strike.

3-11. The dip is represented by the circle surrounding the crossed lines. The circle implies that there is no direction of dip and that there is no angle of dip, or 0° dip.

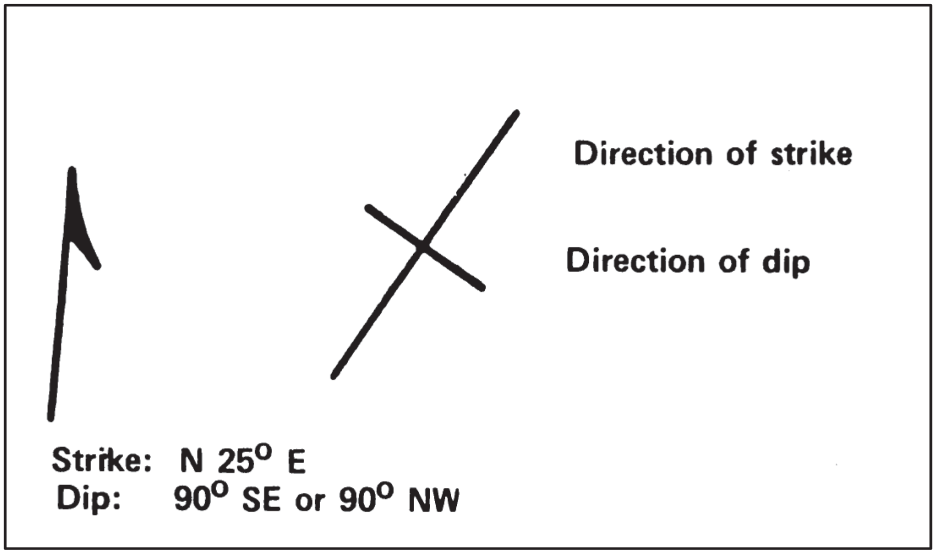

Figure 3-5. Strike and dip symbol for vertical beds

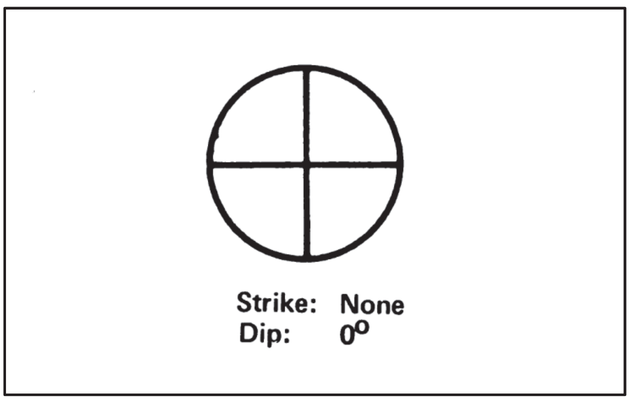

Figure 3-6. Strike and dip symbol for horizontal beds

FOLDS

GENERAL

3-12. 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 may be classified as one of two principal types: the anticline (figure 3-7), which is convex upward so that the limbs of the fold dip away from the crest; and the syncline (figure 3-8, page 3-6), which is concave upward so that the dip is from both sides toward the bottom of the trough. Since symmetry is a rarity in nature, asymmetrical anticlines and synclines are common.

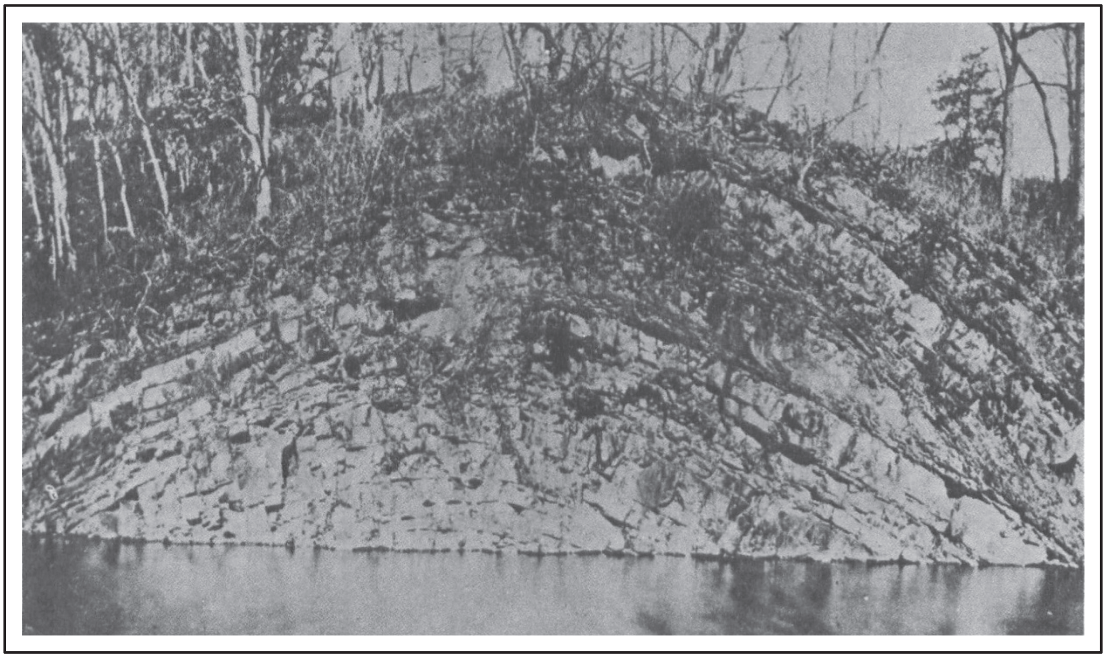

Figure 3-7. Anticlinal fold

Figure 3-8. Synclinal fold

Terminology

Axial plane

3-13. The axial plane of a fold is the plane or surface that divides the fold as symmetrically as possible. In a two-dimensional diagram, the axial plane is represented by a line. In some folds the axial plane is vertical; in others, it is inclined; and in still others it is horizontal depending on the position of the fold (figure 3-9).

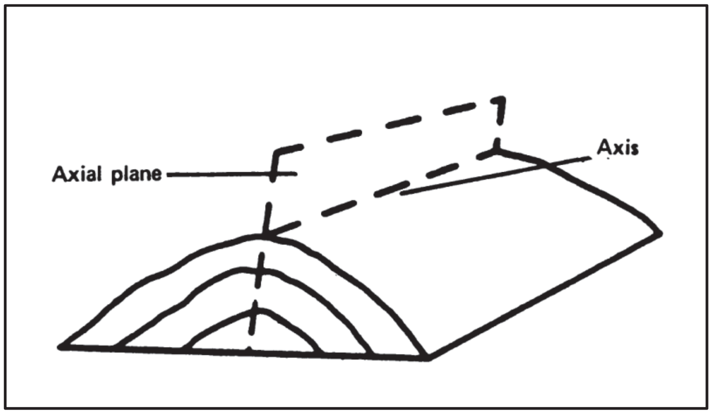

Figure 3-9. Axial plane

Axis

3-14. An axis of a fold is the intersection of the axial plane with a particular bed. Such an intersection is a line (figure 3-9). There is an axis for every bed, and every fold has many axes since each fold will generally affect many beds or layers of rock.

Limbs, or flanks

3-15. The sides of a fold when divided by the axial plane are called limbs or flanks. A limb extends from the axial plane of one fold to the axial plane of the next, such that each limb is mutually shared by two adjacent folds (figure 3-10). In an asymmetrical anticline or syncline, the limbs' dip at different angles. If the dip of the steep limb exceeds 90°, the fold is said to be overturned.

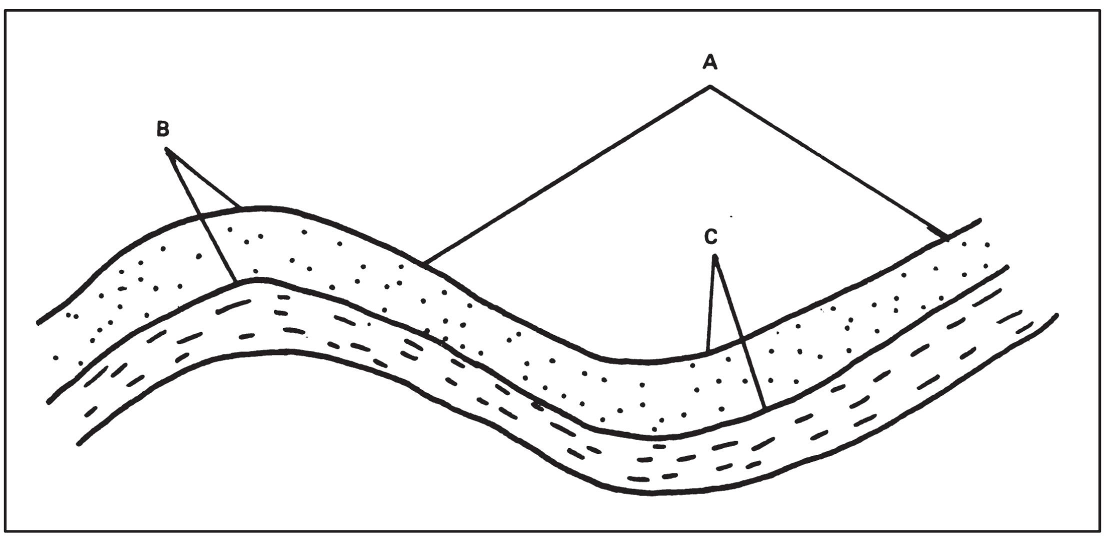

Figure 3-10. Parts of a fold: A—limb, B—crest, C—trough

Crest

3-16. The crest of fold is a line along the highest part of the fold, on a particular bed. More precisely, it is the line connecting the highest points on the same bed in an infinite number of cross sections (figure 3-10).

Trough

3-17. The trough is the line occupying the lowest part of the fold, or more precisely, the line connecting the lowest parts of the same bed in an infinite number of cross sections (figure 3-10, page 3-7).

Dome fold

3-18. A dome fold is a special case of the anticline, in which the beds dip outward in all directions from a central point.

Basin fold

3-19. A basin fold is a special case of the syncline, in which the beds dip inward from all sides toward a central point.

Homocline

3-20. The term homocline may be applied to strata that dip in one direction at a fairly uniform angle (a, figure 3-11).

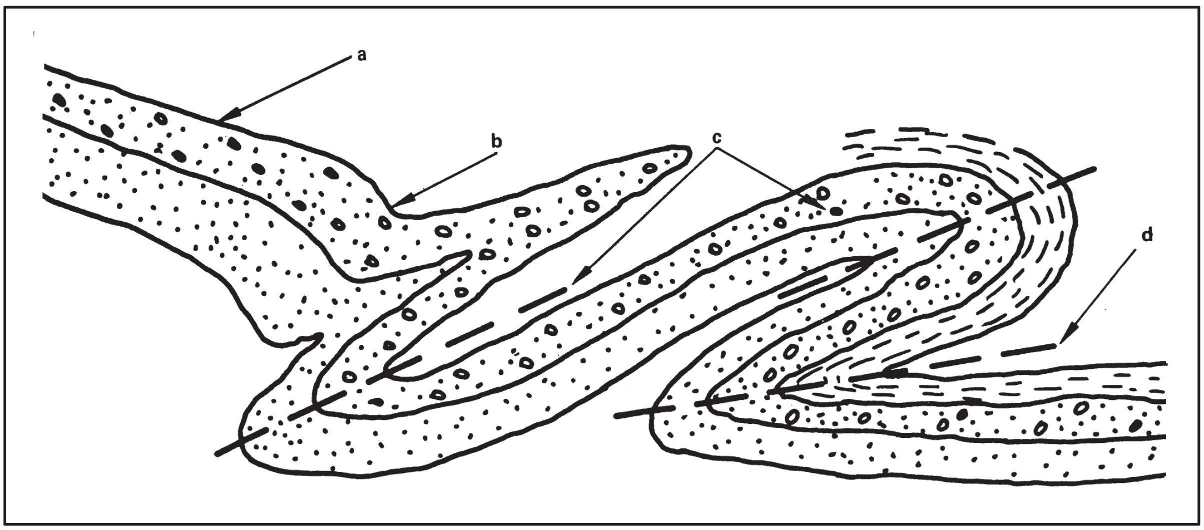

Figure 3-11. Other types of folds: a—homocline, b—monocline, c—isoclinal, d—recumbent

Monocline

3-21. In plateau areas, where bedding is relatively flat, the beds of rock may locally assume a steeper dip. Such a fold is a monocline. The beds in a monocline may dip at angles ranging from a few degrees to 90 degrees, and the elevation of the same bed on opposite sides of the monocline may differ by hundreds or even thousands of feet (b, figure 3-11).

Isoclinal

3-22. An isoclinal fold refers to folds in which the two limbs dip at equal angles from the horizontal and in the same direction (c, figure 3-11).

Recumbent

3-23. A recumbent fold is one in which. the axial plane is essentially horizontal (d, figure 3-11).

Plunging anticline

3-24. A plunging anticline will appear as an open bend when seen in an aerial view. Note that in the plan view, the limbs of the anticline converge in the direction of the axial plunge (figure 3-12). In the symbol for a plunging anticline, the long line represents the axis, the arrow at the end of this long line points in the direction of the plunge, and the short line with two arrows indicates the beds dipping away from the center.

Plunging syncline

3-25. A plunging syncline, when seen from an aerial view, appears similar to the plunging anticline. Note that in the map view the limbs of the syncline converge in the direction opposite to that of the plunge (figure 3-13). In the symbol for a plunging syncline, the long line and its arrow depict the axis of the fold and direction of plunge, as in the case of the anticline. The short lines and arrows indicate that the beds dip toward the center of the fold.

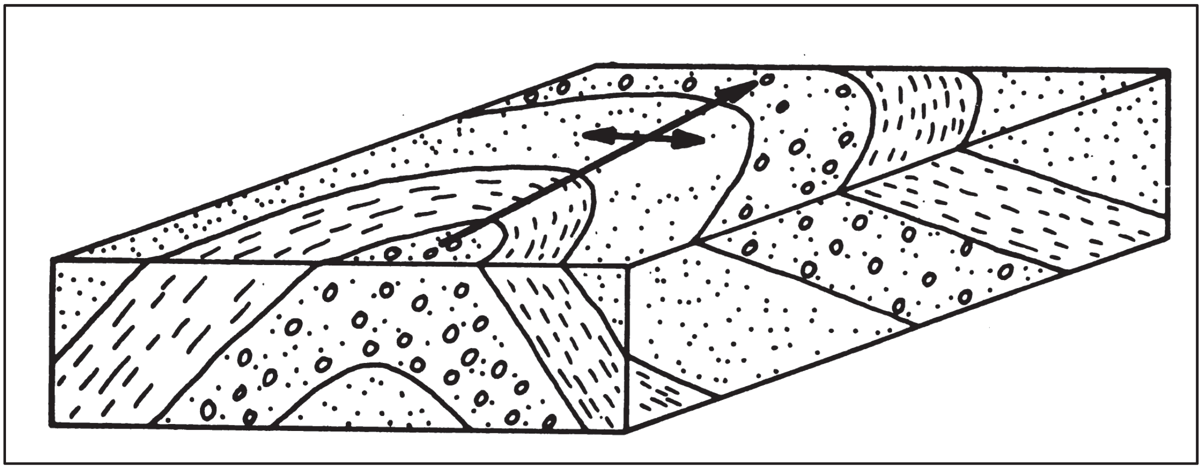

Figure 3-12. Plunging anticline with its symbol

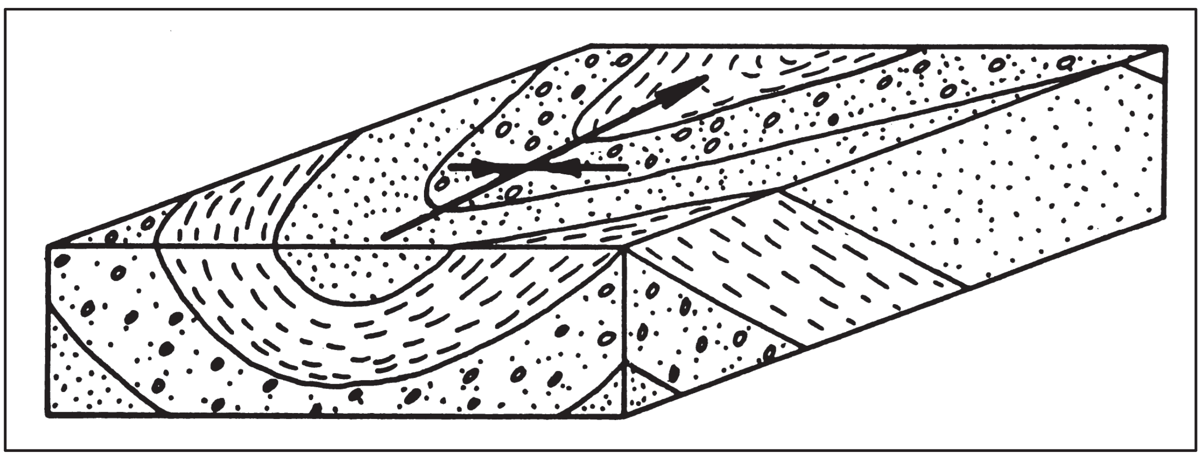

Figure 3-13. Plunging syncline with its symbol

ENGINEERING SIGNIFICANCE OF FOLDS

Tunneling

3-26. Folded rock sometimes shows considerable fracturing along the axis of the fold. With anticlines, these fractures diverge upward; with synclines they diverge downward. If a tunnel is driven along the crest of a fold, the shattered rock may present a problem which can be solved by lining. Synclines give rise to more trouble because even moderate fracturing may cause the blocks bounded by the fracture planes to drop out. Additional problems that arise along the crest of a fold may be caused by fractures acting as channels for surface water.

Quarrying

3-27. The position of folded rocks greatly influences quarrying operations. Often the dip will create a serious safety problem as well as creating drainage problems. In steeply dipping strata, the flooring operation becomes difficult as it is harder to obtain a level working surface.

Dams

3-28. Folding can cause dangerous fracturing which allows leakage or even slipping of the beds under a dam.

Mining

3-29. Crushed rocks along the crests of folds can often play an important role in the formation of ore deposits. The cavities between the crushed fragments often serve as spaces for the deposition of ore minerals. The position of the folded beds may frequently influence the method of mining to be employed. Intense folding may shatter the rocks to such an extent as to make the roof unsafe. This often requires much timbering. Folds, particularly anticlines, are of extreme importance in the location of oil. Crests of large anticlines may contain quantities of oil or natural gas.

FAULTS

GENERAL

3-30. Faults are fractures along which the opposite walls have moved with respect to one another. The 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, there are faults that are hundreds of miles long with a displacement measured in miles and even tens of miles. Faults are classified as either a normal fault (figure 3-14), (sometimes called a gravity fault), in which the hanging wall has been displaced downward relative to the footwall; or a reverse fault (figure 3-15), where just the opposite movement has occurred.

TERMINOLOGY

Fault Plane

3-31. This is the planar surface along which the movement took place.

Attitude

3-32. The dip and strike of a fault is measured in the same manner as it is 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 the horizontal plane and the plane of the fault. The hade is the complement of the dip; that is, the hade equals 90 degrees less the angle of dip (figure 3-16, page 3-12).

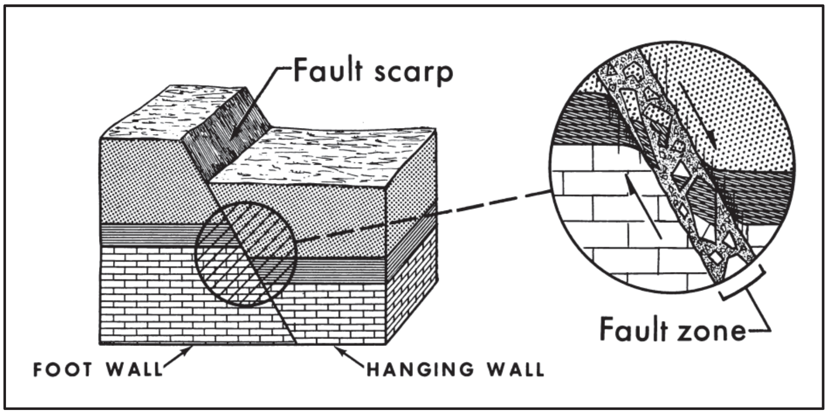

Figure 3-14. Normal fault

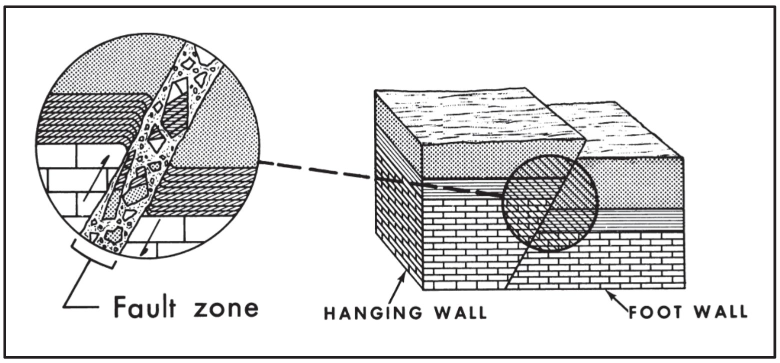

Figure 3-15. Reserve fault

Hanging Wall and Footwall

3-33. The block above the fault plane is called the hanging wall; the block below the fault plane is the footwall. A person, for instance, standing upright in a tunnel along a fault plane would have his feet on the footwall, and the hanging wall would be above him. In the case of vertical fault there would be neither a hanging wall nor a footwall.

Fault Zone

3-34. Although many faults are cleancut, in some instances the displacement is not confined to a single fracture, but is distributed through a fault zone, which may be hundreds, even thousands, of feet wide. The fault zone may consist of numerous small faults, or it may be a zone of broken or crushed rock material.

Fault Line

3-35. The intersection of the fault plane with the surface of the earth is known as the fault line, fault trace, or fault outcrop (figure 3-16).

Slickensides

3-36. Slickensides are polished and striated surfaces that result from friction along the fault plane. These scratches or striations are parallel to the direction of movement of the fault, but caution should be used in determining the direction of movement from the slickensides since they show the trend only of the last movement and several series of movements may have occurred.

Fault Breccias

3-37. Fault breccia is the angular crushed rock material found along the fault zone due to the abrasive action of the hanging wall and the footwall sliding against one another.

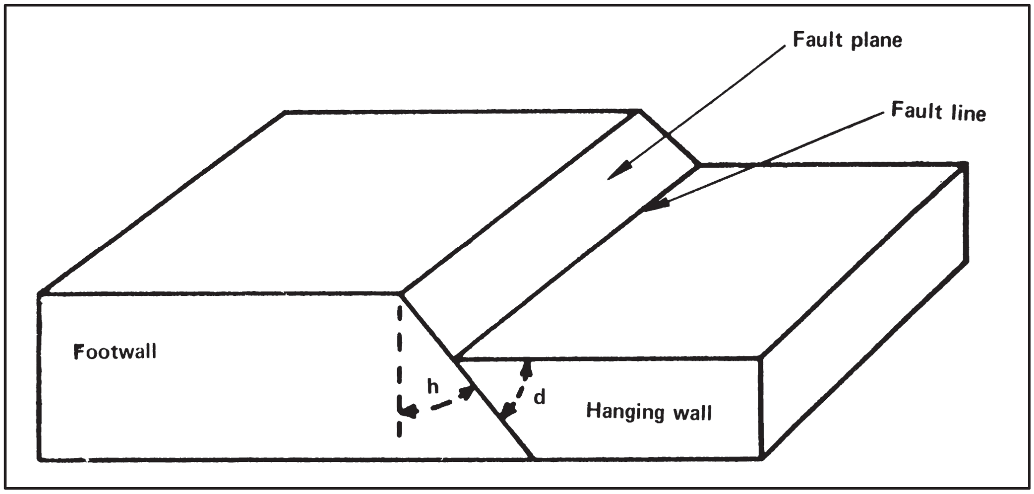

Figure 3-16. Fault terminology, d = dip, h = hade

Gouge

3-38. Gouge is very finely pulverized rock material found along the fault zone which has the appearance and feel of clay.

Drag

3-39. Drag, which is the folding of the rock beds adjacent to the fault, is also an indication of movement along the fault plane.

Fault Scarp

3-40. 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 may even be completely eroded away. As erosion wears a scarp back, the slope may lose its straightness and become irregular (figure 3-17).

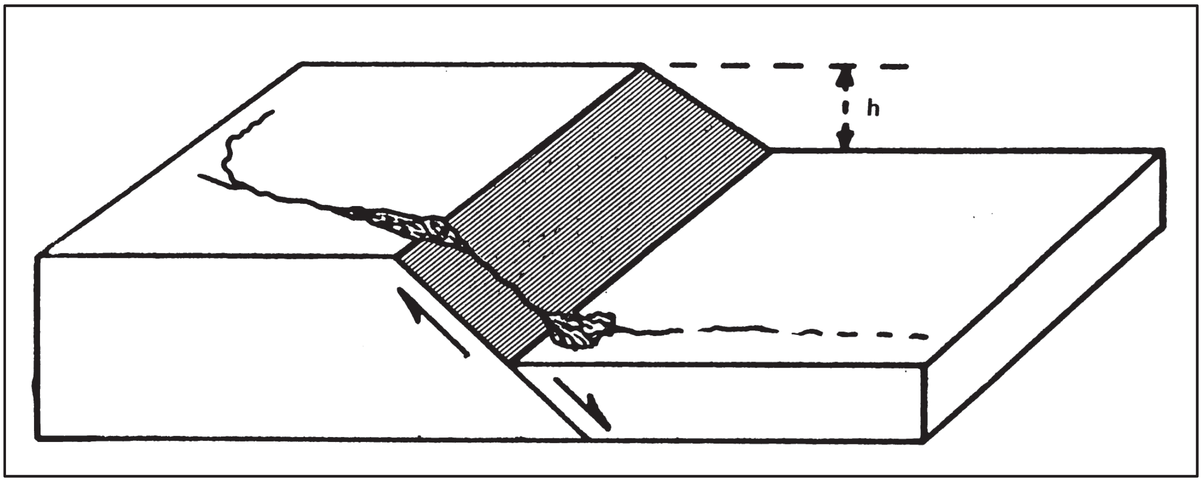

Figure 3-17. The fault scarp is shaded. The height of the scarp is h

RECOGNITION OF FAULTS

Direct Observation

3-41. Faults may be recognized in various ways. If a fault is exposed in a cliff, a road cut, or a mine working, it may be readily observed, and precise data may be obtained concerning its attitude and the displacement of the disrupted strata. In other instances the observations may not be so direct, but careful field work may bring to light data which permit a complete analysis of the fault.

Discontinuity of Structures

3-42. If a layer of rock, in a cross-sectional view, suddenly ends against a completely different layer, a fault may be present. This might occur on a cliff face, a road cut, or a stream bed. This discontinuity of beds, though it often indicates the presence of a fault, could be caused by other means such as intrusive contacts (the upward movement of molten rock material which later cooled in place), unconformities (the omission of beds of rock due to either erosion or nondeposition), and, on a small scale, cross-bedding of deposits.

Repetition and Omission of Strata

3-43. In many cases faults may be recognized by the repetition or omission of beds of rock. In figure 3-18, page 3-14, the manner by which beds may repeat themselves is illustrated. A man walking from X to X^1 would encounter the sequence of beds from A to E which would repeat themselves after crossing the fault at point F. Figure 3-19, page 3-14, illustrates the omission of beds due to faulting. A man walking again from X to X^1 would encounter the series of beds A to E, but after crossing 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 identification is often an effective means since the actual fracture of the fault is usually not visible.

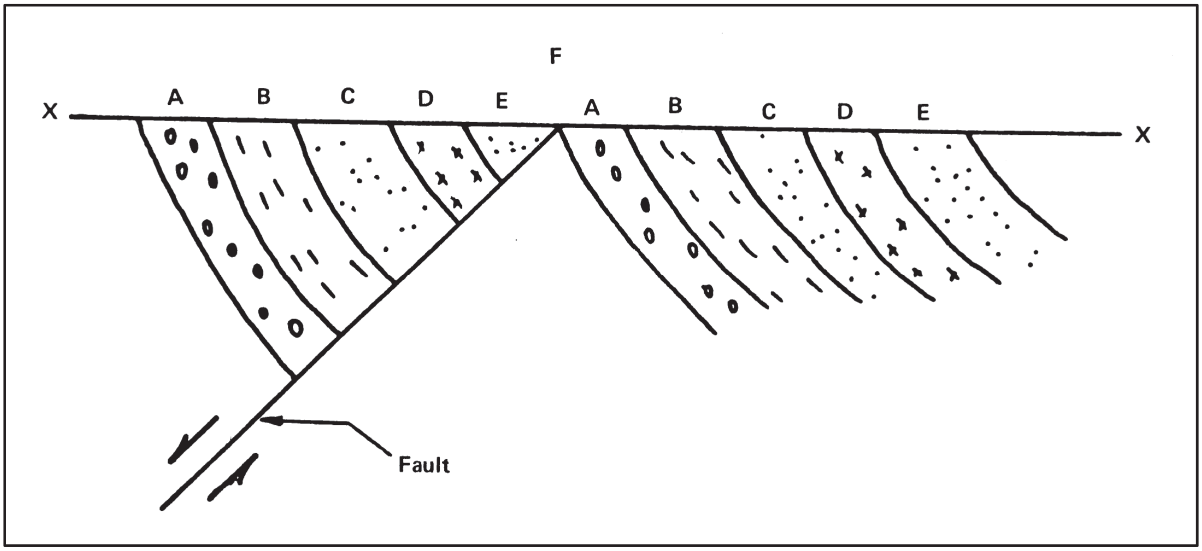

Figure 3-18. Repetition of beds

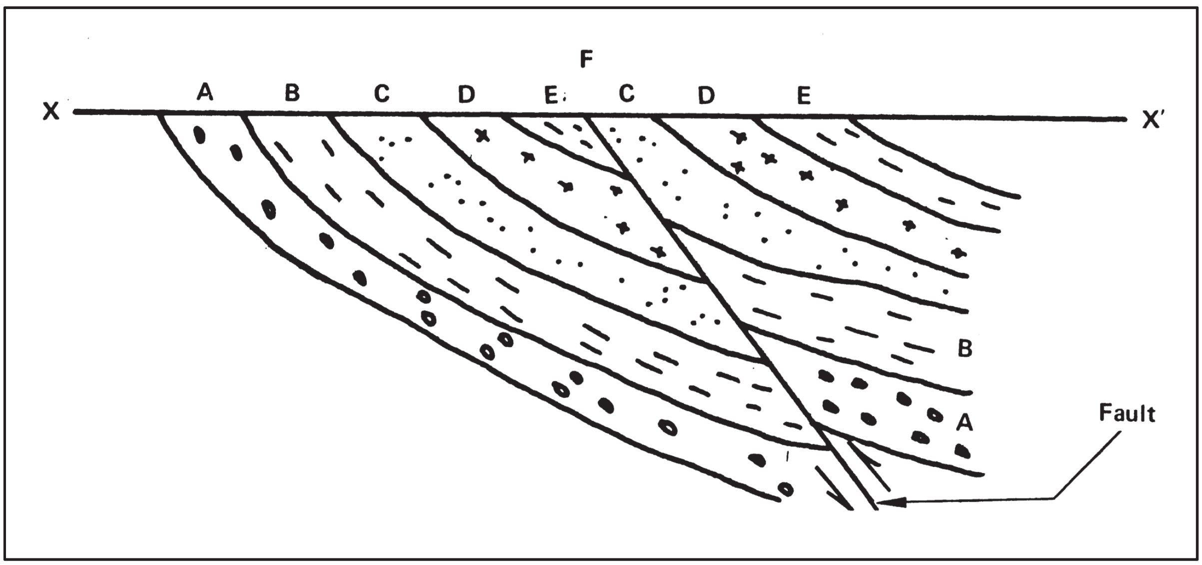

Figure 3-19. Omission of beds

ENGINEERING SIGNIFICANCE OF FAULTS

Tunneling

3-44. If a rock has been deformed by faulting, it is necessary to line the tunnel in the crushed region. Also, if the fault extends to the surface, it very often will act as a channel for surface water.

Dams

3-45. If a dam is to be constructed in a valley floor containing a fault, as is the case in many valley floors, it must be determined whether the fault is active or inactive.

Quarries

3-46. Before a quarry is opened in a faulted area, a careful reconnaissance should be made to insure that the desired rock is not displaced to an unreachable depth near the quarry site.

JOINTS

GENERAL

3-47. Joints may be defined as fractures along which there has been no visible movement along the fracture plane or surface. Although joints characteristically fracture along plane 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. The dip and strike is measured in the same manner as limbs of folds. 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 and even thousands of feet in length. Joints are formed as freshly emplaced igneous rocks contract and cool, during lithification as sedimentary rocks are compacted, during metamorphism as the rocks are stressed, and when rock masses expand as overlying rock is removed by erosion or deformation. The expansion and contraction of rocks due to alternate hot and cold periods also results in a type of jointing known as exfoliation. In dense and compact extrusive igneous rock, such as basalt, a form of prismatic fracturing known as columnar jointing often develops as the rock cools rapidly and shrinks.

CLASSIFICATION OF JOINT

Strike and Dip Joints

3-48. In folded rocks, joints are grouped into strike and dip joints to indicate their attitude. 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 bedding dips.

Oblique Joints

3-49. Oblique or diagonal joints extend in a direction that lies between the strike and direction of the dip of the associated rocks.

Joint Set

3-50. A joint set is a group of more or less parallel joints.

Joint System

3-51. A joint system consists of two or more joint sets or any group of joints with a characteristic pattern.

ENGINEERING SIGNIFICANCE OF JOINTS

3-52. Because of their almost universal presence, joints are of considerable engineering importance, 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. Needless to say, the ideal condition is seldom encountered. 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 insure a fairly even and smooth break, parallel to the face. Joints offer channels for ground water circulation and in workings below the ground water table they may greatly increase water problems. They also may exert an important influence on weathering. In quarry operations, jointing can lead to several problems. The spacing of the joints can control the size of the material removed and can also affect drilling and blasting. Drill steels can break and stick, and explosive gases can escape out of the joints.

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Chapter 4
Weathering and Erosion

INTRODUCTION

4-1. The term *weathering* describes the changes which occur when rocks are in contact with the atmosphere, surface water, and organisms, or by mechanical means. *Erosion* occurs when movement of the weathered material takes place. Water, wind, ice or the action of gravity may accomplish this. The changes brought about by weathering are important in soil formation; however, weathering should be of interest to the engineer for reasons other than its role in soil formation. Many engineering operations are concerned with weathered rock rather than with completely fresh materials, and many problems have been encountered because the effects of weathering were not considered. The forces of erosion act to move the loosened, weathered materials some distance from their starting point. This action is responsible for most of the relief features on the surface of the earth, and many of them can be quickly recognized and classified according to the agent of erosion that produced them. Conversely, some relief features can be anticipated when the major erosion force is recognized. Recognition of either the feature or the force is extremely helpful to the engineer in the solution to his engineering problems.

MECHANICAL WEATHERING

4-2. Mechanical weathering consists chiefly of extensive fracturing of rocks without any relation to the chemical changes which may be occurring simultaneously. Several of the physical processes which produce mechanical weathering are described below.

FREEZING OF WATER

4-3. Most water systems in rocks are open to the atmosphere, but preliminary freezing on the surface encloses the system. When water freezes it expands nearly one-tenth its volume, creating great pressures (up to 4000± lb/in^2) in enclosed spaces. This expansion of the ice fractures the rock and breaks it into smaller particles.

TEMPERATURE CHANGES

4-4. Daily and seasonal temperature changes cause differential expansion and contraction in rocks which result in spalling or exfoliation. This type of weathering is most noticeable in moist, cold climates and results from a combination of frost action, chemical decomposition, and temperature expansion and contraction.

ACTION OF PLANTS

4-5. Trees and plants have an amazing capacity to grow in the joints of rock masses. The wedging action caused by root growth hastens the disintegration process near the earth's surface.

MISCELLANEOUS MECHANICAL AGENTS

4-6. There are many other methods by which mechanical weathering is accomplished. Animals, by their burrowing activities, can accelerate disintegration. Crustal movements, such as faulting and folding, create much damage in a short time. Gravity causes rock slides and avalanches which break up large rock masses. Ice (in the form of glaciers) has disintegrated and transported enormous quantities of rock.

CHEMICAL WEATHERING

4-7. Certain types of chemical weathering are very important in decomposing the rocks, especially in the production of soil. Some of the ways chemical weathering takes place are listed below.

