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MILITARY GEOLOGY AND TOPOGRAPHY.

MILITARY GEOLOGY AND TOPOGRAPHY

A PRESENTATION OF CERTAIN PHASES OF GEOLOGY, GEOGRAPHY AND TOPOGRAPHY FOR MILITARY PURPOSES.

HERBERT E. GREGORY, EDITOR.

PREPARED AND ISSUED UNDER THE AUSPICES OF THE DIVISION OF GEOLOGY AND GEOGRAPHY NATIONAL RESEARCH COUNCIL.

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PREFACE.

THE organization of Students' Army Training Corps in American educational institutions involves a readjustment of courses of instruction. The extent to which the modification of existing courses and the introduction of new courses is desirable has been indicated in a circular transmitted to colleges and universities by the Committee on Education and Special Training of the War Department. This circular includes the statement: "The branches of earth science which contribute most directly to military needs are Military Geology and Geography including Meteorology and Military Mapping," and recommends that some course or courses covering these topics be offered in each institution where geology or geography is taught. This action was taken because the Great War has demonstrated the desirability of more widely diffused knowledge of geology as an aid in conducting military operations and in the solution of economic problems relating to raw materials.

In response to many requests for guidance in the presentation of the courses which were called for by the Committee of the War Department, the National Research Council through its Division of Geology and Geography has prepared Military Geology and Topography, Introductory Meteorology and a syllabus on the Geography of Europe as text books for students.

In the preparation of Military Geology the following have collaborated: Professor Nevin M. Fenneman, University of Cincinnati; Professor C. P. Berkey, Dr. A. K. Lobeck, and Dr. Frederick Morris, Columbia University; Professor W. W. Atwood and Professor J. B. Woodworth, Harvard University; Professor H. L. Fairchild, University of Rochester; Dr. Willis T. Lee, Dr. T. Wayland Vaughan, O. E. Meinzer, and P. S. Smith, United States Geological Survey; Dr. J. E. Spurr, United States Bureau of Mines; Professor H. F. Cleland, Williams College; Professor C. K. Leith and Professor W. J. Mead, University of Wisconsin; Professor W. E. Ford, Professor Herbert E. Gregory, and Dr. George E. Nichols, Yale University. Valuable criticism has been received from M. R. Campbell, N. C. Grover, J. C. Hoyt, B. H. Lane, J. L. Ridgway, and G. M. Wood of the United States Geological Survey, and from others whose duties in connection with the war prevented fuller participation. All contributors have

given their services without compensation; the publishers also have made substantial concessions.

In addition to those furnished by the authors many illustrations have been supplied by the Director of the United States Geological Survey. Electrotypes for nineteen illustrations appearing in Geology, by Chamberlin and Salisbury, and Physiography, by Salisbury, have been provided by Henry Holt and Company. John Wiley and Sons has given permission to use one illustration from Engineering Geology, by Ries and Watson, and the Harvard University Press has furnished an electrotype of one illustration from Handbook of Northern France, by William Morris Davis.

The task assumed by the authors has been a difficult one, for the relation of geology to military activities is unfamiliar to American students, and the time available for the preparation of the text has been very brief. The aim has been to focus attention on those facts and principles that have proven to be applicable to military problems on the assumption that the teacher will develop the topics briefly treated and will supplement the descriptions in the text with models, maps, and lantern views. The book is the result of a preliminary effort, and its authors hope that it will be a nucleus about which will gather material for a more complete volume; it will have served its purpose if it increases the efficiency of the American Army even to a small degree. Teachers and other readers will aid in the preparation of an improved second edition by calling attention to errors, by suggesting emendations, and by furnishing general criticisms. Communications may be addressed to Professor Herbert E. Gregory, Yale University, New Haven, Conn.

National Research Council,
Division of Geology and Geography,
September 10, 1918.

CONTENTS.

CHAPTER I.

ROCKS AND OTHER EARTH MATERIALS.

CHAPTER II.

ROCK WEATHERING.

CHAPTER III.

STREAMS.

CHAPTER IV.

LAKES AND SWAMPS.

CHAPTER V.

WATER SUPPLY.

CHAPTER VI.

LAND FORMS.

CHAPTER VII.

MAP READING AND MAP INTERPRETATION.

CHAPTER VIII.

ECONOMIC RELATIONS AND MILITARY USES OF MINERALS.

ILLUSTRATIONS.

CHAPTER I.

ROCKS AND OTHER EARTH MATERIALS.

INTRODUCTION.

THE consideration of the manner of occurrence, behavior, and adaptability of earth materials is essential to the effective and intelligent conduct of military operations. Earth materials are dealt with in the tunnels and mines under "No Man's Land" and in the trenches, gun pits, and dugouts along the front. The nature of the materials that make up the surface of the ground determines the form and size of shell craters and in a measure the effect of shell fire. Earth materials form the foundations of heavy artillery. They support and surface the overburdened roads. They are in many places the source of water supply and in some places the receptacle of sewage and drainage; consequently they are related to the problems of army hygiene. Back of the lines the ease of construction and security of military railroads, which must be built with great rapidity and in the face of many difficulties, are dependent on the character of the earth materials. The proper construction of foundations and supports for the great warehouses, shops, docks, and other structures depends on the nature of the underlying rock and earth. The location and construction of harbors require in advance a knowledge of the rock and earth material to be encountered.

It is obvious that strategic necessities may prevent the choice for military operations of the locality that is most desirable with reference to the rocks at and beneath the surface. This possibility emphasizes the importance of knowing and understanding the properties of rocks in order to solve problems arising from enforced undesirable locations and the necessity of introducing into the strategic considerations which determine locations a thorough knowledge of subsurface conditions. Furthermore, it is of the highest importance to know what subsurface conditions the enemy is finding and how he is meeting those conditions.

EARTH MATERIALS.

Nature and origin.—It is a matter of common observation and knowledge that the surface of the earth consists largely of various unconsolidated or incoherent earth materials—soil, clay, sand, gravel, etc.—and that beneath these materials and projecting through them here and there is solid rock. The mantle of unconsolidated material may be the soft, decayed upper portion of the solid rock beneath, or it may be clay, sand, gravel, and marl, alone or mixed, in no way related to the underlying rock. Usually there is an upper layer of earth that supports vegetation and is called soil. All these incoherent materials are ultimately the products of the decay of solid rock.

Such of these materials as are found in their places of origin—that is, such as are the products of decay of the rock beneath—may be termed *residual materials*. Those that are not related to the underlying rock but have been formed by the breaking down or decay of rock elsewhere and have been carried to their present places by water, wind, or other agencies are called *transported materials*.

Classification of rocks.(1, 7)[1]—There are certain genetic relations, between various groups of rocks, an elementary knowledge of which seems essential to intelligent observation and interpretation. For these reasons it is advisable to consider rocks according to their manner of origin.

On the basis of origin, rocks may be put into two great classes—(*a*) igneous rocks, which are formed by the cooling of molten rock from great depths in the earth; (*b*) sedimentary rocks, which are the products of the decay of other rocks, redistributed by water or wind.

Essential differences between sedimentary and igneous rocks.(7)—Sedimentary and igneous rocks differ in texture, composition, and mode of occurrence and may present vastly different conditions and problems to the military engineer. Igneous rocks, with minor exceptions, are denser, harder, and heavier than sedimentary rocks and consequently more difficult to work. Sedimentary rocks commonly occur in layers or beds, owing to their manner of origin. Some igneous rocks, such as lava flows and volcanic débris, are deposited in layers and to this extent resemble sedimentary rocks. Others have been forced in and solidified as thin sheets between beds of sedimentary rocks and are therefore likely to be mistaken for sedimentary beds. Most igneous rocks, however, do not show the parallel bedding characteristic of sedimentary rocks.

[1] The numbers are those used in the reference list at the end of this chapter.

SEDIMENTARY ROCKS.

ORIGIN.

All rocks at or near the surface of the earth are attacked more or less rapidly[2] by the destructive action of wind, water, changes in temperature, and other agencies. (4, 5) This attack on the rock is both mechanical and chemical. Soluble portions of the rock are carried away in solution. Some of the original mineral constituents are changed in their nature. Others that are more resistant are merely broken into smaller fragments. The products of this surface decay and disintegration of rocks are fragmental materials and soluble salts. The salts are removed in solution. The fragments are ultimately picked up and transported by water or wind or glaciers, and during the transportation they are assorted to a greater or less extent. (See Chapter II.)

The soluble materials in part ultimately reach the streams and are carried to the sea. Some of the soluble salts, principally the sodium chloride, remain in solution and accumulate in the sea water, which is thus made highly salty. Other dissolved materials, such as silica and the salts of calcium and magnesium, are precipitated by organic or chemical means and produce beds of calcium and magnesium carbonates and siliceous ooze on the sea bottom. By natural processes of consolidation and cementation these deposits become chalk, limestone, dolomite, and chert or flint.

The undissolved products of rock weathering, consisting largely of intermingled sand, clay, and undecomposed rock fragments, are subjected to the vicissitudes of erosion and transportation and are ultimately deposited in the sea, in lakes, or in valleys on the land surface. During their transportation the fragmental materials undergo a natural process of separation or classification, due to differences in size and shape of grain and in density, so that there is a tendency for clay to be deposited in one place, sand in another, and still coarser material elsewhere. As the conditions of deposition vary from time to time successive deposits of calcium ooze, sand, and clay may be laid down in the same area on the ocean bottom, the ultimate result bring in a great series of interlayered beds of limestone, sandstone, and shale.

[2] Although rock decay may be rapid in comparison to other geologic processes, the most rapid decay of solid rock is too slow to be a factor in any but permanent structures.

VARIETIES.

The principal types of sediments as first deposited are sand, clay, and calcareous ooze or marl. In addition to these are the accumulated remains of plants in the form of peat. These incoherent sediments become hardened by natural processes into more solid forms. Sand becomes sandstone, clay changes to shale, calcareous ooze and marl become chalk or limestone, and peat is changed to lignite or soft coal. By continuation of the hardening processes sandstone becomes quartzite, shale is changed to slate, chalk and limestone become marble, and soft coal becomes anthracite. In other words, there are four great classes of sedimentary materials, and each class is a series which grades from soft and incoherent phases to various hard phases. For convenience they may be designated the sand series, the clay series, the carbonate series, and the coal series. (7, 8)

Sand Series	Clay Series	Carbonate Series	Coal Series
Sand, gravel	Clay, loess	Oozes, marl	Peat
Sandstone, conglomerate	Shale	Chalk	Coals
Quartzite	Slate	Limestone	
Quartz schist	Schist	Marble	

SAND SERIES.

The sand series embraces the rocks and unconsolidated sedimentary materials that consist largely of sand. These sandy rocks grade by admixture into the clay series and into the carbonate series. It is usual to find material which must be described as sandy clay or calcareous sand or by other terms descriptive of mixtures.

Sand.—Unconsolidated sand varies in texture from extremely fine-grained material to coarse gravel. Its grains may be sharply angular, subangular, or well rounded. Its color depends on the minerals present. Pure quartz sand is white. A slight amount of oxide of iron imparts various shades of yellow, brown, and red. Sands consisting largely of ferromagnesian minerals are dark colored or greenish; some are black.

Sand consists of the harder and more resistant mineral particles resulting from the decay and disintegration of rocks, both sedimentary and igneous. These particles are separated by the sorting action of water or wind from the accompanying fine-grained and lighter materials. The sorting action depends on the size and specific gravity and to some extent on the shape of the grains. Quartz is the dominant mineral in the earth's crust, and quartz sands are more abundant than any others. Feldspar grains and mica flakes are common. Ferromagnesian minerals are abundant in sands derived from the breaking down of dark-colored igneous rocks.

When igneous rocks disintegrate without much chemical decay the product is a coarse sand made up of fragments of all the minerals present in the rock destroyed. The weathering of sandstone yields a large proportion of sand; limestone and shale yield little or none.

Sand is variously spoken of as beach, dune, stream, or glacial sand, the term used depending on its mode of deposition.

Beach or desert sand may be piled up by wind action into sand hills, called dunes, which travel slowly in the direction of the prevailing winds, as a result of erosion on the windward side and deposition on the leeward side. Moving dunes may invade fertile lands and endanger works of man, and the control of such dunes is an important engineering problem.

Commonly from 15 to 25 per cent. of the volume of a sand consists in voids, or pore space. Well-sorted sand with grains of uniform size has greater porosity than poorly sorted sand with grains of different sizes. The porosity of sand gives it a large capacity for absorbing water, and as the pores are continuous sand is a medium in which water moves freely. Sand may be a source of abundant underground water, or it may be a means of rapid drainage of the surface through its capacity to absorb and transmit water. (See Chapter V.)

A well-packed dry sand is a very good foundation material up to certain limits, provided that the sand is retained in a manner to prevent running. A certain amount of water acts as a cement in sand, as is illustrated on a beach where the damp sand is firm under foot and the dry sand quite the contrary. Beyond a certain point, however, particularly if the sand contains a small amount of clay, water causes it to become very unstable. It is this water-saturated sand that is known as quicksand.

Unconsolidated sand makes a very poor road material and requires some type of surfacing. It affords, however, a very excellent foundation for roads that can be well drained, because of its solidity when packed and its excellent drainage capacity. (12)

It is very difficult to carry on trenching, shafting, or tunneling in sand that is dry or too wet. Damp sand with just the right consistency stands fairly well, although it requires careful watching and proper support. Dry sand requires very tight cribbing or lagging, as it will run through very small openings. If unsupported, dry sand seeks a natural slope of 21° to 37°. Quicksand is extremely difficult if not practically impossible to handle. It will flow through practically any opening that will permit the passage of water, and it behaves so much like a fluid that compressed-air methods of handling it may be necessary in subsurface work. It is obviously very advantageous to anticipate the presence of quicksand where subsurface work is to be done.

Sand is an essential constituent of most cement and concrete work, and a sharp sand having angular grains is preferable to a sand in which the grains are well rounded. Stream and glacial sands are in general sharper than beach or desert sands.

Sandstone.—By the infiltration of various cementing materials, of which calcium carbonate, silica, and iron oxide are the most common, unconsolidated sand is changed to sandstone. Light-colored sandstones formed by the cementation of sand consisting of mechanically disintegrated minerals of light-colored igneous rocks and hence rich in feldspar are called arkose. Dark-colored sandstones containing considerable quantities of ferromagnesian minerals are sometimes called graywacke. A good example of such a stone is the "bluestone" of New York and Pennsylvania, formerly very extensively used as a flagstone. Sandstones are commonly interbedded with shales or limestones.

Sandstone that has been intruded by a large mass of igneous rock becomes very dense and takes on a peculiar spotted appearance, owing to the great heat of the igneous rock and the gases and hot solutions it give off in cooling. (See p. 25.) This effect may extend only a few inches from the contact or may continue for many yards, the distance depending on the size and nature of the igneous mass.

Sandstone weathers to sand, and areas underlain by sandstone commonly have sandy soil.

The porosity of sandstone depends on the completeness of cementation and on the size of grain of the sand and ranges from slightly less than that of unconsolidated sand to only a small fraction of the volume of the rock. Sandstones, therefore, like unconsolidated sand, may afford plentiful supplies of underground water. They form the great reservoirs and conveyors of artesian water (see Chapter V) and also of petroleum and natural gas.

Sandstone layers some distance below the surface, if not saturated with water, may afford means of draining off surface water or even ponds and lakes: a drill hole is sunk to the standstone, and the water is allowed to run downward into it. This method of drainage is sometimes applicable to surface or underground excavations.

Water may be confined under pressure in sandstone layers that are overlain by other rocks impervious to water. When the overlying impervious layer is pierced in underground work the water may rush in with great rapidity from such a sandstone layer and prove very difficult to control. Where such conditions are suspected it is desirable to drill holes in advance of underground work so that preparations may be made to meet them. In sandstone beds that are not saturated with water and are underlain by less pervious rocks any water present will accumulate in the lower portions of the sandstone, such as the bottoms of depressions or folds. It is therefore of advantage in looking for underground water supply to ascertain the geologic structure of the sandstone. (See Chapter V.)

A solid sandstone "in place"—that is, in the place where it was formed—makes an excellent natural foundation for engineering structures. Well-cemented sandstones make good structural stone and, if of the proper texture, good paving blocks. Most sandstone is a very poor material for use in the form of crushed rock for road building unless other material is used for surfacing, as if used directly under traffic it is soon ground to sand.

Excavation in sandstone above the level of ground water involves chiefly the problem of the hardness of the rock, which varies greatly. Some sandstones are soft enough to be very easily worked and at the same time require little support. Other sandstones may be very hard and difficult to excavate. Hard sandstones are particularly destructive to drilling tools because of their abrasive properties.

Conglomerate.—A special type of sedimentary rock, consisting of pebbles of solid rock in a matrix of finer material, which may be sand, clay, mixtures of sand and clay, or carbonates, is called conglomerate. Conglomerate is really a cemented gravel, but it may contain rounded rock fragments of considerable size. It is usually a strong, tough rock, more difficult to excavate than sandstone or shale. Conglomerates weather to gravel. Many beds of conglomerate are relatively thin, although beds 100 feet thick occur and some conglomerates resulting from stream deposition are many hundreds of feet thick. If not too thoroughly cemented conglomerates make excellent road metal and railway ballast when crushed or when naturally weathered to gravel. Clean gravels, or those from which the clay is artificially washed, if the pebbles were derived from strong rocks, make good concrete.

In many places a bed of conglomerate occurs above an unconformity in a sedimentary series and is known as a basal conglomerate. (See p. 36.)

Quartzite.—Quartz sandstone that is so thoroughly and strongly cemented that it breaks directly through the sand grains rather than around them is called quartzite. The cement in such rock is usually quartz. Quartzites are very dense and hard—in fact, they are among the hardest of rocks. They have an extremely small porosity and consequently contain practically no water and are impervious to water. Their great hardness makes them resistant to rock decay and erosion, and thus quartzite usually forms topographic prominences.

Most quartzites are very ancient rocks and consequently occur mainly in series of rocks that have been folded. It is common, therefore, to find quartzite beds tilted to a considerable degree from the horizontal.

Because of its hardness and the consequent difficulty with which it is worked, quartzite is not particularly desirable for structural purposes. Crushed quartzite makes an excellent material for concrete or for road ballast. Because of its low cementing properties it is not a good surfacing material for roads, as a quartzite macadam has a tendency to "ravel" easily. Quartzite "in place," because of its great strength, makes an excellent natural foundation.

Surface or underground excavation in quartzite requires large amounts of explosives, and the rock is very difficult to drill.

Quartzites are commonly interbedded with slates or schists or marble.

Quartz schist.—Quartzites that have been subjected to very great pressures during the folding of rocks accompanying great earth movements may take on a laminated or schistose structure.(3, 4) The rock thus produced will break in thin slabs parallel to many little flat flakes of mica, which have been developed throughout the rock by the pressure. This rock, known as quartz schist, commonly occurs in comparatively thin layers or zones within larger masses of quartzite, and, like the quartzite, it is hard and dense. It breaks more easily than quartzite, however, and should be preferred if possible where excavation is necessary.

CLAY SERIES.

Clay.—Clay consists of the very fine grained products of rock decay. *Residual clays* are formed by the decay of the underlying rock. *Transported clays* have been carried from their place of origin, usually by water, less commonly by wind. The very small size of its grains causes clay to remain in suspension much more readily than sand and consequently to be transported more readily and farther. This difference accounts for the natural separation of sand and clay by the action of water and wind.

One of the principal constituents of clay is kaolin, a compound of aluminum oxide, silica, and water, but clay contains in addition fine-grained sand, oxides of iron, and many other very fine grained materials.

Mixtures of clay and sand or of clay and calcareous material in every conceivable proportion occur. Such mixtures are described as sandy, marly, or calcareous clays.

Some clays possess the property of plasticity in a high degree and are very sticky when wet. Other clayey material may be only slightly plastic.

Water containing much clay in suspension may be made clear by adding small amounts of common salt, alum, iron sulphate, or other salts, which cause the clay to settle rapidly. Mud discharged by rivers into the sea clears more quickly than that discharged into a body of fresh water.

Clay has a high porosity—that is, when saturated it contains a large percentage of water in the very fine pores between the grains. These openings are so small, however, that the water cannot circulate, and clay is therefore said to be relatively impervious to water. Even when saturated with water it does not afford a source of water supply, as the water will not run out of it. For the same reason a clay surface must be drained largely by means of surface drainage.

The imperviousness of clay may be turned to advantage by using clay as a lining for reservoirs excavated in porous material. A pit dug in sand or an excavation in sandstone can be rendered practically water-tight by "puddling" a sufficient amount of clay into the water and allowing it to settle and fill the pores, forming an impervious lining.

Some clay loses its coherence and plasticity on drying, and when it is wet again, after being dried, it quickly goes to semifluid nonplastic mud.

Clay in thick beds makes a natural foundation that is firm but more or less resilient. Clay has the property of yielding very gradually under heavy loads by plastic flow, even when quite dry, hence overloading should be avoided.

Clay is easily excavated by hand tools and stands very well in excavations or tunnels. In some clays it is possible to sink shafts and run tunnels without introducing artificial support.

In countries of abundant rainfall clay in its natural condition makes a very poor road material. Burned clay, however, makes a very good road surface. Clay roads that are not subjected to heavy traffic can be kept in good condition by proper and systematic dragging. Clay roads can be greatly improved by mixing sand with the clay. (12)

Loess.—In many parts of the world there are large deposits of very fine grained sandy clay which have been carried to their present positions by wind. This material is called loess. It has no planes of stratification and possesses the peculiar and characteristic property of breaking along vertical surfaces and of standing with vertical faces or cliffs where it is undercut by streams. Along railway cuts and river bluffs it stands in vertical walls with little tendency to slump or cave. (See Figure 1.)

Loess is soft and easily excavated and should make excellent material for trenches or other surface excavations because of its property of standing in vertical walls, but its resistance to high-explosive shell fire is low. Extensive systems of trenches in loess were used at the siege of Vicksburg in the Civil War.

Loess absorbs water readily and is not impervious like clay.

Shale.—By the natural processes of consolidation, due partly to packing or compression under the weight of overlying beds and partly to self-cementation, clay is converted into a soft rock called shale.

Shale is very fine grained and if not sandy is soft and smooth to the touch. It can be readily scratched and carved with a steel knife blade, and in this respect it differs from certain fine-grained igneous rocks with which it might be confused. Shale varies widely in color. It is commonly gray or bluish gray or buff but may be various shades of yellow, brown, and red. Weathered surfaces of shale may assume colors differing widely from the unaltered portions. Very dark shales are found, and some are black, owing to their content of carbonaceous matter.

Certain shales that contain a large amount of carbonaceous material of vegetable or animal origin yield an oil very similar to petroleum on distillation in retorts. Such shales, known as oil shales, constitute an important source of oil, and their utilization is rapidly increasing.

Shales occur interbedded with sandstone, chalk, and limestone.

At contacts with large masses of igneous rock shale is changed to a dense, hard, flinty rock called hornstone. Rocks with slaty cleavage are also developed at igneous contacts. (See "Slate," below.)

Shale may or may not have the property of splitting easily in a direction parallel to the bedding planes. Some shales soften readily under the action of water, but others, though no harder, may be practically unaffected by water. Shale exposed at the surface reverts to clay, and country underlain by shale commonly has a clay surface.

Shale in natural beds affords a good foundation for engineering structures if the safe bearing load is not exceeded. Like clay, the softer shales may yield under excessive load by slow plastic flow.

Shale, because of its softness and proneness to weather into clay, makes a very poor structural rock. It is useless as crushed rock for concrete. The softer shales make an undesirable road-building material because of their low crushing strength and their tendency to weather to clay. Some of the harder varieties of shale that do not weather easily make good road material and have desirable cementing qualities.

Shale is one of the easiest of the solid rocks to excavate because of its softness and its lack of abrasive material. Some shale can be excavated without blasting and stands very well in cuts, shafts, or tunnels.

Slate.—The continued induration of shale produces slate, a harder, denser material, which is much more resistant to weathering. Slate may or may not have the property known as *cleavage,* which permits it to be split into thin sheets. (3) Cleavage should not be confused with the property that some shales have of splitting into sheets, as shale splits only parallel to the original bedding planes, owing to the fact that it is deposited in layers, whereas slate splits in a direction independent of the original bedding planes. Slaty cleavage is a phenomenon produced by the great pressure or shearing action to which the rock has been subjected during differential movements accompanying great earth deformations. Some slate which has simply been compressed and thoroughly indurated may be perfectly massive and lack the capacity to split. (1, 3)

Slate is even more dense and impervious than shale. It commonly occurs in regions where the rocks have been folded, and in mapping geologic structure the planes of slaty cleavage should not be mistaken for bedding planes. The trend of the bed of slate may be at right angles to the direction of its cleavage.

Slate, like shale, weathers to clay, but it is much more resistant to weathering than shale.

Commonly slate is interbedded with the harder varieties of the other sedimentary rocks, such as quartzite and marble.

Slate makes a good natural foundation and has a higher bearing strength than shale. Except as roofing slate and for some other special uses it has no value as a structural material. Crushed slate is not adaped to concrete work because of the shape in which it breaks and its inherent weakness as compared with other rocks. Some slate makes a fairly good road metal, as it has fair binding qualities and does not revert to clay as rapidly as shale.

Slate requires blasting in subsurface work but is easily drilled.

Clay schist or phyllite.(5)—The continued induration of slate with intense compression and shearing produces clay schist or phyllite, a rock having the property of schistosity to a marked degree. (See "Quartz schist.") It is not suitable for concrete work but makes fair road material.

CARBONATE SERIES.

The carbonate sediments are so called because they consist principally of the carbonates of calcium and magnesium. As they are largely deposited on the sea bottom they are very seldom encountered in their unconsolidated form.

Marl.—The word marl is used somewhat loosely for a variety of deposits ranging widely in composition. In most marls the essential constituent is lime. This is derived chiefly from shells. There may be fresh-water or lake marl; marl derived from sea shells, as the extensive beds of the Atlantic Coastal Plain; clay or sand marl with only slight amounts of lime; glauconitic marl, etc. The material is usually soft enough to be worked by hand tools. It is often associated with beds of sand and clay.

Chalk.—When certain marine beds of calcareous ooze consisting chiefly of the remains of unicellular organisms are elevated and exposed at the surface in a partly cemented condition they form beds of a soft light-colored rock called chalk. This is a white or grayish fine-grained rock that has a considerable capacity to absorb water. It occurs prominently in northern France and forms the well-known Chalk Cliffs at Dover and along the French coast.(4) This chalk contains nodules and layers of a hard, dense, brittle rock called flint, which ranges in color from white to brown, red, and black. Other beds of chalk are relatively free from siliceous matter. Flint is very resistant to weathering and accumulates in the residual clay soil formed by the weathering of the chalk which contains the nodules. Flint-pebble beaches are found where chalk of this kind forms the shore rock.

Reddish clay soil of variable depth forms on the surface of some beds of chalk. This clay represents the insoluble clayey impurities of the chalk and may contain many flint nodules. In northern France this residual clay occurs on the slopes, the more nearly level areas being covered with a fine clay loam.(13)

Chalk is easily excavated and forms admirable material for trenching, shafting, and tunneling. In natural beds it is capable of supporting great weight, but owing to its friability, particular care must be taken in building on it to secure good anchorage for any structure subjected to shock. Chalk is obviously not adapted to concrete work and is not a good road material, though better than clay. The flint from weathered chalk is used for road metal.

Limestone.—Limestone is formed by the hardening and consolidation of chalk, shell marl, and living matter in other forms. It is harder than shale but can be scratched, though not carved, with a steel knife blade. Some limestones exhibit shiny reflecting faces of the mineral calcite (calcium carbonate). Limestone may be distinguished from quartzite and from some light-colored igneous rocks with which it may be confused by the fact that the other rocks cannot be scratched with a knife blade. When hydrochloric acid is dropped on limestone a chemical reaction takes place, with the evolution of carbonic acid gas, which causes the acid to bubble violently. Dolomite, a variety of limestone containing much magnesium carbonate, is not acted on by cold acid but is easily attacked if the acid is hot. The reaction with acid is a common test for limestone.

Some limestones break with a characteristic smooth curved fracture, called conchoidal fracture. Others break with more or less angular fracture. Shells and other fossils are common in limestone. Limestone is usually light colored in various shades of gray to brown, but some limestone that has a considerable content of organic material is very dark. Limestone grades into sandstone and also into shale, and the transition varieties are called sandy limestone and shaly limestone.

Many limestones contain in varying abundance nodules, lenses, and layers or beds of a hard, dense siliceous rock called chert. Chert is essentially like the flint found in chalk; it is resistant to weathering, is hard to drill, and if abundant imposes difficulties in excavation.

Limestone weathers by solution of the calcium and magnesium carbonates. The impurities accumulate as residual clay, which is commonly reddish in color and contains residual nodules of chert and unweathered masses of the more impervious parts. (See Figure 3.) Where the level of ground water is some distance below the surface great caverns are formed in limestone by solution. (See Figure 45.) They are the channels of underground streams, and some of them extend for miles beneath the surface, as in Mammonth Cave. The roofs of some caverns break through, forming "sink holes" at the surface. (See Figure 18.) Caverns are common in limestone countries and may have considerable military value.

At contacts with intrusive igneous rock limestone is altered to hard siliceous rocks of various kinds. (See p. 25.) Because of its solubility it is particularly susceptible to alteration by the hot solutions from the igneous rock. Many valuable ore deposits occur in limestone at intrusive igneous contacts.

Limestone is heated in kilns to make quicklime, which is used in plaster and mortar. The heat drives off the carbon dioxide (CO_2), leaving calcium oxide (CaO), commonly called lime.

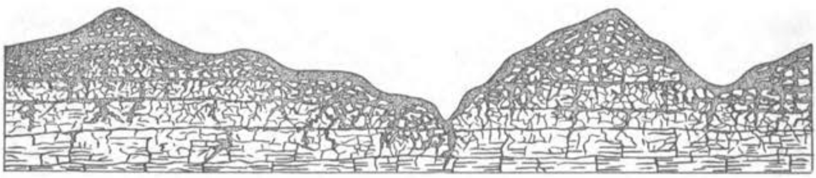

FIGURE 3. Diagram illustrating the relation of residual soil to the underlying rock from which it is derived, showing the completely decomposed rock at the surface, partly decomposed limestone beneath, and the weathering along joints in the undecomposed limestone below. (After W. C. Alden, U. S. Geol. Survey.)

Limestone is a strong rock and affords excellent natural foundations. It is quarried on a large scale as building stone. As crushed rock the hard varieties make excellent material for concrete. Crushed limestone is largely used as road metal in the absence of better material. It has good cementing properties but poor wearing qualities and does not stand up well under heavy traffic.

The underground streams in limestone regions may afford means of water supply or of drainage. The porous zones of certain limestones carry considerable water, which may be obtained by wells. (See Chapter V.)

Limestone is harder than shale and requires blasting, and consequently underground operations are more difficult in this rock than in shale or soft sandstone.

Marble.—Marble is produced by the further induration of limestone. It is a firm, dense rock, made up of many small crystals of calcite. Marble is too dense to contain available water. It is rather more difficult to work than limestone. It is usually found in regions of folded rocks in association with quartzite and slate.

DEPOSITS FORMED BY GLACIERS.

In their slow movement over the earth's surface glaciers effect certain characteristic types of erosion and produce deposits of the eroded material that are so distinctive in constitution and form as to merit special attention. The erosive action of glaciers is discussed in this text in Chapter VI. The present discussion is concerned with the nature of the materials deposited by glaciers.

The outstanding difference between glacial deposits and deposits laid down by water is that glaciers do less sorting of the rock material which they work over and transport. Glacial material that has not subsequently been worked over by streams lacks the stratification so characteristic of water-deposited material and is a heterogeneous mixture of the rock and earth materials torn from the bottom and sides of the glacial bed and caught on the surface of the glacier from rock falls and slides. It usually contains rounded rock boulders ranging in size from small pebbles to huge masses of many tons. These boulders are embedded in a matrix, which may consist of clay, sand, gravel, or partly decayed rock, derived from softer materials over which the glacier has passed. Such material is called *till*.

The deposits laid down by continental glaciers are widespread. They may cover thousands of square miles to depths ranging from a few feet to 100 feet or more. Glacial till characteristically contains in large proportion the assorted and stratified deposits of glacial lakes and streams, which consist of sand, clay, and gravel.

Glacial deposits bear no relation to the underlying solid rock, as they have all been transported greater or less distances. In general glacial till consists of sand, gravel, or clay or various mixtures of these materials, and the discussion of the physical properties and behavior of these types may be applied to any particular deposit as its composition indicates.

Surface and subsurface excavation in glacial till presents much the same problems as similar excavation in unconsolidated sedimentary material, with the additional element of included boulders, which may be large and numerous enough to cause difficulty.

The permeability of till to water depends in a large measure on its clay content. The beds of gravel and sand found in many glacial deposits may be water-bearing and constitute a source of local water supply, which can be procured by means of relatively shallow wells. The size and distribution of these sand and gravel beds, however, are extremely erratic.

The beds of gravel in glacial deposits afford excellent road metal and railway ballast. Glacial sands are in general sharp and angular and very desirable for cement and concrete work. Some glacial gravels make an excellent concrete material in place of crushed rock.

COAL SERIES.

Peat.—In regions of abundant vegetation plant remains may accumulate in large amounts over considerable areas, particularly where the material is submerged in water, which prevents its loss by oxidation. Peat beds are developed in this manner and are commonly found in flat, poorly drained areas such as marshes and swamps. Many of them represent the accumulation of plant remains in old lakes. Peat is in many places underlain by marl.

When dry, peat may be used as fuel. In some localities, especially in Europe, it is compressed by machinery into hard, dense briquets and used for fuel in this form. Many minor uses have been found for it, such as in the manufacture of cardboard and coarse paper and recently in making a surgical dressing for use in the army.

Peat is highly absorbent, having a very high porosity. It commonly occurs in localities where the ground-water level comes to the surface, and consequently the problems of excavation in peat are largely problems of dealing with abundant ground water. Where peat beds have been drained the material can easily be excavated and stands very well in vertical walls. It is soft and weak and would have little resisting power against artillery.

Peat beds are as a rule not thick enough to be encountered in subsurface operations, but in some places, as along the Atlantic coast, peat occurs in beds 75 to 100 feet underground.

Peat and marl beds in swamps and old lake beds offer serious difficulties to railroad construction. These materials are very weak and when saturated with water have little supporting power. They flow out from under railroad embankments or fills and rise in great ridges on either side. If the beds are not too deep piles can be driven into them for support. On a peat deposit too deep for piles it may be possible to support a railroad bed on a brush mattress covered with earth and built wide enough to distribute the load. (See Chapter IV.)

Coal.—Coal beds are old buried peat beds. Coal is developed from peat through the physical and chemical changes due to pressure, heat, and other causes when sediments are deposited above the peat.

Coal is found in varieties representing a practically continuous series both in physical properties and composition from peat to hard coal or anthracite. Coal is an important war mineral. (See Chapter VIII.) It usually occurs in comparatively thin beds interstratified with shale, limestone, or sandstone and is seldom encountered in surface or subsurface excavation, except in coal mining.

IGNEOUS ROCKS.

ORIGIN AND NATURE.

Igneous rocks have their origin in the solidification of molten rock material which has been forced upward through the outer portion of the earth from sources at considerable depth. This molten material finds its way upward through fissures or along planes of weakness and may cool and solidify before reaching the surface, or the molten material may actually flow out upon the surface. Igneous rocks may thus be simply classified in two groups—those which have solidified within the earth, called *intrusive* or plutonic rocks, and those which have solidified at the surface, called *extrusive* or volcanic rocks. (The characteristic structural forms assumed by igneous rocks are discussed on pp. 24 to 27.)

Igneous rocks differ widely in texture and composition. Their color, hardness, ease or difficulty of excavation, weathering, and other properties are more or less closely related to their composition and texture. There is also some relation between the texture and composition of an igneous rock and the manner and form in which it occurs.

Igneous rocks are not homogeneous in composition like glass or porcelain but are made up of small crystalline minerals. A comparatively small group of minerals in various combinations make up the many varieties of igneous rocks. Each mineral has a definite chemical composition and definite chemical properties and is of essentially the same nature regardless of where or how it occurs.

MINERALS OF IGNEOUS ROCKS.(7, 14)

For present purposes igneous rocks can be considered as being made up of the four minerals or groups of minerals described below.

1. Quartz, a colorless mineral, is the oxide of silicon (SiO_2). It is glassy in appearance and like glass it always breaks with an uneven glassy fracture and not with a flat surface—that is, it has no cleavage.

It is harder than a knife blade and will scratch glass, and it can be distinguished from glass by its greater hardness.

2. Feldspar, which occurs in several varieties, all of similar appearance, is the most abundant mineral of igneous rocks, making up over 50 per cent of the average igneous rock. Feldspars are compounds of silica, alumina, and various proportions of potassium, sodium, and calcium oxides. They are for the most part light in color—white or various shades of brownish yellow, reddish, or gray—but some feldspars are dark. They have a well-defined cleavage and always break with flat shiny planes, but they do not split into thin flakes like mica. They are harder than a knife blade, will not scratch glass, and can be scratched by quartz.

3. The ferromagnesian minerals form a large group, most of which are dark colored, commonly greenish or black. For the most part they are not as hard as feldspar and can be scratched with a knife blade, though not without difficulty. They are heavier than quartz and feldspar. They are various compounds of silica, iron, and magnesium, with small amounts of alumina, lime, potash, and soda. The term ferromagnesian minerals is applied to them because they always contain iron or magnesia, or both.

4. Mica is an easily recognized mineral because of its characteristic very well developed cleavage. It can be split into the thinnest of flexible flakes and splits in only one direction. There are two principal varieties of mica—the light-colored variety, called muscovite, and the common dark-colored variety, called biotite. Biotite is in fact one of the ferromagnesian minerals.

In addition to the minerals above described there are always present in igneous rocks certain very minute minerals called accessory minerals, which are usually hard and resistant to weathering. These minerals may be of great importance in the technical description and investigation of rocks, but they can commonly be seen only under the microscope.

TEXTURE OF IGNEOUS ROCKS. (7)

There is a rather wide variation in the texture of igneous rocks, and many technical terms are used in describing it. In the present discussion it is sufficient to describe the texture in non-technical terms on the basis of size of grain, with additional descriptive terms when other textural features are to be indicated.

The size of grain of an igneous rock is determined by the size of the mineral particles which make up the rock. Certain volcanic rocks were chilled from the molten state so suddenly that not sufficient time elapsed in the cooling for minerals to crystallize, and a natural rock glass resulted. The texture of such rock is descriptively termed glassy.

Slightly less rapid cooling results in a rock made up of extremely minute mineral particles, which cannot be separately seen without a lens. A rock of this texture may be described as extremely fine grained.

Under certain conditions igneous rocks are developed which are for the most part extremely fine grained but which contain many prominent large minerals, like raisins in a cake. This texture is called porphyritic and the rock is called a porphyry, with sufficient additional descriptive terms to identify the kind of porphyry in terms of color and the nature of the groundmass (the fine-grained part) or of the larger crystal individuals.

A very common textural type is that of a rock in which the mineral particles are fairly uniform in size and large enough to be plainly discernible, of which ordinary granite is a good illustration. This texture is commonly called granitic. There are rocks with fine, medium, coarse, and very coarse granitic textures.

An igneous rock in which the light and dark minerals are segregated into alternate layers or bands, giving the rock a banded appearance, is called a gneiss, and the texture is called gneissic. Some gneiss is really sedimentary rock intensely altered by heat and pressure. Many gneisses are granitic rocks.

A very much coarser texture, in which the minerals are present as very large crystals measuring several inches or even a foot or more across, is found in a rock called pegmatite, which occurs in dikes or veins.

The surfaces of lava flows are usually filled with many small bubble-like cavities like the blow holes in poor iron or steel castings. This texture is termed cellular or vesicular. If the openings are filled with mineral matter the texture is called amygdaloidal.

IGNEOUS ROCKS DESCRIBED BY COLOR AND TEXTURE.

The fact that quartz and feldspar are for the most part light-colored and the ferromagnesian minerals dark-colored permits a broad differentiation of igneous rocks into light-colored rocks, in which ferromagnesian minerals are minor in amount, and dark-colored rocks, in which ferromagnesian minerals are abundant.

Because of this close relation between color and mineral composition it is sufficient for practical engineering purposes to describe an igneous rock accurately in terms of texture, hardness, and color, as this will give to a geologist sufficient information to enable him to form a fairly good idea of the nature of the rock. It is desirable, however, if possible to classify a rock more definitely by actually noting the minerals present.

GLOSSARY OF IGNEOUS ROCK TERMS.

As igneous rocks are designated in geologic maps and reports by technical names, a glossary of terms applied to the common igneous rocks is given below.

Acidic, acid, a descriptive term applied to rocks containing over 65 per cent. of silica. These rocks are usually light colored. (See Basic.)

Amygdaloid, cellular lava, igneous rock of fine texture with cavities, usually containing mineral matter deposited by underground water subsequent to the cooling of the rock.

Andesite, a volcanic rock, light to medium in color, usually porphyritic, with crystals of feldspar and ferromagnesian minerals.

Anorthite, anorthosite, gabbro composed wholly of dark feldspar.

Aplite, a very fine grained granite, usually occurring in dikes.

Basalt, a fine-grained dark to black igneous rock, usually a lava.

Basic, a descriptive term applied to rocks containing less than 65 per cent of silica. These rocks are usually dark colored. (See Acidic.)

Diabase, a variety of gabbro having long, narrow crystals of light-colored feldspar.

Diorite, a medium to coarse-grained rather light colored igneous rock that resembles granite but is darker and has less or no quartz and more ferromagnesian minerals.

Dolerite, a dark igneous rock intermediate in texture between gabbro and basalt.

Dunite, a rather rare coarsely crystalline green rock, composed of the mineral olivine.

Felsite, a very fine grained light-colored igneous rock.

Gabbro, a dark igneous rock of coarsely granitic texture.

Gneiss, a rock resembling granite in appearance but having more or less parallel bands of alternating light and dark color. Gneisses may be either igneous rocks or highly altered sedimentary rocks.

Granite, a light-colored medium to coarse grained igneous rock containing quartz and feldspar with small amounts of ferromagnesian minerals or mica. The colors range from white to gray; some varieties are pink to red.

Granite porphyry, a very coarse porphyry in which the groundmass is granite.

Granitoid, a term applied to rocks resembling granite.

Granodiorite, a granite resembling diorite, having a large amount of dark ferromagnesian minerals.

Latite, a light-colored fine-grained or porphyritic lava.

Minette, a variety of granite with no quartz and much mica, usually dark colored.
Norite, a variety of gabbro.
Obsidian, volcanic glass.
Pegmatite, a very coarse granite, usually occurring in dikes.
Peridotite, a very dark gabbro composed wholly of ferromagnesian minerals.
Phonolite, a variety of light-colored porphyry.
Porphyrite, a light-colored porphyry usually occurring in dikes or sheets.
Porphyry, an igneous rock in which the crystals of certain minerals are larger than the fine-grained or glassy matrix in which they are set.
Pumice, an excessively cellular glassy lava.
Pyroxenite, a variety of gabbro consisting wholly of the mineral pyroxene.
Retinite, a French term for volcanic glass.
Rhyolite, a light-colored porphyry in which quartz is abundant, sometimes called quartz porphyry.
Syenite, a granite lacking quartz.
Trachyte, a light-colored igneous rock, either fine grained or porphyritic.
Trap, any dark-colored igneous rock, especially those of fine grain.
Tuff, fragmental volcanic material more or less arranged by water or wind and hardened into rock.

LAND SURFACES UNDERLAIN BY IGNEOUS ROCK.

Igneous rocks in their unaltered condition, with the exception of certain volcanic rocks, are hard and solid. Where unaltered igneous rock forms the land surface or is covered only with a thin veneer of soil, surface or subsurface excavations require the usual hard-rock methods of drilling and blasting. All the types of igneous rocks, whether light-colored or dark-colored, require essentially the same treatment, except that they vary in hardness and ease of drilling and require varying amounts of explosive for the same amount of material removed.

In general the dark-colored rocks decay or weather more rapidly than the light-colored rocks. It is usually but not always true that under similar conditions a thicker mantle of decaying rock is found over dark-colored igneous rocks than over the light-colored varieties.

Dark igneous dikes in granite may be weathered to some depth and the adjoining granite may be unaltered. This difference may on occasion afford advantageous locations for trenches or even for dugouts.

Igneous rocks are always more or less jointed—that is, they are crossed by sets of natural fractures which assist greatly in the removal of the rock. They may also have a natural grain or rift which is independent of these joints and which causes the rock to break more readily in certain directions than in others. This natural grain and the joints should be considered in laying out underground work, so that the walls and roof of the openings may be parallel to the direction in which the rock is most easily broken.

The solid surface of igneous rocks, because of their hardness, is very resistant to shell fire, but, being brittle, the rock so far as it is affected is broken into sharp, angular fragments which are distributed by the explosive with damaging effect. Solid rock is practically incapable of absorbing any of the force of shell explosions, and consequently the zone of damage in such rock is wider than over soft earth surfaces.

Mining operations in solid igneous rock can not be conducted noiselessly, because of the need of drilling and blasting.

SURFACES OVER WEATHERED IGNEOUS ROCK.

In dry climates, in the absence of abundant vegetation, igneous rocks are disintegrated without appreciable chemical decay to coarse-grained material made up of rock and mineral fragments, somewhat resembling coarse sand or fine gravel and usually containing rounded boulders of the original rock. (See Figure 2.) In such material surface excavation may be conducted without explosives. Like sand or gravel, the material has a tendency to run, especially where dry, and may require more or less support. If this disintegrated material is deep enough underground excavations can be made in it by using sufficient support. Being angular, the material does not run as readily as sand and has to a slight extent the property of forming an arch, particularly when damp. Disintegrated igneous rock commonly forms on steep slopes and may wash down and accumulate to a considerable depth in valleys and at the bases of mountains. If the débris is very old and saturated with water the constituent minerals may have been sufficiently altered to clay to give a considerable degree of coherence to the rock. This material should have considerable shock-absorbing ability, and although shell fire would probably form large craters in it the material would be distributed in finely divided form that would cause little or no damage.

In regions of abundant rainfall and vegetation igneous rocks are altered by disintegration and the decomposing action of the ground and surface water. The surface mantle of residual decayed rock consists of clay with fragments of minerals which have escaped or resisted decomposition. The depth of the weathered material depends on the rate of weathering and the rate of removal of the decayed rock by erosion. Decayed rock does not have an opportunity to accumulate on steep slopes. It is found to greatest depths in areas of slight relief, or in depressions. It is known to range from a few inches to 100 feet or even more in depth, but depths of over 50 feet are unusual. The surface of contact between the decayed rock and the solid rock is liable to be extremely uneven, owing to the local uneven rates of decay.

Surface excavations in decayed igneous rock are easily made. The material will stand without support in deep trenches or pits. Underground work in such material is limited by the depth of rock decay, and in running tunnels the depth of decay should obviously be tested in advance if possible. Tunnels near the lower limit of decay are very liable to encounter solid masses of unaltered rock.

Igneous rocks, particularly the dark-colored varieties, make excellent material in the form of crushed rock for road ballast and surfacing. Practically all igneous rocks make good concrete material, although it is difficult to crush some of the harder varieties. Disintegrated igneous rock makes excellent road metal or ballast. Thoroughly decomposed rock, because of its high content of clay, is not a good road-making material.

ROCK STRUCTURE.

Engineering and military operations deal with rocks at and beneath the surface, and the efficient conduct of such operations requires knowledge or forecasting of conditions. Actual observations of conditions beneath the surface is impossible except to a very slight extent in excavations and by means of drill holes. In fact, even much of the surface is obscured by vegetation and soil. Knowledge of both surface and underground distribution of rocks, therefore, is dependent on observations made at isolated points, and it is necessary to construct in imagination the conditions existing in the concealed portions. In order to do this with any degree of accuracy, it is plainly essential to know something of the manner of occurrence, form, and attitude of rocks. The branch of geology which deals with these subjects is called structural geology.

FORMS IN WHICH SEDIMENTARY ROCKS OCCUR. (1, 2)

The most characteristic feature of sedimentary rocks is the parallel arrangement produced by deposition in layers. (See Figure 6.) The individual layers may be very thin or may be measured in feet, and the rocks may be described accordingly as thin bedded or thick bedded. Very thick bedded rocks are termed massive. Layers are probably due to differences in the rate of deposition, produced by storms, tides, seasonal changes, and other causes. Although the original sediments were laid down in practically horizontal position beds of sedimentary rocks are not everywhere horizontal but may be tilted at various angles by earth movements. (See "Structural features.")

A prominent bed of one kind of rock between rocks of other kinds is called a stratum or formation and may range from a few feet to hundreds of feet in thickness. One variety of sedimentary rock may grade into another variety. Beds may be lenticular, gradually becoming thinner and giving place to overlapping lenses of other beds. Some beds of sandstone are made up of many inclined layers which terminate against surfaces of other beds that lie at different angles. This arrangement is termed false or cross bedding (see Figure 4) and is characteristic of beds of sand deposited by wave or stream currents or by wind. Cross-bedded rocks should not be confused with bedded rocks that have been tilted.

FORMS ASSUMED BY IGNEOUS ROCKS. (1, 2, 7)

Intrusive igneous rocks may occur at or near the surface in large masses thousands of feet or even miles in extent or in comparatively small sheetlike bodies which have solidified in fissures or been forced between the layers of sedimentary rocks.

Dikes and sheets.—A dike is a mass of igneous rock which has solidified in a fissure in other rocks. At the surface a dike of igneous rock appears as a long, narrow strip, but there may be no surface evidence indicating the presence of a dike beneath. If the dike rock is harder and more resistant to erosion than the surrounding rocks, it may appear as a ridge or series of prominences. If it is softer than the surrounding rocks and more easily attacked by the agencies of decay, it may be marked by a depression at the surface. Dikes range in thickness from a few inches to 100 feet or more but are as a rule comparatively thin.

Because of their small thickness, dikes commonly do not afford an important source of rock for structural purposes or road building. If they are harder than the inclosing rocks their presence may be a hindrance in trenching and a greater hindrance in tunneling. Dikes that are decayed and altered to easily workable, soft clayey material may in some places be chosen as sites for excavation.

It is important that the presence and nature of dikes be recognized in advance so that means may be devised for dealing with them. In tunneling it is possible to determine the thickness of a dike by boring through it with percussion drills or diamond drills. When a dike of hard rock is encountered in tunneling in softer rock the amount of excavation in the dike rock may be reduced to a minimum by passing through the dike at right angles, changing the direction of the tunnel if necessary, unless other considerations preclude a change. A deeply weathered dike in hard rock may afford a place for easy shafting or tunneling, although the direction and extent of such work are limited by the size and direction of the dike.

Dikes, whether in their original condition or altered to clayey material, are impervious to the passage of ground water, unless they are broken or faulted, and consequently an increasing amount of water may be expected in water-bearing beds that adjoin them, particularly where these beds are inclined downward toward the dikes. In penetrating inclined dikes heavy flows of water may be found above them.

A large dike if not decayed too deeply may afford a desirable firm foundation for small heavy structures. A dike of sufficient thickness, whether decayed or solid, even in rocks carrying a large amount of ground water, may afford a location in which a shaft may be put down without encountering much water, because of the imperviousness of the dike rock.

Tabular forms produced by molten rock material which has been forced between the layers of bedded rocks and there solidified are called sheets or sills. Sheets differ from dikes in that they are parallel to the bedding planes of the intruded rock, whereas dikes follow fissures that cross the bedding planes. Sheets range from a few inches to several hundred feet or even more in thickness and may extend over considerable areas. The intrusive material forming the sheets may in places break across the bedding of the intruded rocks and continue at another level. Material from the mass forming the sheet may also be forced into adjacent fissures in the form of dikes. Here and there a succession of sheets occur in a single series of bedded rocks, layers of which separate the sheets.

Sheets may be confused with surface lava flows which have later been buried by sedimentary material. They can usually be distinguished from flows by the presence of heat effects in the overlying beds, by offshoots intruded into overlying beds, by the failure of the sheets to follow a definite position in the sedimentary series, by the absence from their upper surfaces of evidences of surface weathering, by the absence in the adjoining beds of tuffaceous material, and by the absence of the amygdaloidal texture characteristic of the upper surfaces of flows. Moreover, blocks of rock from the overlying beds are frequently found embedded in the upper portions of sheets. (See discussion of "Lava flows," below.)

Sheets that have been tilted into more or less steeply inclined positions by earth movements have much the same engineering significance as dikes. In their natural horizontal position sheets may be of great thickness and cover large areas. The Palisades of the Hudson were formed by a sheet that crops out for a distance of 70 miles from north to south and ranges from 300 to 850 feet in thickness.

Sheets that are exposed at the surface or occur just beneath the soil may be a serious handicap to trenching or surface excavation unless they are weathered or decayed to sufficient depth. They may afford a good source of rock for road building. If a sheet is not too thick tunneling operations may be carried on in softer rocks beneath it, if such rocks exist, but plainly its thickness must first be tested by drilling. The presence of sheets beneath the surface should be ascertained in advance of underground work. The impervious nature of sheets, unless they have been badly shattered or broken by earth movements, makes them an effective barrier to ground-water circulation. Water may be found under artesian conditions (Chapter V) in water-bearing rocks beneath an impervious sheet, or water may be confined to porous rocks that lie above a sheet even though the rocks beneath the sheet have a much larger water content.

Large masses of intrusive igneous rock.—Intrusive igneous rock may occur in large masses measuring tens, hundreds, or thousands of square miles. Such masses are called laccoliths, batholiths, stocks, or necks, the term depending on their manner of occurrence. A laccolith is an exaggerated sheet which has forced the overlying beds up into a dome-shaped form. A batholith is an immense mass of intrusive rock which has melted its way upward through the overlying rocks. It may occupy hundreds or thousands of square miles. A boss or stock may be a small batholith or the protruding smaller portion of a batholith. A volcanic neck is a mass of igneous rock solidified in the throat of an ancient volcano. Any of these masses may be exposed at the surface by erosion of the overlying or adjacent rocks. (1, 2, 7)

Lava flows.—The outpouring of molten rock or lava at the surface from volcanic vents or fissures produces lava flows ranging in size from those covering relatively small areas to great flows many square miles in extent and in thickness from a few feet to 100 feet or more. A series of flows one above another but not necessarily coextensive may be formed by successive outpourings of lava. (See Figure 5.) These flows may be separated by volcanic sediments (see below) or by normal sediments.

Lava flows that have been buried by the deposition of other rocks may be mistaken for intrusive sheets, but they can usually be identified by their characteristic surface structure and their relation to the overlying beds. (See "Dikes and sheets.")

Lava flows that are not too thin afford firm foundations for engineering structures. Investigation should be made to guard against building on a thin layer of solid rock underlain by a bed of softer material. Crushed lava rock is a very good material for road building. It is commonly called trap rock. The cellular or vesicular zones of lava flows (see p. 19) may contain water and if of sufficient size and extent may afford a source of water supply. Lava rock presents the difficulties to subsurface excavation usually imposed by any solid igneous rock. Advantage may be taken, however, of interstratified layers of softer fragmental material between the flows.

Volcanic sediments.—During violent volcanic eruptions large volumes of volcanic ash, pumice, and other débris may be ejected and deposited over the surrounding country. The very fine volcanic dust and ash may be carried for many miles and deposited as a thin layer of material which can with difficulty be distinguished from sediments of normal types. The coarser material is deposited nearer to its source and is more readily recognized as of volcanic origin. By the natural processes of consolidation and sedimentation this fragmental material is converted into more or less solid rock. It may be worked over by running water, deposited as extensive beds, and thus made to resemble sedimentary material of other than volcanic origin.

The fragmental volcanic rocks are generally very porous, and if ground water is present they may afford a source of abundant supply. They range from soft rock that is easily excavated to thoroughly cemented hard rock. It is therefore plainly of importance in volcanic areas to have detailed maps of the rocks in advance of engineering operations.

MINOR STRUCTURAL FEATURES OF ROCKS.

Stratification.—The surfaces between layers of sedimentary rocks are in general planes of weakness along which the rock separates more or less readily. This property of parting parallel to the original bedding is best developed in shales, but it is also possessed in varying degrees by sandstones and limestones. The planes of easy parting may be very close together, or individual layers of limestone or sandstone may be several feet in thickness. Thick layers of bedded rock, although showing no lamination, may break more readily in a direction parallel to the bedding. This property is called rift or grain.

Bedded rock is generally stronger under compression transverse to the bedding than parallel to it, and blocks used in masonry should be placed with the bedding planes horizontal. The harder, completely indurated sedimentary rocks—quartzite, slate, marble, and schist—rarely have the property of parting parallel to the bedding planes, as the processes of induration cement the layers together and may more or less completely obscure them.

The stratification of sedimentary rocks (except in the harder varieties just mentioned) is of importance in surface and underground excavations. Bedding planes afford excellent natural surfaces to break to in blasting. Underground work should if possible be planned so that these natural planes of parting form the floor or roof, or both, of an opening. The depth and grouping of holes for blasting should be determined with regard to the bedding of the rock. Thin-bedded rock in the roofs of tunnels and chambers is liable to come down in slabs and generally requires props.

Joints.—All solid rocks have more or less numerous natural partings called joints. (See Figure 6.) Joints are actual breaks along which the rock is more or less readily separated. They may be open cracks, called "free joints," or they may be more or less firmly cemented "tight joints." A wide open joint is called a fissure.

The spacing of joints varies irrespective of the nature of the rock. They may occur at intervals of a few inches or of several feet or yards. The spacing of joints determines the size of blocks which can be obtained in quarrying—an important consideration where large blocks are required.

Joints have been caused by the breaking of the rock, by earth movements, or by shrinkage due to drying of sediments or cooling of igneous rocks.

Joints afford means of entry of ground water into a rock, and rock decay operates along and outward from joint cracks. Jointing is usually accentuated in natural rock exposures by such alteration.

In massive igneous rocks it is common to find three directions of jointing perpendicular to one another by virtue of which the rock breaks into more or less irregular rectangular blocks. A fourth direction causes the development of wedge-shaped blocks. In granite quarries prominent horizontal joints are common. (See Figure 7.) The rock between these horizontal joint planes is called a "sheet" by the quarrymen, and closely spaced horizontal joints produce what is called sheeted structure. The size of joint blocks plainly depends on the spacing of the joint planes. A well-jointed rock with rather closely spaced joints is much easier to excavate than one with poorly developed and widely spaced joint planes, and excavation should be planned in a manner to take advantage of the natural breaks. The direction, depth, and grouping of holes drilled for blasting should be largely determined by the jointing. A tunnel driven parallel to the principal joint systems may be so handled as to have joint planes for the walls and for the top or bottom, or both. A tunnel driven at an angle to the jointing would have many re-entrant angles on the joint surfaces and would be much more difficult to excavate than one properly located.

Certain lava flows have a characteristic columnar jointing by which the rock breaks into long prismatic columns. (See Figure 8.) Jointing of this type is believed to be due to the stresses set up in the rock during the cooling.

Igneous rocks commonly have a grain or rift which permits the rock to be broken more readily in one or more directions, generally parallel to the jointing. This quality is independent of jointing and differs from jointing in that the joints are actual fractures, whereas the rift is merely the property of breaking more readily in certain directions.