OXIDATION AND HYDRATION

4-8. Oxidation is the chemical union of a compound with oxygen. Hydration is the chemical union of a compound with water. An example is rusting, which is the chemical reaction of oxygen, water, and hematite (Fe_2O_3) to form limonite ($Fe_2O_3H_2O$). Both types of reactions are important in the decomposition of rocks, primarily those with metallic minerals.

HYDROLYSIS

4-9. This is another important decomposition process related to hydration in that it involves water. It is a result of the partial dissociation of water during chemical reactions that occur in a moist environment. It is one of the types of weathering on the sequence of chemical reactions as feldspars are altered to clays. An example of hydrolysis is the altering of sodium carbonate (Na_2CO_3) to sodium hydroxide (NaOH) and carbonic acid (H_2CO_3).

CARBONATION

4-10. This process is an important tool of weathering. It is the chemical process in which carbon dioxide from the air unites with various minerals to form carbonates. A copper penny eventually turns green from union of copper with carbon dioxide in the air to form copper carbonate. Carbon dioxide dissolved in water forms a weak acid (carbonic acid) which reacts readily with many minerals to form carbonates. It is the principal means of weathering limestone. Carbonic acid (H_2CO_3) acts as a solvent to dissolve limestone into calcium bicarbonate ($CaHCO_3$) and carries it away. This creates sink holes and caves in limestone regions (forming a type of topography known as karst topography).

SOLUTION

4-11. In this process, water acts as a solvent on certain water soluble minerals. An excellent example is the solution of sodium chloride (rock salt or halite). The decomposition of rocks containing water soluble minerals is hastened by the removal of these soluble materials. Calcite is nearly insoluble in pure water, but water which contains carbon dioxide, called carbonic acid, readily converts the calcite (calcium carbonate) into soluble calcium bicarbonate which is carried away by percolating ground waters.

END PRODUCTS OF WEATHERING

4-12. Materials produced by mechanical weathering tend to be of angular shape. These particles are composed of the same material as the parent rock. Chemical processes act to change the chemical composition of the parent rock. Materials produced chemically will have a greater volume but a lower specific gravity than that of the original material. The products of both types of weathering include materials moved in solution or colloidal suspension, and residual substances. The former usually are transported from the scene of activity to become sediments. The residual products remain after the soluble constituents have been leached. The chief residual product is clay. Oxides of iron and aluminum are also residual products of weathering and usually are formed, but not exclusively, in tropical climates. Other end products are minerals such as quartz, zircon, and rutile, which are not appreciably soluble under ordinary conditions of weathering. It is important for engineers to be able to recognize weathered rock and to appreciate the limitations it may place on construction. In general, weathered rock will be softer, less dense, and will have more voids than the original material. The greater the decay, the greater will be the potential water and clay content. Weathered material may become highly unstable.

DEPTH OF WATERING

4-13. The depth to which weathering may extend depends mainly on depth of the water table, time, climate, permeability, and type of rock. It may be nonexistent in recently glaciated areas and again may extend to depths of 35 meters or more in humid tropical areas. Some granites are reported to be weathered to a depth of nearly 70 meters. The actual depth of weathering is difficult to estimate in calcareous rocks due to solution removal of overlying materials. In some areas residual clays formed by leaching and destruction of carbonate rocks may reach a thickness of 3 meters which represents approximately 130 meters of original limestone and shale. Weathering may be unusually deep along joints and faults.

EROSION BY RUNNING WATER

4-14. Of all the agents of erosion, flowing water is the most effective and consequently the most important to engineers. Structures have been made totally useless after a comparatively short period by stream deposits or even completely destroyed by stream erosion. From an engineering viewpoint no two rivers are alike, and each one requires complete investigation. However, there are a few general principles common to all.

COMPETENCE

4-15. The power of running water to transport the loose mantle of the earth depends on its velocity of flow which in turn depends on the degree of slope, or gradient, over which it flows and on the depth of the water. Friction of water along the stream channel causes shallow water to move relatively slowly, whereas deeper water in the same channel in time of flood flows much more rapidly. The transporting power of a stream can be measured in terms of the largest piece of rock that the current can move and is referred to as the competence of the stream. 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 2. If the velocity increases to three times the original, then the theoretical increase in competence is 3 to the 6th power, or 729 times the original competence. (The "sixth-power law" does not strictly apply to certain of the smaller sedimentary particles.) This full theoretical value in increased transporting power may not be possible to reach due to natural conditions, but this phenomenal increase helps to explain how flood waters can cause such extensive destruction.

CAPACITY

4-16. The maximum amount of sediment a stream can carry is referred to as its capacity, which is distinct from competence. However, it is almost impossible to compute for natural streams. The smaller particles (clay and silt) are kept in suspension more easily than sand and therefore a stream might move a large amount of the finer sizes if these were available, whereas it would move no clastic sediment at all if these sizes were not available. Also, some clay and silt particles may be carried from their place of origin to the sea without temporary deposition en route, whereas sand and pebbles from the same source might be deposited temporarily many times over before reaching the sea.

ABRASION

4-17. Abrasion by running water depends on its load of abrasive materials—sand, silt, pebbles— and secondly on its velocity. Even swift streams effect no abrasion unless they carry abrasive materials. Both the stream channel and the sedimentary particles themselves are subject to abrasion.

BASE LEVEL

4-18. An important principle which governs the actions of flowing water as it shapes the land surface is the principle of base level. A stream continues the down cutting of its valley only until its bed reaches sea level, which when projected inland is called base level. Lake surfaces likewise limit downward erosion by the inflowing streams, but since, in a geologic sense, lakes are only temporary features, lakes are regarded as temporary base levels. In a similar way, a main stream at any tributary junction limits the depth of that valley of that particular tributary. The few exceptions, such as Death Valley, California, are special cases in that they are local base levels below sea level in an arid climate. If there were sufficient water, such basins would be fresh water lakes with outlets to the sea.

RELATIONSHIP OF DISCHARGE (VOLUME OF A RIVER MEASURED IN TERMS OF CUBIC FEET OF WATER PER SECOND THAT PASSES A GIVEN POINT), SEDIMENT LOAD, AND GRADIENT

4-19. The relationship among these three factors is fundamental to stream action. Erosion, transportation, and friction use up the energy inherent in flowing water. For most streams a larger part of this energy is used up in friction, with the remainder expended in transporting the loads of the sediment. If at any time there is no energy available to transport the sediment, some of the sediment immediately lodges along the channel floor. When that happens the floor at that place is made higher than base level. This results in a steeper average gradient for the river, which increases the velocity of the current to the speed at which it can then carry its load without further deposition. If at a later time the transportation energy should increase, the current will remove the channel sediment, reducing the average gradient leading down to the controlling base level. Therefore, gradient is subject to adjustment by the interaction of river discharge and the load of the sediment to be transported. Seasonal changes in load and discharge and hence gradient go on continuously, but still within such limits as to establish a more or less constant yearly average. When discharge and sediment load can quickly reach equilibrium within this average gradient range, the river is said to become a graded or poised stream. Such streams have a tendency to deposit material far upstream from the point of ponding and this must be considered when estimating the rate of silting in reservoirs.

FLUVIAL CYCLE OF EROSION (TABLE 4-1)

4-20. The fluvial cycle of erosion constitutes the stages of a stream as it erodes and carries away the land masses. These stages are youth, maturity, and old age. Occasionally the land mass is uplifted subsequent to old age stage, resulting in stream rejuvenation and repetition of the fluvial cycle. Streams in parts of the Appalachian region are excellent examples of rejuvenated streams.

Youth

4-21. During the early life of a stream, the gradient is high, and the stream expends most of its energy in down cutting and forms 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 (figure 4-1, page 4-6).

Maturity

4-22. In maturity, the stream valley widens at the expense of the divides, meandering begins, and a flood plain begins to develop. The flood plain is that portion of the valley floor subject to inundation during overbank floods (figure 4-2, page 4-7).

Old age

4-23. In old age the flood plain widens extensively (forms a peneplain), and meandering is marked by frequent oxbow lakes (an oxbow lake is formed when the stream cuts off a meander 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 (figure 4-3, page 4-8).

Table 4-1. Summary of stream valley erosion cycle

	Youth	*Maturity*	*Old age*
Gradient	Steep, irregular	Moderate, smooth	Low, smooth
Valley profile	Narrow, V-shaped	Broad, moderately U-shaped	Very broad
Valley depth	Deep	Deep, moderate, shallow	Shallow
Meanders	Absent	Common	Extremely common
Flood plain	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			
	Youth	*Maturity*	*Old age*
Dissection	Partial	Complete	None
Divides	Broad, flat, high	Knife-edged	Low, broad, rounded
Valley development	Youthful to mature	Mostly mature	Old age
Number of streams	Few	Maximum	Few
Relief	Great	Maximum	Minimum

STREAM TYPES

Consequent

4-24. A consequent stream is one whose position is the result of the initial slope of a land area.

Subsequent

4-25. A subsequent stream is one which has developed along a belt of underlying weak rock and follows the strike of the formation.

Antecedent

4-26. An antecedent stream is one which has developed a channel and maintained this course across areas of later uplift.

Superposed

4-27. A stream is said to be superposed when its course is established in young rocks which overlie an old surface. With uplift, the stream course is maintained as it cuts down through the young rocks and into the old surface.

Figure 4-1. Fluvial cycle of erosion—youth

Drainage Patterns

4-28. Drainage patterns are controlled or influenced by the underlying geologic structure and may be used to determine the general geology of a region: they are classified as dendritic, trellis, radial, annular, and rectangular (figure 4-4, page 4-9).

Dendritic

4-29. Dendritic type drainage occurs in flat lying or homogeneous rocks and areas of generally impervious soils.

Trellis

4-30. Trellis drainage forms in folded mountains. The main streams follow the lowlands and receive tributaries at right angles from adjacent ridges.

Radial

4-31. Radial drainage develops around prominent peaks or domes, the streams radiating outward, like the spokes of a wheel, from a central area.

Annular

4-32. Annular drainage is found on domes uplifted through layers of sediments.

Rectangular

4-33. This type of drainage indicates angularity caused by jointing or changes from massive to flat lying rocks.

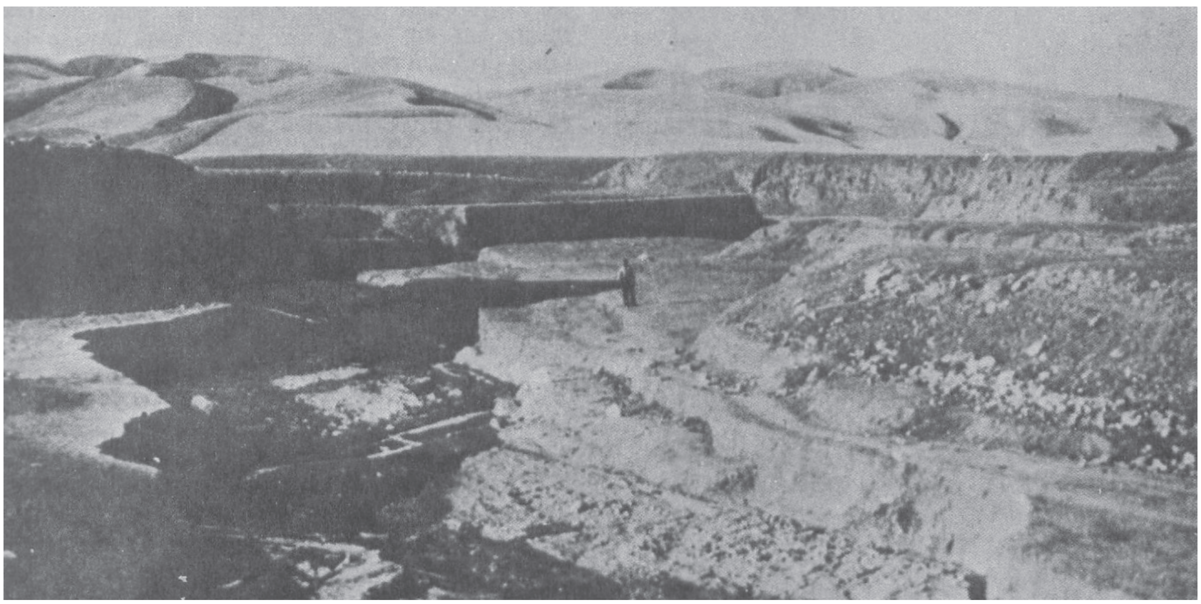

Figure 4-2. Fluvial cycle of erosion—maturity

Figure 4-3. Fluvial cycle of erosion—old age

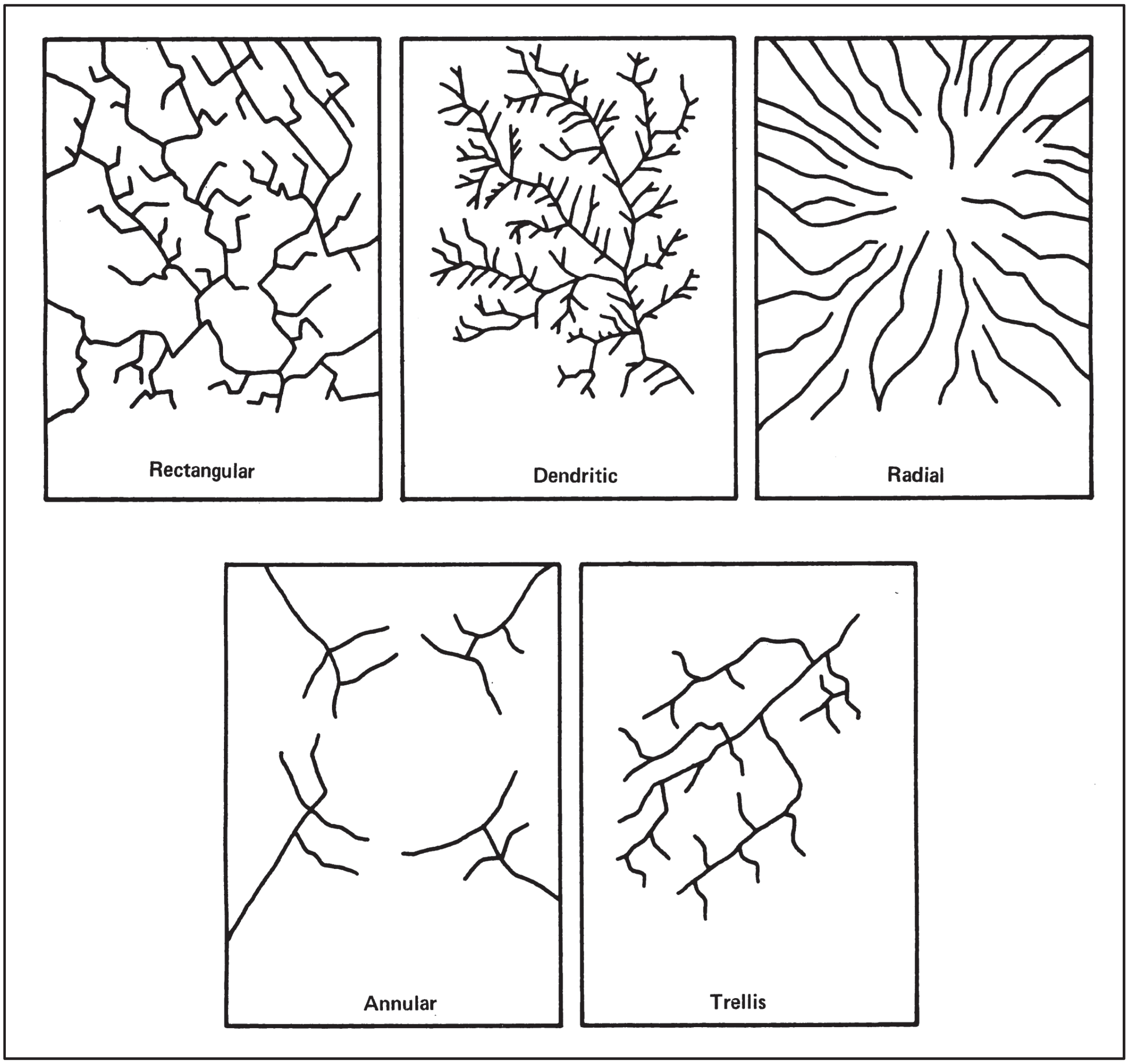

Figure 4-4. Typical drainage patterns

STREAM DEPOSITS

General

4-34. 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. 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 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—gradient lessens, discharge decreases as floods subside, or the water may soak into underlying previous materials, or, in arid regions, the water may evaporate. When it does, the sandy sediment which the stream is carrying accumulates in the channel, forming so many sandbars that at low water stages the river consists merely of a series of branching and reuniting streams flowing among the bars. When this happens, the river is said to have a braided channel. Also, channel bars may form where a tree or other large object has lodged in the channel, causing a local slackening of current velocity.

Alluvium

4-35. All deposits made by streams are included in the board category of alluvium. 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 which characterize almost all marine and lake sediments.

Alluvial Fans

4-36. 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. This then fills up and the process is repeated. As a result, a fan-shaped deposit, 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 as in Western and Southwestern United States. Adjacent fans may grow and overlap each other and form a continuous piedhiont alluvial plain.

Deltas

4-37. 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.) Because of the abrupt decrease in velocity, the coarser sediments, gravel, sand, and silt settle out first at the mouth of the stream and form a delta. There are many large and famous deltas such as the Nile Delta and the Mississippi Delta. However, in Northern United States 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.

EXCAVATIONS FROM RIVERBEDS

4-38. One of the common construction operations associated with streams and rivers is excavation of material from the bed. Streams and rivers are continually transporting and depositing material, but a borrow pit in the bed will intercept transported material and at the same time increase scour downstream from the pit. For this reason, excavations in the vicinity of structures such as bridge piers should be avoided. In general, it is best to locate borrow pits as far downstream from important river installations as possible.

GLACIATION

DEFINITIONS

4-39. A glacier is a mass of snow and ice which 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: valley, piedmont, or continental. A valley glacier (also called mountain glacier) is an ice stream that flows from a snowfield down a steep-walled mountain valley. The merging of several valley glaciers at the foot of a mountain forms a piedmont glacier. Continental glaciers (also called ice sheets) are found only in the high latitudes and cover vast areas. For example, Greenland is covered by such a glacier.

FACTORS INFLUENCING GLACIAL EROSION

4-40. Glaciers are important agents of erosion and transportation, having shaped much of the present topography of the Northern hemisphere including Canada and the United States. Glacial erosion is accomplished by plucking or abrasion. Plucking is the result of frost wedging (the pressure of the ice breaking off unsupported blocks of rock). Abrasion is the primary erosional agent and is accomplished by rock fragments carried in the base of the glacier which remove fine particles from the floor over which the glacier moves. The rapidity with which abrasion proceeds depends upon the resistance of the local bedrock to abrasion, the abundance of cutting materials (rock fragments), the speed of glacier flow, and the weight or thickness of the ice. Effects of abrasion are the most pronounced under the thick continental glaciers (figure 4-5).

Figure 4-5. Unusually large grooves cut in rock by continental glaciers

EROSIONAL FEATURES

Cirques

4-41. Cirques are bowl-shaped hollows with steep sides found at the head of a glacier. They 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

4-42. 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*.

Horn

4-43. When three or more cirques come together they form a high pyramidal peak with steep sides. This feature is called a *horn*. The famous Matterhorn of the Swiss Alps is a typical example of a horn.

U-shaped

4-44. A *U-shaped* valley is a valley formed by glacial erosion and is so called because of its broad U-shaped bottom (as opposed to the narrow V-shaped valley produced by stream erosion). .

Fiord

4-45. A *fiord* is a glacial trough eroded by ice either below the sea level or above sea level and then submerged through diastrophism (the process by which continents, ocean basins, plateaus, and mountain ranges are formed). These features make up much of the Scandinavian coastline.

DEPOSITED FEATURES

Kettles

4-46. As a glacier recedes it sometimes leaves behind large masses of ice imbedded in the valley floor. When the ice melts a depression is left. These depressions are called *kettles* and when water collects in them, they form kettle lakes.

Moraines

4-47. The rock debris deposited by a glacier forms the ridges of loosely consolidated materials known as *terminal moraines* when 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; and medial moraines when formed as a common moraine by the merger of two glaciers (figure 4-6).

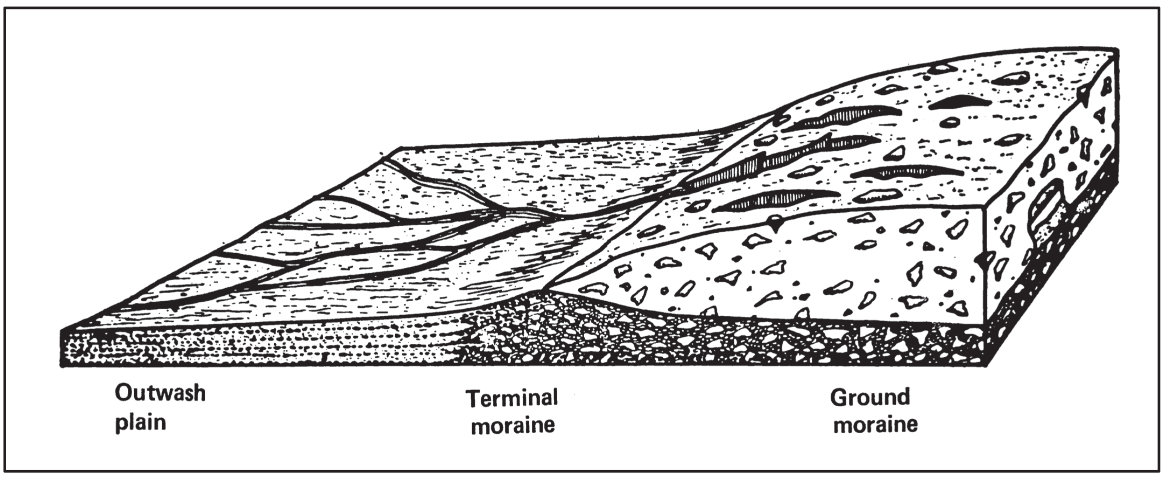

Figure 4-6. A block diagram of a valley glacier showing the relationship and nature of the deposits

Till

4-48. The unsorted material deposited by a glacier is called glacial *till*. The sorted and stratified materials deposited by streams flowing from glaciers are called *glaciofluvial deposits*.

Durmlin

4-49. A *drumlin* is a streamlined, lens-shaped deposit of glacial till with its longer axis parallel to the direction of the glacial movement (figure 4-7).

Figure 4-7. Drumlin

Kame

4-50. A *kame* is a terrace or flat-topped hill causer by the deposition of material carried by streams flowing along the margin of the glacier.

Esker

4-51. An *esker* is a winding ridge of stream built stratified glacial gravel and sand formed between walls of ice (figure 4-8).

Figure 4-8. Esker

Rock Flour

4-52. *Rock flour* is the finely powdered rock material produced by glacial erosion.

Glacial Milk

4-53. The milk-white water (charged with rock flour) that flows from beneath glaciers is called *glacial milk*.

WIND EROSION

METHOD OF EROSION

4-54. Wind accomplishes its erosional work by two processes: deflation and abrasion. Like streams, the amount of material the wind can carry in suspension depends upon its velocity. As the velocity increases, the wind carries increasingly larger particles in suspension; this process is called *deflation*. As the wind carries or drives these particles like bullets against exposed bedrock or loose rock fragments, these particles will, in time, chip off other small particles from the rocks which they encounter. This process is known as *abrasion*. In arid regions, wind erodes the highlands and fills in the low places with deposits of angular particles. When all the basins are filled, the wind is most effective in deflation. Deflation tends to lower the level (to the water table) of large dry plains and hence increases the relief of the high areas. Three types of features associated with arid erosion are ventifacts, desert pavement, and loess deposits.

EROSIONAL AND DEPOSITIONAL FEATURES

Ventifacts

4-55. In windswept arid areas, pebbles may develop smoothly polished facets on the side facing the sand blasts. When the wind shifts or the position of the pebble changes, facets may develop on another side. The process eventually produces many facets on the stones. Pebbles of this type are called ventifacts.

Desert Pavement

4-56. Another wind erosional feature is desert pavement, the equivalent of a well compacted gravel road. It is found in dry regions where a good assortment of well graded pebbles is present. The wind picks up the finer material allowing the heavier pebbles to settle and compact themselves. The sand blast effect of the wind tends to polish the exposed surface of the pebbles, sometimes creating a smooth, shiny mosaic.

Loess

4-57. Loess is loosely arranged grains of silt of very uniform size. When some of the feldspar particles have been weathered to clay particles, loess will stand in vertical cliffs without crumbling as long as it remains dry. Loess has been deposited over vast areas of the world; for example, deposits can be found in the Gobi Desert of Central Mongolia, in the Valley of the Rhine eastward to the Black Sea, and along the Mississippi River in North America. It is used as a building material for dwellings in China, Europe, and to some extent in the United States.

Dunes

4-58. Windblown sand often accumulates in rounded or elongated hills or ridges called dunes, which form in much the same way as snowdrifts. An obstruction, such as a boulder or a bush, causes a decrease in the wind velocity and an accompanying deposition of sand on the lee side of the barrier. In time, the mound of sand is large enough to act as an obstruction to the wind and the dune grows larger. Dunes may take many shapes depending on the source and amount of sand and the characteristics of the wind.

WAVE EROSION

WAVE ACTION

4-59. The passage of wind over water sets up waves by alternately raising and depressing the surface of the water. These are called waves of oscillation. No forward movement of the water actually occurs, but there is a circular movement 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. This causes the wave crests to become more closely spaced, each wave becoming higher and narrower. Eventually, the top pitches forward resulting in a translation of the water which sweeps up sediment. The return flow washes much of the sediment back with it, leaving only the coarser particles behind.

TYPES OF SHORELINES

4-60. Five common types of shorelines may be recognized from contour maps. They are the low-plain coast, embayed coast, fiord coast, deltaic coast, and coral coast. 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

4-61. A low-plain coast is one in which the land slopes very gently toward the sea. Usually it is one in which the shoreline is quite regular. Often an offshore bar will develop parallel to it.

Embayed Coast

4-62. An embayed coast is one along which there are numerous bays. These bays are usually the results of the submergence of the mouth of streams. An embayed coast which has been developed by the submergence of a shoreline in which the streams approached the sea in parallel courses is called a ria coast.

Fiord Coast

4-63. The fiords are submerged glacial troughs. A fiord coast is one in which a region of mature dissection has been glaciated so that the valleys are glacial troughs and then submerged.

Deltaic Coast

4-64. A deltaic coast is one produced by the convergence of several deltas along the shoreline.

Coral Coast

4-65. A coral coast is one in which the development of coral reefs has been a dominant feature in the development of the shoreline.

DEPOSITIONAL FEATURES OF SHORELINES

Spit

4-66. A spit is a bar of sand and gravel which projects from a point of land into the water. It is formed by beach drift.

Hook

4-67. 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.

Bar

4-68. A bar is an elongated body of sand and gravel deposited by beach drift. A bar is described in terms of its position, as a bay-head bar, mid-bay bar, bay-mouth bar, offshore bar, etc.

Crescent Beach

4-69. 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.

Tombolo

4-70. A tombolo is a deposit of sand and gravel deposited by beach drift in such a way that it connects one island to another or an island to the mainland.

Cuspate Foreland

4-71. A cuspate foreland is a projecting deposit of material deposited by beach drift of conflicting shore currents.

Offshore Bar or Barrier Beach

4-72. 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 upon this ridge and the storms may throw additional material from the seaward side upon it. A more or less permanent island may thus be formed.

EROSIONAL FEATURES OF SHORELINES

4-73. The major erosional features of shorelines are the wave-cut cliff, the wave-cut bench, and the stack. Of these, the wave-cut cliff and the stack may be identified from topographic maps.

Wave-Cut Cliff

4-74. A wave-cut cliff is a cliff formed by wave erosion. It is therefore a seaward-facing cliff whose base represents the elevation of sea level at the time the cliff was cut.

Wave-Cut Bench

4-75. A wave-cut bench or terrace is created at the base of the cliff and widens as wave erosion proceeds landward against the cliff.

Stack

4-76. A stack is a remnant of rock left standing on a wave-cut bench as the result of erosion by waves on all sides.

MASS MOVEMENTS

4-77. Gravity is responsible for large mass movements of the earth's surface material. For the most part, the movement is slow, but it may be locally rapid or even catastrophic. The possibilities of this movement occurring must be considered before undertaking any construction project.

SLOW MOVEMENT

Soil creep

4-78. The material on even the gentlest surface moves slowly down the slope, the movement being detectable only by such things as tilted and dislocated telephone poles, trees, fences, roadbeds, and railroad grades. This process is known as soil creep and occurs primarily in the weathered soil above bedrock. The motivating force is gravity acting on material partially saturated with ground water. In regions having a cold winter, each freezing of the water in the soil lifts the soil in a direction perpendicular to the slope; 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.

Solifluction

4-79. Solifluction is common in permafrost regions, or regions in which the subsoil remains permanently frozen. Meltwater has no opportunity to drain and the excess water saturates the soil. On slopes, this saturated soil moves a viscous liquid downhill over the frozen subsoil.

Rock creep

4-80. Rock creep is the slow movement of massive material recently detached from bedrock outcroppings along a slope.

RAPID MOVEMENT

Mudflows

4-81. Fine rock debris that collects on steep slopes in arid and semiarid regions becomes water-soaked during heavy rains and flows down the slope as a viscous mass of mud following stream channels.

Landslides

4-82. In regions of extremely rugged terrain, large masses of soil and rock may break loose and move down the slopes, sometimes slowly but usually very rapidly. This phenomenon is called a landslide. Whereas creep operates almost entirely within the soil layers, landslides often include large amounts of the underlying bedrock. Conditions favoring landslides are found in rugged regions of steeply dipping beds where ground water has the opportunity to percolate along the joint and bedding places, weakening the rock to the extent that it finally breaks away from the parent material.

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Chapter 5
Volcanoes and Volcanism

INTRODUCTION

5-1. Volcanism is one of the processes which renews irregularities in the earth's crust (the other being structural movements which produce the configurations discussed in chapter 3) and thus opposes the leveling action of erosional forces. Although areas of volcanic activity are relatively restricted, they present important and unique problems when military operations take place in their vicinity. In this chapter, the topographic features produced by volcanic activity are discussed.

ORIGIN OF VOLCANOES

5-2. When magma rises toward the earth's surface, it commonly ascends through pipelike conduits or through fissures in the crust. Depending on the chemical composition of the magma and the amount of contained gas, part or all of the molten rock reaching the surface may issue forth as lava; part or all may be ejected into the atmosphere where it cools rapidly, forming pyroclastic material. Slowly, by many eruptions, a cone-shaped hill or mountain called a volcano may be built up of successive lava flows, pyroclastic debris, or combinations of both.

5-3. Most volcanoes have eruptions separated by irregular periods of inactivity. In a volcano's early stages, eruptions may be violent and almost continuous. After a time, eruptions usually become milder and more widely spaced and ultimately cease. The life of a volcano may be from a few weeks to thousands of years.

5-4. Craterlike basins of volcanic origin developed by explosion or collapse during eruption are called calderas (figure 5-1, page 5-2). Many calderas occur throughout the world; the most famous in the United States is Crater Lake in Oregon, which is 5 to 6 miles in diameter.

TYPES OF VOLCANIC CONES

5-5. Volcanic cones can be grouped into three basic types: cinder, lava, and composite, depending largely on the nature of the molten material supplied to the volcano and on the nature of the eruptions.

CINDER CONES

5-6. *Cinder cones* are steep-sided, nearly symmetrical volcanoes composed of pyroclastic material (figure 5-2, page 5-3). Such material is rough and angular, and slopes of 30 to 40 degrees are attained before the angle of repose is exceeded and the accumulating mass begins to slide. Cinder cones are circular in ground plan and generally have the form of a truncated cone with a crater at the top. Most cinder cones appear to have been built up during a single eruption. Numerous examples of cinder cones exist in southwestern United States.

LAVA CONES

5-7. *Lava cones* are composed of many layers of solidified lava that have been extruded without violent eruption. Such cones, usually referred to as shield volcanoes (figure 5-3, page 5-4), are nearly flat and broad. The best examples of this type can be found on the island of Hawaii.

COMPOSITE CONES

5-8. *Composite cones* are those which have been built up of successive layers of pyroclastic material and lava. For this reason, they are commonly referred to as stratovolcanoes. This type of cone is very common and is easy to recognize by its concave, upward slope (figure 5-4, page 5-4). Fujiyama in Japan and Mount Rainier in Washington are examples.

Figure 5-1. Crater at apex of volcano conduit

ERUPTIVE VOLCANOES

EXPLOSIVE TYPE

5-9. In volcanoes of this type the eruption is very violent and of short duration and the ejected matter consists of solids and gases. Around the crater the rough, jagged particles pile up at a steep angle and form a cinder cone. Krakatoa in the East Indies is an excellent example.

QUIET TYPE

5-10. These are the volcanoes which erupt with very little violence. Molten lava, boiling and sputtering in the crater, frequently rises and flows over the rim or bursts through a fissure in the side of the cone. Very little solid or gaseous matter is ejected. The lava is basic in composition with a high degree of fluidity and builds up a lava cone having a slope of 10 degrees or less. The volcanoes in the Hawaiian Islands are fine examples of this type.

INTERMEDIATE TYPE

5-11. Most of the volcanoes of the world are intermediate between the purely explosive and the purely quiet types. Explosive eruptions of fragmental matter alternating with quiet eruptions of liquid lava build up a composite cone of intermediate steepness. Vesuvius, on the border of the Bay of Naples in Italy, is a classic example of the intermediate type.

FISSURE ERUPTIONS

5-12. Another type of eruptive igneous activity is that of fissure eruptions. In this case the lava pours forth quietly from cracks and spreads in sheet-like layers over the earth's surface. Distinct cones are not formed; instead, flows from neighboring fissures tend to merge and cover a large area. Excellent examples of this are found in India, Iceland and Western United States—the Columbia Plateau. These are discussed in more detail in paragraph 5-17.

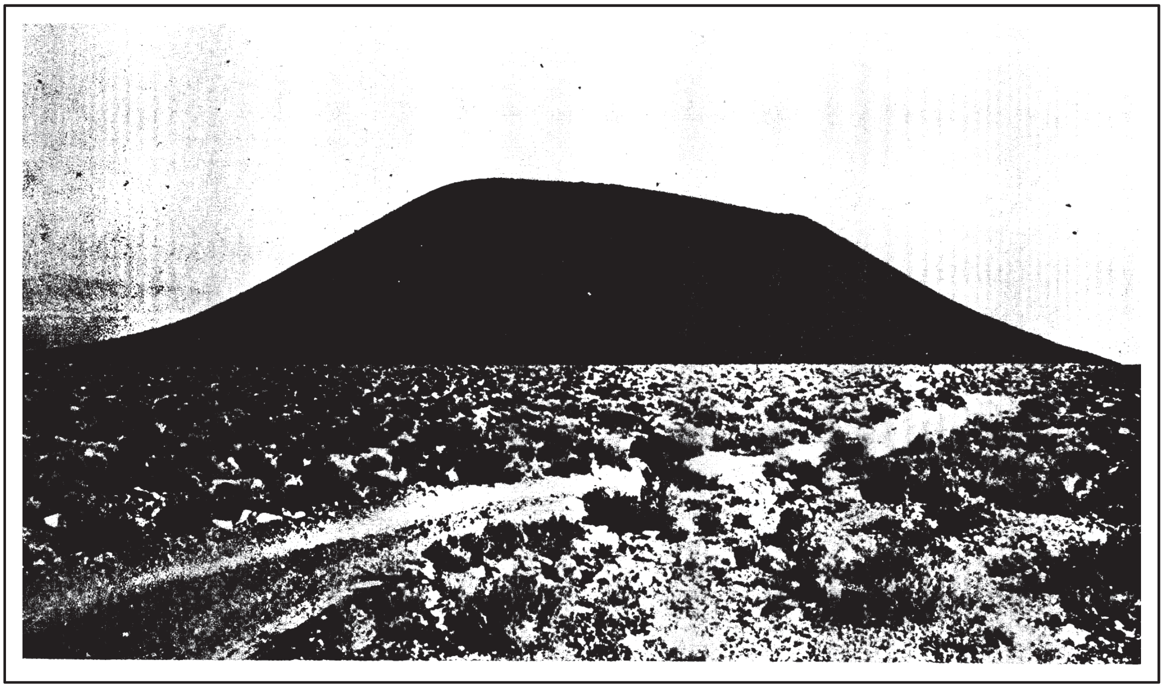

Figure 5-2. Cinder cone

DAMAGE FROM ERUPTIONS

5-13. An eruption in which the output of volcanic material is principally lava may destroy everything in its path, but the lava moves so slowly that it causes little loss of life.