Sedimentary rocks may have the property of parting parallel to the bedding planes, which are planes of natural weakness. Most shales and some sandstones and limestones, particularly the shaly varieties, break in that manner. A limestone that parts in thin slabs parallel to the bedding is said to be "flaggy."

Solid sedimentary rocks commonly have two directions of jointing, usually at right angles and perpendicular to the bedding. A rock that has only one set of joint planes breaks in rectangular blocks. A rock that has more than one set breaks into angular or wedge-shaped blocks. Excavations in sedimentary rocks, as in igneous rocks, should be planned to take advantage of the natural joint planes. Sedimentary rocks that are closely jointed are more easily excavated than those having widely separated joints.

Some sedimentary rocks have a grain or rift independent of the jointing, similar to that of igneous rocks.

Cleavage or schistosity.(3)—The property possessed by some rocks of splitting in certain definite directions is known as cleavage or schistosity. Cleavage should not be confused with the original lamination of sedimentary rocks. It may parallel the bedding but generally crosses the bedding. (See "Slate," p. 11.) It differs from jointing in that joints are definite breaks at intervals, whereas cleavage gives the rock the property of breaking in parallel planes at all points throughout its mass. A fragment of schistose rock can be broken into smaller and smaller fragments, each time breaking in a certain definite direction parallel to the planes of schistosity. This property is well exemplified in ordinary roofing slate. Cleavage resembles rift or grain but is much more prominent. The property of cleavage in rock is due to the parallel arrangement throughout the rock of certain flat, platy minerals, which can usually be seen to glitter in reflected light on the surface of a cleavage break.

Rocks may possess both jointing and cleavage. In fact, a schistose rock always has joint planes. The planning of excavations in schistose rocks should if possible take into account the direction of cleavage. For obvious reasons it is much easier to tunnel in the direction of the cleavage than at an angle to it.

Veins.—Veins are formed by the filling of cracks or fissures in rocks with mineral matter deposited from solution by water. (See Figure 9.) They are more or less abundant in all rocks and vary greatly in size and composition. Veins are particularly abundant near intrusive masses of igneous rock. Many of them contain valuable ores.

Veins are of small importance in engineering or military geology, though wide veins of hard minerals, such as quartz, inclosed in softer rocks may offer some difficulties in excavation.

EARTH MOVEMENTS. (1, 3)

The outer shell of the earth has not been stable and motionless throughout geologic time. It has undergone vast movements and deformation, the geologic evidences of which are very clear. Some portions of the surface have subsided and others have been elevated, not only once but many times. These movements took place very gradually; in fact, such movements are going on at the present time. The Atlantic coast of the United States is slowly subsiding. The continuation of the submerged valley of Hudson River can be traced for many miles on the sea bottom.

Series of strata of sedimentary rocks, originally horizontal, are now found deformed into great arches and troughs called folds, showing that tremendous lateral compressive forces have crumpled the rocks together.

Beds of rock once continuous are found displaced along planes of fracture. These displacements are called faults and show movements ranging from a few inches to thousands of feet. In some places portions of the rock beds have been forced up along gently inclined fault planes and have overridden the underlying rocks for several miles.

Earthquakes are sudden tremors or vibrations of the earth's surface, which may be accompanied by more or less uplift, subsidence, or faulting. Earthquake vibrations may range from feeble tremors that can be detected only with delicate instruments to violent shocks that are very destructive. Earthquakes are due to sudden fracturing or faulting of the rock strata. They occur frequently in regions of active volcanoes, where they are probably due to readjustments in the earth related to the outpouring of lava. Earthquakes also occur in regions of faulted and folded rocks, where they are due to movements which take place from time to time along old fault zones.

Earthquake tremors travel outward from the fault or fracture that produces them, in waves or vibrations which can be recorded on delicate instruments called seismographs at distances of hundreds or thousands of miles, the distance depending on the magnitude of the shock. Intense shocks such as the San Francisco earthquake of 1906 can be detected at all points on the earth. The study of earth vibrations has been developed to such a degree that it is possible to calculate with considerable accuracy the distance of the shock center from the instrument of observation, and observers at two or more points some distance apart can by simple triangulation locate the position of a distant earthquake. For example, from the records of seismographs at Cincinnati, St. Louis, and San Francisco an earthquake in Alaska or South America can be located before news from the locality of the earthquake is received.

The science of seismography has an interesting and important application to warfare in the possibility of locating heavy artillery by means of earth vibrations.

STRUCTURAL FEATURES OF ROCKS PRODUCED BY EARTH MOVEMENTS.(1, 3)

Joints and cleavage, previously discussed, are in large part related to earth movements.

Faults.—Displacements along fractures are called faults. (See Figures 10, 12 and 13.) The plane of the break is called a fault plane and may be horizontal, vertical, or inclined. Fault planes in bedded rocks generally intersect the strata but may be parallel to the bedding, particularly in folded or tilted rocks. Faults parallel to the stratification are easily overlooked because evidences of displacement may be obscure. Movement along fault planes frequently produces a polished, more or less grooved or striated surface called *slickensides*. The direction of the markings indicates the direction of displacement. Masses of claylike material consisting of mashed and ground rock, called *gouge,* are found along many fault planes. The rock in the vicinity of a fault may be broken to a rubble of angular pieces, which may or may not be cemented.

Faults may prove embarrassing in subsurface operations. Rocks may be so displaced by them that a hard stratum is moved into continuity with a soft stratum in which a tunnel is being driven. If the displacement has not been too great and the direction of movement can be determined it may be possible to offset the line of the tunnel

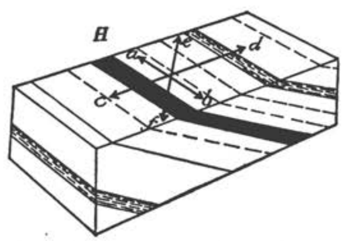

FIGURE 11. Diagram showing an area of rock with monoclinal structure. One layer notably unlike the others. (After Chamberlin and Salisbury.)

and continue it in the soft stratum beyond the fault. Fault planes may afford openings for the easy flow of ground water, and in underground work a large quantity of water may be encountered at a fault.

In faults of very recent origin displacement can actually be seen at the surface, as illustrated in Figures 10 and 13. This condition is rare and is usually found in faulting accompanying earthquakes. Faults that are not exposed may be revealed by excavation. (See Figure 14.)

Faults with considerable vertical displacement may develop great cliffs. Such cliffs, however, soon become so greatly modified by erosion as to make their distinction from cliffs formed in other ways fairly difficult. Blocks between fault planes may be depressed, causing depressions at the surface, which may be occupied by lakes. Even the largest faults, however, may have no expression at the surface, as original irregularities may be entirely obliterated by erosion.

Some faults are marked by depressions or valleys, because the entrance of water along a fault plane promotes rock decay and makes erosion easier than in the more solid rock on either side. Streams may consequently follow fault planes, and in regions where faults are known to occur this fact should be kept in mind. (See Chapters VI, VII.)

Folds.—Natural bends or flexures in stratified rocks are known as folds. They range in size from those small enough to be observed in a single rock exposure (Figures 15 and 16) to those having a span of many miles. Folds vary in degree of curvature or intensity of folding, ranging from broad, gentle arches or troughs to closely crowded folds in which the two sides are parallel.

Folds having the attitude of an arch, convex upward, are termed *anticlines;* those that are convex downward are called *synclines.* A fold consisting of a simple bend the strata on both sides of which continue in parallel attitudes but at different levels is called a *monocline.* Either limb of an anticline or syncline may be a monocline. Most folds are too large to be observed as such in the field. Furthermore, all folds have been more or less dissected by erosion, and the observer in the field sees only the worn edges of inclined strata. (See Chapter VI.) It is only by assembling the data derived from field observations on a map that the nature, size, and attitude of a large fold become apparent.

The crests and troughs of folds are generally not horizontal, being more or less steeply inclined. (See Figure 113.) The degree of inclination of the crest or trough is called the pitch of a fold. Dome-shaped folds may be considered as anticlines having two opposite directions of pitch. A single isolated fold may occur, but generally folds are found in a series of connected anticlines and synclines. Intense folding results in very complex distribution of rocks, both at the surface and underground, and the geologic problems of closely folded regions may baffle the efforts of the most capable geologists.

Contrary to rather prevalent popular conceptions, anticlines do not necessarily appear at the surface as rounded hills, nor are all synclines marked by depressions. In fact, the conditions may be quite the reverse, the syncline underlying a ridge and the anticline a valley. (See Chapters VI and VII.)

In a region of folding the rocks may be so completely planed off by erosion as to show no surface features that are clearly related to the structure beneath. Where erosion is less complete the surface features are largely determined not by the folds but by the distribution of hard and soft rocks. (See Figures 68-71.) Hard rocks tend

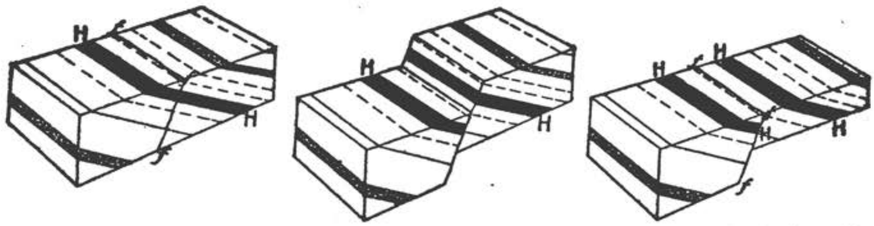

FIGURE 12A. Same as Figure 11, after (1) displacement by a strike fault and (2) base-leveling. The outcrops of certain beds are repeated.

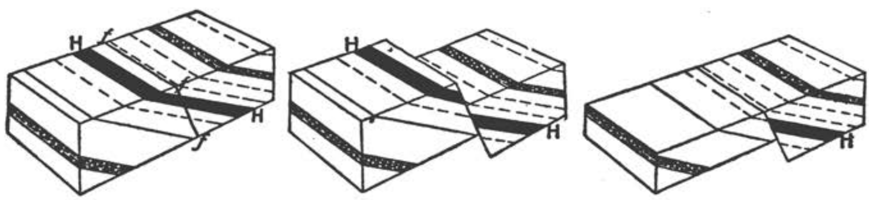

FIGURE 12B. Diagram illustrating how a strike fault in such a structure as that shown in Figure 11 may cause the outcrop of certain beds to disappear.

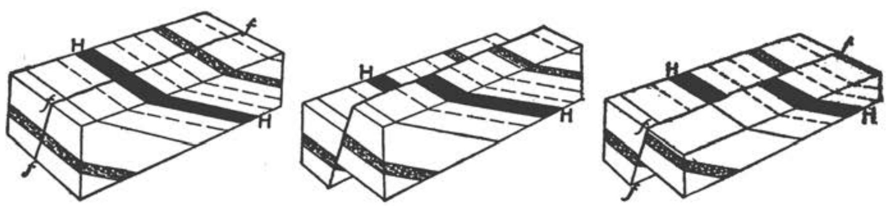

FIGURE 12C. Diagram illustrating how a dip fault in the structure shown in Figure 11 affects the outcrop when the downthrow was on the farther side of the fault-plane.

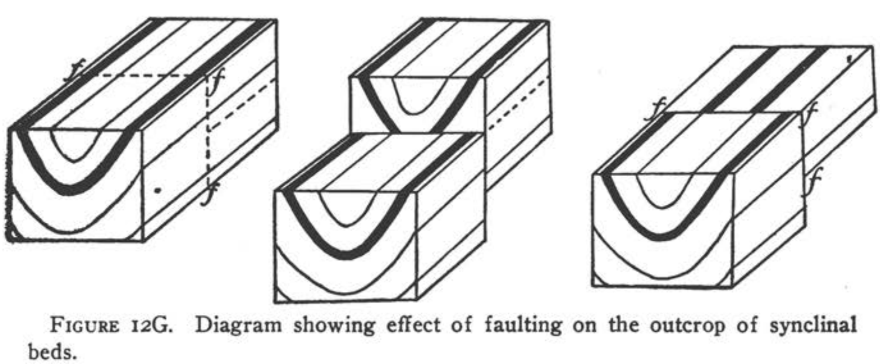

FIGURE 12G. Diagram showing effect of faulting on the outcrop of synclinal beds.

FIGURE 12. Diagrams 12A, 12B, 12C, 12D, 12E and 12F showing various ways showing effect of faulting on folded rocks. (After Chamberlin and Salisbury.)

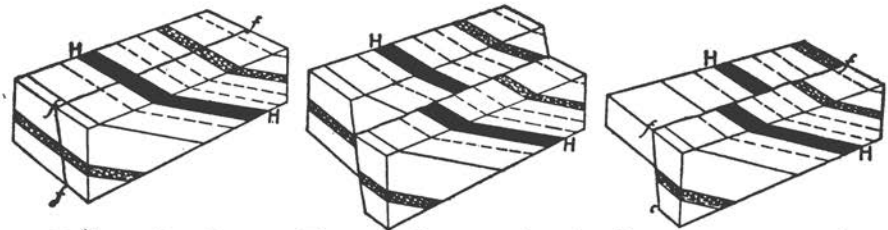

FIGURE 12D. Same as Figure 12C, except that the downthrow was on the opposite side.

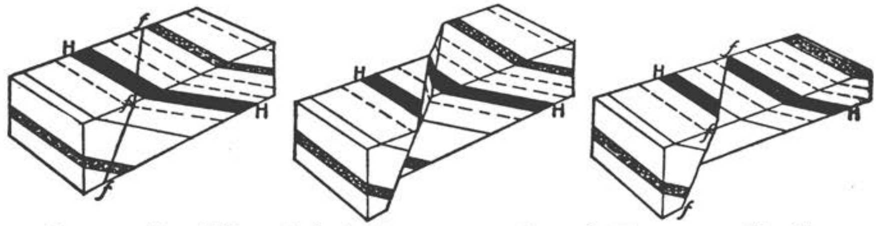

FIGURE 12E. Oblique fault in the structure shown in Figure 11. The downthrow was on the left side. The outcrop of layer H is offset with *overlap*.

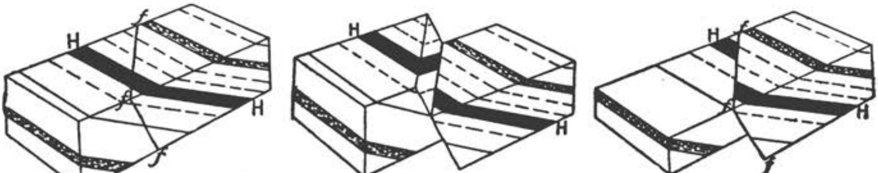

FIGURE 12F. Same as Figure 12E, except that the downthrow was on the right side and the offset is with a *gap* instead of an overlap.

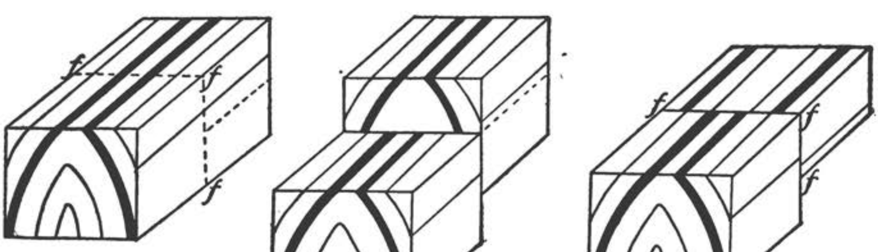

FIGURE 12H. Diagram showing effect of faulting on outcrops of anticlinal beds.

in which tilted beds may be displaced by faulting. Diagrams 12G and 12H

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As an unconformity marks a surface produced by erosion it is very commonly accompanied by a layer of coarse fragmental rock such as conglomerate or coarse sandstone.

The older beds at an unconformity may be much more thoroughly indurated and harder than the younger beds and if near the surface may present difficulties in tunneling. The old erosion surface may be very uneven, and some of the high points may project through the overlying beds. If the older rock is very hard these projections may have considerable bearing on the location of trenches and subsurface work.

GEOLOGIC MAPS AND SECTIONS.

Geology is concerned with the nature and attitude of the earth materials beneath the surface as well as with their surface distribution. The geology of any particular area must therefore be considered in three dimensions. Structural forms of rocks are all three-dimensional. A geologic map should portray not only the surface of the various earth materials but to as great an extent as possible their underground positions and relations. To see the third dimension in a geologic map requires a certain knowledge of the elements of geology and practice in visualizing the space relations of the elements represented. Cross sections in conjunction with geologic maps are a great aid to thorough comprehension of the conditions represented.

ELEMENTS OF GEOLOGIC MAPPING.

A geologic map is a diagram on which all available information pertaining to the geologic features of a locality is assembled in proper geographic relations. After the observed facts are assembled certain inferences can be made as to the geologic conditions in areas lying between points of actual observation. Inferences can also be drawn as to the conditions beneath the surface and expressed on vertical cross sections, which are diagrams of the geologic conditions that would be exposed by making a vertical cut down through the earth along certain selected lines. (See Figure 19.) An accurate map (one showing topography is preferable) can be used as a base on which to assemble geologic data.

The field work in preparing a geologic map consists in studying as many natural and artificial exposures of the rock and earth material as possible and making careful, systematic notes of the features observed. Exposures of hard rock should be looked for on steep

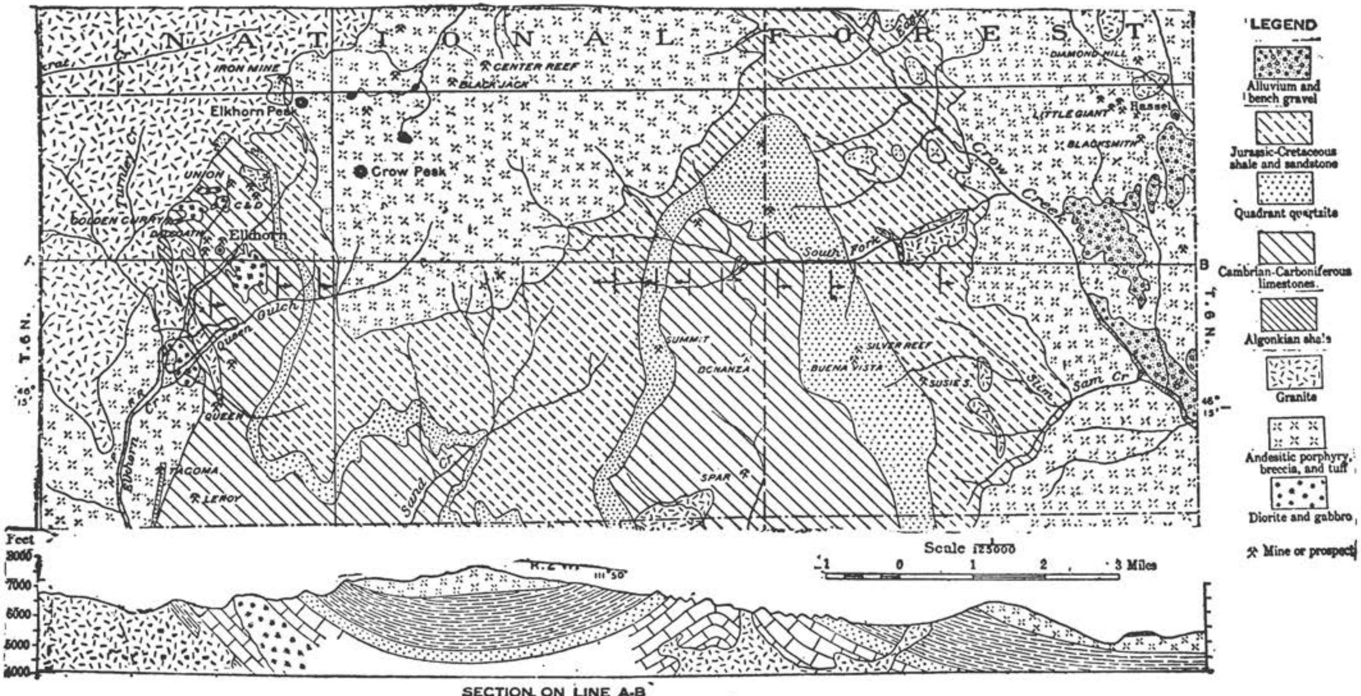

FIGURE 19. Geologic map with strikes and dips indicated along line A-B and geological cross section along same line. (After Ries and Watson; adapted from U. S. Geol. Survey.)

slopes, on prominent ridges, and in the beds and sides of streams. All artificial exposures in trenches, pits, wells, tunnels, etc., should be examined. In many places a little work with the pick and shovel will uncover the rock beneath a thin layer of soil.

Field notes must include the following items, among other things: (1) Location and elevation of the point of observation. If a base map is available field notes can be lettered or numbered and corresponding symbols can be used at the proper points on the map. Elevation is automatically determined with the location if a reliable topographic base map is used. If not, it must be determined by other means, such as hand levels, vertical angles, or an aneroid barometer. (2) Nature of material observed. The rock or earth material should be described in terms of kind of rocks, physical properties, color, hardness, texture, and porosity. (3) Minor structural features—the abundance and spac-

FIGURE 20. Diagram illustrating strike and dip. (After Geikie.)

ing of joints, the direction and inclination of cleavage, the nature of bedding in sedimentary rocks. (4) Attitude of beds, expressed by stating the direction of the intersection of the beds with an imaginary horizontal plane (the strike) and the degree of inclination of the beds from a horizontal position (the dip). (See Figure 20.) The strike is observed by means of a compass or may be plotted directly on a map by graphic or plane-table methods. In practice the direction of an imaginary horizontal line on a natural surface of a bed is taken. The dip is measured with a clinometer, a simple instrument which combines an arc graduated in degrees and either a spirit level or a plumb bob. (Compasses adapted to geologic work contain a built-in clinometer. The clinometer is useful also in measuring vertical angles, slopes, etc.) The strike is recorded in terms of compass direction (N. 20° E.); the dip is recorded in degrees and direction of angular inclination from the horizontal (35° S. 70° E.). A vertical bed has a dip of 90°. Dip is always observed at right angles to the strike, as measurements in other directions give angles less than the true dip. Strike and dip are indicated on geologic maps by means of a conventional symbol, thus:  45°, the straight line indicating the direction of strike, and the arrow and adjoining figures the direction and amount of dip. In observing strike and dip care should be taken not to mistake cleavage, cross-bedding, or close jointing for true bedding. Observations for dip and strike in single outcrops can obviously be made only where the dip amounts to several degrees. Dips too small to be measured in a single outcrop may, however, be of considerable importance. A dip of 1° involves a slope of approximately 90 feet in a mile. A dip of 2° involves a slope of nearly 200 feet in a mile, but this would be too slight to be measured in a single outcrop, because of local irregularities on the bedding surfaces. Dips as small as these are determined by noting the position and elevation at points on the same or approximately the same bedding plane at three or more localities some distance apart. The choice of a plane on which observations of this type can be made accurately is important. Such observations are usually made on the plane of contact between two layers of rock of different kinds, or on a certain distinctive bed or layer within a rock formation which can be easily recognized. (5) Faults, which in some places can actually be observed in outcrops. The direction and inclination (strike and dip) of the fault plane should be noted, and also the direction and amount of displacement of the beds, if possible, sketches being used to supplement the notes. (6) The planes of contact between different kinds of rock. Many contacts are not exposed and their location must be approximated by selecting a line between neighboring outcrops of different kinds of rock. (7) Unconformities. These are very important features. They may be actually observed but are commonly covered. (8) Dikes, to be described in terms of nature, thickness, and attitude. (9) Single folds in closely folded rocks. The attitude, direction, and pitch should be observed. Notebook sketches are useful here.

COMPLETING GEOLOGIC MAP FROM FIELD NOTES.

In assembling the results of observation on the map (also in taking field notes), it is convenient to use pencils or crayons of different colors to indicate different kinds of rock. After these results are assembled it is desirable to draw boundary lines between different rock formations to indicate the distribution of rocks in areas between points of observation. Such lines should be drawn only so far as is clearly warranted by observed facts. It is better to leave parts of the map blank than to make unwarranted assumptions.

In sketching formation boundaries it is necessary to take careful account of the manner in which the boundary planes would intersect the irregular land surface between points of observation. Vertical planes form straight lines over a surface of any kind. Horizontal planes intersect the surface along topographic contour lines. Inclined planes are straight lines only on horizontal surfaces; on irregular surfaces they are not straight and do not follow contours. Their proper drawing requires a clear visualization of the situation in three dimensions.

Topography that is plainly related to the varying hardness of the rocks is a valuable guide in drawing rock boundaries. Hard rock may form ridges and soft rock valleys, but this relation should be definitely established before it is used as a guide in mapping.

SUMMARY OF ENGINEERING CONSIDERATIONS RELATED TO ROCKS.

BUILDING AND STRUCTURAL STONE. (2, 10)

In the present age of concrete very little cut stone is used in building, especially in structures that must be built rapidly. The strength of stone that is to be used in buildings or other structural work generally needs very little consideration, for the crushing strength of practically any rock that will stand handling and dressing is adequate even for foundations.

CRUSHED ROCK, GRAVEL, AND SAND FOR CONCRETE. (10, 11)

Rock is bulky and expensive to transport, and in war only transportation that is absolutely necessary is possible, so that military engineers who want to make concrete must generally use whatever suitable rock or gravel is most easily obtainable.

In a region where no solid rock is exposed or where there are no natural gravels the material for making concrete may have to be carried long distances, even in time of war. The flat-lying clay and chalk country of Flanders is such a region. The concrete in some of the machine-gun shelters captured by the British forces in Flanders was made of Rhine river gravel, which was probably carried through Holland in violation of the principle of neutrality.

Crushed rock for making concrete should be hard enough to insure a strong aggregate—that is, it should be as strong as the cement. It should be a rock that behaves well in a crusher—that is, it should break into angular fragments of fairly equal dimensions and should not yield an unduly large proportion of fine material. A brittle rock that will snap and shatter readily is preferred to a tough rock that will cling together after it is fractured. A rock that breaks with rough surfaces binds better and makes a stronger concrete than one that breaks with smooth surfaces. Rocks that have well-formed cleavage planes and tend to break into thin plates do not make good crushed rock for concrete work; they do not break up satisfactorily in the crusher, and the shape of their fragments is not well adapted to proper mixing. Each fragment has little strength and is easily split in the direction of the cleavage. Schistose rocks on the whole are weak.

Any fresh, unaltered brittle igneous rock makes good material for concrete. Soft, partly altered rocks should be avoided. Partly altered igneous rock may appear brittle and solid when first broken but will soften rapidly when wet, particularly the darker varieties. Sandstone, if thoroughly cemented, hard, and brittle, can be used; but sandstones from which grains of sand can easily be rubbed out are undesirable, because they are weak and because they do not unite firmly with the cement matrix. Quartzite makes excellent concrete. It is brittle in the crusher and is very strong. Shale is on the whole very poor rock for making concrete, because it is weak and is likely to soften in water. Some hard shales that do not slake in water can be used but are not desirable. Most slate, because of its cleavage, is a poor rock for making concrete, but some of the massive varieties make good concrete. Chalk is a weak and poor cement material. The firm, clean, and brittle limestones and dolomites make excellent rock for concrete; the sandy or shaly varieties are less desirable.

Sharp sand, consisting of angular grains, is preferred for making concrete because it binds better than sand made up of rounded grains. Streams and glacial sands are more likely to be sharp than beach sand or dune sand.

ROAD METAL. (11, 12)

Any easily available rock that can be had in chunks of proper size can be used for making road foundations. The rock used for the surfaces of roads should be one that will bind well—one that under the roller and traffic will form a firm, smooth, durable surface that will shed rather than absorb water. Rock that does not bind properly makes a macadam that ravels—that is, the fragments of crushed rock are drawn out of place by the suction of automobile tires or by the wheels of other vehicles and the shoes of draft animals.

On the whole the dark-colored igneous rocks bind better than the light-colored igneous rocks. Disintegrated light-colored igneous rocks bind well and make good roads. They are very desirable road material, because they are easily excavated and do not require crushing. Partly decayed igneous rocks, particularly the dark varieties, bind excellently and make good road metal. If they are greatly decayed their large content of clay makes them much less desirable.

Gravel is common in glaciated areas and is found in streams and along beaches. It makes roads that are easily and cheaply repaired. Pebbles that are well rounded are not likely to bind well. Gravel that consists of pebbles of uniform size is less desirable for making roads than gravel that consists of pebbles ranging in size from very fine particles to stones two or three inches in diameter. A gravel in which most of the pebbles are limestone will bind better in a road than one in which most of the pebbles are quartz or igneous rock.

A gravel or crushed stone that does not bind well of itself may be bound with clay, which has been naturally mixed with many glacial gravels. A gravel pit whose banks contain clay enough to make them stand vertical will almost certainly supply good road material.

Sandy roads can be improved by mixing enough clay with the sand to bind it together, and clay roads can be improved by mixing sand with the clay. The sand used should be sharp and should contain much gravel, to supply the stiffness which the clay lacks when wet.

SURFACE EXCAVATIONS. (9, 11)

Large surface excavations are made in military operations—in trenching, digging gun pits, preparing foundations, building reservoirs, and grading highways and railroads. Where solid rock forms the surface or is thinly covered with soil it must be removed by drilling into it and using explosives. Obviously the difficulties of drilling and the amount of explosive necessary depend on the hardness and structure of the rock. Rocks that are abundantly jointed are easier to work in than rocks that have few joints.

In making excavations in igneous rocks it may be possible at some places to remove the rock of a softer altered dike or a mass of softer dark-colored rock, or even to dig a trench in an altered dark-colored dike that is surrounded by hard unaltered light-colored igneous rock. Where unaltered hard rock forms the surface trenching may involve so much time and labor that it will be practically impossible.

The ease or difficulty of surface excavation in flat-lying beds of sedimentary rock depends on the hardness of the rock. Some of the softer sandstones can be excavated by using a comparatively small amount of explosives in such a manner as to shake up and loosen the rock rather than to blast it out of position. For excavating the harder sedimentary rocks the methods used for excavating igneous rocks must be employed.

Quartzite is one of the hardest rocks, and the task of making large excavations in it is practically impossible.

Shale is one of the softest of the solid rocks. Surface excavations can be made in soft shale without the use of explosives or with the use of a small amount of explosives in a manner to shake up the rock.

Slate is a tough rock and requires the use of high explosives.

Chalk is perhaps the most easily excavated of the coherent rocks. It can be excavated without the use of explosives or with the use of small jarring charges of black powder.

Limestone is a fairly hard rock and can be excavated only by using hard-rock methods and the shattering type of explosives.

In making excavations in sedimentary rocks that are tilted at a high angle or that stand nearly vertical the softer beds should be chosen. If there is a choice of location soft sandstone or chalk beds may be chosen, but of course only if the strike of the beds is in the proper direction.

In making excavations in unconsolidated sediments or in decayed igneous rock it is necessary to support the sides of the pit and to control water. Firm clay, clayey sand and gravel, loess, and partly decayed igneous rock stand well and require little support. Clean sand, gravel, soft clay, clay that softens or slakes in water, and soft marl do not stand well. A thin seam of sand or clay which works out of a wall will ultimately undermine it and cause it to slump. Dry sand and gravel in shallow excavations stand unsupported at slopes as great as 70°. Soft clay and mud or muck flow more or less rapidly and have very flat angles of repose.

Excavation in frozen ground.—If solidly frozen while they are moist unconsolidated materials are very hard and tough and are difficult to excavate. A damp or wet sand when frozen may be harder than sandstone. Perfectly dry sand is of course not affected by freezing.

Frozen clay or mud is harder and tougher than shale. Frozen earth is on the whole rather more difficult to excavate than solid rock, because it contains no planes of weakness, such as joints or bedding planes. It is extremely tough and does not fracture cleanly like solid rock. Frozen ground can be excavated by drilling and blasting or by thawing it with steam or fire. Ground that contains considerable ice can be excavated by means of steam jets. In Arctic regions the ground just beneath the surface is perpetually frozen.

Excavation in snow and ice.—Military campaigns in the high mountains and in winter in the higher latitudes involve trenching and other types of excavation in snow and ice, which can usually be handled without blasting and present little difficulty to surface excavation. Their resistance to artillery fire, however, is not great.

UNDERGROUND EXCAVATIONS.(2, 9)

The difficulties in subsurface work are due largely to the hardness of the rock, the necessity of supporting soft materials, and the superabundance of ground water. In order to conduct subsurface operations most advantageously a knowledge of the rocks beneath the surface and their attitude is very essential.

Igneous rocks generally become harder with increase of depth, and subsurface operations in such rocks are slow and require the use of much explosive. At some places dark-colored dikes have been altered to a depth considerably below the surface and afford soft ground for excavating underground chambers and tunnels.

In flat-lying sedimentary rocks a knowledge of the nature of the successive beds beneath the surface may make it possible to choose a soft stratum between harder strata for constructing chambers and tunnels—for example, a chalk bed that lies beneath a hard sandstone, or a bed of soft shale that lies between harder rocks. The presence and the places of these softer beds may be determined from geologic cross sections and maps made by observing the rocks exposed in the sides of ravines or cliffs or by exploratory boring.

Tilted beds of sedimentary rocks come to the surface, and in subsurface excavation it may be possible to follow the softer beds. Excavations in a tilted bed are, however, limited to one direction. Here again previously made geologic maps, careful field observation, and drilling should be used to the fullest extent.

Underground excavation in unconsolidated material involves principally the problems of supporting the roofs and sides of openings and of handling the ground water. Sand and sandy material in general are both difficult to support and if they lie below the level of ground water contain abundant water. Work in a deep excavation that encounters quicksand is extremely difficult if not impossible. Work in clayey material involves less trouble with water, because clay is impervious and more coherent and consequently requires less support. Good firm clay will stand very well in chambers and tunnels and may require little support.

The decayed upper parts of igneous rocks are admirably adapted to subsurface work, as they are generally sufficiently coherent to stand well and are sufficiently impervious to prevent much trouble with ground water, though remnants of undecayed rock in the form of boulders and projecting masses of solid rock from below may interpose difficulties.

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CHAPTER II.

ROCK WEATHERING: AGENCIES, PROCESSES, PRODUCTS AND THEIR DISPOSITION.

INTRODUCTION.

THE surface features of the earth are continually changing, though the changes are so slow that their effects in historic time can only here and there be observed. The geologic record, however, is very clear and is easily read. We can see that the surface of the land is at some places being gradually worn away. We can observe rivers cutting back their banks and can note that at some places the sea is invading the land. In mountainous districts we can see the effects of landslides and of rapid stream erosion. Reasoning from the present back to the past we can easily conceive that the great river valleys were cut by the streams which flow through them. The Grand Canyon of the Colorado is a wonderful example of change made on the surface of the earth by a river. The very large amount of sediment carried by rivers is further evidence that the land is continually being worn down by running water. The Mississippi carries about 370,000,000 metric tons of sediment into the Gulf of Mexico every year. "Over 270,000,000 tons of dissolved matter and 513,000,000 tons of suspended matter are transported to tidewater every year by the streams of the United States. This total of 783,000,000 tons represents more than 350,000,000 cubic yards of rock substance, or 610,000,000 cubic yards of surface soil. If this erosive action had been concentrated upon the Isthmus of Panama at the time of American occupation it would have excavated the prism for an 85-foot level canal in about 73 days."[1]

The unconsolidated materials on the earth's surface—such as soil, sand, gravel, and clay—form only a thin mantle over the solid rock beneath. Any large modification of the earth's surface must involve the solid rock. Water and wind are the principal agencies that transport unconsolidated earth materials, but they are comparatively power-

[1] Dole, R. B., and Stabler, Herman, Denudation: U. S. Geol. Survey Water-Supply Paper 234, p. 83, 1909.

less to act on the solid rocks of the earth; before they can act on the material in solid rocks it must first be made soft and friable by natural decay. That rocks do decay and are not permanent and everlasting is one of the fundamental truths of geology. No rocks, however hard and resistant, can long withstand the natural processes of decay.

Exposed rock surfaces are everywhere attacked by the weather and in places show a complete gradation from solid granite or limestone or other rock upward through softer decayed phases to the thoroughly decomposed rock that forms the soil. We are familiar with the weathering and decay of stone in old buildings, and, in fact, many kinds of rock are unfit for use as building stone because they will not resist the destructive action of the weather.

The fact that rocks are naturally destroyed when they are exposed to the weather has led to the use of the term *weathering* as meaning the natural breaking down of rocks at or near the surface of the earth.

THE NATURE OF ROCK WEATHERING.

A study of rocks that are undergoing destructive weathering shows that they are thus destroyed in part by the mechanical breaking of the rock into small fragments, in part by the softening or decay of the rock, and in part by the dissolving of soluble portions of the rock. The mechanical breaking down of the rock has been termed *disintegration,* the decay of rock *decomposition,* and the dissolving of rock material *solution.* These three processes work hand in hand, and in nearly all weathering all three are active. We commonly find, however, that in any one place or rock a single type of weathering is predominant, the type depending on the kind of rock and the conditions under which it is weathered.

WEATHERING PREDOMINANTLY BY DISINTEGRATION.

Disintegration is essentially a mechanical process by which rocks are broken into fragments or, as in the disintegration of certain igneous rocks, into rather cleanly separated fragments of their constituent minerals. Any force or action that sets up internal stresses in a rock aids in its disintegration. Changes in temperature, the action of frost, the growth of plant roots, gravity, and the abrading action of wind-blown or water-borne sand and gravel all play a part in rock disintegration.

Abrasion.—Abrasion by wind-blown sand and water-borne sand, gravel, and rock fragments is on the whole rather unimportant. At some places solid rock is cut by mountain streams that carry gravel and boulders, but this action makes up only a very small part of the total work of weathering.

Changes in temperature.—Changes in temperature expand and contract rocks. If the changes are rapid the rate of expansion or contraction in the surface of the rock is different from that in the part just below the surface. This difference produces powerful stresses which cause thin shells of rock to break off in planes parallel to the rock surface. This process is called *exfoliation*. Different minerals expand and contract at differing rates under the same change in temperature. Mineral crystals, also, do not expand and contract uniformly in different crystallographic directions. These differences produce stresses between the minerals in igneous rocks that are exposed to sudden changes in temperature.

The work of frost.—Water expands on freezing, and in expanding it exerts great pressure. The fact that freezing water will burst iron and steel pipes is only too well known. Water freezing in a joint plane or in any other crack or crevice in a rock exerts the same powerful expansive force that it does in freezing in a pipe: it may widen the crack or crevice and may break the rock apart. Moreover, alternate freezing and thawing exerts a wedge-like action, for the expansion gained in one freezing is increased by each successive freezing. It might be said that the ice takes a fresh hold each time.

The work of plant roots.—The expansive force of the roots of growing plants is well known. Concrete sidewalk or stone flagging may be lifted and broken by the roots of trees. Along the edges of concrete and stone walks where plants are growing we can see the tiny rootlets of plants working into minute crevices and actually forcing the rock apart. Many have marveled that mountain trees find nourishment and moisture on apparently barren rock. These trees send their roots into crevices in the rock, and their comparatively soft growing roots gradually widen the crevices and may break up the rock.

The work of gravity.—In mountainous regions and along steep cliffs gravity stands ever ready to pull down any blocks of rock that may be loosened by frost or the roots of growing plants, and when the blocks fall they are likely to be broken into fragments. Occasionally great masses of rock cliffs—in fact great mountain masses—fall or slide thousands of feet into the valleys below. The fall of such masses may thoroughly shatter the rock, and some mountainous regions contain many great motionless rivers of broken or shattered rock that were formed in this manner.

Conditions favoring disintegration.—The continuity of the action of all the agencies and processes of disintegration outlined above depends on the removal of broken rock material as rapidly as it is formed. Changes in temperature have slight effect on rock that is protected by a covering of such material. The effect of frost, particularly of alternate freezing and thawing, on rock that is overlain by a protective covering of a few feet of rock débris is relatively slight. Plant roots need not work their way into crevices and cracks in solid rock if they can find openings in thoroughly broken rock, and gravity can obviously produce rock falls only on steep slopes and precipitous cliffs. The conditions most favorable to rock disintegration are therefore found in regions of considerable relief, in regions that lack a protective covering of vegetation, in regions where the daily range in temperature is great, and in regions of alternate freezing and thawing—in mountains, steep cliffs, arid countries, and cool or temperate climate.

Products of disintegration.—Weathering predominantly by disintegration produces certain distinctive results. Disintegrated rock accumulates at the foot of steep rocky slopes and cliffs in great piles of angular material called *talus*. The fragments in talus range from fine sand to large angular blocks. Talus slopes may be large or small, their magnitude depending on the size of the rock slope or cliff which supplies them and on the conditions favorable to their preservation or destruction. Talus very commonly accumulates along the sides of a stream valley, where the stream may work into the toe of the talus slope and transport and rework the angular talus into rounded gravel and sand. Excavation or the removal of blocks from the base of a pile of talus is likely to start the surface moving downward with destructive results. Sudden jars, such as earthquake shocks, blasting, or the vibrations set up by gunfire, may start blocks into motion or dislodge them from the face of a cliff.

Extreme caution is necessary in moving large bodies of men along talus slopes or at the foot of cliffs that have long been exposed to weathering or especially to the action of frost. In the snow-clad mountain valleys of southern Europe many lives have been lost by the sudden fall of large masses of snow and ice that entangle rock débris and form avalanches. The paths of these destructive slides are not always discernible from the traveler's route, but he should make his halts and camping sites on shoulders in the line of lofty spurs, in the expectation that rock falls and avalanches from cliffs higher up will be diverted into channels or valleys on either side of such a well-chosen resting place or temporary redoubt. For the same reason one who is climbing a steep-sided mountain may well travel on the spurs between valleys or gulches rather than up the stream courses, where he will find the most mud and water and fallen timber.

The disintegration of rocks in desert regions produces large amounts of sand and other fine material, the nature of which depends on the nature of the rock. This sand and dust is picked up and transported and sorted by winds.

WEATHERING PREDOMINANTLY BY DECOMPOSITION AND SOLUTION.

Decomposition is essentially a chemical process in which the active agents are air and water. It is aided or preceded by disintegration. It destroys rocks by altering their constituent minerals, producing new materials which on the whole are softer and less dense than the original minerals.

Conditions favoring decomposition.—Decomposition or decay goes on more slowly than disintegration. Decay is aided by moisture or dampness and, like most other chemical reactions, is accelerated by warmth and retarded by cold. Decay is favored by a covering of vegetation or of weathered rock material, which conserves moisture. Decomposition is therefore promoted by conditions which are just the reverse of those that promote disintegration. Rock weathering by decomposition is favored by a warm, moist climate, by moderate relief, and by the accumulation of products of weathering.

Agencies of decomposition.—The agencies that cause the decay or decomposition of rocks are air and water. Contact of rocks with dry air has little or no decomposing effect. We all know that iron or steel will remain bright and untarnished in dry air but will rust in moist air. When iron rusts it simply combines with the oxygen of the air. But the oxygen of the air acts much more readily when it is brought into contact with the iron by water. In other words, water dissolves oxygen, and water containing dissolved oxygen in contact with iron causes the iron to rust. Rock decay is much the same. Air contains oxygen and carbon dioxide, both of which are effective agents of rock alteration. Dry air containing carbon dioxide has little or no effect on rock, but oxygen and carbon dioxide dissolved in water are effective. The most effective agent of rock decay is water containing oxygen and carbon dioxide in solution, and practically all natural waters contain these gases.

The chemical work of oxygen, carbonic acid, and water.—Oxygen carried in solution by water attacks the iron-bearing minerals and forms iron oxides. Iron oxides contain water in different amounts and are colored in various shades of yellow, red, and brown. Oxidation therefore produces a very notable change in the color of rocks, and this coloration is one of the most obvious signs of weathering. Rocks altered by waters that do not contain oxygen are not discolored and may be of lighter color than their original unaltered phases.

Carbon dioxide or carbonic acid is one of the most effective agents of rock decay. Many of the minerals in rocks, particularly igneous rocks, are compounds of silica and the metallic oxides lime, magnesia, soda, and potash. In other words, they are salts—chemical compounds in which silica is the acid radicle. When these minerals are undergoing weathering carbonic acid displaces silica and forms carbonates of the metallic oxides, just as hydrochloric acid displaces carbonic acid when it is added to limestone. Most of the carbonates thus formed are soluble and are removed from the decaying rock in solution. Water containing carbonic acid is a solvent for limestone, which is not dissolved in pure water. Carbonic acid is derived from air, but a large part of that in ground water originates in the decay of vegetable matter by oxidation. For this reason a covering of vegetation aids weathering by providing one of the most active chemical reagents.

Water is not only a medium which carries oxygen and carbonic acid that promote rock decay; it is itself an effective chemical agent of decay. When the carbonic acid removes the metallic oxides as carbonates, water enters into chemical combination with the remaining silica and alumina. This process is called *hydration,* and the water-containing minerals thus formed are called *hydrous minerals.* Clay is the most common of the hydrous minerals thus formed. Water also unites with the oxide of iron produced by oxidation, forming hydrous iron oxide. Practically all the new minerals formed by weathering are hydrous minerals.

Products of rock decomposition.—The decomposition of rocks produces a mantle of weathered rock consisting of clay intermingled with sand and fragments of rock and minerals, which differ in character and proportions according to the nature of the rock altered. The thickness and extent of this mantle of weathered rock depends on the rate of weathering and the rate of erosion of the weathered material. At some places in certain South Atlantic States, in Brazil, in Cuba, and in other countries the absence of erosion has permitted weathered rock to accumulate to depths of many feet. The granitic rock in the bauxite district of Arkansas is weathered to soft clayey material to depths as great as 50 to 60 feet; in Georgia there are accumulations of weathered granite as much as 50 feet deep; in Cuba serpentine rock (a fine-grained dark-colored igneous rock) is weathered to depths reaching 40 feet. When streams cut into and erode such accumulated products of weathering they carry them away and sort them into sand and clay.

The weathering of rock yields some material in soluble form, which is taken into solution by the water that causes the decay. The elements that are dissolved most abundantly are silica, lime, magnesia, potash, and soda. Quartz is said to be relatively insoluble, but only a very small part of the silica taken into solution during weathering is derived from quartz. Minerals that contain silica, such as feldspar and the ferromagnesian minerals, yield silica in a very soluble form on decomposition, and it is this silica that is taken into solution. Part of the material dissolved by weathering is deposited by waters underground as cementing material in spaces in the sediments they traverse. The cement of sandstone is thus deposited. Fissures and joints in rocks are filled by dissolved material that is precipitated from solution and forms veins. A considerable part of the material dissolved, however—largely the lime, magnesia, and soda—is carried into streams and by them to the ocean, where it is precipitated both by chemical reaction and by the aid of organisms as deposits of calcareous ooze and shell beds, which are ultimately solidified to chalk and limestone.

WEATHERING OF IGNEOUS ROCK.

Under conditions favorable to disintegration with little decomposition igneous rocks are transformed into angular fragments of different sizes. On steep slopes and along cliffs the disintegration of igneous rocks produces angular talus. In arid regions disintegration breaks down igneous rocks into coarse angular sand made up of the original minerals of the rocks in unaltered condition. This material resembles in color and composition the rock of which it was formed.

Under conditions favorable to decomposition igneous rocks are changed to residual clays containing more or less abundant fragments of the minerals that have not been completely altered.

The first effect of the decomposition of a rock is a general dulling of the bright faces of its constituent minerals and a slight softening of the rock. Commonly yellow-brown or red iron-oxide stains appear. A very slightly weathered igneous rock lacks the brittle crispness of a perfectly fresh rock and can be more easily broken up. Some rock found in excavations or quarries appears perfectly fresh but breaks down rapidly on exposure to the air and water. Occasionally an apparently unaltered igneous rock begins to go to pieces after exposure for a few months or a year, because of incipient alteration. This has led to numerous losses to quarrymen and expensive changes in buildings into which such rock has been incorporated.

Igneous rocks are made up of various combinations of quartz, feldspar, ferromagnesian minerals, and mica. Quartz is a simple oxide of silica (SiO_2). It is not altered to softer forms or to other minerals by weathering and is attacked only by mechanical disintegration and solution. It is dissolved very slowly and commonly remains unchanged in residual clays. Consequently an igneous rock that contains quartz produces a clay containing particles of quartz.

Feldspar (see p. 18) contains silica, alumina, and different amounts of the oxides of calcium, sodium, and potassium. The decay of feldspar produces clay, which is a combination of silica, alumina, and water. The calcium, sodium, and potassium are largely removed in solution in the form of calcium carbonate and sodium and potassium silicates and carbonates. Feldspars that contain calcium and sodium are more readily decomposed than those that contain potassium.

The ferromagnesian minerals (see p. 18) are compounds of silica with the oxides of iron and magnesium and with minor amounts of calcium, sodium, and potassium oxides and different amounts of aluminum oxide. Their partial alteration produces certain soft greenish minerals, which are very commonly found in clay. Their more complete alteration yields clay, iron oxide, and soluble carbonates of lime and magnesia. The ferromagnesian minerals on the whole are rather more easily altered than other minerals of the igneous rock, although some are resistant to weathering.

The micas are fairly resistant to decomposition. They are first leached and softened, the dark micas become lighter in color, and they are ultimately changed to clay that will yield a certain amount of soda and potash in soluble form.

The dark-colored igneous rocks contain calcium and sodium feldspars and little or no quartz. As quartz and potassium feldspars are the most resistant of the igneous rock minerals to weathering, light-colored igneous rocks are on the whole decomposed less rapidly than the dark-colored varieties. Under similar conditions, side by side, a dark-colored rock may be considerably decomposed and a light-colored rock only slightly altered. For this reason a dark-colored dike in a light-colored igneous rock may be weathered to some depth, whereas the light rock may be practically unaltered.

WEATHERING OF SEDIMENTARY ROCKS.

As sedimentary rocks are themselves the transported and redeposited products of the weathering of preëxisting rocks, they are on the whole less subject to decomposition than igneous rocks. Sandstone, if thoroughly cemented, produces coarse, angular talus at the bases of steep slopes and cliffs; if it is poorly cemented, disintegration simply reduces it to sand. In a desert sandstone is disintegrated into sand.

Under conditions favorable to decomposition sandstone, which consists largely of grains of quartz, is changed to residual sand by solution of its cementing material, and weathered sandstone is simply soft sandstone, which, however, never becomes quite so incoherent as sand that has never been cemented. The rock may be stained or its color may be changed by infiltration of compounds of iron or manganese or of organic material. Some sandstones contain crystals of pyrite (iron sulphide). This mineral is attacked by oxidation, so that iron-stained cavities shaped like the former crystals of pyrite are found in weathered sandstone. Because of its ease of weathering, rock containing pyrite is avoided in selecting building stone. Sandstone that contains considerable amounts of feldspar and ferromagnesian minerals becomes clayey by the decomposition of these minerals to clay. An arkose is altered to a residual clay, as is also ferromagnesian sand.

Quartzite is extremely resistant to weathering by decomposition and is very slowly altered to sand by the solution of its siliceous cement. This alteration is seldom more than superficial. Under conditions favorable to disintegration it breaks into angular fragments and forms angular sand and very angular sharp pits. Shale is a soft rock and does not form steep slopes. It produces a fine-textured earth talus, in contrast to angular talus formed from hard rocks, and in a desert it breaks down to an earthy dust which is easily swept about by wind. Being comparatively soft, shale is more readily abraded by wind-blown sand than other solid rocks. On disintegration, slate breaks into thin, flat plates, so that slate talus has a very distinctive appearance. On decomposition slate is changed to clay.

Chalk is a soft rock, which does not form talus but is changed by disintegration to a chalky, powdery earth. When decomposition is dominant, chalk yields readily to solution, and the residual material is commonly a reddish clay, which represents the impurities of the chalk and in which are embedded the flint nodules and layers of the chalk rock, which are very resistant to decay.

Limestone in its harder phases produces angular talus at the foot of steep slopes and cliffs. It is rather resistant to the disruptive action of changes of temperature, and in an arid climate it tends to resist disintegration rather more than other rocks, and consequently it forms prominent features in a desert region. Under conditions favorable to decomposition rather than disintegration limestone yields to weathering by the solution of its calcium and magnesium carbonates. Residual soils over limestone are therefore composed of the impurities and the nodules and fragments of chert in the limestone. Where the level of the ground water is some distance below the surface, solution of the limestone produces great caverns. In the peninsula of Yucatan solution by rain water and by underground streams has progressed so far that the entire drainage system is subterranean; there is almost no surface water. Marble behaves in a similar manner, but as it is harder and denser it is more resistant.

When a peat bed is drained the peat is no longer protected by water from decay and undergoes slow oxidation, which converts much of its organic material into carbon dioxide and produces great shrinkage of the bed and a proportional increase in the percentage of mineral matter in the peat, owing to the loss of organic material. The shrinkage in drained peat lands may be measured in inches per year and actually lowers the surface.

SOILS.

Soil is earth that supports or has supported plant life. The term as popularly used includes all unconsolidated earth at or near the surface. "Topsoil" and "subsoil" are familiar terms, used respectively for the upper soil and the underlying earth. Soil may be the residual product of rock decay or it may be material that has been transported by streams. The rich soils of the piedmont district of the southeastern United States are largely residual. The fertile soils of many river valleys consist of transported material.

Soils may be sandy, clayey, silty, or gravelly, their nature depending on the nature of the material from which they were derived.

The fertility of soils depends on numerous and various factors, and soil may be fertile for one kind of crop and infertile for another. In general, plants are dependent on certain mineral constituents which are essential to the growth of plant tissue. The composition of the ash obtained by burning vegetable matter tells us what mineral elements are used by plants. Chemical analyses of this ash show that it contains silica, calcium, potassium, and phosphorus, as well as traces of iron and other elements which are essential to plant growth and which must be in the soil in a form that is available to the roots of the plants if that soil is to support vegetation. All these elements are common constituents of rocks and occur in soils in varying amounts.

Soil contains fragments of unaltered rock and rock mineral that are undergoing decomposition and are therefore yielding certain soluble mineral salts. It is interesting to note that many of the soluble elements produced by the decay of rocks are those needed by plants, so that the decomposition of rocks and the growth of plants are part of a wonderful coöperative system. The roots of growing plants themselves aid in getting the plants mineral food by exuding active solutions which aid in rock decomposition. Decaying vegetation also, by producing certain acids, aids in the same process; it helps to supply growing plants with the soluble mineral elements which they require. For this reason a soil is made more fertile by a certain content of partly decayed plant remains called *humus*. Humus absorbs moisture and keeps the texture of the soil open and porous so that the plant roots may have the air they need.

A very essential element in plant tissues is nitrogen, which, being volatile, is not found in the ash. Nitrogen is not an abundant rock constituent, and its presence in soils is dependent on other processes than rock weathering. Nitrogen is added to soils in nitrogenous fertilizers, which are manufactured in part from animal refuse obtained from the great packing plants. It is also obtained from natural deposits of nitrates, principally in Chile, and in the form of guano, the accumulated excrement of birds, from deposits on certain islands. Nitrogen salts are also obtained by electrical fixation of atmospheric nitrogen. The greatest quantity of nitrogen in soils, however, is that provided by certain bacteria which have the power of abstracting it from the air and fixing it in a form available for plants.

HARMFUL BACTERIA IN SOIL.

In addition to the nitrifying bacteria the soil contains a host of other kinds of bacteria, including varieties that are harmful to man. Among these are the bacillus of tetanus or lockjaw, that of the quartan evil, and that of malignant edema. Tetanus is peculiar to the soil of certain tracts. Men and horses are subject to infection by it through wounds on the hands and feet or limbs, either from a dirty knife or a gardener's fork. The bite of an insect or the prick of a thorn may permit the bacillus to enter the body. Quartan evil or symptomatic anthrax is a fatal disease that affects animals. The bacillus exists in the upper layer of the soil. Malignant edema is a gangrenous disease afflicting men and animals that have become infected through contact with soil, straw dust, or decomposing organic matter.

Damp soils are more favorable to the spread of bacterial disease than dry soils, either because they lower the vitality of man and animals or because they favor the vigorous action of harmful bacteria. A rapid fall of ground water after a rise is favorable to the spread of enteric fever. Even the germ of summer diarrhea has been traced to the temperature of the soil, fatal cases appearing when the soil in summer attains a temperature of 56.4° F. The germ of typhoid fever grows abundantly in certain soils but quickly dies out in grass-covered tracts. The dust blown up by the winds from bacteria-infected soils is the vehicle by which tuberculosis, anthrax, and typhoid may be introduced into the human system. A knowledge of the action of bacteria in the soil has led to the disposal of sewage in inland towns near large sand plains by a system of filter beds by which the sewage is conveyed in pipes to shallow reservoirs or embanked flat-floored tracts of sand exposed to the open air. As soon as the bacteria have had time to act on the sewage that has seeped into the subsoil and the surface layer has become dried in the sun the solid refuse is raked up and burnt. By the action of the bacteria the originally polluted water in the subsoil is deprived of its deleterious organic compounds and drained away through the filtering sand, the bacteria and any undecomposed organic matter being alike left in the filtering bed. Were it not that this beneficial chemical action is promoted by bacteria in the soil and limited practically to the surface portion of beds of gravel and sand, our underground supply of water would become a fruitful source of disease communicated by germs.

DAMAGING EFFECTS OF MILITARY OPERATIONS ON THE SOIL.

The soil is a product of successive generations of plants and of years of cultivation and differs markedly in composition and texture and, consequently, in fertility from the material beneath, which may be identical in origin. Most soils are less than two feet deep, and the mixing of the subsoil with the topsoil by extensive systems of trenching and by intensive artillery fire very seriously damages the fertility of any region in which such work is done. The regions in France and Belgium which have been so fiercely fought over have thus suffered a loss of fertility that will be felt for many years—in fact, the fertility may never be fully renewed.

PROPERTIES OF SOIL SURFACES.[2]

One of the purposes of cultivation is to increase the water-absorbing power of the soil and to produce a light, open texture that is favorable to the growth of crops. For this reason cultivated soils are softer than virgin soil and offer poorer footing for troops, vehicles, and field guns. When dry they are very dusty and when wet they form deep mud. Clay soils are more or less impervious, work up into deep, sticky clay when wet, and hold rain water in all undrained depressions. Shell craters in clay soils hold rain water for many days and become places of danger rather than shelter. Sandy soil, being pervious, allows rapid underdrainage and is firmer under foot when wet than when dry.

TRANSPORTATION AND DEPOSITION OF PRODUCTS OF WEATHERING.

All the unconsolidated materials that make up the soil are the products of comparatively recent rock weathering. All the sedimentary rocks are solidified ancient products of weathering. The various unconsolidated materials produced by the weathering of rocks, by both disintegration and decomposition, remain only temporarily in their places of origin. Sooner or later they are picked up, transported, and deposited after more or less sorting by water or wind or by another though less important agent of erosion—glaciers.

THE WORK OF THE WIND.

Winds can reach only material that is not protected by vegetation and water and, except unusually high winds, can transport only material that is very fine. This limits the field of wind erosion to arid countries, non-vegetated river flats, and tidal flats and beaches.

[2] See discussions of unconsolidated sediments, Chapter I.

The material transported by wind is limited to comparatively fine sand and the dry, clayey products of weathering. In arid regions the work done by wind in erosion and transportation and the deposits built up by wind-borne materials are of considerable magnitude. Wind erosion scours out depressions and pockets and builds up hills of sand called *dunes*. Sand dunes are also constructed by wind on beaches. (See "Sand," p. 4.) Wind exerts a sorting or winnowing action on the material it carries, separating the fine dust from the coarser sand and carrying it much farther. The fine dust consists of mixtures of extremely fine sand and clay, and deposits of this wind-blown material are known as *loess* (see p. 10).