5-14. An eruption in which the output of volcanic material consists of both hot gas and lava that is violently ejected into the atmosphere may cause considerable damage and loss of life, particularly if the fall of pyroclastic material is in large quantities. For example, during the eruption of Mt. Vesuvius in March 1944, 84 B-25 airplanes were partially destroyed in a few minutes by pyroclastic material. The airplanes were located on the Pompeii airfield on the south slope of the volcano about 8 miles from the center of the crater. Some of the volcanic fragments were as large as 5 to 10 inches in diameter and fell through the wings and fuselages of the aircraft. The surface accumulation of pyroclastic debris was 10 to 20 inches deep, making it necessary to abandon the airfield.

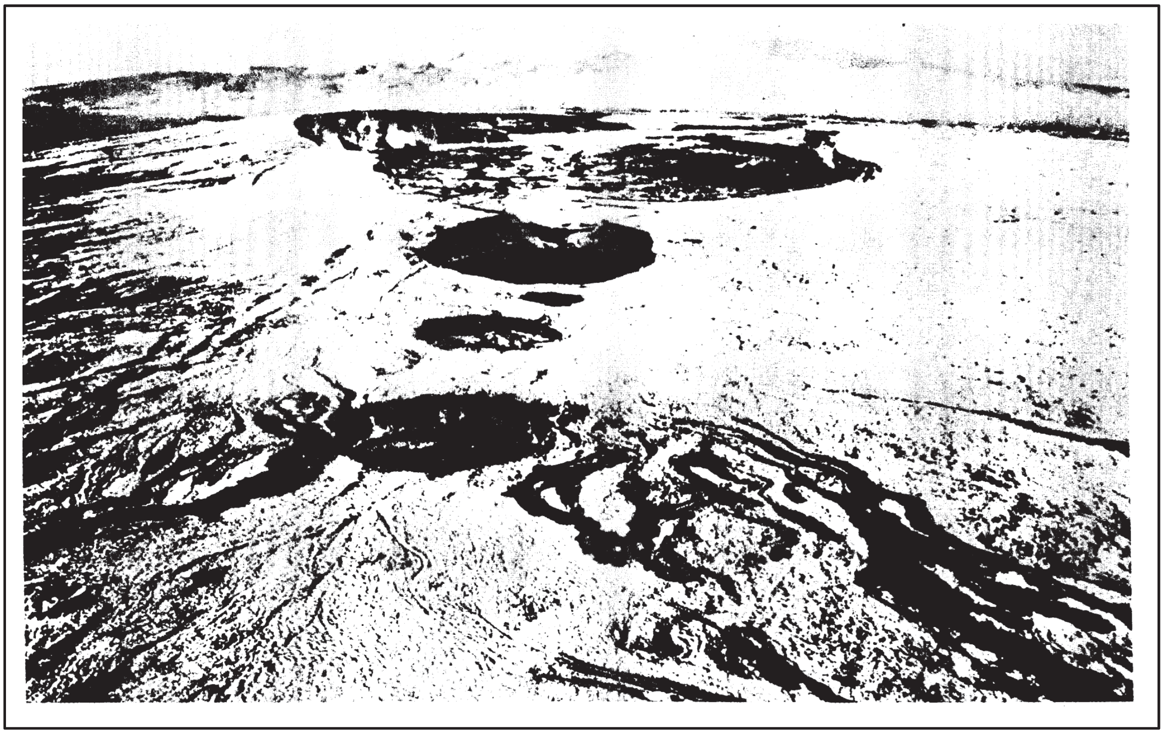

Figure 5-3. Shield volcano

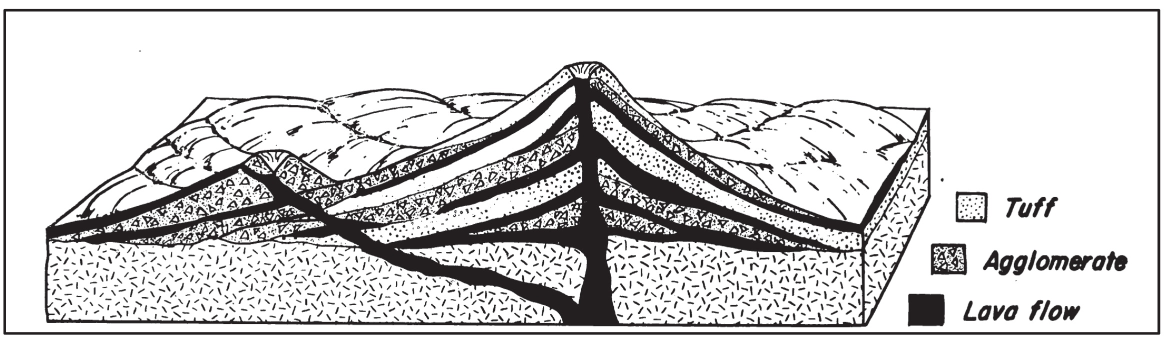

Figure 5-4. Sectional view of stratovolcano

GEOGRAPHIC DISTRIBUTION OF VOLCANOES

5-15. Active volcanoes are especially numerous in a belt around the Pacific Ocean (figure 5-5). Other regions of active volcanoes are the Mediterranean, Iceland, East Africa, and Hawaii. The occurrence of ancient volcanic rocks in many other parts of the world shows that in the remote past volcanoes did not have the same distribution they have at present.

5-16. In the United States, volcanic mountains are best developed in the Cascade Range of Washington, Oregon, and northern California. A linear series of volcanic peaks (Mount Rainier, Mount Adams, Mount Hood, Mount Shasta (figure 5-6) and others) surmounts a dissected plateau like upland, formed in part by lava flows. The latest eruption in this region was that of Lassen Peak, California, in 1914 and 1915.

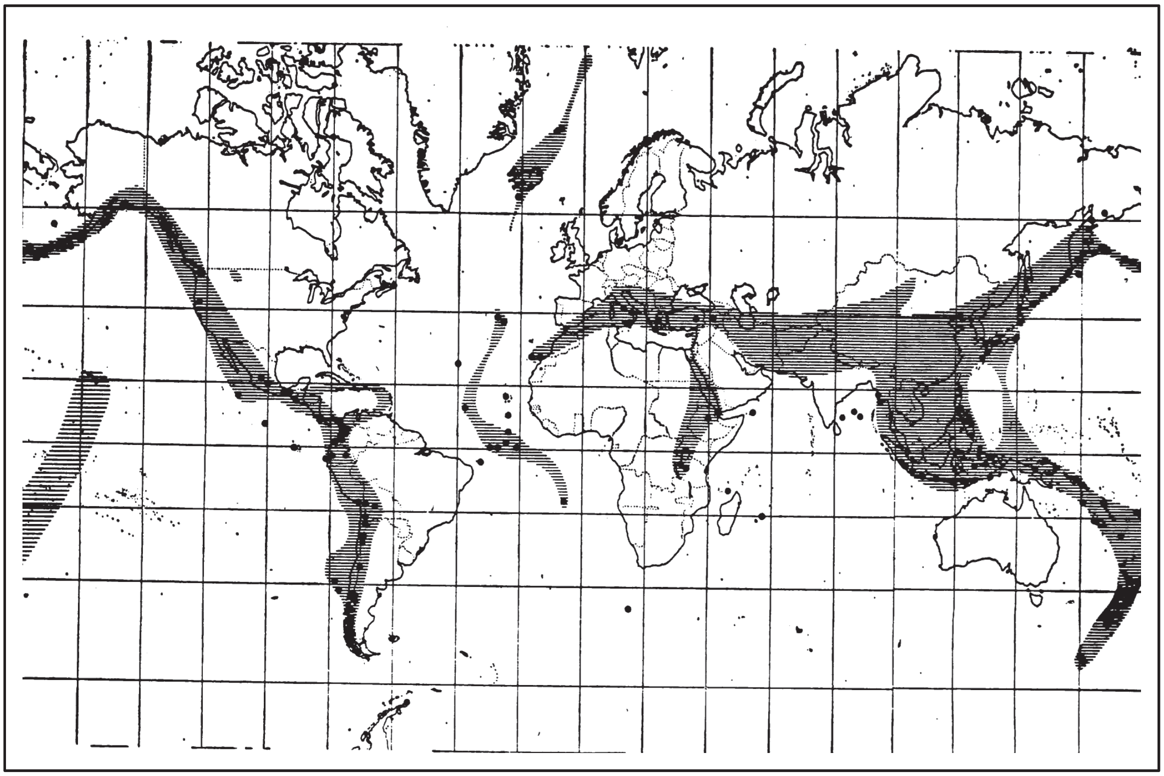

Figure 5-5. Volcanic areas of the world

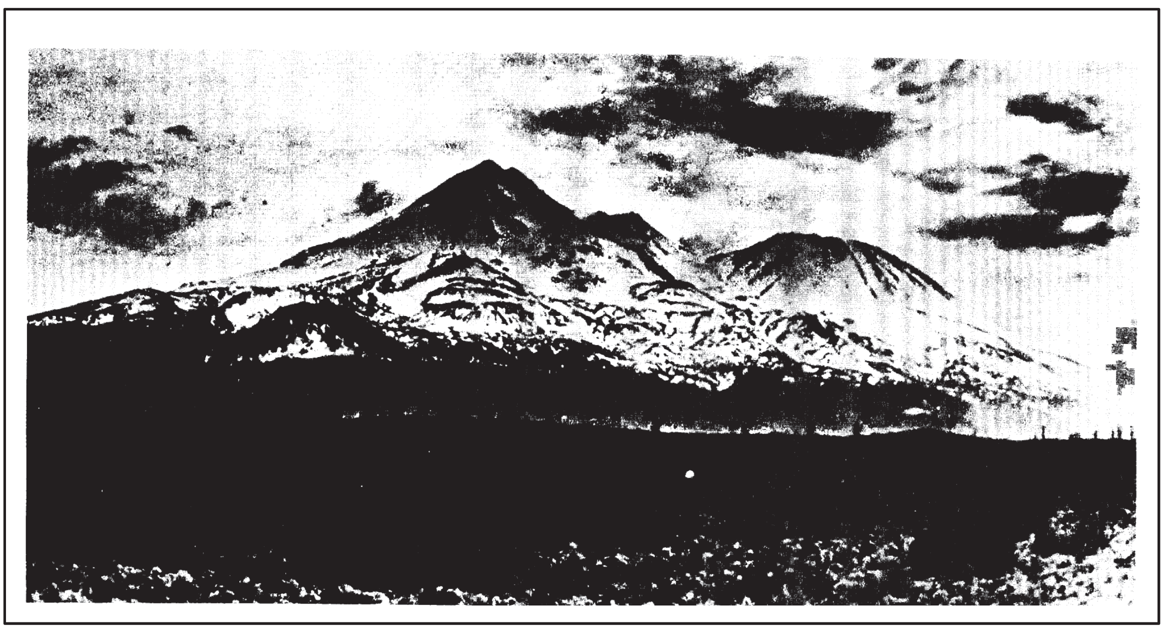

Figure 5-6. Volcanic mountains, Cascade range

FISSURE FLOWS

5-17. Horizontal sheets of congealed lava discharged through fissures in the earth's crust have produced in some areas immense plains or plateaus. The lava was apparently discharged with little explosive activity and from fissures not connected with volcanoes. This extrusive lava is commonly basaltic in composition. Surfaces of such areas are usually rough and irregular due to the unequal and uneven disposition of the individual lava sheets.

5-18. A basaltic plateau in the United States formed from fissure flows is the Columbia River Plateau of Washington, Oregon, and Idaho. The lava sheets cover approximately 200,000 square miles and the succession of flows has a known originally more extensive than the Columbia cumulative thickness of 4,000 feet. The Deccan River Plateau, have lava sheets piled up to a plateaus (basalt) of central and western India, thickness of 10,000 feet.

Chapter 6

Applications of Geology to Engineering Projects

INTRODUCTION

6-1. Very few engineering operations can be performed without utilizing in some fashion the basic geological principles because it is the crust of the earth on which and with which the engineer must work. Unsatisfactory results, including complete failures, can be avoided by the proper application of geology to engineering projects. The construction engineer is not expected to have thorough knowledge of this complex subject, but he should be familiar enough with it to recognize potential problems and, if necessary, call in the expert for their solution. This chapter briefly explains geologic considerations in the construction of dams, tunnels, roads and airfields, bridges, and buildings, and provides information on prospecting and quarrying for aggregates.

DAMS

DAM FAILURES

6-2. Numerous cases of dam failure are on record. Investigation of the failures reveals that for the most part, each was the result of erroneous geologic information or improper application of the correct information. One such failure occurred at the St. Francis Dam, near Sangus, California, October 1928. This was a gravity dam, built to store water for the city of Los Angeles. The dam was constructed on schist and conglomerate. The schist was fairly strong, but the conglomerate was interbedded with sandy and shaley layers, easily disintegrated when saturated with water. In addition, the contact between the schist and the conglomerate was a fault that had been considered inactive for many years. Immediately following completion of the dam, seepage was noted with failure occurring shortly thereafter. After-disaster investigation revealed that no geologic survey of the site had been made.

SITE SELECTION

6-3. Desirable sites usually are selected on the basis of topography, followed by a geologic investigation. The geologic investigation should include at least the following:

- Determination of the soundness of underlying foundation beds and their ability to carry the designed load.
- Determination of the degree of water-tightness of the foundation beds at the dam location and of the necessary measures, if any, to make the underlying geologic strata watertight.
- A study of the effect on the foundation bedrock of prolonged exposure to water.
- An investigation of the possibility of earth movements occurring at the site of the dam and the measures to be taken as a safeguard against such failures.
- An investigation of natural material available near the site (potential quarries, sand, gravel, earth, etc).

FOUNDATION MATERIALS

Igneous Rocks

6-4. As a general rule, igneous rocks make the most satisfactory material for a dam foundation. Most igneous rocks are as strong as or stronger than concrete. However, may tuffs and agglomerates are weak. Solution cavities do not occur in igneous rocks since they are relatively insoluble, although leakage will take place along joints, shear zone, faults, and other fissures. These can usually be scaled with cement grout.

Metamorphic Rocks

6-5. Most metamorphic rocks are similar to igneous rocks insofar as their foundation characteristics are concerned. Many schists, however, are soft and not suitable as foundation for high concrete dams. Marble is soluble and sometimes contains large solution cavities. As a rule, metamorphic rocks are treatable with cement grout.

Sedimentary Rocks

6-6. Sandstones allow seepage through pores as well as along joints and other fissures. The high porosity yet low permeability of many sandstones makes it difficult to treat them with cement grout. Limestones' chief problem is caused by their solubility which creates large under-ground cavities. However, many dams built by TVA are on such limestones and their reports contain valuable information concerning this problem. Generally speaking, the strength of shales compares favorably with that of concrete but their elasticity is a good bit greater. Shales normally are fairly watertight.

TUNNELS

GENERAL

6-7. Of all civil engineering activities, tunneling is by far the one to which the subject of geology can be most usefully applied. Once the general location and basic dimensions are determined, geological problems are the primary consideration for design and construction procedure control. Since civil engineers engaged in tunnel construction realize the absolute need of geological data in this field, there are few cases of failure due to lack of geological information; however, many failures do occur through improper interpretation of the geological facts available.

TUNNELING THROUGH FOLDED STRATA

6-8. Along the axis of folded rock there is often extensive fracturing which presents difficulties in tunneling operations. In the anticline these fractures diverge upward, whereas in the syncline they diverge downward. Where a tunnel is driven along the crest of a fold much trouble may be experienced from shattered rock, and lining of the tunnel may be necessary throughout its length. In the case of a syncline additional trouble may be encountered, even with moderate fracturing, because the blocks bounded by fracture planes are like inverted keystones, and very liable to drop out. When driving tunnels in areas of folded rocks, the engineer should give careful consideration to the geologic structure, since neglect to do so has led to costly mistakes. When a tunnel is constructed through horizontal beds, the same type of rock may be met throughout the entire operations; however, in folded strata many series of rock types may be encountered, and diversified methods of excavation must be used. From this standpoint, it is always necessary in tunnel construction to carefully map the geologic structures in the area under consideration.

TUNNELING THROUGH FAULTED STRATA

6-9. As in the case of folded rocks, the importance of having firm solid rock cannot be stressed too greatly, not only for safety and convenience in working, but for easy tunnel maintenance after completion. If a rock which has been pierced by a tunnel is shattered by faulting, it usually becomes necessary to line the tunnel, at least in the crushed territory. In addition, if the fault fissure extends to the surface, it may serve as a channel for rainwater.

GROUND WATER PROBLEMS

6-10. The presence of ground water is often the main source of trouble in tunnel construction. This immediately introduces the necessity for drainage facilities throughout the tunnel and when the tunnel grades cannot be chosen to facilitate such drainage, the additional trouble and expense of pumping is necessitated. It is of the greatest importance, therefore, to have as accurate information as possible about the ground-water conditions liable to be encountered, before construction starts. It is extremely important to keep careful check on all water that is met during construction, not only with a view of determining its source and therefore the possibility of sealing it off in some way, but also to check so far as possible the course that the water follows in order to ensure that it is causing no serious undermining or cavitation. When water becomes a problem in the construction of a tunnel a process known as grouting is usually necessary. Grouting, or cementation, has been applied extensively but not exclusively, for reducing the flow of underground water into tunnels. The methods adopted in its application in tunnel work are similar to those generally used in other types of grouting, a cement mixture being usual, although sometimes special chemical compounds are injected first to insure cementation of fine cracks in the rock.

ROADS AND AIRFIELDS

6-11. In the majority of road and airfield construction projects that fail, the cause lies with faulty soil information or improper engineering construction practices. This subject is not within the scope of this manual; however, geology is useful when prospecting for construction materials (paragraph 6-22) as well as when selecting airfield sites and road alinements. Geology also has numerous applications to drainage problems, slopes for cuts and fills, determination of stable slopes, etc.

6-12. It is important to determine whether drainage problems will be caused by surface water, perched water, ground water, or capillary water. Disposal of surface water and perched water is relatively easy. Ground and capillary water, however, may offer very difficult problems and it often may be desirable to design on the basis of sub-grade saturation, rather than to attempt drainage of the subgrade.

6-13. The stability of slopes in soil usually is determined by methods covered in all standard publications on soil mechanics. However, when rock is involved, the structural details and physical characteristics of the material become an important geological problem. Also, the problems often increase due to faulting or the occurrence of soft strata above or below harder layers. When flat excavation slopes are required due to a thick stratum of soft rocks near the bottom of a deep cut, the hard rocks lying over this strata must be cut to the same flat slope, or the slope will fail with the shearing and deformation of the soft materials.

6-14. When cuts are made through flat lying strata of thick, hard rock and clay or soft shales, disintegration of the clay or shale should be expected, especially if the ground water table has been intersected. While benching may help in maintaining stability, the only sound solution is to flatten the slopes and expect constant maintenance requirements.

6-15. Loess, which has a strong ability to stand on almost vertical slopes and which usually is cut vertically, should be cut wide enough so that in case of failure the banks will not block traffic. Failure of loess cuts is due to water penetrating along cracks and fissures, softening the material and eventually causing blocks to slough away. This occurs mostly after heavy and prolonged rains.

6-16. Indications of previous slides, surface creep, and other such phenomena should always be looked for on slopes above side-hill cuts. Road alinements should be kept as far away from unstable hillsides as possible. If this cannot be done, then every effort must be made to divert surface and sub-surface water from the slopes above the cut.

6-17. The possibility for settlement should be investigated. Application of geology to the problems of settlement of fill material is limited, but underlying strata may cause settlement also. For example, peat and other types of organic strata sometimes permit excessive settlement of fills of only moderate height.

BRIDGES

6-18. Geological principles cannot be avoided in bridge construction. No matter how scientifically a bridge pier may be designed, the whole weight of the bridge itself and of the loads it supports must be carried by the underlying foundation bed. In many cases, the piers and abutments are relatively uninteresting to the structural engineer and he will concern himself primarily with the design of the superstructure, often not paying the necessary time to the geological considerations. Actual records show that the cost of foundations almost equals the cost of superstructures, even on large bridges. Whatever may have been the cause, it cannot be denied that the importance of bridge foundation design has not always been fully recognized, thereby betraying on occasion the basic assumption of the superstructure designer that his foundation bearing surface will provide him with fixed and solid stands on which he can support his structure, without fear of serious movement.

6-19. In almost all cases, bridges are constructed for convenience and economy and must be located in a specified area. For this reason, the engineer cannot always choose the best site for piers and abutments, but must utilize to the best of his ability the chosen site. Also once bridge construction has started, the location cannot readily be changed except under the most exceptional circumstances.

6-20. Bridges, as a rule, are constructed to cross rivers or other valleys, which often suggest some departure from normal, geological structure. In districts that have been subjected to glaciation, it is not unusual to find an older riverbed or other depression completely hidden well below the existing riverbed by either subsequent glacial or river deposits. If the existence of a buried valley is not determined before construction begins, it can lead to difficulties. Riverbeds are prone to contain many types of deposits, including large boulders; if preliminary work is not carefully done and correlated with geological principles, any extensive boulder deposit can easily be mistaken for solid rock. Such an example was a bridge at Cornwall, Ontario which failed with the loss of 15 lives. The failure resulted from a pier being founded on a boulder imbedded in a much softer material which had not been previously explored by borings and which proved to be only 2 feet thick. It was scoured out in the vicinity of one of the piers, disclosing the clay beneath, the pier eventually tipping over and dropping two of the bridge spans into the St. Lawrence River which it crossed. This is only one example of this type of failure which could have been averted with the proper preliminary investigation.

BUILDINGS

6-21. Ground conditions at a building site may be one of three general types: solid rock may exist either at ground surface or so close to it as to render possible the foundations of buildings directly on it; bedrock may exist below ground surface but at a distance that may economically be reached by a practical type of foundation so that the building load can be transmitted to it; or the nearest rock stratum may be so far below the surface that it cannot be used as a foundation bed, the structure having to be founded upon the unconsolidated material forming the surface stratum.

6-22. The influence of geology is shown by this broad classification, the three types of ground conditions being the result of geological processes of the past. The city of New York is the typical example of the first type, in certain parts; some of the buildings of Manhattan are founded directly on the Manhattan schist which outcrops over part of the island. Much of the area covered by the city of Montreal, Canada, is of the second type, a great portion of the area being overlain by unconsolidated materials of the Pleistocene and recent periods with thickness varying to 35 meters or more. The city of London is an example of the third type, the London basin with its deposits of clay, sand, and gravel overlying chalk which renders impracticable the placing of the foundation of the building on hard rock.

6-23. When solid rocks are present for the building foundations, few geological determinations must be made so long as the strength and physical properties of the rocks are understood. When the foundation consists of loose unconsolidated sedimentary material, however, proper planning must be made to solve the problem of subsidence. Structures which are supported on bedrock directly or through piles or piers will settle by extremely small amounts. If a foundation has to be supported in unconsolidated strata, appreciable settlement is to be expected. Modern practice takes this settlement into account; foundation structures usually are now so designed that uniform settlement may be obtained throughout the building to prevent serious structural distortion. One example of improper precaution shows that a large building settled more than 1/2 meter owing to the compression of a layer of clay located between a depth of 35 and 50 meters below the surface of the ground. Unfortunately, the subsidence was uneven, causing the building to lean. Many large buildings show evidence of settlement in the form of long cracks and displaced building material, although the majority of these are not too critical.

PROSPECTING FOR AGGREGATE MATERIALS

INTRODUCTION

6-24. Whenever practicable, the engineer in command is informed regarding the approximate quantity of the aggregate required, the maximum size to be used, and the general nature of the proposed construction. Those to whom prospecting work is assigned should be familiar with the grading, physical characteristics, and composition of aggregates. Judgment and thoroughness in conducting preliminary field investigations usually are reflected in durability and economy of the finished structures.

6-25. Most factors pertaining to the suitability of aggregate deposits are related to the (geologic history of the region. The geologic processes by which a deposit was formed or modified are responsible for many of the characteristics that may affect its utilization. Among these are size, shape, and location of the deposit; thickness and character of the overburden; types and conditions of the rocks; grading, rounding, and degree of uniformity of the aggregate particles; and ground water level.

TYPES OF DEPOSITS

6-26. Deposits of natural sand and gravels when prevalent usually are the most economical source of aggregate. They are commonly obtained from stream deposits, glacial deposits, and alluvial fans. Talus accumulations may sometimes be processed for use. Fine blending sand may sometimes be obtained from windblown deposits.

6-27. Stream deposits are the most common and generally most desirable because the individual pieces usually are rounded; streams exercise a sorting action which may improve grading; and abrasion caused by stream transportation and deposition leads to a partial elimination of weaker materials. Extensive depots of sand and gravel frequently occur along the borders of a stream or in its channel, but often the search must be extended to include "terrace" deposits at higher elevations. For example, the Colorado River in Texas is flowing on or near bedrock and extensive gravel deposits are found only in adjacent areas of higher topography.

6-28. Glacial deposits are restricted to northerly latitudes or high elevations. Glacial deposits are of two types—true glacial and fluvial glacial—which have very different characteristics. True glacial deposits have been transported by glacial ice and have not been subjected to abrasive or sorting actions of river transportation. Therefore, such deposits usually will contain material having various shapes and sizes and ranging widely in quality, the weaker constituents not having experienced the abrasive disintegration associated with stream action. True glacial deposits usually occur as hummocky hills and ridges (moraines) and fluvial glacial deposits occur mainly in stream channels or on outwash plains, downstream from moraines. True glacial deposits, being uninfluenced by fluvial agencies, usually are too mixed to be suitable as aggregate and at best are usable only after elaborate processing. Fluvial glacial deposits frequently yield satisfactory aggregate materials.

6-29. An alluvial fan is a gently sloping, semi-conically shaped mass of detrital material deposited at the mouth of a ravine. Alluvial fans are characteristic of semiarid and arid regions and are formed by repeated torrential floods. Where the stream leaves the mountains and enters an adjacent valley, the abrupt flattening in the grade causes the stream to deposit the greater part of its load. Sands and gravels laid down under such conditions are very different from those of normal stream deposition; the particles are angular, and the material is poorly stratified and graded. Alluvial fan deposits are frequently used as sources of aggregate, but they commonly require more than usual processing.

6-30. Talus accumulations form at the bottoms of sharp topographic elevations by the sliding and falling of loosened rock. There is no grading action, very little rounding, and no segregation of different materials. Normally, however, there is little variety in rock type. In some cases, talus accumulations may be crushed and otherwise processed to form suitable aggregate.

6-31. Windblown material is confined to the fine-sand sizes and is useful as blending sand. It normally is very well rounded and composed predominantly of quartz because the intense attrition produced by the wind effectively removes the less durable constituents.

CHEMICAL SUITABILITY OF AGGREGATES

6-32. Some aggregate materials undergo chemical changes which may possibly be helpful but are often definitely injurious. Such reactions may be of various kinds, including reaction between aggregate material and the constituents of cement, solution of soluble materials, oxidation by weathering, and complicated processes which impede the normal hydration of cement.

6-33. Reaction between certain aggregate materials and the alkalies in cement is associated with expansion, cracking, and deterioration of concrete. Small amounts of opal, rhyolites, and certain other rocks and minerals in aggregates that are otherwise unobjectionable have caused excessive expansion and rapid deterioration. Opal is the most reactive constituent in many rock types or may form coating or encrustations on sand or gravel particles.

6-34. Rocks and minerals known to react harmfully with cement alkalies are volcanic rocks of medium to high silica content; silicate glasses; opaline and chalcedonic rocks (including most cherts and flints); some phyllites, tridymite, and certain zeolites. In general, aggregates which are petrographically similar to known reactive types, or which on the basis of service history or laboratory experiment are suspected of reactive tendencies, should be used only with cement which is low in alkalies. Such reactions are reduced in intensity and probably eliminated in some instances by the limitation of the alkalies to 0.5 to 0.6 percent of the cement.

6-35. Certain sulfide minerals such as the iron sulfides, pyrite, and marcasite readily oxidize through atmospheric attack, resulting in un-slightly rust stains and loss of strength and coherence of the affected particle. Such reactions may also generate acidic compounds which are injurious to the surrounding concrete matrix and which may cause associated reactions that result in volume increase conducive to popouts. Clays are subject to swelling and shrinking by absorption and dehydration and when they occur as constituents of rocks such as limestones, the absorptive character greatly increases the rock's susceptibility to disruption by weathering.

6-36. The extremely fine fractions of aggregate materials are commonly classed as silt or silt and clay and should not be permitted in large amounts because of their tendency to increase the water requirements of a mix and thus contribute to unsoundness and decreased strength.

PROSPECTING

6-37. When searching for suitable aggregate, it is important to bear in mind that ideal materials are seldom found. Deficiencies or excesses of one or more sizes are very common; objectionable rock types, coated and cemented particles, or particles of flat or slabby shape may occur in excessive amounts; clay, silt, or organic matter may contaminate the deposit; or weathering may have seriously reduced the strength of the particles. Moreover, ground water conditions or excessive overburden may seriously impede operations at a deposit. Unfortunately, the conditions within the body of the deposit cannot be directly observed at the surface. However, interpretations based on surface observations are greatly aided by an understanding of the geologic conditions and processes which have acted on the material. Frequently, such an understanding will permit a distinction to be made between conditions which are merely superficial and those which may be expected at some depth. Final conclusions on these matters usually will require thorough exploration, but as much pertinent information as practicable should be obtained during the reconnaissance and preliminary exploration.

6-38. The quantity of aggregate which a deposit may yield should be roughly estimated and compared with the probable requirements. Areas may be estimated roughly by pacing. Depth and grading of the material may be judged by examining the banks of channels or other exposures. Except for an estimated deduction for waste, based on the appearance of the material, it generally may be assumed that a cubic yard of material in place will produce aggregate for a cubic yard of concrete.

QUARRY OPERATIONS

USE

6-39. Natural sand and gravel are not always available and it is sometimes necessary to produce aggregate by quarrying and processing rock. Quarrying normally is done only where other materials of adequate quality and size cannot be obtained economically.

SUITABLE ROCK TYPES

6-40. Many rock types suitable for construction exist throughout the world. The quality and durability of the rock type selected will therefore depend on local conditions. The following rock types are generally easy to quarry, durable, and resistant to weathering. When these are not available, it may be necessary to use softer rocks for base courses and surfacing on a temporary basis. The softer rocks will usually require little or no blasting. More detailed information on the rocks listed is given in section II of chapter 2.

Granite

6-41. As a dimension stone, granite is fairly durable and has a texture and color desirable for polishing. As a construction material for base courses and aggregate, it is not as desirable as some of the more dense, fine-grained igneous rocks.

Felsite-rhyolite

6-42. This is durable and makes a good aggregate for base courses. It is not suitable for concrete aggregate.

Gabbro-diorite

6-43. Gabbro and diorite both have good strength and durability. The mineral crystals of both rocks are deeply intermeshed, making them very tough and excellent for construction aggregate.

Basalt

6-44. The dense, massive variety of basalt is excellent for crushed rock for base course or bituminous aggregate. It is very strong and durable. Due to the high compressive strength of basalt, production may be more difficult than for other rocks.

Sandstone

6-45. Few sedimentary rocks are desirable for construction due to their variable physical properties. Sandstone is generally durable, however. Because of the variable nature of the types of grains and cement, each deposit must be evaluated individually.

Limestone

6-46. Limestone is widely used for road surfacing, in concrete, and for lime.

Gneiss

6-47. Most varieties of gneiss have good strength and durability and make good road aggregates.

Quartzite

6-48. Quartzite is both hard and durable. Due to these qualities, it is an excellent rock for construction, although it is often difficult to quarry.

Marble

6-49. The texture and color of marble make it very desirable for dimension stone, and it can be used for base course or aggregate material.

REFERENCE

6-50. Detailed information on quarry operations, including site selection, evaluation, and development, is given in TM 5-332, Pits and Quarries.

Chapter 7
Geology and Water Supply

INTRODUCTION

7-1. Weathering and deposition illustrate how water acts as a powerful agent of destruction by wearing away large quantities of rock material. The Grand Canyon of the Colorado River is an excellent example of how water cuts into rock layers and carries away tremendous amounts of rock material. On the other hand, the thick layers of sedimentary material of the Mississippi River delta are an illustration of the enormous building potential that water possesses. Few, if any, engineering projects are unconcerned with water. Its importance is very obvious with respect to tunnels, dams, reservoirs, water supply, irrigation, and excavation. Locating adequate water supplies for troops in the field is perhaps on even more important concern for the military engineer. This chapter presents the basic principles on the location of water supplies and the control of water in military engineering operations.

THE HYDROLOGIC CYCLE

7-2. The hydrologic cycle consists of several processes. The first stage of the cycle begins with the evaporation of water from the oceans. This moisture is condensed as it rises to form cloud formations. Next, from these clouds the land surfaces receive precipitation of rain, snow, sleet, or hail which is dissipated either by simple surface runoff into lakes and streams or by seepage into the soil and thence into the underlying rock formations (figure 7-1, page 7-2).

7-3. The cycle does not usually progress through a regular sequence, however, and may be interrupted or bypassed at any point. For example, rain might fall in an area of thick vegetation and a certain amount of this moisture will remain on the plants and not reach the ground. This moisture may return to the atmosphere by direct evaporation, thereby causing a break in the hydrologic cycle.

7-4. The two .most important stages of this cycle to the military engineer are those which pertain to the surface runoff and to the infiltration of water into the ground. Surface water is of course the most evident at first glance, and by far the simplest to understand.

SURFACE WATER AS A SOURCE OF WATER SUPPLY

GENERAL

7-5. Streams and lakes are the most available and most commonly used sources for military water supply, especially when the water must be obtained quickly, as during combat operations. Of course, rainwater may be collected when streams and lakes are not present but this is not a predictable source: it may not give sufficient quantity and may not occur when needed. Lakes and streams should not be relied upon entirely for water supply, however, because almost any stream or lake may become dry during a drought. When permanent installations are planned, it is desirable not only to utilize the existing surface water, but also to make preparations for use of any subsurface water available, should it become needed.

QUALITY OF SURFACE WATER

7-6. Since no surface water is ever chemically pure, but contains varying amounts of sediment, bacteria, or dissolved salts, the water may be unfit for drinking and other purposes. Therefore, all surface water must be tested for purity, and proper precautions taken before consumption by troops.

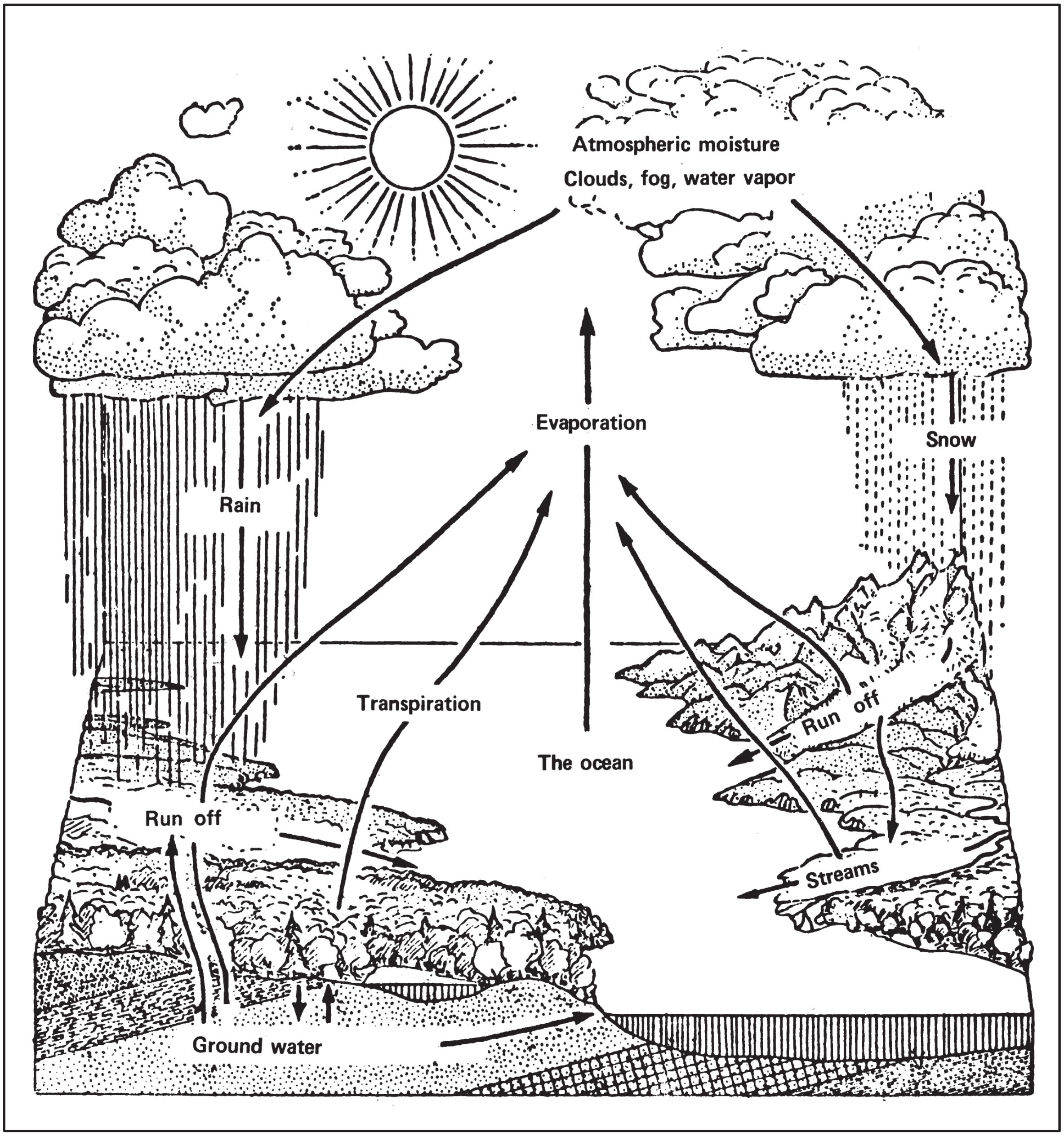

Figure 7-1. The hydrologic cycle

CONTAMINATION

7-7. Physical and chemical impurities found within the water can contaminate it. Atomic fallout, silt and clay particles carried by the natural turbidity of rivers, and detergents and industrial chemicals can compose the contaminants of surface water. If such conditions do exist it will be necessary to obtain surface water of usable quality from large settling basins such as lakes or ponds. This will enable the impure material being carried to drop out of suspension or to form a dense layer near the bottom of the basin.