High winds in deserts produce sand and dust storms, which cause serious inconvenience to armies and may be important factors in military movements.

THE WORK OF WATER.

The work of running water, like the work of wind, consists of erosion, transportation, sorting, and deposition. Streams are the great agencies of transportation. They carry the soluble products of weathering in solution and the fine sedimentary material in suspension and roll the coarser material along the bottom. All the material transported ultimately finds a more or less permanent resting place in stratified beds of sediments deposited in the sea, in lakes, or in broad valleys on the land. (See Chapter III.)

CHAPTER III.

STREAMS.

INTRODUCTION.

In a military sense streams constitute perhaps the most important features of a landscape. Aside from being sources of water supply they are routes of transport by boat and by wagon road and railroad along the banks and are important guides for airplane pilots, who can recognize them when other landmarks are dimmed. They constitute defensive lines and obstacles to advance or retreat. The depth and velocity of the water, the nature of the channel bottom and sides, the character of the country immediately adjoining the stream are matters of commanding importance. On an officer's ability to interpret them may hang success or failure. For this reason the character of streams is here emphasized rather than fine distinction of origin or classification.

ORIGIN AND CLASSES OF STREAMS.

The water which falls to the ground in the form of rain and snow is disposed of in three ways: part of it is evaporated and returns directly to the air, another part enters the ground and joins the body of underground water, and a third part flows on the surface of the ground as streams, which occupy streamways of various lengths and shapes. For convenience these parts may be termed the *fly-off,* the *run-in,* and the *run-off*. The amount of water disposed of in each of these three ways chiefly depends on the climate and weather, capacity of the soil and rocks and vegetation to absorb water, and the steepness and extent of the slopes. All these factors vary within wide limits and give rise to a remarkable variety of streams. The largest percentage of the total preciptation is recovered and retained by streams in regions characterized by relatively small evaporation, by heavy precipitation distributed throughout the year, by fairly steep slopes, and by impervious soil and rock. On the other hand, only a small part of the total rainfall enters streams in regions of dry, hot climate and porous soil.

From charts showing annual precipitation and annual run-off it appears that the average run-off in the United States east of the Appalachian range is between 20 and 30 inches. The rainfall in this area generally varies from 40 to 50 inches. West of the Appalachian Mountains to the center of the Mississippi Valley the run-off gradually decreases to about 10 inches and the rainfall to 30 inches. At the 99th meridian the run-off is about 3 inches and the rainfall less than 20 inches. From the 99th meridian to the Sierra and the Cascade ranges the rainfall, except on the high mountains, is less than 20 inches, and the annual run-off is less than 3 inches. In general, the streams in this region of low run-off gather their waters either from tributaries draining mountainous areas in which rainfall exceeds 20 inches or from areas of less rainfall during the occasional periods of excessive precipitation. In the region between the Sierra and Cascade ranges and the Pacific coast, except the floor of the Great Valley of California and the coastal area below San Francisco Bay, rainfall and run-off are higher than in any other part of the United States."[1] Here the annual precipitation ranges from less than 40 to more than 120 inches and the run-off from 20 to 90 inches. In some regions, as in parts of Arizona, the rainfall is insufficient to compensate for normal losses by evaporation and soil absorption, and there is no run-off except during and immediately following showers. In some flat surfaces of highly porous rock, like the Nullarbar Plains of Australia and the "Dry Champagne" region of France, practically all the rainfall passes directly into the ground, and in some desert basins with impervious floors all the water is evaporated.

Streams differ widely with respect to amount of water carried and the distribution of the water throughout the year and along the streamway or valley. They may be classified as: (1) *intermittent* or *ephemeral* streams, (2) *interrupted* streams, (3) *perennial* streams.

The intermittent stream flows in response to showers and ceases to flow soon after the shower has passed. It carries the direct run-off or storm water. The water which flows in road gutters during and after showers is essentially an intermittent stream, as are most small streams of semi-arid regions. To this class belong also those streams which flow only during the rainy season of the year.

The interrupted stream flows under normal conditions only in parts of its course, and its channel presents alternating stretches of running water and dry channel bed, like the Rio Grande in New Mexico and Texas. The stretches of water in an interrupted stream are essentially

[1] Hoyt, J. C., and Grover, N. C., River Discharge, John Wiley & Sons, 1916.

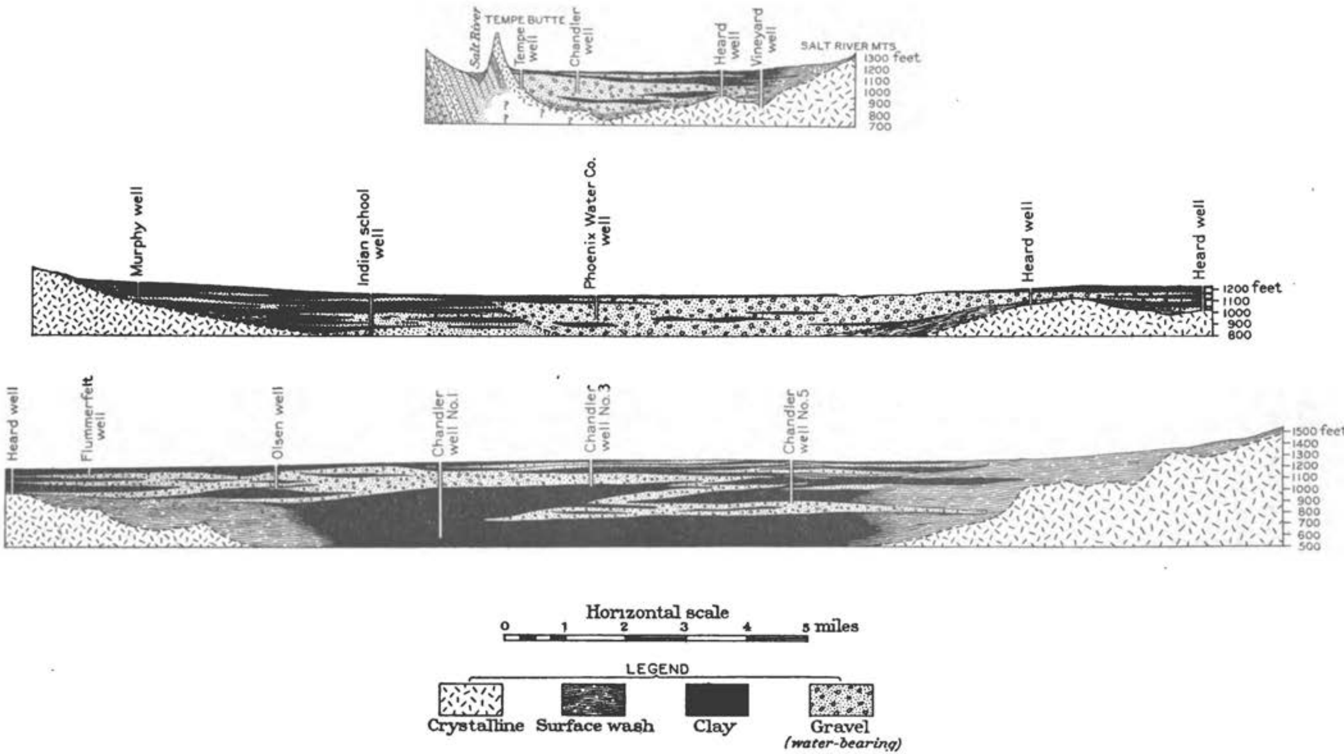


FIGURE 21. Work of Salt River, Arizona. The profile sections showing the character of the valley filling as interpreted from well borings. From the "underground river" which flows through the coarse gravel water enough is pumped to irrigate several thousand acres of land. (After W. T. Lee, U. S. Geol. Survey.)

short perennial streams and may be at the valley head or near its mouth or distributed along the stream's course at intervals of a few hundred feet or several miles. For military purposes it is essential that the places where water may be found should be indicated on a map.

Perennial streams flow throughout the year and from source to mouth. They receive water not only from the rain but also from underground sources at springs and seeps and owe their permanency to the fact that the level at which ground water stands in the regions adjoining the streams is higher than the stream beds. In other words, if streams were fed only by storm water coming directly from rains, all of them would be intermittent. The permanent (perennial) part of the flow is supplied by seeps and springs which issue from rocks and alluvium below the surface of the stream.

Streams are ordinarily rivers and other bodies of moving water visible at the surface, but in some places there are streams which flow wholly underground. Where the rock is readily soluble these streams follow definite channels, such as the caves in limestone and gypsum regions. Where great quantities of sand and gravel have accumulated in the valleys a stream may disappear from the surface and become a *sunken stream,* an *underflow,* or a *lost river.* Such streams are especially common in arid regions where all except the flood waters enter the underflow. (See Figure 21.)

There are other bodies of moving material which are sometimes called streams, such as glaciers, which are streams of ice; ice flows; and some landslides, which have slow movement when the material composing them is saturated with water.

THE WATER OF STREAMS (HYDROLOGY).

Measurement of water in streams.—The amount of water carried by a stream is the *discharge* of the stream, and the determination of the amount is known as *gaging* the stream. The discharge is measured in cubic feet per second (second-feet) and is obtained by measuring the cross section of the stream in square feet and multiplying this number by the average velocity of the current stated in feet per second.

Carefully standardized methods for obtaining continuous records of stream flow have been developed by the U. S. Geological Survey as the result of extensive practice and experience (22). These methods consist essentially of (1) measuring the flow of a stream by determining its cross-section area and the velocity of the water at different points in this cross section, (2) developing, from such measurements at several different stages of the stream, a rating curve whereby the flow at all intermediate stages can be estimated, and (3) installing an automatic water-stage register or a gauge that can be read daily or semi-daily. Rough estimates of flow can be made by observing the velocity of sticks floating at the surface, ascertaining the approximate average cross-section area in the stretch in which the velocity observations are made, and applying a correction factor of 75 per cent., more or less, for retardation at the sides and bottom.

Fluctuation in volume.—The amount of water perennially supplied to streams by seeps and springs in the channel varies somewhat in response to variations in the amount of water in the ground but does not produce large or sudden variations in volume of water in a stream. The water flowing from the surface and supplied by rains or melting snow varies widely in amount and in place. In general, the water of floods is derived from surface flow and that of medium and low stages from ground flow. All streams have stages of high and of low water as phases of their normal behavior and entirely apart from exceptional flood stages during which the stream overflows its banks. The amount of fluctuation, its suddenness, and its distribution in time depend primarily on climate, and on this basis four classes of streams have been recognized for the United States, as follows:

"Streams in the northeastern part of the United States are typified by Kennebec River, Maine. Their low-water flow generally occurs during the summer (growing) and winter (frozen) months and is broken only by occasional rises caused by heavy rains; their high waters occurring during the spring months are caused by rains and melting snows. Occasional high waters occur during periods of excessive rain in the autumn and of high temperature in the winter.

"Streams in the western part of the United States, draining mountainous areas and fed by melting snows, have pronounced periods of high and low water. High water usually begins in April and continues until July and is caused by melting snow and ice. The high water is followed by gradual decrease in stage until the flood period of the next year, though occasional minor rises result from local rains. Grand River, Colorado, is typical of these streams.

"Streams in the southeastern part of the United States, of which Yadkin River, North Carolina, is typical, have no defined periods of high or low water. High waters may occur at any time, depending on precipitation, and are of short duration.

"Streams in the arid West, where the rainfall is usually insufficient

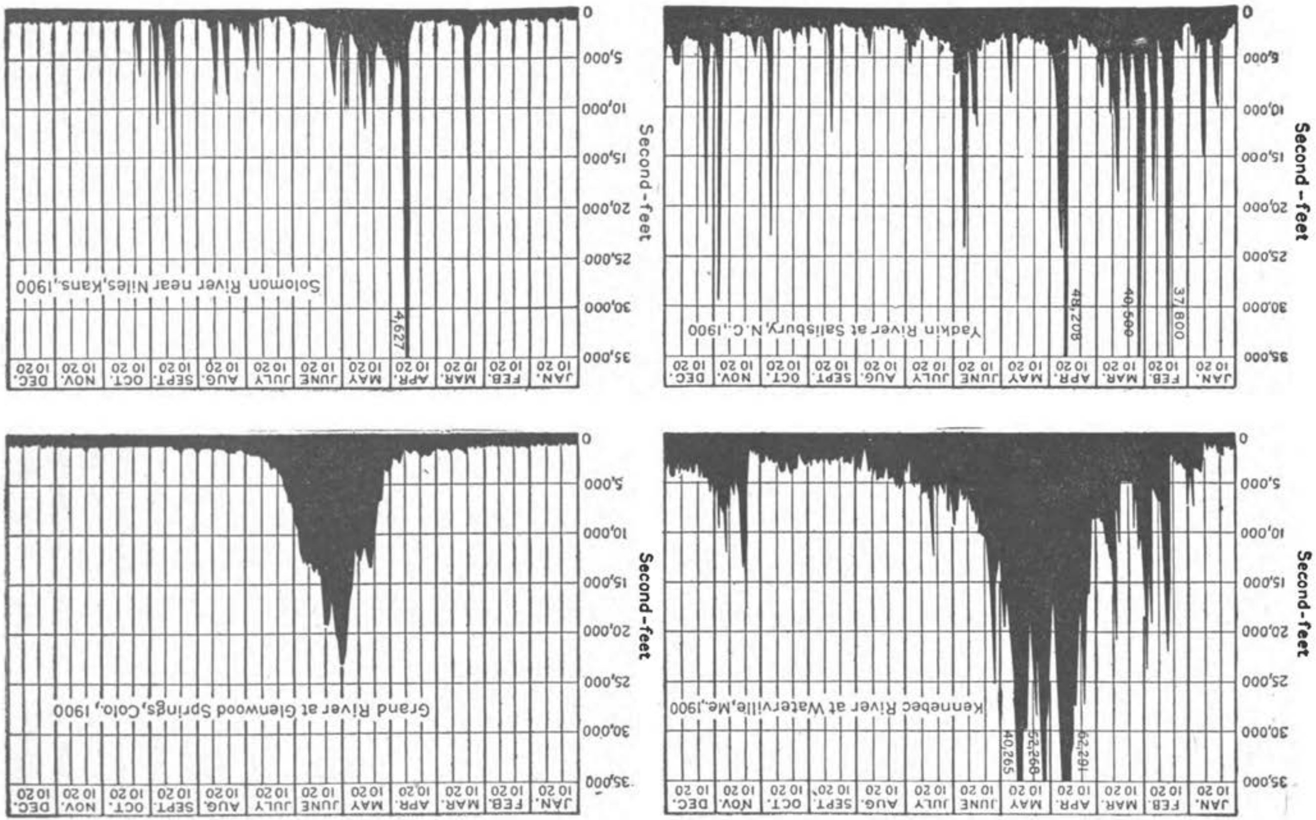


FIGURE 22. Hydrographs of four typical streams, showing volume of flow at times of high and low water. Note that flood time on the Kennebec is during and closely following the spring melting of snow and on the Grand during the maximum melting of snow in the Rocky Mountains. On the Yadkin the floods are well distributed through the year, but show some influence of spring thaw, while on the Soloman high water is confined chiefly to the spring and summer when short violent storms or so-called "cloudbursts" occur. (After Hoyt and Grover, U. S. Geol. Survey.)

to satisfy evaporation and other losses, of which Solomon River, Kansas, is typical, derive their flow from occasional heavy rains that may occur at any season."[2]

Hydrographs of streams representing these four classes are shown in Figure 22.

STREAM FLOW AND ITS COMPLEXITY.

The flow of a stream is not a straightaway forward movement of strands of water along lines parallel with its banks but an intricate and changeable system of cross currents, eddies, and rising, falling, and swirling masses of water. This may be easily illustrated by introducing colored matter into a stream of clear water. Because of the complexity of flow the water of the stream is thoroughly mixed. Even in a straight channel or artificial trough the current is swifter near the middle than at the sides and is swifter near the surface than below. In a channel with bends the movement is more complex. On arriving at a bend, the upper part of the current tends toward the outer bank and the lower toward the inner, thus imparting a twisting motion to the strands of water. This complexity of movement of streams of water has an important geologic bearing, for "the process of suspension depends on the diversity in direction of the strands of the current. If the lines of flow were parallel to the stream bed . . . there would be no suspension. In the sinuous and swirling movements which characterize the flow of streams strands of current are continually passing upward and downward and are as continually dividing and blending. Particles of débris too light to resist the lower elements of the current are swept upward and are retained in the body of the stream through a process analogous to the stirring of the domestic pot. While thus incorporated they are impelled downward by gravity, and all but the very finest actually move downward with reference to the surrounding water. From time to time they may touch the stream bed, but only to be lifted again by the next adequate rush of water."[3]

TYPES OF CHANNEL.

For military purposes the most useful classification of channels is one based on physical character. It is more important to know whether a channel has soft or hard bottom and walls and whether it is shallow or deep than to know its origin and geologic history. Hence

[2] loc. cit.

[3] Gilbert, G. K. U. S. Geol. Surv. Prof. Paper 86. 1914.

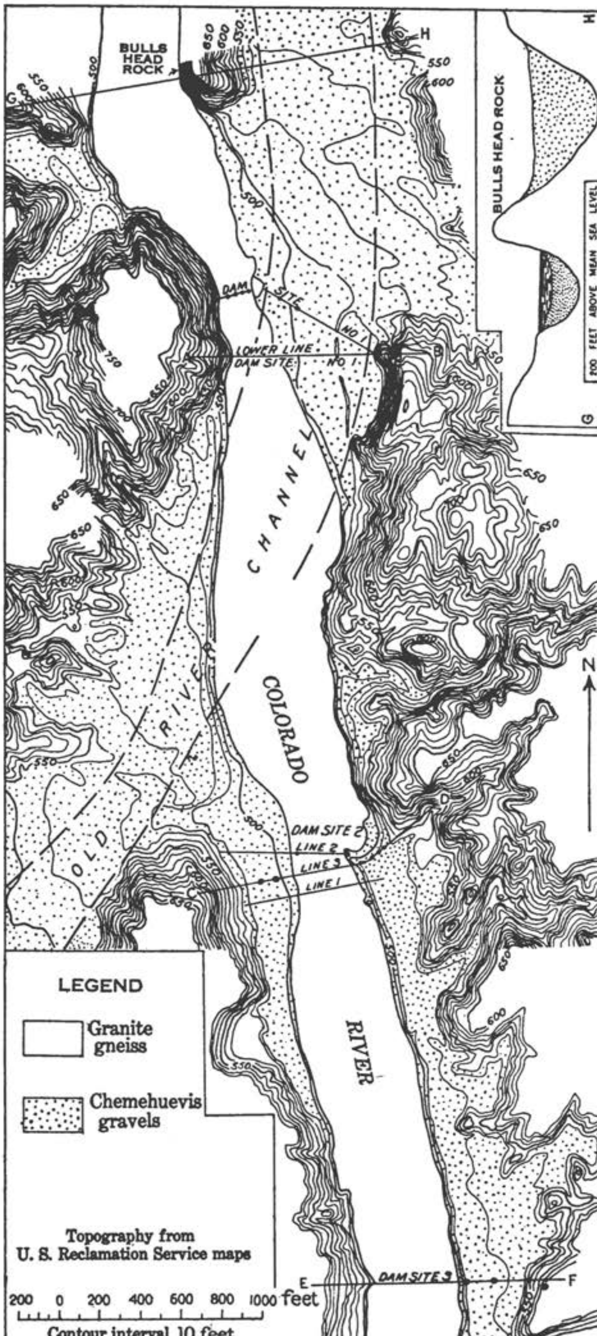


FIGURE 23. Work of Colorado River. Map and section at south end of Pyramid Canyon, showing an old debris-filled channel, a newer superimposed course, and proposed dam sites where drill holes were put down in search for bed rock. (After W. T. Lee, U. S. Geol. Survey.)

the present discussion recognizes two kinds of channels, the rock-walled channels and the alluvial channels.

Rock-walled channels usually but not always confine swift currents, such as most mountainous streams, which are cutting downward into the rock or degrading their bed. In some streams like the lower Colorado (See Figures 23, 24) the down-cutting has been suspended and the rock gorge partly filled with sediment. An alluvial channel

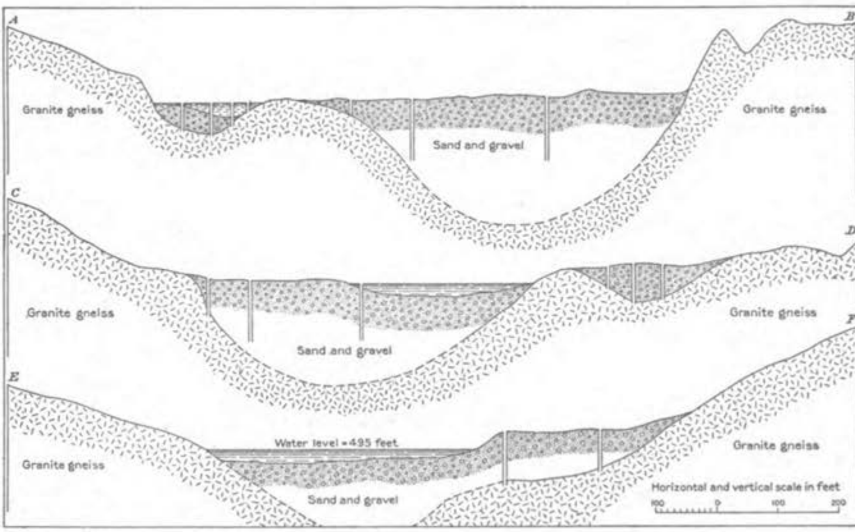


FIGURE 24. Profile sections across Colorado River at the southern end of Pyramid Canyon constructed from the records of drill holes, showing relations of old and new channels. (For location, see Figure 23.) (After W. T. Lee, U. S. Geol. Survey.)

is built up by the stream that occupies it, as described later, and hence is soft both at bottom and sides. Rock-walled channels are relatively permanent, and changes in their form take place slowly. Alluvial channels are changeable. They shift location and form with every flood. These changes are accomplished by a process commonly called "cut and fill." In shifting position the stream cuts away its bank in one place and deposits the material in another. Such shifting channels sometimes leave bridges spanning stretches of dry sand.

DEVELOPMENT OF A RIVER SYSTEM.

A river may develop from a simple beginning into a complicated system of branching streams in much the same way that a growing tree spreads by branching. Rain water falling on a sloping land surface gathers in a depression and flows through it down the slope. The water thus concentrated into a stream wears the surface and starts a gully. (See Figure 26.) This grows in length and in width with each recurring shower. The water entering at the upper end extends the gully up the slope. This is known as *headward* erosion. Water entering laterally starts new gullies in the sides of the older one, and tributary gullies are formed. By headward erosion these in turn are extended, and by the formation of other lateral gullies along the tributaries a dendritic river system is formed. (See Figure 111.)

The rate and manner of development depend on many circumstances, such as the character of the ground drained and the distribution of rainfall. The growing tributaries may interfere with one another. One may push headward and join a neighbor or capture its water by providing a lower outlet. This process is called *stream piracy*. Or one stream may develop in such a manner as to rob the neighbor of its supply and thus prevent further growth or even cause its extinction. A stream draining high land and having a narrow valley and steep slope is said to be *young;* a stream having a broad valley, a flood plain, and a gentle slope is said to be *mature;* and a stream meandering widely over a plain which it has formed either by degradation or aggradation has reached *old age*. A stream may be *rejuvenated*—that is, its gradient may be increased and its flow thereby accelerated—by uplift of the land or by some other "accident," such as tilting of the surface over which it flows, and it may be *superimposed* on land forms which it did not make. A stream flowing in a gorge or narrow valley is said to be *intrenched*. (See Figures 25 and 27.) When a stream develops on a land surface in harmony with its slope, it is said to be *consequent*—that is, the course is developed because of the slope. When a stream has once established a course it tends to persist in that course even though the surface over which it flows is warped or deformed. If the rate of uplift is less than the rate of down-cutting of the stream, the stream persists in its course although that course is not one that would have been developed in consequence of the slope. It is then called an *antecedent* stream, for the establishment of its course antedated the present shape of the surface. (For further discussion of the relation of streams to topography see the chapters on "Land forms" and "Map reading.")

ALINEMENT.

A free stream does not tolerate a straight channel. If a straight channel is provided the current swings from bank to bank, and if the banks yield *meanders* are developed. The meandering habit, the rhythmical swinging from side to side, is most easily acquired by streams flowing between banks of alluvium and on a gentle slope. On nearly flat surfaces of sand and mud streams wind about in an intricate pattern. They meander also in rock-walled channels, but the width of the belts over which they wind is relatively small. The bends in a meandering stream constitute the greater part of its course.

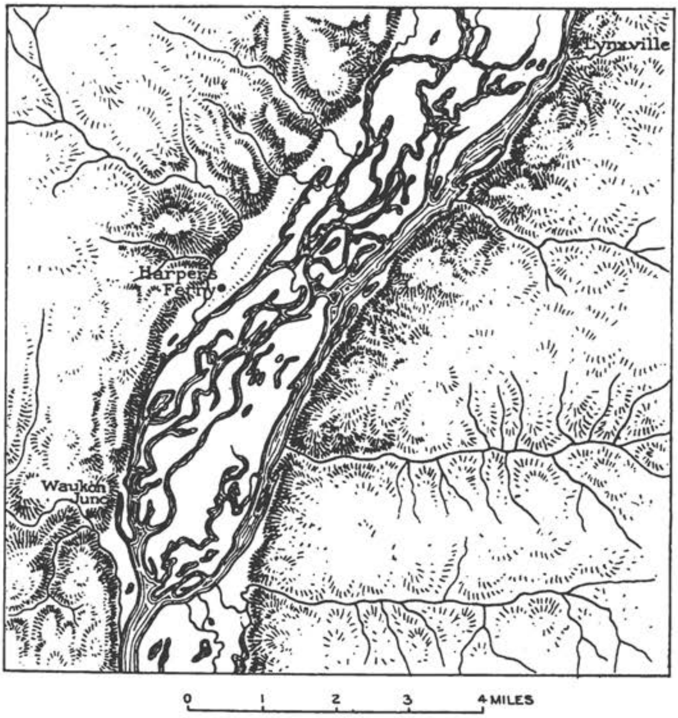


FIGURE 28. A well-developed river flat. Mississippi Valley near Prairie du Chien, Wis. Note the steep confining bluffs and numerous lagoons, crescent lakes, ox-bow cut-offs and abandoned channels, showing various stages of silting.

RELATION OF DISCHARGE TO CHANNEL FORM.

With few exceptions streams form their own channels, and the channels of large and of small streams are similar in form. But the needs of streams vary with the volume of water in them, and a channel to be adequate must be large enough to accommodate a stream at high-water stage. Thus it comes about that most stream channels are during much of the year unnecessarily wide and deep for the streams which occupy them. Many surprisingly large dry channels in arid regions have been formed to accommodate floods which may not recur for months or even years. The stream at low-water stage modifies the channel bed in an effort to fit the bed to its needs, but the work is usually interrupted by another flood. The change in volume of the stream brings about significant changes in the channel bed. (See Figure 28.)

In the development of the channel the cross currents come into play, for the increase in their force where the stream is swift enables them to lift material from the bed and thus deepen the channel. On the

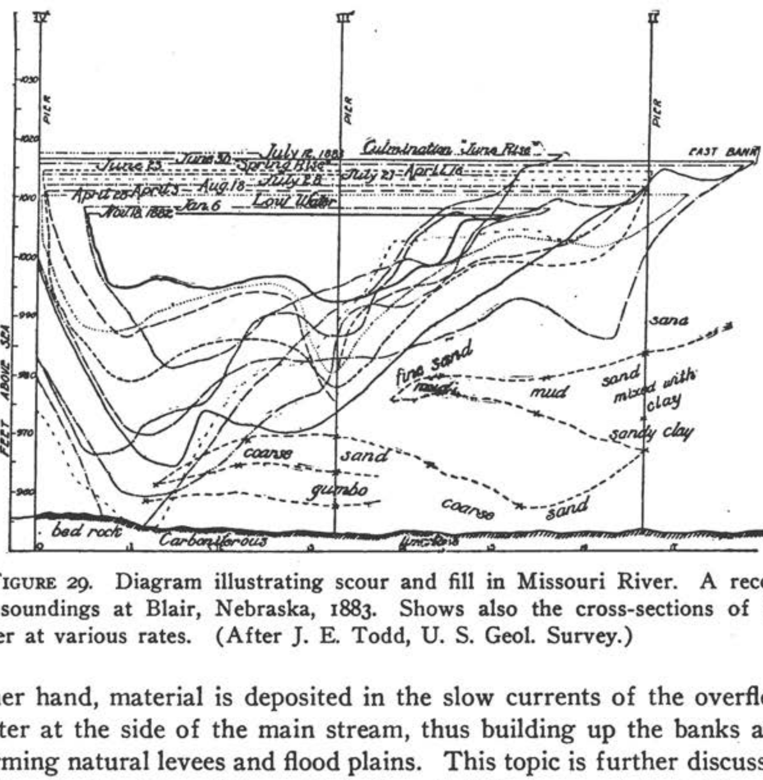


FIGURE 29. Diagram illustrating scour and fill in Missouri River. A record of soundings at Blair, Nebraska, 1883. Shows also the cross-sections of the river at various rates. (After J. E. Todd, U. S. Geol. Survey.)

other hand, material is deposited in the slow currents of the overflow water at the side of the main stream, thus building up the banks and forming natural levees and flood plains. This topic is further discussed under the headings "Degradation" and "Sorting and deposition of material."

The depth of a channel varies with the velocity and volume of the stream. The Missouri River is said to scour to bedrock at Blair (see Figure 29), where extended observations were made on scour and fill. In places where bedrock is farther below the surface the river is believed to scour occasionally to depths of 70 to 90 feet. The material thus cut out may not be moved any great distance: it may be simply stirred. The rising river scours from the deeps to deposit on the shoals, and the falling river scours from the shoals to deposit in the deeps.

FLOODS AND THEIR CONTROL.

As the normal capacity of the channel is adequate only to carry the ordinary flow, floods, or overflows of banks, result from extraordinary conditions that bring to a channel a quantity of water in excess of its normal capacity. All the factors which affect run-off (p. 63) affect also the stage and duration of floods. The chief conditions which favor floods are (1) excessive rainfall, (2) rapid melting of accumulated snow, (3) steep slopes, (4) absence of vegetation suitable to retard run-off, (5) impervious soil, one which has few cracks or other open spaces, or is already saturated with water, or is frozen. An intense rainfall within a small drainage basin causes many disastrous floods. The flood of August 3, 1915, near Erie, Pa., was of this character. "Mill Creek drains an area of 12.9 square miles of such slope and strata as to be favorable to high run-off. After a month, in which the precipitation was nearly 2 inches above normal, 5.77 inches of rain fell in 13 hours, producing a maximum discharge in the creek of about 11,000 second-feet, or at the rate of nearly 1,000 second-feet per square mile." In arid regions concentrated rainfalls ("cloud-bursts") are characteristic and floods are therefore common. In fact, the typical desert stream is a series of torrents of short duration, and its surprisingly large channel, much too large for the dwindling, interrupted stream, is adjusted to the occasional flood. Floods are rare in regions where surface waters may spread widely—for example, the broad, swampy areas of northern Minnesota. Streams fed by lakes likewise are not subject to floods. Niagara River where it leaves Lake Erie cannot vary in height any more than the surface of the lake. Two feet a year would be extreme.

Measures taken to combat floods fall into two classes, flood *prevention* and flood *control*. Preventive measures are based on plans for increasing percolation or retarding run-off. They include, among other things, the preservation of forests and grass on steep slopes, thus preserving the soil cover also; the drainage of lands, thus reducing the chances of a heavy rain finding the soil already full; plowing on horizontal lines ("contour plowing") instead of up and down hill; and the construction of large reservoirs from which the quickly accumulated water may be released slowly. Measures to control or regulate floods include such devices as the straightening of channels to insure more prompt discharge, the building of levees, and the local deepening of channels.

INDICATORS OF FLOODS.

In a well-known region the extent of flooding is determined by observation at flood times, but for regions that are not well-known records of continuous observation are not available. In their absence a variety of methods may be used, including observations on floated material, such as driftwood, stranded at times of high water; coloration, or so-called "water lines," on rock walls; evidence of wave erosion and lateral stream cutting during high water; and plant growth.

The ordinary flood plain or area covered at times of flood with standing or slow-moving water is not the only kind of plain on which travel is made difficult during wet seasons. Many of the nearly flat, poorly drained areas in the semi-arid Southwest become almost impassable during times of heavy precipitation, not because the surface is covered with standing water, but because the rain water which cannot escape as run-off so softens the surface of the plain as to make it virtually a temporary bog. The heavier rains on such a plain wash the fine material into the lower portions, which in consequence remain boggy longer than the higher portions. In many places where the difference in surface elevation is not sufficient to be apparent to the eye, the lower places may be recognized by the character of the growing plants, and soft ground may thus be avoided. For example, stunted sagebrush may be found on the higher ground and bunch grass on the lower.

The relation of plant growth to flood time and to character of land surface might be worked out with considerable accuracy, but until definite determinations have been made plants can be used only in a general way for this purpose. A luxuriant growth of trees and shrubs along an intermittent stream or on portions of a plain may indicate only that their roots reach ground water. But if a rank growth of plants having no great length of root is found the inference is safe that the surface of the ground is habitually wetted. For example, the annual overflow of the Colorado River in Arizona and California spreads out sheets of silt each year in certain places. On this silt springs up each summer a sparse growth of certain plants from seeds deposited by the floods. Some of the shrubs, however, notably those of the kind there called "arrow weed," succeed in maintaining themselves even though the surface on which they first took root may be buried under several feet of silt.

WORK OF STREAMS.

STREAM LOAD.

The débris supplied to a stream from the wasting of the rocks constitutes its load. Some of this material is carried in solution and some in suspension. These make up the *suspended load*. Still other parts are dragged over the stream bed and form the *tractional load*. Some of the tractional load is taken into suspension when the carrying power of a stream increases, and some of the suspended load becomes tractional when the carrying power diminishes. On these principles depend the character of a stream, whether it is one that cuts down its bed or one that builds it up. When the débris supplied to a stream is less than its capacity for carrying load the stream abrades its bed and is said to be a *corrading, down-cutting,* or *degrading* stream. Whenever and wherever a stream's capacity to carry load is overtaxed it drops débris, builds up its bed, and is said to be an *alluvial* or *aggrading* stream.

TRANSPORTATION.

Streams transport their load in three ways—in solution, in suspension, and by traction. Large streams carry most of their load in suspension and a small part of it by traction, but many small streams carry it chiefly by traction. Some streams need all their power to transport their load; others have power not expended in this way to degrade their channels. Some receive more load than they can carry and must drop part of it and thus aggrade their channels. Where the power of a stream is just sufficient to forward its load the stream is *at grade* and can neither cut nor build.

The amount of mineral matter carried in solution depends upon the solubility of the rocks drained. Limestone contributes the largest amount, and water containing lime carbonate in solution is said to be "hard." Other easily soluble but less common rocks are salt and gypsum. Salt River in Arizona takes its name from the salty character of its water, and gypsum sinks and caves are numerous in some places, as in parts of New Mexico. Streams which gather their waters from areas of crystalline rock, like the Adirondacks and Rocky Mountains, carry little mineral matter in solution, and their waters are said to be "soft." In arid regions various kinds of alkali are carried in solution. Generally speaking, streams of arid regions contain more mineral matter per unit of water than streams of humid regions, partly because the greater evaporation has concentrated the solution.

With few exceptions river waters are not clear, and some streams, like the Missouri and the Colorado, are nearly always brown. The amount of mud carried is enormous. Ohio River carries 230 parts of mud in 1,000,000 parts of water, and nearly a ton of mud passes Cincinnati in this way every second.

No figures are available for the tractional load of streams, but the quantities of sand and gravel along stream courses indicate that this part of the burden is large. The range of dissolved and suspended load is illustrated in the accompanying table. Gila River in Arizona, said to be the muddiest river in the world, is about 50 per cent. muddier than the Colorado, but figures are not available showing its load. The Mississippi River carries annually to the sea about as great a load as that carried by all the freight trains of the United States. Its burden for one year would cover one square mile to a depth of 370 feet.

Illustrations of load carried by streams.

	Dissolved load, parts per million.	Suspended load, parts per million.
Androscoggin River at Brunswick, Me.	42	trace
Hudson River at Hudson, N. Y.	108	16
Missouri River at Kansas City, Mo.	426	2,032
Colorado River at Yuma, Ariz.[4]	707	6,964[5]

DEGRADATION.

Clear water has little ability to wear away rock; hence clear streams do little work. But few streams are clear at all times. Each particle of rock carried in the form of silt or sand (suspended load) or dragged over the bed (tractional load) grinds the floor or walls of the channel to a minute extent, and the stream carrying myriads of these particles acts like a ribbon of sandpaper, slowly cutting downward. (See Figure 30.) Turbid streams of steep slope grind rapidly and produce rock-walled canyons and gorges. If, in its down-cutting, the stream

[4] The load of matter in solution carried to the sea each day by Colorado River ranges from 10,300 to 175,000 tons, and the load of suspended matter carried each day ranges from 7,500 to 6,250,000 tons.

[5] Average for 9 years.

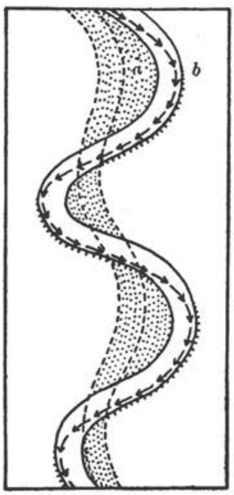
encounters a local obstruction, such as a mass of unusually hard rock, a fall or rapid may be formed. The limit of down-cutting is the level of the sea or other body of water into which the stream empties—except that owing to cross currents the bed of the stream may be lowered slightly below sea level. The down-cutting continues theoretically until the whole channel is reduced to sea level (base-level), but practically it ceases when the stream reaches so low a slope that it can just carry its load and can expend no energy in down-cutting—in other words, when the stream reaches grade.

In military maneuvers the ability to determine, without investigation of the ground, whether a stream is cutting or building its bed may be of great value. In general, a stream having a steep slope and walls close together, features which may be determined from a good map, is likely to be down-cutting. Such a stream will probably furnish good fords and rock bottom near the surface, as well as solid rock bluffs, suitable for bridge heads. There may even be rock islands and lines of so-called "stepping stones," due to uneven corrasion of unusually hard layers outcropping in the stream bed. Such lines of outcrop are familiar in some places in the Delaware and Susquehanna rivers.

AGGRADATION.

An alluvial stream is usually an aggrading or up-building stream, because some of the material held in suspension is dropped when the velocity of the stream is checked. In its simplest form aggradation results in building up the bed of the stream. This is done unevenly, depending on varying velocity of current. Sandy parts of the bed built up higher than other parts are called *sand bars*. In a winding stream these are usually narrow and are neither parallel with nor at right angles to the medial line of the water. They tend to run from the inner bank of one curve to the inner bank of the next one. In alluvial streams with flat bends separated by long straight stretches, the bars are broad and may occupy the entire width of the channel and form the "crossings" of navigable rivers. A stream whose velocity is checked by the spreading of flood waters beyond the banks is bordered by an alluvial plain called a *flood plain,* which is built up of successive deposits from the suspended load. An alluvial stream having a relatively straight channel is known as a *direct alluvial* stream, and one which develops a winding course over the plain is called a *meandering* stream.

An up-building stream may usually be recognized by low slope and broad, low bottom lands, meandering course, and confining bluffs far apart. In such a stream fords are likely to be soft and crossings difficult, for bedrock is not near the surface, and the bluffs are likely to be composed of loose materials unsuitable for bridge heads. An aggrading stream bed may constitute as formidable a barrier to traffic as a canyon. Both kinds of barrier are well illustrated by Colorado River, which has cut impassable canyons in the highlands and filled the valleys along its lower reaches with loose gravel, sand, and silt that render crossings treacherous and bridge anchorage insecure. It



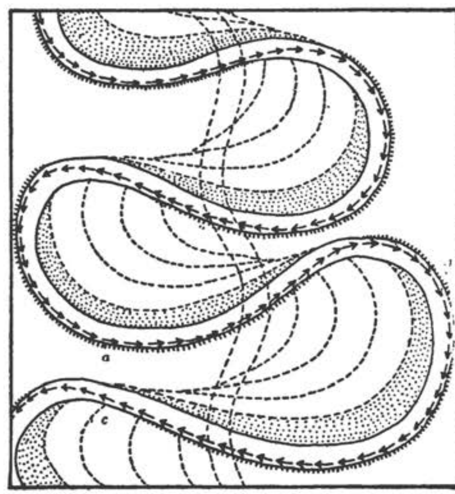


FIGURE 32. Diagram illustrating an early stage in the development of river meanders. The dotted area represents the area over which the stream has worked.

FIGURE 33. A later stage in the development of meanders. (After Salisbury.)

is almost as difficult to construct a railroad through the filled basins as across the deep canyons. (See Figures 23 and 24.)

A stream normally develops a winding course and normally cuts on the outer side of a curve, depositing material on the inner side. In a rock channel this cutting is done by corrasion, when the suspended particles impinge against the walls, and rock bluffs result. In poorly consolidated material the stream may produce cut banks by undermining the bluffs. (See Figure 31.) The side cutting produces a winding course in which the river is said to meander. (See Figure

FIGURE 34. Flood plain characteristics.—Mississippi River near Vicksburg, Miss., and its plain built against the dissected highlands to the east which rise 150 to 250 feet above it. Note: (1) The meandering course of the river; (2) its change of course since the interstate boundary was fixed; (3) recently abandoned channels, as Paw Paw Chute and Old Channel; (4) bayous, as Wilton Bayou; (5) ox-bow cut-offs, as that at DeSoto Island; (6) crescent lakes, as Long Lake; (7) artificial channels, as Yazoo River Diversion Canal and Grant's attempted diversion of the river near Delta; (8) cut-banks near Vicksburg; (9) artificial banks or levees near Delta; (10) deposition on the inner side of the curve, as south of Delta; (11) "Made land," or islands of deposition in the river; (12) concentric ridges and silted hollows near Wilton Bayou, representing lateral migration of the channel; (13) swampy lowlands recently abandoned by the river and imperfectly silted.

27.) The tendency is the same whether the rock is hard or soft. In the course of lateral cutting a stream may straighten itself in places by cutting across a narrow neck (See Figures 32 and 33), leaving along its former course "ox-bow cut-offs," lagoons, crescent lakes, and abandoned channels of various forms, as well as low marshy flats, in which the filled deeps now abandoned by the stream are especially boggy.

Characteristics of a flood-plain.—Because of the importance of low-lying plains in military operations, an understanding of their features is as essential as that of the characteristics of rocky highlands. From the manner in which these plains are formed it is obvious that there are two principal types—those having rock floors, at least in some places, and those whose floors consist wholly of soft beds. Those of the first type are relatively rare and are characterized by low rocky "islands" and shallow abandoned channels and mud-filled hollows. Those of the second type are common and consist of nearly level areas of packed silt separated by irregularly shaped marshy areas. The packed silt is relatively firm when dry but is easily worked up into bogs when wet. The marshes are soft and may represent any stage of silting from a body of muddy water recently derived from the stream to the well-silted hollow. The surface features of such a plain can be illustrated (See Figure 34) better than described, and its characteristics may best be realized from a knowledge of the manner in which such flood plains are formed, which is set forth above.

SORTING AND DEPOSITION OF MATERIAL.

As the ability of a stream to carry its load changes with velocity of the current, the checking of velocity in a loaded stream causes it to drop some of its load. The velocity may be checked in several ways, as by lessened slope, by islands and other obstructions such as ice jams, or by spreading over shallows in broad parts of the stream or over flood plain. Also, the volume may decrease, as in a stream whose water is diverted for irrigation, like the South Platte in eastern Colorado, whose entire flow is so used; or in a stream which flows through long stretches where for any reason it loses more than it receives, as the Nile, which loses five-sixths of its volume before reaching its delta; or in a desert stream, like many in the Southwestern States, which lose their entire volume of flow by evaporation or absorption into the loose valley filling. Also the carrying power of a stream may be lessened because of its subdivision into smaller streams, as the distributaries on a delta or the interlacing portions of a braided stream. (See Figures 35 and 36.)

As the velocity of a loaded stream is checked the material of the load is dropped in order from coarsest to finest. Coarse sand and gravel lodge in the channel where the current is relatively swift, while the fine sand and silt are distributed over the flood plain. It thus happens that a stream may have firm banks and bed while its flood

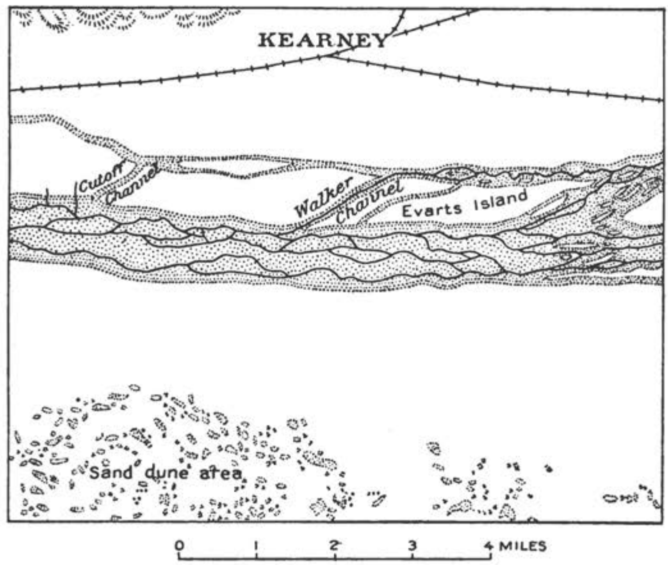


FIGURE 35. A braided stream. Platte River in the broad alluvial valley near Kearney, Nebr. A mile-wide sandy channel filled with water only at flood time. Over the bottom during most of the year a little water not diverted for irrigation percolates through the sand or finds its way in a tortuous course through a series of interlacing channels whose pattern changes with every flood. Northwest winds here lift the sand from the channel, sweep it across a grassy plain and pile it in dunes nearly two miles south of the river. (From Kearney, Nebr., topographic sheet, U. S. Geol. Survey.)

plain is boggy. The mud carried out over the plain sometimes forms beds of clay almost impervious to water. During dry weather such beds may appear firm but in reality be impassable because they are so soft immediately beneath the surface that they may be quickly worked up into bogs. Under certain conditions beds of sand may be similarly treacherous. A fine sand consisting of well-rounded grains that is saturated with water may be readily mobile or as easily displaced by mud and is known as *quicksand*. Such beds are often founded in streams but are not confined to the stream channel. Caution is necessary in crossing beds of wet sand and of soft clay even when the surface is dry, because there may be no surficial evidence of their presence.

GRADING.

As an underloaded stream cuts its channel and an overloaded stream builds it up, there is a constant tendency for a stream to establish an equilibrium—that is, a slope at which it will neither cut nor deposit. In parts of its course steeper than the average the velocity increases and cutting takes place; in parts less steep than the average the velocity diminishes and deposition takes place. When equilibrium is established and the stream neither cuts down nor builds up its bed it is at grade.

A degrading or down-cutting stream does destructional work. It is tearing down the land, forming gorges, canyons, falls, and various obstructions that acts as barriers to travel. (See Figure 37.) But later it forms valleys, which are graded routes favorable for lines of travel parallel to the stream; still later it forms graded plains, which offer little obstruction to travel in any direction; and in the end it produces on these graded plains marshes, which constitute barriers as difficult to overcome as the steep-walled young valleys formed in the early stages of its cycle of erosion.

An aggrading or up-building stream produces similar results in a very different way. It tends to produce graded plains by filling the valleys and burying the hills, as in the Southwestern States, where old valleys have been filled with sand and gravel to depths of more than 1,000 feet. (See Figure 24.) Such filling may be consolidated into hard rock, or it may remain unconsolidated, as in the ancient valley of the Rio Grande in northern Mexico and southern New Mexico. During the military operations there it was found that roads were not improved by grading because the gravelly, wind-sorted material at the surface—the "desert crust"—is harder than the sand underneath the crust.

A generally degrading stream does not cut in all places alike, nor does a generally aggrading stream build up in all places along its course. In most streams there is more or less cut and fill. The constant shifting of the stream course and of the material along it is likely to force quick decisions during an expedition. Changes effected in stream channels and on flood plains during times of high water are too familiar to need more than mention here. Washouts occur and deeps are filled, banks cave and bridge heads are ruined, fords change position, bars shift, and the channel changes in profile. (See Figures 28, 29, 34.)

PRACTICAL CONSIDERATIONS.

Many of the results of stream cutting and stream building are so obviously applicable to military uses that they scarcely need mention, for streams have formed the naturally graded highways now utilized by lines of traffic, such as the Susquehanna, which has cut a passageway through the Appalachian Mountains. (See also the description of the Rhine, on p. 87.) On the other hand, streams set barriers to communication. This is accomplished in two conspicuous ways—by digging deep trenches such as those of the Hudson and the Rhine and by building flood plains in which marshy conditions may be set up. It was the natural barriers of marsh and scarp formed by the Meuse, rather than any artificial fortifications, that proved disastrous to the Germans during the memorable battle of Verdun.

The tendency of a meandering stream to straighten itself by making ox-bow cut-offs suggests that this might be done artificially in favorable places, as Grant attempted to do in an unfavorable place before Vicksburg. (See Figure 34.) His failure to divert the Mississippi River illustrates the difficulty, well known to hydraulic engineers, of directing or controlling a stream. However, that diversion of a large stream is not impossible, though difficult and expensive, is shown by the million-dollar job of turning the Colorado River back into the channel which it left to enter Salton Sea. The manner in which stream flow may be controlled is well illustrated by several of the rivers in central Europe which have been transformed into important avenues of traffic.

For present purposes perhaps minor applications of principle are more useful than the major applications—for example, the quick selection of a place to ford a stream or the determination whether bluffs are sufficiently strong to support bridges or whether bedrock is to be expected close enough to the surface to make bridge building possible.

As fine material is deposited in slow currents and coarse material in swift ones, the swifter parts of a stream are likely to drop gravel and form ripples where good fords may be expected, while the broader areas of slow water are likely to cover soft material. In a swift mountain stream, however, the ripples are formed by accumulations of boulders which make fording difficult, while in its quieter portions the stream may deposit sufficiently coarse material to make good crossings.

Fords across down-cutting streams bear an evident relation to grading. Relatively shallow water, solid bottoms, and solid banks go together where rapids have been nearly but not quite effaced. But this applies only to one stage of the stream's development—the stage when it is approximately graded. Such moderately steep places in a stream's profile may be indicated by ripples, because the water, being shallower, flows faster. Perhaps suitable places for fording are selected more frequently from such rippling than from anything else, the best crossing being just above the ripples. It is plain that the advantage of smaller depth is to some extent counterbalanced by greater velocity. A rough but serviceable rule is that the depth in feet multiplied by the velocity in miles per hour should not exceed 8.

The profiles of aggrading streams are characteristically smooth and uniform. The one conspicuous exception is where a recent cut-off has occurred by the intersection of meanders. Then for a short time all the fall which was formerly distributed over a large ox-bow is concentrated in the short cut-off. There may even be a faint rapids, causing all finer materials to be washed away, leaving only gravel in the channel. The relation of this condition to the fording of a meandering stream is evident. The depth is less and the bottom firm. Moreover, as cut-offs are relatively straight, the current is not concentrated along one bank, as in the ox-bows, hence the steep bank is wanting.

The safety of a ford may depend upon the carrying power of the stream. Sudden swift currents sometimes carry cobbles and small boulders at such velocity as to cripple animals and break spokes out of wheels. The buoyancy of muddy water is greater than that of clear water, and the carrying power increases with velocity. The energy (striking force) of the water increases as the square of the velocity—that is, if the velocity is doubled the striking force is quadrupled, and a three-fold velocity means a nine-fold striking force. Water with double velocity and four-fold striking force can therefore push a stone of four times the weight of the original. The weight of such a stone is 4 x 4 x 4 or 64 times that of the original.

The rate and direction of the flow of a stream are of prime importance in the construction of pontoon bridges. As the force of the current is directed against the floating pontoons, it follows that a crossing where the current is slow is more favorable than where it is swift. On the other hand, where the current is slow the channel is likely to be wide and to require a greater length of bridge. Also a bridge constructed directly across the current at right angles to the direction of flow sustains the force of the stream better than one built diagonal to the direction of flow.

The character of the approach to a ford may often be judged by the character of the plant growth, in the same manner as that of habitually flooded areas. No one would think of fording a stream bordered with tule marshes. On the other hand, a stream bordered by tuft-grass marshes might be forded in favorable places, and a stream bordered by grassy slopes which extend to the water's edge is likely to have good crossings. Streams like many on the Atlantic Coastal Plain are fed chiefly by seeps and springs which issue from the banks. The seepage water on its way to the stream keeps the bottom land soft and swampy, even when the bottoms consist of sand. Along many of these streams dense undergrowth and thick stands of rank plants of annual growth warn the observer of soft bottom lands.

The determination without experimental sounding of the character of bottoms as foundations for piers and of banks for bridge abutments is difficult and involves a broad knowledge of physiographic principles, but these principles are fully competent to point the way for intelligent experimental work. Examination along the lower part of the Colorado River indicated that the stream is now building up the surface along its course, or that it has done so in relatively recent time, and that there is an old débris-filled channel now abandoned and a new one, rock-walled in places, where the river left its former course. It was foreseen that bedrock was far beneath the surface in the abandoned débris-filled channel and near the surface in the new channel. This was proved by the drill (See Figure 23).

Similar abandoned stream courses are common in glaciated regions. In areas formerly covered with glacial ice filled channels may occur where there is no surface indication of their presence. In many places these buried channels are sources of underground water supply. Water percolating slowly through the filling into surface depressions produces bogs and marshes. Even where the surface is dry and reasonably firm the filling of the channel may be soft and cause annoyance to the construction engineer. Such a channel at Nicholson, Pa., was especially troublesome and expensive. A solid-rock base was necessary for the piers of the great viaduct of reinforced concrete by which the Delaware, Lackawanna & Western Railroad crosses Tunkhannock Valley. The plans adopted called for one of the central piers at a point which proved to be in a filled channel. The soft filling was so troublesome that the engineer's skill was severely taxed before a proper foundation was secured, at great expense and loss of time.

STREAMS AS NATURAL HIGHWAYS.

The tendency of streams to grade their course makes them excellent builders of highways. Not only do they cut passageways through rough country, as instanced by the passage of the Susquehanna River through the Appalachian Mountains, but to some extent they produce the power for traffic, as in lumber regions where logs are floated down streams to the mills. The use of large streams for navigation is familiar, and their growing use as producers of power through electric transmission is well known. But the use of shallow streams and of intermittent streams is not so familiar.

A stream so shallow as to be little more than a thin sheet of water over wet sand may be navigated by specially constructed boats such as are used on the Nile, which virtually dig a temporary channel in which they progress. Streams too shallow for boats may be used as highways for the hydroplane recently constructed by a South American inventor, which is a flat boat with airplane propeller, designed to glide over the surface of the water. In cold climates frozen streams may become highways. Some swamps and bogs are traversed when frozen in winter, although they are impassable at other seasons.

In some rough, sparsely settled regions the stream channels are the only possible lines over which wheeled vehicles can be taken. In some semi-arid regions the beds of intermittent streams are used as roads, in spite of the danger of sudden floods, which sometimes sweep unheralded down their channels. In sharp contrast with such rude avenues of communication, the river Rhine is well known for its highly developed routes of transportation and the gorge for its natural means of defense. The precipitous walls, famous for their ruined castles, look down on a great, swiftly flowing river which from earliest recorded time has been one of the important lines of traffic in western Europe. At the present time, aside from the steamboat route on the river itself, two railways and two auto roads parallel the stream.

STREAMS AS LINES OF DEFENSE.

"The two ends of the Rhine trench are guarded by Mainz and Cologne, two of the strongest fortified cities in Germany; while near the middle stands the strong fortress of Coblenz. Here, then, is a

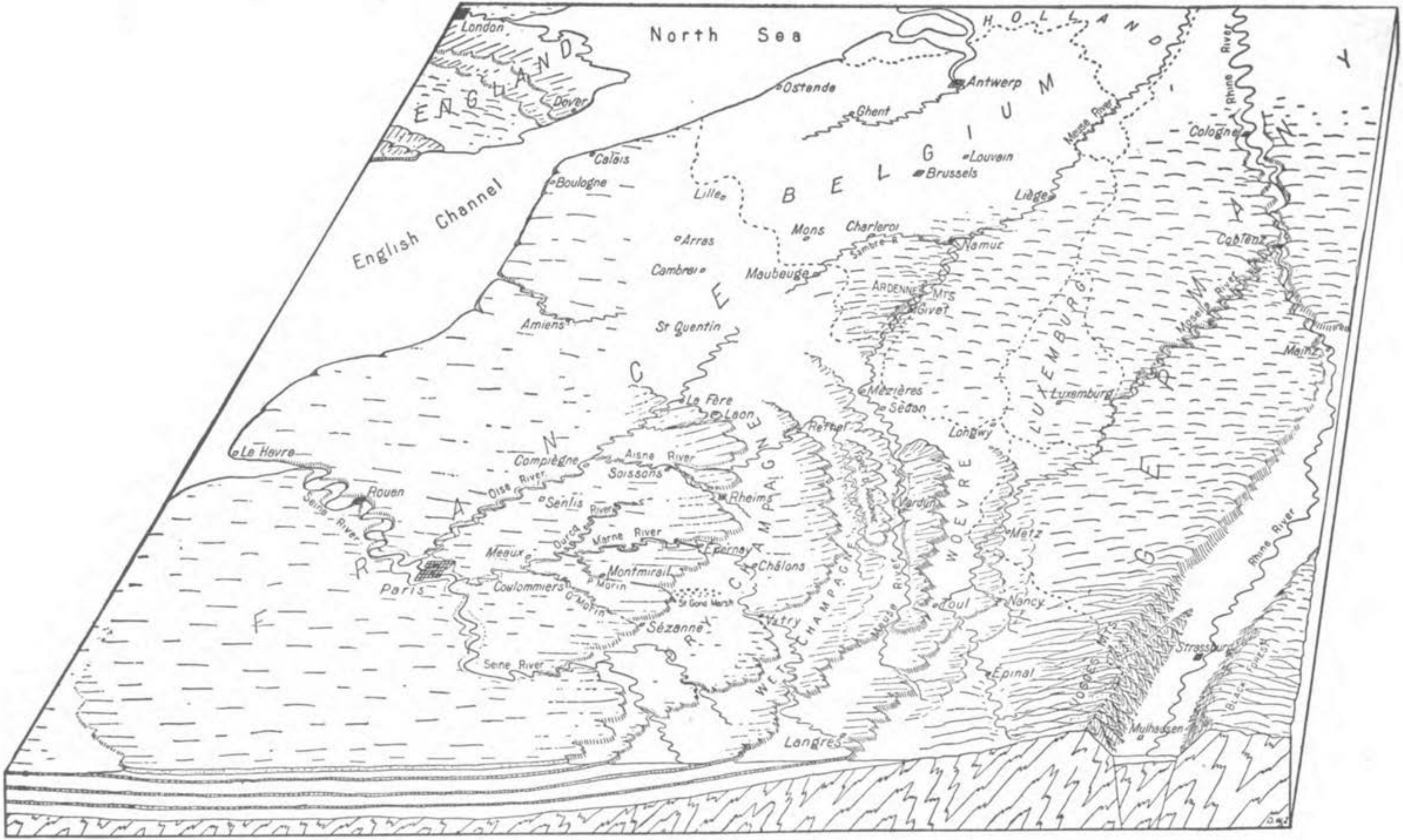


FIGURE 38. Diagrammatic view of the theater of war in France and Belgium, showing the principal plateaus and plains, mountains and lowlands, cliff scarps and river trenches which have influenced military operations. The underground rock structure is shown in the front edge of the block. (After D. W. Johnson.)

natural moat of impressive dimensions, carrying a swift, deep river and heavily fortified at its most accessible points. German armies retreating from Belgium in the north could hope to check, along this trench, the most vigorous assaults of a pursuing enemy. Thus far, however, we are concerned with the Rhine trench as a line of communication connecting central Germany with military bases in the west from which attacks on France could most conveniently be launched. It is evident that two armies with headquarters at Coblenz and Cologne, and supplied by the railways, auto roads, and steamer routes which pass through the Rhine gorge, could attack France simultaneously if one ascended the Moselle to Luxemburg and the other passed from Cologne westward around the north side of the hilly country to the Meuse and then followed southward up that valley. Hence it was that in the early weeks of the war we heard much of the 'army of the Moselle' and the 'army of the Meuse'; and the capture of Liège, Huy, Namur, Dinant, and Givet marked the progress of the latter army along the best pathway through the Ardennes." (D. W. Johnson.)