POLLUTION

7-8. Pollution by harmful bacteria is by far the most dangerous form of pollution found in surface water. This is true not only in many foreign countries, where sanitary conditions are poor, but also in the United States, where many cities dump raw sewage into rivers and streams. Pollution is especially pronounced in countries where human excrement is used as fertilizer.

STREAMS

WATER SUPPLY

7-9. Streams generally supply an abundant quantity of water. Surface water is readily obtainable and ground water is usually available at shallow depths on the flood plains and at somewhat greater depths on the terraces. For the initial phase of field operations, the surface water supply source need only be adequate for that time of the year for which the operation is planned. When, however, it is necessary to learn the permanent status of the stream flow, for long-term supplies, the discharge record of the area must be used to determine the constancy of the stream. When these records are not available or are too scanty to supply the required information, certain field examinations can be made to determine the persistence of flow in the stream.

Field Examination During Wet Seasons

7-10. A field examination of streams during the wet season should search for the following features, which indicate permanency of flow:

- A stream channel deep with respect to its width, rather than a wide belt of interconnecting shallow channels.
- Relatively fine material in the stream bottom, consisting of gravel and sand rather than large boulders, and very fine material along the banks of flood plains, mostly silt with a little sand and no cobbles or boulders.
- A moderate to sluggish current in plains or lowland areas where unconsolidated deposits make up the stream bottom.
- Water-loving vegetation along the stream banks, for example, willow, cottonwood, and tamarix (salt cedar). If the flood plain, as well as the banks, has a dense cover of plants demanding moderate to high year-round water supplies, the probability of year-round flow is strengthened.
- Stream temperature which is warmer than the average air temperature in cold weather, and colder in warm weather, strongly suggesting ground-water feeding which will continue through the dry season.
- Water which never gets very muddy, also suggesting continuous ground-water feeding.

Field Examination During Dry Seasons

7-11. The dry season is naturally the best time to observe a stream's minimum water-supply potentialities.

MILITARY OPERATIONS

7-12. In terrain evaluation for both offensive and defensive operations, rivers are considered primarily as to the ease or difficulty of crossing. Tactical terrain evaluations of streams and rivers should include the size (width and depth) of the stream, velocity of the current, bank and bottom materials, and stream pattern and shape.

7-13. Construction materials include abundant amounts of sand, gravel, and binder material which are easily obtainable along stream channels and in terrace scarps. Hard rock is scarce in flood plains but may crop out along the scarps of terraces. Flood plains and terraces are generally well suited for construction of airfields and roads, but foundations may be poor. Some of the best airfield sites are located on well drained terraces. In narrow valleys orientation of runways may be limited to the direction of the valley. Excavations in flood plains are generally limited by the high water table.

LAKES

WATER SUPPLY

7-14. Most lakes are excellent sources for water supply. They serve as natural reservoirs for storing relatively large amounts of water which are available for immediate use. Lakes are usually more constant in quality than the streams that feed them. Large lakes are preferable; usually, the larger the lake, the purer the water. Very shallow lakes and small ponds are more likely to be polluted, containing aquatic vegetation, such as algae, and other microscopic plants that commonly give the water a foul taste and smell. The purity of water improves as the distance from shore increases. If a lake is large enough, the sediment from even the muddiest streams will settle out and any sewage dumped into the lake near shore will not affect the purity of the water in the interior of the lake. In small lakes the purifying effect is only partial.

7-15. In humid regions, lakes are fresh and generally permanent. In the desert regions, lakes are extremely rare but occasionally do occur in basins between mountains. Many of these desert lakes are only temporary and the water may not be usable due to the high percentage of dissolved salts. In the tundra regions of the Arctic, drainage is poorly developed and lakes are very numerous, and as a rule, though unpalatable, they are excellent water supply sources. Shallow lakes in these regions may freeze to the bottom during winter months.

MILITARY OPERATIONS

7-16. When a lake basin is drained or the water evaporates, the smooth surface of the sedimentary deposits becomes a *lacustrine plain*. The surfaces of such plains are generally featureless and essentially level. They are ideal for airfield sites and road alinements, but the fine soil makes a poor foundation, particularly in humid climates. When locating a road or airfield on a lacustrine plain, it should be kept in mind that sudden flash floods may submerge the area in a matter of minutes.

SWAMPS

7-17. Swamps are often, but not always, the successors to lakes and sluggish streams. Some swamps cover areas that never contained lakes, and coastal swamps may be the salt marshes of former tidal flats. Swamps are likely to occur wherever there is a wide stretch of relatively flat-lying, poorly drained land and an abundant supply of water. Such conditions generally occur on the poorly drained till plains of recent glaciation, along the coastal region adjacent to a broad, shallow continental shelf. Water is generally available in large quantities in swamps but may be of poor quality, in part brackish or salty. Because of an abundance of decaying matter, the water is easily polluted by bacteria.

7-18. The commonly thick soil mantle and deep weathering make firm rock difficult to obtain. In humid, tropical areas laterites are unique and often used as construction materials. In coastal and flood-plain swamps, sand and fine binder materials are generally abundant, but gravel is scarce and hard rock absent. Poor foundations and drainage problems are prevalent in swampy areas. Location of airfields and alinement of roadways are generally confined to levees of tributary streams and high areas. Orientation on levees is limited to the direction of the levee. Foundations of buildings and other structures not built on levees are unreliable because of the possibility of settlement on the low, poorly drained ground and the danger of periodic flooding. Drainage is a serious problem and elaborate canal systems and pump lifts must often be constructed to dispose of surface waters.

SUBSURFACE WATER AND ITS OCCURRENCE

7-19. Subsurface water may be defined as any water existing below the earth's surface. Most engineering projects are concerned with this type of water, and especially tunnels, dams, reservoirs, water supply, irrigation, and excavation. To discuss in detail all the problems of subsurface water is beyond the scope of this manual. However, the general principles are given and once they are understood it is possible to apply them to specific problems.

7-20. Ground water found to occur in two principal zones (figure 7-2). The first zone is the zone of aeration which consists of three major layers. As water starts to infiltrate the surface of the ground it encounters a layer of organic matter. Here, some of the water is held in suspension by the root systems of plants, decaying organic material, and by the rather small pores found within the upper soil zone. This narrow layer is called the belt of soil moisture. Once the water passes through this belt, it continues in its downward descent through the intermediate belt. Here the pore spaces are generally larger than at the surface and the amount of organic material is considerably reduced. Since this belt contains voids, the water is not held up but gradually drains downward. This draining continues until the second zone is reached. The zone of saturation is that area where all of the pores are filled with water. The contact between the two major zones is the water table. This planar feature fluctuates up and down depending upon the recharge rate and the rate of flow away from the area. Cohesive forces, the attraction between similar molecules and adhesive forces, the attraction between dissimilar molecules, permit water to ascend by way of the smaller openings from the water table up into the Zone of aeration. This belt above the water table is called the capillary fringe.

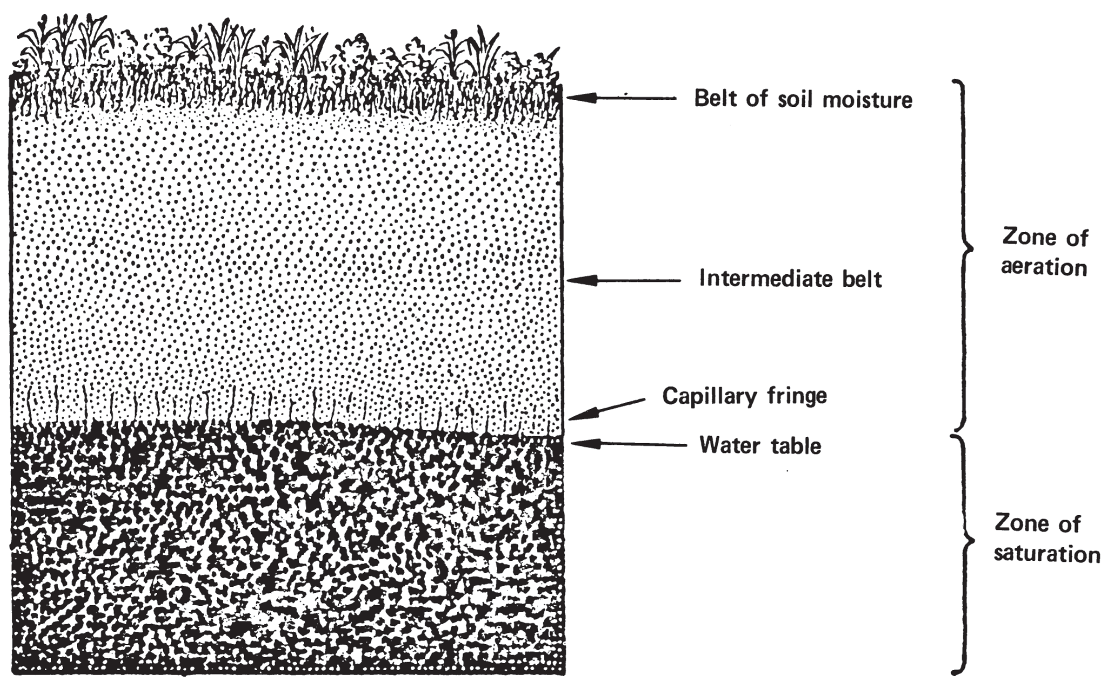

Figure 7-2. Ground water zones

POROSITY AND PERMEABILITY

7-21. The water-bearing capability of a natural material is determined by two properties, porosity and permeability.

POROSITY

7-22. The amount of water that rocks can contain depends on the open spaces in the rock. Porosity is the percentage of the total volume of the rock that is occupied by voids. Rock types vary greatly in size, number, and arrangement of their pore spaces and consequently, in their ability to contain and yield water. The porosity values of the different kinds of rock also vary widely, as illustrated in figure 7-3, page 7-6:

- The decrease in porosity due to compaction of spheres (A and B, figure 7-3).
- A natural sand with high porosity due to good sorting (C).
- A second natural sand with low porosity due to poor sorting and a matrix of silt and clay (D).
- Low porosity due to cementation (E).
- Very high porosity produced by loose, well-sorted grains that are themselves porous (F).
- Porous zones between lava flows (G).
- Limestone made porous by solution along joints (H).
- Massive rock made porous by fracturing (I).

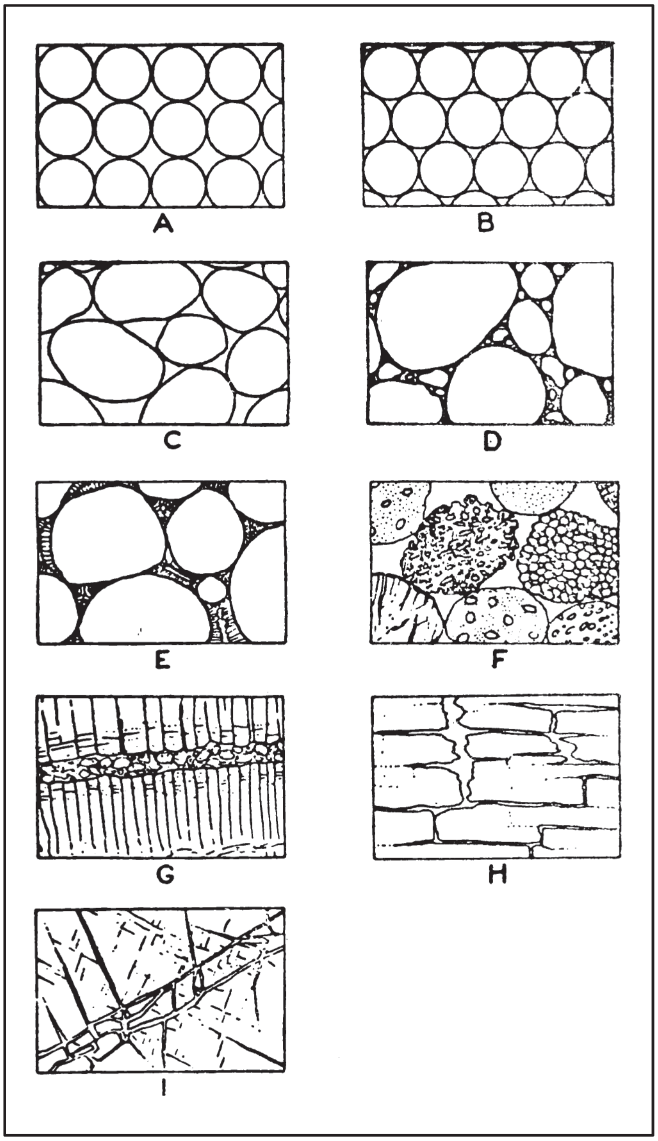

Figure 7-3. Porosity in rocks

PERMEABILITY

7-23. The permeability of rock is its capacity for transmitting a fluid. The amount of permeability depends upon the degree of porosity, the size and shape of the interconnections between the pores, and the extent of the pore system.

THE WATER TABLE

GENERAL

7-24. In most regions the rocks are saturated with water to a depth that depends largely on the permeability of the rocks, the amount of rainwater, and the topography of the land. In permeable rocks this surface below which the rocks are saturated is the water table. The water table is not a level surface, but is irregular and reflects the surface topography, standing relatively high beneath hills, and approaching the surface in valleys.

PERCHED WATER TABLE

7-25. If impermeable layers are present, descending water is stopped at their upper surfaces. In areas where the water table lies well below the surface, a mass of impermeable rock may intercept the descending water and hold it suspended above the normal saturated zone. This isolated saturated zone then has its own water table (figure 7-4). It is not desirable to drill wells into this zone because such wells may quickly be drained of their water supply. Subsurface depths of existing wells should be correlated with that of a newly drilled well to determine the location of the normal water table.

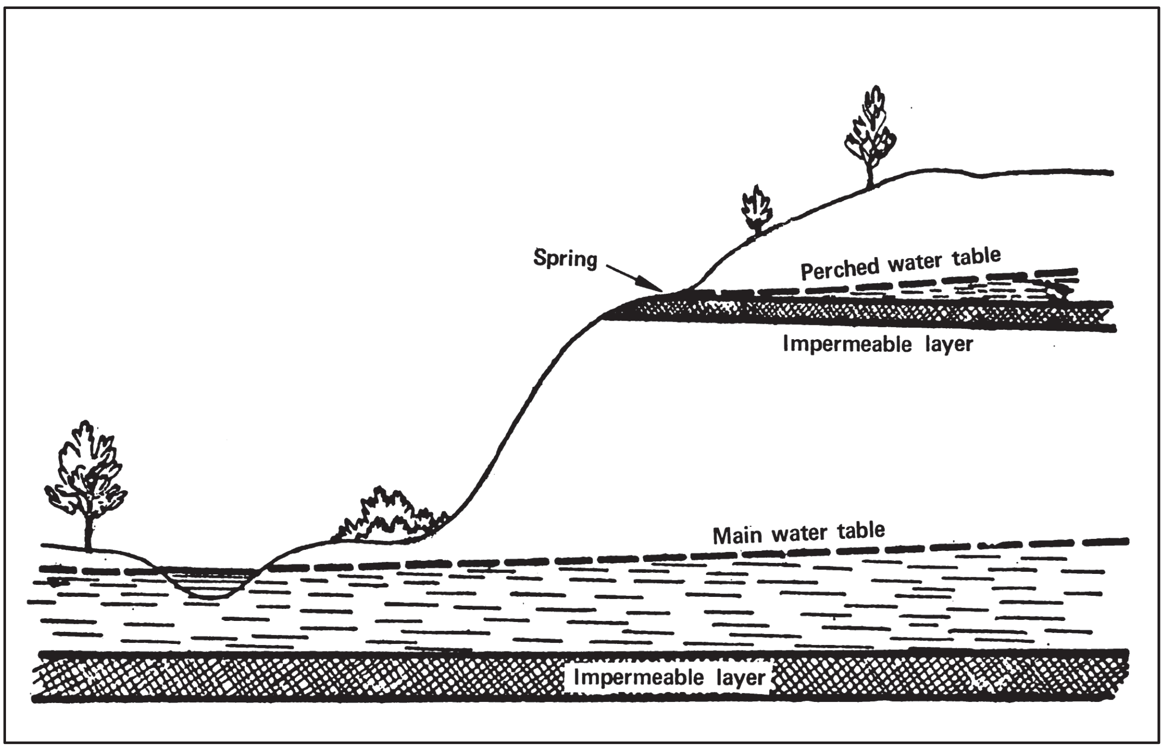

Figure 7-4. A perched water table

AQUIFERS

7-26. An aquifer is a layer of rock below the water table from which water can be obtained. It is sometimes referred to as a waterbearing formation or water-bearing stratum. Aquifers can be found in almost any area. However, where sedimentary rocks are lacking, the aquifers are much more difficult to locate. Sands and sandstones usually constitute the best aquifers, but any rock with both porosity and permeability can serve as a good water producer. In some cases a fractured igneous or other impermeable rock can produce economic supplies of water, even though it has very little porosity and permeability, as long as the well intersects enough fractures or joints to cause a sufficient amount of water to flow into the well bore. That is why in regions where the bedrock is of an impermeable type, some wells will yield water, usually enough for single family needs. Some igneous rocks may become porous and permeable by weathering processes and thereby constitute good aquifers.

Salt Water Intrusion Below the Water Table

7-27. Along coastal areas and on islands there is always the danger of salt water intrusion into ground water sources. Since the salty water is unfit for most human use and has a harmful effect on automotive cooling systems and other types of machinery, a serious problem can result. By chemical analysis an accurate determination, of the saltiness or degree of contamination can be made. For average sea water the concentration of dissolved salts (mostly chlorides), is about 35,000 parts per million (3.5 percent). When salt water intrusion is discovered in the ground water supply, steps should be taken to determine the cause.

7-28. Fresh water tends to float on salt water when both are present within sediments. The position of the contact between the two is determined by the head of the fresh water above sea level and by the relatively greater specific gravity of the salt water. Using the specific gravity of salt water (1.025), each foot of fresh water between sea level and the water table indicates approximately 40 feet of fresh water below sea level in homogeneous material. This condition is best exhibited by small islands and peninsulas composed of permeable sand completely surrounded and underlain by salt water (figure 7-5). The hydrostatic head of the fresh water and the resistance of the pores in the sand prevent the salt water from entering the middle zone and mixing with the fresh water. The zone of diffusion (zone of contact) between fresh water and salt water is narrow (less than 100 feet wide) unless affected by heavy pumping. Along coasts which have alternating beds of pervious and impervious materials, the contact between salt water and fresh water in the various pervious strata depends upon the hydrostatic pressures of fresh water in each of these pervious layers.

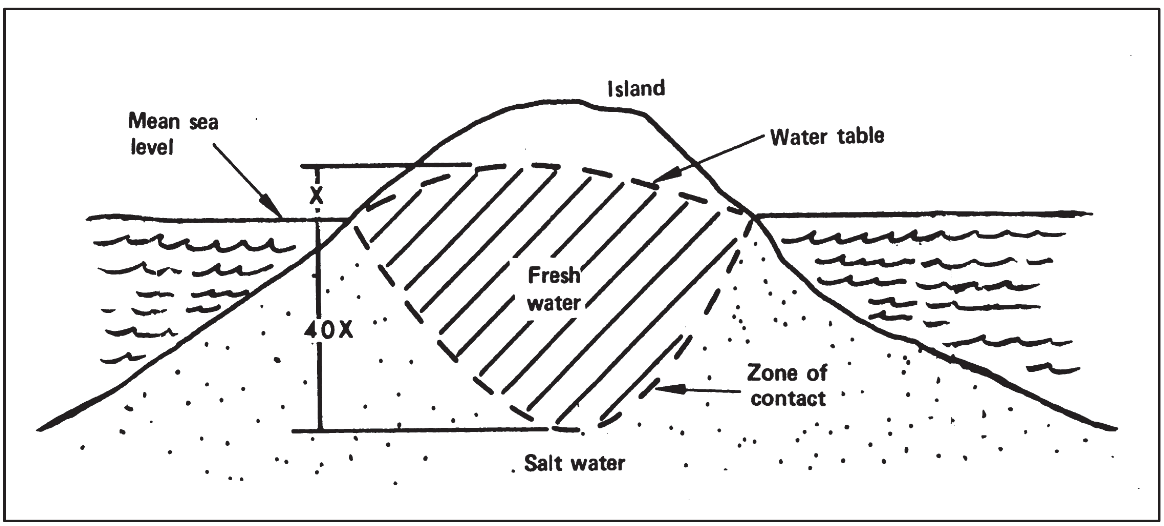

Figure 7-5. Relationship between salt and fresh water

7-29. Where small amounts of fresh water do exist on islands and peninsulas, conservation is usually necessary to prevent salt water invasion. The amount of fresh water that can be pumped without intrusion of salt water depends on local conditions, type of well, rate of pumping, and the rate of recharge of the sand by fresh water. In areas of high rainfall, the recharge rate of the sand is usually rapid, but if the rainfall is seasonal the wells may become dry if water rationing is not introduced during the dry period. A rise in the level of the salt water occurs if the head of fresh water is reduced for any reason such as excessive pumping or decrease in rainfall. The drawdown ("cone of depression") in the fresh water level around the well causes a rise in the underlying salt water (figure 7-6). Pumping of any one well should be restricted according to drawdown, for salt water will enter the well if drawdown is maintained substantially below sea level for extended periods. The pumping rate should not exceed the rate of recharge.

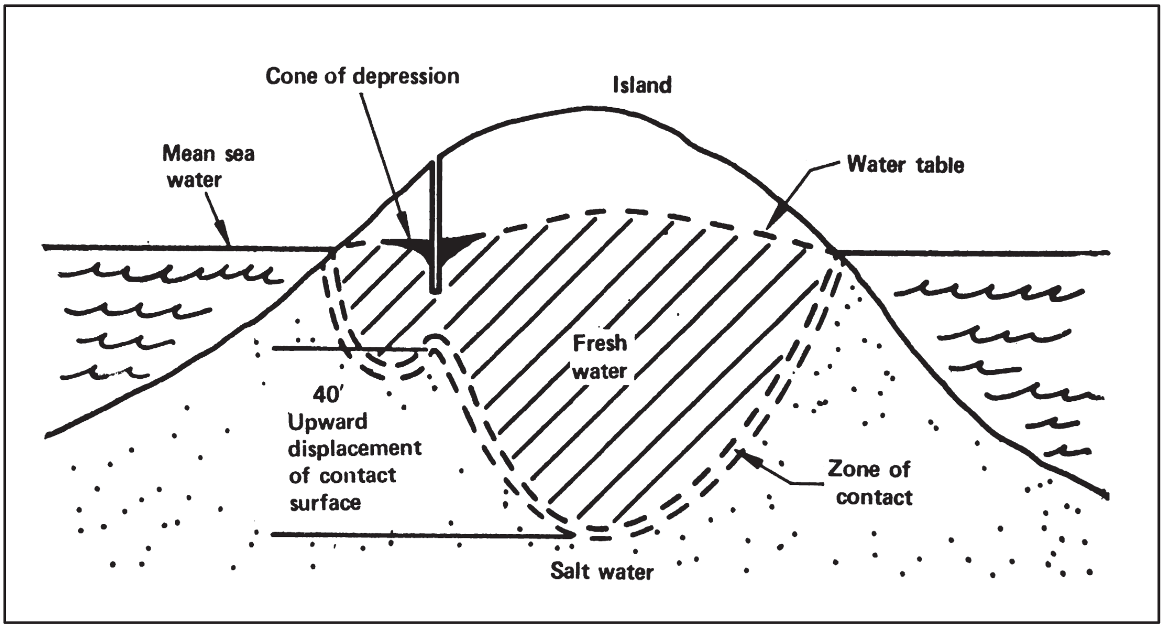

Figure 7-6. Cone of depression due to pumping

SPRINGS

GENERAL

7-30. Water which emerges at the surface naturally with a distinct current is called a spring (figure 7-7, page 7-10). When a distinct current is not present, the flow is called a seep. Most springs and seeps represent water from rain or snow on some nearby higher ground which has moved slowly under gravitational force to its place of emergence. Its underground course depends upon the permeability and structure of the material through which it moves. The most favorable materials are sandstones, cavernous carbonate rocks, vesicular lava flows, and highly jointed or fractured rocks of any kind. In some springs the water bubbles up with a measurable force, indicating that it is under pressure in the subterranean passageway. These are called artesian springs and are discussed in paragraph 7-33. Some of the largest springs develop along the borders of karst regions where capacious subterranean channel ways have been developed by solution. Any spring having a temperature higher than the yearly average temperature for a given region is termed a thermal spring and indicates a source of heat other than that of the surface climate, of which magmatic heat is an example.

GRAVITY SPRINGS AND SEEPS

7-31. Based upon the pressure of the emergent water, any spring or seep which is not artesian may be classified as the gravity type. Gravity springs and seeps are those in which subsurface water flows by gravity, not hydrostatic pressure, from a high point of intake to a lower point of issue. The two most important types are water-table springs and seeps, which occur where the water table comes near or intersects the surface of the ground, and contact springs and seeps, which occur along an exposed contact between a pervious stratum and an underlying impervious stratum. Water-table springs and seeps are normally found around the margin of depressions, along the slope of valleys, and at the foot of alluvial fans. Contact springs appear along slopes, but may be found at almost any elevation, depending on the position of the rock formations.

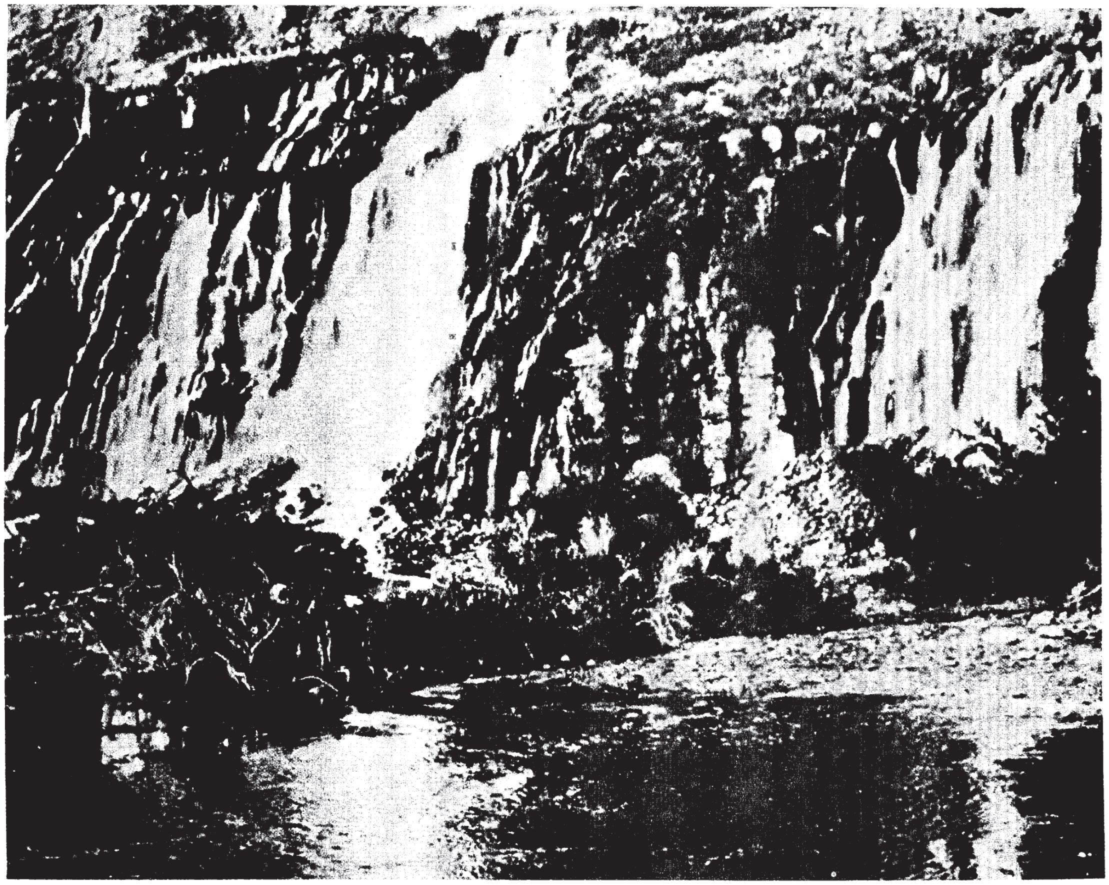

Figure 7-7. Springs issuing from basaltic lava

MILITARY IMPORTANCE OF SPRINGS AND SEEPS

7-32. Although springs and seeps are relatively common in some areas, other regions are completely void of them and it is probably safe to assume that most areas have few, if any. The springs and seeps that are present often are very small and wholly inadequate for large numbers of troops, although their source may be a good aquifer into which wells may be drilled. Like surface water, they often become polluted when they reach the surface so that the water should be decontaminated before use. In most areas with little population, the spring water is good for drinking in its natural state, but often becomes contaminated at the outlet on the ground surface. The chief factor influencing the quality of subsurface water while still in the ground is the mineralogical character of the reservoir rocks. Water has been called the universal solvent, and even though most minerals are soluble only to a slight degree, no ground water is without some dissolved mineral substance. Water suitable for drinking or cooking should not contain more than 500 parts per million dissolved solids.

ARTESIAN WATER

7-33. When water is confined in a rock layer under hydrostatic pressure, an *artesian* condition is said to exist. If a well is drilled into an aquifer where there is such a condition, it is called an artesian well (figure 7-8). Such a well, if it has enough pressure to bring the water above the ground surface, is called a flowing artesian well; if the water rises only to an intermediate level, it is a nonflowing artesian well. Certain conditions are necessary for an artesian condition to exist. First, there must be a permeable aquifer with impervious layers above and below it to confine the water. Second, there must be an intake area where water can enter the aquifer. Finally, a structural dip must exist so that hydrostatic pressure will be produced in the water in the lower areas of the aquifer. Whenever a natural outlet occurs in an artesian aquifer, an artesian spring is formed.

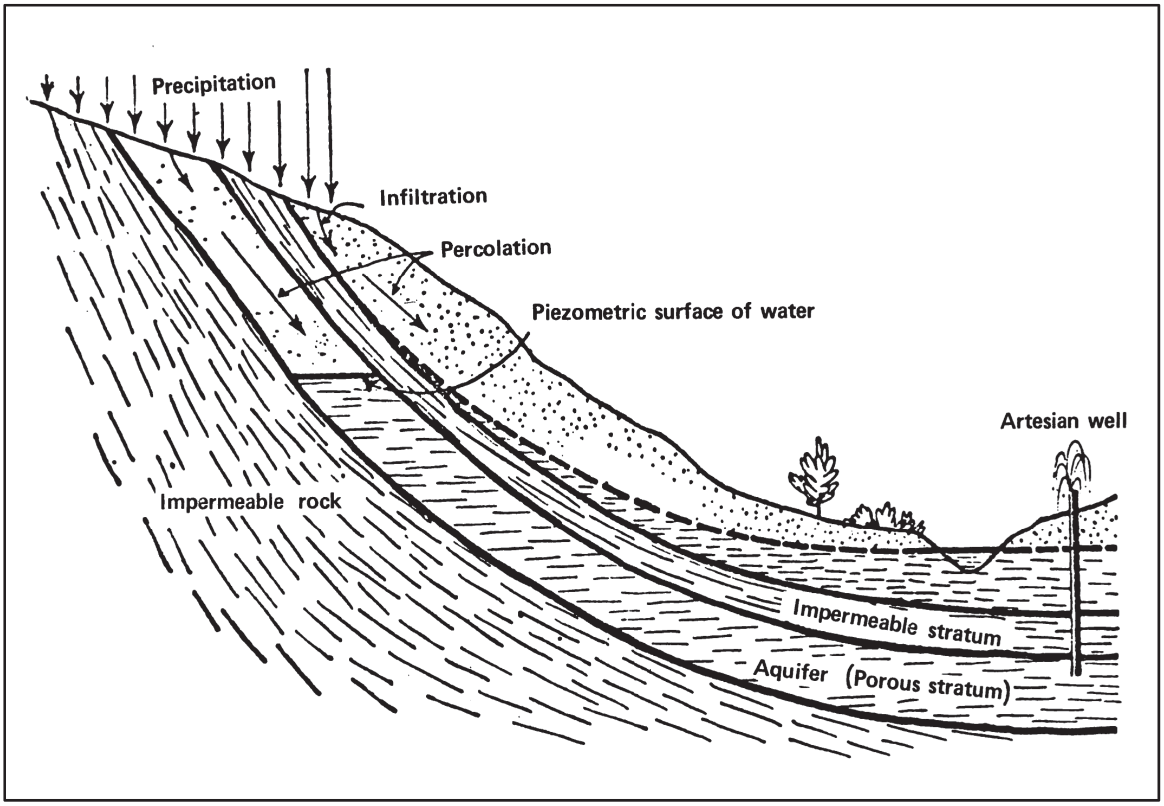

Figure 7-8. Artesian ground water

7-34. Ideal artesian conditions occur in areas having a general synclinal rock structure in which the aquifer is a permeable sandstone overlain by an impermeable shale. A renowned aquifer of this type is the Dakota sandstone which has long been an invaluable source of water for the semi-arid western Great Plains. However, of late, its hydrostatic pressure has decreased due to the enormous amount of water that has been taken from it. Another example is New York City and its neighboring Long Island communities which derive large supplies of water from artesian flow. The public water supplies of Memphis, Tennessee, and Houston, Texas, are also furnished by artesian flow. In some districts well must be bored very deep before artesian water is encountered. In St. Louis and Pittsburgh, for instance, the necessary depth is 4,000 feet. Along the Atlantic Coast, however, most of the artesian wells are only 100 to 300 feet deep. The volume of water developed by some is large; the great 12-inch well of St. Augustine, Florida, with a depth of 1,400 feet, supplies 10 million gallons per day.

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Chapter 8
Physiography and Terrain Evaluation

BASIC DEFINITIONS

8-1. Because of variations in the composition of the earth's crust and differential erosion over portions of the earth, many types of landforms exist and each type is characteristic of certain areas of the earth. *Physiography* is that branch of science that deals with the extent, shape, and form of the land surface. An important aspect of this in military operations is *terrain evaluation*, an evaluation of an area of land considered as to its use for a specific purpose.

8-2. Continents are the major physiographic units. They are subdivided into separate portions of similar characteristics, called divisions. Divisions may be extremely large: a single division may cover up to half a continent. The United States is composed of eight divisions. These are discussed in paragraph 8-17. Divisions are subdivided into provinces on the basis of the predominating types of landforms present. For example, the Blue Ridge Mountains make up the Blue Ridge Province. Provinces are widely used in physiographic study since they represent a unit containing landforms of the same general type throughout. Each province may include small sections which differ from the primary type of landform which distinguishes the province. These are included within the province because they are too small to merit a provincial name for themselves or because they are entirely surrounded by the named province.