Farther west two tributaries of the Rhine, the Moselle and the Meuse, cut deep trenches across an upland. As shown on the map, Figure 38, the meandering Moselle gorge forms a pathway through a broad mountain barrier. It served as a line of communication for the German army of invasion. The gorge of the Meuse, likewise, is a great natural highway through the heart of the Ardennes Mountains. As lines of defense the sharply cut valleys of the Meuse and the Sambre afford obvious advantages.

FEATURES DUE TO STREAM WORK.

The tendency of streams is to tear down the uplands and sweep them into the sea. This they would accomplish in time except for uplifts, which set new tasks for them. Computations based on the determined load of streams indicate that the rivers of the United States carry to the sea each year about 783,000,000 tons of rock waste, or enough to cause an average lowering of the surface one foot in 9,120 years. In another estimate it is stated that the rivers of the world carry to the sea each year 6,500 cubic miles of rock material. The amount of loose material on its way to the sea is many times greater than this, for large amounts of the material are dropped along the streams to form either temporary or more or less permanent deposits.

The land forms described in Chapter VI result largely from the activity of streams. The degrading or down-cutting stream excavates a gulch that is enlarged to a valley, which varies in form from gorge or canyon to the broad excavations of gentle slope called "open valleys." Rapid down-cutting is likely to produce canyons, and slow down-cutting open valleys. If the down-cutting is intermittent because of land movement or obstruction to stream flow, terraces or benches may be formed in the walls. Benches may also be formed on hard layers of stratified rock which are separated by beds of soft rock. Hard layers may likewise cause falls and rapids to develop. In regions of soluble rock, such as salt, gypsum, or limestone, streams may disappear from the surface and work entirely underground. Surface sinks may form in such regions by the collapse of cavern roofs. (See Figure 18.)

As the tendency of a stream is toward a winding course. it cuts laterally. As it approaches grade the down-cutting diminishes and the lateral cutting becomes increasingly apparent. Ox-bow cut-offs in a degrading stream may form isolated "islands" of rock, or outliers, standing above the general level of the valley floor. As the stream changes its course it swings from side to side of the valley, cutting the confining bluffs down to grade and forming a peneplain. (See Figure 39 and p. 182.) Where the plains formed by several streams meet laterally, a broad graded plain may be formed, such as the Great Plains east of the Rocky Mountains. The final possible result, which is never quite reached, is the base-level, or a sea-level plain.

The land forms produced by aggrading streams are very different in character but no less important in military operations than those produced by degrading streams. A boggy plain may form a barrier as difficult for an army as a steep-walled gorge. The difficulty of transporting guns and heavy equipment across marshes or even dry plains composed of soft material suggests possibilities of defense where water can be diverted onto low lands. Large areas in the Mississippi Valley might be flooded in seasons of high water, and still larger areas made so soft in places as to render military maneuvers difficult. An army operating in an irrigated district might be greatly embarrassed by relatively small quantities of water so diverted that portions of the surface would be softened.

The extent to which diversion of water may interfere with military operations was well illustrated in Flanders in the early part of the

Great War. On the low, wet Flanders plain is an endless system of ditches by which the marshy soil is drained, and streams are confined by artificial levees. Over this plain the German infantry made slow and painful progress until the dikes of the Yser were opened and the plain was flooded. This ended the Germans' best efforts to plant their guns on the edge of the Strait of Dover. The marshes of Flanders were as impregnable as fortified walls of rock.

INFLUENCE OF DEGRADATION.

The influence on military operations of land forms due to the down-cutting of streams is well illustrated by the uses made of so-called "gateways" or narrow, rock-walled openings where for any reason a narrow passageway has been cut through highlands. Familiar examples are found in the Water Gap on Delaware River and the Royal Gorge in Colorado. In the western theater of the Great War several gorges cut by rivers through the ridges east of the Paris Basin (see Figure 38) have proved to be of prime importance in the military operations. These passages at Metz, Nancy, Verdun, and many other places tempted the invading Germans and offered adequate means of defense for the French. Metz and Nancy guard gateways cut through escarpments. The first line of cliffs east of Paris is cut by gateways at La Fère, Laon, Rheims, Epernay, and Sézanne. At passages through the second line of cliffs stand Rethel and Vitry. The gateways at Verdun and Toul are strongly guarded by fortifications which dominate roads, canals, and railway lines. (See Figure 38.)[6]

INFLUENCE OF AGGRADATION.

Many an illustration might be given of the influence of soft ground on military operations. The swamps of the Woevre and the meanders of the Meuse played an important part in the battle of Verdun. The plain of the Woevre in winter and early spring, the time when the great struggle was at its height, is practically impassable for large bodies of troops because of poor drainage. Here in the bogs and marshes the hosts of Prussian militarism fairly tested the strength of the natural defenses of Paris and went down in defeat.

Also marshy lowlands played an important part in the defense of

[6] The influence of the valleys and passes of France on the conduct of the Great War is fully discussed in "Topography and strategy of the war," by Douglas W. Johnson.

Verdun during the attack from the north. The Meuse River occupies an intrenched valley. Over its flood plain the meandering stream swings from side to side, causing the invading Germans to cross it in many places. "German troops once in possession of the meander spurs sometimes found themselves in a natural trap. On more than one occasion a swift French counter stroke was so planned as to sweep across the neck of a meander spur, thus imprisoning large bodies of German troops on a peninsula surrounded on three sides by an unfordable stream. It was by this maneuver that the French made their largest captures of German prisoners."

CHAPTER IV.

LAKES AND SWAMPS.

LAKES.

LAKES[1] may act as waterways or as barriers in military manœuvers; they may be desirable or undesirable. In the Revolutionary War and the War of 1812 large flotillas transported troops on Lake Champlain, and on the waters of this lake battles were fought whose outcome was of great moment in our history. Lakes Erie and Ontario were also important portions of our military frontiers in the naval battles of the War of 1812. Where lakes and marshes are interspersed, as in the Masurian Lake region of East Prussia, they are features of the greatest military significance. The lakes which play and have played important parts in military operations do not all have the same characteristics nor the same origin, and as the characteristics of many lakes may be foretold with a considerable degree of accuracy if their origin is known in advance it is desirable that lakes be considered from this point of view.

Glacial lakes.—During the glacial period ice sheets advancing from the north covered large parts of the earth. The southern margin of the ice sheets in North America extended from Long Island westward through New Jersey, Pennsylvania, Ohio, Indiana, Illinois, Missouri, Kansas, Nebraska, South Dakota, North Dakota, Montana, Idaho, and Washington. In Europe the ice covered most of Great Britain, Scandinavia, northern Germany, and northern Russia. The Alps and most other high mountain areas were also buried by the ice sheet. The glaciers remodeled the landscape and produced many basins, some of them dug into rock, others formed by depositing material unevenly over the surface. Upon the retreat of the glaciers these basins became filled with water, forming thousands of lakes. In fact the most common lakes are those of glacial origin, and the regions of numerous lakes are the regions formerly occupied by ice.

Most of the larger lakes in a region of glacial drift are irregular in outline, and their shores are marked by marshy flats (see "Swamps")

[1] The term *lake* is used broadly to mean a body of water, either fresh or salt, in a depression of the land. Ponds, lagoons, and inland seas are included.

and steep gravelly banks. Few of them are very deep, but they may contain hidden boulders and reefs that are dangerous to navigation. Some of the smaller lakes are rather symmetrical in outline and many are steep-sided. The direction of the drainage of these glacial lakes is usually very difficult to determine from a distance, and the topography of the region in which they lie is therefore confusing to a person not expert in outdoor craft. Most of the lakes formed by glacial scour are long, narrow, and deep, and their shores are steep. Many of these lakes have been formed by both excavation and deposition and consequently show some features produced by each process. Belts of country several miles wide in which glacial lakes are numerous may be separated from one another by belts in which lakes are scarce. The best ford near a lake, if any is available, is generally found at its outlet; the head of the lake or the shores near the mouths of streams that enter the lake are usually swampy and afford poor footing.

The Masurian Lake region of East Prussia and its continuation in Russia are due to the deposition of glacial drift, the lakes and swamps lying in depressions between hills of glacial origin. In such a region the defiles between the lakes and swamps are narrow and movement of large bodies of troops is difficult. Hindenburg's victory over the Russians in 1914 was due largely to the natural obstacles imposed by the lakes and swamps whose characters and location the German general knew well but which were less familiar to his opponents.

The lakes and swamps of the Polish plain were formed by the deposit of glacial drift on a nearly level preglacial surface, and in this region all military movements must be planned with these barriers in mind—barriers which not only prevent the rapid movement of a large army in an attack but which are traps into which an unwary army may be driven. Their chief importance in the Great War, however, has been as almost impregnable barriers. In the United States similar lake regions are to be seen in Wisconsin, Minnesota, and other northern States.

The success of Napoleon's Italian campaign of 1796 was due in a large measure to the barrier afforded by Lake Garda (Figure 82 B). By successively attacking the two Austrian armies which were on the two sides of the lake and which were prevented from sending reinforcements to each other because of the lake, he was able to defeat them separately although unable to withstand the combined armies. Lake Garda lies in a deep valley excavated largely by stream erosion but partly by glacial scour. The damming of the lower end of the valley with a deep deposit of glacial drift converted the valley into a long, deep lake with precipitate sides.

The Great Lakes of North America, which are playing such an important part in the present war in the transportation of iron ore for munitions of war and on whose surfaces naval battles were fought in the early days of the Republic, were formed partly by glacial scouring and damming, but in part they occupy depressions in the earth's surface due to crustal movements.

Lakes on flood plains.—As the flood plain of the river has been formed by the river itself and is overflowed by it during periods of high water, any depressions in its surface may retain water that forms lakes and ponds. Lakes on a flood plain are of two kinds, those that occupy depressions on the plain and those that are the abandoned channels of former courses of the river. Both kinds usually have marshy shores and low banks. Parts of the old channels of streams that have very winding courses are likely to be abandoned, for the erosion of the opposite sides of a bend (see "Streams") may cut off the loop and form a shorter, straighter channel. River-borne mud is gradually deposited at the ends of this old loop, which thus becomes a crescentic lake, or oxbow. Figure 34 shows a region containing many lakes of this kind. Few of the lakes on flood plains are deep, and the best traveling on such plains is along the strand formed near the high-water level, but the best footing along oxbow lakes is on the plain near the edge of the cut bank, though due care should be taken to avoid caving banks. The bottoms of most oxbow lakes are covered with soft mud, which generally makes a treacherous footing, but in some lakes the layer of mud is thin and rests on a firm bottom of river gravels. Other types of lakes that occur on flood plains are noted in the section on swamps. Such lakes in the valleys of the Mississippi, the lower Danube, the Narew in Russia, and elsewhere have constituted obstacles of some military importance.

Delta lakes.—On approaching the sea many rivers develop a number of independent channels. The streams, known as *distributaries,* frequently change their courses and deposit sediment in such manner as to form lake basins. Lake Borgne and Lake Pontchartrain in Louisiana are examples. Such lakes have swampy shores but may be of considerable depth over large areas. In the attack on New Orleans in 1815 the British transported troops on Lake Borgne.

Lakes on coasts.—Bars and sand dunes inclose indentations of coast and form lakes, most of which are small but some of which are more than 50 miles long. Frisches Haff in East and West Prussia, is a long lagoon or lake about five miles wide connected with the Baltic Sea by a deep passage. On this lake, or rather on a navigable stream which enters the lake, stands the fortress and seaport of Königsberg, an important German sea base. A lake on the Island of Curaçao, similar in location but of different origin, sheltered Cervera's fleet in the Spanish-American War and hid it so perfectly that the American Navy was unable to learn of its whereabouts. Numerous lakes formed by bars and sand dunes are to be seen on our seacoasts and on the seacoasts of other countries. As their origin suggests, they are separated from the sea by low ridges.

Travel along lakes of this sort is difficult because they are bordered by marshes and farther back by loose sand. The best footing on the shores of salt-water lakes that have a considerable tidal range is usually on the strand between high and low tide.

Lakes formed by elevation and depression.—Where the land surface has been raised or depressed more in one place than in another lakes are sometimes formed. The Caspian and Aral seas are believed to be examples of lakes of this origin. Lakes formed by a sinking or "down warping" of the earth's crust are represented by Lake Superior. The most important class of lakes formed by crustal movements are lakes resulting from faulting. Such lakes for the most part occupy deep troughs or have one steep and one gentle shore. The trough in which the Dead Sea, the River Jordan, and the Sea of Galilee rest was formed in this way. The great African lakes, Nyasa and Tanganyika, on which battles between the Germans and British were fought in the Great War, are of this origin. In general such lakes are much longer than they are wide.

Lakes of other origins.—Lakes of less military importance than those discussed above are: (1) Those formed by "sink-hole action" (see page 170), that is, by the solution of thick beds of limestone or gypsum. These lakes are generally small with steep sides, and some of them are surprisingly deep. Many such lakes occur in Florida, Kentucky, Tennessee, Indiana, and elsewhere in the United States. The Karst region, east of the Adriatic, is famous for its sink holes, in some of which lakes occur. (2) Crater lakes, such as Maare, in the Eifel district of West Germany; Lakes Broccaiano, Bolseno, and the Alban Lakes of Italy; and Crater Lake, Oregon, should be mentioned. The contour and depth of such lakes depend upon the shape of the craters in which they lie. (3) Earthquake lakes, such as Reelfoot Lake in Tennessee; cirque lakes, produced by glaciers, such as occur in high mountains; and lakes of other origins have little military significance. They are discussed in the reference books listed below.

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Hobbs, Earth Features and their Meaning, pp. 401-434.
Ries and Watson, Engineering Geology, pp. 396-413.
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SWAMPS.

A SWAMP may be defined as any area where the ground is saturated with water throughout a good part of the year but where, at least during most of the year, the surface of the ground is not deeply submerged. There are all degrees of transition between swamps and lakes or ponds, on the one hand, and between swamps and uplands, on the other. Swamps may be divided into two groups—Inland (or Fresh-water) Swamps and Coastal (or Salt-water) Swamps. Coastal swamps include all those that are exposed to the influence of salt water; inland swamps include those that are not so exposed. The swamps of the inland group can be further classified under four heads—Lake (or Lacustrine) Swamps, River (or Alluvial) Swamps, Spring (or Seepage) Swamps, and Flat-land Swamps. As a result of differences in origin and development, these various types of swamp differ from one another in many ways, and an ability to distinguish one type from another may be of value in planning military operations.

INLAND (OR FRESH-WATER) SWAMPS.

LAKE SWAMPS.

Filled-in lake swamps.—Lake swamps are of two sorts—filled-in swamps and floating swamps. Filled-in lake swamps are due to the partial or complete filling of a former water body by plants and plant remains. The process is somewhat as follows. When the plants in a lake or pond die, their remains sink to the bottom, and because of insufficient oxidation the vegetable débris may become only partially decomposed, giving rise to either muck or peat. The continued accumulation of muck or peat on the floor of a lake decreases the depth of the water. Ultimately the open water may become completely replaced by plant remains and the lake become a swamp.

Floating lake swamps.—Many water bodies are filled in a somewhat different manner. The vegetation along the edge of the pond grows so vigorously that it spreads away from the shore out over the open water, giving rise to a floating mat. A swamp formed in this way is commonly referred to as a quaking bog. The floating raft of vegetation, rising and falling with fluctuations in the water level, may overlie clear water or soft ooze. So firm, however, may the mat become that although it trembles and quakes under foot it is quite capable of supporting the weight of a man. The depth of muck or peat in a lake swamp varies. It may be only a few feet but commonly exceeds ten feet and may be as much as seventy feet.

Both peat and muck form soft, unconsolidated deposits, but muck is softer and more thoroughly decomposed than peat, has a darker color (typically muck is almost black, peat is light brown), and contains a larger proportion of mineral matter (ash). Peat, dried and usually compressed by machinery, is widely used in Europe for fuel. Coal is essentially petrified peat.

Many lakes are filled by a combination of the two methods just described, and stream-fed lakes present formations intermediate between filled-in lake swamps and river swamps. Lake swamps may occur in any region and are especially characteristic of glaciated regions.

RIVER (OR ALLUVIAL) SWAMPS.

Ox-bow and back-water (or terrace) swamps.—River swamps are the result of stream activity. Three classes are recognized—back-water (or terrace) swamps, ox-bow swamps, and estuarine swamps. Back-water swamps and ox-bow swamps are commonly associated with meandering streams and flood plains. Ox-bow swamps, developing in or about abandoned channels of the stream itself, are much less numerous than the back-water swamps, in connection with which they usually occur. Back-water swamps are formed in the following manner. A river in times of flood overflows its banks and spreads out over the adjoining low lands. As the water spreads out, the current becomes more and more sluggish and deposits its load of detritus. The bulk of this sediment, especially the coarser material, is deposited in the places where the current first begins to slow down after leaving the relatively narrow confines of its usual channel. As a result of the more rapid accumulation near the immediate stream banks, there is usually built up along both sides of the stream a dike or natural levee, which tends to cut off the stream from the remoter parts of its flood plain. When the water subsides and the stream once more resumes its normal course, this dike acts as a barrier which prevents much of the flood water from draining back into the channel, and in consequence permanent or temporary swamps and even shallow lakes and ponds may be developed on parts of the flood plain. This ridge near the river or similar ridges that mark former courses of the river or its side streams may be the only traversible routes through swampy areas of this sort. (See flood plains, Chapter III.)

Estuarine (including delta) swamps.—Estuarine swamps are found near the outlet of a river or stream and are built up largely by the accumulation of sediment which results from the slackening of the current in the vicinity of the river's mouth. On a river that enters the sea, for example, the outflowing river water may be backed up for miles above the mouth by the inflowing tide water. Delta swamps have substantially the same origin. The bulk of the material forming the bottoms of estuarine and delta swamps and also of back-water swamps consists of alluvium, and there is only a small proportion of organic matter. The "back swamps," or ox-bows, and delta swamps of the lower Mississippi furnish excellent illustrations of river swamps, but on a smaller scale such swamps are developed along the courses of most large streams.

SPRING (OR SEEPAGE) SWAMPS.

Spring swamps owe their existence primarily to the presence of springs or seeps and include considerable areas of flat, usually sloping ground which is continuously or intermittently wet. The necessary conditions are an abundant supply of underground water in the form of springs and the absence of closed basins suitable for the formation of lakes or ponds. Such springs are generally found on the slope just below the line where the surface cuts the contact of an impervious rock with a porous rock containing water under hydrostatic head. (See Chapter on Water Supply.) Owing to their mode of origin such spring swamps have a more or less definite linear trend, and their position can be rather closely predicted from a distance. A swampy zone of this kind is generally hard to cross, but usually the near-by topographic features which cause the springs offer even greater obstructions to military operations.

Most spring swamps are characterized by the presence of a rather thin surface layer of peat; many of them have practically no peat, but a favorable combination of moist air and an abundant seepage may result in the accumulation of peat to a depth of several feet. Spring swamps are common in eastern North America and are widely distributed in other regions of abundant rainfall and relatively high atmospheric humidity.

FLAT-LAND SWAMPS.

Flat-land swamps are found on flat, poorly drained land. The favorable conditions are heavy precipitation in the form of rain or snow, relatively impervious soil, and poor surface drainage. In many areas where other conditions are favorable evaporation at certain seasons is so great that most of the water disappears—that is to say, the swampy condition is intermittent. In other areas the swamps are permanent. Peat or muck may be poorly developed, but in the best-known examples of this type of swamp it not only is present but plays a very important part in the maintenance of the swampy condition, for a compact, water-soaked layer of peat in itself soon becomes very effective in obstructing drainage and retarding evaporation.

Coastal plain swamps.—Flat-land swamps are particularly characteristic of two regions in eastern North America—the Atlantic Coastal Plain from New Jersey southward, and the region along the coast from eastern Maine northward. The flat-land swamps of these two regions are very different from one another. The southern type is well illustrated by the Great Dismal Swamp, which occupies an area of more than two thousand square miles in Virginia and North Carolina, and probably by the Everglades of southern Florida, which cover an area of approximately four thousand square miles. In both of these areas the surface of the swamp is essentially a flat plain, but the vegetation is unlike—in the Great Dismal Swamp it is very largely forest, in the Everglades mostly reedy marsh. In both of these swamps and in similar ones the rock substratum is nearly everywhere overlain by a layer of peat or muck, commonly shallow but in places more than ten feet deep.

Raised bogs.—The characteristic flat-land swamp of the North is the raised bog or high moor, the "Hochmoor" of the Germans. It is confined to regions of copious precipitation, high atmospheric humidity, and relatively cool summers. This type of swamp is of particular interest in the present connection, since it is very common in northern Germany and covers vast stretches of territory throughout the forested portions of northern Russia and Siberia. In eastern North America it is extensively developed in eastern Maine, New Brunswick, Nova Scotia, and Newfoundland. Raised bogs owe their development very largely to the habit of growth of a certain kind of moss, the sphagnum, which grows in great luxuriance in favorable climate on flat, poorly drained areas. Absorbing the water that falls in the form of rain and snow, this mass of sphagnum slowly grows upward, so that in time the mossy surface, underlain by a spongelike mass of peat, comes to lie ten, fifteen, or even twenty feet above the original rock floor. Raised bogs are so termed from the fact that commonly they are much higher near their centers than at their margins, the surface contour roughly resembling an inverted saucer. In this respect they differ from other swamp types, in which the surface tends to be level or to conform in contour with the underlying bedrock surface. In contrast to other flat-land swamps, the vegetation on the surface of a raised bog consists very largely of sphagnum moss and low bushes. Most raised bogs have originated in the manner just described, but many of them were formed on top of former lake swamps or spring swamps.

In arctic and subarctic regions, such as large parts of the plains of Alaska and of northern Russia, seasonal changes in temperature produce intermittent swamps, because the soil and unconsolidated material are in places frozen to a depth of several hundred feet. The lower part of this material does not thaw, but the upper foot or two melts during the summer, and as there is no underground drainage the water does not run off but forms swamps that are extremely difficult to traverse on foot, as the traveler sinks knee-deep into mud. These swamps cannot be drained by clearing away the overburden or digging ditches, for such work only exposes fresh surfaces to melting and forms chasms. Railroads can be best built in country of this kind by disturbing the surface vegetation as little as possible and building on it mattresses of bushes on which to lay the ties and tracks. Although fatiguing to traverse, these swamps can be crossed without danger, for a solidly frozen mass lies a short distance below the surface. During the winter, of course, the entire zone that is melted in the preceding summer is frozen again.

COASTAL (OR SALT-WATER) SWAMPS.

Salt marshes and mangrove swamps.—Coastal swamps are exemplified by the salt marsh, which is the only swamp of this type found in temperate regions. Salt marshes are characteristic of areas along the seacoast that are exposed to the influence of salt water. They are commonly developed between low- and high-tide levels in sheltered bays and harbors, in the lee of barrier beaches, and in other situations which are protected from excessive wave action. Coastal swamps are built up through the combined activity of plants and silt-laden tidal currents. Plants assist in the building-up process in two ways—first, by checking or retarding the flow of tidal currents, thereby causing a deposition of silt; second, by the accumulation of their own remains. The deposit which underlies a salt marsh therefore consists of a mixture of silt and peat. In parts of the marsh near low-tide level the substratum is soft and muddy, but in passing to higher levels it becomes firm and peaty. The height to which the surface of the marsh can be built is determined by the height of the tides. Salt marshes are common along most of the Atlantic and Gulf coasts and are also found along the Pacific coast. In tropical and subtropical regions, like southern Florida, there are formed the so-called "mangrove swamps," which are essentially like the salt marshes except that they are wooded.

SWAMP VEGETATION AS INDICATIVE OF DEPTH AND NATURE OF THE BOTTOM.

To a certain degree the nature of the substratum in a swamp or other area is reflected by the kinds of plants that grow there. Conversely, it follows that within limits the character of the vegetation can be taken as an indicator in judging the nature of a given terrain, and in this connection a little botanical knowledge may sometimes prove of great practical assistance. The distribution of plants is influenced by the amount of water in the soil, its acidity, the drainage relations, and the amount of organic and mineral matter present. The vegetation of a very wet swamp is quite different from that of one that is only moderately wet; the vegetation of a filled-in lake swamp, its soil composed of peat, very acid and poorly drained, differs to a marked degree from that of a near-by river swamp, in which the soil, composed largely of alluvium, is not acid and is well drained. Unfortunately the extent to which plants can be used as indicators is small. Some plants are rather definitely restricted as to soil; others will grow indiscriminately on a variety of substrata, and the same plant may occupy different habitats in two different regions. The value of plants as indicative of swamp types is also lessened by the fact that the composition of the plant population on different portions of the earth varies greatly. However, under conditions such as exist in the northeastern United States, a knowledge of plants may prove of service in estimating the character of a swampy terrain with respect to the depth of water-soaked muck and the nature of the bottom.

The character of the vegetation may give a general idea as to the wetness of a swamp. This is well illustrated in marginal lake swamps in which the plants tend to grow in more or less definite zones parallel with the shore. The outermost zone may be made up of pond lilies; then may occur in order, as the shore is approached, a zone of pickerel weed, bulrushes, and cat-tails, a zone of grasslike plants, a zone of bushes, and finally a zone of forest. In general, a swamp filled with a rank growth of tall, reedy plants, such as the cat-tail, bulrush, and wild rice, is sure to be very wet. A swamp overgrown with shorter, grasslike vegetation and having more or less the aspect of a meadow will usually be much drier. Bushes likewise indicate relative dryness, although certain shrubs, such as the button bush, suggest very wet conditions. Wooded swamps tend to be drier than swamps of any other type, although here also there are exceptions: arbor vitae and coast white cedar, for example, favor wet localities.

The character of the vegetation may furnish a clue as to the nature of the ground itself, particularly as to whether the surface is underlain by a thick deposit of peat or muck or whether the mineral soil lies close to the top. In this connection trees have some value as indicators. The forest cover of a lake swamp may be made up very largely of coniferous trees, such as the tamarack, black spruce, arbor vitae, or coast white cedar; or it may consist wholly of broad-leaved trees, such as red maple, elm, and black ash. But it would almost never include the swamp oaks, swamp hickory, blue beech, tulip, sycamore, and red ash. A river-swamp forest, on the other hand, while it very likely would include red maple, elm, and black ash, would be characterized by the abundance of some or all of the trees that have been mentioned above as lacking in a forest of the lake-swamp type. In the same way, a spring swamp in which the mineral soil lies near the surface may be covered in part with tamarack, arbor vitae, or coast white cedar, maple or elm, but it is also likely to support hemlock and white pine, yellow birch, white ash, and various of the trees cited as characteristic of river swamps. A spring swamp in which the mineral soil is overlain by a considerable depth of peat, on the other hand, may differ little in its vegetation from a lake swamp.

In swamps that are not wooded the vegetation may be dominated by bushes, reeds, grasslike plants, or moss. Of the swamp shrubs, the commonest is the alder, which, like the red maple, may grow on a variety of substrata. Where present in abundance it probably overlies a mineral soil, usually somewhat muddy. Associated with the alder in spring or river swamps grow a variety of other shrubs, such as the willows, red osier dogwood, winterberry, swamp rose, elderberry, and arrow wood. In striking contrast to associations of this sort are the associations known as heaths, so called because of the predominance of shrubs belonging to the heath family, including the cranberry and bog huckleberry, the lambkill and bog laurel, the leather leaf, and the Labrador tea. As compared with the shrubs of alder swamps, which are mostly tall and have deciduous leaves, the heaths are scarcely more than knee-high and for the most part have evergreen leaves. Associations of this sort are characteristic of bogs and almost invariably indicate a considerable depth of peat. Many boggy lake swamps are covered by vegetation of this type, and it is very characteristic of raised bogs. Associated with the heaths and commonly covering the ground completely, grows the sphagnum moss, which, while it occurs in other types of swamp, nowhere develops so luxuriantly as in a bog. Scattered trees are commonly present, mostly scrubby black spruces. The general aspect of the vegetation in bogs, both in Europe and in various parts of the northern United States and Canada, is very similar: everywhere the heaths and the sphagnum predominate.

Reeds and grasses have small value as indicators of soil conditions. A rank growth of reedlike plants ordinarily indicates very wet and usually very soft ground, but it tells little about the depth of the deposit and whether or not peat or muck are present. Grasses and sedges (which are so similar to one another in general appearance that popularly they are not distinguished) may grow equally well on peat, muck, or mineral soil, on soft or firm ground. In salt marshes, where the vegetation is practically all grasslike, the lower, softer areas are occupied by an open growth of coarse, reedlike grasses; the higher, firmer areas are covered by a rich sward of low grasses and rushes whose densely matted, tough roots and underground stems account for the relative solidity of the ground.

PRACTICAL APPLICATIONS.

In a military sense swamps may be either favorable or unfavorable terrain. Swamps containing varied vegetation afford excellent "cover" for scouts and troops, and swamp-land positions are easily camouflaged. The chief element of danger lies in the frequent presence of a considerable depth of peat or muck. A lake swamp may present a practically impassable barrier to artillery, cavalry, and even infantry; for even if the ground at the surface appears quite firm, the soft, wet, bottomless mire beneath offers absolutely no foothold. By laying plank roads some lake swamps may be crossed with safety. Lake swamps that have been formed through the intervention of a floating mat are especially unsafe. In a river swamp, on the other hand, where the substratum consists very largely of alluvium, the soil is relatively stable and when dry affords reasonably safe footing. During wet periods the ground may be soft and quite unsafe for horses and artillery. Along fairly rapid streams the alluvial deposits are usually sandy, and bordering swamps present no serious obstacle to military operations. Spring swamps and flat-land swamps likewise may be safely traversed unless the mineral substratum is overlain by a considerable depth of peat or muck. Raised bogs should always be avoided for heavy loads, for while the surface may be firm enough to permit the passage of infantry, it is treacherous ground for cavalry or artillery. Salt marsh peat, intermixed with more or less silt, tends to be much more firm and compact than fresh swamp peat; but while the higher parts of a salt marsh may be firm enough over most of an area to afford safe passage for horses and even for light railways, numerous soft spots and tidal creeks constitute a source of danger. In general, wherever horses and artillery are involved, peat or muck deposits of any description should be avoided, if possible. If an area of this sort must be utilized, the thickness and firmness of the deposit should be ascertained by the use of a long, smooth, sharp-pointed pole, and if the thickness of muck is considerable a road of planks or earth should be constructed.

Swamps are a factor in the problems of army health and sanitation. They are the breeding places of malaria-carrying mosquitoes, and control of mosquitoes is necessary where operations are carried on in infected areas. Drainage and sewage-disposal problems are difficult in swamp areas.

Surface excavations in swamps are obviously impossible unless the area has been artificially drained. Swamps commonly have an under layer of impervious material, and underground tunneling and mining operations can be conducted in or under such impervious beds. The principal difficulty is in constructing a water-tight shaft where the entrance to the tunnel is within the swamp area.

Swamps are artificially drained for agricultural purposes by ditching and tiling. In some places, particularly in glacial swamps, a comparatively small and narrow barrier can be cut through, allowing the swamp to drain after proper ditch systems are constructed. The drainage of swamps can probably be attempted only to a very small extent in military operations. In permanent improvement work in connection with camps and cantonments swamp-land drainage may be important.

The construction of railroad grades or highways over swamps is made difficult by the very low bearing strength of the peat, muck, and marl. This material will sometimes not even support the weight of a spoil-bank produced in dredging a channel or canal through it. A railway or highway fill slowly sinks and a compensating ridge of swamp soil rises on either side. Sometimes the sinking of fills goes on gradually from the start, but some fills have stood and supported traffic for a while and then suddenly begun to sink and become impassable within a few hours. Possible ways of meeting this condition are to bridge the swamp with a trestle supported on piles driven in a firm support below, to construct a shallow, broad fill reinforced beneath with brush mattresses, or to build up the fill as it subsides until equilibrium is established. About 1907 a railroad was built across the Apalachicola River, in Florida, near its mouth. Five miles of trestle were necessary, four-fifths of it through swamps densely wooded with gum, cypress, and other trees, and the rest through open marsh. In some places the mud was so soft and deep that a firm bottom could not be reached by piles spliced together and driven to a depth of 170 feet. In such places piles of ordinary length driven much closer together than usual gave satisfactory results for a time, but now (1918) earth is being brought from a considerable distance to fill in the trestle.

Foundations for buildings and other heavy structures over swamps must necessarily be of the floating type or be carried down to the solid bed of the swamp. The floating type of foundation is simply a rigid flat support large enough to distribute the load carried over an area sufficient to permit the low-bearing strength of the swamp surface to carry it.

In the high latitudes swamps remain frozen throughout the year below the depth of summer thawing. The problem of support for structures under these conditions has been ingeniously solved at army posts in Alaska by melting holes beneath the depth of thawing, by means of steam pipes, and allowing posts to freeze into the permanently frozen swamp below, thus giving a solid and lasting support.

In the temperate latitudes swamps do not freeze deeply or solidly because of the excellent heat insulation properties of peat. Even in severe winters the frozen crust cannot be trusted to carry heavy loads.

Swamps in military operations.—The following references to the effect of swamps on military campaigns are of interest:

During one of the battles of the Seven Years' War (May 6, 1757) a small marshy area near Prague was of disadvantage to the Prussian infantry under Frederick the Great, who, mistaking for meadow land a marshy area in which fish-ponds were coated with green slime, ordered his troops to advance. They struggled through but were shattered by the fire from the Austrian guns.

The severe defeat of Frederick the Great in the battle of Kunnerdorf, near Frankfurt, in 1759, was due more to the natural defenses of the Austrians and Russians than to their military strength. The Austrian left was shielded by impassable swamps, and the right by a dense forest.

Napoleon's campaign in Italy was nearly brought to a disastrous close by the river marshes of the Adige, at Arcola (November, 1796), over which the French could advance only on a causeway and where they were easily held by the Croats. It was here that Napoleon fell into the marsh and was saved from a miry death by his troops.

The combined use of a delta swamp and a river in defensive warfare is illustrated in the battle of New Orleans (January, 1815), where the American Army under General Jackson was entrenched on a front of three-quarters of a mile with its flanks protected on one side by the delta swamp and on the other by the Mississippi River. (This region is shown on the St. Bernard topographic sheet of the United States Geological Survey.)

The Seven Days' Battle, near Richmond, Va., was controlled by the swamps through which the Chickahominy and its tributaries flow and by other swamps. The failure of the Confederate attack at Malvern Hill was in large measure due to swamps which impeded their attacks. Had not McClellan's flanks been protected by White Oaks Swamp and the swamps of the Chickahominy, the Seven Days' Battle would have ended even more disastrously for the Union forces than it did.

During the present war the marshes along the Save played an important part in the first attempt to invade Serbia, and the delta swamps of the Piave River were partly responsible for the defeat of the Austrians at Capo Sile.

CHAPTER V.

WATER SUPPLY.

MILITARY REQUIREMENTS REGARDING WATER SUPPLY.

GENERAL REQUIREMENTS.

IN developing water supplies for most purposes three important factors must be considered: (1) the quantity of water available, (2) the quality of the water, and (3) the cost of producing the water. Quality is a complex factor. Thus water that is satisfactory for drinking and other domestic uses may be poor for boiler use, and water that is excellent for boiler use may be very bad for domestic use. Moreover, water that is satisfactory for boiler use may be unsatisfactory for some other industrial uses. The cost of both installation and operation involves various factors. Thus in utilizing ground-water supplies it involves the depth to the water-bearing bed, the nature of the formations through which it is necessary to sink wells, the head of the water (which determines the energy required to lift the water), and the yield of wells (for it is much cheaper to pump a certain amount of water from one well of large yield than from a number of weak wells).

The three factors—quantity, quality, and cost—are not of the same relative importance for different purposes and under different conditions. For supplies for farms, small settlements, or small industrial plants there may be no problem as to quantity, the only practical considerations being quality and cost. For municipal supplies in large cities, however, large supplies are required, and the problems of obtaining sufficient quantities of water assume an importance not generally appreciated except by those who deal with these problems. As water is essential for the support of human life and also for the prosecution of many important industries, very high costs are borne in some places for water supplies, as for the water that is hauled to rich mines in desert regions or piped and pumped to them for many miles against great pressure, or the water that is transported by railroad companies in trains of tank cars to distant stations in the desert and thence, perhaps, hauled in wagons to isolated points. However, water occurs in very large quantities in some places and is therefore available for such purposes as irrigation, in which large quantities are required to produce relatively small financial returns and the factor of cost is always important.

For domestic and industrial uses the quality of the water is very important as affecting the health and comfort of the people and the success of the industrial operations. The disasters that have resulted from polluted water furnished by city waterworks can hardly be overstated. Moreover, the financial losses sustained by industries through the use of poor water are very great, as, for example, the cost of repairs and breakdowns in locomotives on a railroad where only very hard water is available. Therefore, in providing a water supply for a city or for a large industrial establishment both quantity and quality may present serious problems. Where supplies of satisfactory quality can not be obtained very inferior water is sometimes used. In some parts of the arid West highly mineralized water is used in locomotive boilers, although, according to all rules of classification, it is utterly unfit for steam-making, or it is used for public waterworks, although it is so salty that under ordinary conditions it would be spurned as a drinking supply. No community, however, is justified in drinking water that is not free from pollution by disease germs, and, fortunately, where water has been polluted purification by one of several methods is always possible.

MILITARY REQUIREMENTS AT THE FRONT.

For military purposes near the front both quantity and quality of water are important. A minimum supply necessary to support life and essential mechanical operations must be provided, regardless of difficulties, or operations must be abandoned. Thus in the Gallipoli campaign water for the Allied troops had to be transported from Alexandria, Egypt, and had to be hauled inland to the troops in quantities required for drinking, regardless of cost or interference with other military operations. Moreover, to maintain the health and efficiency of the troops it is highly desirable to provide much more than the minimum supply required. For large-scale military operations the quantities required are comparable to those needed to supply city waterworks. The water consumption of different cities differs widely, but the average municipal requirement is generally reckoned at 100 gallons a day for each inhabitant. The water consumption of armies is less but commonly ranges between 10 and 50 gallons a day per soldier, depending on the supply available, on the number of horses, and on various other conditions. Thus at 25 gallons per soldier the daily consumption of a division of 10,000 soldiers is a quarter of a million gallons a day. The water must be practically free of disease germs. To guarantee this it is necessary to make sanitary surveys of the source and bacteriological and perhaps other sanitary tests of the water. If there is any doubt as to its purity the water must be sterilized and perhaps filtered. If there is any chance that the enemy is not regarding the laws of civilized warfare the water, besides being sterilized for disease germs that might have been introduced, must be tested for poisons that are not destroyed by sterilization. The water should not contain so much mineral matter that it will cause diarrhea or otherwise interfere with the health of the soldiers. As it is not practicable to remove this mineral matter from water that is to be used for drinking it is essential to find a supply that is not excessively mineralized. In addition to being satisfactory for drinking the water should be of as good quality as possible for boiler and laundry use and for any other use to which it may be put near the front. It is possible to treat water for the removal of the constituents that make it hard and cause it to deposit scale in boilers, and it may be practicable to apply such treatment even near the front.

For military purposes near the front quantity and quality are both of vital importance, but the urgency of holding a certain position may render the factor of cost of only minor importance. Somewhat different factors, however, become peculiarly important, such as the situation of the source of supply and the time required to develop a supply.

It is advantageous to have the source of supply near the point where the soldiers who consume the water are stationed. Long pipe lines or elaborate waterworks are generally impracticable, and hauling water in railroad cars, automobile trucks, or wagons involves a serious tax on transportation facilities that are generally strained to the limit for moving troops, food supplies, guns, and ammunition. Moreover, there is serious disadvantage in having the water supply piped or hauled any long distance to the troops who need it, because of the danger of having the troops cut off from this supply by operations of the enemy. The battle line may extend for hundreds of miles, and it is determined by the conditions and fortunes of war, generally without reference to available water supplies. However, the battle line is not a fixed line. All the energies of the entire military establishment are exerted to push it into the enemy's territory, and the grim possibility of its moving irresistibly in the opposite direction is always present.

Hence, it is vital to obtain water supplies from widely distributed sources.

Time is an important element in the development of water supplies near the front, as it is in all other phases of military operation. The requirements of most cities increase gradually with slow growth in population, and there is generally ample time to make careful investigations and estimates before any construction work is undertaken, and the work can be carried on without haste. Many months are sometimes consumed in drilling a single deep well. At the front, however, water must be produced without delay.

MILITARY REQUIREMENTS BEHIND THE LINES.

In the highly organized modern warfare not all the activity is near the front, but operations of prodigious magnitude and great diversity are required far from the scene of actual combat. The present war has made necessary hundreds of new and increased water supplies in the United States for army encampments, naval bases, aviation fields, ordnance depots, powder factories, and many other establishments, all of which are directly involved in the prosecution of the war. A number of serious problems relating to military water supplies have recently arisen on the Pacific coast of this country, 6,000 miles from the nearest firing line. The problems of military water supply at points remote from the scene of conflict are largely the same as ordinary water-supply problems, but they partake somewhat of the nature of the problems at the front. The time element, although not nearly so acute as at the front, is nevertheless always important. The cost receives more consideration than at the front but not so much as in ordinary water-supply work. The requirements as to quantity and quality are exacting. A large army camp or large powder factory will consume several million gallons of water in a day, and for each purpose water of high quality is essential, although the properties that constitute high quality may differ for different purposes.

COMPARISON OF SURFACE-WATER AND GROUND-WATER SUPPLIES.

Water supplies are derived from two sources—surface water and ground water. Which of these sources is utilized depends on local conditions and needs. Surface water is most commonly utilized where large supplies are needed in one place, as for the waterworks of large cities and for irrigation, whereas ground water, which is more widely distributed but not so easily recovered in large quantities and which does not generally require purification for human consumption, is commonly used for domestic supplies on farms and in villages.

On account of the exigencies of war and the great variety and wide distribution of modern military operations, both surface water and ground water are important for military use. For the large permanent encampments of troops, such as the national cantonments, water from a good-sized perennial stream or other surface source is usually more available than ground water, although for some large encampments ground water is used, as at Camp Dodge, Des Moines, Iowa, which is supplied with ground water that was chosen in preference to the water of Des Moines River, and Camp Cody, Deming, N. Mex., which is supplied with ground water because this is the only kind of supply available at that place. Near the front ground water is used extensively because of its wide distribution and relative safety. Wells are used largely on the western front in France, and successful wells sunk for water supplies in the arid region traversed by the British forces in the Palestine campaign constituted an important advantage over the enemy.

An army engineer should be prepared to develop both surface-water and ground-water supplies. He should understand at least the elementary principles of ground water, so that he can locate well sites intelligently and can use effective methods of development. In the following pages these principles are presented with a view to their practical application.

GROUND WATER AS A DETRIMENT IN MILITARY OPERATIONS.

Ground water is a detriment in military operations when it stands so near the surface that it will fill trenches or other excavations and thereby create drainage problems, as frequently occurs in the deep trenching and tunneling required on the field of battle. It is also a detriment when it causes the slumping of unsupported walls of excavations. It may prove to be a very serious detriment where it is so near the surface as to prohibit digging trenches and necessitate the construction of protecting embankments and where it causes swampy conditions that interfere with gun emplacements and with the transportation of troops and supplies, as was shown on a large scale and with gruesome results in the Mazurian Lakes campaign on the Russian front.

To cope promptly and effectively with problems of this sort it is necessary to know the characteristics of different kinds of rock with respect to ground water, to be familiar with the significance of topography, structure, and vegetation with respect to the occurrence of shallow water, and to understand the underground conditions that govern drainage through surface ditches or into wells.

OCCURRENCE OF GROUND WATER.

Rocks as receptacles of water.—The rocks that form the crust of the earth are rarely if ever solid throughout. They contain numerous open spaces, or interstices, which are the receptacles that hold the ground water. There are many kinds of rocks, and they differ greatly in the number, size, shape, and arrangement of their interstices and hence in their properties as containers of ground water. The occurrence of ground water in any region is therefore determined by the character, distribution, and structural relation of the various rocks—that is, by the geology of the region. A rock formation that will yield water in sufficient quantity and at a rapid enough rate to be of consequence as a source of supply is called an *aquifer,* or, simply, a water-bearing formation, or water-bearer. (1, 2, 3, 4.[1])

Kinds of interstices.—The interstices in the rocks are of many kinds and have been produced by a large variety of geologic processes. They may be grouped in two main classes—(1) original interstices, or those which came into existence when the rocks were formed, and (2) secondary interstices, or those which were produced by changes that have taken place in the rocks.

The principal types of original interstices consist of (a) original spaces between adjacent fragments or grains of sedimentary rocks, (b) partings between successive layers of stratified rocks, (c) numerous but small spaces of various kinds that occur originally between or within the crystals of igneous rocks, and (d) vesicles and other original openings in lavas produced by escaping gas and vapor, by the flow of partly congealed lava, or by other agencies. Of these, the spaces between fragments or grains of sedimentary rocks are by far the most important as containers of water. They furnish the principal water supply for perhaps most of the successful wells. The partings are also important in many widely distributed formations, and the vesicles and other original openings in lavas locally contain water. The original spaces between or within crystals of igneous rocks are

[1] Numbers refer to titles of reference works, listed at the end of this chapter.

numerous and widely distributed but are too small and isolated to be of consequence as sources of water.

The principal types of secondary interstices consist of (a) openings produced by solution, chemical change, or recrystallization, (b) joints and openings produced by faulting and by various other processes, which may be either mechanical or organic, and (c) openings produced by weathering or deformation of rocks having slaty cleavage and foliation, such as schists. Both solution openings and joints are very important as sources of water. Solution openings are of most importance in relatively soluble rocks, such as limestone, while joints are important in many hard, brittle rocks, including limestone, sandstone, quartzite, gneiss, and nearly all igneous rocks. A large proportion of successful wells draw their supplies from joints in rocks that would otherwise not yield water. Cleavage and foliation are important chiefly in affording conditions favorable to weathering, which may produce openings that supply water in formations that would otherwise be unproductive. Weathering, whether by chemical, mechanical, or organic processes, tends to produce interstices in rocks near the surface. (See Chapter II.) (4, 5.)

The two forces controlling water in rocks.—The rocks with their interstices form huge natural systems of waterworks. If the interstices were all large the ordinary laws of hydraulics, in which gravity is the controlling force, would apply without much modification. However, the interstices are of very small average size, and for this reason a different force manifests itself and is as effective as the force of gravity. This is the force of adhesion. It is the attraction of rock molecules for water molecules, and it acts perceptibly through only a minute range but within this range is comparable with the cohesion of the rocks themselves. Because the interstices are so small the aggregate area of the rock surfaces exposed to the water is very great as compared with the mass of the water. The effectiveness of the force of adhesion is approximately proportional to the area of surface over which it acts. Therefore this force is very important in ground-water systems, and its importance is greatest in the rocks that have the smallest interstices.

Properties of rocks with respect to water.—Rocks have three important properties with respect to the occurrence of water, all of which are determined by the number, size, shape, and arrangement of their interstices. These properties are (1) perviousness, or permeability, (2) porosity, or aqueous capacity, and (3) water-yielding capacity.

Perviousness of rocks.—The perviousness of a rock is its capacity for transmitting water under pressure. Some rocks, such as certain dense clays or shales, are impervious under the pressures usually found in ground water—that is, they will transmit no water under these ordinary pressures. An impervious rock may be devoid of interstices, it may contain only isolated interstices, or it may have many very minute communicating interstices whose spaces lie wholly or at least largely within the range of the molecular attraction of their walls. Most rocks are more or less pervious, but they differ greatly in their degree of perviousness, according to the number and size of their interstices and the extent to which these interstices open into one another. A clayey silt, with only minute pores, may transmit water only very slowly, while a coarse clean gravel or a cavernous limestone, with

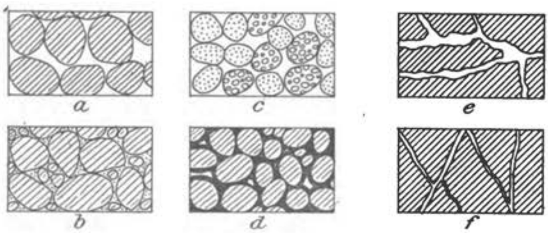

FIGURE 40. Diagrams to show relation of rock texture to porosity. *a.* Well-assorted sedimentary deposit having high porosity; *b.* poorly assorted sedimentary deposit having low porosity; *c.* well-assorted sedimentary deposit made of pebbles which are themselves porous, giving the deposit as a whole very high porosity; *d.* well-assorted sedimentary deposit whose porosity has been diminished by deposition of mineral matter in the interstices; *e.* rock rendered porous by solution; *f.* rock rendered porous by fracturing.

large openings that communicate freely with one another, will transmit water very freely.

Porosity of rocks.—The porosity of a rock is its property of containing interstices. It is expressed quantitatively as the percentage of the total volume of the rock that is occupied by interstices, or that is not occupied by solid rock material. A rock is said to be saturated when all its interstices are filled with water. In a saturated rock the porosity is practically the percentage of the total volume of the rock that is occupied by water, which may be called the specific aqueous capacity. The porosity of different rocks ranges from less than 1 per cent. to nearly or quite 50 per cent. but is rarely more than 40 per cent. A porosity of less than 5 per cent. may be regarded as small porosity, one between 5 and 20 per cent. as medium porosity, and one greater than 20 per cent. as large porosity.

The porosity of a sedimentary rock (see p. 3) depends chiefly on (1) the degree of assortment of its constituent particles, (2) the cementation and compacting to which it has been subjected since its deposition, (3) the removal of its mineral matter through solution by percolating waters, and (4) the fracturing of the rock, which has resulted in joints and other openings. An aggregation of perfect spheres of solid matter of equal size has been mathematically shown to have a porosity between 25.95 and 47.64 per cent., according to the arrangement of the spheres. Well-assorted deposits of uncemented gravel, sand, or silt have porosities approximating these figures. If, however, a gravel, for example, is poorly assorted, small particles occupy the spaces between the larger ones, still smaller ones occupy the spaces between these small particles, etc., with the result that the porosity is greatly reduced (Figure 40, *a* and *b*). A bed of till, which is an unassorted mixture of glacial drift containing particles of great variety

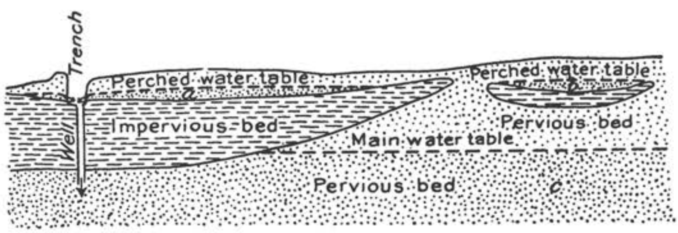

FIGURE 41. Diagrammatic section showing zones of saturation, water tables, and conditions favorable for draining trenches by means of wells; *a* and *b* are perched bodies of ground water; *c* is the main zone of saturation.

in size, may have very low porosity, whereas the beds of outwash gravel and sand, derived from the same source but thoroughly assorted by running water, may be highly porous. On the other hand, a well-assorted uncemented gravel may be composed of pebbles which are themselves porous, thus giving a very high porosity for the deposit as a whole. (Figure 40, *c*.) A well-assorted porous bed of gravel or sand may gradually have its interstices filled with mineral matter deposited out of solution from percolating waters, and, in extreme cases, it may become a practically impervious conglomerate or quartzite of very low porosity (Figure 40, *d*). On the other hand, a relatively soluble rock, such as limestone, though originally dense, may become cavernous as a result of the removal of its substance through the solvent action of percolating waters (Figure 40, *e*). Furthermore a hard, brittle rock, such as limestone or hard sandstone or as most igneous and metamorphic rocks, may acquire large interstices through fracturing that results from shrinkage or deformation of the rocks or through other agencies (Figure 40, *f*). Solution channels and fractures may be large and of great practical importance, but they are rarely abundant enough to give an otherwise dense rock a high porosity.

The zone of saturation.—The rocks that lie below a certain level are generally saturated with water; they lie in what is called the *zone of saturation*. Water that enters the earth from the surface is drawn down by gravity to the zone of saturation, except as it is held by adhesion. In most places there is only one zone of saturation, but in certain localities, chiefly in arid regions, the water may be hindered in its downward course by an impervious or nearly impervious bed to such an extent that it forms an upper zone of saturation, or perched water body, that is not associated with the lower zone of saturation. (Figure 41.)

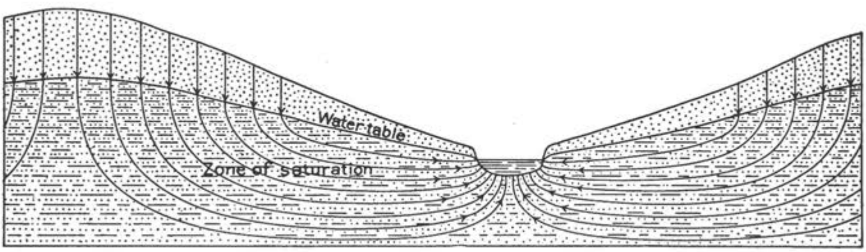

FIGURE 42. Diagrammatic section showing areas of ground-water intake and discharge, and the consequent irregularities of the water table and movement of ground water.

The water table.—The upper surface of a zone of saturation in porous soils and rock is called a *water table*. The water table is not a level surface but has irregularities comparable and related to those of the land surface, although it is on the whole much less rugged (see Figures 42 and 43).

Definition of ground water.—All the water in the crust of the earth is called subsurface water, to distinguish it from surface water and atmospheric water. That part of the subsurface water which occurs in a zone of saturation is called ground water (that is, the basal water), or *phreatic water,* a term derived from the Greek word meaning a well. The terms underground water and subterranean water are also applied to the water in the zone of saturation rather than to subsurface water in general. Between the surface and the zone of saturation there is much water which is in a sense suspended—that is, it is held by molecular attraction against the attraction of gravity. It is regarded as subsurface water but not as ground water. If a well is sunk the walls of the well may be moist at various levels above the water table, but it is not until the zone of saturation is reached that water flows into the well and becomes available for use as a water supply.

The capillary fringe.—For a distance of several feet above the water table the earth is invariably moist. This is due to the well-known phenomenon of capillarity. Small communicating interstices form irregular capillary tubes through which water is drawn up by molecular attraction acting against gravity and is held in this suspended

FIGURE 43. Diagrammatic map showing the form of the water table by means of contours (continuous lines), and directions in which the ground water moves (arrows) from intake areas to areas of discharge along the streams.

position at a height above the water table where the two opposing forces are in equilibrium. As can readily be shown mathematically or by experiment, this height varies inversely with the size of the tubes. Therefore, the moist belt above the water table, which may be called the *capillary fringe,* is relatively thick in rock or soil with small interstices, such as silt or clayey loam, and relatively thin in substances with large interstices, such as clean gravel or coarse sand. (Figure 44.) It has been observed to be 8 to 10 feet thick in various loamy and silty materials, but it is greater in clayey material and less in sand and gravel. Well diggers and borers generally recognize the capillary fringe and interpret it correctly as a prophecy of available water. Its water content and wet appearance increase downward because progressively larger interstices are filled with water. However, not until the water table is reached does water enter the well.

Water-yielding capacity.—Not all the water in the zone of saturation is available for recovery through wells, a fact of great practical importance in making ground-water developments. The part that is available is called *gravity ground water,* and the part that is not available is called *attached ground water.* This distinction can be illustrated as follows: If the water is withdrawn from the zone of saturation more rapidly than it is replenished, as may happen in dry

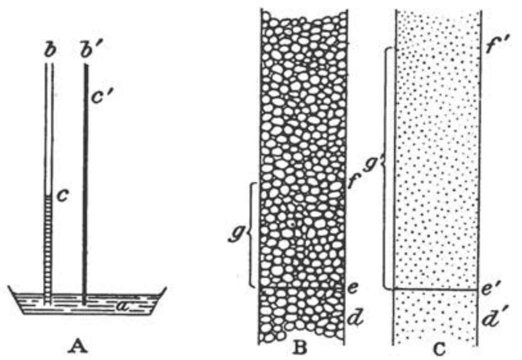

FIGURE 44. Diagrams illustrating the effect of capillarity in holding water above the zone of saturation. *A* is a pan (*a*) that contains water in which are immersed two capillary tubes (*b*, *b′*) in which the water rises to levels *c* and *c′*, respectively. *B* and *C* are columns of assorted material, the material in *C* being of finer grain than that in *B*. *d*, *d′* is the zone of saturation; *e*, *e′* is the water table; *f*, *f′* is the height to which the water rises by capillarity in the interstices of capillary size; *g*, *g′* is the capillary fringe.

seasons or after heavy pumping, the water table will move downward and with it will go the capillary fringe, which is always definitely related to the water table. The gravity ground water in a given body of rock or soil in the zone of saturation is the water that would be withdrawn from the body by the direct action of gravity, if the water table and capillary fringe moved downward through the body until both were entirely below it. The attached ground water is the water that would remain.

The specific water-yielding capacity, or *specific yield,* of a rock or soil is the percentage of its total volume that is occupied, when it is saturated, by gravity ground water—that is, by water which it will yield to wells. Its specific water-retaining capacity, or *specific reten-*

tion, is the percentage that is occupied by attached ground water—that is, by water which it will not yield to wells. Though the latter can not be recovered through wells, it may, if it occurs near the surface, be utilized by growing vegetation. The specific yield and specific retention of a rock are together equal to the porosity, or *specific aqueous capacity.* The specific yield of an impervious rock is zero, its specific retention being equal to its specific aqueous capacity.

The specific yield and specific retention of a rock or soil are not the same as the percentage of water that would respectively be yielded and retained by the same material if a small isolated sample of the material were saturated and then allowed to drain. In such a sample the percentage of water retained would be greater than the specific retention for somewhat the same reason that a filled capillary tube that is longer than the height to which water will rise in it would hold all its water if it were broken into little pieces, whereas if it were kept in one piece and were held vertically with its lower end immersed in water it would remain only partly filled.

The relative amounts of ground water yielded and retained differ in different kinds of rocks. The retaining force is chiefly adhesion, which increases with the aggregate area of the rock surfaces in contact with the water. Therefore, in rocks with a given porosity the yield is least in those which have the smallest interstices. A clean gravel (that is, one which is not mixed with fine-grained materials) may have no higher porosity than a bed of silt or clay, yet it may be an excellent source of water, while the silt or clay may be worthless. The specific yield of the gravel may be nearly equal to its porosity, while that of the clay may be nearly or quite zero, all or nearly all of its water being held against gravity. Dense rocks, such as limestones or lavas, containing good-sized solution channels or joints, may have low porosities and yet be excellent sources of water, because the interstices which they contain are large and hence yield freely nearly all of their water.

CHARACTERISTICS OF DIFFERENT KINDS OF ROCKS WITH RESPECT TO OCCURRENCE OF WATER.

Complexity of rocks.—There are many kinds of rocks of diverse composition, texture, and history and hence of diverse hydrologic properties. (See Chapter I.) Even rocks that are lithologically similar enough to be called by the same name may differ radically as water bearers. The general water-bearing characteristics of the principal classes of rocks are briefly outlined in the following paragraphs. (1, 2.)

Unconsolidated clastic deposits.—The unconsolidated clastic deposits include gravel, sand, silt, and clay, and various mixtures of these. Well-assorted gravel beds form the best aquifers, for they are capable of containing much water and they yield it very freely. They supply most of the strong irrigation wells in the western United States. Coarse clean sand ranks nearly as high as gravel, but fine clayey sand and silt yield little or none of their water and, moreover, may cause an immense amount of trouble by running into wells. The homogeneous wind-blown, siltlike deposit known as loess stands up well in excavations and yields small supplies to large wells. True clay is so fine-grained that it yields none of its water, and, moreover, it is so plastic when wet that no joints or other large interstices can form in it. Mixtures are abundant and of variable value as aquifers. Many of them are popularly called clay. They supply many dug wells, which have large infiltration areas, where only small quantities of water are required. Among the most common of the mixtures are the till, also called boulder clay (p. 15), of glaciated regions and the fanglomerate (a mixture of sand, gravel, clay, and boulders), which forms the bulk of the deposits underlying the huge alluvial fans of desert basins. The less dense varieties of both till and fanglomerate commonly furnish domestic supplies to dug wells, but the large supplies of drilled wells that pass through either of these materials are furnished by interbedded or associated gravels. (4, 6, 7.)

Consolidated clastic deposits.—Conglomerates, sandstones, and shales are the indurated derivatives of gravel, sand, and clay. The conglomerates and sandstones range, according to their degree of cementation and compacting, from excellent aquifers to beds which are unproductive or which yield water only from joints along which the hard rock has been broken. On the whole, however, conglomerates and sandstones rank high as water-bearers. They include such prominent aquifers as the Dakota sandstone, the Saint Peter sandstone, the thick Cambrian sandstones of Wisconsin and adjacent States, and the succession of productive sandstones of the Atlantic and Gulf Coastal Plain. Some sandstones have been thoroughly cemented and later had much of the cement redissolved, generally along irregular solution channels. Such sandstones are likely to be water-bearing at certain horizons or in certain so-called veins. Hard shales may contain joints that yield some water, but soft plastic shales are remarkably water-tight, as for example, the Pierre shale in the northern part of the Great Plains. (1, 2, 7.)

Sedimentary deposits of organic and chemical origin.—Limestone is generally compact and nearly impervious except the recently formed and unconsolidated deposits, which may be conglomeratic and porous. Beds of indurated limestone are, however, commonly broken by joints, and if water has circulated through these they have generally been enlarged by solution. Above the water table, where circulation is active, a limestone formation is likely to become very cavernous. If, after it became cavernous the zone of saturation was moved upward through the formation, as a result of the sinking of the land, the deposition of glacial drift, or other cause, such a formation may be an

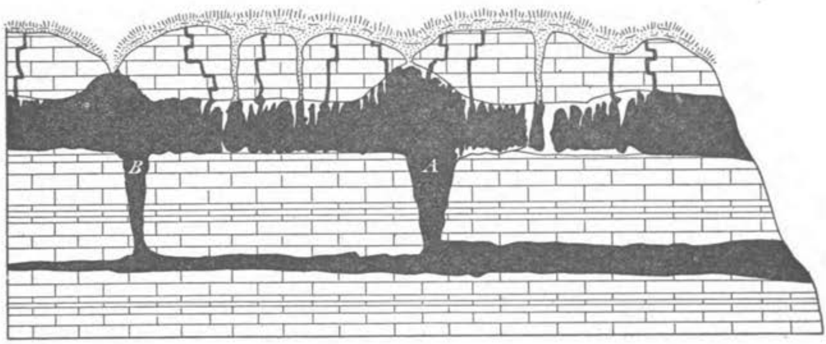

FIGURE 45. Diagram of a cavern, showing different levels of the underground stream. (After G. C. Matson, U. S. Geol. Survey.)

excellent aquifer. Examples of good water-bearing limestones (or dolomites) are the Galena and Niagara limestones in the Mississippi Valley region. Beds of gypsum and salt generally contain water that is too highly mineralized for use. Beds of coal are commonly good aquifers. Their water may be colored but is nevertheless generally of good quality. Examples of conditions in limestone areas are shown in Figures 45 and 46. (7, 8.)

Igneous rocks.—Although igneous rocks present a great variety in texture and composition, most of them (especially the granitic, porphyritic, and felsitic varieties) are much alike in respect to yielding water. These rocks, if unmodified, have low porosities and yield little or no water. However, in most places they contain at least a few joints which, though not so much enlarged by solution as those in limestone, yield small supplies. There are numerous drilled wells throughout the areas of crystalline rocks in New England and the Piedmont Plateau, a large majority of which are successful wells, although few have large yields. (4.) The igneous rocks are in many places also rendered moderately porous by weathering near the surface and along sheared or fractured zones to greater depths. These weathered parts may yield small though often valuable supplies and commonly do so in dug wells in the Piedmont Plateau and some of the arid regions in the western United States. (9.) The prospects of obtaining water in igneous rocks decrease rapidly with the depth and become very poor at depths of a few hundred feet. Some igneous rocks, chiefly fine-grained basalt, are broken by regular systems of large joints and may be excellent water-bearers. Extrusive sheets of basalt may also be rendered porous, especially near their upper surfaces, by numerous vesicles and by caverns and pipes formed during the process of con-

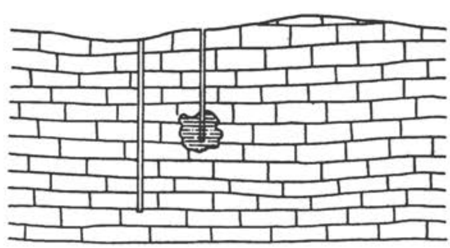

FIGURE 46. Diagram showing differences in conditions in adjacent wells in limestone.

gealing. Such a sheet will allow water to flow through it freely and may yield large supplies to drilled wells, especially if covered by younger lava sheets or other deposits so that its porous upper part is within the zone of saturation. Good aquifers of this kind are formed by the extensive basalt sheets in Idaho, Washington, and adjacent States and by those in the Hawaiian Islands. (10.)

Volcanic sediments.—Agglomerates, volcanic breccias, and tuffs, which consist of fragmental materials ejected by volcanoes, are not uncommonly porous enough to yield considerable water. In many places they form aquifers between successive lava sheets (p. 26). (10.)

Gneisses, schists, and quartzites.—Metamorphic rocks are unpromising as sources of water. They are hard to drill and, with rare exceptions, they yield only small supplies or are entirely unproductive. Gneisses, which are banded granitoid rocks, resemble granite in their water-bearing characteristics. Though unpromising they may furnish meager supplies from cracks or weathered parts near the surface. (8.) Deep wells should never be drilled into them in search of large supplies. Schists and slates likewise make poor aquifers, but where no other water is available they may yield valuable supplies from joints or from openings along their cleavage or foliation surfaces, especially if there has been some weathering. Quartzite may yield water from joints or poorly cemented strata, as the very hard Sioux quartzite, which is a dependable aquifer of small yield in Minnesota and South Dakota. (11.)

Military application.—Any of the rocks that have been mentioned may be encountered in developing water for military purposes. Generally, though not invariably, large supplies are required for these purposes, and therefore the rocks that do not yield freely are usually of no value. Gravel is doubtless the most valuable of all types of deposits, while as a rule clay and shale are unproductive and the igneous rocks are not practicable as sources of military water supply.

STRUCTURE OF ROCKS WTH RESPECT TO OCCURRENCE OF WATER.

Rock formations.—The earth's crust consists of (1) layers, or strata, of rocks of various kinds, superimposed one upon another, and (2) massive or foliated bodies of rock that underlie or interrupt these stratified series. Most of the sedimentary rocks and some of the igneous are more or less stratified. Most of the igneous rocks form massive bodies solidified from fluid lavas that before solidification were intruded into or extruded through the stratified rocks.

A rock formation is a more or less distinct unit of the earth's crust, consisting of stratified or massive rocks of one or more kinds. Formations of stratified rocks range from a few feet to hundreds of feet in thickness, and they may extend over thousands of square miles, either at the surface or buried beneath other formations. In most places there are several formations superimposed one upon another, and these may be penetrated, in succession, when a well is sunk. The different formations differ from one another in their water-bearing character, and there are also likely to be important differences in the same formation at different horizons and in different localities. Therefore, a study of the ground water of a region involves, among other things, a study of the areal distribution of each formation and of its character, thickness, and depth below the surface in each locality.

To evaluate rightly a given formation and to understand its variations from place to place, it is helpful to know its origin. Glacial drift, for example, has a very chaotic structure and consists of nearly impervious till with interbedded lenses of water-bearing gravel (p. 15). In the valleys beyond the drift sheets there may be great deposits of porous gravel made by the streams that flowed from the glacial ice. Such deposits, formed beyond the margins of the great North American ice sheets, are perhaps the strongest water-bearers in the northeastern and central parts of the United States. (7, 11.) Alluvial or stream deposits differ from glacial drift in important respects, but they are also irregular in structure and include much water-bearing sand and gravel. They are commonly confined to stream valleys, but in arid lowlands adjacent to mountainous regions deposition may be so rapid and extensive that the entire lowlands may be deeply filled with alluvium, as in the desert intermountain basins of the western United States and much of the Great Plains. (6, 9.) Deposits made in lakes or in the ocean are much better stratified than either glacial drift or

FIGURE 47. Diagrammatic sections showing three kinds of folds in stratified beds.

alluvium, and they have fewer local irregularities. Their composition, like that of drift and alluvium, depends largely on the kind of rocks whose erosion supplied the material out of which they were formed. (7, 12.)

Tilting and folding of rock formations.—The strata of rock formations are rarely horizontal; in most places they have been tilted or have been warped into anticlines, synclines, or monoclines (Figure 47). The degree of tilting or warping can to some extent be ascertained by observing the dip at different points along the outcrops of the strata and by calculating the dip through correlation of distinctive strata recorded in well logs where the altitude of the mouths of the wells and hence of the strata penetrated is known. A survey of the dip of a series of rocks is important in order to determine the distribution of the water-bearing strata and their depths below the surface in different places (Figure 48.) Knowledge of the dip of the strata is necessary in order to forecast the depth to water at particular points in regions underlain by thick series of stratified rocks, such as the Cretaceous and Tertiary series below the Atlantic and Gulf Coastal Plain (12), the Paleozoic series in the Mississippi Valley region (7), and the Cretaceous series in the northern part of the Great Plains (13). An excellent example of its importance is afforded in parts of eastern Montana, where, on account of the alteration of water-bearing and non water-bearing beds in a thick series and the extensive folding of the series, the ground-water conditions differ radically within short distances but can be predicted with considerable accuracy on the basis of rock structure. A survey of the dip is also necessary in order to determine the artesian prospects, because flowing wells are more likely to be obtained in synclines or where the beds are tilted than in anticlines or where the beds lie horizontal. (See p. 33.)

Faults.—A fault is a structural feature that results from a fracture and slipping in the rocks whereby the rocks on one side of the fracture

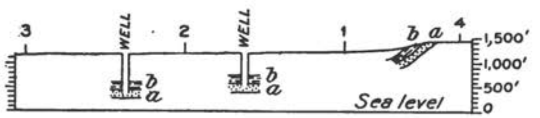

FIGURE 48. Diagrammatic section to illustrate how the dip of stratified rocks is ascertained from outcrops and well logs. Problems: The formation, *a*, is an aquifer. At what depths will it be struck at localities 1, 2, 3, and 4?

plane are displaced with reference to those on the other side. (Figure 12 and p. 31.) As already mentioned, openings associated with faults may act as water-containers, like more ordinary fractures. In addition, large faults may have either of two functions: (1) They may cause openings which extend deep into the earth and which allow deep-seated waters to escape, often in large quantities and at high temperatures, as along the huge fault lines of the basin ranges in Nevada and Utah. (6.) (2) They may produce underground dams that block the movement of ground water and cause springs or abrupt drops in the water table, as at the Niles-Irvington fault in Santa Clara Valley, Cal., or the faults in Big Smoky Valley, Nev. (6, 14.)

Unconformities.—In many regions there are two or more series of rocks separated from one another by unconformities (p. 36). In such regions the lower of two unconformable series was formed first and was submitted to erosion and perhaps to tilting or warping before it was covered by the deposition of the upper series, which may be very different in composition and mode of origin. Obviously the distribution of a given aquifer in either the upper or the lower series may be controlled largely by the unconformity. (Figure 49.) As unconformities are very common and far-reaching features they are of great importance in the study of ground water in nearly all regions. The lowest bed in a series resting on an unconformable surface is in many places a water-bearing gravel or conglomerate. In most regions the lowest known formation consists of crystalline, igneous rocks or of a complex of rocks. This basal complex extends to unknown depths. It commonly has an eroded upper surface, and it may be overlain by various younger rocks, some of which may be water-bearers. If in drilling in a series of younger rocks the drill reaches the basal complex the remaining prospects are very poor, and it is generally advisable to abandon the hole. (7, 11, 12, 13.)

Structure of igneous rocks.—Extrusive rocks, which were poured out as molten lava and then cooled at the surface, differ from intrusive rocks, which solidified deep below the surface, in two important

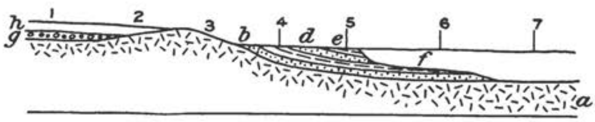

FIGURE 49. Diagrammatic section to illustrate unconformities and their effect on ground-water conditions. *a* to *h* are formations in the order of their age, *a* being the oldest and *h* youngest. *b, d,* and *g* are aquifers. Unconformities exist between *a* and overlying formations and between *f* and underlying formations. *b, d,* and *g* are aquifers. Problems: What will be the result of drilling at localities 1, 2, 3, 4, 5, 6, and 7, and to what extent are these results determined by the unconformities?

respects. (1) Many of them, especially the basaltic types, are more vesicular and more jointed and hence are better water-bearers, and (2) in some places the basaltic rocks, which were formed from the more fluid lavas, comprise relatively thin sheets below which there may be aquifers, such as gravel or limestone, whereas the intrusive masses so generally extend to great and indefinite depths that it is practically hopeless to drill deep into them to find underlying aquifers. Extrusive rocks may lie at the surface or may have become buried by other deposits. Intrusive rocks form irregular bodies of various shapes and sizes that may interrupt the aquifers of a sedimentary series. In some places they form dikes which act as underground dams, like the faults mentioned above (p. 14).

Military application.—In developing water supplies for military purposes any of the structural features that have been described may be encountered. However, faults and the structural features of igneous rocks are the least likely to be decisive factors; but the physical characteristics of the deposits, the dip of the strata, and the prominent unconformities between the successive series are significant, and knowledge of these features is required for intelligent action.

ABSORPTION.

Origin of ground water.—Some ground water is probably derived from internal sources and has never been at the surface; some is doubtless water that was mingled with rock particles when these were laid down to form sedimentary deposits, which now perhaps lie deeply buried. But almost all of the ground water that is near enough to the surface and of good enough quality to be considered as a source of supply has been absorbed at the surface from water precipitated out of the atmosphere and has percolated down to the zone of saturation. It may have entered the earth as soon as it fell from the clouds, or it may have flowed for a longer or shorter distance in a sheet or stream before it found a place where it could enter the earth.

Most of the ground water is obtained from the numerous ephemeral streams that flow in direct response to rain. The rain that is absorbed where it falls is generally not sufficient in quantity to penetrate more than a few inches or a few feet into the soil, and if so, it is eventually evaporated or withdrawn by plants without reaching the water table. On the other hand, the surfaces of large streams and lakes are generally lower than the water table beneath the adjacent lands, and, hence, are receiving water from rather than contributing to the ground-water reservoirs. Desert regions may have perennial streams which are supplied by the rain or snow water from adjacent mountains and which are so far above the water table that they lose water by downward seepage until no water remains in them.

Factors controlling absorption.—The amount of water annually absorbed by an aquifer depends on (1) the extent and character of the *intake area,* the place where water enters the ground, (2) the extent and character of the *catchment area,* which comprises the intake area and the drainage basin tributary to it, and (3) the meteorological conditions in the catchment area.

The extent of the intake area is obviously important. A formation that lies at the surface over hundreds or thousands of square miles, such as the glacial drift sheet of the north-central United States or the alluvial deposits that immediately underlie the Great Plains, will have its supply replenished much more rapidly than a formation with smaller outcrops, such as some of the older formations below the Great Plains, which are exposed only in narrow bands where their upturned edges come to the surface. The character of the intake area involves (a) the perviousness of the material through which the water must percolate, (b) the nature of the surface, and (c) the topography. Clean gravel, such as is found in the intake areas of the wonderfully productive waste-filled valleys of California, and cavernous limestone, such as the Edwards limestone of Texas (33), are the best intake media, and clay or shale is the most effective protection against intake. The nature of the surface is affected by such factors as vegetation, frost in the soil, surface hardpans and caliche, and beds of clay that lie at or near the surface. Topography is also important. For example, a sand-dune area or a poorly drained region, such as that underlain by the glacial drift sheet, affords much better opportunity for the absorption of rain than a rugged region that has been greatly dissected by stream erosion and consequently offers maximum opportunities for surface run-off.

Of fundamental importance in a study of ground-water absorption is the extent and character of the catchment area of the aquifer which includes the drainage basin that supplies water to the intake area. An aquifer whose outcrop is adjacent to a large tributary mountain range may receive a heavy recharge, while a similar aquifer that does not get water from the mountains may have but little recharge.

The meteorological conditions that affect intake include (a) amount of precipitation, (b) distribution of the precipitation in time, (c) kind of precipitation, whether rain or snow, and (d) temperature and other factors that determine evaporation. Light rains are absorbed chiefly by the upper layers of soil and may contribute little or nothing to the ground-water supply. On the other hand, sudden heavy rain storms, although contributing considerably to the ground-water supply, may send such large quantities of water directly to the lower stretches of a stream that their ground-water contribution may be only a small part of the total water precipitated. If a mountain range receives much of its precipitation as snow, which is fed gradually to some adjacent aquifer as the snow melts, the recharge may be much greater than if the precipitation comes as rain that runs off rapidly.

Methods of estimating amount of absorption.—Fairly definite estimates of the amounts of ground water absorbed can be made by measuring the loss of water from certain streams in arid regions that flow above the water table for considerable distances and for periods of considerable duration, but in most regions only indirect methods that give somewhat uncertain results are available. (Figure 50.) The ground-water intake commonly ranges from less than 1 per cent. to several per cent. of the precipitation, but estimates based on assumed percentages of precipitation are of little value and are frequently too high. (6, 15.)

Military application.—In developing water supplies for military purposes there is no time for making refined investigations leading to quantitative estimates, and such investigations are seldom needed. General surveys of drainage basins or of smaller districts with respect to intake may, however, be needed to obtain information as to the dependability of a ground-water supply or as to possible sources of pollution. With respect to pollution there are two important fields of observation—(1) the area tributary to a given ground-water

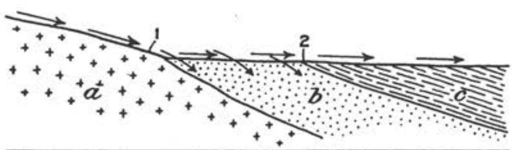

FIGURE 50. Diagrammatic section showing method of estimating ground-water intake. *b* is a pervious formation; *a* and *c* are nearly impervious. Arrows show direction of stream and of water that enters the pervious formation. The intake area of the formation *b* is between 1 and 2; its catchment area is the entire drainage basin above 2. The intake is estimated by measuring the flow of the stream at 1 and 2.

reservoir and the pollution of this area, and (2) the protection of this reservoir from intake from the polluted parts by clay beds or other impervious deposits.

DISCHARGE.

Kinds of discharge.—Ground water is discharged by three natural processes: (1) it flows to the surface out of openings in the earth, forming springs, (2) it is discharged by plants whose roots extend into the capillary fringe of the zone of saturation, and (3) it is evaporated from the soil where the capillary fringe comes to the surface. Of these three processes, discharge through springs is the most conspicuous and is the only one that yields water under conditions that permit it to be utilized for water supplies. Discharge by plants disposes of large amounts of ground water. It is a common process in all humid regions but is most noticeable in arid regions, where there is much greater contrast between the available soil water of shallow-water areas and of areas in which the roots can not reach down to ground water.

Types of springs.—Springs are caused by various structural and topographic conditions. These conditions determine whether the yield of the springs can be increased by excavation and to what extent they may be exposed to pollution.

Some springs in volcanic regions or along large faults or other fissures apparently yield water that comes from very great depths and is brought up by unknown forces. Among the types of springs that owe their origin to less deep-seated conditions are the following:[1] (1)

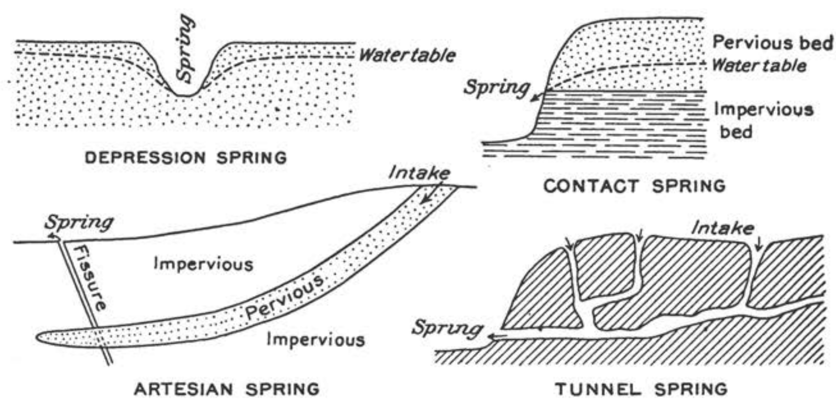

FIGURE 51. Diagrammatic sections illustrating 4 types of springs.

Depression springs, which are caused simply by irregularities in the land surface whereby the surface reaches down to the water table in underlying porous material and allows the water to flow out by gravity, as in ravines on hillsides, along the margins of valleys, or in channels cut into the valley floors. (2) *Contact springs,* which issue by gravity from the porous rock along the outcrop of the contact between the rock and an underlying impervious bed. (3) *Artesian springs,* which are due to the escape of water that is confined under pressure in a porous bed between impervious materials, the escape being either at an outcropping edge of the porous bed or through fissures in the overlying impervious bed. (4) *Tunnel springs,* which flow by gravity from more or less rounded channels in relatively impervious rocks, such as solution channels in limestone or caverns in basaltic lavas. (5)

[1] This classification is taken from a paper entitled "Classification of springs" by Kirk Bryan, now in press as U. S. Geological Survey Water-Supply Paper 450-A. The terminology is subject to revision.

Crevice springs, which flow by gravity from joints or other openings in relatively impervious rocks. (Figure 51.)

Development of springs.—The available supply from a spring or group of springs can often be increased by making excavations that will bring into one spring or pool the water which otherwise would seep out at various points and would largely be lost through evaporation. Under some conditions it is also practicable to increase the flow by enlarging the outlet from the aquifer (16). Many depression springs and some tunnel and crevice springs can be developed in this way, and in many places where there is no spring but where the water table comes near the surface and has considerable slope ground water can be led to the surface by gravity, through ditches or tunnels with slight grade, extended from the surface into the zone of saturation. (Figure 52.) A few such infiltration ditches and tunnels yield large supplies. Generally, however, they are expensive and produce but little water (3). Enlargement of the vents of artesian springs is seldom practicable, but additional vents can be made by drilling holes to the aquifer through which the confined water may escape. Such artificial vents are called flowing wells. They are obtained in many places where no natural vents have been found and are locally of much importance (see p. 135). Although in certain places they have special conditions it may be practicable to obtain water supplies by developing springs, digging infiltration ditches or tunnels, or procuring flowing wells. The method of recovering ground water that is most widely applicable and generally most dependable and economical consists of sinking wells into aquifers and pumping water out of them.

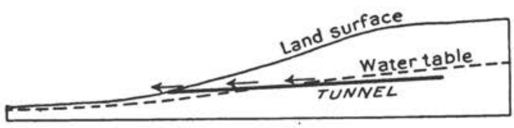

FIGURE 52. Diagrammatic section showing an infiltration tunnel.

Pollution of springs.—Deep-seated and artesian springs are practically safe from pollution except as their water may be polluted after it has reached the surface. Tunnel and crevice springs are especially susceptible to pollution because they may receive surface water and sewage from near-by sources and their interstices are so large that this water or sewage may flow rapidly and without filtration to the point of discharge. Springs issuing from limestone at the base of a populated upland should always be under suspicion. Depression springs are also likely to be affected by near-by sources of pollution. If the water-bearing material is gravel the danger is greater than if it is sand, because there is freer percolation with less effective filtration. In depression, contact, tunnel, and crevice springs, the danger of pollution depends largely on the presence or absence of protective material above the aquifer (2, 4).

Yield of springs.—Springs differ in yield from a small fraction of a gallon to many thousands of gallons per minute. Silver Spring, Florida, a tunnel spring, yields 368,000 gallons per minute (32); Comal Spring, Texas, an artesian spring, yields 147,200 gallons per minute (33); Warm Spring, Oregon, yields 116,500 gallons per minute.[2] Yields of such magnitude are, of course, rare. The yield of small springs may fluctuate widely but that of large springs is generally nearly uniform.

Criteria for locating ground water.—The criteria for locating areas of ground-water discharge are of considerable military importance, both in finding water supplies and in recognizing localities where trenches will fill with water. These criteria are furnished by the topography, the position of springs, the moisture of the soil, alkali crusts, and vegetation. In the arid regions, as in the southwestern United States, ground water can almost invariably be located where it comes near enough to the surface to be tapped by the roots of native plants, and with this definite information in regard to the water table in certain localities forecasts can be made as to its position in a large surrounding area. Thus in Steptoe Valley, Nevada, salt grass (*Distichlis spicata*) indicates that the water table is not more than seven feet from the surface, rabbit brush (*Chrysothamnus graveolens*) that it is not more than 15 feet, and greasewood (*Sarcobatus vermiculatus*) that it is not more than 20 feet, while a certain type of "running" mesquite may indicate that it is somewhere within about 50 feet of the surface. With some practice shallow-water areas can also be located with considerable accuracy in humid regions. (6.)

Quantitative estimates of discharge.—Estimates can be made of the quantity of water discharged annually from a given shallow-water area, and hence of the annual supply of the discharging aquifer, by making tests of discharge under similar conditions in specially designed tanks in which the quantities of water can be measured (15). These methods, however, are too refined to be applied in military work.

[2] For fuller data on these and other large springs see Bibliography and index of the publications of the U. S. Geological Survey relating to ground water, by O. E. Meinzer (in press as Water-Supply Paper 427).

MOVEMENT OF GROUND WATER.

Direction of movement.—In general, ground water is not stationary but is moving slowly. This movement is abundantly proved by the vast alterations in rocks throughout the earth's crust that have been caused by the solution, transportation, and deposition of mineral matter, and it has also been demonstrated for certain aquifers by experiment. Ground water, like surface water, moves in response to gravity from higher to lower levels. With unimportant exceptions it moves from the points where it is received from the surface toward points where it is returned to the surface, although, on account of the structure of the rocks, it may make this journey by a circuitous route. (Figures 43 and 51.) (3, 4.)

Laws of rate of movement.—The rate of movement through rocks that have ordinary small interstices is approximately proportional (1) to the perviousness of the rocks (see p. 112), and (2) to the difference in head per unit of distance, or to the pressure gradient. It also increases with the temperature.

Methods of testing direction and rate.—Both the direction and the rate of movement in shallow aquifers have been investigated in many localities. The standard method for making velocity measurements is that devised by Slichter, which consists of introducing ammonium chloride or some other electrolyte into one well and observing the time that elapses before it affects a pair of electrodes in a well that has been sunk to the same stratum but is lower down on the slope. If there is any doubt as to the direction of movement of the ground water electrodes must be placed in wells in various directions from the one that receives the electrolyte (17). A method that has been used with much success for exploring the course of ground water where pollution is suspected consists of introducing fluorescein into the cesspool, sewer, or other possible source of pollution and watching for its appearance in the wells under suspicion. Fluorescein is a harmless but very powerful coloring matter whose green appearance can often be observed with the naked eye and can be detected with a fluoroscope if one part is present in 10 billion parts of water. It is, however, decolorized by peaty formations and free acids, except carbonic acid, and to some extent by calcareous deposits (18). Explorations of the course and velocity of ground water can also be made by using sodium chloride (common salt) or ammonium chloride and testing samples from the observation wells for chlorine at frequent intervals.

Data on rate of movement.—The rate of movement of course varies greatly with diversity in the rocks and differences in pressure gradient. According to experiments and calculations by Slichter, with a pressure gradient of 10 feet per mile the rate is 53 feet per year in fine sand; 845 feet per year in coarse sand; and 5,386 feet, or about a mile, per year, in fine gravel. In tests made by the U. S. Geological Survey in gravelly valley deposits in California, Kansas, and Nebraska the velocity was found to range from about 1 foot to about 50 feet per day, and in sandy and gravelly deposits on Long Island from practically zero to about 100 feet per day. In tests in gravelly deposits in Arizona the maximum velocity was found to be 420 feet per day. The average velocity is doubtless much smaller in the deeper and less pervious aquifers than in the surface deposits that have been tested.

Military application.—In military work the direction and rate of movement are important chiefly in connection with problems of pollution. Only rough estimates based on field observations can generally be made. The direction of movement can be determined by comparing the water levels in different wells that tap the same aquifer. If there are no wells the direction of movement can be approximately ascertained from studies of intake and discharge. Some idea of the rate of movement can also be obtained from the above-mentioned observations and from inferences as to the perviousness of the aquifer, based on examinations of outcrops and well drillings and on the yield of wells.

HEAD.

Relation of the water table to absorption and discharge.—The water table is not a level surface but has irregularities that can be shown on maps by means of contours just as irregularities of land surfaces are shown on ordinary topographic maps. (Figure 43.) The highest parts of the water table are beneath intake areas and the lowest are at areas of discharge, where the water table approaches the land surface.

The water table is not a stable surface but fluctuates with variations in absorption and discharge. In rainy seasons it is built up, especially in intake areas, and in dry seasons it goes down in these areas because of percolation to lower levels without any compensating absorption. This is especially noticeable where the year is divided into distinct rainy and dry seasons, as in California. Where Santa Clara Valley, Cal., receives the water of Coyote Creek the water table has an average annual fluctuation in different parts of 10 to 45 feet. By comparing for such an area the topographic map of the water table before the rainy season with a map of the water table after the rainy season an estimate can be made of the volume of material that becomes saturated during the rainy season, and with an assumption as to the porosity, or, rather, as to the specific yield, an estimate can be made of the volume of water annually absorbed. In summer, when evaporation and vegetal discharge are great, the water table generally falls a few feet in areas of discharge, and in autumn and winter, when evaporation and vegetal discharge are at a minimum, it is raised chiefly by percolation from higher levels, even though there is no intake at these higher levels. To this cause is due the frequently observed phenomenon in California and other regions of increase in the flow of springs in the fall, before the approach of the rainy season. (19, 20.)

Relation of the water table to movement.—All rocks offer resistance to the percolation of water through them, but they differ greatly in the amount of resistance. The resistance is the converse of perviousness. It is least in very pervious rocks, such as clean gravel and cavernous limestone, and greatest in rocks that are nearly impervious,

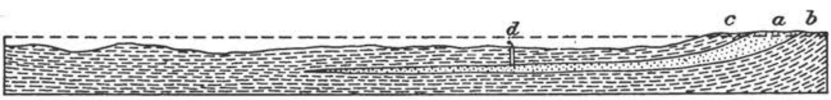

FIGURE 53. Diagrammatic section showing artesian structure. *a* is an aquifer between the impervious beds, *b* and *c*. *d* is a flowing well.

such as the clayey and silty deposits. The differences in the height of the water table from place to place, due to inequalities in intake and discharge, provide the resultant pressure that overcomes the resistance of the rocks and keeps the ground water in motion.

Artesian systems.—If a dipping aquifer were encased by impervious material except at its upper edge, where it outcrops, as shown in Figure 53, it would become filled with water received at the outcrop, and this water would remain confined in the aquifer indefinitely. If, however, a well were drilled through the impervious material and into the aquifer, the water would rise in the well to the level to which the aquifer was filled—that is, approximately to the level of the outcrop. Such an aquifer with the confining formations would be called an *artesian system,* the well would be called an *artesian well,* and the water would be said to be under *artesian pressure*. If the land surface at the well site were considerably below the level of the outcrop the water would rise to the top of the well and would overflow at the surface, forming a *flowing well.*

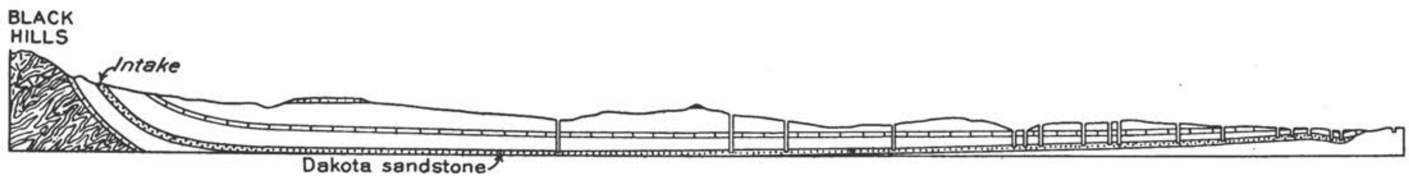

FIGURE 54. East-west section across South Dakota to show the Dakota artesian system.

If the confining beds were not entirely impervious or not entirely continuous some water would escape even before the well was dug, but if the opportunity for escape were slight in comparison with the supply at the intake the head would be only slightly reduced and the water would still rise in the well and might still overflow. There are probably no completely confined aquifers, but aquifers that are overlain by beds which retard the percolation of water sufficiently to produce some artesian pressure are abundant. Water above the overlying confining bed exerts a counter pressure. Hence a well is not regarded as having artesian pressure unless the water rises above the zone of saturation. Rarely the confining beds are sufficiently effective to produce artesian pressure that will lift the water in wells far above the local water table—for example, the uninterrupted deposits of plastic

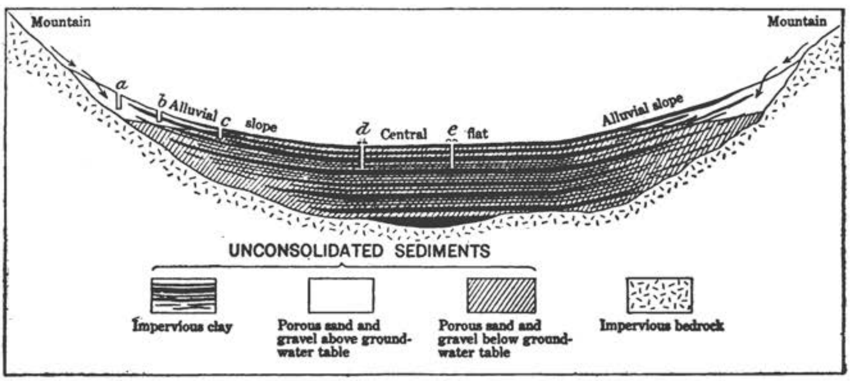

FIGURE 55. Diagrammatic section showing artesian conditions in Sulphur Spring Valley: *a*, Dry hole which if sunk deeper would strike rock without finding water; *b*, Dry hole which if sunk deeper would find water; *e*, Shallow pump well; *d* and *e*, Flowing wells.

shale, hundreds of feet thick, which overlie the Dakota sandstone, are reported to have originally produced in some places heads of more than 500 feet at the surface. Generally, however, so much water escapes through the confining beds that the water fails to rise far above the water table. This fact is of great practical importance. Unless the structure is especially favorable the prospects are poor for obtaining flowing wells in a locality in which the water table is not near the surface.

Various features of structure produce the conditions necessary for artesian flow. (5, 21.) The most important are extensive well-stratified series of formations differing greatly in perviousness, not much disturbed by faulting, and passing from relatively high outcrops downward beneath lower land, as the Dakota sandstone and overlying Cretaceous formations that outcrop along the edge of the Rocky Mountains and thence extend below the eastward-sloping Great Plains (Figure 54) or the alternating sandstones and clays of the Atlantic and Gulf Coastal Plain that outcrop along their landward edges and thence extend to increasing depths in the direction of the lower lands adjacent to the sea. (7, 11, 12, 13.) Others of much importance are the synclinal troughs formed by the gravelly and clayey deposits of the waste-filled intermontane valleys (Figure 55) (6, 9) and the irregular features of glacial drift that give rise to artesian flows in many small areas in the northern United States (7, 11). Conditions that are very unfavorable for obtaining flowing wells are shown in Figure 56.

Although flowing wells are locally very valuable, their importance

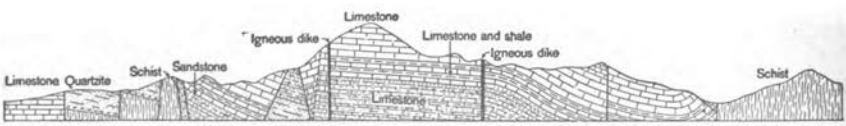

FIGURE 56. Section of rocks near Bisbee, Ariz., showing faulting and absence of artesian structure. (After F. L. Ransome, U. S. Geol. Survey.)

is on the whole greatly overrated. On account of the reckless waste of water permitted in most areas of artesian flow, the head and yield generally decline rapidly. In developing military supplies reliance must be placed on pumping.

QUANTITY.

Flow of streams.—If a water supply is to be obtained from a stream, the fact must be recognized that the flow of most streams fluctuates between very wide limits. It is important to know the flow in times of extreme drought. Dependable estimates of flow can be based only on systematic observations covering a period of years, although rough estimates can be made by considering the size and character of the drainage basin, the records of precipitation in the basin, and the percentage that runs off in comparable basins for which run-off data are available. For example, streams that are fed by lakes or springs or by snow in lofty mountains are less affected by periods of drought than streams whose basins do not have these features (p. 73). If the stream may dry up or its daily flow may become less than the daily requirement it is necessary to plan reservoirs of sufficient capacity to store enough water to supply the deficiency during the period of low flow.

Quantity of ground water.—The determination of the quantity of ground water presents several problems—(1) the total quantity of ground water stored in a given aquifer, (2) the total quantity of gravity ground water in the aquifer, or the total quantity that it would yield if it were completely drained, (3) the annual supply of the aquifer, or the quantity it can yield each year without serious depletion, and (4) the rate of yield of wells sunk to the aquifer.

The total quantity and the total yield can be estimated by multiplying the total volume of the saturated part of the aquifer by the porosity and specific yield, respectively (23). The annual supply can be estimated under certain favorable conditions, by one of the following four methods: (1) Measurements of seepage losses of streams (see p. 127), (2) estimates of increased storage during the rainy season based on observed rise of the water table and specific yield (see p. 118), (3) estimates of the quantity percolating through a given cross section of an aquifer, by measuring the velocity and estimating the cross section and porosity (see p. 133), and (4) estimates of the discharge through springs, plants, and soil (see p. 129). Refined investigations of quantity are not practicable in military work, but rough estimates based on general consideration of the factors involved are frequently required.

Yield of wells.—The capacity or yield of wells differs greatly with the perviousness of the aquifer and its head of water, with the character and size of the intake of the well, and with mechanical details in the construction of the well. Wells in till and in many igneous and metamorphic rocks commonly yield only a few gallons per minute. A good proportion of the wells of medium diameter drilled a considerable depth into sandstone, limestone, or basalt yield 25 to 100 gallons per minute, but many wells supplied from these rocks yield several hundred gallons per minute and a very few yield more than 1,000 gallons per minute. Wells in beds of clean gravel at least a few feet thick generally yield 100 to several hundred gallons per minute, and a few yield more than 1,000 gallons per minute, but if the gravel is mixed with fine material the yield may be very small. Probably a large majority of the wells in the United States yield less than 10 gallons per minute. The yield of shallow wells commonly fluctuates with the seasonal fluctuations of the water table.

Wells that will not yield at least a few gallons per minute are frequently abandoned as of no practical value. However, if the well has a large enough diameter and extends far enough below the water level to have a storage capacity equal to the daily consumption it may be satisfactory for domestic use even though it yields only a fraction of a gallon per minute. For instance, if in a dug well that extends only a few feet below water level there is a continuous infiltration of only one-tenth gallon per minute, the well will produce 144 gallons per day, an amount ample for the needs of most families. A well that yields 5 to 10 gallons per minute will with protracted pumping provide an ample supply for 25 to 50 men. A well that yields 100 gallons per minute, if pumped half time, will supply about 70 gallons a day per man to a camp of 1,000 men. On the same basis a cantonment of 40,000 men will require 2,800,000 gallons a day, which would be about the half-time yield of 40 wells, each of 100 gallons capacity per minute, or of 8 wells, each of 500 gallons capacity per minute. A continuous draft of such magnitude will invariably cause considerable mutual interference among the wells and some decrease in yield. It will involve appreciable depletion of even a strong aquifer and will compel consideration of annual supply to the aquifer. Ground-water developments of this magnitude have been successfully made at Camp Dodge, Iowa, and Camp Cody, N. Mex., but are not practicable in most regions.

Specific capacity of wells.—During pumping the water level in a well is drawn down, but when pumping ceases the water returns approximately to its original level. In all wells the drawdown increases with the rate of pumping, and in many it is in nearly direct proportion to the rate of pumping. In wells in which there is a nearly direct relation the yield per unit of drawdown is called the specific capacity. Thus a well that yields 20 gallons per minute with 5 feet of drawdown has a specific capacity of 4 and will probably yield about 100 gallons per minute if it is pumped hard enough to draw the water level down 25 feet. That is, with a drawdown five times as great it will probably yield five times as much water. (17.)

Pumping tests.—Pumping tests involve two essential measurements—measurements of yield and measurements of drawdown. There are various methods of measuring the yield (24). If it is less than 100 gallons per minute it can generally be measured most conveniently and accurately by observing the number of seconds required to fill a tub or other good-sized vessel. Larger yields can also be measured by the volumetric method if the water can be discharged into a tank or reservoir of considerable capacity. Otherwise they can be measured with a weir if there is enough fall below the discharge pipe to give the required head, or with a current meter if the yield is as much as 500 gallons per minute.

QUALITY.

Relation of the content of water to its use.—The quality of water depends upon the substances which it contains either in solution or in suspension. These substances may be solids, liquids, or gases and may be organic or inorganic. The quality of the water is of great practical importance as affecting its adaptation for various uses, but different properties are important in different uses. Therefore, to say that water is good or bad has little significance unless the purpose is specified for which it is good or bad, as for drinking, washing, use in steam boilers, or irrigation. In military water supplies drinking and other personal uses are the most important, but use in steam boilers and for other industrial purposes are also of much consequence.

Sanitary quality of surface water.—Surface water is a great natural scavenger which picks up and carries away, chiefly in suspension, loose particles of mineral matter and also vegetable and animal refuse. The loose particles of mineral matter make the water roily, which renders it objectionable although not necessarily harmful for drinking and causes it to make deposits in boilers and to some extent to produce foaming in boilers. The vegetable and animal refuse is objectionable for drinking, particularly if it includes human excreta which may contain disease germs such as those of typhoid fever. As persons who are apparently healthy may be carriers of these germs, any water from a source that may have been contaminated by human excreta is dangerous for drinking unless it has been purified by natural or artificial means. The drainage from populated districts is obviously unsafe and in former years caused numerous epidemics, and even the apparently pure water of streams from sparsely settled mountain regions sometimes conveys typhoid germs from isolated cases to communities that depend on the streams for water supply. (24.)

Sanitary quality of ground water.—When water is absorbed and percolates through the earth it loses nearly all of its suspended matter by filtration through the small interstices of the rocks, and hence, when it reappears from springs or wells it is generally clear. It acquires the temperature of the earth's crust, which at depths of 25 to 100 feet is about the mean annual temperature of the atmosphere in the region. Nearer the surface its temperature fluctuates slightly with the season; at greater depths the temperature increases—in most regions at the rate of 1° F. for 50 to 100 feet increase in depth. Hence, in regions having a temperate climate ground water from moderate depths is not only clear but also cool. For this reason it is in much popular favor and is assumed to be pure, notwithstanding the fact that clear cool water may contain deadly disease germs.

The removal of matter held in suspension in the water is due mainly to the entanglement of the suspended particles among the grains of the rocks through which the water passes. The efficiency of this process depends largely on the size of the interstices, on the pressure gradient, and on the temperature of the water. The slower the filtration the more effective it will be, fine material is more effective than coarse, and low-pressure heads and low temperatures better than high ones.

In ordinary materials and with waters free from sediment there is relatively small decrease in the number of bacteria. Where sediment of any sort is present in considerable amounts, however, many bacteria are entangled in the filter and remain behind with the residue. Free oxygen is present in the interstices above the water table and is in solution in the water for some distance below the water table. Either by direct chemical action or through the influence of bacteria it attacks and breaks down the impurities, reducing them to harmless mineral compounds. Even more important than the oxidation of impurities by the aid of bacteria is the work done by the so-called nitrifying bacteria, which not only break down the organic polluting materials but destroy most of the disease-producing organisms. Under artificial conditions, as in filtration plants, the action is almost perfect, 99.5 per cent. or more of the dangerous bacteria being removed; under natural conditions, however, the action is less complete. In brief, polluted ground waters are more or less purified through the removal of their suspended matter and a part of their bacteria by entanglement among the grains of the material through which they pass, by oxidation, and by nitrifying bacteria, but more or less polluting matter remains in the water for a considerable length of time.

The alternation of layers of materials of different texture and even the stratification of uniform materials tend to obstruct the downward passage of water and to confine pollution to the upper part of the zone of saturation—the part immediately below the water table. For safety from pollution wells should be tightly cased and carried to a considerable depth below the water table.

Where a single source of pollution exists and only a small amount of polluting matter enters the ground the contamination in sandy deposits does not commonly extend more than 150 feet from the source, provided the water is not pumped in great quantity. Where there are several sources of pollution and large amounts of polluting matter are introduced into the ground the contamination may extend in porous materials for some hundreds or even thousands of feet, especially where the ground water moves with considerable velocity (2, 11, 25). Water may flow rapidly and for long distances through caverns and joints in limestone or other hard rock or through the large openings in coarse gravel, without being filtered (8, 26). Although ground water is generally purified within a moderate distance from the place where it is absorbed, very large allowances for safety must be made on account of the variable and somewhat indeterminate conditions that affect purification, so that generalizations as to distances required for purification are of little practical value.

Sanitary investigations of ground water.—Sanitary investigations of ground water consist of tests of the water and field surveys. Tests of the water give information as to actual pollution, while field surveys discover sources of pollution and conditions that will become dangerous as soon as a source of pollution is supplied. Bacteriologic tests of total bacteria and of *Bacillus coli,* which inhabits the intestines of man and other animals, are more trustworthy than sanitary chemical tests. Tests for chlorine, for example, which is not necessarily derived from polluting materials, are worthless unless numerous analyses of unpolluted waters from the same aquifer in the same locality are available for comparison. Arbitrary rules based on such tests may lead to the condemnation of safe supplies.

Sanitary field surveys should include observations on the following subjects:

1. The possibility of pollution entering the mouth of the well or getting into the water after it has been recovered from the well or spring. This is the most common manner in which ground water is polluted. Dug wells are most liable to pollution at the mouth, especially if they are not curbed or are curbed with boards rather than with tile or cement casing that extends some distance above the surface. Drilled wells with heavy iron casing extending several inches above the surface are least liable to pollution at the mouth.

2. The possibility of pollution entering the well below the surface, either by seeping down in the vicinity of the well to the water level and thence into the well or by seeping down on the outside of the casing and eventually coming up on the inside. Obviously tight heavy iron casing extending considerably below the water level is the best preventive, but there is nearly always a possibility that there are leaky joints or,

in old wells, that the casing has become corroded. A well in a polluted environment is necessarily under suspicion. A flowing well is less likely to pollution than a pumped well because the pressure of its water is outward. A well in which the casing is used as the suction pipe is most liable to draw in surficial polluting matter.

3. The depth below the surface and below the water table of the bed from which the well draws its water, and the presence or absence of a protective cover over the water-bearing bed, such as a layer of clay. Porous deposits at the surface are obviously more exposed to pollution than deep protected aquifers overlain by impervious or only slightly pervious material. This exposed position is, however, no reason in itself for condemning the shallow water, for many valuable supplies come from such sources, but it makes imperative the keeping of possible causes of pollution at a safe distance.

4. The approximate course of the ground water in the region that may contribute to the wells or springs, determined through studies of topography, structure, position of water table, intake, and discharge areas, etc., by methods already outlined.

5. Character of the materials through which the water percolates, in order to estimate their value as filters. Deposits with only small interstices are the best filters, whereas rocks that contain large cracks or crevices are not dependable.

6. Sources of pollution within the region whose surface waters or ground waters may reach the vicinity of the wells or springs.

Methods of purifying polluted waters.—Methods of purifying polluted water have been greatly developed in recent years, with corresponding decrease in the prevalence of typhoid fever, dysentery, cholera, and other intestinal diseases. Water can be purified by filtration or by sterilization. Small filters are generally unreliable, but large filtration plants under competent supervision are efficient and economical. They, as well as large chlorination plants, are adapted for large, relatively permanent cantonments. It may be desirable to filter and to chlorinate a cantonment water supply. For mobile military operations and for small camps chemical sterilization by chlorination is more feasible and should be practiced whenever there is any doubt as to the purity of the water. The following is a description of a sterilizing field bag used in the United States Army:

An appliance carried on the supply table as "Water bag, field sterilizing," consists of a canvas bag of specially woven flax, 20 inches in diameter and 28 inches in length, sewn to a flat galvanized-iron ring, hinged so it folds at one diameter. Spliced at four equidistant points on the ring are two crossed pieces of hemp rope, enabling the bag to be suspended on any convenient support capable of holding the weight of the bag when filled with water, which is about 330 pounds. Five nickel spring faucets are placed at equal spaces about the bottom edge of the bag. The neck of each faucet is small enough to enter a canteen, which can be filled in 10 seconds. The self-closing faucets prevent wastage.

The purpose of the bag is not to transport water but to provide a stationary receptacle in which water can be held long enough to sterilize and then distribute it. The empty bag weighs from 7 to 7½ pounds and folds into a convenient package for carriage in the field.

After the bag is suspended and filled with water, the water is sterilized by the addition of a small amount of hypochlorite of calcium. This is carried in measured doses, sealed in glass tubes. A package of 60 of these tubes weighs 10 ounces and measures 7½ by 3½ by 4¼ inches. Packed in corrugated paper it will stand rough usage.

The tubes themselves are 3 inches in length by three-fifths of an inch in diameter and are marked with a file, enabling them to be easily broken with the fingers. Each one contains from 14 to 15 grains of calcium hypochlorite. This chemical contains from 30 to 32 per cent. of chlorine, which forms hypochlorous acid in the water and sterilizes the water by a process of oxidation. In the strength used (1 to 500,000) this chemical renders highly infected waters safe, but of course it will not purify grossly polluted water, such as sewage. As the chemical acts more efficiently in clear waters, a filter cloth, to be fastened over the opening of the bag and weighing 1 ounce, is provided, or water may be strained through a blanket. The bag is filled after the filter cloth is in place. Suspended matter, such as clay, is thus largely removed and not left to interfere with the action of the chlorine.

Comprehensive experiments demonstrate the bacteriological efficiency of this appliance. The organisms causing typhoid fever, the dysenteries, including amoebic or tropical dysentery, and ciliates are promptly destroyed. Even the vegetative forms of amoebae are killed in 15 minutes. Ordinarily 5 to 10 minutes suffices after the addition of the powder to render the water safe to drink, and exposure of 30 minutes has been found to destroy all amoebae and ciliates under most severe conditions in a test.

The fact can not be too strongly emphasized that water can be effectively sterilized by the simple process of boiling. In the Gallipoli campaign, when the men suffered so much from thirst that they could not be restrained from drinking the dangerously polluted drainage that accumulated in the trenches, they were supplied liberally with tea to encourage them at least to boil the trench water before drinking it. (24, 27.)

Mineral content of ground water.—When water percolates through the earth it gives up its load of materials held in suspension but instead takes up a load of substances dissolved from the rocks themselves. It holds these dissolved substances, for the most part, throughout its subterranean journey and after it is returned through springs to the streams. Therefore, all ground waters and waters of spring-fed streams contain dissolved mineral matter, but on an average the ground waters contain more than the streams because in streams the spring discharge is diluted with direct surface run-off, which contains but little dissolved matter.

Ground waters differ greatly in their content of total dissolved mineral matter and in the proportions of the different kinds of mineral matter. The following table shows the classification of waters with respect to their mineralization, according to standards adopted by the U. S. Geological Survey:

	Total dissolved solids (parts per million).	
	More than	Not more than
Low	....	150
Moderate	150	500
High	500	2,000
Very high	2,000	....

Ground waters contain a great variety of dissolved mineral substances. Those most commonly determined in chemical analyses because of their usual abundance or because of their importance for the most general uses are as follows: Silica (SiO_2), ferric oxide (Fe_2O_3), and alumina (Al_2O_3); the basic radicles iron (Fe), aluminum (Al), calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K); and the acid radicles carbonate (CO_3), bicarbonate (HCO_3), sulphate (SO_4), chloride (Cl), and nitrate (NO_3).

Relation of mineral content to kind of rock.—The amount and kind of mineral matter dissolved in a water depend chiefly on the character of the rocks through which it has percolated and the extent to which the rocks have been leached by percolation. Igneous rocks are composed chiefly of difficultly soluble silicates of the various bases, and accordingly their waters are relatively low in mineralization. The chief constituents of these waters are sodium and calcium, derived from the decomposed igneous rocks, and the bicarbonate radicle, derived directly or indirectly from the carbon dioxide of the air. In the sedimentary rocks the most highly mineralized waters are as a rule found in deposits of salt lakes or seas in which were precipitated gypsum, common salt, etc. Next in general order of mineralization are the waters found in marine deposits and the subaerial deposits of arid regions, many of which are red and more or less gypseous. The least mineralized waters are those of the fresh-water deposits and the subaerial deposits of humid regions. Much, however, depends on the source of the sediments that make up the sedimentary formations. Thus the glacial drift in New England, derived from relatively insoluble crystalline rocks, has water of low mineralization, whereas the glacial drift of western Minnesota and Iowa, derived from formations that are impregnated with soluble salts, contains water that is highly mineralized. The quantity of soluble matter rocks may give up to circulating ground water depends in large measure on the opportunity for leaching the rocks have had since their formation. For example, the marine deposits of the central United States are highly mineralized where they occur far below the surface, although the same deposits contain only moderately mineralized water where they are near the surface and there has been appreciable circulation of water through them. The opportunity for leaching depends on the perviousness of the formation and on its topographic attitude. Limestone waters all contain at least moderate amounts of calcium and bicarbonate and hence are more or less hard. Many limestone waters are, however, excellent for drinking. (6, 7, 11, 24.)

Relation of mineral content to use for drinking.—The effects of specific quantities of mineral substances dissolved in water upon the health of persons who drink the water are not well understood. There are wide differences in the effects of the same water on different persons, and many of the supposed effects, both curative and injurious, are no doubt imaginary rather than real. It sometimes happens that virtually the same water is in one community avoided as unfit to drink and in another prized for its medicinal properties. The effect of any mineral ingredient is generally greater on a person unaccustomed to the water than on one who has used it for a long time. Moreover, a person may at first object to a certain water because of the taste given by its mineral matter, but the same person after drinking the water for some time may become unable to detect any taste in it and may even prefer it to less mineralized water.

Any classification based on total solids alone is unsatisfactory because the different constituents do not have the same effects, and hence much depends on the proportions of these constituents. The calcium salts are less objectionable in water used for drinking than the same amounts of the sodium salts, and the different sodium salts are not equally objectionable. The older authorities on drinking waters for England and the eastern part of the United States fixed 570 parts per million as the extreme limit of mineral content. It is desirable, when practicable, to use waters of low or moderate mineralization, but in desert regions waters containing as much as 2,500 parts of total dissolved solids may be considered satisfactory for drinking and have not been demonstrated to be injurious, while waters containing 4,000 or even 5,000 parts may be used for drinking where no other supplies are available.

Waters that contain 250 to 300 parts of chlorine derived from common salt have a slightly salty taste, but waters that contain 600 parts are frequently used for drinking, apparently without injurious effects, and even waters that contain 1,000 parts are used by man in case of necessity. Waters containing considerably over 1,000 parts are sometimes given to horses but are likely to make them sick.

About 400 parts of the sulphate radicle in the form of sodium sulphate or Glauber salt are perceptible to the taste. Waters that contain still more of this constituent are salty and bitter. Magnesium sulphate or Epsom salt is also perceptible when present in considerable quantities. Both Glauber salt and Epsom salt are laxative, and waters containing several hundred parts per million of these salts are prized by some persons for their medicinal properties. (24, 28.)

Relation of mineral content to other uses.—Hardness in water is its capacity for consuming soap by forming insoluble compounds through chemical reaction between the soap and certain of the substances dissolved in the water—chiefly calcium, magnesium, iron, and aluminum. The term temporary hardness is applied to that kind of hardness that can be removed by heating and by treatment with lime (CaO); permanent hardness is the kind of hardness that can be removed only by treatment with soda or other alkali. The hardening constituents are also the chief sources of scale deposited by water in boilers. Therefore hard waters are poor for boiler use but can be improved by the application of softening processes. Iron, even when present in only a few parts per million, is objectionable for laundry and toilet use on account of the yellow stain which it produces. It can largely be removed by aeration of the water. Sodium and potassium when present in considerable quantities are the chief cause of foaming in boilers. (24.)

Analyses of waters for their mineral content are best made in a properly equipped chemical laboratory, but simple field tests are practicable for the approximate determination of hardness, chloride, carbonate, bicarbonate, and sulphate. Of these, the chloride determination is the most satisfactory. (24.)

CONSTRUCTION OF WELLS.

Wells may be constructed by many different methods, most of which require the application of skill and of various ingeniously devised tools and machinery (29). Such work should preferably be put in charge of a well driller who has had training and who has also good judgment and is resourceful, especially for deep drilling and work in territory that has not been explored for ground water.