PLAINS AND PLATEAUS

DEFINITIONS

8-3. Plains and plateaus are areas of moderate relief (more than 50% of the topography has a slope of less than 4°) occurring at any elevation above sea level. Generally, a plain with an elevation high above sea level is called a plateau.

CHARACTERISTICS

8-4. The most troublesome obstacles to movement of military units encountered on plains and plateaus are vegetation and poorly drained ground. In plateau regions, especially the more arid areas, steep and precipitous ravines and valleys also exist which hinder movement on the otherwise nearly level surfaces. Observation on plains and plateaus is limited by vegetation and by the lack of prominences which would provide commanding positions. In those areas which are bare of trees, however, long distance observation is good, but cover, concealment, or defilade is poor except for that locally provided by low topographic forms such as escarpments. Plains and plateaus are superior to hills and mountains as sources of sand and gravel, but not as sources of hard rock suitable for construction. Hard rock is exposed only locally and is less easily quarried, although some plateau escarpments are excellent sources of construction stone in the form of limestone and trap rock. Large airfield sites are almost entirely limited to plains and plateaus. Road construction is generally easier and alinements are much less restricted than in mountains. Foundations, however, may be poor because of bad drainage and the low bearing strength of soils. The ground is generally easily excavated but a high water table may limit the depth in many places. Some plateaus and terraces are well drained and are excellent sites for large structures.

TYPES OF PLAINS AND PLATEAUS

GENERAL

8-5. Plains and plateaus may be formed through depositional or erosional processes or a combination of the two. Variations in landforms arise from differences in the materials that underlie the plains or plateaus, the geologic agents that deposited the material, the erosional processes that have taken place, and the climatic environment of the area.

COASTAL PLAINS

8-6. Coastal plains may be either former parts of the sea floor that have been lifted above present sea level, eroded areas partly submerged, or alluvial deposits built seaward from higher lands. In general, the topography of coastal plains permits free movement of tracked vehicles. However, because of the unfavorable soil conditions and dense vegetation in areas of medium to heavy-rainfall, trafficability may be locally poor or impossible. Movement along an indented shore is difficult because of streams and estuaries that separate the land into compartments. Movement inland is limited to narrow land areas bordered by water. As a result, flank attacks are difficult or impossible without amphibious support and surprise is hard to achieve. Coasts with beach ridges hinder a direct advance inland, because vehicles are compelled to cross poorly drained areas between relatively stable sand ridges. Terrain of this type, common on the larger islands of the southwest Pacific, confines movement and prevents adequate dispersal of men and supplies. The sand dunes and the low, readily inundated land behind them along the North Sea coast of Europe are examples of obstacles to landing operations.

8-7. Along coastal regions where the underlying sediments dip more steeply than the ground surface, the truncated ends of the most resistant rock layers stand out in low ridges that more or less parallel the coast. The slope of these ridges is apt to be steeper on the landward side than on the seaward side. Such topographic features are called cuestas. In an otherwise nearly featureless coastal plain, cuestas are of great tactical importance. For example, a succession of eight semicircular cuestas, with their steep slopes facing eastward, have been used to protect the approaches to Paris from the east. The objective of many of the campaigns in western Europe has been to exploit or avoid these concentric, asymmetric ridges.

8-8. The degree of observation on coastal plains is variable. Long stretches of the coast are generally open to view. Inland the flat ground and vegetation provide few observation points and limit observation to short distances. The cover provided by topographic forms is almost always poor.

8-9. Numerous airfield sites exist and long straight road alinements in various directions are possible. The ground of coastal plains is generally easily excavated but the depth of excavation is limited in many places by a high water table. Sand and gravel are abundant along beaches and streams while hard rock is generally absent.

8-10. Supplies of surface and ground water are commonly adequate. On beaches a small amount of fresh ground water generally lies above the salt water.

DELTA PLAINS

8-11. Deltas are accumulations of sediments deposited by streams where their velocities are abruptly checked and thus their carrying powers are reduced. This occurs where they enter oceans or seas. The delta deposits are gradually built up to slightly above the level of the ocean and form low, generally marshy plains. The largest delta plains are formed at the mouths of the main rivers of the world; for example, the Mississippi and Volga.

8-12. Movement on delta plains is hindered by poor soil conditions of the marshy, waterlogged ground, the shifting streams with loose sand and mud bottoms, and the generally thick vegetation. Soils are better drained at the inner margin of the delta. The most trafficable parts of the delta are the highest and best drained areas at the inner margin, the sandy areas, and the natural levees adjacent to the present stream or adjacent to former channels. Deltas have been invasion routes for centuries, despite unfavorable terrain, because they give ready approach to the interior.

8-13. Observation is commonly limited on deltas because most of the low, flat ground is thickly covered by vegetation. Cover is lacking except for that provided by the levees.

8-14. Delta plains are a good source of fine binder materials and may be a source of sand, but gravel is scarce and hard rock is absent. Major construction of any type must generally be confined to levees. All other ground is unreliable because of the possibilities of settling and periodic flooding. This restricts airfield runway alinement and road alinement to the direction of the levees.

8-15. Water is available in large quantities but may be of poor quality. Particularly, the water may have a brackish taste.

VALLEY (ALLUVIAL) PLAINS

8-16. A valley plain is formed by alluvium, which is soil consisting of gravel, sand, silt, and clay that has been deposited by streams over the valley floor.

8-17. Stream valleys are gently sloping corridors through areas of greater relief. In dry weather, movement is excellent except for obstacles such as streams and local areas of poor ground and vegetation. In wet weather or during floods, movement may be limited to small areas of higher, better-drained ground, such as levees. Alluvial terraces are above flood levels and are consequently better drained than the flood plains, but they are commonly isolated by steep slopes.

8-18. Observation on flood plains is variable. On valley bottoms it is poor, but bordering slopes provide commanding views into the valley. Cover is limited, but some is available along terrace scarps, river banks, and levees.

8-19. Sand, gravel, and binder material are abundant and easy to obtain along stream channels and in terrace scarps. Hard rock is scarce in flood plains but may crop out along the scarps of terraces. Flood plains and terraces are generally well suited for construction of airfields and roads but foundations may be poor. In narrow valleys, orientation of runways may be limited to the direction of the valley. Excavations in floodplains are generally limited by the high water table. Terraces have good sites for large bunkers in many places.

8-20. Water supply is abundant. Large amounts of surface water are obtainable on flood plains. Ground water is generally available at shallow depths on flood plains and at somewhat greater depth on terraces.

GLACIAL PLAINS AND PLATEAUS

8-21. Glacial plains were created by the scouring and depositional action of large continental ice sheets. The ice scoured the bedrock, removing much of the soil in the areas beneath the main glacial mass. As it melted, the ice sheet deposited a thick mantle of its transported debris near the outer margins of the glacial areas.

8-22. Movement of military units over glacial plains and plateaus is generally possible. Occasional large boulders may block the route of travel and, additionally, prevalent soft ground, lakes, and marshes may seriously hinder movement.

8-23. Observation on glacial plains is variable. Concealment and moderate cover are available in the more knobby and forested parts. Cover is lacking on the flatter portions, especially on the outwash plains. In cultivated areas, where vegetation does not interfere, observation may be good on the flat sections of the plains.

8-24. Sand and gravel are widely distributed. The best sites for pits are in kames, eskers, and outwash plains. On till plains, boulders can provide building stone but hard bedrock is available in only a few places, such as deep valleys where the overlying. till has been cut through. Rock is abundant in the areas of glacial scour where till is lacking. Many good airfield sites are available on the better drained parts of the plains away from the knob-and-kettle areas. Road alinements are generally unrestricted. Wet ground and weak soils create foundation problems in many places. The ground is easily excavated. Large excavations can be made in the better-drained portions.

8-25. Supplies of surface and ground water are generally satisfactory for use and occur in adequate quantities.

LACUSTRINE PLAINS

8-26. Lacustrine deposits are sediments laid down on lake bottoms. The smooth surface of the deposits becomes a lacustrine plain when the lake basin is drained or the water is evaporated. The surface of such a plain is essentially featureless and level. However, if the lake was drained by a series of successive lowerings, the former margins generally show old shore features such as step-like terraces. Lakes may still occupy the lowest parts of some plains and may be intermittent. Some are remnants of the large lakes that extended over the entire plain area, and are commonly salty or alkaline. Lacustrine sediments are mostly fine clay and silt. This may grade into sand toward inlets of the lake and around the margins and outlet, depending on the type of surrounding terrain. Floods may include sand and coarser material in lake deposits, and in glacial areas, ice-rafted boulders may be present.

8-27. Movement over lacustrine plains is easy in dry weather, but when wet the fine-grained material is a serious obstacle and may be non-trafficable.

8-28. Observation is unlimited over the flat surfaces where trees are lacking, as is the case in the lake basins of the United States. Marginal slopes provide commanding views into the basins, although cover is generally absent.

8-29. Except at the margins of the plains, where old beach sand and gravel as well as hard rock may be obtainable along bordering slopes, the plains can provide only clay and fine sand for construction purposes. Lacustrine plains are ideal airfield sites and are unrestricted for road alinements, but the fine soil makes a poor foundation, particularly in humid climates.

8-30. Surface water is usually absent and when present it is likely to be of poor quality. Wells may be satisfactory water sources, but must be deep and may still yield water of poor quality.

SAND PLAINS AND PLATEAUS

8-31. Areas of wind-blown sand are common on arid plains and plateaus. The distinctive irregular, hummocky topography of such areas is comprised of low swells and ridges with intervening undrained depressions. The sand is commonly loose and shifting, but in many places dunes are stabilized by a mantle of vegetation.

8-32. Movement of military units may be hindered by swampy, undrained depressions and slopes of loose sand, except when tracked vehicles are used. The ground is firmest when moist.

8-33. Some concealment and cover are afforded by sand dunes, depending on their size. Observation is variable.

8-34. Sand dune areas contain suitable sites for airfields. These sites are easily graded, but the loose sand must be stabilized. The soil is a good foundation if confined. Emergency airfields and roads are easily constructed with portable surface mats. Sand is usually the only material available for construction purposes.

8-35. Water supply is generally limited. A small amount of fresh ground water may be available at shallow depths from dunes in coastal areas and locally elsewhere, where conditions are favorable. This important source of fresh water originates from rain which sinks rapidly into the porous desert sand and possibly from condensation.

LOESS PLAINS AND PLATEAUS

8-36. Windblown particles smaller than sand, mostly silt size (loess), have been deposited over broad tracts, generally along the margins of glacial plains and major streams flowing from formerly glaciated regions. The loess covers the underlying topography, tending to smooth out irregularities and produce a gently sloping surface. However, the peculiar ability of loess to stand in vertical walls produces very steep to precipitous escarpments along gullies, stream valleys, and artificial cuts.

8-37. In wet weather, ground conditions are very poor and movement may be stopped. In dry weather, movement conditions are good except for the escarpments and ravines.

8-38. Where vegetation is sparse, observation is generally good. Escarpments and ravines provide local concealment and cover.

8-39. Many good airfield sites and road alinements are available. Foundations need stabilization; in cold climates the loess may heave. Cuts in loess are unstable. In dry climates, thick loess deposits are well suited for underground installations because they are easily excavated. Little construction material is available except that from underlying deposits, where exposed.

8-40. Water supply is generally poor in loess. Small amounts of ground water may be procured by sinking shallow wells, but the yields are apt to fluctuate seasonally.

VOLCANIC PLAINS AND PLATEAUS

8-41. Many areas have been buried by volcanic material to form extensive plains and plateaus. Ash and coarser material ejected from volcanoes may spread over land surfaces, completely burying the old topography and producing an area of low relief. Lava that flows from volcanic vents or fissures may also flood areas and form plains and plateaus. The surface of freshly formed volcanic plains is generally featureless in large view. However, in detail, some types of lava flows may be angular and extremely rough, whereas others may be rounded and billowy. Lava terrain is commonly dissected by steep-walled valleys which form isolated plains or plateaus. Ash terrain may be highly dissected plains with almost all divides reduced to knife edges.

8-42. Ravines, dissected margins, and marginal scarps are obstructions to movement. Soils on volcanic material are commonly well drained and suitable for cross-country movement throughout most of the year.

8-43. Observation is generally good. Cover is poor on the surface of the plains and plateaus, but can be obtained at the erosion scarps.

8-44. Potential sites for airfields are common. However, although the topography and foundations are good for roads and airfields, grading requires drilling and blasting of hard rock.

8-45. Surface water is difficult to obtain because streams are few. Some ground water is available, but the distribution is erratic and careful prospecting is necessary.

KARST PLAINS AND PLATEAUS

8-46. A distinctive pitted or pinnacled erosional surface may be formed on limestone because of its soluble characteristics. This is called karst topography.

8-47. Movement across karst plains and plateaus is usually easy if sinkholes are avoided. In some instances, swamps, ponds, and steep slopes are also encountered.

8-48. Observation is restricted by vegetation. Some concealment and cover is provided by the sinkholes.

8-49. Limestone, good for building stone and crushed rock, is abundant. Sand and gravel are generally lacking. In places, fair airfield sites can be found. Grading usually will require excavation of hard rock. Excavation is made difficult by the irregular rock surfaces of deep clay-filled pits and high pinnacles of rock beneath the residual soil. The possibility of foundation subsidence should be considered.

8-50. The supply of surface water is relatively small. Large springs, common in karst areas, are the best source. Wells can yield large supplies if correctly located, but careful prospecting is required.

HILLS AND MOUNTAINS

GENERAL

8-51. The terms hill and mountain are not sharply distinguished in either popular or technical usage and seem to be largely arbitrary. In the Rocky Mountains, elevations a few hundred feet high may be termed hills, whereas in the Middle West such elevations are termed mountains. Eminences higher than 1,500 or 2,000 feet are almost everywhere considered mountains. In hills and mountains, most of the slopes are greater than 4 degrees and many slopes may be vertical or even exceed the vertical in the case of overhanging cliffs. With respect to arrangement, mountains may form isolated summits, groups, ridges, or complex units termed mountain ranges. Two or more associated ranges may constitute a mountain system; for example, the Rocky Mountains. The terms mountain chain and cordillera are sometimes used to designate units of an even larger order of magnitude. Hills and mountains of different localities vary widely in altitude, relief, area, and arrangement. The shape or form differs also. Some of the more important types of mountain forms, rising from rock structure, include fold mountains, fault-block mountains, dome mountains, and complex mountains. Other types are volcanic mountains and the distinctive forms produced by mountain glaciation.

MILITARY ASPECTS

8-52. Hills and mountains are usually obstacles to movement. They generally favor the defense. History records many cases in which forces inferior in numbers and equipment have held off superior attackers in mountainous areas. Factors which are unfavorable to troop movement over mountains are the difficulty of movement, the lack of space for maneuvering, and the vulnerability of the lines of communications. If a mountain crossing is chosen, these unfavorable factors must be outweighed by important strategic considerations. Military records include many instances in which such obstacles have been successfully overcome.

8-53. Valleys provide corridors through hilly and mountainous regions, and most of them are narrow defiles. In fold mountains, the valleys present are generally oriented parallel to the mountain trends and favor movement in that direction. In other types of mountains, the valleys are arranged radially or provide corridors across the mountain trend. Passes across divides include such features as water gaps, wind gaps, cols, and rarely, calderas.

8-54. Ground factors bear directly on rapidity and safety of movement on mountain slopes. Although the opposite sides of a peak or ridge may look rather alike on a topographic map, actually they may differ in features which make movement much easier on the dip slope than on the scarp side. The sides may differ with respect to the hazards of rockfalls, avalanches, and snow slides; the firmness and abundance of holds that must be used in climbing; the amount of snow and ice in crevices; dryness of rock surfaces; and the kind and amount of cover for troops. Crestline movements along ridges may be much more advantageous in certain directions. Alternate routes are commonly available in volcanic mountains over slopes of hard lava or loose ash and cinders. Although loose ash and cinders are usually difficult to cross, they have the advantage of allowing troops to dig in rapidly. However, if excavation is easy, the walls of foxholes and bunkers may collapse readily and require support. In other types of mountains, the choice may lie between operating on shaly limestone, which is unreliable because it is brittle and crumbly on weathered surfaces; or on gneiss, a firm, granite-like rock that gives excellent footing. Some rocks, such as argillaceous limestone, give good footing when dry, but are treacherous when wet. Others, granite for example, are little affected by water.

8-55. The rugged topography of hills and mountains provide abundant opportunity for concealment and cover. Above the timber line, movement across most slopes or crests is exposed to view from many directions. Observation is variable.

8-56. Precipitation is high in mountains. On the lower slopes, numerous streams or springs can provide small to moderate supplies of water. In the higher slopes, dependable sources are small and few. When vegetation is sparse the runoff is rapid and the flow of streams in hills and mountains fluctuates considerably. Where vegetation is abundant, the runoff may be retarded so that water from small perennial streams can be used for troop supply. A large, permanent water supply generally can be obtained only from lakes or reservoirs. In crystalline rocks, wells generally yield small quantities of water. Although large-yielding wells have been developed in this type of terrain, the factors controlling the presence of ground water may be so variable that the chance for finding adequate supplies may be small. The alluvial bottoms of the larger streams provide good locations for wells.

8-57. Many types of hard rocks suitable for construction are easily obtained in hills and mountains. Sand is scarce, but gravel is obtainable in the lower stretches of streams, where they approach the foot of mountains or flow through hills. Locations for runways are few. Ever present problems are excavation in hard rock, obstructed or limited approaches, poor accessibility, strong air currents, and the hazards of bordering peaks and escarpments. Highways, railroads, and tunnels are highly vulnerable to attack in hills and mountains. Geologic data is useful in indicating rock conditions where bombing or artillery fire can initiate slides and block lines of communication. Geologic data can also be of use in selecting sites suitable for gun emplacements and other fortifications, in estimating the probable effect of fire on rock fragmentation, and in determining the possibility of the ricocheting of projectiles. The digging of foxholes and other temporary fortifications is generally difficult in mountains, because if any soil exists it is thin or stony and the bedrock is commonly hard. In certain mountains, however, areas may have soil several feet deep. Geologic study will assist in the selection of slopes on which troops can most readily dig in. Where bedrock is at or near the surface, a geologic map will usually indicate areas underlain with softer rock, like shale and tuff, in which excavations may be possible with hand-tools. Where harder materials are involved, geological data can aid in the estimation of the amount of blasting required and the selection of the proper excavating equipment.

PHYSIOGRAPHY OF THE UNITED STATES

GENERAL

8-58. The United States is broken into the following major divisions: Laurentian Upland, Atlantic Plain, Appalachian Highlands, Interior Plains, Interior Highlands, Rocky Mountain System, Intermontane Plateaus, and the Pacific Mountain System. Each of these major divisions is composed of a number of provinces which are further subdivided into sections. The 25 provinces are, running from East coast to West coast—

1 Superior Upland
2 Continental Shelf
3 Coastal Plain
4 Piedmont Province
5 Blue Ridge Province
6 Valley and Ridge Province
7 St. Lawrence Valley
8 Appalachian Plateaus
9 New England Province
10 Adirondack Province
11 Interior Low Plateaus
12 Central Lowlands
13 Great Plains Province
14 Ozark Province
15 Ouachita Province
16 Southern Rocky Mountains
17 Wyoming Basin
18 Middle Rocky Mountains
19 Northern Rocky Mountains
20 Columbia Plateau
21 Colorado Plateau
22 Basin and Range Province
23 Sierra-Cascade Mountains
24 Pacific Border Province
25 Lower Californian Province

LAURENTIAN UPLAND

8-59. This area, for the most part, extends into Canada for an undetermined length. The province which lies within the United States is the Superior Upland. It is an area consisting of Precambrian rocks of all origins and histories, mainly crystalline and resistant. Having become stable, it was worn down to a peneplain (a plain raised from the sea) then attacked by weathering processes and streams flowing down to the sea until it reached an ultimate level. This area is characterized by destroyed drainage lines, streams few and ungraded, lakes and swamps in abundance, low rounded hills and shallow valleys. It is in this Superior Upland Province that is found the Mesabi, or Giants Range, the site of the greatest iron mines in the world and Lake Superior, the largest of the five Great Lakes.

ATLANTIC PLAIN

8-60. This is one of the largest of the major physiographic divisions of the United States. It consists of two provinces, the Continental Shelf (which is submerged) and the Coastal Plain (which is the emerged portion). The Atlantic Plain area includes the Eastern and Southern margin of the U. S. from Newfoundland to Florida, and around the Gulf of Mexico. This area is termed a lowland and passes under the sea almost without change from its gentle slope. The plain continues under shallow water for a distance varying from a few miles to a few hundred miles. The slope then steepens and descends rapidly to the abyss (deep sea).

8-61. The Atlantic Coastal Plain is composed of many different terrain features. These include normal and terraced coastal plains, sandhills, swamps, sinkholes, lakes (found in Florida), flood plains (found in La. and Miss.) and deltas. Many of these features were once part of the ocean bottom or were formed by alluvial deposits built seaward from inland.

8-62. Movement of military units will normally be free for tracked vehicles, but in certain areas such as Florida, Louisiana, and Mississippi, movement may be restricted by unfavorable soil, marshes, dense vegetation, and medium to heavy rainfall. Movement may also be difficult on the Eastern Coast where the land is separated into compartments because of the many streams and estuaries.

8-63. The supply of water for military purposes is adequate, although adjacent to the shoreline, streams may be brackish and only small amounts of fresh ground water may be found.

8-64. Problems faced by the engineer in this area are numerous. The problem of flood control is one of the most important. Construction of dams has eased this situation, but not entirely. The engineer is also faced with the problem of suitable foundations. Because of the high water table and the sandy areas common along the Coastal Plain, large pilings are driven into the ground to support modern size buildings. However, sinking may still occur because of the lack of a solid foundation. Another important problem in this area is that of highways and runways. If a good foundation does not exist, the only solution will be a continuing repair program.

8-65. Moving inland from the coast, a new problem exists. Here is found a mixture of clay and sand, with clay predominant, commonly called *gumbo*. This material, when wet, becomes plastic and slides so that highway and airfield construction would prove troublesome. Upon further consideration of this area large deposits of limestone and coal will be found further north, particularly in the Alabama region around Birmingham. Once this region is reached, the earlier problems of lack of foundations and poor roads are no longer encountered.

8-66. The Atlantic Plain affords abundant supplies of materials for construction purposes. Sand deposits are plentiful and quantities of gravel will normally be adequate. Hard rock, however, will usually be absent. Airfields and straight roads are easily constructed, but excavation depths are limited because of high water tables.

APPALACHIAN HIGHLANDS

8-67. Like other physiographic divisions, the Appalachian Highlands takes its name from its most prominent feature, and is therefore designated as a highland. Other features are contained in this major division, however, which stretches from the Gulf Coastal Plain to the St. Lawrence Valley and from the Atlantic Coastal Plain to the Central Lowland. The Appalachian Highland contains seven provinces, the major ones being the Piedmont, a peneplain on the seaward side, and the Appalachian Plateaus.

8-68. The Piedmont is particularly suitable for military engineering operations because strong rock occurs in quantity and water supply is generally adequate. Much of the granite used as a building stone in eastern cities comes from this province. On construction work in the Piedmont, the engineer does face one serious problem, however. In many areas of the province, erosion is in a new cycle and has done considerable destruction. Sixty-five per cent of the topsoil and ten per cent of the subsoil in the region from New York to Alabama has been washed away.

8-69. The other major province of the Appalachian Highlands is the Appalachian Plateau. The province is generally a shallow syncline and contains a large portion of shale. All the formations, however, contain sandstone members at intervals. From a military standpoint, movement in the province may be rugged along the ridges and valleys. Here deep escarpments may hinder or prevent cross-country travel. Vegetation may also prevent travel to a large .degree. Good construction material is limited to the harder sandstone members which are prominent in the escarpments but also outcrop elsewhere. Sand and gravel may be found in terraces and in stream channels. On a construction problem, the engineer may encounter a lack of suitable foundations. Drainage is poor in some areas, and the bearing strength of soils is relatively low. However, plateaus do offer good construction sites for roads and airfields. Here alinements are not as restricted as in mountainous areas. In those areas where drainage is good, the engineer should find excellent sites for large structures, but in some areas where a high water table prevails, excavation will be limited to some degree.

INTERIOR PLAINS

8-70. Moving westward toward the central portion of the United States, the Interior Plains are encountered which consist of three, provinces: the Interior Low Plateaus, the Central Lowland, and the Great Plains. Characteristics of this division are young to mature plateaus, mature to old plains on weak rocks which may be slightly uplifted, and low, maturely dissected plateaus with silt-filled valleys; moraines, lakes, and lacustrine plains; submaturely to maturely dissected till plains, old escarped plains, and entrenched streams; old glaciated plateaus, isolated and maturely dissected dome mountains; and trenched peneplains, as well as lava-capped plateaus and buttes.

8-71. From a military aspect, transportation will be difficult in some areas due to large boulders and marshy ground when encountering glacial topography. Supplies of ground and surface water are generally good. Sand and gravel will be widely distributed with the best pit locations in kames, eskers, and outwash areas. On till plains, boulders will provide building materials, but hard bedrock is generally limited to deep valleys. Good airfields may be located in the better drained plains away from knob and kettle areas. Road construction is generally unlimited. Wet ground and weak soils will create foundation problems. The area is usually easily excavated. Surface water is of low supply, but deep wells may solve this problem.

ROCKY MOUNTAIN SYSTEM

8-72. This major division consists of four provinces: the Southern Rocky Mountains, Wyoming Basin, Middle Rocky Mountains, and Northern Rocky Mountains. The Southern Rocky Mountains are complex mountains of various types. Elevated plains in various stages of erosion and isolated low mountains characterize the Wyoming Basin. In the Middle Rocky Mountains, complex mountains and intermontane basins predominate. The Northern Rocky Mountains have deeply dissected mountain uplands and intermontane basins.

8-73. The first aspect to be considered by military engineers will be water supply. Precipitation is high in mountainous regions. On the lower slopes, numerous streams or springs will provide a small to moderate supply, whereas on the higher slopes dependable sources are fewer and smaller. Large and dependable sources will be available mostly from lakes and reservoirs. Large quantities of hard rock will be available throughout the area, and by using geological maps, exact locations may be determined. Sand is scarce in mountainous regions and gravel will be found in the lower stretches of river streams. Runway locations are limited due to excavation problems and wind currents resulting from mountain formations. Transportation facilities will prove problematical unless geological information is used to avoid the digging of areas that will slide from aerial or artillery concussion and cause blocking. Foxholes and field fortifications will prove troublesome because of the thinness of soil and the presence of hard rock underneath.

INTERMONTANE PLATEAUS

Columbia Plateau Province

8-74. The Columbia Plateau is found in the states of Washington, Oregon, and Idaho, and is mainly built up from lava flows. Soils on the volcanic material are commonly well drained and suitable for crosscountry movement most or all of the year, however, ravines, dissected margins, and marginal scarps are obstructions to movement. Surface water is difficult to obtain since streams are few. Some ground water is available, but the distribution is erratic and careful prospecting is necessary. Construction materials are present. Hard trap rock is abundant and is easily quarried because of its close jointing. This rock makes good surfacing material and building stone. Sand and gravel are generally scarce. The topography and foundations are good for roads and airfields, but grading commonly requires excavation of hard rock.

Colorado Plateau Province

8-75. This province is distinguished by its approximately horizontal rocks. Travel is not as restricted as in the Columbia Plateau Province, due to fewer ravines and surface dissections. Strong rocks and aridity cause steep slopes to waste away slowly and provide a good source of construction materials for roads and airfields. The lack of rain causes a water supply problem in this area.

Basin and Range Province

8-76. Isolated, roughly parallel mountain ranges separated by desert basins characterize the topography of this province. Climatically, it is the driest province in the United States and has insufficient runoff to carry its load of weathered material. This results in the formation of alluvial fans at the bases of mountains. They serve as an excellent source of construction materials and may also be ideal sites for airfields. Movement is difficult except in the valleys because of the many fault scarps and spurs. Water supply is scarce away from the northern mountainous area and a depth of 100 feet or more to the water table is common.

PACIFIC MOUNTAIN SYSTEM

Sierra-Cascade Province

8-77. Characteristics of Sierra-Cascade Province are sharp alpine summits, high volcanic cones, and volcanic mountains variously eroded. The Sierra-Nevada and Cascade Mountains form a single mountain barrier between the plateaus on the east and the Pacific valleys on the west. The topography of the higher regions is controlled in detail by glaciation. Most of the hills are rounded knobs or domes of granite, many without soil.

Pacific Border Province

8-78. Throughout most of its length from north to south, this Province is divided into a chain of mountains on the west and a chain of valleys on the east. The topography is very diverse. The Pacific border is a lowland area, some of which is submerged. Also found are accordant (of equal elevation) crests with local alpine peaks, uplifted peneplains, monadnocks of igneous rock, extensive monadnock ranges, low fluviatile plains, parallel ranges and valleys on folded, faulted, and metamorphosed strata, rounded crests of subequal height, narrow ranges and broad fault blocks, alluviated lowlands, and dissected westward sloping granite upland.

Lower California Province

8-79. This whole province appears to be composed of fault blocks which have displaced in different ways and at different times, some of them still moving. Because of the large number of faults and the recency of some, the details of topography and physiography differ for each fault block. In general, this area consists largely of rolling uplands surmounted by residual hills and small mountain ranges subdivided by deep valleys.

PHYSIOGRAPHIC CHARACTERISTICS OF THE EARTH'S SURFACE

8-80. The choice of construction procedures and tactical moves at any point on the earth's surface is aided by the use of physiographic principles. A description of all the landforms present on the earth is beyond the scope of this manual; however, the general principles presented in this chapter and in particular the more detailed discussion given of the physiographic features of the United States should provide enough background for analysis of any of the local variations which may be encountered. As a further aid, a generalized distribution of physiographic features is presented pictorially in figure 8-1 and figures 8-2 through 8-4, pages 8-12 through 8-14.