The four main groups of methods of constructing wells are as follows: 1. Digging with picks, shovels, and spades or with a steam shovel or other dredging or trenching machinery. 2. Boring with hand or power auger, the material being brought up, for the most part, by the auger. 3. Driving a casing at the end of which there is a drive-point (without the aid of any boring, drilling, or jetting device). 4. Drilling (by percussion or rotary methods). Digging, boring, and driving are adapted to places where water occurs in unconsolidated deposits near the surface. The various methods of digging may find considerable application either near or behind the front with expeditionary forces. Driving is a quick, inexpensive method, but it can be used only in small areas, chiefly in sandy valley deposits. Drilling is by far the most dependable and most widely applicable for recovering ground water.

Outline of principal methods of drilling.

1. Percussion methods.
    - A. Drillings removed with bailer.
        - a. Standard cable or solid-tool methods.
        - b. Portable cable or solid-tool methods.
        - c. Pole-tool method.
    - B. Drillings forced continuously upward through hollow drill rods—Self-cleaning method.
    - C. Drillings held in hollow drill tool, which is periodically withdrawn.
        - a. Mud-scow or California method.
        - b. Punching method.
        - c. Core-drill method.
2. Abrasion methods (diamond, calyx, and chilled shot).
3. Hydraulic methods.
    - A. Jetting or hydraulic-percussion method.
    - B. Hydraulic rotary method.

Of these methods the most useful for obtaining water supplies are the portable solid-tool percussion method, the mud-scow method, the jetting method, and the hydraulic rotary method (29). Methods of developing water in alluvial sediments are shown in Figure 57.

For exploratory work in connection with military operations medium-weight portable solid-tool percussion rigs are most dependable, but it is practicable to include with such rigs both mud-scow and jetting attachments.

PUMPING.

A large number of ingenious mechanical devices are applied in various ways and in numerous combinations for lifting water. Most of these may be grouped in two classes—receptacle elevators and pumps.

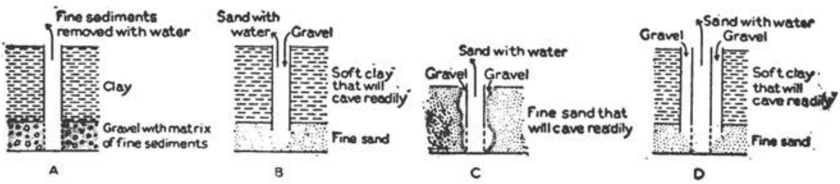

FIGURE 57. Diagrammatic well sections showing methods of developing gravel streams: A, Method applicable where water-bearing bed consists of gravel with matrix of finer sediments, especially if there is a roof of hard pan that will not readily cave; B, Method applicable where water-bearing bed contains no coarse material or where roof consists of soft material that will cave readily; C, Method applicable where water-bearing bed is near the surface and the overlying material consists entirely of unconsolidated sediments that will cave readily; D, Method applicable where conditions are the same as in B.

A receptacle elevator is a device that consists of one or more buckets or other receptacles with apparatus for alternately lowering these receptacles into the water and lifting them after they have become filled with water. Receptacle elevators doubtless include the oldest lifting devices. They comprise (1) ordinary buckets lifted by hand, with cables, or with cables and pulleys, windlasses, well sweeps, or other convenient appliances; (2) bailers, or cylindrical vessels with valves at the bottom, provided with various appliances similar to those with ordinary buckets; (3) chain and bucket elevators; and (4) various curious devices, such as the Archimedes screw, of ancient origin used largely in India and Egypt.

A pump is a mechanical device for moving a fluid by drawing or pressing it through apertures and pipes. The principal kinds of pumps used for lifting water are (1) displacement pumps, (2) centrifugal pumps, and (3) air lifts. (Figure 58.) Pumping machinery is discussed in standard engineering manuals (30).

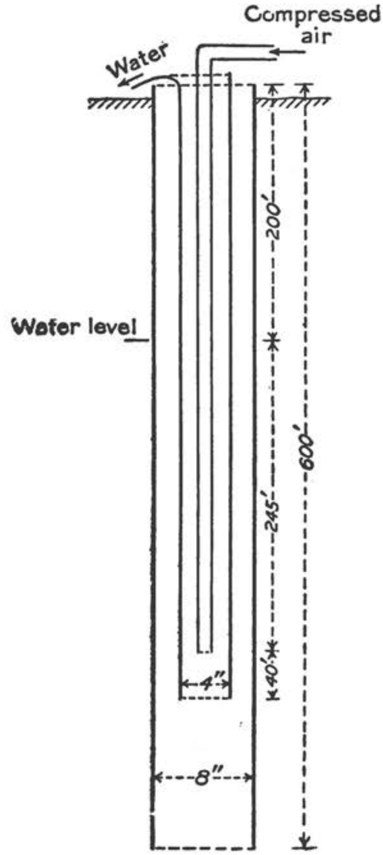

FIGURE 58. Diagram of typical El Paso waterworks well showing air lift. The water level indicated is the approximate level when the well is not in use.

In mobile military operations, in which temporary installations must be made, centrifugal pumps are probably the most serviceable, especially if fairly large yields can be obtained. As there is abundant man power in military operations there is generally little difficulty in enlarging a well so that an ordinary centrifugal pump can be installed about at the water level. However, the deep-well turbine centrifugal pump is doubtless also well adapted for military use.

METHODS FOR MILITARY WATER SURVEYS.

Surveys of existing supplies.—Field work on water supplies has two phases: (1) systematic collection of data on existing water supplies, and (2) study of the topography, geology, and vegetation with reference to ground-water conditions.

Data on existing supplies are collected for two purposes—(1) in order that in an emergency definite information will be at hand for any district as to the location of existing water supplies, the yield of the wells or other source at each point, the capacity of the pumps that are installed, the quality of the water, and other useful facts; (2) in order to have a tangible basis for interpreting the available information on topography, geology, and vegetation in forecasting conditions for new developments. Both purposes are important. Ground-water surveys should always include systematic collection of data on existing supplies. The following schedules are used by the U. S. Geological Survey in collecting data on water supplies: (1) Well schedule; (2) spring schedule; (3) stream schedule; (4) impounded water schedule; (5) public water supplies schedule. If a supply is used for municipal waterworks the information called for by all five schedules may be needed.

WELL SCHEDULE.

Date ....19..... Field No. ....
Record by .... Office No. ....
1. *Location:* State .... County ....
Quadrangle ....
.... ¼ sec. .... T .... N/S, R .... E/W ....
2. *Owner* .... Address ....
Driller .... Address ....
....
3. *Topography* ....
4. *Altitude* .... ft. above/below ....
5. *Type:* Dug, drilled, driven, bored ....
6. *Depth* .... ft. Date ....19......
7. *Diameter:* top .... bottom ....
8. *Chief aquifer* ....
....
From .... ft. to .... ft. Others ....
9. *Casing:* Type ...., Depth .... ft., Diam. .... to ....
Finish ....
10. *Water level* .... ft. below/above ....

11. *Pump:* Type .... Capacity .... G.M.
Power: Kind .... Horsepower ....
12. *Yield:* Flow .... G. M., Pump .... G.M.; Meas., Rept.
Drawdown .... ft.; pumping .... G.M.; time ....
13. *Use:* Dom, Sto, PS, RR, Ind, DW, Irr .... Quantity ....
Adequacy, permanence ....
Yes
14. *Quality:* Good, fair, bad .... Sample No. ....
Taste, odor, color .... Temp. ....° F.
Unfit for ....
Sanitation ....
15. *Cost:* Well, $...........; Plant (well, pump, power, etc.), $...........
inc.
Operating, $........... per .... exc. ....
back
Log, analysis, authority, ... on page ....

SPRING SCHEDULE.

Date ....19..... Field No. ....
Record by .... Office No. ....
1. *Location:* State .... County ....
Quadrangle ....
N E
.... ¼ sec. .... T .... S, R .... W ....
2. *Owner* .... Address ....
....
Name ....
3. *Topography* ....
above
4. *Altitude* .... ft. below ....
5. *Kind of rock* ....
6. Structure ....
....
....
7. *Openings:* Number .... Character ....
Source ....
....
8. *Improvements, accommodations* ....
....
9. *Yield* .... G.M. .... Meas., Rept.
....
Fluctuation ....
Dependability ....
10. *Use:* Dom, Stock, Irr, Med, Bath, Bottling ....
Quantity ....
Yes
11. *Quality:* Good, fair, bad .... Sample No ....
Taste, odor, color ....
Temp. (° F.) ....
Gases: Quantity .... Character ....

Unfit for ....
Sanitation ....
12. *Deposits:* Kinds .... Quantity ....
Features ....
Sketch map, analyses .... on page back ....

STREAM AND LAKE SCHEDULE.

.... River, Creek, Brook, Spring, Lake, Pond, Ditch, Canal, Reservoir, in States of ....
Rises near ...., ... Co., ... Quad., State of ....
Discharges into ...., near ...., ... Co., ...
Quad., State of .... It is part of .... drainage.

Tributaries entering from left (going downstream):	Entering from right (going downstream):
....	....
....	....
....	....

Drainage area above mouth as measured on .... map, dated ....,
scale .... or as given by .... square miles.
Water is used for ....
Possible use for water ....
Quality: Good, fair, bad .... Sample Yes No. ....
Taste, odor, color .... Temp. ....° F.
Unfit for ....
Sanitation ....
Gaging stations have been maintained at (give dates) ....
....
....
Quantity of flow: Maximum ...., minimum ...., mean ....
Sources of information ....
....
General description: Of drainage basin, as to altitude, topography, soil, cultivation, forests, etc.; stream swift, sluggish, broad, shallow, intermittent, spring fed, etc. ....
....
....
....
....

ARTIFICIALLY IMPOUNDED WATER SCHEDULE.

Date ....19..... Field No. ....
Record by .... Office No. ....
1. *Location:* State .... County ....
Quadrangle ....
.... ¼ sec. .... T .... N S, R .... E W ....

2. *Owner* .... Address ....
....
Name ....
3. *Topography* ....
....
above
4. *Altitude* .... ft. below ....
5. *Rocks* ....
Structure ....
....
6. *Type of Reservoir* ....
Gal.
7. *Capacity* .... Acre ft., Area .... Acres, Max. Depth .... ft.
8. *Construction:* Nat., Art.; Lining ....
Dam: Material ...., Length .... ft., Height .... ft., Content .... Cu. Yd.
Excavation: Material .... Quantity .... Cu. Yd.
Other improvements ....
Acres
9. *Catchment* .... Sq. M.; Precipitation .... In. Year
Topography ....
Soil .... Vegetation ....
....
10. *Use:* Dom, St, PS, RR, Ind, DW, Irr, ...; Quantity ....
Dependability ....
Yes
11. *Quality:* Good, fair, bad .... Sample No. ....
Taste, odor, color, turb. ....
....
Unfit for ....
Sanitation ....
....
12. *Cost:* Total $................; Maintenance $................ per year.
back
Sketch map, analysis .... on page ....

PUBLIC WATER SUPPLY SCHEDULE.

Date ....19...... Field No. ....
Record by .... Office No. ....
1. *Location:* State .... County ....
Town .... Quadrangle ....
2. *Owner* .... Sup't ....
3. *Source:* Wells, Spr., Str., Lake ....
Location ....
above
Surface elevation .... ft. below ....
Works at source ....
Pumps (to surface): Number .... Type .... Capacity .... G. M
4. *Reservoirs:* Number .... Capacity .... Gal.
Type ....
Location ....

Surface altitude .... ft. above/below ....

5. *Source to Reservoirs:* Gravity, pumps ....
Conduit: Type .... Capacity .... G. M.
Pumps: Number ...., Type .... Capacity .... G. M.

6. *Distribution:* Gravity, direct, pneumatic ....
Mains ...... M.; Diam. ...... to ...... In.; Hydrants ......; Taps ......
Pressure: Domestic: Maximum .... lbs.; Minimum .... lbs.
Fire ....

7. *Power:* ....

8. *Capacity (Gal. Day)*: Source .... to .... System ....

9. *Consumption (Gal. Day)*: Max. ....; Av. ....
By R. R. .... By Mfg. .... Inhabitants ....%

10. *Sanitation* ....
....

11. *Cost of waterworks (total)*: $...

12. *Rates:* Flat (Min. Dom.) $................................ per year
Meter (Max.) .... Cents per 1,000 gal.

Sketch map, analyses, authority .... on page back ....

(Report details on well, spring, impounded water, or stream schedule.)

Surveys of water-bearing gravels near the surface.—Just as a systematic survey of existing water supplies will give information as to the supplies that have been developed in each locality, so a systematic survey of ground-water conditions will give information as to the quantity, quality, and other characteristics of supplies that can be developed in each locality. This information will, of course, be less specific than that on existing supplies. The methods employed in procuring it will be some of those suggested on preceding pages, or perhaps other geologic methods. They will differ greatly with the geology of the region and with the nature of the requirements.

Perhaps the first set of observations to be made is as to whether there are any water-bearing alluvial gravels or other surface deposits in the region, and, if so, whether they are the result of some recent geologic event, an understanding of which will give a definite clue to the distribution of these deposits. It may be well first to examine the valleys to ascertain whether they have been partly refilled since their excavation and whether the valley fill is good water-bearing material. Next observations should be made to ascertain whether such deposits are confined to the present valleys or are more widely distributed and to determine the nature of the process that produced the deposition.

The importance of water-bearing gravels or other unconsolidated deposits near the surface is shown by the fact that in the northern and western parts of the United States, taken as a whole, the largest number of wells, the strongest wells, and the wells yielding the least mineralized water are supplied from such deposits.

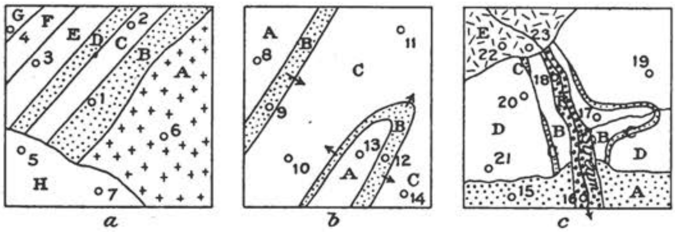

FIGURE 59. Hypothetical geologic maps presenting problems in locating well sites.

(a) Area 10 miles square; nearly level. A to H are outcropping formations, in the order of their age, A being oldest and H youngest. The contact between A and B and the contact between H and the older formations are unconformities. A is granite; B to G form a series of beds that dip about 200 feet to the mile toward the northwest; B and D are water-bearing sandstones, and C, E, F, and G clayey formations. H is a clayey formation that has a maximum thickness of 100 feet.

Problems: Forecast the results that will be obtained by sinking wells at localities 1, 2, 3, 4, 5, 6, and 7. Draw cross sections to illustrate your predictions.

(b) Nearly level area. A, B, and C are outcropping formations, A being oldest and C youngest. B is water-bearing sandstone; A and C are shales which will not yield water. The arrows show the direction of dip.

Problems: Forecast the results that will be obtained by sinking wells at localities 8, 9, 10, 11, 12, 13, and 14. What is the unknown factor in these problems? Draw cross sections to illustrate your predictions and the unknown factor.

(c) Area dissected along the streams, elsewhere only gently undulating. A to F are outcropping formations, in the order of their age, A being oldest and E and F (which were formed at the same time) being youngest. A is an ancient quartzite. B, C, and D constitute a conformable series of nearly horizontal beds resting on an irregular surface of the quartzite. B is impervious; C is a good aquifer except near the outcrop, but it is locally absent; D generally yields small supplies. E is boulder clay with interbedded gravel lenses. F is gravelly glacial outwash.

Problems: Forecast the results that will be obtained by sinking wells at localities 15, 16, 17, 18, 19, 20, 21, 22, and 23. Draw cross sections to illustrate your predictions.

In the northern part they are glacial drift or outwash; in the western part they are alluvial fill. In both regions a knowledge of the origin and character of the deposits gives definite clues as to where to look for water in unexplored territory. Thus, the water-bearing characteristics of the alluvial fill in the intermontane valleys of the western United States have been extensively studied and are well understood.

Surveys of older aquifers.—After examination has been made for surface deposits, the next set of observations relate to the character and relations of the older rock formations, which outcrop in the region or lie below the surface but within depths that can be reached by the drill. Information regarding the buried formations is obtained from their outcrops in adjacent regions or from deep wells that have already been drilled. For most regions general information is already available in regard to the rock formations and their structural relations.

Many of the problems relating to the rock aquifers are rather simple although there is a large variety of possible geologic relations. There are never more than a few aquifers in a given region, and many regions have only one aquifer that is worth consideration. With a general knowledge of the succession of the formations and their structure, it is usually not very difficult to make an approximate forecast of the position of an aquifer in any given locality. The 23 problems presented in Figure 59 are of the kind encountered in field work.

DRAINAGE OF GROUND WATER.

Indications of shallow-water areas.—As explained on page 132, there are various criteria for recognizing tracts of shallow ground water that can with experience be applied in the location of trenches and in other military operations. The fact should also be remembered that the water table fluctuates and that trenches which are entirely above the water level at the time they are dug may later fill with water. Early in the spring or in other wet seasons shallow ground water is not confined to low tracts but may be found on hillsides or on the tops of ridges provided the subsoil is a dense clayey loam that is only slightly pervious. Water in such positions is often "perched," and it disappears entirely in dry seasons. When the subsoil is porous sand or gravel shallow water will not be found on hillsides or hilltops.

DRAINAGE OF TRENCHES.

Trenches are generally drained by digging ditches from them to lower land, so that the water will flow out by gravity. Of course this method is possible only where there is lower land to which to drain and not too much high ground between the trenches and the low land.

In some localities the water that enters the trenches can be removed by draining it into wells that end either in an unsaturated porous bed or in an aquifer whose water is not under sufficient head to rise to the bottoms of the trenches. (31.) In such localities the water that causes the trouble is a perched body, supported above the general water table of the region by some impervious or difficultly pervious bed. (See Figure 41.) Perched water is common in elevated areas underlain by irregular deposits of alternate beds differing in perviousness, such as glacial drift and alluvial deposits.

The capacity of a drainage well depends on the perviousness of the formation that receives the water and on the distance from the mouth of the well to its normal water level. Drainage wells that end in porous gravel or cavernous limestone and in which the upper surface of the water table is considerably below the surface of the ground may dispose of large quantities of water. A drainage well whose specific capacity is 25 and whose normal water level is 10 feet below the bottom of the trench which it is to drain will carry off about 250 gallons per minute, just as the same well would yield about 250 gallons per minute with a drawdown of 10 feet. If there are no underlying pervious formations or if the underlying pervious formations are saturated with water that is under sufficient head to rise in wells above the surficial water table this method of draining trenches is not applicable.

Any refuse or sediment that is allowed to be carried into a well will rapidly reduce its capacity, especially if the receiving formation has small interstices that are easily clogged, such as those in sand and sandstone. On account of this tendency of sandstone and like rocks to clog cavernous limestone is the best drainage medium. Draining trenches into an aquifer will of course pollute it and will render its water unsafe for human use.

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CHAPTER VI.

LAND FORMS.

INTRODUCTION.

In all warfare the conformation of the land—what military men call the character of the terrain—constitutes an element of the first importance. The height, form, and trend of mountains, the width and depth of valleys, and the nature of the soil determine to a large degree the facility with which an army can advance or retreat through a given country. A knowledge of the topographic features of a battle zone is a fundamental part of an officer's equipment, and familiarity with the character and arrangement of the features of a particular region can be most quickly attained if it is preceded by a general knowledge of land forms.

Topographic features are not unrelated individuals with haphazard forms and positions. They have been developed by geologic processes in an orderly fashion and to a large extent reveal their origin and history. They may be classified in a number of ways. For the present purpose two groups with many subdivisions are recognized. The first group includes those topographic features which owe their form chiefly to the composition, structure, and attitude of the bedrock. This group includes the mountains, plateaus, and other large features. The second group consists of land forms that are composed of loose soil and are not dependent upon the character of the underlying bedrock.

CLASSIFICATION.

I. BEDROCK TYPES. (Land forms dependent upon the solid rock.)

A. Forms characteristic of stratified or sedimentary rocks.

1. Cliffs and slopes; the chief rocks which act as cliff formers and those which produce gentle slopes. (Allegheny escarpment, Grand Canyon, Niagara Falls, Palisades, etc.)

2. Plains; rocks horizontal, relief slight. (Great Plains, Siberia, central Russia, etc.)

3. Plateaus; rocks horizontal, relief great. (Arizona and New Mexico, Allegheny Plateau, Karst region.)

4. Coastal plains, cuestas, outliers; beds dipping slightly. (Eastern United States, north-central United States, England, northern France.)

5. Dome mountains, hogback ridges; beds strongly dipping, pushed up from beneath. (Henry Mountains, Black Hills, Rocky Mountains, Weald.)

6. Folded mountains, longitudinal ridges and valleys; beds strongly dipping as result of folding. (Appalachian Mountains, Jura Mountains.)

B. Forms characteristic of crystalline and complexly distorted rocks.

1. Complex mountains; formed on granite, gneiss, and schist. (Adirondacks, Rockies, Vosges, Black Forest, Alps, Rhodopes, etc.)

C. Forms characteristic of both sedimentary and crystalline rocks.

1. Rolling uplands and entrenched streams; features due to peneplanation and uplift. (New England upland, Rhine upland, Ardennes upland, Piedmont upland, Rocky Mountain upland.)

2. Grabens, block mountains, straight valleys, etc.; forms due to jointing and faulting. (Great Glen of Scotland, Rhine graben, Palestine region, African rift, California earthquake rift, Great Basin, Wasatch Mountains, Sierra Nevada.)

3. Matterhorn peaks, sharp crests, cirques, troughs; features due to glacial erosion in mountains. (Alps, Canadian Rockies, Glacier Park, Norway.)

4. Bays, sounds, and harbors; features due to sinking of the land. (Chesapeake Bay, Maine coast, Scotland, Greece, Dalmatia.)

5. Cliffs, headlands, destroyed islands; features due to wave action on rocky coasts. (Helgoland, Normandy.)

6. Volcanoes, cinder cones, volcanic necks, lava flows; forms due to volcanic action. (Cinder Cone, Vesuvius, Hawaii, Auvergne region, Crater Lake, Azores.)

II. LOOSE SOIL TYPES. (Land forms dependent upon loose soil.)

1. Alluvial fans, deltas, flood plains, terraces; forms built by streams. (Hoangho, Italian plains, Lannemezan area, central California, Mississippi, Tagliamento, Danube, Rhine, etc.)

2. Moraines; forms built by glaciers. (Alps, terminal moraines of United States and Europe, East Prussia.)

3. Beaches, bars, spits; forms built by waves. (New Jersey, Texas, Gibraltar.)

4. Dunes; forms built by wind. (Cape Cod, Cape Henry, Belgium.)

LAND FORMS.

I. Bedrock types. (Land forms dependent upon the solid rock.) Forms characteristic of stratified or sedimentary rocks.

1. Cliffs and slopes; the chief rocks which act as cliff formers and those which produce gentle slopes. (Allegheny escarpment, Grand Canyon, Niagara Falls, Palisades, etc.)

Resistant rocks tend to form cliffs, non-resistant rocks tend to form gentle slopes. For example, take a series of horizontal formations in which resistant beds alternate with non-resistant ones. The edges of the beds are exposed at the side of a valley. Where the resistant rocks outcrop the valley has steep slopes; where the non-resistant rocks outcrop the valley slopes are gentle. (Figure 60, A.)

This difference is due to the fact that the less resistant rocks readily decay under the action of the weather, and the particles do not adhere together enough to maintain a clear-cut vertical wall. As decay goes on particle by particle of the soft rock is washed or blown away and in time the hard resistant overlying formation is undermined. (Figure 60, B.)

As undermining proceeds and the overlying mass is deprived of its support it cracks off as a block, and thus the face of the cliff above is kept upright and sharp. (Figure 60, C.) The accumulation of

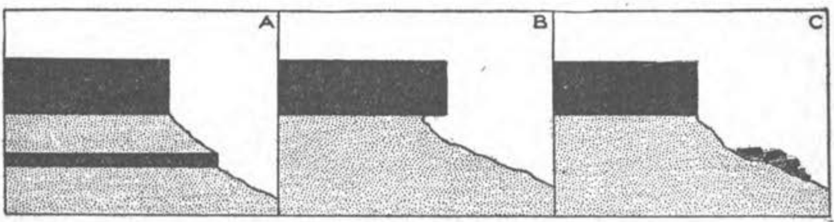

FIGURE 60. Development of cliffs. A, Section of a cliff developed in horizontal formations. Where the rocks are resistant the cliff face is vertical; where the rocks are weak the slope is gentle. B, The decay and wearing away of the softer beds leaves the hard beds above overhanging. C, Large blocks from the hard overhanging bed have cracked off, leaving the cliff above clean and sharp, and covering the gentle slope below with loose material known as talus. (Drawn by A. K. Lobeck.)

material which has fallen from the face of the cliff and which covers the gentle slope below is called talus. In some places enough of this loose material is broken off from the resistant rock to protect effectively the less resistant rock beneath. These blocks of hard rock gradually decay, and the continuous decomposition and removal of the softer rocks undermines the cliff still further. The cliff therefore tends to wear slowly back. If the material which drops off the cliff were removed immediately by some means, the cliff would retreat much more rapidly. This is the condition at Niagara Falls. The Niagara River falls over a cliff 160 feet high. The swirling of the water at the foot of the falls tends to wear away the soft beds and leave the hard bed at the top unsupported. Large blocks of this hard bed drop off and are ground up below. The particles are quickly carried downstream and there is no accumulation of material to protect the soft beds. Indeed, it is known that in this way Niagara Falls work backward at the rate of nearly five feet a year.

Even when the talus is not removed by streams it is broken up and carried away by the action of the weather, by the gradual creep of the soil, and by the wash of the rain, but these processes act so slowly that the movement does not generally attract attention. Cliffs which once formed the walls of the gorge or canyon cut by the stream may be many miles distant and appear to have little or no relation to the stream.

Sandstone, conglomerate, massive limestone, and trap are resistant formations, and many cliffs are due to such rocks. In France and England chalk beds act as cliff formers, and in the central United States beds of gypsum may be thick and massive enough to form cliffs. (Figure 61.)

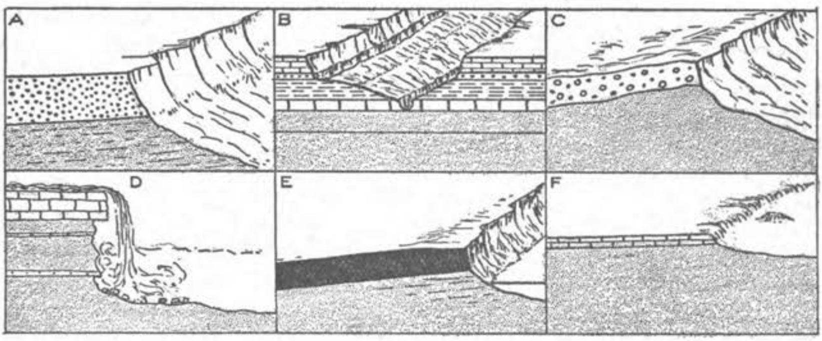

FIGURE 61. Types of escarpments. A, Section of Allegheny Front; escarpment due to massive bed of sandstone. B, Section of the Grand Canyon; escarpments due to sandstone and limestone. C, Section of Shawangunk Mountains, N. Y.; escarpment due to conglomerate. D, Section of Niagara Falls; escarpment due to limestone. E, Section of Palisades; escarpment due to layer of trap rock. F, Section of upland east of the Champagne, France; low scarp due to bed of chalk. (Drawn by A. K. Lobeck.)

An example of a pronounced escarpment due to a massive bed of sandstone is the "Allegheny Front," or Allegheny escarpment, forming the eastern edge of the Allegheny Plateau in western Pennsylvania. The steep eastern edge of the Catskill Mountains is another example. Many of the cliffs in the walls of the Grand Canyon and on the mesa and plateau country of the southwestern United States are due to sandstone, and the steep cliffs forming the east side of the Shawangunk Mountains in eastern New York are due to a thick bed of conglomerate. Some massive limestones are effective cliff formers—

for example, the Niagara escarpment, the long escarpment in south Germany known as the Swabian Alps, and many of the small escarpments in northern France. However, many limestone formations are not resistant. The Palisades along the Hudson owe their bold aspect to a resistant bed of trap rock, and this is true also of the Watchung Ridges in New Jersey. Cemetery Ridge, on the Gettysburg Battlefield, is due to a similar bed of hard rock.

The non-resistant formations which tend to produce gentle slopes are the shales and the beds of material which have not become consolidated. Loose marl, sand, and clay are of this character. Some limestones, too, give way readily to weathering. The Champagne lowland of France is developed upon weak unconsolidated clays and sands.

The observations heretofore noted may now be extended one step further. The same types of rock formations that tend to produce cliffs and steep slopes tend also to produce uplands. The types that produce gentle slopes tend to produce lowlands. It will be seen later that where the rocks are folded so that the edges of different formations are exposed to weathering and to erosion it is the sandstones and conglomerates that form ridges, and the shale and in places the limestone that underlie the valleys.

2. Plains; rocks horizontal, relief slight. (Great Plains, Siberia, central Russia, etc.)

Plains are portions of the earth's surface possessing slight relief. They are underlain by resistant or non-resistant rocks which lie in a horizontal or slightly inclined position. The underlying rocks may be resistant or non-resistant. There is no essential difference between a plain and a plateau other than that the valleys on a plain are shallow, whereas the valleys of most plateaus are deep.

Plains are usually thought of as being low and near sea level, as, for instance, the Coastal Plain of the eastern and southern United States and the plains of Normandy and north Germany. But there are other plains which are far above sea level. For example, the Great Plains of the West are, over large areas, almost a mile above sea level. Nevertheless, they are called plains, because the streams upon them flow in very shallow valleys. Plateaus, on the other hand, are usually thought of as being rather high above sea level, as is the plateau country of Arizona and southern Utah. The Allegheny Plateau of the eastern United States, however, stands very much lower and indeed only about half as high above sea level as the Great Plains of Colorado, Wyoming, and Montana. In the plateaus of Arizona the streams flow in canyons cut deep down below the surface, and in the Allegheny

Plateau the rivers and their tributaries all occupy deep valleys. So these two regions and others like them are called plateaus because they are felt to be distinctly different from plains where the relief is only slight. Indeed, as was first noted, there is no sharp dividing line between a plain and a plateau. In the Paris Basin of northern France some of the upland belts are called plateaus by some observers and plains by others. The traveler there who has been accustomed to our plateau country of the Southwest would tend to call them plains because the depth of dissection does not seem so very great to him, whereas another traveler who has lived most of his life in low coastal regions might be impressed with the greater depth of the valleys and call the region a plateau.

The drainage pattern on a plain or plateau is dendritic—that is, it is like the branches of a tree. It may be imagined at first that this is the pattern of all stream systems. Such, however, is not the case. Where rocks are so folded that their outcrop has a definite trend across the country, the streams in general follow this trend and the trellis pattern to be described later is the result. But where the rocks lie horizontal and the entire surface of the country is made up of the same material a simple dendritic pattern is formed. (Figure 111.)

A river system develops by the working headward of its tributaries, the formation of new tributaries, and the widening of valleys. The effect of these processes upon a plain is to change materially its aspect during long periods of time. This gives a very convenient and useful means of classifying plains as young, mature, or old, the name given depending upon the extent to which drainage development has taken place. (Figure 62.)

A young plain has comparatively few streams, so that most of the original even surface remains undissected. This is the condition in parts of the Coastal Plain of Virginia and North Carolina. The streams are far apart. They are separated from one another by extensive flat tracts of country. Lines of communication—roads and railroads—generally follow the flat upland areas rather than the valleys, because the uplands are so flat and continuous. The great plain of western Siberia preserves an even surface over hundreds of miles. Vast areas, stretching farther than the eye can reach, are monotonous in the extreme, almost as uniform in soil as in surface. The flat areas between the streams, having no distinct lines of water parting and no distinct channels of water discharge, are as yet practically undivided among the rivers. The valleys are few and far between; they are narrow; hence the rivers have as yet worked only for a comparatively short time in the earth's history. Such plains are still young. (Figure 62, A.)

A mature plain or maturely dissected plain has so many streams and is so much dissected that almost none of its original level surface remains. Its aspect is somewhat more rugged than that of a young plain—in fact, it represents the greatest ruggedness that a plain can attain. (Figure 62, B.)

An old plain represents the extreme stage in development. The valleys have been greatly widened, the hills have been worn away, and the whole region has been reduced to a rolling lowland, a worn-down plain. Central Russia is a nearly level region of moderate altitude. It is a large worn-down plain. At first sight it might be mistaken for a young plain, so nearly even is the greater part of its

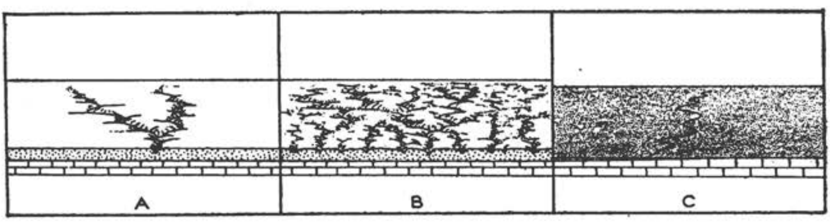

FIGURE 62. Diagrams showing the aspects of a plain. A, In youth, with few streams; B, in maturity, dissected by many streams; C, in old age, when worn again to a lowland. (Drawn by A. K. Lobeck.)

surface; but a closer examination reveals many features that do not correspond with those of young plains. The rocks below the soil lie in almost horizontal layers, but they do not consist of loose sands and clays. Many of them have a rather firm texture, showing that they have existed long enough to have their particles bound together by the very slow action of infiltrated waters. Besides this, the surface of the plain does not quite agree with the surface of the uppermost rock layer, as it does in young plains, but bevels across the nearly horizontal layers at a slight angle, so that from place to place different layers are exposed, causing advantageous changes of soil and slight variations of form. (Figure 62, C.)

3. Plateaus; rocks horizontal, relief great. (Arizona and New Mexico, Allegheny Plateau, Karst region.)

Plateaus are parts of the earth's surface where the rocks lie horizontal and where the relief is great. Like plains, plateaus may be classified as young, mature, or old. (Figure 63.)

A young plateau is an extensive level upland traversed by deep and narrow valleys or canyons branching in various directions. In the canyon walls may be seen the horizontal rock layers of which the plateau is built. Such a plateau is the one in western Arizona that is cut into by the Colorado River and its tributaries. The broad upland has a comparatively even surface, so monotonous that it receives less attention from explorers than the canyons that dissect it. The irregular course of the canyons indicates that the rivers which cut them had no well-defined slope on the original upland to guide their flow. The irregular branching of the side canyons shows that it has been about as easy for the streams to wear back the headwater ravines in one direction as in another. Although a great deal of work has been done in cutting down and widening these canyons, it is

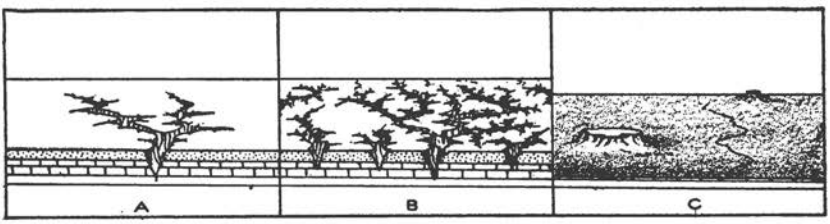

FIGURE 63. Diagrams showing the aspects of a plateau. A, In youth, with few canyons; B, in rugged maturity, dissected by many gorges; C, in old age, when worn to a lowland with mesas and buttes, remnants of its former surface. (Drawn by A. K. Lobeck.)

manifest that a vastly greater work still remains to be done before the broad mass of the plateau is worn down; hence a plateau of this kind must be called young, however deep its canyon may be.

A mature plateau is one so thoroughly dissected by stream systems that little if any of the original upland still remains. Its aspect is very rugged. In fact, some of the most rugged parts of the world are maturely dissected plateaus. The Allegheny Plateau of Kentucky, West Virginia, and Pennsylvania is such a region. The altitude of the original upland in West Virginia is roughly 3000 feet, and this is great enough to permit the erosion of valleys 1000 feet or more deep; hence some of the intervening plateau remnants have strong relief and fairly deserve the popular name "mountains," which is locally applied to them. Many resistant sandstone layers stand out in cliffs 10 to 50 feet high, running in bands around the spurs of the great hills. The weak strata occupy the intervening slopes, covered with a thin stony soil and supporting a vast forest. In contrast to the young plateau this district has nearly everywhere lost its once continuous upland surface and is now transformed into a hill and valley country. A great part of its surface consists of hillside slopes. Drainage is not delayed on extensive uplands, as in young plateaus; but at times of rain or during late winter thaws water is quickly shed from the hills and the main streams rise in destructive floods.

An old plateau has the aspect of a broad plain with a gently rolling surface surmounted by flat-topped mountains and buttes and drained by streams flowing in wide, flat-floored valleys. The mesas and buttes are the scattered remnants of strata that once spread far and wide over the region, forming an extensive plateau. The original surface of the plateau may have been much higher than the tops of the mesas, for the uppermost strata may now be completely swept away. The valleys have widened so greatly that their floors occupy a great part of the surface. The plateaus of western New Mexico are surmounted by numerous remnant mesas. Settlement here is limited chiefly to the lower lands. The isolated mesas and buttes, which rise several hundred feet over the plain, are generally uninhabited; thus the old plateau reverses the conditions of its youth, in which the uplands alone could be easily occupied. In general it may be said that the aspect of an old plateau differs from that of an old plain only in having scattered mesas and buttes.

Some plateau regions are made up largely of limestone beds. Limestone is more or less easily soluble and conduces to the development of underground drainage. Ground water finds its way down along the joints in the rock, and by dissolving away the material enlarges the passageways so as ultimately to form large caves. When the caves become very large their roofs are unable to support themselves and collapse. The hollows thus formed in the surface of the ground above are usually known as sink holes, because the surface water flowing into them sinks and disappears through the underground channels. Sink holes and caverns are common in Kentucky, Tennessee, and Florida, where limestone is the prevailing bedrock. However, in the United States, sink holes are usually small and of only local interest. In portions of Europe, on the other hand, they play a vital part in the destinies of the people. The country bordering the eastern shore of the Adriatic from the region about Trieste south to Montenegro and Albania is literally a great barrier between the ocean and the people of the interior. The soluble limestone permits most of the rainfall to pass underground through sink holes, which are there known as "dolines." As a consequence much of the mountain country is dry and barren, springs are far apart, and such open watercourses as occur are difficult of access because they are deeply intrenched in rock-walled gorges. The only inhabitable parts of the country are the broader basins or "poljes" opened out in the limestones. The "gaunt, naked rocks of the cruel Karst country" are not only themselves of little value to mankind but they render inaccessible and therefore comparatively useless many excellent harbors on the east coast of the Adriatic.

4. Coastal plains, cuestas, outliers; beds dipping slightly. (Eastern United States, north-central United States, England, northern France.)

A coastal plain represents the floor of the ocean lifted above the surface of the sea. It may be narrow or broad, its width depending

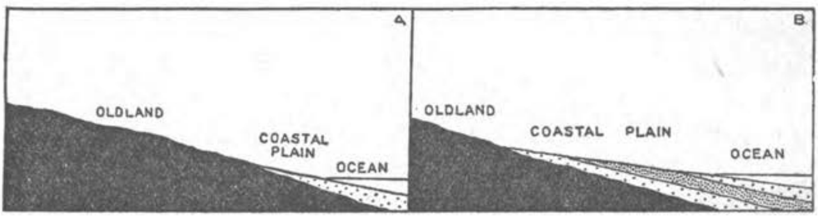

FIGURE 64. Profile sections of coastal plains. A, Cross section of a narrow coastal plain, only one kind of rock showing on the surface. B, Cross section of a broad coastal plain with several different layers outcropping on its surface. (Drawn by A. K. Lobeck.)

upon the extent to which the land has been uplifted. Its surface slopes gently seaward. The material making up a coastal plain consists of beds of sand, gravel, clay, marl, or lime, which was washed from the land and deposited upon the floor of the ocean. These beds dip toward the sea, and their edges outcrop or come to the surface of the coastal plain in parallel belts. (Figure 64.) If a coastal plain is very narrow its surface may be all one kind of material, but usually a coastal plain is wide enough to display the edges of several beds.

A coastal plain that was lifted above the sea in comparatively recent geological time is called a recent coastal plain. The sand, clay, marl, and other sediments which compose a recent coastal plain are usually not much consolidated. Such a coastal plain is that of the eastern United States. A coastal plain that was lifted above the sea in earlier geological time may be termed a former coastal plain. The sand, clay, marl, and lime which composed a former coastal plain are now usually consolidated into sandstone, shale, and limestone by the ground waters that slowly filter through them. Unlike recent coastal plains, former coastal plains may now be far away from the sea and at first glance may not seem to have had any connection with it; but that is only because the land has been lifted higher and higher and the sea has been drawn off, leaving the former sea floor far inland, possibly with mountain ranges now intervening. Such a type of coastal plain is found in the north-central United States, extending from Wisconsin far into New York. The northern half of France, ordinarily called the

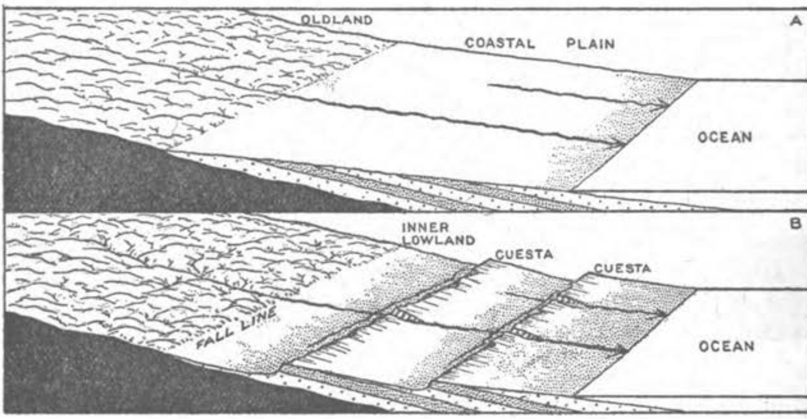

FIGURE 65. Dissection of a coastal plain. A, Diagram of a young coastal plain, crossed by few streams. Some streams rise in the oldland hills, others rise on the coastal plain. B, Diagram of a mature or dissected coastal plain. Valleys have been eroded along the weak belts. The hard belts stand as uplands or cuestas. (Drawn by A. K. Lobeck.)

Paris Basin, was formerly a coastal plain but is now somewhat removed from the sea.

A young coastal plain (Figure 65) has the aspect of a lowland gently sloping from the foot of the oldland hills on one side to the coast line on the other. The oldland is that part of the land mass which projected above sea level while the materials of a coastal plain were being deposited in the sea. The surface of a young coastal plain is traversed by streams which flow down its slope approximately parallel with one another. Some of the streams are short and rise on the coastal plain itself. Presumably they represent watercourses which developed upon the surface of the plain immediately after it was lifted above sea level. Such rivers and streams are often called "consequents" because their flow is consequent on the slope of the plain. Other rivers that rise in the oldland are much longer and apparently have extended their courses across the new plain, guided by its slope. These may be called "extended consequents." The main streams have few tributaries and the original surface of the plain is practically intact. The Coastal Plain of Virginia, North Carolina, and South Carolina may be described as young. The James, Roanoke, Yadkin, Santee, and Savannah rivers rise in the oldland and traverse the Coastal Plain as extended consequents. Numerous independent smaller streams which originated upon the plain itself rise near the coast.

A mature or dissected coastal plain shows a belted arrangement of its features, due to the erosion of the different belts of rock which outcrop upon it. (Figure 65, B.) If one travels across such a coastal plain from the oldland to the sea he will meet a succession of lowlands and uplands corresponding with the softer and harder belts of rock which come to the surface. Where the weaker beds outcrop the original surface of the plain is worn down to a lowland. Where the more resistant beds outcrop the wearing down is delayed and the upland height is preserved. If the coastal plain is comparatively narrow there may be only one lowland and one upland belt, as in southern New Jersey, but if the plain is broad there may be a series of alternating lowlands and uplands running parallel with one another, as in northern France. Each upland belt has a steep descent on one side facing inland and a long gentle, almost horizontal slope on the other side, inclined toward the sea. An upland of this kind is called a cuesta, a name of Spanish origin for ridges of steep descent on one side and gentle slope on the other. The lowland developed upon the bed of weak rocks closest to the oldland is termed the inner lowland.

The drainage of a belted coastal plain possesses some peculiar features. The larger rivers, extended from the oldland hills, still run directly to the sea, passing across the inner lowland in shallow, open valleys and trenching the upland belts in deep, narrow valleys. Smaller tributary streams flowing longitudinally (subsequent or strike streams) occupy the lowlands and join the main streams at right angles. The longitudinal streams are also joined by short streams (obsequent streams) that flow down ravines in the infacing slope of the upland belts.

Where a larger stream passes from the more resistant rocks of the oldland out from the softer rocks of the coastal plain there are falls and rapids, indicating that the stream is having difficulty in cutting into the hard oldland rocks, whereas on the weaker beds of the coastal plain it readily provides a suitable valley for itself. The term "fall-line," frequently used in this connection, refers to the line forming the inner margin of the coastal plain next to the oldland, where falls are likely to occur. Above the fall-line the streams are apt to be unsuitable for navigation because of the numerous rapids where they are cutting into the hard oldland rocks. Below the fall-line, on the other hand, the streams are apt to be navigable because the less resistant rocks of the coastal plain permit the development of deeper channels. Because of this fact settlements at the head of navigation may become large cities. The fall-line along the inner margin of the Atlantic coastal plain of the United States is marked by important cities on

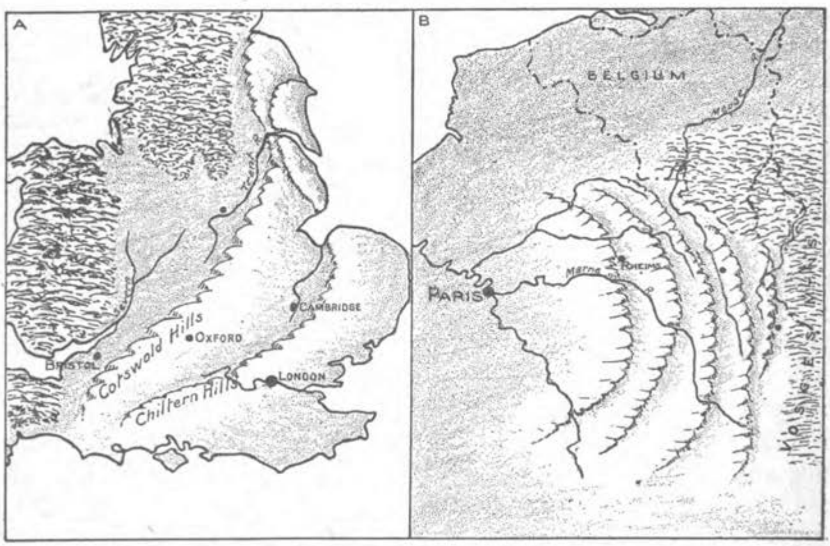

FIGURE 66. Examples of coastal plains. A, The belted coastal plain of England. B, The belted coastal plain of northern France. (See also Figure 38.) (Drawn by A. K. Lobeck.)

nearly every large river that crosses it. Trenton, Philadelphia, Washington, Richmond, Raleigh, Camden, Columbia, and Augusta are all thus located.

Examples of dissected coastal plains showing parallel belts of lowlands and uplands are to be found in England and France. (Figure 66.) The traveler passing from Wales to London would encounter in succession all the features of the coastal plain of southern England. First there is the oldland, represented by the rugged hills of Wales and the highland of central England. Flanking the oldland on the southeast is the inner lowland, eroded upon soft formations. On this lowland stand the cities of Bristol, Nottingham, and York. In the north the inner lowland is drained by the Trent River system, in the south by the Severn. Overlooking the inner lowland is the first upland belt, known near Bristol as the Cotswold Hills. A second lowland upon another bed of weak rocks is then crossed. Upon this second lowland stand the cities of Cambridge and Oxford. Finally there is the second upland belt, known as the Chiltern Hills, whose long back slope drops down to the sea at London.

The layers of rock in northern France have the form of a gigantic saucer or shallow basin. Paris is in the center. These layers may be conveniently pictured as a stack of shallow basins, one within another. Around the margin of the area alternate layers of hard and soft

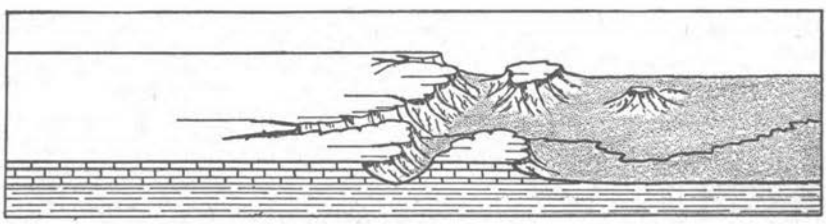

FIGURE 67. Typical plateau outliers on the French battle front. (Drawn by A. K. Lobeck.)

rock are exposed. The Vosges and Ardennes Mountains constitute part of the oldland upon whose western flank the basin-shaped layers of the coastal plain were deposited. The soft formations have been eroded to form lowlands like the Champagne region and the Woevre district east of Verdun. The harder limestone and chalk beds are not worn so low, and form parallel belts of sloping plateaus or cuestas. The fact that the rock layers dip toward the center of the basin and away from Germany has been of profound military importance in the war. Every plateau belt is bordered on the side facing Germany by a steep cliff representing the edge of a hard rock layer, while the other side is a gentle slope toward Paris, but going from Germany westward is like ascending a flight of stairs. It is easy to go from Paris eastward because the grades are gentle. These plateau escarpments, the cuestas of the former coastal plain of northern France, have consequently been termed the natural defenses of Paris. (See Figure 38.)

The edges of the escarpments are very ragged in appearance because they have been dissected by streams. In this way the escarpments are being worn back. Some pieces of the plateau are left standing like islands out in front of the escarpment. (Figure 67.) Outliers like these have played an important part as observation posts and artillery positions on the French battlefront, notably at such places as Noyon, Ornes, and Laon.

5. Dome mountains, hogback ridges, beds strongly dipping, pushed up from beneath. (Henry Mountains, Black Hills, Rocky Mountains, Weald.)

Dome mountains are caused by an updoming or arching of the surface of the earth. By such arching the sedimentary beds are pushed up from their horizontal position and are made to dip in all directions away from the center of the dome. (Figure 68.) A dome may be only a few miles across, like the Henry Mountains of Utah, or it may

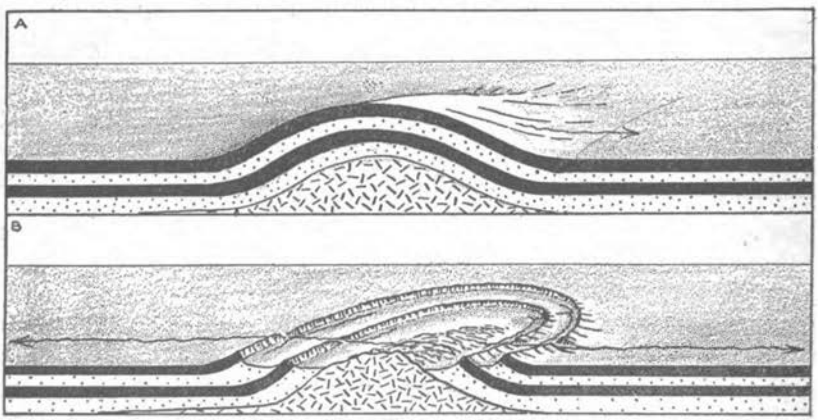

FIGURE 68. Dissection of a dome. A, Diagram of a young dome mountain, the cross section in front showing how the strata are up-arched. B, The same after mature dissection, showing the central core and the rimming hogback ridges. (Drawn by A. K. Lobeck.)

extend over a large part of a state, like the Black Hills of South Dakota, the greatest diameter of which is 100 miles. As soon as a dome mountain is formed erosion sets in actively because the strong slopes and the layers covering the top of the dome are weathered and worn away. This erosion may expose in the center of the dome a core of much harder and possibly very different rocks upon which the sedimentary beds were resting. Around the flanks of a dome so eroded will appear the edges of the sedimentary layers which dip steeply away. The edges of the more resistant layers will form ridges that surround the dome like a series of rings. The edges of the softer layers will be worn down to form lowlands. In general the succession of lowlands and ridges is not unlike the succession of lowlands and uplands on a coastal plain. The layers, however, dip more steeply and the ridges rimming a dome are not like plateaus but are sharp on top and are about as steep on one side as on the other. Such sharp-crested ridges are termed "hogbacks." They are very common around the flanks of the Black Hills in South Dakota, and along the edge of the Rocky Mountains in Colorado, where the beds have been bent steeply upward. Streams

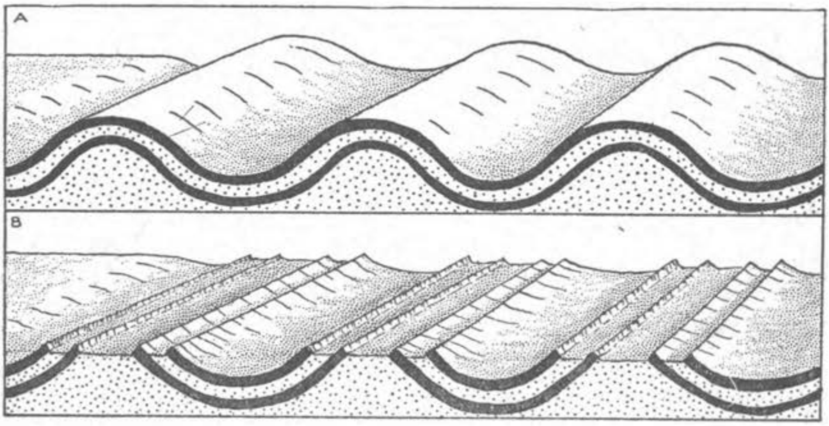

FIGURE 69. Erosion of folded rocks. A, A series of folds. B, The same after erosion, showing the parallel ridges formed upon the harder beds. (Drawn by A. K. Lobeck.)

coming from the central part of a dome mountain region find their way out to the plains through notches or water gaps in the rimming ridges.

In southern England the region known as the "Weald" has the structure of a dome mountain. The North Downs and the South Downs represent the ridges rimming the dome. The layers covering the center of the dome have not been entirely worn away, and no core of crystalline rock is exposed.

6. Folded mountains, longitudinal ridges and valleys; beds strongly dipping as result of folding. (Appalachian Mountains, Jura Mountains.) (See Chapter I.)

Folded mountains are due to a folding of rock layers which were at one time horizontal. (Figure 69.) The strata may be compressed by a force of inconceivable power, which gradually bends them into corrugations that consist of successive arches and troughs running parallel with each other. The upward folds are called anticlines, the downward folds are called synclines. During and following the formation of folds erosion of the strong slopes becomes active, and as the tops of the anticlines are gradually worn away the strata beneath the surface are exposed. If the anticline is made up of a series of hard and soft layers the edges of these different layers come to view, and as erosion progresses valleys or lowlands are formed along the edges of the soft layers. The hard layers will not be worn down so rapidly and will stand out as parallel ridges. (Figure 69.) The great chain of parallel ridges that constitute the "folded" or "newer" Appalachian Mountains was formed in essentially this way. The best European example of a similar type is the Jura Mountains, on the boundary between France and Switzerland.

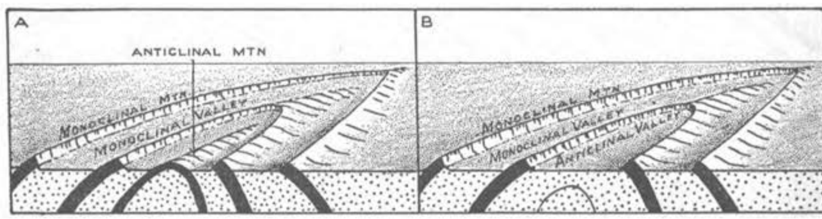

FIGURE 70. Development of concentric ridges in anticlinal structures. A, An anticlinal or cigar-shaped mountain results from position of hard rock. B, The anticlinal mountain A is replaced by an anticlinal valley because of the position of the strata.

One important fact regarding folded mountains must not be overlooked: the height of the mountain ridges is due not to the original fold but to the presence of the hard layers of rock. Where originally there was one large fold there are later many smaller ridges representing the hard beds which were turned up on edge. (Figure 112.)

The scheme of folded mountains thus presented is very simple. In addition to this simple scheme, however, there are two modifications which add interest and variety. Consider first the effects of anticlinal folds. If an anticline, instead of continuing on indefinitely as an arch running along the surface of the earth, at one point pitches down beneath the ground, as in Figure 70, the fold has the shape of a big cigar. Where the top of this big cigar is worn away and the layers below are exposed the ridges formed upon the hard rocks will not continue indefinitely in one direction but will swing around in a curve near the end of the cigar, joining there with a similar ridge from the other side. Indeed, to draw another simile, the smooth end of the cigar, where two ridges come together, looks like the prow of a speedy motor boat. Each hard formation as it is uncovered repeats these features. (Figure 113.)

Consider next the effects of synclinal folds. If a syncline, instead of continuing on indefinitely as a trough, at one point rises above the ground, the end of this trough has the form of a canoe. The ridges formed upon the hard rock layers will then not continue indefinitely in one direction but will swing around at the end of the canoe and be continuous with a ridge from the other side. (Figure 71.)

It will be noted from the diagrams that the end of a cigar-shaped mountain tapers gradually with the pitch of the anticline. The end of a syncline or canoe-shaped mountain, however, is blunt. In a cigar-shaped mountain the rocks dip away from the center in all directions. In a canoe-shaped mountain the rocks dip toward the center from all

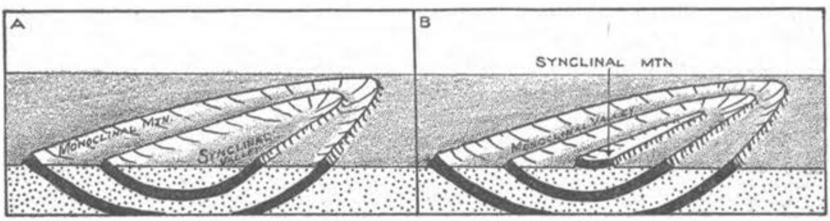

FIGURE 71. Development of concentric ridges in synclines. A, A region with synclinal or canoe-shaped folds. In B the synclinal valley shown in A is replaced by a mountain because of the occurrence of a hard stratum in the center. (Drawn by A. K. Lobeck.)

directions. As cliffs form only on the edges of hard formations the ridges of a cigar-shaped mountain or anticlinal fold are steep on the inside and slope more gently toward the outside, whereas in a canoe-shaped mountain or syncline the ridges are steep on the outside and slope more gently toward the center.

Single ridges formed upon a single layer of hard rock that dips in one direction, whether part of an anticline or a syncline, are termed monoclinal mountains. For the same reason valleys between ridges if developed upon soft beds that dip in but one direction are termed monoclinal valleys. (Figures 70, 71.) A mountain in which the rocks dip in both directions from a middle axis is termed an anticlinal mountain. (Figure 70, A.) For the same reason, if the axis of an anticline consists of soft rock so that a valley occurs there, such a valley is termed an anticlinal valley. (Figure 70, B.) A valley developed in rocks that dip in both directions toward a middle axis is termed a synclinal valley.