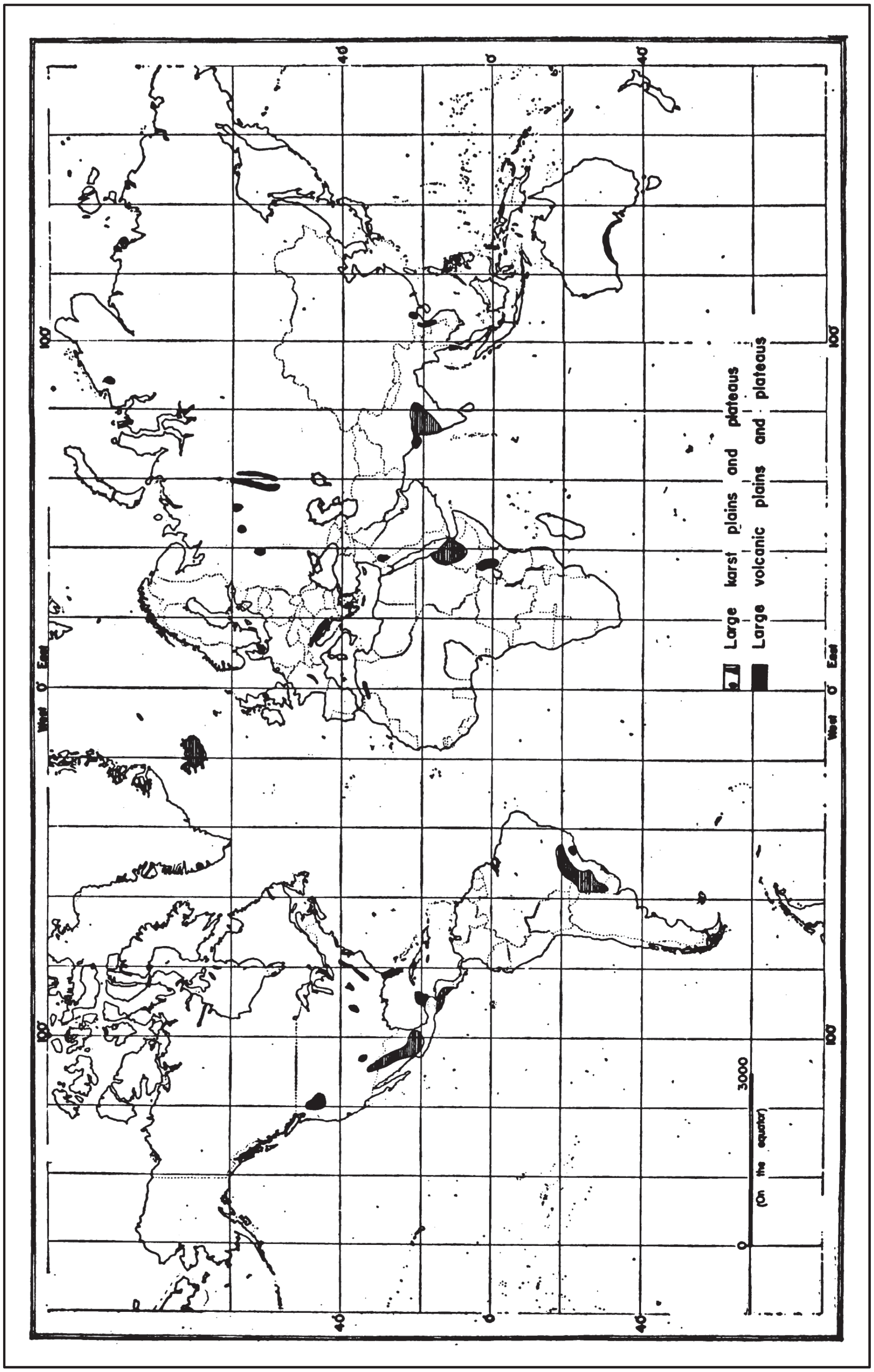


Figure 8-1. Distribution of large volcanic and karst plains and plateaus

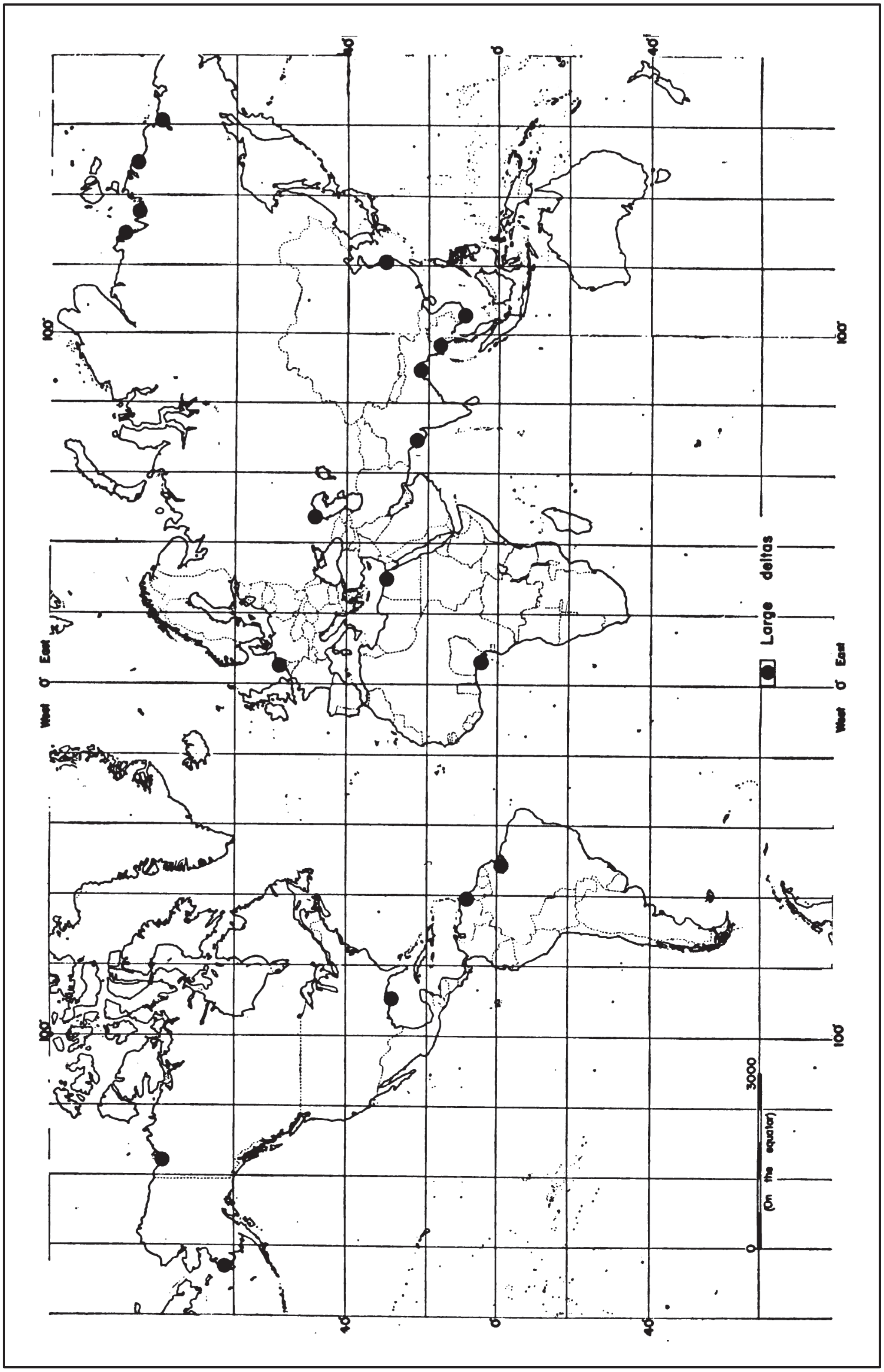


Figure 8-2. Large deltas of the world

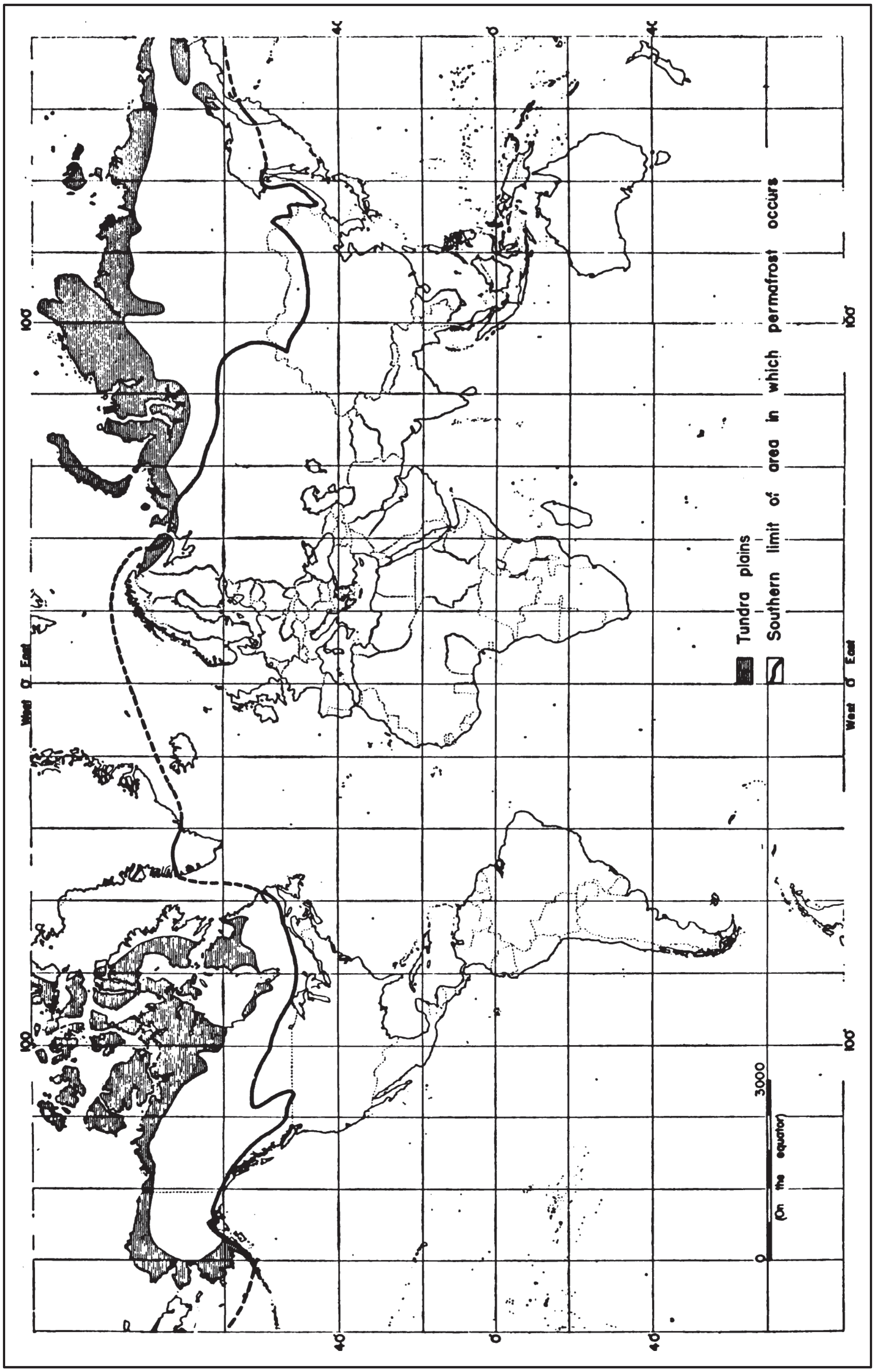


Figure 8-3. Tundra plains of the world, and southern limit of permafrost region

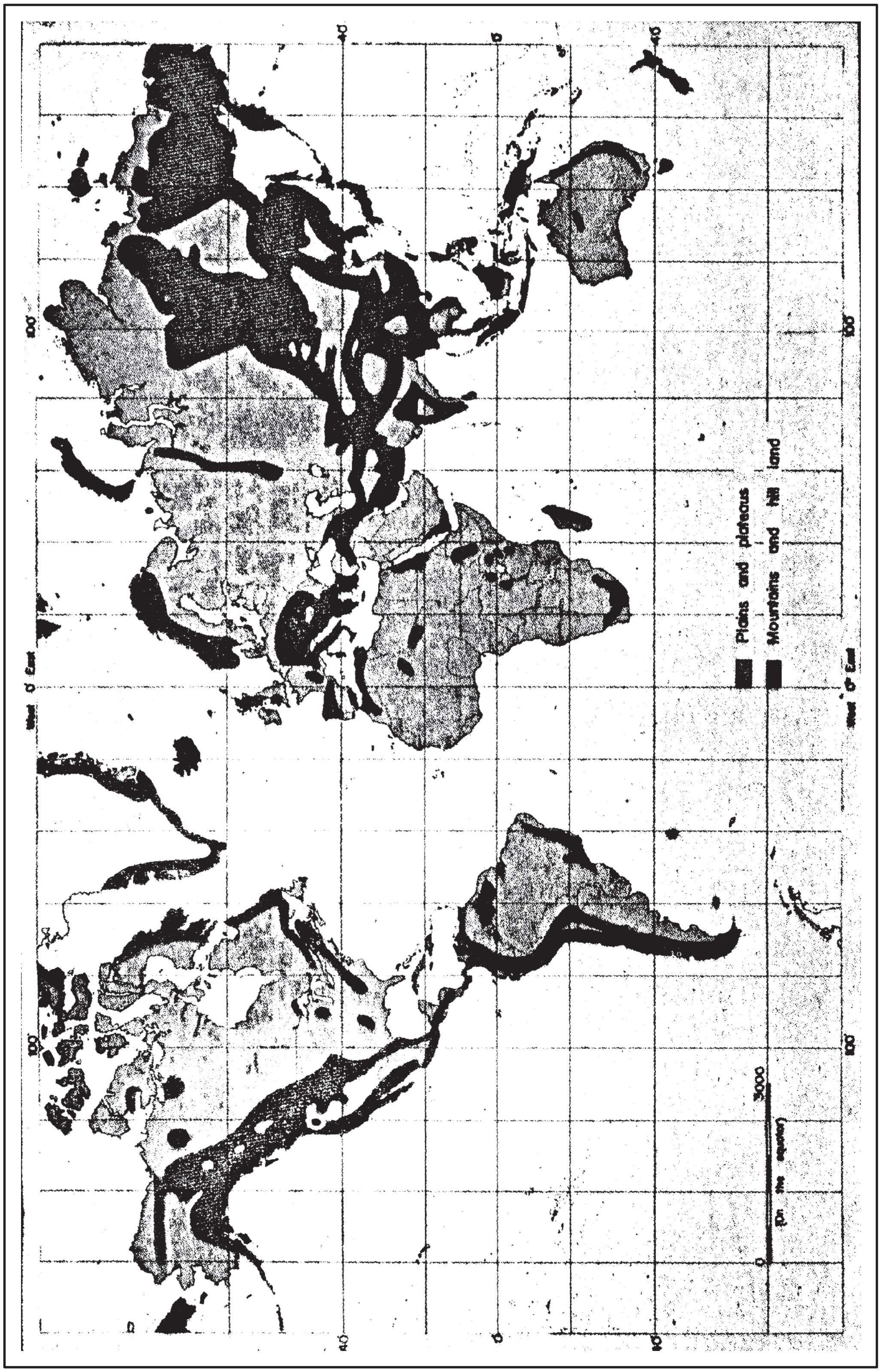


Figure 8-4. Worldwide distribution of plain and plateau and mountain and hill areas

Chapter 9
Field Geology

INTRODUCTION

9-1. Field geology is the study of rocks and rock structures investigated in their natural relationships to one another. Field geology seeks to describe and to explain the surface features and subsurface structure of the crust of the earth. The data obtained from field exploration is then placed on geologic maps. This chapter describes the methods and analysis necessary to obtain detailed geologic reports. Included are the procedures of investigation, the instruments, and the approaches to problems encountered in field work.

PRELIMINARY INVESTIGATION

9-2. Before going into the field, it is advisable to conduct as much of the investigation as possible in the office. This preliminary investigation consists of analyzing previous work done on the area under investigation and examining maps and literature of the area. The types of study already conducted in the area should be definitely considered. Areas where detailed work has been done need only be checked, whereas areas in which only a quick reconnaissance was conducted must be remapped to provide a detailed report.

EQUIPMENT

9-3. The type of equipment needed on a field trip depends upon the types of survey to be conducted. However, a certain few items are always required regardless of the procedure.

9-4. The hammer, usually a geological hammer, is used to break or dig into rock or soil and to prepare samples for examination back in the laboratory. A hammer is also useful in determining the strength and resistance of the rock, as well as the toughness of the grains.

9-5. The hand lens is a small magnifying glass (preferably 10 power) used to examine the individual mineral grains of a rock, for identification as well as shape and size.

9-6. Dilute hydrochloric acid (1 part concentrated HC1 to 4 parts water) is used in the determination of carbonate rocks. Dilute acid is preferred because the degree of its reaction with different substances is more easily seen. For example, the reaction of dilute acid with dolomite is only slight, while the reaction of the same acid with limestone is rapid.

9-7. One of the most important pieces of equipment to the field geologist is the Brunton compass (M2). This instrument is an ordinary magnetic compass with folding open sights, a mirror, and a rectangular spirit level clinometer. It has a rotating dial graduated in degrees or mils. In some cases the dial is numbered to 360° while in others it may be graduated in 90° quadrants. With this compass the field investigator can measure not only dips and slopes but strikes and directions as well.

9-8. The base map is essential in all types of field work except when the plane table and alidade method is used.

9-9. Although an auger is not always essential, it is often extremely helpful. With it one can obtain soil samples or rock material where outcrops are scarce.

PROCEDURE OF INVESTIGATION

9-10. Everywhere below the soil there is solid rock known as bedrock. Where the bedrock sticks out through the soil covering, it is called an outcrop. This outcrop is the primary concern of the field geologist. He needs to note certain characteristics and follow certain procedures at each outcrop.

9-11. Classification of minerals, shape and size of grains, amount of cementation, structures if any, color, plasticity, and any other distinguishing features should be recorded.

9-12. Location and elevation of outcrops should be noted. (This information should be put on the base or control map, as well as in notes.)

9-13. The dip, strike, and width of the formation or rock unit should be determined and recorded.

9-14. Stratification, thickness of layers, origin of deposition, to include specialized features such as cross-bedding, ripple marks, mud cracks, and wave marks should be recorded. When possible it is well to note the origin of the material as to whether it was deposited by an alluvial, marine, aeolian, or glacial mode of transportation.

9-15. The age of the formation may have been determined in a preliminary report, but if not, it should be done by comparing the rockbed with adjacent rocks. In many cases it will be necessary to collect fossil remains and study them in the laboratory.

9-16. The contact where two beds join should be examined to determine whether it is gradational or sharp. When deposition has been continuous, the bedding usually is gradational. On the other hand, if an erosion surface has developed, a sharp contact may be present between the overlying and underlying beds.

9-17. The topographic relief of the rock unit should be mentioned as it is significant to both the geologist and the engineer. Resistant beds may form mesas, hogbacks, or other types of ridges, whereas the nonresistant beds may form depressions and valleys.

GEOLOGICAL SURVEYING

GENERAL

9-18. The instruments and methods of geological surveying are numerous and varied. Instruments to be used on a particular project depend on the scale, time, detail, and accuracy required on the project.

PACE AND COMPASS METHOD

9-19. The pace and compass method is probably the least accurate procedure used. The survey is conducted by pacing the distance to be measured and determining the angle of direction with the compass. To record this information, the field geologist uses either a topographic quadrangle or any other map which shows a few control points. It is preferable, however, to use a topographic quadrangle when available because elevations are recorded on this type of map. When a topographic map is not available, the field geologist must use an aneroid barometer or some type of accurate altimeter to record elevations.

PLANE TABLE—ALIDADE

9-20. When accurate horizontal and vertical measurements are required, the plane table—alidade method is used. The equipment required consists of a stadia rod, tripod, plane table, and alidade. Sheets of heavy paper are placed on the plane table to record station readings. After the stations have been recorded, the geologist places formational contacts, faults, and other map symbols on the paper. This information can later be transferred to a finished map. The alidade is a precision instrument consisting of a flat base which enables it to be moved at will on the plane table. Along the side of the flat base is a straight edge which is parallel to the line of sight, and is used to plot directions on the base map. The alidade also consists of a telescopic portion which has a lens containing one vertical and three horizontal hairs. These are stadia hairs. The vertical hair is used to aline the stadia rod with the alidade. The horizontal hairs are used to read the distance to the rod. Vertical elevations are determined from the stadia distance and the vertical angle to the points in question.

Brunton Compass and Airphoto

9-21. The Brunton compass and vertical airphotos provide a rapid but accurate method of geological surveying. Instead of a base map, the airphoto is used. Contacts, dips and strikes, faults, and other features may be plotted directly on the airphoto or on a clear acetate overlay. Detailed discussion of the geological features must be kept in a separate field notebook. If topographic maps are available, they will supplement the airphoto and eliminate the need of an aneroid barometer. The topographic map may be used for the base map and also used to plot control for horizontal displacements.

Plane Table, Mosaic, and Alidade

9-22. A mosaic of airphotos may be used with the plane table and alidade, thus eliminating the base map. This procedure is used to eliminate the rodman and speed up the mapping. By using the mosaic as a base, horizontal distance need not be measured and vertical elevations can be computed by the instrumentman. The angle of variation from the horizontal is read, the distance is scaled from the map, and by trigonometric calculations the difference is found. Although this is faster than the normal plane table method, the accuracy is not as great.

Photogeology

9-23. Photogeology is the fastest and least expensive method of geological surveying; however, a certain amount of accuracy and detail must be sacrificed. Usually this type of survey is used for reconnaissance of large areas. When a geologic map is constructed from airphoto analysis alone, it shows only major structural trends. After preliminary office investigation, the geologist may wish to go into the field and determine the geology of particular areas in detail.

9-24. Photogeology, which utilizes vertical airphotos to do the actual mapping, is usually carried out in the office or laboratory. The photos are viewed stereoscopically and information is plotted directly on the photo. When a series of photos has been completed, the information is transferred to a controlled mosaic. The finished product is then transferred and compiled into a map. This is discussed in more detail in chapter 11.

GEOPHYSICAL SURVEYING

9-25. Many times only scattered outcrops are present or the entire rock structure may be buried beneath a cover of soil. In this case it is necessary to conduct geophysical surveys which shed light on the type, size, shape, and structure of rocks beneath the surface of the earth. The more important physical properties which are measured by geophysical surveys are density, magnetic susceptibility, elasticity, electrical conductivity, variations in temperature, and variations in radioactivity. It should be emphasized that geophysical instruments do not make maps or produce structural cross sections, but they do give important additional information to the mapmaker.

SURFACE GEOPHYSICAL SURVEYING

Gravimetric Methods

9-26. Because the earth is made up of numerous mixed types of rocks and minerals, variations exist in the force of gravity from place to place. Instruments used to measure this variation are the torsion balance and the gravimeter. When gravimeter readings are made over a formation of low density rock, an area of low gravimeter readings occurs. By interpreting the gravimetric readings and allowing for variations, a good idea may be gained of the subsurface structure.

MAGNETOMETRIC SURVEY

9-27. As the different rocks of the earth show different forces of gravity, they also show different degrees of magnetism. The physical properties of rocks which allow them to have these different amounts of magnetism may be measured by the magnetometer. The information gained from the magnetometer may be used to study subsurface structures. This method is not entirely reliable. In some cases, the magnetic readings will not agree with information, derived from drilled wells. Many of these differences have not been explained. Magnetrometric surveys are most useful when used in airborne surveying. The method is also economical because large areas may be surveyed in a minimum of time.

SEISMIC METHOD

9-28. In the seismic methods of geophysical exploration, artificial waves produced by explosives are sent through the rocks to be studied. Seismic methods have been widely used in searching for subsurface structures that might yield oil or gas; in localizing certain types of ore deposits; in mapping the bedrock floor beneath gravel deposits where dams are to be constructed; in measuring the thickness of glacial ice; in studying the configuration of the basement beneath stratified layers of rock; and in many other ways. This is the most useful method of determining hidden subsurface geologic structures. The seismic method utilizes two important characteristics of rock formations. First, rock materials vary in the speed with which they transmit an elastic earth wave. Second, sedimentary rock types are divided by sharp contacts which reflect part of the energy generated as elastic earth waves. It is the ability of rock units to reflect, refract, and transmit artificially induced wave lengths that enables graphical exploration. Hard, compact rocks, granite, basalt, sandstone, and limestone transmit wave length with greater speed than softer or less consolidated rocks. The rate of speed varies through a wide range, from about 5500 feet/second in ordinary elastic sediments to over 23,000 feet/second in some of the harder materials.

9-29. Seismic waves, in their behavior underground, may be compared in many respects to light waves. They are transmitted, refracted, and reflected by the rock units. Seismic waves are produced for seismic surveying by discharging an explosive placed in a drill hole, known as a shothole. In most areas, there is a surface layer of weathered material known as the weathered zone. The thickness of this zone varies from a few feet to a few hundred feet, with an average velocity of 2000 feet/second. To facilitate the transmission of waves and to conserve on explosives, the shothole is drilled to a slightly greater depth than that of the weathered zone. The waves produced by the explosive move out from the shothole at an equal rate of propagation and in all directions. The reflected and refracted waves are received by instruments called geo phones. The geophones transmit the impulse to the seismograph which records them.

9-30. The two basic properties, reflection and refraction, are the methods utilized in geophysical surveying. The refraction method is used for reconnaissance work, and to establish the depth of a high speed stratum, usually the basement complex. The reflection method complements the refraction method and is used to obtain detailed information. In general practice, the refraction method uses a spacing, between the shothole and geophones, of 3 to 7 miles. When the explosive is discharged, the shock waves are transmitted and refracted to the geophones. Figure 9-1 shows the path of a refracted wave. In this hypothetical case the strata will represent different relative velocities. V_1 has a slow velocity, V_2 slightly faster, and V_3 about four times faster than V_2. Considering the distance, path "a" has the shortest distance to travel, whereas path "c" has the longest. However, path "c" is transmitted through the medium with the highest velocity and will be detected by the geophones first. Thus, the first response recorded is usually the critical data needed in the refraction method. In the reflection method, the distance from shot point to geophones is much shorter than in the refraction method (usually not more than 3000 feet). The purpose of this method is to determine dip, depth, and thickness of rock units. By comparing several graphs of an area, it is possible to correlate formations and interpret the geologic structure. Figure 9-2 shows the paths reflected waves will follow. Some of the energy is reflected by the contact between V_1 and V_2 while the remaining energy is refracted through V_2. At every contact between rock units the same process is repeated. Interpretation of the graphs and mathematical computations will reveal the dip, depth, and thickness.

9-31. Several types of spreads are used. A *spread* is the spacing and plan of the geophones with regard to the shothole. The fan type is used for refraction shooting and has primarily been used to locate salt domes.

In this type the shothole is the apex of the fan and the geophones are placed in an arc about the apex. The midspread method is where the shothole is placed between the geophones.

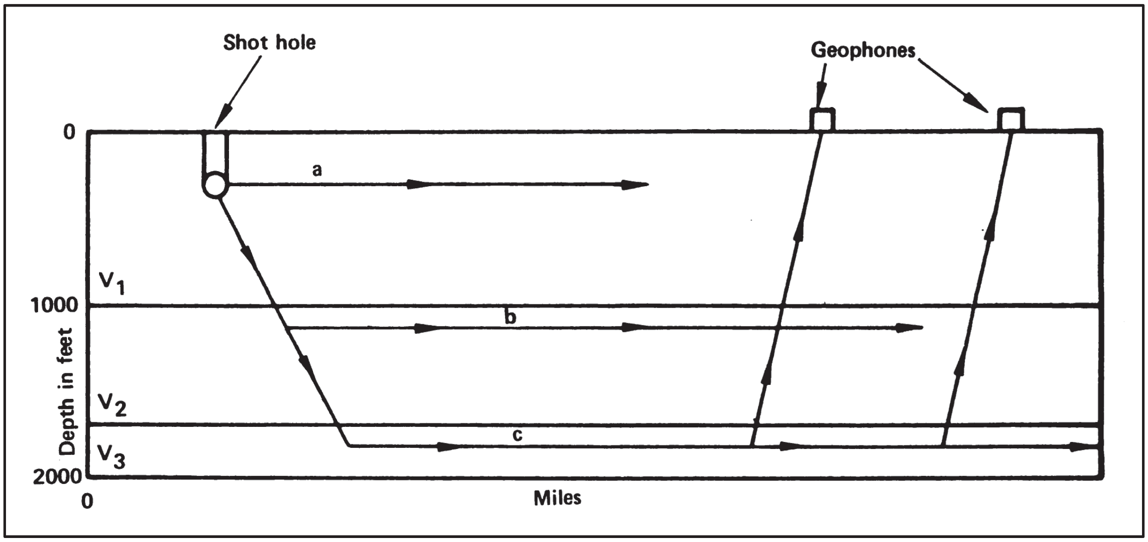


Figure 9-1. Paths of direct and refracted waves

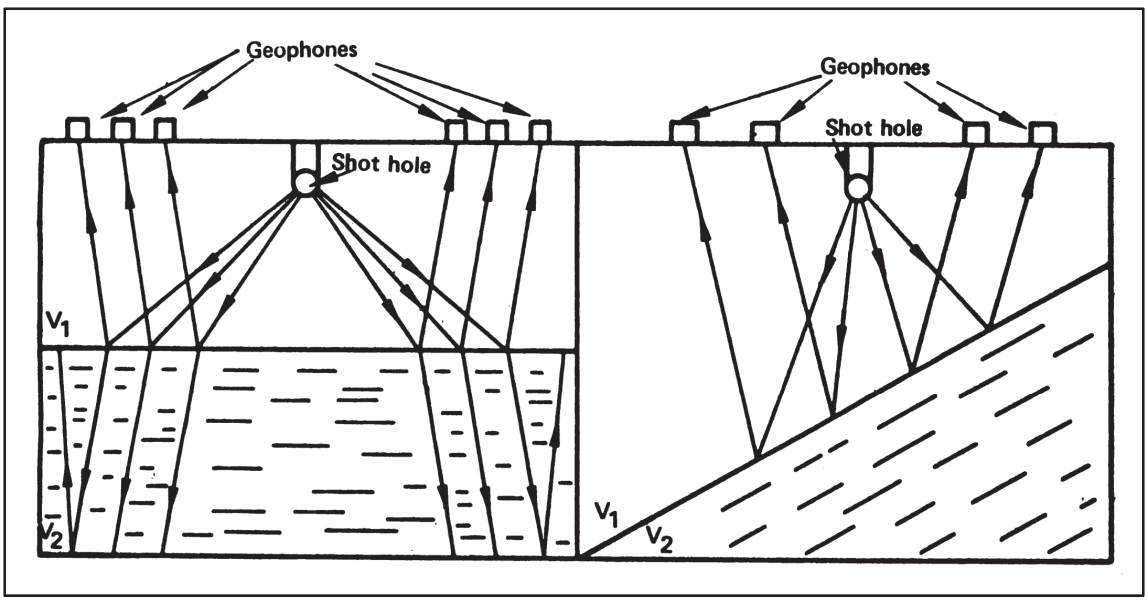


Figure 9-2. Paths of reflected waves

SUBSURFACE GEOPHYSICAL SURVEYING

ELECTRICAL METHOD

9-32. Each rock type has certain electrical properties which may be measured and recorded by lowering instruments into well borings. By interpreting the electric log (graph recorded by the instrument) it is possible to determine the relative fluid content of the rock, the type of rock, and the formational contact.

GEOTHERMAL METHODS

9-33. The rate of increase of temperature with depth beneath the earth's surface is called temperature gradient or geothermal gradient. Generally, the average increase is 1°C. per 100 feet. Subsurface temperatures are measured with a resistant thermometer which is lowered into a well. The temperature at various intervals is recorded simultaneously at the surface. These observations are made along with electric logging of the hole. The geothermal method is used by geologists to indicate lithologies and fluid content of rocks and to determine structural conditions when they can be correlated between numerous wells. As an example, it has been found that temperatures measured on the crest of an anticline increase much more rapidly than those measured on the flanks.

RADIOACTIVE METHOD

9-34. Rocks of various kinds are radioactive in different degrees. Because of this property, radioactive logs may be taken in wells to facilitate use of the electric logs. The primary importance of radioactive logs is the fact that they can be taken after the hole has been cased. Since the increased demand for uranium, radioactive surveys have been conducted by airplanes. These surveys are not conclusive but do indicate areas of high radioactivity.

Chapter 10

Sources of Geologic Information

GEOLOGIC MAPS

DEFINITION OF A GEOLOGIC MAP

10-1. A geologic map is an overlay of a topographic map giving a two-dimensional representation of the distribution and structure of bedrock in a given area. Generally, the smallest rock unit that is mapped is a formation. A formation is an individual mappable rock unit that extends over a fairly large area and can be clearly differentiated from overlying or underlying beds because of a distinct difference in lithology, structure, or age.

TYPES OF GEOLOGIC MAPS

Bedrock or Areal Geologic Maps

10-2. A geologic map showing a plan view of the bedrock in the area is a bedrock or areal geologic map. Such a map shows the boundaries of the visible formations and the inferred distribution of those formations covered by soil or plant growth. Areal maps do not show soil or unconsolidated rock except that they usually show thick deposits of alluvium. In areas of complex geology where exposures of bedrock are scarce, the location of the contacts between formations is often only approximate or hypothetical and is so indicated. Areal geologic maps are commonly accompanied by one or more geologic sections.

Surficial Geologic Maps

10-3. These maps differentiate the unconsolidated surface materials of the area according to their geologic categories, such as stream alluvium, glacial gravel, and windblown sand. These maps indicate the areal extent, characteristics, and geologic age of the surficial materials.

Structural Geologic Maps

10-4. Areal geological maps of moderately deformed areas often carry enough structure symbols to provide an understanding of the structural geology of that region. In highly complex areas, however, where a great amount of structural data is necessary for interpretation, special structural geologic maps are prepared. These maps are more complete in their coverage of the structural details of the region and have many symbols to represent the characteristics of folds, faults, joints, and the different kinds of flow structures. Often larger symbols are placed on the map to indicate the general trend of the individual observations. These maps also may show structural contours and isopachs (points of equal stratum thickness), both of which require detailed subsurface data obtained by drill records or mining. Structural geologic maps are particularly useful for interpreting ground-water supply and conditions for underground installations.

General Purpose Geologic Maps

10-5. These maps are a composite of both the surficial and bedrock geologic maps. Where soil covering is sufficiently thick, it is represented by appropriate symbols, but bedrock present is also shown, even if it has a thin covering of soil. The general purpose map is the most desirable if for some reason a bedrock and surficial map of an area cannot both be obtained. Also, when one map will do, it is more economical to prepare a single map which can be used for two purposes.

DIVISIONS OF GEOLOGIC HISTORY

10-6. Geologic history is divided into eras, periods, epochs, and ages (table 10-1). The major divisions, eras and periods, are divided by episodes of mountain building that alternate with long intervals of erosion and deposition. The smaller subdivisions, epochs and ages, are divided by localized breaks in the sedimentary record.

Table 10-1. Divisions of geologic time

Eras	*Periods*	*Symbol*	*Predominant life*
Cenozoic (60 million years ago)	Quaternary (recent) (Pleistocene).	Q	Age of man.
	Tertiary	T	Age of mammals.
Mesozoic (60-200 million years ago)	Cretaceous	K	
	Jurassic	J	Age of giant reptiles.
	Triassic	Tr	
Paleozoic (200-500 million years ago)	Permian	P	Age of primitive reptiles.
	Carboniferous (Pennsylvanian) (Mississippian).	C	Extensive coal swamps.
	Devonian	D	Age of fishes.
	Silurian	S	Widespread ancient coral reefs.
	Ordovician	O	Primitive fishes.
	Cambrian	C	Primitive marine invertebrates.
Precambrian (500-2000 million years ago)	Divisions not standardized	_ _ _ _	

Eras

10-7. Eras are long intervals of geologic time which are usually terminated by major orogenies, or episodes of intense mountain building. Although these orogenies are identified throughout the world, it is fairly certain that they did not all occur at the same time.

- The *Cenozoic* era is the most recent and is still continuing today. Its beginning was about the time when such mountains as the Rockies, Andes, and Alps began to rise for the first time.
- The *Mesozoic* era preceded the Cenozoic and began about the time of the first appearance of mountains on the site of the present Appalachians, Urals, and others.
- The *Paleozoic* era began with the formation of mountains which today are recognizable only by their eroded stumps, as in many places of eastern and central North America.
- The *Precambrian* era is a general term for all geologic time before the Paleozoic. Most probably it consists of two or three eras separated by times of widespread mountain building, but the geologic history is obscure. Most of the rocks are metamorphosed and fossils are absent or poorly preserved.

Periods

10-8. Less severe but worldwide episodes of mountain building subdivide the eras into periods. Table 10-1 lists the generally accepted period names. With minor modifications these terms are used by geologists throughout the world.

10-9. Periods through the Cretaceous are usually named after a locality where the rocks of such age are best and most typically developed. These periods, therefore, bear geographic names. The Permian period for example, is named after the town of Perm in the Ural Mountains, and the Devonian period after the county of Devon in England.

Epochs and Ages

10-10. Periods, in turn, are subdivided into smaller time units called epochs and ages. A great many epoch and age names are used throughout the world; many are of local significance only. Like periods, they are usually named after a locality where the rocks are best and most typically developed.

SYMBOLS USED ON GEOLOGIC MAPS

10-11. In addition to standard topographic map contains specialized symbols to show age, structure, and lithology of the rocks. A formation is generally the smallest unit which is mapped. Geologic maps indicate the areal extent of these formations by means of letter symbols, color, and symbolic patterns. Standard color patterns are used to indicate age on maps produced by the United States Geological Survey. Tints of yellow and orange are used for different Cenozoic rocks, tints of green for Mesozoic rocks, tints of blue and purple for Paleozoic rocks, and tints of red for Precambrian rocks. Structural features are also shown on geologic maps by the use of symbols. The most important of these include symbols for bedding, folds, contacts between formations, and faults. These symbols are illustrated in figure 10-1, page 10-4. Other symbols are often placed on geologic maps. They include standard topographic symbols and special geologic symbols, and they are always defined in the marginal information.

PREPARATION OF GEOLOGIC MAPS

General

10-12. Various methods may be used in the preparation of geologic maps. In the last chapter, several methods of field exploration were discussed. The cost of this type of operation is usually very high since much time and many technical people are required to construct an accurate geologic map.

Field surveys

10-13. At the present time, the majority of geologic maps are produced through actual surveys in the field. This method is the most accurate, but at the same time the most expensive. A rather extensive crew of men must spend much time in the field with surveying instruments to arrive at accurate conclusions. Geologists must be present to analyze rock types and geologic structures, and to determine the economic value of the area in the search for natural resources. Accurate field surveys of a geological nature have been conducted in only a small percentage of the total land surface of the United States. Certain areas of Europe have been mapped rather extensively, but the remainder of the earth's land surfaces has been mapped only where natural resources are of definite economic importance. Factors such as cost, time, and availability of technically trained personnel have limited this type of investigation.

Composite surveys

10-14. Composite surveys, using both the field method and aerial photographs, have proved very worthwhile. The entire area under consideration is photographed from the air and interpreted. Localized areas which have a questionable interpretation are then examined by a field party to establish the correct interpretation. When time and money permit, other areas are spot checked to estimate the accuracy of the airphotos. The composite method is being widely used and not only provides reasonable accuracy, but also reduces operating costs.

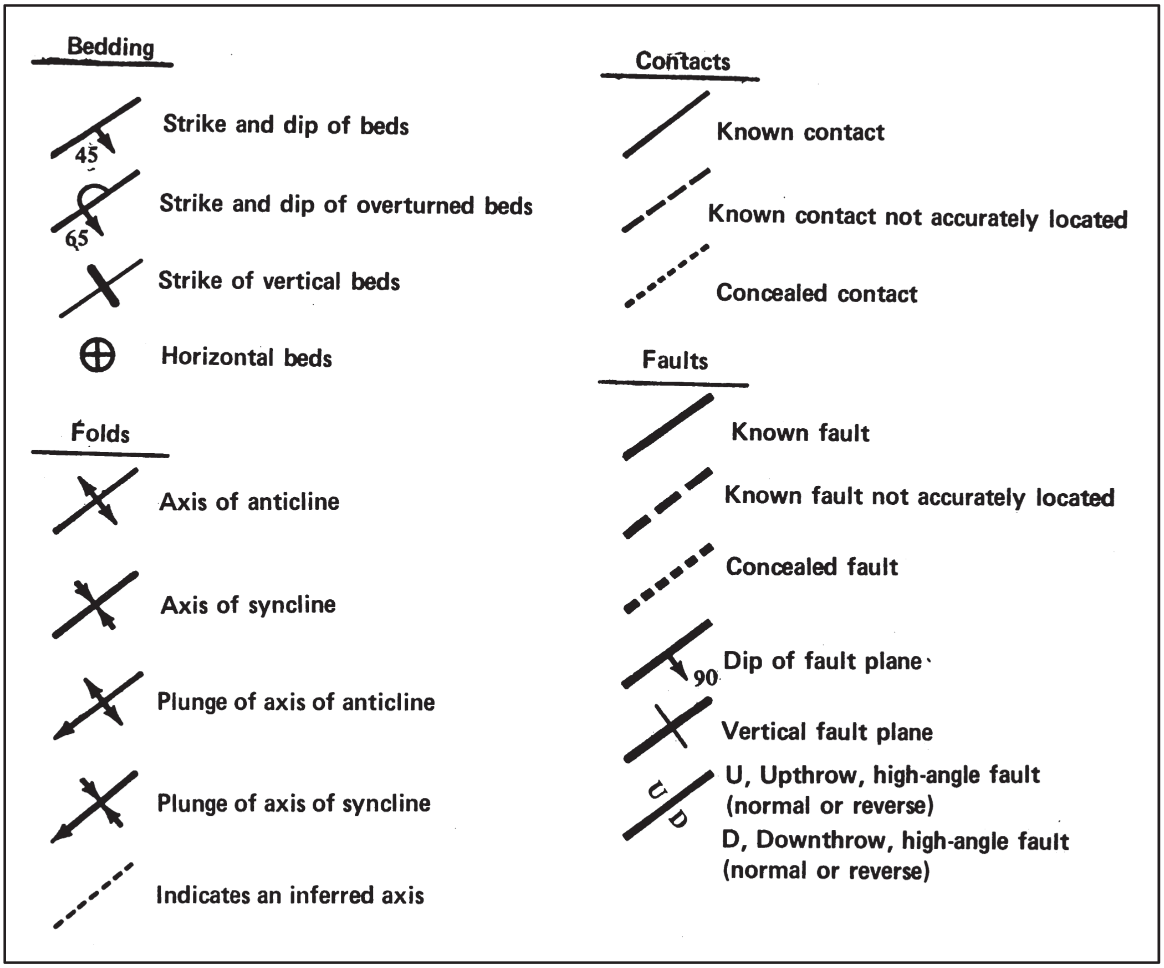


Figure 10-1. Conventional structural symbols

GEOLOGIC SECTIONS

10-15. A geologic section illustrates an inferred relationship of rock units as they would occur in the sides of a vertical cut made along the line of the section. Sections published by the U. S. Geological Survey and various state geological surveys usually have the same horizontal and vertical scale However, in engineering projects it often is necessary to exaggerate the vertical, in which case the angle of the dip component cannot be read directly from the section. Even though no special training is required to read sections, it should be remembered that they are drawn on an inferential basis. Their accuracy depends in the end on matching of age relationships or correlations of the surface outcrops.