If the axis of synclinal structure contains soft rocks a long valley is developed there, representing the inside of the canoe. (Figure 71, A.) If, however, the axis of a syncline contains a hard formation the middle of the canoe may be occupied by a mountain, such a mountain being termed a synclinal mountain. (Figure 71, B.) A synclinal mountain is steep on the sides and blunt on the end. An anticlinal mountain has more gentle slopes and tapers off gradually at the end. The Appalachian ridges near Harrisburg, Pa., provide examples of all of these forms.

The drainage system in a region of folded rocks has a pattern which distinguishes it from drainage systems elsewhere. The main streams of the region usually flow across the axes of the folds and cut through the ridges in steep-sided water gaps, like the Delaware Water Gap, the Lehigh Water Gap, and the Susquehanna Water Gap of Pennsylvania. Most of the tributaries, however, flow in the longitudinal valleys, only

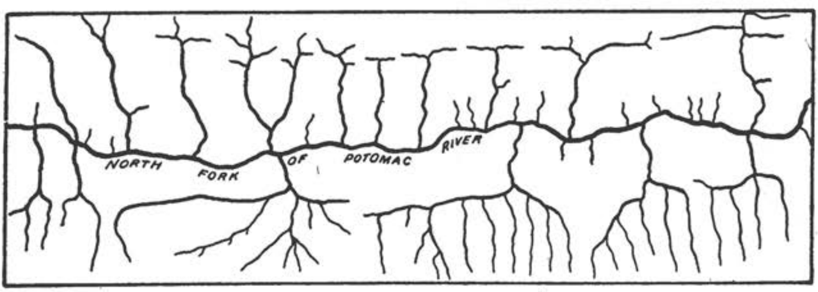

FIGURE 72. Trellis drainage pattern. (From Franklin, W. Va., topographic sheet.)

here and there cutting across a minor ridge. This arrangement of parallel streams that join the main stream at right angles resembles that of a vine from whose central stem branches are trained on a trellis. It is therefore called the trellis or grapevine system. (Figure 72.) Although most conspicuously developed in the Appalachians, this trellis system is common in regions where beds of hard rock lie steeply inclined to the general surface. Thus it appears that the hard rocks have influenced the arrangement of the streams.

Forms characteristic of crystalline or very complexly distorted rocks.

1. Complex mountains; formed on granite, gneiss, and schist. (Adirondacks, Rockies, Vosges, Black Forest, Alps, Rhodopes, etc.)

Complex mountains usually consist of such rocks as granite, gneiss, and schist. They show no orderly arrangement of formations such as are seen in folded mountains or dome mountains. Granites, schists, and similar rocks have a crystalline structure, are firmly bound together, and are able to withstand weathering better than rocks of looser texture. As a consequence, rocks of this character do not wear down easily and thus constitute large parts of the mountainous and rugged parts of the world. Complex mountains usually show no orderly arrangement of peaks or of river gorges. In some regions, however, the mashing of the rock has followed a general direction and has imparted a somewhat definite trend or grain to the features. This is true of the complex region just north of New York City. The main elements of the Swiss and Austrian Alps also reveal a certain trend in structure, but in neither of these regions is there the systematic arrangement characteristic of simple folded mountains.

Among mountains which may be classed as complex are the Adirondacks, the White Mountains, the Great Smoky Mountains of North Carolina, the Rocky Mountains of Colorado, the Sierras, the

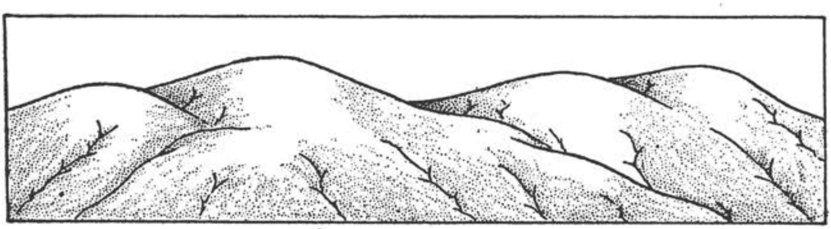

FIGURE 73. The rounded, smooth-flowing outlines of non-glaciated complex mountains. (Drawn by A. K. Lobeck.)

Vosges, the Black Forest, the Ardennes, the Alps, the highlands of England and Scotland, and the Rhodope Mountains of the southern Balkans.

A complex mountain dissected by streams is a region of rounded summits, which drop down in smooth spurs to the valleys below. (Figure 73.) The stream courses form no particular pattern. They apparently are not controlled by any well-defined structure but spread out in all directions like the branches of a tree. Such a pattern is called dendritic or branching. If streams are particularly active and vigorous, which they are likely to be in a very elevated region, the valleys may be deep and may have steep walls. Sharp rock ledges may then be common, and there may be cliffs and ridges in the mountains where bands and masses of specially resistant rock occur. However, a complex mountain area which has been subjected to erosion for a very long time will usually have all its sharp rock edges rounded off by weathering. Normally a complex mountain area that has long been subject to erosion shows smooth outlines, but if it has been subjected to glaciation, it contains sharp peaks and serrate crests, such as are seen in the Alps, the Canadian Rockies, and the mountains of Norway. (See page 187.)

Forms characteristic of both sedimentary and crystalline rocks.

1. Rolling uplands and entrenched streams; features due to peneplanation and uplift. (New England upland, Rhine upland, Ardennes upland, Piedmont upland, Rocky Mountain upland.)

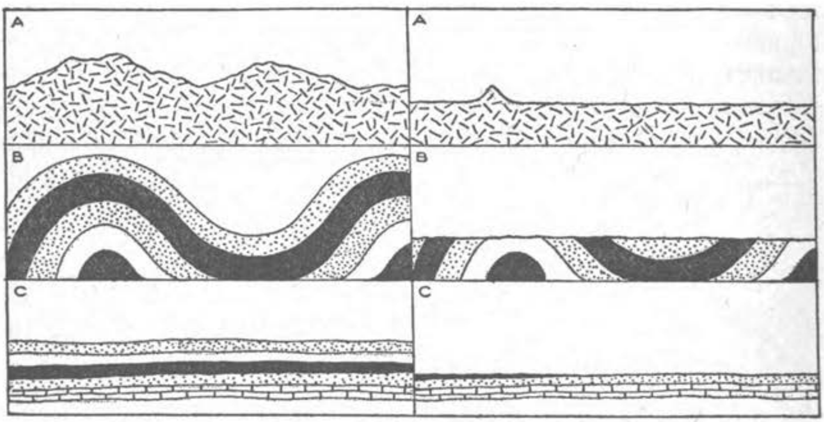

FIGURE 74. Appearance of a region before and after peneplanation. A, A complex mountain region; B, a folded mountain region; C, a plateau. (Drawn by A. K. Lobeck.)

By long-continued erosion a region may gradually be worn down to an undiversified rolling country that has but little elevation above sea level. Such a region is called a peneplain—that is, almost a plane or flat surface. Here and there a particularly high hill or mountain may still remain, representing an area of uncommonly hard rock. These are residuals or remnants of the former land mass and are known as monadnocks. The process of wearing down is called peneplanation, and it may take place in any of the types of country that have been described. (Figure 74.)

Peneplains are found in many parts of the world, as in the Piedmont region of Virginia, the Lake Superior region of northern Wisconsin, New England, the Rhine upland, and the Rocky Mountains. In all these regions the land was uplifted and dissected after planation, so that the peneplain is now represented by an even-topped upland cut into by valleys. Thus the New England upland stands at an elevation of 1000 feet or more in northern Massachusetts. In this upland the Deerfield River and numerous other streams have eroded deep valleys. The effect of this dissection is to give a certain degree of ruggedness to the region. Most of the railroads and roads follow the valleys, and the towns are built on the valley floors, even where those floors are narrow. The result is that most people see southern New England from points below its real surface and consequently call it a hilly country. Any one who climbs to the tops of the hills will find spread before him a very even sky line which represents the old peneplain surface. Only an occasional residual or monadnock breaks

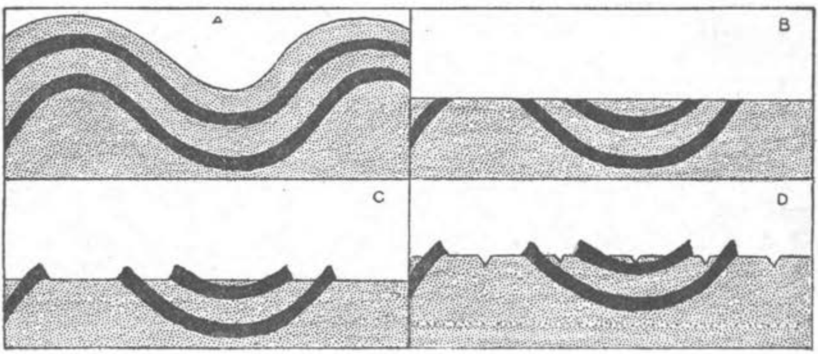

FIGURE 75. Peneplanation of a folded region. Four stages in the development of the Appalachian region. A, The folding; B, the first peneplanation; C, uplift and second peneplanation on softer rocks; D, uplift and dissection of the second peneplain by present-day streams. (Drawn by A. K. Lobeck.)

the view, such as Mount Monadnock in southern New Hampshire and Mount Wachusett near Worcester.

The great Rocky Mountain Front Range in Colorado is not a tangled group of peaks, as often imagined. It is a level-topped upland dissected by such gorges as the Royal Gorge of the Arkansas. Pikes Peak rises as a monadnock above the upland surface. The summits of the Vosges and the Ardennes are similarly rolling uplands.

The Appalachian Mountain region presents an unusually interesting example of peneplanation. Figure 75 illustrates the successive events in the history of the region. After the folding there occurred the first peneplanation, which beveled across the hard and soft rocks indiscriminately. Uplift then caused a revival of stream activity. Upon the softer rocks the second peneplain was then developed. This was followed by another uplift, which permitted the streams to incise themselves below the second peneplain. Thus the first peneplain determined the even crest of the ridges, and the second peneplain determined the broad, flat valley floors, such as the Shenandoah Valley, which stands 200 feet above the present stream valleys.

2. Grabens, block mountains, straight valleys, etc. Forms due to jointing and faulting. (Great Glen of Scotland, Rhine Graben, Palestine region, African rift, California earthquake rift, Great Basin, Wasatch Mountains, Sierra Nevada.) (See Chapter I.)

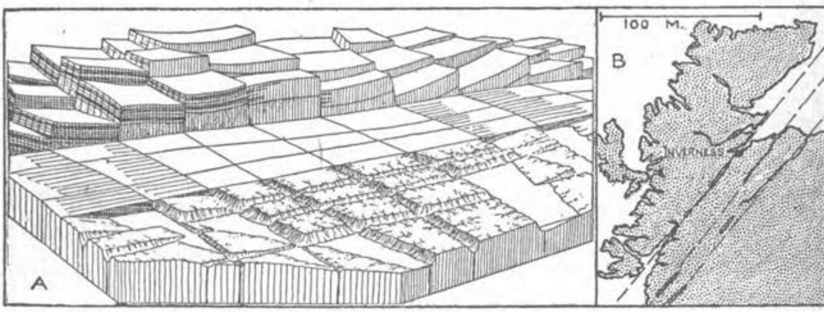

FIGURE 76. Origin of rectangular valleys and parallel earth fractures. A, The origin of the rectangular valleys in south Sweden. The rear of the block represents the checkerboard dislocation of the country. In the center the region has been planed down. In the foreground the present features are shown. The valleys follow fault lines. (After Davis.) B, Northern Scotland, showing parallel earth fractures in the Great Glen region.

A joint is a crack or fracture in solid rock. The shifting of the rock on each side of a joint, so that the rock formations are displaced, produces a fault. The shifting may be vertical or horizontal. It may be a few feet or thousands of feet. When a fault is formed the movement of the rock masses against each other causes great friction. The rock is ground and crushed between the moving surfaces.

A joint or a fault in the earth's crust follows a nearly straight line. Joints or faults usually occur in sets so that many run parallel. Occasionally there is a second set at right angles to the first. The result of this kind of faulting is to break the crust of the earth into blocks, checkerboard fashion. Many joints and faults appear to be unrelated to valleys, but some of them serve to determine the position of drainage lines, and in a much jointed or faulted region the drainage pattern may be more or less rectangular, as it is in parts of the Adirondacks and Canada. Southern Sweden is the best known example of a region with rectangular drainage lines due to faulting. (Figure 76.)

Very straight valleys that run in the same direction for many miles and that have no relation to the rock structure are best accounted for by assuming that they have been eroded along a fault line. Thus the Great Glen of Scotland from Loch Linnhe to Moray Firth is absolutely straight and has a length of nearly 100 miles. In the Coast Ranges of California there are long straight valleys, which are occupied partly by streams and partly by lakes. That these are fault lines is well known, because occasionally faulting is renewed and the sides of

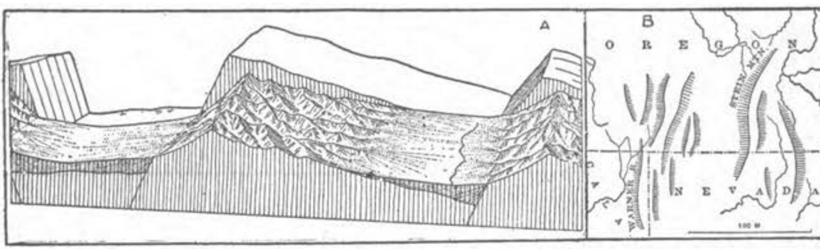

FIGURE 77. Diagram and map of block mountains. (After Davis.) The rear of the diagram (A) shows the region immediately after tilting of the blocks. The foreground shows the form of the mountains after they have been dissected by streams flowing down their steep front and gentle back slopes. B, Sketch map of the block-mountain ranges of Oregon and Nevada.

the valleys are shifted in relation to one another. At the time of the California earthquake of 1906 there was a sidewise movement of the ground of 20 feet along a line many hundred miles long.

In many regions of the world the crust of the earth seems to have been broken into long, narrow blocks by parallel faults and the blocks tilted one way or the other so that their uplifted edges form mountain crests. (Figure 77.) Such mountains are known as block mountains. In the Great Basin region of Utah and Nevada there are many small mountain ranges that trend in the same general direction. Usually the side of the range along the line of the fault is steep, and the other side is more gentle. The Wasatch block stands at the eastern edge of the Great Basin, and its steep side faces westward, toward Great Salt Lake. The Sierra Nevada block stands on the western side of the Basin, and its steep side faces eastward. Its long back slope drops off gently to the Valley of California.

In Germany a long block of the earth's crust has dropped down between the Vosges Mountains on the west and the Black Forest on the east. (Figure 78.) This long trench, now occupied by the Rhine, is called a graben (or grave). The steep face of the Vosges Mountains, directed toward Germany, has been a great obstacle to German advance from the east, but the long gentle back slope offers no especial difficulty to the French and Americans moving from the west. The Great Rift valley of eastern Africa, occupied in part by Lake Tanganyika, is a similar graben. In Palestine the straight valley of the River Jordan, occupied by the Dead Sea and the Sea of Galilee and continued in the Gulf of Akabah, is of similar character.

3. Matterhorn peaks, sharp crests, cirques, troughs; features due to glacial erosion in mountains. (Alps, Canadian Rockies, Glacier Park, Norway.)

When ice has accumulated to a considerable depth it tends to spread, and if it rests on an inclined surface it tends to move down the slope. When the ice begins to move it becomes a *glacier*—that is, a moving

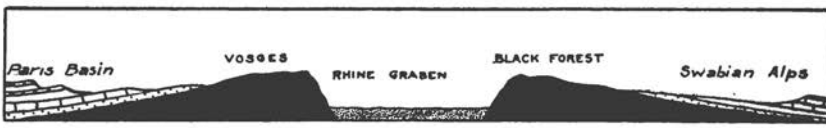

FIGURE 78. Section across the Vosges Mountains and Black Forest, separated by the down-dropped Rhine graben.

sheet or stream of ice. The glacier, especially when confined within a valley, is a powerful agent of erosion. It secures hold of the materials of its bed, pulls out fragments of rock and carries them along, and scours and abrades the rock that forms the floor and the sides of the valley. Glaciers in mountains therefore deepen and widen valleys, cut deep notches in ridges, steepen the slopes of peaks, and gradually transform a smooth mountain range into a region of pointed peaks and sharp crests.

In the Alps, Norway, Glacier Park, and the Canadian Rockies, glaciers are notable features, but the glaciers there now are very much shorter than they used to be. Their earlier gigantic channels or troughs may be seen extending far below the ends of the present glaciers. In many other regions of the world, as in the Vosges, the Carpathians, the Rocky Mountains of Colorado, and other places where glaciers do not occur now, there are similar features which were formed by glaciers during an earlier period.

A region which has been occupied by glaciers has a very different aspect from one which has been eroded only by streams. (Figure 79.) In the Alps, for example, the long trough-like valleys represent the great channels gouged out by the early glaciers. The view down such

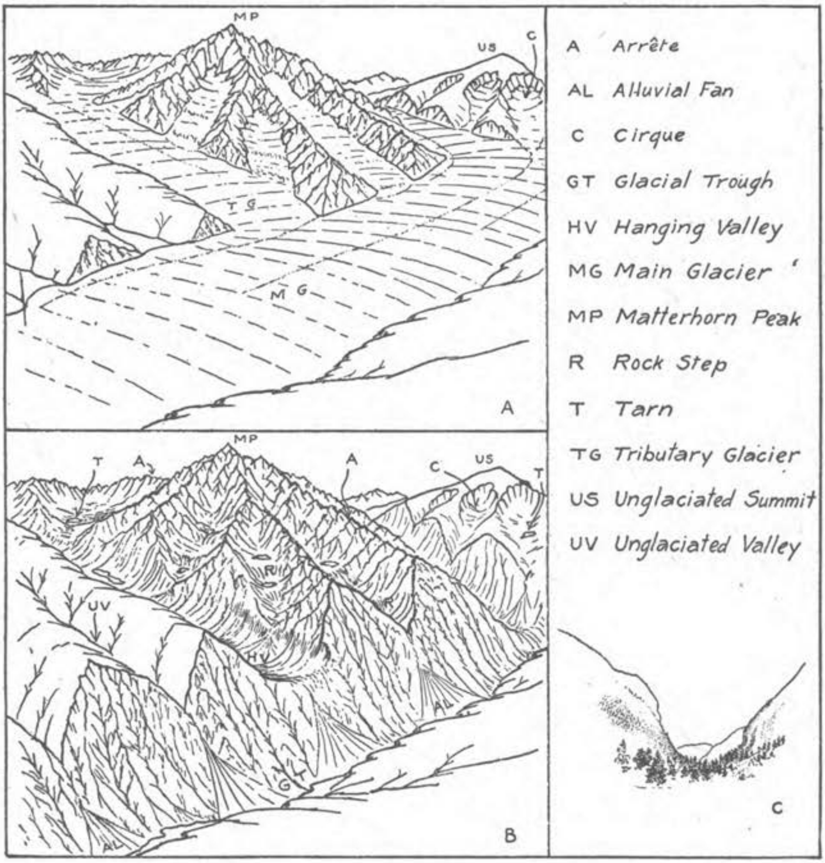

FIGURE 79. Land forms due to ice sculpture. A, A mountain mass occupied by a glacier system. B, Same mountain mass after melting of the glaciers. (After Davis.) C, Sketch of a glaciated valley showing its U-shaped form.

a valley is not interrupted by spurs from the mountain sides. Bare rock appears almost everywhere. The mountain walls are steep and in places give way and form destructive avalanches. Long lakes occupy the valley floors. Near the mountain crests there are cup-shaped hollows or cirques half a mile or more across, formed by the sapping action of the ice at the head of the glaciers. Many of the cirques contain small round lakes or tarns. The trough-like channels formerly occupied by the smaller tributary glaciers enter the main channel high up on its walls and are therefore often called hanging valleys. Waterfalls drop from the lips of these valleys to the lower level. Railroads have difficulty in going from the main channel up a tributary channel and have to resort to complicated tunnels, loops, and bridges. Along the course of a river in an unglaciated region it is easy to go from the main valley up any of the tributary valleys because they all meet at the same level. There is no step such as is found in a glaciated region.

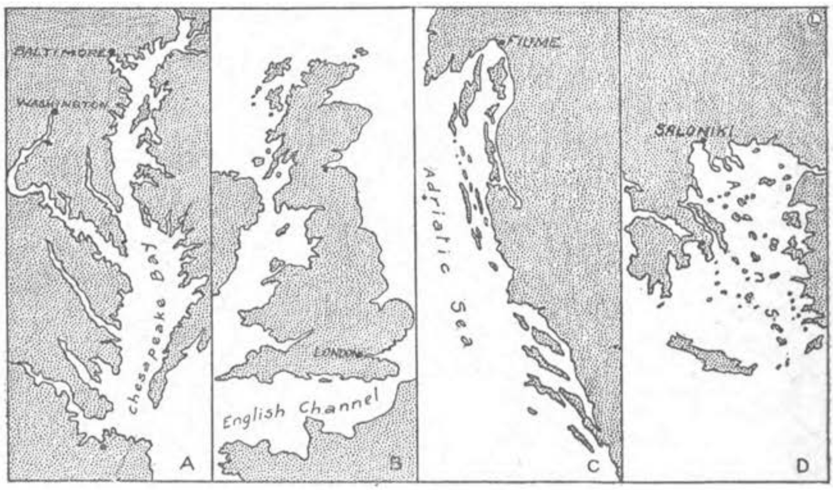

FIGURE 80. Drowned coast lines, due to sinking of the land. A, Chesapeake Bay; B, England; C, Adriatic coast; D, Greece.

In general, then, it may be said that glaciated mountains are bolder and offer more obstacles to travel than non-glaciated ones. The steep mountain sides and bold rock faces, the sharp crests and peaks, the discordance of main and tributary valleys—all interfere with lines of communication.

4. Bays, sounds, and harbors; features due to sinking of the land. (Chesapeake Bay, Maine coast, Scotland, Greece, Dalmatia.)

When the land sinks the ocean flows up the river valleys and forms bays. If the land sinks enough the ocean may fill a large part of the main valleys and then occupy the tributary valleys also. The bays will thus have arms and branches like a river system. Such a system is called a drowned river. The sinking of the land makes the coast line very irregular, producing numerous bays, promontories and islands. Splendid harbors are thus formed; indeed the best harbors in the world are due to the drowning of the coast. Chesapeake Bay, the coast of Maine, Scotland, Norway, Greece, the deep bays which indent the coast of England (Figure 80) are all due to sinking of the land. An exceptionally interesting and striking example of a drowned coast is the eastern shore of the Adriatic, where the sinking of a folded mountain region permitted the ocean to fill the longitudinal valleys and leave the ridges standing as more or less parallel islands fringing the coast. Many very excellent harbors exist here and are used as bases for the Austrian navy.

When the land rises the old shore line and beach is lifted above sea level. Thus raised beaches and wave-cut and wave-built terraces, forming level benches of country terminated inland by sea-cut cliffs that may be pierced by wave-formed caves, show the elevation of a former sea margin.

5. Cliffs, headlands, destroyed islands; features due to wave action on rock coasts. (Helgoland, Normandy.)

When waves beat against a rocky coast they exert so much force as to cut cliffs and steep headlands. The blocks of rock which are broken off are rolled about by the waves and are rounded into boulders. The shores of rocky islands that face the ocean are similarly cut into cliffs. If the islands are small the waves may gradually wear them entirely away. The root of the island under water will then be a continual source of danger to navigation unless it is carefully charted. Thus on drowned coasts where many rocky islands occur it is important that this danger be recognized. One of the best known examples of an island that is rapidly being worn away by wave action is the island of Helgoland, Germany's naval base in the North Sea. (Figure 81, A.) In the year 800 this island was 120 miles in circumference, in 1300 it was 45, in 1649 it was 8, and now it is less than 3.

The cliffs of Normandy, in northwestern France, stand 200 to 300 feet above the sea. They are cut in white chalk of the same kind as that across the channel, in England. So there is good reason to believe that England and France were once united and that the gradual retreat of the sea cliffs has separated them farther and farther. So much land has been cut away that the lower trunks of many rivers have disappeared, leaving the upper branches to enter the sea as independent streams, as shown in Figure 81, B. The valleys of the smallest streams end at the face of the cliff, and the streams fall to the beach below. Larger streams have cut their valleys down to sea level and formed little harbors at which villages are built close to the shore, as at Dieppe. Such stream harbors are kept open with difficulty on account of the plentiful supply of sand and cobbles that drifts along the beach.

6. Volcanoes, cinder cones, volcanic necks, lava flows; forms due to volcanic action. (Cinder Cone, Vesuvius, Hawaii, Auvergne region, Crater Lake, Azores.)

Most volcanoes have a very symmetrical and graceful conical outline. They are made up of layers of lava poured from the crater over the flanks of the cone and of loose material, such as ash and pumice,

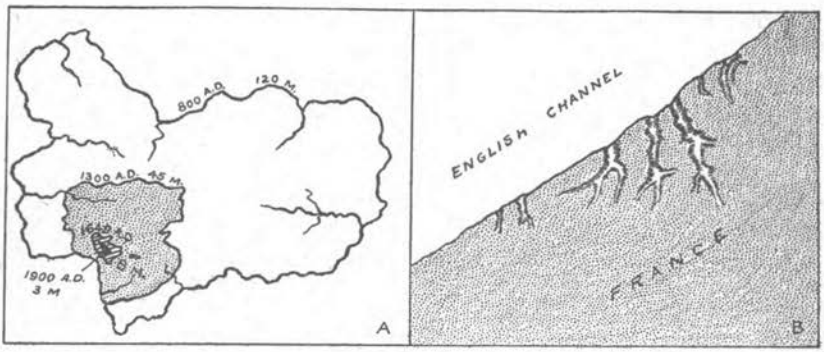

FIGURE 81. Work of the waves in cutting away rocky coasts. A, Successive stages in the destruction of the island of Helgoland. B, Cliffs of Normandy. The coast has been cut back so far that the tributaries of an old river system now enter the sea independently.

which has been blown out with more or less violence. It takes many eruptions to build up a great volcano. A small volcano formed by the ejection of loose material is called a cinder cone. Such a cone may be 500 to 600 feet high and may be formed in a very short time. One of the best known examples in the United States is near Lassen Peak, California, and is called "Cinder Cone." It has a height of 640 feet, its base is less than half a mile across, and the little crater is 240 feet deep.

Some volcanoes, such as the Hawaiian volcanoes, pour out lava in a quiet way and so never build up a cone.

In some volcanic regions the high central part of a cone is replaced by a broad and deep basin or caldera, due to the blowing off or sinking in of the top of the volcano. The Azores, a group of volcanic islands in the North Atlantic, contain a number of large calderas. The cone of Vesuvius has been built in a large caldera of ancient origin, the rim of the earlier volcano being known as Monte Somma. (Figure 82, A.) Crater Lake, in Oregon, is the finest example of a caldera in the United States.

When volcanoes are worn away by erosion the neck or column of lava that occupied the central tube-like passage may still remain standing up as a butte. In the Auvergne district in central France, where there are now no volcanoes, there are many remnants of ancient volcanoes. Most of the volcanoes there have been very much worn down, so that only the volcanic necks remain.

Lava flows may spread over a great area of country and form a more or less level plateau. The great lava plateau of Idaho, Oregon, and

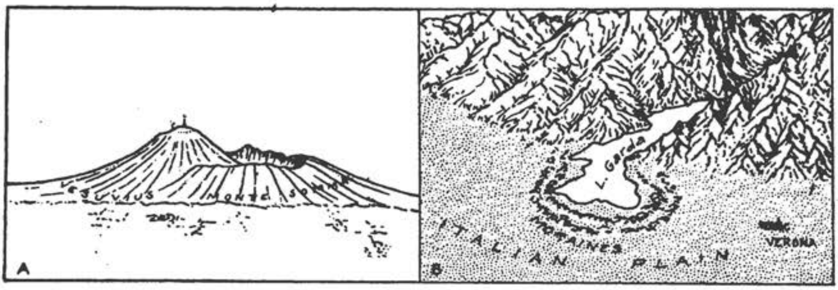

FIGURE 82. Volcanic cone and a lake basin. A, The old and new cones of Vesuvius. (After Davis.) B, Lake Garda, on the Italian plain at the foot of the Alps, held in by a terminal moraine. (Drawn by A. K. Lobeck.)

Washington is now trenched by deep canyons. The Yellowstone plateau and the Deccan plateau of India are other examples. After a region covered with lava flows has been long subject to erosion, some of the lava sheet may be left capping flat-topped hills or table mountains, known as lava-capped mesas, such as are seen in central France and in many parts of the western United States.

II. LOOSE SOIL types. (Land forms dependent upon loose soil.)

1. Alluvial fans, deltas, flood plains, terraces; forms built by streams. (Hoangho, Italian plains, Lannemezan area, Central California, Mississippi, Tagliamento, Danube, Rhine, etc.)

Streams do two things. They erode the land and form valleys; they also deposit material and form alluvial fans, deltas, flood plains, and other features. In the chapter on streams these two topics have been considered, but further emphasis is to be laid here upon the second topic.

Streams which have narrow valleys are usually actively cutting down. They rarely deposit material. On the inside of a curve a little gravel may be accumulated but there are no extensive deposits. The speed of such a stream enables it to carry all the soil and rock particles which it wears off the land. If such a stream passes from mountains out upon level plains it loses its speed and deposits most of its sediment just beyond the mouth of its canyon as an alluvial fan. This is exactly what happens in a gully on a hillside. The material washed from the gully is spread out at its mouth as a fan-shaped accumulation. Large streams deposit very large fans of gentle slope. One of the largest alluvial fans in the world is that of the Hoangho, in eastern China, which is more than 300 miles across. The soil of alluvial fans is very fertile and supports dense populations. But rivers that flow down the slope of an alluvial fan are subject to overflow in flood, when they suddenly change their course and invade fields and villages on the adjoining plains. (See Figure 114.)

The great plains of northern Italy, at the foot of the Alps, represent the material spread out by many streams emerging from the mountains. The Po, the Adige, the Brenta, the Piave, the Livenza, and the Tagliamento all helped to build these fertile plains. These rivers flow in general parallel to one another in their course from the mountains across the plains. With their braided pattern and interlacing network of channels they have served Italy as successive defense lines during the Austrian advances.

The great plain of Lannemezan, in southwestern France, which spreads northward from the base of the Pyrenees, is another example. The rich valley of central California is formed mainly of alluvial fans spread out from the Sierra Nevada on one side and from the Coast Ranges on the other.

A river that enters the sea where the currents and waves are not very active drops the sediment it is carrying and forms a delta. A delta does not differ essentially from an alluvial fan. A stream may split on the surface of a delta and enter the sea by several mouths, just as a stream that flows on the surface of an alluvial fan may divide and flow in several channels. A stream may build out a delta actively in one direction for a while and then change its main channel so as to build in a different direction, this change giving the delta several projections, like a hand with fingers. That is the shape of the Mississippi delta. The alluvial fans of northern Italy are now being extended forward into the sea by the deltas of the Po and the Tagliamento.

Rivers may deposit material on the floors of these valleys and thus form flood plain—that is to say, in time of floods the river spreads out over its valley and covers it with silt. In time the accumulations thus formed become very thick.

Many rivers that flow on a flood plain are sluggish, often overflow their banks, and generally swing in big meanders across the surface of the plain. They frequently change their courses, leaving their old meandering channels filled with stagnant pools of water. Such pools are called ox-bow lakes and are very common features on the flood plain of the Mississippi River. Streams of this character are most formidable barriers to advancing armies. The Danube is such a stream. On either side there is a broad belt of marsh and lake, which varies in width from three to six or more miles. The lakes are in part abandoned ox-bow lakes and in part bodies of stagnant water filling lower portions of the backswamps or depressions between two sets of natural levees built up by the river at different periods. (See Chapter III.)

Streams of this character, which change their shallow channels from time to time, are not suitable for navigation unless they are kept under careful control. The Rhine in the Rhine graben has been made suitable for navigation by straightening its course. Canals have been built to avoid going around lengthy meanders and to increase the gradient of the stream by shortening its course and thereby assisting it to erode its channels and keep them from silting up.

Even streams on flood plains may change from depositing streams to eroding ones. This may happen if the land rises so as to increase the gradient of the streams or if the tributary streams stop supplying the main stream with so much sediment. The river may then cut down its flood plain, leaving terraces on each side. There may be several seats of terrace-like steps going up from the river to the top of the plain. Many of the New England rivers show three or four sets of terraces.

2. Moraines; forms built by glaciers. (Alps, terminal moraines of United States and Europe, East Prussia.)

Glaciers do two things: First, they erode material from the land over which they ride; second, they deposit the material which they have eroded. Much of the material is deposited as irregular hills at the lower margin of the glacier. This is called a terminal moraine. (Figure 115.)

The glaciers that fill the valleys on the south side of the Alps formerly projected out onto the Italian plains. When the glaciers melted away the terminal moraines which they left on the plains blocked the ends of the valleys and enclosed basins which became filled with water. Lake Garda (Figure 82, B) is due to such action.

During the glacial period great ice sheets covered the northern part of North America and Europe and left generally terminal moraines that mark its southern margin. In the United States the terminal moraine forms the backbone of Long Island and runs thence westward across New Jersey and into Pennsylvania, Ohio, and westward across the continent. It is generally a hilly belt of gravel, sand, and clay, mixed with boulders, only one or two miles wide and seldom more than 100 feet in height. Among the moraine hills will be found hollows and swamps and numerous small lakes. The Mazurian Lake district of East Prussia is a morainal belt region noted for its intricate network of marshes and lakes. This belt, twenty miles in breadth, is an endless maze of irregular hills covered with wild, uncultivated areas of barren sandy soil, alternating with swamps, lakes, and forests. In this forbidding country the Russian armies met more than one disaster. (See Chapter IV.)

North of the terminal moraine in North America and Europe the surface of the country is covered with a stony soil left by the ice sheet as it melted. This is termed ground moraine, till, or drift. Many stream courses were blocked by this material, so that lakes and swamps prevail in the northern half of these two continents, whereas there are practically no lakes south of the terminal moraine.

3. Beaches, bars, spits; forms built by waves. (New Jersey, Texas, Gibraltar.)

Like streams and glaciers, waves do two things. They wear down and they build up. Waves running toward a shallow coast pile up loose sand in the form of a bar which may be a mile or more away from the actual shore line. Such a bar or barrier beach may in time, by the accumulation of material, attain a width of a quarter to half a mile or even more, and may stretch for many miles along the coast. Barrier beaches are very common features along shallow coasts. The coast of Texas, New Jersey, the south side of Long Island, the north coast of Prussia are all fringed with beaches of this kind. The strip of water or marsh between the beach and the mainland is called a lagoon. In East Prussia the bars are known as nehrungs and the lagoons as haffs. Coney Island and Rockaway Beach are barrier beaches. Jamaica Bay is the lagoon back of them. Great South Bay, Long

Island, and Barnegat Bay, New Jersey, are lagoons. The resort places of the Jersey coast are built upon the barrier beaches. (Figure 83, A.)

Shore currents carry loose sand alongshore and deposit it as beaches in the quiet water of bays. The material which waves wear off from steep headlands may be deposited as a spit that encloses behind it a little harbor. Sandy Hook is a spit of this kind. About the only harbors on the west coast of Africa have been formed in this way.

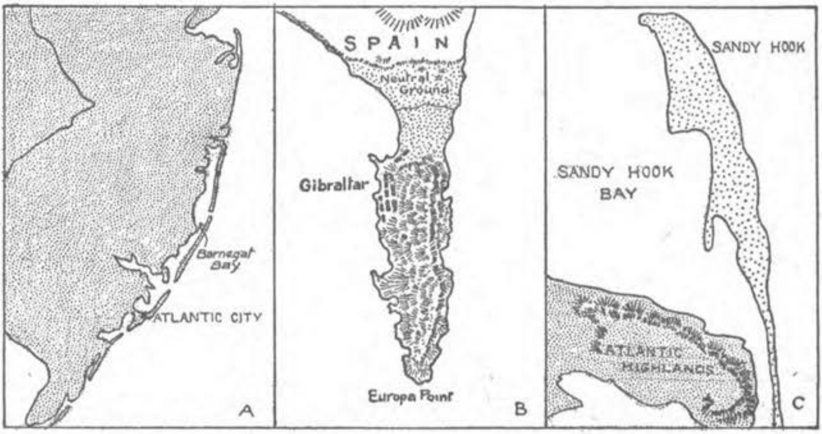

FIGURE 83. Lands built by waves. A, Barrier beaches along the New Jersey coast; B, Gibraltar, a rock island tied to the mainland by a wave-built beach; C, Sandy Hook, a wave-built spit. (Drawn by A. K. Lobeck.)

Islands lying close to shore are often tied to the mainland by a sandy beach built by the waves and currents. Gibraltar is an example. (Figure 83, B.) There are other examples along the New England coast.

4. Dunes; forms built by wind. (Cape Cod, Cape Henry, Belgian coast.)

Wherever there is sand unprotected by plant growth, as in deserts and along the seacoast, the wind is able to blow it about and pile it up in the form of dunes. On the barrier beaches of the Atlantic Coast the numerous sand dunes are rarely over 20 or 30 feet high. On Cape Cod and Cape Henry the dunes reach a height of almost 100 feet. The regularity of the wind from the sea is forcing the dunes slowly to advance landward and even to cover the forests adjacent to them. Other well-known dune areas are along the southern shore of Lake Michigan.

The low coast of Flanders, in northern France and Belgium, is bordered by dunes. (Figure 84.) The land is very low, having very recently been raised above the water, and the sea is so shallow that the retreating tide lays bare a broad flat of sand. The dunes are therefore the only features in the landscape, and although they rise but a few feet above the surrounding country they form important posts of

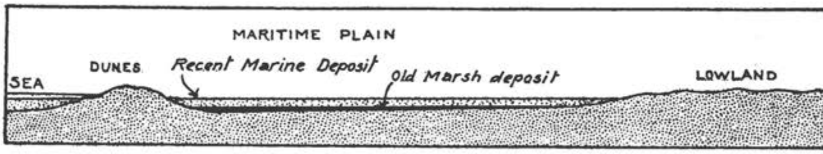

FIGURE 84. Sand dunes along the low coast of Flanders. (After Davis.)

observation and are the only means of natural protection to armies operating there. In the Landes region, along the southwest coast of France, the dunes have an exceptional height of several hundred feet.

PROBLEMS.

I. *Army Cantonments.*

Among the essential requirements that determine the location of an army cantonment are good water supply, good drainage, broad expanses of flat country, loose soil that is not rocky, easy communication with the main centers of population, and not too close proximity to densely inhabited regions.

Camp Dix is on the back slope of the coastal plain cuesta in southern New Jersey, almost on the cuesta front. In what way do you think its situation meets these requirements?

Camp Upton is on the outwash plain front of the terminal moraine in eastern Long Island. How does its position satisfy the requirements?

Prepare a series of simple sketch maps of the larger cantonments in the country, showing the position of each with regard to the physiographic features of the region. Does the camp stand on the flood plain of a river, upon unconsolidated horizontal rocks of a plain, or upon the weathered soil of a hard rock region?

II. *Army Movements.*

1. In moving an army over a complex mountain region, what do you think would determine the best route to be followed? In such a region what would you do for water supply? What would be the chief hindrances to the passage of the army? Would the army move

over a broad front or would it be restricted to a narrow file, subject to dangerous attack? In such a region who would have the advantage, the attacking or the defending force? Under what conditions in a complex mountain area might you find a sufficiently extensive flat tract to serve as location for a large camp?

2. Would you consider the movement of armies on a large scale impracticable in a folded mountain region? How would such a region compare with complex mountains in ease of communication? What would determine the natural routes to be followed? Could the army move over a wide front?

3. For defensive purposes which would you prefer, the flood plain of a large mature river, or a low cuesta overlooking the lowland occupied by the enemy? Outline the advantages of each.

4. Which would offer the greater obstacle to movement of troops—a very young plain with practically no streams or a maturely dissected one with well developed stream systems? Mention the obstacles each would offer.

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CHAPTER VII.

MAP READING AND MAP INTERPRETATION.

SECTION I. MAPS AND MAP READING.

DEFINITION AND AIMS.

MAP reading is the use of maps to gain the information they have to impart. It is an accomplishment that includes a thorough knowledge of the symbols and conventions used and the ability to interpret in terms of actual landscape the facts recorded. A knowledge of the symbols and conventions can be readily obtained by a little study, but a thorough comprehension of the facts they impart—in other words, the ability to read maps—is like the ability to read music, it is work in a field whose horizon constantly broadens as capacity to understand and appreciate the facts recorded is gained. A proficient map reader may deduce many significant and interesting things from the map in addition to the actual facts recorded, just as the reader of books may gain new suggestions by reading "between the lines," or as the musician may find shades of expression that it is impossible to represent by printed notes or notations.

The map maker's thoughts are constantly bent on depicting the large features of the earth on the small sheet that is to be the map. The map reader's object is to translate the map into the original field features. If these two processes were perfectly done there would be no loss in the accuracy or completeness of the translation. Such accuracy, however, is never attained, and many of the facts that are seen either can not well be depicted, or their complete representation would require unwarranted expense. As a consequence, the map reader must supply many minor details from his general familiarity with map-making procedure and his personal acquaintance with natural features.

Owing to the variety of uses to which maps are put and the variety of features shown on them a number of different kinds of maps have been developed, each of which has certain special characteristics. The maps that will be discussed in the following pages, however, are general geographic maps showing topographic features. They are commonly called topographic maps to distinguish them from maps on which relief is not shown.

TOPOGRAPHIC MAPS.

A topographic map is one that shows not only the location of places, but also the relief of the surface, steepness and height of hills, and the courses of rivers. On most modern maps, the forests are also indicated. Airplane route maps show rivers, towns and railroads, but not mountains. Other maps show coasts and water depths, but not the height of the land. The Danish survey map shows cultivated fields, but not relief, except that the heights are marked in meters. None of these are strictly topographic maps.

In general, topographic maps are used (a) to tell accurately the location of both natural objects and artificial structures; (b) to orient one's self—that is, to find one's position on a map; (c) to plan the movement of troops and supplies; (d) to lay out new roads, railroads, etc.; (e) to lay out defensive structures, such as trenches, and to plot data learned concerning the enemy's positions; (f) to serve as a base map, from which larger and smaller maps may be made. Thus the airplane maps are made from ordinary topographic maps by omitting some features and inserting and emphasizing others.

Thus a topographic map is a reference book of information available for many purposes. As far as possible it should show:

1. All land forms—shapes, slopes, and heights of hills, cliffs, valleys, etc., called the Relief.

2. All water bodies—rivers, lakes, swamps, glaciers, called Hydrography.

3. All railroads, roads, paths, towns and scattered houses, bridges, ferries, tunnels, canals—called the Culture.

4. Vegetation—the forests, and if possible, rows of trees, orchards, brushlands, vineyards, hop gardens, berry vines, which seriously hinder movement of troops, offer concealment, or prevent airplane landing.

5. Cultivated fields—ploughed lands—suggesting food supplies, open ground for manœuvering and good airplane landings.

6. Special features which are of use in finding the way, repairing machinery, signalling, etc. Such features are churches, chimneys, factories, electrical establishments, blacksmith shops, mills, conspicuous trees, graveyards, roadside shrines, schoolhouses.

To show all these features, a map must represent the country on as large a scale as possible. The preparation of such maps requires much time and labor.

Modern military practice requires maps that can be used:

(a) In planning large movements—those campaigns which are the modern "battles." For this purpose *strategic maps* of comparatively small scale and which cover large areas of country are desirable.

(b) In planning and carrying out complex details of the troop movement. For this purpose large scale maps are needed. These are the *tactical maps,* the typical military map in all countries.

(c) For the defense of or attack upon a position, that is, one of those knots of trench and supporting trench systems such as Dead Man Hill near Verdun. Maps constructed for this purpose are called *position maps,* and are drawn on the largest scales in modern use.

In choosing the details to be represented on a map the purpose for which it is to be used should be carefully considered.

REPRESENTATION OF RELIEF.

Relief is difficult to represent on a flat sheet, and various methods not at once easily understood are used. There are four principal methods—by color, by shading, by hachures, and by contours. (See Figures 85, 86, 87, and 88.) Combinations of two or more of these methods are by no means uncommon.

Relief shown by colors.—The representation of relief by colors is effected by tinting all areas of the same height above sea level the same color. Obviously this can not be carried out so as to show small differences of elevation, so in practice tracts representing different belts of elevation are shown in different colors—for instance, tracts between sea level and 1,000 feet above it are shown in one color, tracts between 1,000 and 2,000 feet another, and so on. This method is sometimes used for representing continents or other large areas, and the resulting map is called a hyposometric map. The disadvantages of this method of representation are that owing to the small number of colors that can be easily distinguished the range of elevations that must be represented by one color is great, and consequently details and relative relief are not shown. The advantages of this method are that areas shown in the same color are readily recognized.

Relief shown by shading.—In making maps on which relief is shown by shading the light is assumed to come from some definite direction. The white parts of the map represent the parts of the land on which the light strikes directly and the darker parts land on which the light strikes indirectly or not at all. If the light is assumed to come from directly overhead the tops of the hills and the floors of the valleys appear white and the slopes are shaded—the steeper the slope the darker the shade. If, on the other hand, the light is assumed to strike obliquely across the mapped area, one side of a hill appears lighter than the other. The advantage of this method of representing relief is that it makes the map easily legible to the untrained eye and it gives an impression of solidity to the features as represented not attained by other methods. The use of shading alone, however, affords no information regarding the actual elevation of the points shown on the map and indicates only relative relief. Inasmuch as a single direction for illumination must be maintained throughout the map, some features will

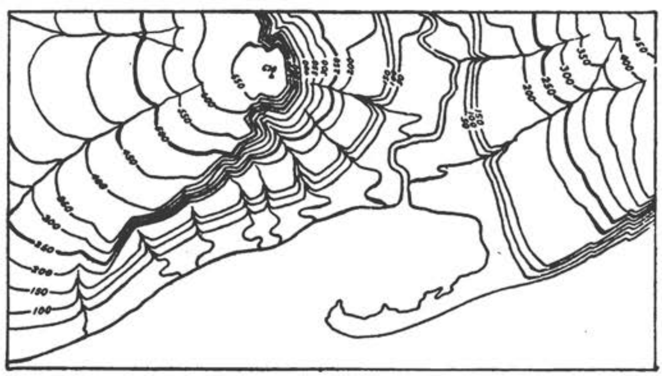

FIGURE 85. Land forms shown by contours.

not be as adequately or distinctly represented as others, and consequently an incorrect effect is produced. (See Figure 88.)

Relief shown by hachures.—Hachures are lines so drawn on the map as to express by their length and direction the slope of the ground. The lines point directly up or down the steepest slope. On some maps the length of the hachures is made to indicate a definite height, for instance, the vertical distance between the points on the ground which fall at the ends of a hachure line is a constant. All hachure maps are constructed on this general principle, though the difference in length of the hachure lines usually does not express an exact difference in elevation. It is evident, therefore, that where the hachures are short the slope is steeper than where the hachures are long. Furthermore, the thickness of the hachure lines is greater on steep than on gentle slopes. As a result, steep slopes appear darker on the map than gentle

FIGURE 86. Hachure map of the region about Verdun, France. See also Figure 87.

slopes. Flat surfaces, whether they are the tops of hills or the floors of valleys, are without hachures. On a sloping surface having a strong gradient, such as a valley occupied by a swift stream, the

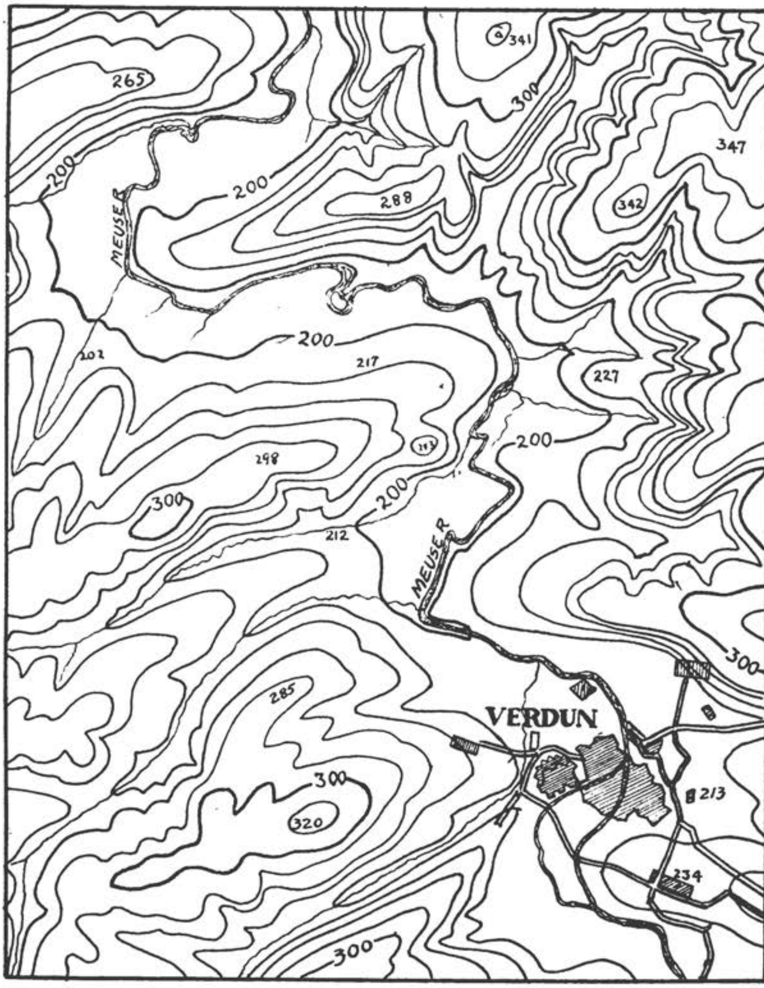

FIGURE 87. Contour map of the region about Verdun, France. The area mapped is that shown in Figure 86. (Drawn by Frederick Morris.)

hachures point straight down the valley wall and then turn slightly down the slope of the flood plain, pointing downstream. The hachures representing the opposite sides of the valley therefore nearly meet in an acute angle that points down the stream. On a ridge the hachure lines follow the crest of the ridge and diverge toward both sides, sending off branching hachures that point down the slopes.

Figure 86 shows part of the region around Verdun and illustrates the method of representing relief by hachures. The winding course of the Meuse is bordered by flat lowlands which are shown without hachures. Rising rather steeply above it are the spurs which lead to the uplands and on several of which, as for instance, west of Charny, are the forts and the network of military defenses.

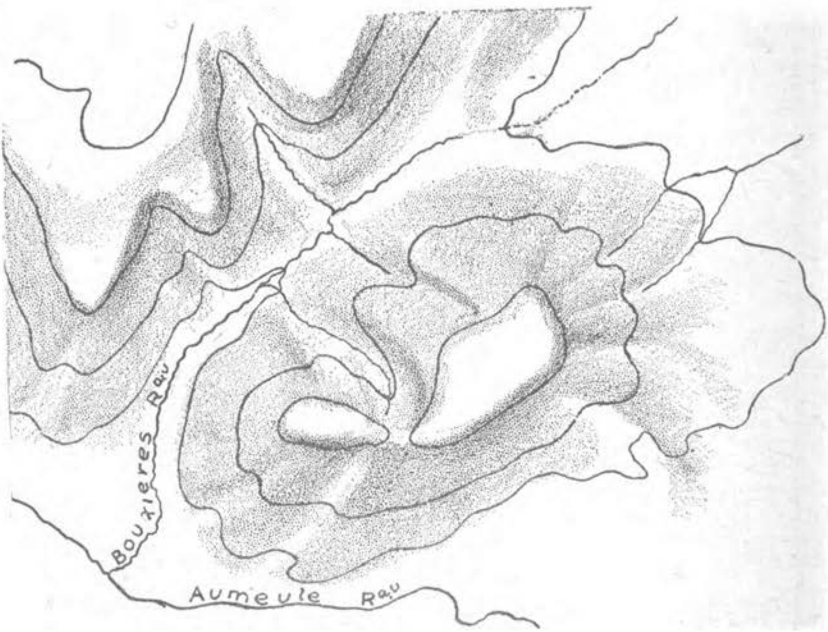

FIGURE 88. Shading-contour map of a hill northwest of Nancy, France. Contour interval, 50 meters.

Hachure maps are relatively easy to read and show with fidelity the relief of the country. The preparation of a good hachure map is difficult, however, as it requires considerable manual and artistic skill in addition to ordinary topographic training. Their most vital defect, if the maps are to be used in engineering projects, is the fact that they do not accurately express the actual elevations of all parts of the surface. On most hachure maps this defect is partly met by inserting at certain places figures showing the elevation. Thus in Figure 86 the Meuse is 198 meters and Côte de Talou 288 meters above sea level. This method does not supply sufficient information for any but the most general needs, and a combination of hachures and contours (see pp. 208, 209) has been adopted by many governments as giving the most easily read picture and at the same time affording accurate engineering data. (See the Carte de France de l'Etat Major, the official maps of Germany, Austria Hungary, etc.)

Relief shown by contours.—The representation of topography by contour lines is one of the commonest and most accurate methods of mapping relief. (See Figure 85.) A contour line on a map represents an imaginary line (a contour) that passes through all points on the ground that have the same elevation above a selected plane—usually sea level. For each map the lines are drawn to indicate certain regular differences in elevation, and the difference represented by two adjacent contour lines is called the *contour interval*. As contour lines drawn to represent only slight differences in elevation would for most regions make a map illegible, in practice only a few of the possible contour lines are drawn. The selection of the contours that are to be shown depends on the scale of the map, the kind of country to be represented, and the degree of detail to be shown. Thus on a large map of a flat country, to show individual trenches in detail, contour lines might be drawn so that they represented differences of 5 feet in elevation—that is, the contour interval would be 5 feet. In rough mountainous country, where the expression of minor detail is not necessary, a contour interval of 100 feet might be selected. The contour intervals on maps published by the United States Geological Survey range from 1 foot to 250 feet.

This method of representing relief is graphically shown in Figure 85, where the area of hills and a valley near the sea coast shown in the sketch is also shown by contour lines on the map. The difference between the contour method of representing relief and the hachure method is well illustrated by comparison of Figures 86 and 87, which show the relief of the same area in the vicinity of Verdun, one by hachures and the other by contour lines.

All the best detailed Government maps of areas in the United States represent relief by contour lines, and practically all the foreign governments also use this system, either alone or in combination with hachures or shading. It is important, therefore, that facility in reading contour maps should be acquired, and this can be done only through practice. The practice should not be confined to regular schoolroom exercises but should be carried into the student's daily life—his tramps afield or his rides in cars and autos—until he can readily see the landscape in terms of contours and can read contour lines on his map in terms of landscape.

ORGANIZATION OF LARGE-SCALE MAP SYSTEMS.

Topographic maps are published in separate sheets; but the sheets are so made as to match when laid edge to edge, so that large maps may be made by joining the units together. The first great topographic map of France, "La Carte de France de l'Etat-Major" was laid out

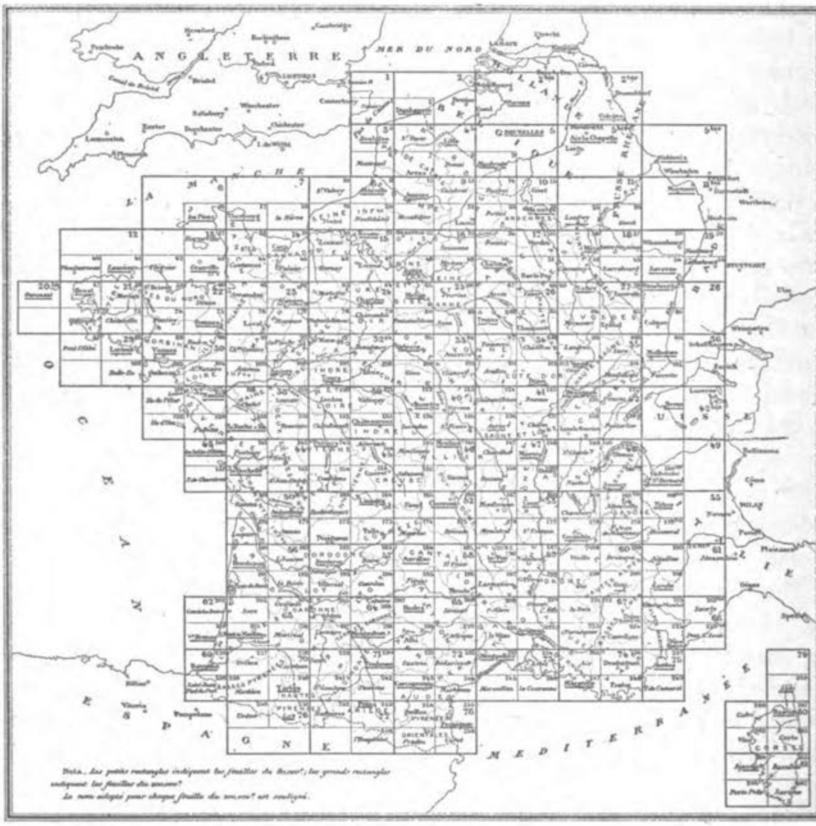

FIGURE 89. Plan of a survey in rectangles, the sides of which are not true north and south lines.

in rectangles which were numbered in series from West to East, beginning with the northernmost row of sheets; so that the numbers of the maps run like the words on a printed page. (Figure 89.) This system has the disadvantage that the edges of the map units do not follow true North-South, East-West lines, because the meridians converge toward the poles and the parallels are curved lines.

England, Germany, and other countries that followed France in organizing a general survey, improved upon the French plan by using parallels and meridians for boundary lines. These maps are not rectangular; in the northern hemisphere the northern edge of a map is shorter than the southern, because the meridians converge toward the North Pole and the parallels that form the East-West boundaries are curved lines, convex toward the equator. English, German and French maps are numbered from the West toward the East, so that sheet No. 1 is the upper, left hand corner sheet of a combined map.

Because of the large area covered no system of numbering has been adopted for maps of the United States. Each sheet bears the name of a city or village.

Austria has adopted an ingenious plan, which Japan has imitated, and which other countries use for their military maps. On Austrian maps the sheets in a line from West to East are called a Zone, and those in a line from North to South form a Column. Each map sheet has an Arabic numeral for its zone, and a Roman numeral for its column. Thus three sheets in line from North to South would be called respectively Zone 21 Kol. 18, Zone 22 Kol. 18, Zone 23 Kol. 18.

A map called the International Map is being issued on the scale of 1 : 1,000,000, to cover the entire world. Two editions are printed, one showing relief by means of contours, the other by plotting different colors for different elevations above sea level. In some places where larger maps are lacking, such as Mesopotamia, these have been important war maps.