GEOLOGIC MAPS

10-16. Geologic maps are of primary importance to the geologist in the search of material resources. In addition, they are often of great importance to the engineer, not only for evaluating foundation sites, but also in the location of useful construction materials for military and civilian jobs.

GEOLOGIC BULLETINS AND REPORTS

10-17. One of the most noteworthy sources of geological information is provided by publications of the U.S. Geological Survey. These publications provide surface and subsurface geological data which may be used by the engineer in locating construction materials for military and civilian jobs, evaluating foundation sites, mineral resources, surface water and ground water resources. The published materials include maps, bulletins, water supply papers, and other reports. From 1894 to 1945, the Geological Survey also published geologic folios which included much of the above information in one report. These folios are still useful where more recent materials are unavailable. Most states also have geological surveys which publish bulletins and reports. These organizations are closely associated with the U.S. Geological Survey. In foreign countries, the best and most accessible sources of information, aside from U.S. military maps, are the national, state, or provincial geological surveys. Although much of the information is presented in the language of the publishing country, many of the symbols and conventions are universal, which facilitates use of the publications. Other reports may be obtained by contacting oil and mining companies, but these are often of a highly technical nature of little value to the layman, and they tend to be rather localized.

SECONDARY SOURCES OF INFORMATION

SOIL MAPS AND REPORTS

10-18. Soil maps show the areal extent of soil units that are classified on the basis of the characteristics of the different soil horizons and the texture of the surface soil. The soil separations usually are made with an agricultural rather than an engineering aim, so it is usually necessary to interpret the information and sometimes to reclassify or regroup the units. To do this, the interpreter should be familiar with both the agricultural and the engineering soil classifications.

10-19. If soil maps and reports are available in addition to geologic maps, they can be used to amplify the details of the ground interpretation, for several soils having important characteristic differences may be present on one geologic formation. For example, an area which is shown on a geologic map simply as alluvium may include such widely differing forms as sandy natural levees; gravel bars; silty, clay bottomland; and organic deposits in swamps. These would all be shown separately and in detail on a soil map.

TOPOGRAPHIC MAPS

10-20. The contours of topographic maps, especially when the contour interval is 20 feet or more, tend to give only a generalized view of the land surface. For example, sharp irregularities in the land surface may appear on the map as smooth elements; and some important features such as ravines, low escarpments, rock knobs, and sinkholes may not appear at all. When however, a topographic map is used together with a geologic map, geologic interpretations permit interpolation of features that would otherwise not appear.

10-21. Through geologic inference, topographic maps may yield considerable information other than topography. Inspection of the pattern of the topography, steepness of slopes, and stream pattern can provide clues to the relative nature of the rocks, depth of weathering, soil, and drainage. For example, sinkholes may indicate limestone; hills and mountains with gently rounded slopes usually indicate deeply weathered rocks; and parallel ridges are commonly related to steeply folded, bedded rock with hard rock in the ridges. Features such as levees, sand dunes, beach ridges, and alluvial fans can be recognized by their characteristic shapes and geographic location.

AERIAL PHOTOGRAPHS

10-22. Aerial photographs are most useful and reliable when they are used along with other information or with ground investigation.

10-23. The most satisfactory results are obtained from large-scale photographs, 1:15,000 or larger. Some topographic features, such as some ravines, rocky knobs, and sinkholes, are too small to be shown on maps. These features as well as the larger topographic forms, such as stream channels and swamps, can be observed directly from aerial photographs.

10-24. Such surface features as glacial drift or eskers are easily recognized on aerial photographs. The presence of permafrost and ground ice can be determined by the identification of such features as thermokarst lakes and polygonal ground. Recognition of sand dunes not only indicates the texture of the soil but also provides a clue to the prevailing wind direction.

10-25. Some of the more obvious geologic structural features can be directly identified from aerial photographs.

Chapter 11

Airphotos

INTRODUCTION

11-1. Airphotos are particularly useful for study of areas which have not been recently mapped. They provide reasonably accurate geologic information, but require less time to prepare than does a map. Airphotos may be used to determine surface materials in much the same manner that topographic and geologic maps are used to make similar interpretations. The photograph adds several elements to the interpretation procedure, however. The maps are used to recognize landforms and drainage patterns from which the interpretation is made. The airphoto adds many details such as gully shape an cross sections, erosional characteristics of less than contour interval size, the distribution of vegetation, and the use of the land at the present time. Each of these elements yields much valuable information so that a more clear evaluation is made possible. Photointerpretation involves a systematic inspection of available photographic information, with the interpreter finally reaching the conclusion that certain types of material and objects exist in the area shown in the photograph. Interpretation is not infallible, and in certain cases an accurate prediction of ground conditions cannot be made. The interpretation should be *field checked* when possible.

TYPES OF AIRPHOTOS

OBLIQUE AIRPHOTOS

11-2. Oblique airphotos are made by tilting the optical axis of the camera at an angle to the vertical. In other words, obliques are any photos which are not taken vertical to the earth's surface. The two types of oblique airphotos are high angle obliques and low angle obliques.

High Angle Obliques

11-3. The high angle oblique (figure 11-1, page 11-2) is any airphoto that shows the horizon. It is taken with the axis of the camera inclined at an angle greater than 60 degrees from the vertical. These are particularly effective for pictorial and illustrative purposes. Many times a series of photos is taken perpendicular to the line of flight; thus, a panoramic view is provided. The high angle oblique covers the largest ground area of any type single photo. However, the effective coverage is limited owing to loss of detail and reduction in scale toward the background. The high oblique gives a perspective view of the land surface, but because of this it does not present a true scale and compilation of maps from obliques is difficult.

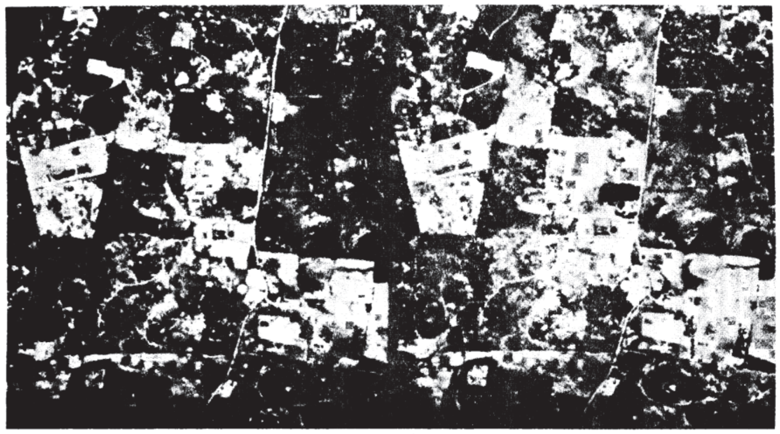
Low Angle Obliques

11-4. Low angle obliques are those taken with the angle of the camera decreased until the horizon is not within the field of vision. These have much the same perspective view as the high obliques. When the angle of inclination approaches the vertical, the picture appears to have the characteristics of a vertical photo. Sharpeness of detail in the background is improved. The scale of the photo is usually distorted too greatly to be sufficient for mapping purposes.

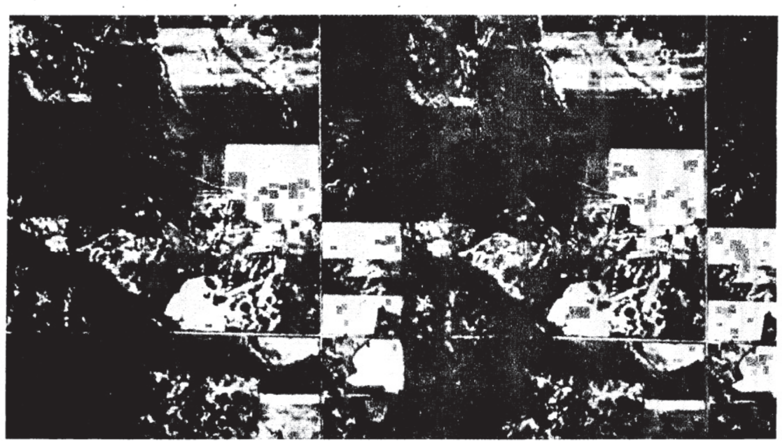
VERTICAL AIRPHOTOS

11-5. Vertical airphotos are made with the axis of the camera perpendicular to the earth's surface. Due to difficulty in keeping the plane on a perfectly level flight, the photos are seldom truly vertical; however, when the angle of inclination is small, it is disregarded. The photo looks like a pictorial map and is used as a basis for compiling geologic, soil, and other maps. An enormous amount of fine detail is shown and the scale is reasonably uniform throughout the central part of the photo. However, parallax (caused by ground relief) and distortion around the edges of the photo tend to disrupt the scale. Because of this distortion, only the central part of the photo is used for steroscopic interpretation (figure 11-2, page 11-3).

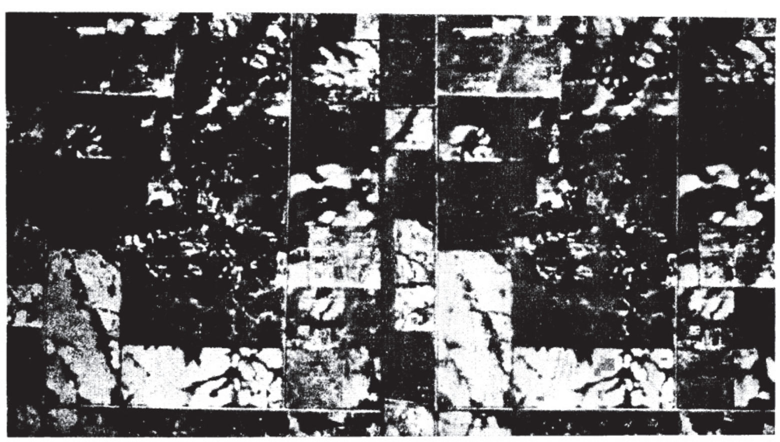
Figure 11-1. High oblique photo of alluvial fan



1 Limestone bedrock area with thin mantle of residual soil



2 Limestone bedrock area with a thin mantle of glacial drift. Some evidence of limestone bedrock is present



3 Limestone bedrock area with a deep mantle of glacial drift. No evidence of limestone bedrock is present

Figure 11-2. Steropairs of three contrasting areas underlain by limestone bedrock

Composite Airphoto

11-6. Composite airphotos or composites are similar to verticals in characteristics, but are made with multilens cameras, taking two or more low obliques with or without a vertical at the center. Usually, they are made with four or five-lens cameras. The four-lens camera produces a square print, while the five-lens camera produces one that has the shape of a maltese cross with the vertical in the center. Distortion by tilt and parallax is much greater on the edges of these photos than on the verticals. Also, the different parts of a composite often show variations in average color tone.

Mosaics

11-7. A mosaic is a patchwork assemblage of verticals or composites, or both, and is used to provide a continuous vertical view of areas too large for coverage by a single print. It is similar in appearance to a single-lens vertical photo, but is actually a photo made up of an assemblage of photos with the matching lines carefully camouflaged. The three types of mosaics include uncontrolled, semicontrolled, and controlled.

11-8. In a controlled mosaic the assembly is so constructed as to correct for distortion and to tie' in with ground control points. Uncontrolled mosaics are assemblages without correction for distortion and ground control points. Semicontrolled mosaics are assemblages where corrections are made for horizontal distortion within each flight line without regard to the adjacent flight lines.

OBTAINING AIRPHOTOS

Flight Planning

11-9. Aerial photography is always carefully planned in advance. Careful consideration must be given to the time of day, season of the year, and climatic conditions. These factors contribute to the final quality of the photos. Another important consideration is the altitude at which the flight will be made, as this determines the scale of the photos. The altitude is prearranged to obtain the correct scale for the desired photos.

Airphoto Classification

11-10. Each airphoto is classified by marginal information or titling data and the laboratory serial number put on by the laboratory during printing. The newest type of military aerial camera exposes most of the marginal information on the negative at the time the actual picture is taken. The marginal information includes the exposure number, mission number, lab identification, unit requesting the photography, date, time, altitude, geographic coordinates, and security classification. The laboratory number will include the number of the film roll, number of the strip, and the number of the exposure.

Sources of Airphotos

11-11. Many areas of the United States have previously been covered by aerial photography, either by government agencies or private companies. These sources should be checked before planning any new photography. The federal agencies that have the majority of coverages are the Department of Agriculture, Soil Conservation Service, Forest Service, the Geological Survey, Coastal and Geodetic Survey, Tennessee Valley Authority, and the U.S. Air Force.

INTERPRETATION METHODS

General

11-12. An aerial photograph contains more information about a given area than a map of that same area. However, certain difficulties arise when using these photographs which make interpretation difficult. For example, heavy foliage and dark shadows hide much of the detail and distort manmade and natural patterns. When identifying objects from an aerial photograph, the interpreter must make use of certain characteristics, including object shape and size, photographic tone, object patterns, shadow, topographic location, and texture.

OBJECT SHAPE AND SIZE

11-13. Shape alone may serve to identify some objects. For example, shape can distinguish between an airfield and a football field. In addition, the relative and absolute sizes of objects are useful in identification. Comparison of the relative sizes of buildings in a given area in relation to their surroundings aids in determining their probable purpose. Absolute size is also very helpful, but the photographic scale is needed before this can be determined.

PHOTOGRAPHIC TONE

11-14. Objects of different color and texture reflect light differently and therefore register in varying shades or tones on a photograph. Tonal values may aid in the discrimination of several objects. Spaces between trees and their foliage produce different tones. Shadows of solid objects like mountains are more uniform in tone. Careful inspection of the mountain shadows may unfold a lighter tonal effect that offers a clue to the presence of vegetation which otherwise appears to be hidden in the shadow.

11-15. Smooth-surfaced roads, especially those constructed with concrete, show as light bands on photos. Dirt and rough-surfaced roads appear much darker in tone. The ballast between railroad ties shows in sharp tonal contrast to the metal rails on large scale photos. Airstrips and surfaced parking areas reflect light and, consequently, are much lighter in tone than the darker ground usually surrounding them.

11-16. Shallow water produces a lighter tone than deep water. Sand bars, subsurface shelves, and reefs can be spotted by lighter tones in clear water bodies. Much, therefore, can be learned about foreshore, offshore, and stream-bed features by studying the varying tonal intensity of water bodies.

11-17. Freshly plowed fields show as dark patches on photos because the moisture, which has been brought to the surface by plowing, darkens the ground. The surfaces of plowed fields dry out rather rapidly, with the result that pictures taken a short time after plowing will show a lighter toned image than for newly plowed fields. Fields of growing crops will produce still other tones that are keys to interpreting the amount, density of growth, and type of crop.

11-18. The use of good quality photographs is essential for interpretation because tone is lost on under- or over-developed prints. Regardless of quality, however, the interpreter should study only the area near the principal point. Areas in the perimeter of the photograph have poor definition and tones and should be avoided.

PATTERN

11-19. If the arrangement of trees in an orchard is compared with that of natural vegetation, a contrast in patterns will be seen. The time of year that the photograph was taken will have some effect on the patterns. For example, an intermittent stream shows different patterns at different seasons. During periods of heavy thaw or rains a stream may be a wide, raging torrent, but when the dry periods come only a narrow trickle or even just the dry streambed remains.

SHADOW

11-20. All objects will cast shadows when there is a directional source of light. Their shadows may reveal characteristics about the shape of an object which are vital to its accurate identification. Shadows are extremely helpful because they emphasize the relief of the photo, produce an exaggerated profile of buildings and structures which aids in their identification, and may aid in the classification of foliage.

TOPOGRAPHIC LOCATION

11-21. Relative elevation, including that of drainage features, can be an important indicator of soil conditions. The surface configuration will not be as useful, however, when snow is on the ground. Snow lies longer on protected slopes and affects normal shadow patterns by lessening the contrast between sunny and shaded slopes. An optical illusion of reversal of these slopes may result from a highly reflecting snow cover on one side of a hill and barren slopes on the other side where snow has melted.

TEXTURE

11-22. The degree of coarseness or smoothness shown can be useful in the identification of images. Texture is directly related to photo scale. For example, the texture of a cornfield on a small-scale photo may appear the same as the texture of a grass meadow on a large-scale photo.

IDENTIFICATION OF ROCK TYPES

11-23. Many of the broader characteristic features which serve to separate rocks into the three great classes described in chapter 2 can be seen on airphotos and used to aid in the interpretation. Among the more obvious are the irregular massiveness and flow characteristics of certain igneous rocks, the bedded characteristic of the sedimentary rocks, and the foliated nature of many of the metamorphic rocks.

SEDIMENTARY ROCKS

11-24. Layers separated by bedding planes are the best differentiators between sedimentary and igneous rocks. The most common types of sedimentary rocks are discussed in this paragraph.

CONGLOMERATE AND SANDSTONE

11-25. The photo characteristics of these two granular sedimentary rocks are similar and are given below.

Landforms

11-26. These rocks are relatively resistant to erosion and form areas of high relief. In a temperate climate 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.

Drainage Patterns

11-27. Flat-lying sandstones and conglomerates usually develop a dendritic pattern. These rocks are massive and in many cases have a joint pattern which produces a rectangular type of drainage. 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.

Vegetation

11-28. In humid climates, sandstone and conglomerates will support a heavier growth of vegetation than will limestone and shale.

Photo Tone

11-29. The tone is generally light-colored, because of good drainage and light-colored minerals.

Special Keys

11-30. Angular relief, bold massive hills, light tone, and a curved or pincer-like dendritic drainage pattern are special keys to sandstone.

SHALE

Landforms

11-31. 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, shale will 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 will develop. Shale in humid regions forms low rounded hills and valleys.

Drainage Pattern

11-32. Shale shows fine-textured dendritic and angular patterns which often show small rounded projections (crenulations). A trellis pattern will develop on shale when it is interbedded with harder rocks and has been folded. V-shaped gullies develop in arid regions; U-shaped gullies develop in humid regions.

Vegetation

11-33. In humid areas, shale may be heavily forested, but in arid regions it is usually barren.

Photo Tone

11-34. 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.

Special Keys

11-35. Mottled tone, dendritic drainage, and subdued landforms are indicators of shale, as well as the definite badlands topography.

LIMESTONES

Landforms

11-36. Because of its solubility, limestone is very susceptible to chemical weathering in humid regions. Sinkholes, which appear as depressions in the limestone terrain, are very characteristic of this rock type in humid areas and are easily identified on aerial photos. 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 also may form the caprock of plateaus or of ridges.

Drainage Patterns

11-37. Dendritic and rectangular patterns are most likely to form on limestone terrain. Interbedded and tilted rock will develop a trellis pattern. In many areas streams will be found that disappear into the sinkholes. Where they are present, sinkholes will be the main surface drainage.

Vegetation

11-38. 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.

Photo Tone

11-39. 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.

Special Keys

11-40. The occurrence of sinkholes and the mottled tone are easy to see and are excellent photo aids. There should be no confusion in the identification between basalt and limestone. Each has a mottled tone, but the association of this tonal feature and columnar jointing indicate basalt while sinkholes and mottled tone indicate limestone. Stratification should, of course, be evident on limestone, but a coarse layering sometimes is exhibited by basalt.

INTERBEDDED FLAT-LYING SEDIMENTARY ROCKS

11-41. 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 stairstepped 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. Differences in drainage will indicate differences in rock types.

INTERBEDDED TILTED SEDIMENTARY ROCKS

11-42. Tilted sedimentary rocks may be identified by the characteristic topography of each individual rock type. Generally, the rock types will be shown by differences in drainage pattern and topographic expression, or by tonal and vegetation changes. Folded sedimentary rocks will usually show a trellis drainage pattern which accentuates alternating valleys and ridges. Major streams and gullies will he parallel to ridges. If all three rock types are present, sandstone will form the highest landforms, limestone the intermediate slopes, and shale the valleys.

IGNEOUS ROCKS

11-43. Igneous rocks vary greatly in mineral and chemical composition, texture, and mode of occurrence. Intrusive rocks are emplaced as dikes, sills, batholiths, laccoliths, and stocks. Extrusive igneous rocks generally occur as lava flows and volcanos.

INTRUSIVE IGNEOUS ROCKS

Landforms

11-44. Depending upon the climate, intrusive igneous rocks will weather in different ways. Some intrusive bodies like dikes and laccoliths, upon exposure by erosion, will form characteristic shapes. A dike will usually appear as a distinct ridge while laccoliths, stocks, and batholiths generally appear as dome-like masses. Generally, in a humid or temperate climate, granitic rocks will produce rounded or knobby topography while in arid or semiarid climate 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 airphotos and, in most instances, specific directions can be ascertained. Because 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. In regions where granitic rocks alone cover extensive areas, they may be eroded by glaciation or stream action to low rolling plains.

Drainage Patterns

11-45. 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. Annular drainage is frequently developed in association with small intrusive bodies.

Vegetation

11-46. In humid climates igneous rocks are affected by chemical weathering and form a deep soil horizon which will support much vegetation. In arid climates, the jointing and fracturing in the mass may be evidenced by alinement of vegetation.

Photo Tone

11-47. Since intrusive igneous rocks are usually primarily composed of light colored minerals, the photo tone will usually be light, providing the surface of the mass is not too rough.

Special Keys

11-48. Jointing, rectangular drainage, exfoliation, angular relief, lack of banding, and light photo tone are basic keys in the identification of intrusive igneous rock types.

EXTRUSIVE IGNEOUS ROCKS

11-49. Extrusive igneous rocks are typified by lava flows or volcanic cones composed of dark colored minerals.

Landforms

11-50. Lava flows sometimes build up deposits many thousands of feet thick. Layering due to the intermittent outpouring of lava is common. Depending upon 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 shape. Lava flows may be recognized by the rounded projections along their edges or by the vegetation patterns.

Drainage Pattern

11-51. Since the flows are homogeneous masses and relatively flat lying, a dendritic pattern may develop. In many cases, however, there will be little visible drainage pattern. The cracks in the basalt render it very porous and much of the drainage is internal.

Vegetation

11-52. In humid areas much vegetation may be present because basalt weathers rapidly and develops a thick soil profile. In more arid areas very little vegetation is found.

Photo Tone

11-53. Basalt usually shows dull and dark tones on aerial photos. One feature of basaltic lava flows is a characteristic mottled tone which is usually easy to identify unless the soil cover is too thick.

Special Keys

11-54. 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.

METAMORPHIC ROCKS

11-55. Generally, massive metamorphic rocks are difficult to identify as such from photographs, especially when metamorphic rocks and igneous rocks are together. When these two rocks are closely associated, it is usually sufficient to name them crystalline rocks. It is also not possible or necessary to differentiate between lightly metamorphosed sedimentary rocks and the original rocks.

GNEISS

11-56. Gneissic rocks are laminated and show 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 where the gneiss is banded due to formation from several different rock types.

SCHIST

11-57. Schistose rocks are highly altered and thinly laminated. Large areas of schist may show parallel features of alternating hard and soft layers. The topography is rough in arid regions, while the topography may be subdued with a deep soil cover in humid regions. A rectangular or angular drainage pattern will develop where jointing and faulting occur.

SLATE

11-58. Shale is hard and dense and forms rugged topography in all climates. A highly developed fine-textured dendritic or rectangular drainage pattern will usually develop on this rock. The terrain will be deeply dissected. When the rock is well exposed, it will show a light gray tone.

SOILS INTERPRETATION

11-59. Soils are usually of comparatively recent geologic age, being made up of such material as glacial till and outwash, dune sand, loess, lacustrine and playa deposits, alluvial fans, flood plains and delta deposits, and various types of shore and near shore deposits. Where recent enough to have kept the characteristics of their mode of deposition, the soils may be identified by physiographic criteria. More often they do not keep these characteristics and must be identified by their respective soil patterns. Any two soils derived from the same parent rock, deposited in a similar environment, occupying the same relative topographic position, and existing under the same climatic conditions will have similar soil profiles. They will support the same native vegetation, will have similar engineering properties, and will show the same airphoto pattern. The elements of the airphoto pattern are landforms, soil color tones, primary drainage patterns, shape of gullies, and vegetation patterns. In addition to the elements of the pattern produced by nature, there are man-made features which are often directly related to the natural elements since climate, topography, and soils often govern land use practices.

LANDFORMS

11-60. Of all the elements of the airphoto pattern, the landform is perhaps the most important because it is so closely associated with the origin of the material and the subsequent erosional history.

COLOR PATTERN

11-61. On airphotos various soils usually appear in different shades of gray, but may range from brilliant white to black. This variation in color tone is a direct reflection of the moisture content of the soils. Damp soils are dark colored; dry soils are light colored. Clay soils retain moisture, are usually damp, and hence are dark colored in air photos. Silts have better internal drainage than clays and will be lighter colored (except when kept wet by a high ground water table); on slopes, the edges of gullies, or other locations where the moisture can easily seep out, the soils will be almost white. Gravelly soils, usually a mixture of fine and coarse material with the coarse predominating, have good internal drainage, and will be dry and light colored with dark spots marking the slight drainage depressions. Sands and sandy soils will be a brilliant white. Sharp clean color changes indicate a granular porous soil; smooth color changes, a plastic impermeable soil.

PRIMARY DRAINAGE PATTERN

11-62. The network of small drainage channels which first catches the surface runoff and conducts it to gullies or larger stream channels makes up the primary drainage of the area. These patterns are different for the various soil types.

11-63. In sands in silty sands, virtually all the surface water soaks in at once. Rarely are there any surface drainage lines. If the slopes are so steep or the layers so thin that some water must escape over the surface, the channels are short, with few branches, and have steep sides and gradients. They disappear upon reaching flatter ground.

11-64. Gravels and silty gravels are not normally as pervious as sand because of the grading of coarse to fine materials; however, most of the water falling on the soil soaks in. Only a few surface drainage channels are formed. Channels which do exist are short and have few branches. The internally drained depressions appear as dark circular spots.

11-65. Silty soils, being made up of very fine bulky particles, have only minute internal openings into which surface water can seep. Though some water soaks in, most of the rainfall runs off on the surface. Since the soil particles are quite small, they are washed away easily. The result is a complex primary drainage pattern that extends from the major channels. There is active and destructive erosion of the soil even on low slopes.

11-66. Clays are highly impermeable; therefore, little water soaks in and virtually all of it runs off over the surface. The result is a very complex pattern of surface drainage lines that, as in silts, branch out from the main channels.

SIZE, SHAPE, AND SLOPE OF GULLIES

11-67. There are three basic gully characteristics which are associated with the three major soil texture groups. Granular soils develop sharp V-shaped gullies having a short steep gradient. Nongranular, cohesive, and plastic soils produce a gully whose cross section is broad, softly rounded, saucer shaped, and whose gradient extends far back into the uplands. Loess soils and sand-clays show a gully whose cross section is U-shaped; i.e., gullies have steep, nearly vertical sidewalls with a flat bottom. Gully systems, or the local arrangement of the erosional features, are closely associated with the particular soil types and are rarely duplicated in unlike soils. In densely wooded areas it is seldom possible to see such details as shape and gradient when viewed through a stereoscope. In such areas, soil determination must be made from a study of other elements with particular emphasis placed on landform and regional drainage.

VEGETATION

11-68. Variations in the vegetation pattern of an area may reveal two important items: difference in soil fertility or difference in soil moisture. In temperate climates the vegetation is mainly important in confirming suspected soil conditions and types, but in forested or tropical jungle areas, where the heavy growth completely obscures other identification, the vegetation pattern is a major indication of the soil in the area. There may be several other features which would produce similar vegetation variations such as change in slope, lack of drainage, lack of irrigation, and artificial fertilization. The most common condition causing variation in the vegetation pattern is the differing soil moisture available to the plants. The more moist soil supports heavier plant growth than the drier soil. Since clay soils normally have a higher moisture content than other soils, patches of heavy growth may indicate clay soils. A narrow band of heavy growth along the side of a hill may indicate that along this band lies an outcrop of impermeable material underlying a more permeable zone. Thus, ground water seeps down through the more permeable layer, reaches the impermeable bed, and seeps along it to the outcrop on the slope. Swamp areas with an overabundance of water are covered with low swamp grass in contrast to the sturdy vegetation on the adjacent, drier ground.

ECONOMIC USES

11-69. A limited amount of information is available from analysis of the uses to which man has put the soil. It is impossible to list all the different land uses which may give a hint as to soil type, but the following are certain items which are worth mentioning. The size of drainage structures on railroads and highways indicates, somewhat, the rate and volume of water runoff. Most roads, especially major highways, are built on the best drained and strongest soils locally available. Where possible, airfields or large buildings are also built on such soils. Highway and railroad cuts expose the subsurface soils and parent material. Any tendency for the soil to slide is aggravated and revealed by road cuts. The presence of such slides suggests the occurrence of underlying layers of clay. The extensive use of orchards, especially in flat areas, suggests that the landform is a gravel terrace. Areas which have been permitted to grow up in brush, scrub, or local wood lots are usually infertile soil, or soil which is excessively wet or susceptible to surface erosion and gullying. Dead furrows are used to improve drainage in a plastic, poorly drained soil. Gravel and sand pits are a specific indication of the soil. Rock quarries are not a specific indication, but their presence limits the land form to certain types, for only certain rock is economically worth quarrying. There are innumerable other indications which only a very detailed examination will reveal.

STRUCTURAL INTERPRETATION

DIP AND STRIKE

11-70. Dip can be determined only where the dip slope is exposed or revealed by relief at the outcrop. When a channel cuts through the outcrop of dipping beds, the "V" formed by the outcrop pattern points down dip, except when the bed dips downstream with a dip less than the stream gradient. In this case, the "V" points up dip. The angle of dip cannot generally be determined from an airphoto.

11-71. Strike may be found from the airphoto if a recognizable bed or bedding plane is exposed. Where the surface is flat, the strike is along the line of the outcrop. Where the surface is dissected, the strike may be measured by picking two points of equal elevation on a horizon and drawing a straight line between the two.

FAULTS AND FRACTURES

11-72. The surface trace of a fault depends on the type of displacement. In folded rocks, an offset, interruption, or repetition of beds offers good evidence of faulted strata. The dip of a fault cannot be determined from an airphoto, however, although high angle faults have a linear trace and low angle faults have a sinuous trace. The following are general criteria for the recognition of faults:

- Gaps, breaks, or offsets in outcrops or streambeds.
- Beds striking into another bed.
- Transection of folded structure.
- Rectilinear stream courses.
- Rectilinear escarpments.
- Distinct alignment of springs and vegetation.
- Linear ridges unrelated to resistant beds.
- Rectilinear boundaries between vegetation.

FOLDS

11-73. Steeply sloping, sharp ridges; parallel or converging ridges and valleys; and looped or zigzag ridges with narrow, U-shaped valleys are characteristic of folded areas. The drainage pattern is of the trellis or angular type. Anticlines, synclines, and monoclines are differentiated through analysis of dip or stratigraphic sequence.

Glossary

Acronym/Term	Definition
Aa	Basaltic lava flow with rough, clinkery surface.
Ablation	The surface wastage of glacial ice by melting and evaporation.
Abrasion	The wearing away of rocks and minerals by rubbing or friction, with the aid of sand or other particles.
Acidic rock	An igneous rock that contains more than 66 percent silicon dioxide.
Adjusted stream	A stream which tends to flow parallel to the strike of a rock formation.
Adobe	Pertaining to the clay and silt deposits in the desert basins of Southwestern North America that are used for sun-dried brick.
Aeolian	Related to, formed by, or deposited from wind.
Agglomerate	Angular volcanic fragments. A coarse volcanic breccia.
Aggrade	To deposit sediments on a stream bed or valley floor.
A-horizon	The uppermost zone in a soil profile, in which organic matter has accumulated and from which soluble salts and colloids have been leached; topsoil.
Alabaster	Compact, fine-grained gypsum.
Albite	A high-soda plagioclase.
Alluvium	Any type of detritus deposited by streams.
Amorphous	Pertaining to rocks and minerals having no definite crystalline form and no orderly ar¬rangement of atoms.
Amphibole group	A group of silicate minerals containing iron and magnesium. A common example is hornblende.
Amygdale	A vesicle or vapor cavity in volcanic rock which has become filled with secondary minerals. The diminutive form is amygdule.
Anchor ice	Ice formed on the bottom of a stream (also called "ground ice" or "bottom ice").
Andesite	A fine-grained igneous rock composed essentially of andesine plagioclase but also containing ferromagnesian silicates.
Anhydrite	A sulfate mineral similar to gypsum, but free of water. Composition: anhydrous calcium sulfate ($CaSO_4$).
Anorthite	One of the plagioclase feldspars, high in calcium.
Antecedent stream	A stream that maintains, during and after uplift, the course it had established prior to uplift.
Anthracite	Hard coal.
Anticline	A fold or arch of rock strata dipping outward in opposite directions from an axis.
Apatite	A group of mineral phosphates.
Aphanite	A dense, fine-grained igneous rock in which the crystalline mineral grains are too small to be distinguished by the naked eye.

Aquifer	A permeable rock formation or subsoil through which ground water moves more or less freely.
Arenaceous	Pertaining to rocks that contain sand.
Arete	A narrow, rugged ridge formed by glacial plucking on opposite sides of a ridge.
Argillaceous	Pertaining to a rock containing considerable clay.
Arkose	A clastic sedimentary rock composed of sand-sized grains of quartz and orthoclase. Generally formed from the disintegration of granite.
Arroyo	A vertical-walled, flat-floored channel of an intermittent stream, in the semiarid Southwest.
Artesian basin	A subsurface geologic structural feature in which water is confined under hydrostatic pressure.
Asbestos	Highly fibrous minerals such as chrysotile, a variety of serpentine. Also some amphiboles, such as actinolite and tremolite.
Asphalt	A brown to black semisolid bituminous substance occurring in petroleum.
Atoll	A ringlike coral island encircling or nearly encircling a lagoon.
Augite	An abundant ferromagnesian silicate mineral (a pyroxene) ; commonly found in some basic igneous rocks.
Avalanche	A large mass of snow or ice that falls from higher to lower parts of mountains.
Axis	The linear trend of the crest of an anticline or the trough of a syncline.
Backwater	Water in lagoons between shore and offshore bars.
Badlands	Topography characterized by an intricate maze of ravines and sharp divides.
Bajada	A compound alluvial fan that merges with a valley floor.
Banded	Designating the structure of rocks having thin and nearly parallel bands of various minerals, textures, or colors.
Bar	A sand embankment built on the floor of the sea by waves and currents. May also occur on stream beds.
Barchan	A crescent-shaped dune with horns pointing in the direction of wind movement.
Barite	An orthorhombic mineral composed of barium sulfate (BaS04).
Barrier beach	Offshore bar. A sand ridge parallel to shore, slightly above high-tide level. Commonly separated from shore by a lagoon.
Barrier reef	A coral reef parallel to shore and beyond a lagoon.
Basal conglomerate	A conglomerate formed over an old erosion surface, such as the near-shore deposits of a slowly advancing sea.
Basalt	A fine-grained, black to medium-gray igneous rock with a high percentage of ferromagnesian minerals. Common in lava flows.
Base	A substance capable of accepting protons and of combining with silica in a rock. Lime and potash are common examples.
Base level	The base that limits downward erosion by streams. A level inclined slightly toward sea level.
Basic rock	An igneous rock in which the dominant minerals are comparatively

	low in silica and rich in metallic bases, as in the ferromagnesian minerals.
Batholith	A huge intrusive body of igneous rock that flares outward with depth and is thought to be "bottomless," with an area of exposure exceeding 40 square miles.
Bauxite	The principal ore of aluminum. Composed essentially of aluminum hydroxides.
Bay-head bar	A bar built a short distance out from the shore at the head of a bay.
Beach cusps	Beach deposits of sand and gravel in the form of a succession of ridges with sharp points facing the water.
Beach drifting	The movement of beach sediments parallel to the beach.
Bedding	Planes dividing sedimentary beds, or layers of the same or different kinds of rocks.
Bedrock	Any solid rock exposed at the surface or underlying soil, sand, or any type of mantle-rock.
B-horizon	The soil zone that lies below the A-horizon in the soil profile. Colloids, soluble salts, and fine mineral particles from near the surface accumulate in this zone.
Bicarbonate	A salt containing a metal and the radical HCO_3 such as $Ca(HCO_3)_2$.
Biotite	Black mica. A common ferromagnesian silicate mineral with one perfect cleavage, yielding very thin, translucent, flexible sheets of scales.
Bitumen	A tarry hydrocarbon mixture soluble in carbon disulfide.
Bituminous coal	Soft coal, containing about 80 percent carbon and 10 percent oxygen. Despite its name, it contains no bitumen.
Black sands	Sands in which heavy black minerals have been concentrated by wave and current action. Common minerals are magnetite, ilmenite, tourmaline, rutile, and hornblende.
Blowout	A shallow, saucer-shaped hollow formed by wind erosion on a preexisting dune or other aeolian deposit.
Blue mud	A variety of deep-sea mud, consisting mainly of land-derived fine silt and clay. Turns red when oxidized.
Bog	A swamp or tract of wet land commonly covered with peat.
Bombs, volcanic	Ellipsoidal or spindle-shaped masses of viscous lava ejected from a volcano. They range in size from a fraction of an inch to several feet.
Bore	A tidal wave moving upstream in a river or estuary.
Bottomset beds	The layers of sediment on the bottom of a delta.
Boulder clay	Unsorted glacial drift with embedded rock fragments of boulder size; till.
Braided stream	A stream choked with sand bars that divide it into an intricate network of interlacing channels.
Breaker	A wave that drags on the shallow bottom of the sea and breaks on or near the shore.
Breccia	A fragmental rock resembling conglomerate but having angular, instead of rounded, fragments.
Brownstone	A ferruginous sandstone in which the grains are coated and cemented with iron oxide.

Butte	A conspicuous isolated hill with precipitous sides and a small crest. Commonly an erosion remnant.
Calcareous	Containing varying amounts of calcium carbonate.
Calcite	A mineral composed of calcium carbonate, the principal constituent of limestone.
Caldera	A large, basin-shaped volcanic depression, with a diameter many times greater than that of the included vent or vents, produced by either collapse or explosion.
Caliche	Desert surface debris cemented by porous calcium carbonate.
Carbonaceous	Pertaining to or composed for the most part of carbon.
Carbonate	A salt or mineral containing the radical CO_3.
Carbonation	A chemical process during weathering that converts basic oxides into carbonates.
Cementation	The deposition of minerals around grains in rocks by precipitation from solution. Quartz, carbonates, and iron oxides are common cementing materials.
Centrosphere	The central, highly metallic core of earth.
Chalk	A variety of unindurated limestone composed of tests of microorganisms.
Chert	A compact, fine-grained, siliceous rock composed of chalcedonic silica. Flint is a variety.
Chloride	A compound of chlorine with an electro-positive element.
Chlorite	A complex group of platy, blackish-green hydrous magnesium aluminum silicates containing iron.
C-horizon	The weathered zone under the B-horizon in the soil profile. It grades downward into the unweathered rock.
Cinder cone	Volcanic cone composed of gravel-sized and coarse-sand-sized cinders.
Cinders	Volcanic-glass fragments of gravel sizes and coarse-sand sizes.
Cirque	A steep, blunt, bowl-shaped valley head in a mountainside at high elevation, formed by glacial plucking and frost action.
Clastic sediments	A textural term applied to sediments and rocks composed of fragmental material derived from preexisting rocks.
Cleavage	In minerals, the tendency to break or split so that smooth surface planes are produced, which parallel a possible crystal face; in rocks, splitting along closely spaced, parallel planes.
Cobble	A rock fragment larger than a pebble and smaller than a boulder. Between 64 and 256 millimeters in diameter.
Col	A saddle on a divide, such as a pass through a glaciated mountain ridge.
Columnar jointing	Vertical fractures in igneous rocks formed by contraction during cooling. The fractures bound columns, many of which are hexagonal.
Compaction	Decrease in volume of sediments due to compression by overlying strata.
Conchoidal fracture	The curved shell-like form of a surface produced by the fracture of brittle minerals and rocks, such as quartz and volcanic glass.

Concretion	A variously shaped mass or nodule with concentric structure developed by the deposition of material from solution about a nucleus.
Confluence	The point where two streams flow together to form one stream.
Conformable	Designating beds, or strata, that lie upon one another in an unbroken and parallel order.
Conglomerate	A clastic sedimentary rock composed of gravel or boulders cemented together.
Connate water	Water trapped in the pore spaces of a sedimentary rock when the sediment was deposited.
Consequent stream	A river whose course was determined by the original slope and irregularities of the surface on which it developed.
Contact metamorphism	Alteration of rocks that takes place near their contact with magma or lava.
Continental shelf	The margin of a continental mass submerged by the sea. It slopes gradually from the coast line to a depth of about 70 fathoms (420 ft).
Contour line	A line connecting points of equal elevation above or below a datum plane, such at sea level.
Coquina	A variety of limestone made up chiefly of coarse shell fragments.
Corrosion	Mechanical erosion performed by running water or other moving agents of erosion using rock particles as tools.
Correlation	The establishment of the equivalence in geologic age and stratigraphic position of two or more sedimentary units in separated areas.
Corrosion	Erosion accomplished by chemical solution.
Corundum	A hexagonal mineral, A1203. Ruby and sapphire are gem varieties.
Cove	A small bay or baylike recess in the coast.
Creep	A slow downward movement of soil and rock fragments on a slope.
Cross-bedding	The structure of sedimentary beds characterized by parallel laminations lying at an angle to the planes of general stratification.
Crust	The solid rock of the outer part of the earth to a depth of 18 to 20 miles.
Crystal	A solid with an orderly atomic arrangement. It commonly is bounded by plane surfaces.
Cuspate bar	A crescent-shaped bar attached to shore at one end.
Cycle of erosion	The succession of events involved in the reduction of a region from its youthful stage to base level through normal processes of erosion.
Dacite	The fine-grained equivalent of a quartz diorite.
Debris	The material resulting from the disintegration and decay of rocks.
Decomposition	Chemical weathering of minerals and rock.
Deflation	The removal of fine clastic materials by wind.
Degradation	The process of lowering the land surface by erosion.
Delta	The accumulation of sediment where a stream empties into a body of quiet water, resulting in the building out of the shoreline.
Dendritic	A branching treelike pattern of tributaries of a main stream.

Denudation	The removal of surface materials by erosion.
Desert	A region with little rainfall and sparse vegetation.
Desiccation	Evaporation of water in unconsolidated sediments, resulting in shrinking and compaction. Tension cracks may form during the process.
Detrital	Clastic particles derived from former rocks.
Detritus	Accumulations arising from the waste or disintegration of preexisting rocks.
Diabolic	Designating the texture of certain basic igneous rocks.
Diaspore	An aluminum hydroxide mineral.
Diastrophism	All movements of the earth's crust resulting in relative vertical or horizontal changes of position and in the deformation of rocks.
Diatomaceous earth	An earthy siliceous deposit consisting mainly of the shells of diatoms.
Differential weathering	Unevenly weathered rock surface due to differences in the character of the constituent rocks. Such forms as isolated stacks, buttes, and flutings are the results of such weathering.
Dike	A tubular mass of igneous rock intruded in a crack or fissure.
Diorite	A coarse-grained igneous rock composed chiefly of medium plagioclase and ferromagnesian minerals.
Dip	The angle at which a stratum, vein, dike, or sill is inclined from the horizontal.
Discharge	Volume of stream flow, per unit of time, through a given cross section of the stream.
Disconformity	An unconformity in which the beds on opposite sides of the surface of unconformity are parallel.
Discontinuities	Zones in the earth where rapid velocity changes in earthquake waves occur because of changes in the elasticity and density of the rock.
Discordance	A lack of parallelism between contiguous strata.
Dismembered river system	A drowned stream valley which, as a result of flooding, has its former tributaries enter the sea by separate mouths.
Dissection	The work of erosion on flat, upland areas that cuts them into rugged hills, valleys, and ravines.
Distributary	An outflowing branch of a river that does not rejoin it. Characteristically occurs on a delta.
Diverted stream	In stream piracy, the stream that was diverted from the beheaded stream and that flows to the pirate stream.
Dolomite	A mineral composed of both calcium and magnesium carbonates, $CaMg(CO_3)_2$. Also applied to those rocks that approximate the mineral dolomite in composition.
Dome	A roughly symmetrical upfold, the beds dipping in all directions from the crest of the structure.
Dreikanter	Three-faceted pebbles shaped by sandblasting.
Drowned valley	A valley whose lower end has been inundated by the sea and thus converted into a bay or estuary.
Drumlin	A small, smooth, oval hill of glacial till with its long axis parallel to

	the movement of the ice.
Druse	A crust of small crystals lining a cavity.
Dune	Hillock of wind-blown sand.
Dust well	A small pit in glacier ice, produced where tiny rock and mineral particles on the ice absorb heat from the sun's rays and sink down into the ice.
Dyrwmic metamorphism	Textural and mineral changes produced largely by rock deformation.
Earthquake	A group of elastic waves in the solid earth, generated by a disturbance of the* elastic equilibrium, which causes rocks to break or slip along preformed fractures.
Effusive	Designating igneous rock formed from lava poured out or ejected at the earth's surface.
Einkanter	One-faceted pebbles shaped by sandblasting.
Ejecta	Rock material hurled out of the earth by a volcano.
Elastic rebound	The springing back of rocks, after rupture, to a position of no strain.
End moraine	Terminal moraine. An accumulation of glacial drift at the end or margin of a glacier.
Entrenched meander	A meandering stream in a deeply incised valley. Entrenched during uplift.
Epeirogenic movements	The raising or lowering of land masses of continental magnitude with little, if any folding.
Epicenter	The area on the earth's surface directly above the focus of an earthquake.
Epicontinental sea	Shallow sea that lies far in upon a continental mass.
Escarpment	A steep slope or cliff separating gently sloping areas.
Eskers	Winding ridges of irregularly stratified sand and gravel that occur in the area of ground moraine.
Estuary	The portion of a stream valley influenced by the tide of the body of water into which it flows.
Eustatic	Relating to a worldwide rise or fall of sea level, caused by melting or accumulation of continental glaciers.
Evaporite	A sediment deposited from solution as a result of extensive evaporation of the solvent.
Exfoliation	Process by which concentric sheets or scales peel off from bare rock surfaces.
Exposure	An outcrop of rock exposed at the surface of the earth.
Facet	A plane surface abraded on a rock fragment.
Faceted spur	The end of a ridge which has been truncated by erosion or faulting.
Fades	Rock features reflecting the environment in which the rock was formed.
Fan	Detrital material deposited in the shape of a fan, as an alluvial fan.
Fault	A fracture in the rock along which there has been movement.
Fault block	A unit of rock bounded by faults.
Fault scarp	A cliff formed by faulting.
Feldspars	A group of minerals classed as alumino-silicates.

Ferromagnesian	Pertaining to certain dark-colored minerals and rocks containing iron and magnesium.
Fiord	The seaward end of a glaciated, steep-walled valley that is partly submerged.
Fim	Compacted, granular snow. Also called neve.
Fissure	An extensive break, crack, or fracture in the rocks.
Flint	A tough, fine-grained form of silica. Breaks with conchoidal fracture. Commonly occurs as nodules in limestone.
Float	Pieces of rock separated from the parent beds or ore veins by agents of weathering and erosion.
Floe ice	Floating pieces of sea ice.
Flood plain	Portion of a stream valley bordering the channel, built of sediments brought there by the stream during time of flood.
Flow breccia	Fragments of solidified lava welded or cemented by lava, as at the top of a lava flow.
Flow cleavage	Rock cleavage caused by parallel alignment of minerals, as in schists.
Flowing well	A well from which water or oil flows at the surface without pumping. Hydrostatic pressure lifts the fluid to the surface.
Fluorite	A mineral composed of calcium fluoride, an ore of fluorine.
Foliation	A structural lamination produced during metamorphism. Schists are foliated.
Footwall	The mass of rock beneath a fault plane or vein of ore.
Foreset beds	Inclined strata dropped by river currents on the frontal slope of a delta or a channel bar.
Fossils	Remains or traces of plants or animals preserved in the rocks.
Fracture cleavage	A system of closely spaced parallel fractures, along which a rock breaks readily.
Gabbro	A coarse-grained basic igneous rock composed for the most part of pyroxene and calcic plagioclase.
Galena	A mineral composed of lead sulfide. The principal ore of lead.
Gangue	The nonvaluable minerals associated with ore minerals in a vein.
Geode	A thick-walled, rounded or egg-shaped rock cavity lined with crystals.
Geomorphology	The origin and development of the topography of the continents.
Geosyncline	A long troughlike belt of sediments within a continent that has warped down during the long period of accumulation.
Glacial milk	Melt water from glaciers, colored by suspended particles of clay and silt.
Glacial retreat	The recession of the frontal margin of a glacier.
Glacial striae	Glacial scratches on smoothed rock surfaces.
Glacier table	A large block of stone supported by a column of ice on the surface of a glacier.
Glauconite	A green, granular mineral composed of hydrous potassium iron silicate.

Gneiss Coarse-grained, imperfectly foliated feldspathic rock, usually metamorphic.

Gouge Crushed and abraded material occurring between the walls of a fault.

Graben A fault trough or a fault block down-thrown relative to both margins.

Gradation The processes that tend to bring the earth's surface to grade through erosion and deposition.

Graded bedding A gradation in grain size within a sedimentary layer, from coarse below to fine above.

Graded stream A stream in which the long profile is in equilibrium. It neither degrades nor aggrades.

Granite A coarse-grained, intrusive igneous rock composed of orthoclase, quartz, and a ferromagnesian mineral.

Granitoid Designating the texture of a coarsely crystalline, igneous rock.

Graphite A mineral composed of carbon.

Gravity fault A normal fault. The hanging wall appears to have moved downward relative to the foot-wall.

Graywacke A gray, clastic sedimentary rock composed of fragmental granite debris and other rock and mineral fragments in a muddy matrix.

Greensand Highly glauconitic sand.

Grit Very coarse-grained sand.

Groundmass The fine-grained or glassy matrix of a porphyritic igneous rock.

Ground moraine A moraine with low relief, consisting mainly of unsorted till, deposited as a widespread veneer over a bedrock surface.

Ground-water level The upper surface of the zone within the earth below which the openings in the rocks are filled with water.

Gumbo Soils that yield a very sticky mud when wet.

Gypsum A common mineral, consisting of hydrous calcium sulfate. Varieties are called satin spar, selenite, and alabaster.

Hade The angle of inclination of a vein or fault measured from the vertical.

Halite Rock salt. A common mineral consisting of sodium chloride and formed as an evaporite.

Hanging valley A tributary valley whose floor is notably higher than the floor of the trunk valley into which it leads.

Hanging wall The mass of rock above a fault plane, vein, or bed of ore. The opposite of a footwall.

Hardness The resistance of minerals and rocks to abrasion or scratching.

Headland A bold cape or promontory projecting into the sea.

Headward erosion The lengthening of the upper end of a valley by the water that flows in at its head, as illustrated by gullies gnawing back into slopes.

Hematite The principal ore of iron, consisting of iron oxide.

Hogback A resistant ridge produced by the erosion of highly tilted strata.

Homogeneous Of the same nature; consisting of similar parts; opposite of heterogeneous.

Hook A hook-shaped spit.

Horn	A high pyramidal peak with steep sides formed by the intersecting walls of several cirques.
Hornblende	The dark, aluminous variety of the amphibole group of minerals.
Hornfels	Dense, finely granular metamorphic rock. A product of contact metamorphism formed at temperatures above 1,200°F.
Horst	A block of the earth's crust, generally long compared to its width, that has been uplifted along faults relative to the rocks on either side.
Hydration	The chemical combination of water with another substance.
Hydrocarbon	A compound containing only carbon and hydrogen, such as petroleum.
Hydrologic cycle	The water cycle, in which water is evaporated from the sea, then precipitated from the atmosphere to the surface of the land, and finally returned to the sea by rivers and streams. Some water is evaporated again before it reaches the sea.
Icecap	A small ice sheet.
Ice foot	A fringe of ice frozen to the shore along the coasts of polar seas.
Ice jam	Fragments of broken river ice lodged in a narrow of a river channel.
Iceland spar	A transparent variety of calcite that has double refraction.
Ice sheet	Glacier forming continuous cover over a large land surface and moving outward in many directions.
Igneous rock	Rock formed by cooling and solidification of hot, mobile, mineral material called magma.
Impervious	Applied to rocks, such as clays and shales, that do not allow the penetration of solutions, oil, or gases.
Inclusion	A fragment of older rock enclosed in an igneous rock.
Induration^	Hardening of sediments by compaction through pressure, cementation, or heat.
Infiltration	The percolation of water into soil and rock through pores. Also, the deposition of mineral matter by the permeation of water carrying it in solution.
In situ	In its natural position or original place.
Insolation	The action of the sun's heat upon the rocks at the surface, or the solar radiation received by the earth.
Intercalated	Pertaining to material interbedded with another kind of material.
Intermediate rock	Rock that is intermediate between acidic and basic. Containing between 52 and 66 percent silica.
Intermittent stream	A stream that flows only part of the time. One that has not cut its valley below the water table.
Interstitial water	Water contained in the pores between grains of rock.
Intrusive rock	Rock consolidated from magma beneath the earth's surface.
Isoclinal fold	Fold with parallel limbs.
Isomorphous	Having similar crystalline form.
Isopach	On a geologic map, a line drawn through points of equal thickness of a given formation or stratigraphic unit.
Isoseismals	Imaginary lines on the surface of the earth connecting points of equal seismic disturbance.

Isostasy, theory of	The hypothesis that different masses of the earth's crust stand in gravitational equilibrium with each other at some depth within the earth.
Isotherm	An imaginary line connecting points of equal temperature.
Jasper	A variety of very fine-grained quartz, red to dark brown in color.
Joint	A fracture in a rock formation along which there is no evidence of displacement.
Joint chasms	Deep indentations formed along coasts where joints have been quarried out by the waves.
Joint system	Two or more sets of joints which may have characteristic patterns.
Kame	A conical hill of stratified glacial drift deposited as an alluvial cone or fan against the outer margin of an ice sheet by a melt-water stream from the ice.
Kame terrace	A terrace along a, glaciated valley wall formed from stratified drift deposited along the margin between the ice and the bounding rock slope of the valley.
Kaolinite	China clay. A common clay mineral consisting of hydrous aluminum silicate. Has a greasy feel and is plastic when wet.
Karst topography	Rough topography etched out in a network of numerous short gullies and ravines which terminate in sinkholes produced by the solution of limestone strata. (Named from Karst Mountains, northeast of the head of Adriatic Sea.)
Kettle	A depression in a drift sheet, made by the melting of a mass of glacial ice that had been either wholly or partly buried in the drift.
Labradorite	A calcic plagioclase feldspar.
Laccolith	A lens-shaped intrusive body that has domed up the overlying sedimentary beds and that has a floor, which generally is horizontal.
Lag gravel	Residual material of coarser fragments, from which finer particles have been blown away.
Lagoon	The quiet water on the landward side of an offshore bar.
Lamination	Thin bedding, less than 1 centimeter in thickness, in a sedimentary rock or in unconsolidated sediments.
Landslide	Large masses of earth and rock that slide bodily down a slope.
Lapilli	Volcanic ejecta ranging from 4 to 32 millimeters in diameter.
Lateral moraine	A moraine built along the edge of a valley glacier and composed of angular rock fragments that had fallen on the glacier from the valley wall.
Laterite	A residual product of weathering in hot, humid climate. It is composed of iron and aluminum hydroxides and occurs as a red, porous, concretionary veneer over bedrock
Lava	Fluid rock material that issues from a volcano or a fissure in the earth's surface. Magma that reaches the surface.
Lava cone	A volcanic cone built almost entirely of lava flows.
Leaching	The process by which the more soluble mineral compounds are removed in solution by percolating ground water.
Lignite	Low rank, brown coal with a woody appearance.
Limestone	A sedimentary rock consisting chiefly of calcium carbonate.

Limonite	Brown, hydrous iron oxide. An important iron ore.
Lithification	The complex processes that convert unconsolidated sediments into solid rock.
Littoral zone	The zone along the coast between the average extent of the highest flood tide and the average recession of the lowest ebb tide.
Load	The quantity of material being transported by a current of water, wind, or glacial ice.
Loess	Nonstratified, yellowish silt deposited primarily by the wind. Consists of fresh, sharp-cornered particles of quartz, feldspar, calcite, and numerous other minerals mingled with some clay.
Longshore drift	Sediment transported by currents parallel to the shore.
Lopolith	A large, floored intrusive that is centrally sunken into the form of a basin.
Magma	Hot, fluid rock material generated within the earth and capable of intrusion or extrusion. When cooled and solidified, it forms igneous rocks.
Magmatic differentiation	Process by which different types of igneous rocks are derived from a single mass of magma.
Magmatic water	Water that exists in, or which is derived from, magma.
Magnesite	A mineral consisting of magnesium carbonate.
Magnetite	A magnetic, black mineral consisting of iron oxide. An important ore of iron.
Mantle-rock	Unconsolidated rock debris that overlies the bedrock surface.
Marble	A metamorphic rock composed essentially of granular calcite or dolomite. A product of the recrystallization of limestone.
Mass movement	Surface movement of earth materials induced by gravity.
Meander	One of a series of looplike bends in the course of a stream.
Medial moraine	A ridge of drift formed by the joining of adjacent lateral moraines below the junction of two valley glaciers.
Mesa	A low, flat-topped mountain or tableland bounded on at least one side by a steep cliff.
Metamorphic rock	A rock that has been changed in texture and/or composition by heat, pressure, or chemically active solution.
Millidarcy	One-thousandth of a Darcy. A measure of permeability.
Mineral	A naturally occurring, homogeneous, inorganic, crystalline substance.
Monadnock	A mountainlike mass such as a butte, standing above a peneplain as a remnant of erosion.
Monocline	A succession of beds dipping in one direction or folded in a steplike bend from an other¬wise horizontal position.
Monzonite	A coarse-grained igneous rock containing equal amounts of orthoclase and plagioclase feldspar.
Moraine	Glacial drift or till deposited chiefly by direct glacial action.
Moulin	A circular depression on the surface of a glacier and the underlying well into which melt waters plunge.
Muck	A substance similar to peat but containing more soil minerals.

Mud volcano A mud geyser, commonly formed by the eruption of bituminous mud from a central vent.

Muscovite White mica, a member of the mica group of minerals.

Muskeg A moss-covered bog or marsh.

Nappe A large body of rock that has moved a great distance from its original position, either by overthrusting or by recumbent folding.

Neve Snow converted into granular ice. Also called firn.

Nonconformity An unconformity where the older rocks are of plutonic origin.

Normal fault A fault in which the hanging wall has moved downward relative to the footwall.

Obsidian Volcanic glass. Characterized by glassy luster and conchoidal fracture, with composition close to that of rhyolite and granite.

Offlap A relationship of strata that develops where a shoreline has retreated seaward and progressively younger strata have been deposited in layers offset seaward.

Oil shale A shale with abundant organic material that yields oil when distilled slowly.

Olivine A green, rock-forming mineral composed mainly of magnesium silicate.

Onyx A banded variety of cryptocrystalline quartz. Mexican onyx is translucent banded calcite.

Oolite A rock consisting of sand-sized, spheroidal grains of calcareous material or, less commonly, ferruginous, siliceous, or phosphatic material in concentric layers around a nucleus, generally of quartz.

Ooze Fine-grained deep sea deposits containing more than 30 percent of organic residues.

Opal An amorphous form of hydrous silica. A solidified silica gel.

Ore A mineral deposit from which a metal or nonmetal can be extracted at a profit.

Orogeny The processes of folding and faulting that result in the formation of mountain ranges.

Orthoclase A mineral of the feldspar group composed of potassium aluminum silicate. An essential mineral of granite.

Outcrop That part of a rock formation which appears at the surface.

Outwash Stratified drift deposited by melt-water streams beyond the margin of glaciers.

Overturned fold A fold in which one limb has been rotated past the vertical. Compare with recumbent fold.

Oxbow lake A crescent-shaped lake formed in an abandoned river bend by a meander-neck cutoff.

Parting The separation of crystals along planes that are not true cleavage planes.

Peat A dark-brown, spongy residue produced by partially decomposed vegetative tissue in swamps and bogs.

Pediment Gently sloping rock plain eroded at the foot of steep slopes or cliffs.

Pegmatite Very coarse-grained granite that occurs in dikes. Some pegmatites contain rare minerals and gems.

Peneplain A land surface worn down by erosion to a nearly flat or broadly undulating plain.

Perched boulder A glacial boulder deposited in an unstable position on the top of a hill.

Perched water table Ground water that lies above the regional ground water table and is separated from it by impervious strata.

Peridotite A coarse-grained basic igneous rock composed of olivine.

Perlite Volcanic glass having numerous concentric cracks formed by contraction during cooling.

Permafrost Permanently frozen subsoil.

Permeability A rock's capacity for transmitting a fluid.

Pervious rock A stratum or formation that contains voids through which water will move under ordinary hydrostatic pressure.

Petrifaction The conversion of organic matter into stone.

Petrology The study of the natural history of rocks.

Phaneritic Designating igneous rocks with a coarse-grained texture.

Phenocryst A relatively large and conspicuous crystal in a porphyritic igneous rock, surrounded by much smaller grains.

Phosphate rock A sedimentary rock containing nodular and irregular masses of concretionary calcium fluorophosphate.

Phyllite A slaty metamorphic rock with fine mica crystals that give the cleavage surfaces a silky sheen.

Piedmont Lying or formed at the foot of a mountain. Examples are piedmont alluvial plains and piedmont glaciers.

Piracy The diversion of the upper part of a stream by the head ward growth of another stream.

Pitted plain A glacial outwash plain with numerous small kettle holes.

Placer deposit An alluvial deposit containing particles or nuggets of gold, platinum, tin, or other stable, valuable minerals derived from the weathering of rocks or veins.

Plagioclase A group of rock-forming feldspar minerals.

Plastic deformation A permanent change in the shape of a solid that occurs without fracturing or rupture.

Playa lake A flat-floored, shallow desert basin containing a temporary lake.

Pluton A great body of intrusive igneous rock that formed beneath the surface by the cooling and consolidation of magma.

Podsol A highly bleached soil that is low in iron and lime.

Porphyritic Designating a rock texture in which large phenocrysts (crystals) are set in a finer groundmass.

Pothole A cylindrical hole worn into the solid rock at rapids or at the foot of waterfalls.

Pumice A cellular, volcanic froth. Sufficiently buoyant to float on water.

Pyrite A brass-yellow mineral composed of iron sulfide. It has cubic crystals and is commonly striated. Popularly called fool's gold.

Pyroclastic	Designating detrital volcanic materials that have been ejected explosively.
Pyroxenes	A group of ferromagnesian minerals.
Pyroxenite	A coarse-grained basic igneous rock composed of pyroxene.
Quartz	A mineral, composed of silicon dioxide, with six-sided crystals tapering to pyramids at the ends. Colorless or white when pure, but commonly tinted. Without cleavage.
Quartzite	A granular metamorphic rock consisting essentially of quartz.
Recessional moraine	A ridgelike accumulation of drift deposited by a glacier along its outer margin, back from the position of its maximum advance.
Recumbent fold	A fold in which the axial plane is approximately horizontal.
Rejuvenate	To stimulate, as by uplift, the erosive activity of a stream.
Repose, angle of	The slope on which any given deposited material will come to rest or remain at rest.
Residual clay	A clay deposit formed by the decay of rock in place.
Reverse fault	A fault plane along which the hanging wall appears to have moved upward relative to the footwall.
Rhyolite	A fine-grained equivalent of a granite.
Ripple marks	Small undulations produced on the surface of unconsolidated materials by waves or by currents of wind or water.
Rock	A mineral or an aggregate of minerals forming an essential part of the earth's crust.
Rock glacier	Talus glacier. ice. A tongue-shaped mass of angular boulders that creeps slowly from high, rugged terrain with the aid of interstitial
Rock terrace	Terrace cut into solid rock rather than alluvium. More resistant horizontal beds are worn back from the valley wall less rapidly than beds above them.
Runoff	The discharge of water through surface streams.
Salinity	A measure of the total concentration of dissolved solids in water.
Saltation	The process whereby a particle is picked up by a turbulent current and carried forward by leaps and bounds.
Salt dome	A domelike, subsurface structure resulting from a roughly cylindrical mass of common salt being pushed upward through surrounding sediments.
Sandstone	A sedimentary rock composed of sand-sized grains of minerals and rock fragments cemented together.
Saucer lake	A lake that occupies a shallow basin between a natural levee and a valley wall.
Scarp	An escarpment or cliff.
Schist	Metamorphic rock which has a foliated structure. Micaceous minerals are prominent.
Scoria	Volcanic glass characterized by vesicularity resulting from expanding gases. The frothy texture is retained.
Sedimentation	The process by which mineral and organic matter is deposited to make sediments.

Seepage	The infiltration and percolation of water through or out of openings in rocks.
Serpentine	A common rock-forming mineral composed mainly of magnesium silicate.
Shale	A laminated, detrital sedimentary rock in which the particles are predominantly of clay size. Shales, however, are not limited to clay minerals but may contain silt-sized fragments of quartz, feldspar, calcite, dolomite, and other minerals.
Sheet erosion	Erosion caused by a continuous sheet of surface water.
Silica sand	Sand high in quartz (silicon dioxide).
Silt	Clastic sediment in which the particles are coarser than clay and finer than sand, that is, between Vie and 1/256 millimeter in diameter.
Sinkhole	A funnel-shaped depression in the surface that occurs where rocks such as salt, gypsum, or limestone have been dissolved and the roof of the solution cavern has collapsed.
Slate	A fine-grained metamorphic rock possessing a well-developed secondary cleavage which allows it to break into sheets that have smooth surfaces.
Slickenside	A polished and scratched surface that results from friction along a fault plane.
Slip face	The steep face on the lee side of a sand dune.
Slumping-	See Creep.
Soapstone	A massive, impure variety of talc.
Soil profile	A vertical section of the soil from surface downward through all of its horizons into the parent material.
Solifluction	Soil flow. See Creep.
Specific gravity	The ratio of the mass of a body to the mass of an equal volume of water at a temperature of 40°C.
Specularite	Crystalline hematite (iron oxide) occurring in disk-like crystals with metallic luster.
Spheroidal weathering	Production of rounded, residual boulders by chemical weather of rock along fractures.
Stalactite	Icicle-shaped pendants of dripstone hanging from the roof of a cave.
Stalagmite	Cone-shaped posts of dripstone growing upward from the floor of a cave. Stalactites and stalagmites often meet, forming a pillar from floor to roof.
Stock	An intrusive rock mass, covering less than 40 square miles, that has steep contacts and no determinable floor.
Stoss	The side of a glacially shaped hill that faces the direction from which the glacier came.
Stratification	The deposition of layers, or strata, of sediments as tabular units.
Stratum	A single layer of sedimentary rock, regardless of thickness.
Streak	The color of the powder of a mineral.
Striae	Minute grooves or scratches on fault surfaces or on rock over which glacial ice has moved.

Strike The direction, or compass bearing, of the outcrop of an inclined stratum, dike, or vein on a level surface. It is always perpendicular to the direction of the dip.

Subsequent stream A stream that adjusts its course to fit belts of weak structure.

Subsidence A sinking of part of the earth's crust.

Superimposed drainage A drainage system that, because of the erosion of the strata in which it was established, has been imposed on the older, underlying rocks, which have a different structure.

Syenite A coarse-grained igneous rock consisting essentially of orthoclase and hornblende or biotite.

Symmetrical fold A fold in which the axial plane is essentially vertical, so that the limbs are of equal length and the dips at similar angles.

Syncline A downfold or trough in which the strata dip inward from both sides toward the axis. The opposite of an anticline.

Synclinorium A broad regional synclinal trough on which minor folds are superimposed.

Taconite A granular ferruginous chert containing varying amounts of magnetic, hematite, siderite, and hydrous iron silicates. An ore of iron in the Lake Superior region.

Talc A very soft mineral with a greasy or soapy feel. A magnesium silicate.

Talus An accumulation of coarse rock waste at the base of a cliff. Also known as scree.

Tarn A small mountain lake which occupies a cirque.

Terminal moraine A rugged ridge or belt of unsorted till marking the outermost margin of a glacier.

Terminus The end, or outer, margin of a glacier.

Terrace A level-topped surface bordered by a steep escarpment. May be composed of alluvium or of solid rock.

Test The external shell of many small invertebrates.

Throw The vertical component of the net slip of a fault.

Thrust fault A fault along which the hanging wall appears to have been raised relative to the footwall. Generally characterized by a low angle of inclination, with reference to the horizontal. Commonly called a reverse fault.

Till Nonstratified glacial drift.

Tillite A rock composed of indurated and cemented till.

Topset beds The layers deposited horizontally on top of a delta. See also foreset and bottomset beds.

Trachyte The fine-grained equivalent of syenite.

Traction load The bottom load, or bed load, of a stream, carried by rolling, sliding, or saltation.

Travertine A somewhat porous or cellular variety of calcium carbonate, deposited from solution in surface and ground waters. Deposited also as stalactites and stalagmites in underground caverns.

Trellised drainage A drainage pattern that parallels deeply eroded, folded strata. Pattern resembles a garden trellis. Also called grapevine drainage.

Truncated spur The cutoff or steepened end of a divide between the tributaries of a glaciated valley, resulting from the widening of the main valley by glacial erosion.

Tufa A porous spring deposit composed of calcium carbonate or silica.

Tuff Consolidated volcanic ash. Fragments are generally less than 4 millimeters in diameter.

Tundra A treeless plain or swampland in the arctic region, generally developed over regions of perma¬frost.

Turbidity current A current due to differences in density produced by suspended clays and silt in the water.

Unconformity An old erosion surface that separates younger strata from older rocks.

Vadose water Subsurface water in the zone of aeration or leaching, above the zone of saturation.

Varve An annual pair of thin sedimentary beds, one coarse and one fine, deposited as glacial-lake sediment, the coarse laid down during the summer, the fine during the winter.

Vein A crack or fissue filled with mineral matter deposited from underground water solution.

Ventifact Designating pebbles or boulders shaped by the abrasive action of wind-blown sand.

Vermiculite A platty, mica-like mineral that expands markedly when heated.

Vesicle A small cavity in a fine-grained or glassy igneous rock formed by a bubble of gas during the solidification of lava.

Viscosity The internal friction of a fluid that offers resistance to flow.

Vitreous Having the luster of broken glass; noncrystalline; amorphous.

Vitrophyr A consolidated, glassy, igneous rock, containing occasional phenocrysts.

Volcanic ash Uncemented volcanic ejecta consisting of fragments mostly under 4 millimeters in diameter.

Volcanic breccia An indurated pyroclastic rock consisting mainly of angular fragments more than 32 millimeters in diameter.

Volcanic glass Natural glass produced when lava cools too rapidly to permit crystallization. The best example is obsidian.

Volcanic neck A roughly cylindrical mass of igneous rock that represents the filling of the vent of an extinct volcano. Volcanic necks range in diameter from a few hundred yards to a mile or more.

Volcano A mountain which has been built up by lava and pyroclastic fragments ejected from the interior of the earth through a vent. Also the vent itself.

Vulcanism The generation and migration of magmas and lavas and the formation of their products.

Warping A gentle bending of the crust of the earth that does not result in the formation of pronounced folds or faults.

Watershed A term used loosely to mean both drainage basin and drainage divide.

Water table The upper surface of the zone of saturation.

Wave-built terrace An embankment built along or near the shore by the aggradational work of waves.

Wave-cut terrace A leveled rock bench produced by the retreat of a sea cliff through wave erosion. Also called wave platform, shore platform, and plain of marine abrasion.

Wave of translation A wave in which there is a pronounced forward movement of the water.

Weathering The complex set of natural processes, both chemical and mechanical, involved in the breaking up and decay of rocks.

Winnowing The process by which the wind separates fine particles from coarser or heavier ones.

Xenolith An inclusion or rock fragment broken from the wall or roof of a magma chamber and found embedded in the igneous rock mass.

Zeolite A secondary mineral occurring in the cavities of a lava flow.

Zone of aeration The portion of the ground in which the pore spaces in permeable rocks are not filled with water. The zone that lies above the zone of saturation.

Zone of fracture The zone near the surface of the earth's crust in which rocks are deformed by fracture.

Zone of saturation That part of the ground within which all openings are filled with water. Its upper surface is the water table, and it extends as far down within the earth as connected openings can exist.

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