The Carte de France de l'Etat Major, R. F. 1 : 80,000, was begun in 1818; the work had its inspiration and inception in plans of Napoleon. It is primarily a military map, and all the military maps of continental Europe are its logical descendants. On this map relief is shown by means of hachures, with numbers scattered over the map, telling the elevation in meters above sea level. Water bodies are shown in black—an obvious disadvantage, but not a serious one. Lake shores are shaded with horizontal lines jutting out into the waters—a device copied by the Germans. Rivers that run all the year are shown in black "crinkly" lines, not to be confused with the road-symbols, which are smooth, simple lines. Intermittent streams are not marked, and their valleys are indicated only by the hachures. Forests are indicated by printing many small circles, to look like trees from above, and cultivated land is shaded with fine dots where it is possible to print them. The conventional signs are those shown in Figure 90. It will be seen that churches are distinguished from other buildings, roads are sub-divided as to quality and regularity of repair, and railroads are also classified. The direct information given is adaptable to both civil and military purposes; but for engineering work a contour map is more serviceable.

French Conventional Signs

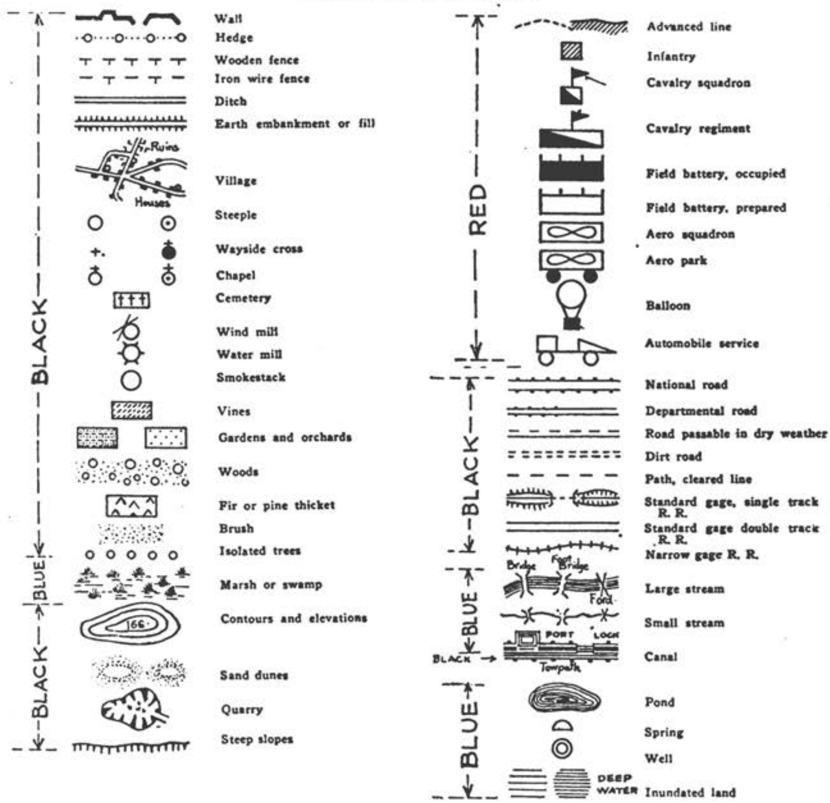

FIGURE 90. Symbols used on a French military map.

The Karte des Deutschen Reiches, 1 : 100,000, was first systematically organized in 1872, to take the place of the unsatisfactory maps which the small German states had possessed prior to the German union in 1866. It is a hachure map, based on the French map but with many more vegetation symbols and culture symbols than are shown on the French map. The map aims to give information for all purposes, but especially for military service. Thus all metal-working mills are carefully marked; all large trees, tall buildings, churches, factories, windmills, etc., receive special symbols.

The Spezialkarte of Austria-Hungary is a hachure map, R. F. 1 : 75,000, with 50 meter contours, and is the most elaborate map of

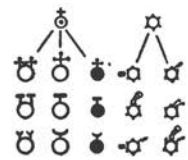

FIGURE 91. German and Austrian map symbols. In the top column are the German symbols for churches and mills. The Austrian church symbols are read as follows: left to right, two towers, one tower, small chapel; top to bottom, Christian churches, synagogues, mosques. The mill symbols read: top line, watermill, sawmill; middle line, metal working plant operated by steam, ore stamp mill; bottom line, hydro-electric plant, electric plant operated by steam.

its scale in the world. Its symbols are borrowed from the German map, but many modifications of each are printed so as to minutely define the objects represented on the map. In Figure 91 are given the German symbols for churches and mills, with their Austrian modifications.

MAP MEASUREMENTS.

DISTANCE.

One of the three necessary measurements which must be known in order to read maps is the distance between the objects represented. On this knowledge the military officer bases his estimate of the time required to go from one place to another, the setting of his gun sights, the length of his bridges, railways, and telephone lines, and countless other details which enter into his daily routine. All maps should therefore state their scale—that is, the ratio between distances measured on the map and the corresponding distances on the ground. This scale may be expressed in different ways. The three most common are as a representative fraction, as a scale of equivalents, and as a bar (or graphic) scale.

When the scale is expressed by a representative fraction, the numerator of the fraction indicates the number of units measured on the map and the denominator the number of units of the same kind on the ground that are represented by the number of units expressed by the numerator. For convenience 1 is usually taken as the numerator. The representative fraction scale 1/1,000,000 means that 1 inch, centimeter, foot, etc., on the map represents 1,000,000 inches, centimeters, feet, etc., in nature. This scale is therefore universal, as it is applicable to any units of measurement and is readily convertible into other scales when occasion arises for enlarging or reducing the map. The smaller the representative fraction the smaller is the scale of the map. Thus a map on a scale of 1/100,000 is on a larger scale than one on a scale of 1/1,000,000 and is on a smaller scale than one on a scale of 1/10,000. Maps with scales smaller than 1/200,000 are generally regarded as on a small scale.

Maps on which the scale is expressed in equivalents give the distance on the map in units of one kind and the distance in nature it represents in units of another kind. A very common scale of equivalence used in the United States is inches on the map and miles in nature—for example, "a mile to the inch," "2 inches to the mile," "1 inch = 1 mile," "2 inches = 1 mile." Maps on a scale of 1 inch to 3 miles are generally regarded as on a small scale.

The scale of some maps is shown by a bar, on which each subdivision indicates graphically the distance on the map which is equivalent to a certain specified distance on the ground. An example of a bar scale is shown in Figure 86. It is highly desirable that distance should be indicated on maps by bar scales, even though other modes of expressing the scale are also given. Large maps on even the most carefully prepared paper will shrink or swell perceptibly with changes in the moisture content of the air. Consequently, as the bar scale is on the same paper as the map, it expands and contracts equally with the map, and therefore is more accurate than the other scales.

The air-line distance between two points is readily measured on a map by laying a ruler graduated to the scale of the map on the two points and reading the distance directly. The use of dividers also affords a means of determining the mapped distance between the points, and the distance thus determined can then be referred to the bar scale to find the actual distance in nature.

Often, however, it is necessary to measure distance by circuitous courses, such as along streams or roads. A common way of doing this is with a measuring wheel, which is a small disk mounted in a handle in such fashion that it can be guided readily to follow the bends in the road or stream. The edge of the wheel has small teeth to prevent slipping. In use the wheel is guided over the course as shown on the map, and the number of revolutions is noted. By then revolving the wheel the same number of times along the bar scale or a small straight graphic scale constructed for the purpose the distance may be determined.

Distance along an irregular course may also be measured by using a strip of paper. By this method a mark is made on the long edge of the paper and this is placed on the starting point. The edge of the paper is turned until it corresponds with the direction of the course from the starting point to the first bend. A mark is then made on the paper at this bend, and, this second mark being carefully held at the same point on the map, the strip of paper is swung until it conforms with the direction from the first to the second bend. In this way the entire course is carefully measured. The distance between the two outside marks on the strip of paper shows the entire distance along the course, and by referring this measurement to the map scale it may be converted into terms of actual distance on the ground.

Irregular lines may also be measured by laying a piece of thread along the mapped route, care being taken to make the thread conform accurately to all the irregularities of the course. The distance between the two end points on the thread may then be measured by comparing it with the scale. The use of thread for accurate measurements is not recommended, as it stretches or can not be made perfectly straight when it is compared with the bar or graphic scale.

DIRECTION.

Maps are so drawn that the direction of one feature from another is readily determined. In general, a line drawn through the center of the map from top to bottom is a true north-south line, and a line drawn through the center of the map from right to left is a true east-west line. On all good maps certain parallels and meridians of latitude and longitude are shown. The parallels indicate true east-west directions and the meridians true north-south directions. Owing to the impossibility of representing part of a spherical body accurately on a flat sheet of paper all maps show some distortion. In general, however, the amount of distortion is so light that it may be disregarded except for long-distance measurements and on small-scale maps.

Direction is measured on maps by using a protractor. This is an instrument consisting of a circle, or part of a circle, having on its circumference marks which show the angle at the center intercepted by lines passing through the center to the respective marks. The entire circumference of the protractor is divided into 360°. In use, the center of the protractor is placed on the point from which the direction is to be determined. The protractor is then revolved until its line of 0° corresponds with the direction of true north on the map. A reading is then made of the number of degrees between the zero line and the line joining the center with the point whose direction is to be determined. Formerly it was the practice to express this direction as so many degrees east or west of north or south, the entire circle being regarded as being made up of four quadrants—that is, northeast, northwest, southeast, southwest. This system, however, leads to much confusion, and consequently current practice is to express direction by stating the number of degrees from north, read in a clockwise direction entirely around the circumference. In accordance with this plan, a point having a bearing of due north is referred to as bearing 0°, due east as 90°, due south as 180°, due west as 270°, 1° west of north as 359°, and so on for all intermediate directions. (See pages 216 and 217 and Figures 93 and 94.)

As most of the measurements of direction obtained from maps are true to nonmagnetic directions they can not be applied directly to field observations with the compass, because the compass is affected by magnetism. Two rather distinctly different kinds of magnetic influence affect the compass. One is the so-called local attraction, and the other is due to the earth itself being a magnet. Local attraction is caused by magnetic bodies such as railroads, wire entanglements, and deposits of iron minerals. It must be avoided in making compass readings, or if it can not be avoided some device such as the solar compass, which does not depend on the magnetic principle, must be used for measuring direction. Local attraction is seldom constant over large areas and consequently can not readily be compensated for.

The disturbance of the compass needle due to the earth's magnetism is constant through fairly large areas, and consequently its effect can be counteracted by adjustment of the compass. The deflection of the compass needle as affected by this force is usually indicated on good maps by a diagram showing the angle between true north and magnetic north. The angular value of this factor may also be learned by reference to tables of magnetic declination which are published from time to time by certain governments. It may be determined in the field by noting the difference in bearing between the direction of one point from another as found from the map and the direction of the same points as read by the compass. For example, if the direction of a hill from camp as determined from the map is 30° (N. 30° E.) and the direction of the same hill from the same camp as read by the compass is 50° (N. 50° E.), the magnetic declination of that region is 20° to the west.

In order to convert compass readings, which are affected by magnetic variation, to true directions it is necessary to know the amount of the magnetic declination, and if the declination is west to subtract the amount of the declination from all readings made with the compass or vice versa. If the older system of notation is used, whereby the compass circle is expressed in quadrants, the rule is, if the declination is west, subtract its amount from the compass readings in the northeast or southwest quadrants and add it to all readings in the northwest or southeast quadrants. The opposite procedure should of course be followed if the declination is east or if it is desired to convert true direction to compass readings.

ELEVATION.

The description already given of the method of representing relief by contours makes it evident that the height of any place on the map falling on a contour line is directly determinable by ascertaining the elevation that the contour represents. To facilitate such determinations, the elevations represented by the different contour lines are stated in figures at a number of places on the map. Furthermore, in order to guide the eye, every fifth contour line (rarely every fourth) is accented, or drawn heavier than the others.

The elevation of points not precisely on a contour may be closely estimated by reference to the contours between which they lie. Thus on a map whose contour interval is 50 feet a point lying midway between the 550 and 600 foot contours may be assumed to have an elevation of 575 feet. Estimates of this sort are only approximate, but if they are made with discretion and with due regard to the topographic character of the region they are of considerable value. The greatest inaccuracy will be found in estimates of the height of points that lie between contours in places where contours are widely spaced, as for instance, on the tops of mountains or on plains. In all determinations of elevation from contour maps, however, it should be recognized that the contour interval adopted indicates the degree of refinement with which the map should be read. Thus on a map having a contour interval of 100 feet knobs less than 100 feet high or pits less than 100 feet deep would not show a contour line. Therefore, although these features might be prominent landmarks in nature they would not be represented at all directly on the map. Furthermore, in making the map the topographer does not actually run the contours with an instrument, so even the contour lines themselves are not absolutely correct. They only indicate within the degree of accuracy represented by the contour interval adopted the elevation of the region mapped.

In order to show with great accuracy the elevation of certain points, numerals indicating their exact height are put on the map. The points thus designated are usually summits of mountains or other well-recognized or much used features, such as road intersections, bridges, and lake surfaces.

The difference in elevation between two mapped points may be readily determined by finding the elevation of each point as described above and subtracting the smaller figure from the larger. If the difference in elevation of two points on a plane and the distance between them are known, the slope between the two, expressed either in feet per mile or as an angle, can be calculated. If the two points do not lie on a plane, the same factors may be estimated by treating the distance between them as if it were broken up into different planes at each point where the slope appreciably changes. Problems connected with the air-line slope between places are constantly arising in the operation of artillery. Problems connected with the actual slope of the surface between two points arise in all operations utilizing roads or streams.

EXERCISES IN MAP READING.

To change the R. F. into any convenient scale of equivalents:

The R. F. of a map is $\frac{1}{62500}$

1. One inch on the map represents how many miles on the ground?

   1 inch on the map = 62,500 inches on the ground.

   1 inch on the map $= \frac{62500}{63360} = 0.98$ mile on the ground.

2. One mile requires how many inches on the map?

   62,500 inches on the ground require 1 inch on map.

   63,360 inches on the ground will require $\frac{63360}{62500} = 1.013$ inches on the map.

3. One centimeter on the map represents how many kilometers on the ground?

   1 cm. on the map = 62,500 cm. on the ground.

   100,000 cm. = 1 km.

   1 cm. on the map $= \frac{62500}{100000} = 0.625$ km. on the ground.

Rule: Write out the R. F. as an equation, in terms of inches, centimeters, etc.; and then reduce the units on one side of the equation to whatever new unit the problem calls for.

CONSTRUCTION OF GRAPHIC SCALES.

Each subdivision of a graphic scale must represent some very simple, convenient number of larger units on the ground.

1. Construct a graphic scale of yards for a map whose R. F. is $\frac{1}{62500}$.

1 yard or 36 inches on map = 62,500 yards. Since 62,500 is an inconvenient number to use the equation may be multiplied or divided in order to obtain more desirable figures.

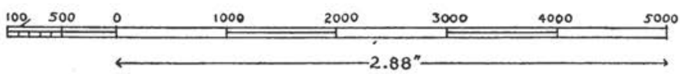

FIGURE 92. Diagram showing the construction of a graphic scale of yards for a map with the representative fraction 1 : 62,500.

Multiplying both sides by 8.

288 inches on map = 500,000 yards on ground.

Dividing by 5.

57.6 inches on map = 100,000 yards on ground.

5.76 inches on map = 10,000 yards on ground.

Draw a line 5.76 inches long; sub-divide this line into tenths, each of which will represent 1,000 yards. Figure 92 represents one half of 5.76 inches, sub-divided into units as small as 100 yards.

2. Construct a graphic scale of your own paces for use with a map, whose R. F. is 1 : 20,000.

First pace a distance that has been carefully measured. Count your paces, and take the average of at least five separate pacings of the distance. Divide the distance, reduced to inches, by the average number of paces and so determine the average length of your pace. Suppose this to be 30 inches, the Army pace. Then 1,000 paces = 30,000 inches. From the R. F. 20,000 inches on the ground = 1 inch on map. 30,000 inches on the ground = $\frac{30000}{20000}$ = 1.5 inches on the map. That is, each 1.5 inches will represent 1,000 paces, and this length can be sub-divided to show 500, 100, etc. paces.

To find the R. F. when an equivalent is known.

Two places, known to be 6.35 km. apart, are separated by 10 inches on an Italian military map. What is the R. F.?

10 inches on the map = 6.35 km. on the ground.
Since 10 inches = 25.4 cm,
25.4 cm. on the map = 6.35 km. on the ground.
25.4 cm. on the map = 635,000 cm. on the ground.
1 cm. on the map = 25,000 cm. on the ground.
R. F. = $\frac{1}{25000}$.

Had we changed the 6.35 km. to miles we should have found the R. F. to be $\frac{1}{24944.882}$ but this is near enough to $\frac{1}{25000}$ when we make allowance for the error involved in changing from the metric to the

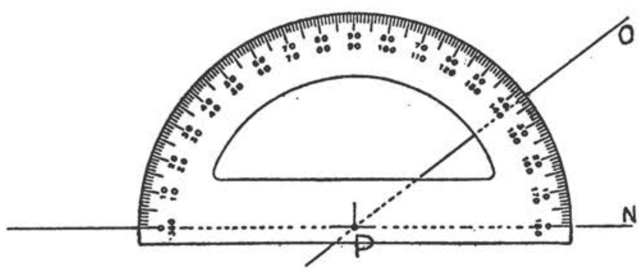

FIGURE 93. Protractor placed to measure the angle OPN.

English system. Allowance must also be made for inexact measurements of distance; so that we generally find the R. F. only approximately.

To find the distance between two places. The distance between two places on the map is 6.4 inches—what is the actual distance in miles, the R. F. being 1 : 20,000?

1 inch on map = 20,000 inches on the ground.
6.4 inches = $\frac{6.4 \times 20000}{63360}$ = 2.2 miles.

TO MEASURE AN ANGLE.

Angles are measured by means of a protractor which is a half-circle of paper, metal or celluloid. On the diameter is printed the center of the circle and the 180 degrees are printed around the semicircumference. To measure an angle: (1) place the *center* of the protractor on the point of the angle, P in Figure 93 and the diameter along one line, P N of the angle, then (2) read the angle in degrees at the point where the other line P O of the angle crosses the semi-circular scale.

The bearing or exact direction of a line is the angle between that line and true north. To determine the bearing of town A from town B, Figure 94, draw a line through A and B and prolong it until it meets a meridian line making an angle. Then measure this angle with a protractor.

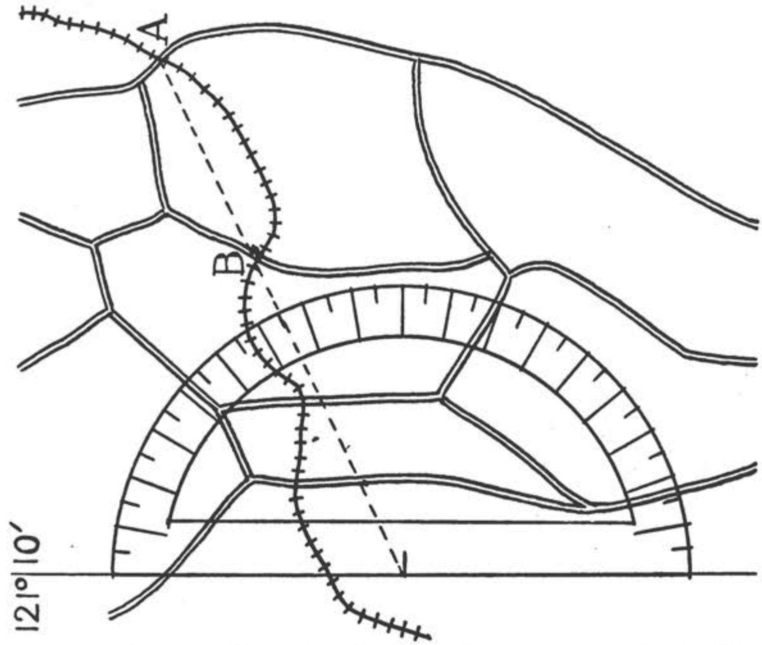

FIGURE 94. Diagram illustrating the use of a protractor in obtaining a measurement of the bearing of a given point on a map.

ENLARGEMENT OF MAPS.

Maps may be enlarged:

1. By means of a pantograph.

2. By photography—a very rapid and serviceable method if the right apparatus is available.

3. By the "method of squares"—the only method requiring no special apparatus. Suppose a map whose scale is 1 : 40,000 is to be enlarged to a scale of 6 inches = 1 mile.

Since 6 inches on map = 63,360 inches on ground,
1 inch on map = 10,560 inches on ground.

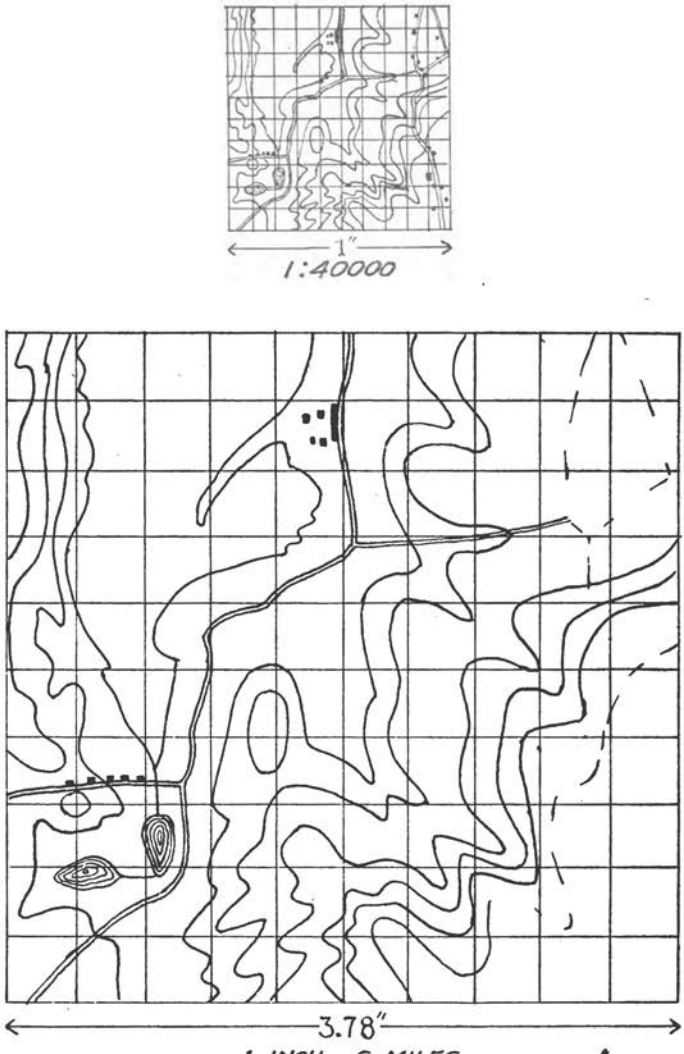

FIGURE 95. Sketch showing the method of enlarging a map by the use of similarly placed squares of different size. (Drawn by Frederick Morris.)

Then the new map will be $\frac{40000}{10560}$, 3.78 times as large as the old one. Rule the old map into convenient squares, say 1 inch or 1 cm. On a large paper rule squares exactly like those on the old map, but with each dimension 3.78 inches or centimeters. On both maps sub-divide

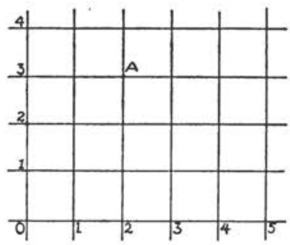

FIGURE 96. French coördinate system, showing method of numbering lines which are 1 kilometer apart.

the squares into the same number of smaller squares, making those of the old map as small as can be drawn conveniently. Then accurately copy the rivers, contours, etc., in each smallest square of the old map, enlarging them to fit each smallest square of the large map. Watch the shape of each curve and see that each line you draw crosses the enlarged squares at the same angle and cuts its side at a corresponding point. (See Figure 95.)

CO-ORDINATE OR GRID SYSTEMS.

Military maps on large scale are marked off in squares whose lines can be numbered or lettered, so that any place on the map can be accurately located by the numbers of the intersecting lines; just as a building can be located in a city by means of intersecting streets. Such

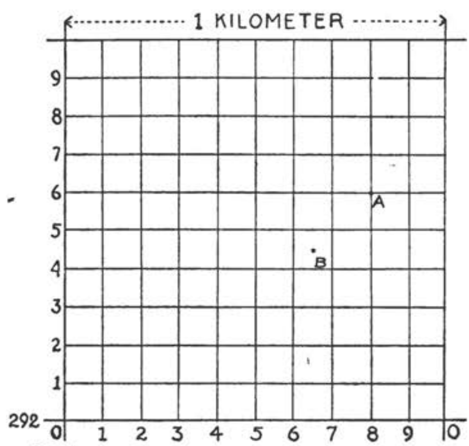

FIGURE 97. Enlargement of a 1-kilometer square of the French coördinate system (see Figure 96), showing method of numbering. The location of A is 2158, 2926, and of B is 21565, 29245.

maps are called *pinpoint maps,* and the index numbers that locate a place are called the pinpoint of that place.

The French war map is divided into squares by a web of lines crossing each other at right angles, one kilometer apart. The "central point" of the system is near Trèves in Germany, the coördinates of which are respectively $x = 500$ and $y = 300$. From this point the grid lines are numbered with decreasing values toward the west and the south. Consequently, any place on these lines can be indicated by two numbers, the first given being the E-W number, the second the N-S number.

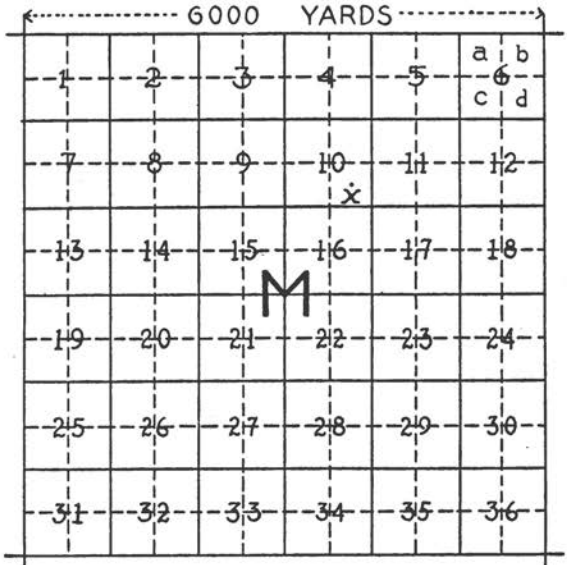

FIGURE 98. One lettered square of the British grid system, showing subdivision into numbered squares and lettered quarters. Position X is M 10 d 55.

Each kilometer of the web is divided into tenths, so that each square kilometer contains 100 smaller squares each 100 m. on a side. (See Figure 97.) These are numbered from the southwest corner which is 0, 0 to 9 toward the E. and toward the N. The W-E number is given first. Thus A, Figure 97, is 2158,2926. Each of the small 100 m. squares can be further sub-divided into 100 squares, so that B, Figure 13, would be 21565,29245, determining the position of B to within 10 meters of accuracy.

Only the kilometer lines are actually plotted even upon the maps of largest scale. The finer sub-divisions must be judged by the eye.

In practice, the large kilometer numbers are replaced by letters, A, B, etc., which are changed every week so that the enemy cannot understand orders or signals if he intercepts them.

The British pinpoint or ***grid system*** divides the map into large rectangles 6000 yards on a side and lettered from W toward E in lines thus:

A B C D E F
G H I J K L

On large scale maps the letter is printed in each corner of the square; on maps of 1 : 40,000 or smaller the letter appears only in the center.

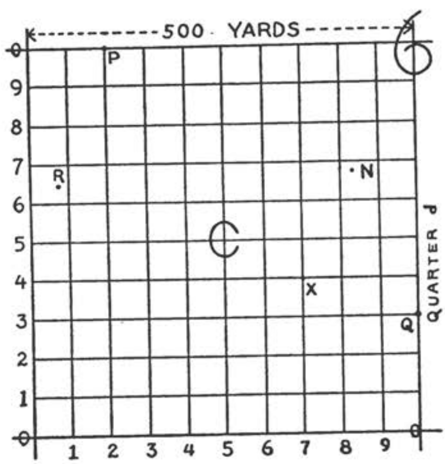

FIGURE 99. Enlargement of quarter c of square 6 of Figure 98. The location of X is M 6 c 74; of N, M 6 c 8368; of R, M 6 c 0765; of P, M 6 a 20; of Q, M 6 d 03.

(See Figure 98.) Each square is divided into 36 smaller squares, each 1000 yards on a side and numbered from left to right, beginning in the N.W. corner. Each of these is again divided into quarters 500 yards square, called by small letters a, b, c, d. Each lettered quarter is again sub-divided into 100 small 50 yard squares, numbered, as in the French system, from the southwest corner of the quarter (see Figure 99); the first number given is the number of the W-E line, then the one on the S-N line. Thus if the area represented by Figure 99 is quarter c of square 6 of large square M (Figure 98), the pinpoint of x would be M 6 c 74; that of n would be M 6 c 83, 68; that of r would be M 6 c 0, 765.

The British system locates points to within 5 yards of accuracy when used with maps of largest scale. To make the British grid system approximately match the French kilometer-web, some of the "rectangles" are not made square, but are 5000 by 6000 yards, and are divided into 30, instead of 36, squares of 1000 yards. Since the meridians of a map converge toward the north and the parallels are mapped as arcs of circles, the grid systems will not quite fit the true N-S and E-W lines.

DETERMINATION OF GRADE AND VISIBILITY.

GRADE.

The grade of a road is the steepness of slope of that road. It may be expressed in three ways:

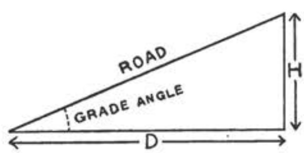

FIGURE 100. Diagram showing how the grade of a slope is obtained from height and horizontal distance. The grade is height divided by distance.

1. By the *grade fraction,* in which the numerator, usually 1, is the height the road ascends in the horizontal distance represented by the denominator. Thus a grade of 1/15 means that the slope ascends 1 foot in every 15 feet of horizontal distance. (Figure 100.)

2. By the *grade percent.* This is merely the grade fraction changed to per cent. Thus 1/15 means a 6⅔ per cent. grade.

3. By the *grade angle,* which is the angle between the slope and a horizontal plane. The grade fraction is the tangent of the grade angle, so that one can easily find the angle from the fraction by means of a slide rule or a table of natural tangents.

To determine the grade by means of a contour map: 1. Choose a place along the road where the grade is uniform, that is, where the contours crossing the road are *equally* spaced. If maximum grade is required, choose the place where the contours are closest together, yet *uniformly* spaced. The result will be wrong if the spaces between the chosen contours are unequal, for then several different grades are involved. (See Figure 101.) 2. Read the vertical height in feet between the selected contours. Call this H. 3. Measure in inches the distance along the road between the selected contours. By means of the R. F., change this distance into feet and call it D. 4. Divide $\frac{H}{D}$, and reduce it to per cent., or to a grade fraction with numerator 1.

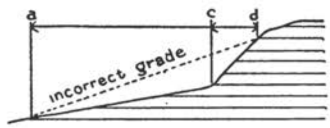

FIGURE 101. Diagram illustrating the method of finding the grade from a map. If the distance a-d is chosen the result will be incorrect because the grade is not uniform. The steepest uniform grade is c-d.

VISIBILITY.

General Problem.—The following questions may require answers: 1. Can a helio-signal be sent from the hill A to hill B? Can the railway station at X be seen from the hill A? 2. What areas of country would be visible to a man stationed on the top of hill A? 3. Can troops lie concealed on hill A, especially from aerial observation?

The first type of problem may be solved either mathematically or by a graphic method. In Figure 102 let S be the observer's station and T the target at which he fires or toward which he signals. Let O be an intervening hill which may cut off the view of T from S. That ray of light which just grazes the crest of the obstruction O as it travels to the eye of the observer at S is the lowest ray which the observer can see from beyond O. This is the line SOA. If the height of S be 720 feet, and that of O, 680 feet, then the line of sight is 60 feet lower at O than it is at S. How much lower will it be at A than it is at S?

In the diagram, Figure 102, Sx is the difference in altitude of the line of sight between S and O. Call this h. It is 60 feet in the problem proposed. Sy is the drop in the *line of sight* from S over O to A. Call this H. The horizontal distance between station and obstruction is xO, which we will call d, and that between station and target is yA, which we will call D. Since the two triangles SOx and SAy are similar, their homologous lines are proportional each to each. Then

$$d : D :: h : H$$

The distances d and D can be measured on the map. Assume that we found d = 2.5 inches, and D = 3.2 inches; we found h to be 60 feet; the one unknown quantity is H. Solving,

$$2.5 : 3.2 :: 60 : H, \quad H = \frac{3.2 \times 60}{25} = 76.80$$

That is, the *line of sight* is 76.8 feet lower at the target than it is at the station. Since the altitude of the station is 720 feet you can just see a target at T whose altitude is 720—76.8 = 643.2 feet. Now, read the actual altitude of the target from the map; say it is 620 feet; then the target is invisible by 23.2 feet.

Rules for determining intervisibility of points.—1. Find the difference in altitude between the station and the supposed obstruction. Call this, h.

2. Measure the distance in inches or cm. from the station to the obstruction. Call this, d.

3. Measure the distance in inches or cm. from the station to the target. Call this, D.

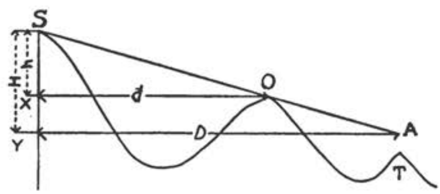

FIGURE 102. Diagram illustrating the determination of visibility of points. SA is the line of sight from station S over obstruction O toward target T, which is invisible.

Required, the difference in altitude between the station and the *line of sight* from station, over obstruction, to the target. Call this unknown quantity, H. Then

$$d : h :: D : H$$

Solve for H and subtract H from the altitude of the station. This will give the *altitude* of the line of sight at the distance D from the station. If this remainder be *greater* than the altitude of the target, the target is invisible. If *less*, the target is visible.

If the target is invisible, then the difference between the altitude of the target and the altitude of the line of sight at the distance D will be the height of a tower needed to render this target visible.

This problem can be solved with the slide rule as follows:

1. On slide C set distance from station to obstruction (d) opposite

2. On scale D, the difference in elevation between station and obstruction (h)

3. On slide C read distance from station to target D and opposite to this

4. On scale D read the difference in elevation between station and the line of vision at the distance D.

Subtract this last reading from the altitude of the station. If the remainder be *less* than the altitude of the target, the target is visible; if *more,* the target is invisible.

There is a graphic method of solving visibility problems, which is of especial service in determining areas of visibility. Upon the map, Figure 103, lay a sheet of paper along the line of sight. Mark along the paper's edge little sharp points where the contours touch the paper and write the elevation of each contour below its point. (See M-P, Figure 103.) Mark also the tops of all hills and the bases of valleys and note their elevations. (On American maps it will be enough to mark only the heavy-brown contours, everywhere except *at the crests* of hills, whose heights must be determined as precisely as possible.)

Lay this strip of paper along a sheet of coördinate ruled paper. Call each smallest space on the paper one contour interval, and put a dot on the profile sheet exactly above each point on the paper slip, and at the height that represents the elevation of that contour or hilltop. Connect these dots with a smooth curve, which will represent the profile of the country.

Now rule upon the profile a line of sight from the station tangent to the top of each hill, prolonging each line until it touches the next hill beyond. These lines determine all the visible and invisible places along that profile and show by how many feet the unseen points fall below the lines of sight.

Areas visible from a station point are determined by the following steps:

1. From the station point, rule radiating lines of sight out across the map (Figure 103, lines 1-2-3-4-5).

2. Plot a profile along each line of sight.

3. Determine all visible and invisible points along each line of sight.

4. Transfer these visible and invisible points back to the lines of sight upon the map.

5. Connect the visibility limits on each line with those on adjacent lines so as to enclose *areas* that are visible or invisible.

6. Shade the invisible areas lightly and smoothly.

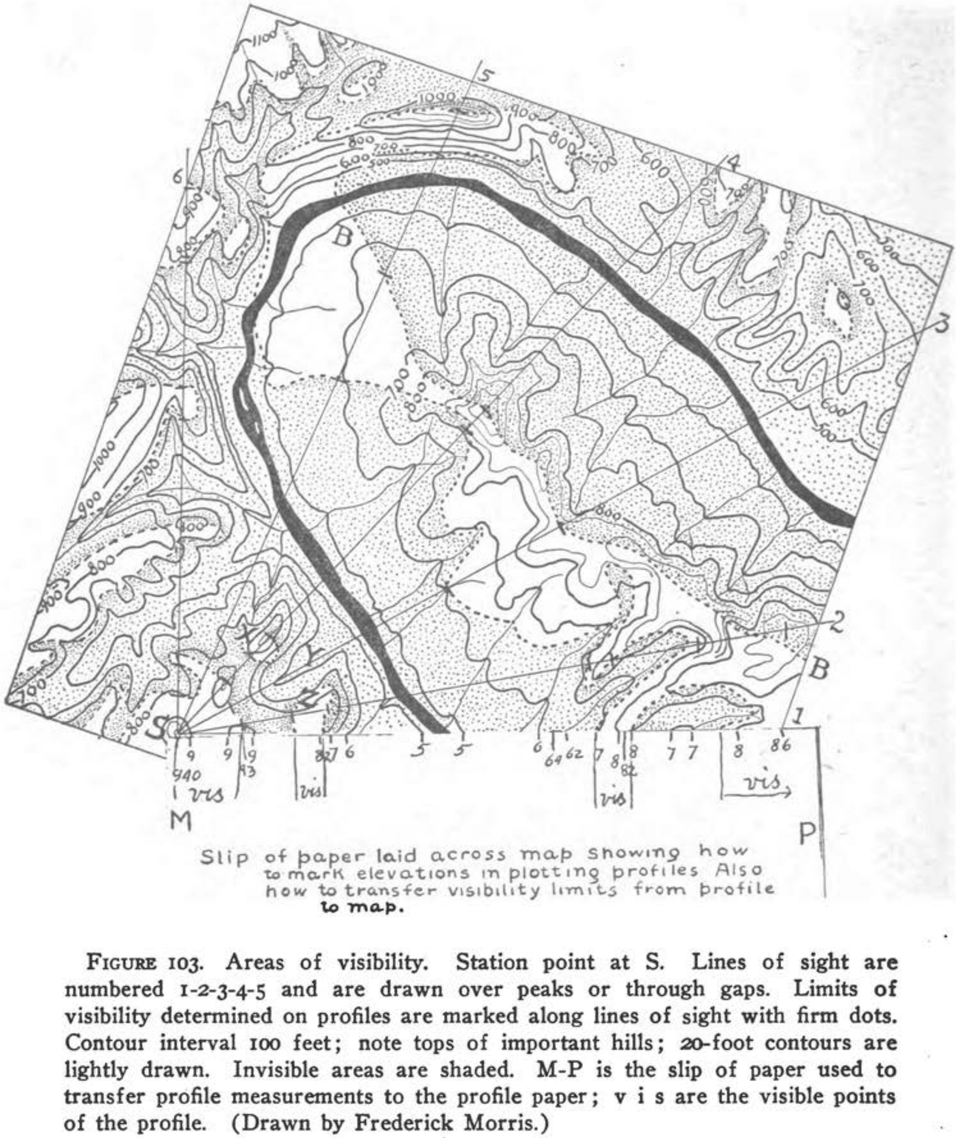

FIGURE 103. Areas of visibility. Station point at S. Lines of sight are numbered 1-2-3-4-5 and are drawn over peaks or through gaps. Limits of visibility determined on profiles are marked along lines of sight with firm dots. Contour interval 100 feet; note tops of important hills; 20-foot contours are lightly drawn. Invisible areas are shaded. M-P is the slip of paper used to transfer profile measurements to the profile paper; v i s are the visible points of the profile. (Drawn by Frederick Morris.)

Precautions:

1. A hill in the landscape conceals the ridges behind it, while a gap or a valley permits some of the country to be seen. Draw your lines of sight on the map so that some pass over the tops of hills and

others through gaps or valleys: then your profiles will determine the maximum and minimum limits of visibility.

2. In connecting the visibility points of adjacent lines, remember that there is on any hill an upper and a lower limit of the visible area. The upper limit is usually the crest line of the hill; the lower limit will be determined largely by the obstructions that lie between that hill and the station point. Thus, in plotting the areas of visibility on the hill B-B, Figure 103, the lower limit of visibility descends across the contours when we look along the line 3 through the deep gap at Y, broadening the visible area; while the visibility boundary rises across the contours toward the lines 4 and 2, where we are looking across

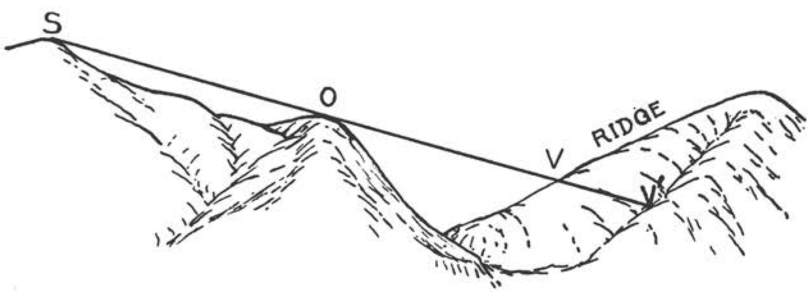

FIGURE 104. Visibility in a valley facing toward the observer. (Drawn by Frederick Morris.)

hills at X and Z. Allowance must also be made for valleys on the hills on which we are plotting. If the valley faces *toward* the observer, S in Figure 104, and the line of sight is slanting downward, the valley will be visible to a somewhat lower contour, V′, than the ridge at V. An upward-sloping line of sight would strike the valley bottom at a higher level than it would the ridge. If the valley lies across the line of sight, the whole valley will be invisible from the crest line of the *nearer* valley wall to some point on the opposite valley, as shown in Figure 103. Thus, plotting of areas of visibility requires a critical study of the topography, both on the hill that is being plotted and on the land intervening between it and the station point.

In this statement of the problem of visibility no account has been taken of vegetation. It is necessary to allow 30 to 80 feet for forests where these are known to exist. Forests, hop-gardens, and other tall vegetation also afford *cover* or invisibility for troops, even from the scrutiny of airplanes.

MAP READING IN THE FIELD.

For use in the field the uncut map, mounted or unmounted, may be creased and folded or the unmounted map may be cut into strips along E-W lines. These strips may then be folded and held in a notebook by means of a rubber band. Preferably the map should be ruled in squares, in indelible ink, and the squares numbered according to either the French or British coördinate system (p. 219). The French web of

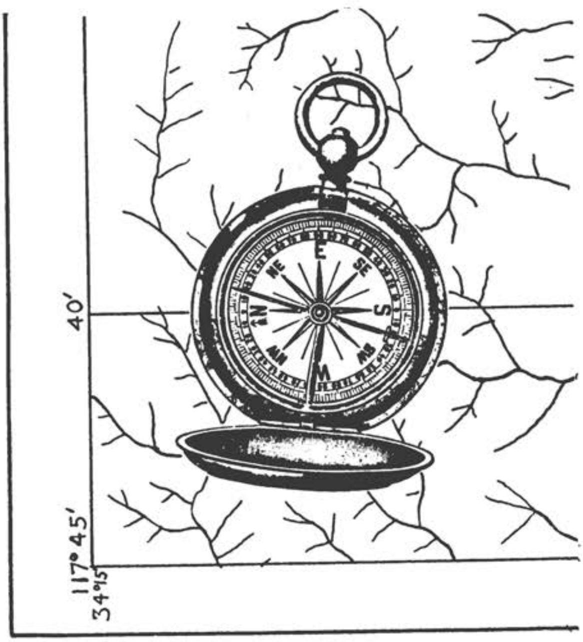

FIGURE 105. Orientation of a map by a compass in California, where the declination is 12° E.

square kilometers is especially well adapted to American topographic maps, and gives training in the use of the metric system.

In route-marching the following rules should be observed:

1. Keep the map always in hand or in sight.

2. Begin to use the map at the place where the march begins.

3. Keep the map oriented so that it lies in just the same position as the country it represents.

4. Watch the country and identify every hill and stream and road and house with its image on the map. Practice estimating heights.

5. Supplement the map by noting new roads, bridges, and houses, especially tall chimneys or towers. Note the kind and condition of roads, the speed of streams, the presence of dense underbrush, forests and open fields.

Orientation.—The map may be oriented by a compass or by a watch.

A. To orient by means of a compass, set the map upon a flat surface, lay the compass upon it, and turn the map until N-S lines upon it lie in a N-S direction. (See Figure 105.)

Precautions: (1) See that the compass is level. This can be done accurately if the compass has a spirit level; if not, level the compass by eye as best you can. (2) Allow for magnetic declination. Since the North Magnetic Pole is in Boothia, Central Northern Canada, the magnetic needles east of Boothia point somewhat westward, and those west of Boothia point a little east of true north. The variation from true north is called the declination, and it must be learned for each place. Even for a given place it varies slightly from year to year. If the declination is 12 degrees to the west, turn the compass box so that the needle points to the mark 12 degrees west on the graduated dial. Then the N-S line in the compass box will be the true N-S line with which to orient the map. (3) The compass is disturbed by electric currents, or masses of iron, or, in some regions, by iron ore in the earth. Avoid these disturbances when you can.

B. To orient a map by means of watch and sun: point the hour hand of a correctly-timed watch toward the sun; then midway between that hour hand and twelve of the dial will be the N-S line. (Figure 106.)

Precautions: (1) In these days during part of the year, all American watches are one hour fast; set back the watch before using it. (2) It is not possible to point the hand exactly toward a sun high in the heavens; hang up a plumb bob, or stick a pencil vertically in the ground, and let its shadow lie just parallel to the hour hand of the watch; then the watch hand points toward the sun. (3) There is nearly always an error in this method, and it may be considerable because watches do not keep the exact time of the local meridian, but an average "Standard" time. A watch set by the sun may be carried.

Intersection.—If an object, such as a tall chimney, is not marked upon the map its position can be determined as follows: (1) Standing at a place whose position is known, orient the map and then lay a ruler, pencil, or any straight-edged object on the map so that it passes through the map image of the known place where you are standing.

Keeping it so, sight along it toward the chimney, moving the ruler until it both runs through the known point and is in line with the chimney. Now rule a line along the ruler. The map location of the chimney will be on this line. (2) Walk to some other known place from which the chimney can be seen, and again orient the map, sight along the ruler, through the map-image of your new station toward the chimney. Rule this line. Where the two lines intersect will be the location of the chimney.

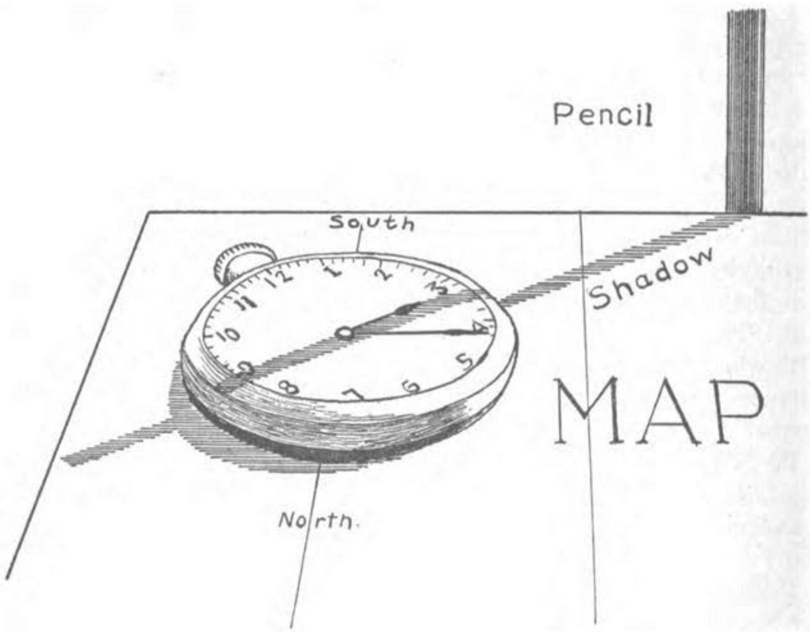

FIGURE 106. Diagram showing method of determining direction by means of a watch. (Drawn by Frederick Morris.)

Resection.—Resection is the process of locating your own position in the field by means of two visible objects whose location is known. (1) Orient the map. Lay a straight edge on the map, with its edge passing through the map-image of a known, visible, object, and sighting along the straight edge, bring it in line with the real objects seen in nature. Draw this line. It passes through your location. (2) Being careful not to move the map, sight in the same way upon another known object, and draw a new line through that object's map-image toward its real self. Where these two lines cross will be your own position.

SECTION II. THE INTERPRETATION OF MAPS.

INTRODUCTION.

Map interpretation is the critical study of a country as revealed by its topographic maps. The facts told by the contours become the basis of logical reasoning by which we deduce the probable structure, geologic history, nature of soil, behavior of streams, and other important data. By map study many problems can be solved without going into the field.

INTERPRETATION OF RIVERS.

GENERAL FEATURES.

In crossing a valley all contours bend upstream. The direction of stream flow is thus indicated (p. 205). On all maps perennial streams are shown by full lines; the American and some foreign maps show intermittent streams as dotted or broken blue lines; and most maps show only a valley for ephemeral streams, that is, those which flow only after heavy rains or melting snows. Ephemeral streams cut many valleys which although usually small may be large and long as in dry regions or among steep, high hills where drainage is rapid (p. 62). At Verdun small valleys of ephemeral streams afforded sloping approaches to the upland for French supplies and for German assaults. They also served as concealed emplacements for guns, cover for men, and barriers of the first order of importance behind which the French awaited attacks, as at Louvemont and Cote du Poivre. (Figures 86, 87.)

The width of a stream is suggested by the width of the blue line. Large rivers are shown by many fine blue lines all drawn parallel to the shore. These lines are merely a form of shading and do not indicate the depth of water.

The gradient of a river is the grade or slope of the river bed, and is measured usually in the number of feet the river falls in flowing a mile. The gradient may be read from a map by noting the number of contours that cross a stream in a given distance, say five miles measured along the stream.

The speed of a river can be read only qualitatively from a map. The speed depends directly upon the gradient, which can be easily read; but it depends also largely upon the volume of water, the character of

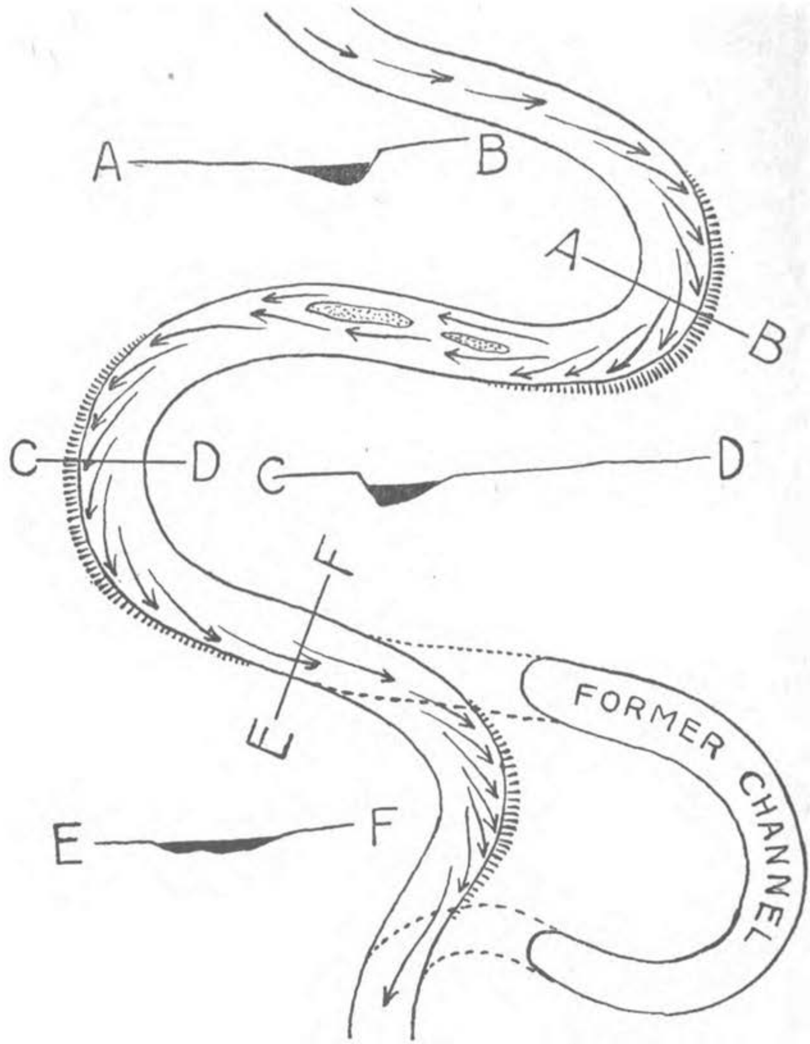

FIGURE 107. Map of a river showing meanders, the process of undercutting banks, and change of course. The sections A-B, C-D, and E-F indicate the form of the channel at different places. (Drawn by Frederick Morris.)

the bottom, and the shape of the channel. In general, a river of steep gradient may be judged a rapid stream, and one of large volume may be fairly rapid despite a slight gradient. The vast volume of the Mississippi enables it to flow fast enough to tear up trees and buildings, but its gradient is less than 1.5 feet per mile for hundreds of miles.

A topographic map of a meandering river shows contours close together on the outside of each bend and far apart on the inside or convex bank. The undercutting continues around the bend and for a short distance down the succeeding straight part of the river. This results from the fact that in rounding a bend the current of a river is thrown against the outside of the bend (Figure 107) and undercuts this bank, making it steep while the opposite bank is more gently sloping (p. 78).

The water is deepest just under the undercut bank. The current crosses from side to side in order to undercut the outside of each bend, and in the straight stretches of the river between two bends neither bank will be undercut and the current will be less strong than at the bend. Shallow water, islands, shoals, gently sloping banks may be found along the straight stretches. Favorable places for fording or building pontoon bridges are thus indicated (p. 78).

TYPES OF RIVERS.[1]

Streams have such widely different behavior and character under varying conditions and at varying stages of their development or history that it is found advantageous to group them for discussion and study. For the particular purposes of this chapter rivers are classified as follows: (1) young rivers, (2) mature rivers, (3) braided rivers, (4) rejuvenated rivers, (5) drowned rivers.

Young rivers.—Young rivers have some or all of the following characteristics, which may be read from a topographic map:

1. Their course is very irregular, as distinguished from the regular, meandering course of a mature river. A straight course is really an irregular course, for a river will develop meander curves as soon as it opens out the initially straight valley.

2. The river bottom is irregular. Instead of an even slope flattening progressively from the source to the mouth, the slope is irregular, uneven, and is marked by rapids and falls, alternating with lakes and stretches of quietly flowing water. Entering a lake, a river deposits its sediment, but a river leaving a lake is generally clear. The map therefore may indicate the quality of water.

Two or more contours crossing the stream at the same point indicate

[1] A list of topographic maps illustrating the features here discussed will be found at the end of this chapter.

a waterfall. In diagram *a,* Figure 108, the contours give the height of the fall almost exactly; in *b,* a fall of the same height appears on the map nearly two contour intervals less than its true height; in *c,* where the fall is less than one contour interval, it is not shown at all. It is generally necessary to mark the fall by some special legend on the map.

In canyons, the river flows swiftly and covers the whole of the

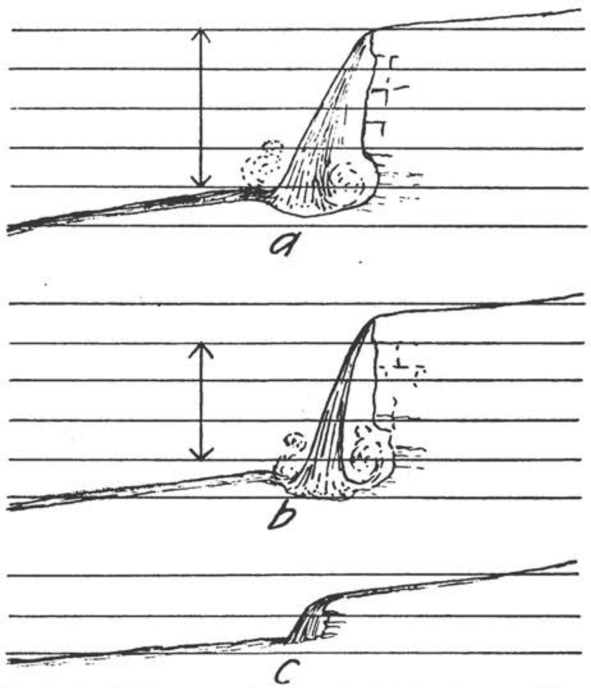

FIGURE 108. A, B, C, Diagrams showing the height of waterfalls, as measured by contour lines. (Drawn by Frederick Morris.)

narrow valley floor. The crowded contours begin at the very water's edge. (See Canyon, Wyoming map.)

Mature rivers.—When a river has drained its lakes, cut back its falls, diminished its gradient, and broadened its valley, it becomes a mature river, like the Missouri River (see Elk Point, South Dakota map) or the Republican River (see Arapahoe, Kansas map). The following characteristics of mature rivers can be read from maps:

1. *Flood plains.*—All mature rivers have flood plains made of loose material deposited by the stream itself. The level land on each

side of the river may be gravel, sand, or fine silt and clay or any combination of these, according to the speed of the depositing stream. Hard rock is not to be looked for until we reach the valley walls, shown by the more crowded contours and the numerous dissecting tributary valleys, of which many are youthful. (See Elk Point, South Dakota, map and Arapahoe, Kansas, map and Figure 34.)

2. *Natural levees.*—When a mature river overflows, it becomes a lake upon its flood plain for the time being and must deposit part of its load. It drops the coarsest sediment close to its banks, where the speed was first slackened, and carries the finest silts out to the edges of the flood plain. Thus the land is higher near the river. (Figure 109.) All mature rivers build these natural levees, but they are too

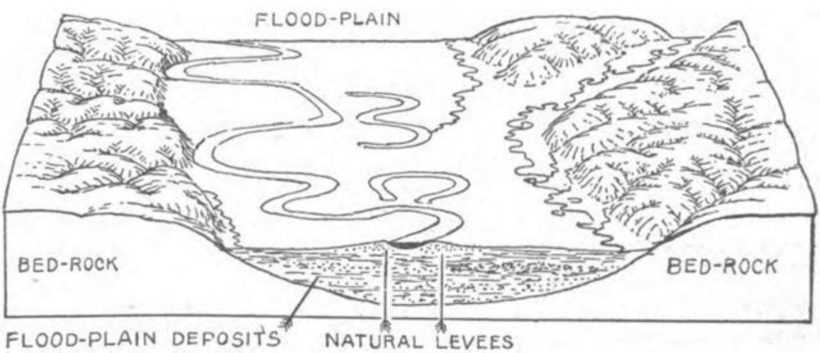

FIGURE 109. Diagram showing flood-plain deposits and natural levees. (Drawn by Frederick Morris.)

low to be shown by twenty-foot contours. (See Donaldsonville, Louisiana, map.) But tributary rivers entering the flood plain are barred from the master stream by the natural levee and so run parallel to it down the outside edge of the flood plain for some distance before joining the main river. (See Elk Point, South Dakota, map.) This position of tributaries shows the presence of a levee.

3. *Changes of course.*—Mature rivers take a winding course, swinging from side to side in curves called meanders. As the river undercuts the outer bank and builds the inner one (Figure 32) it enlarges the meander until a maximum size is reached. (Figure 33.) The size of the meander is roughly but still definitely related to the volume of the river. (Compare the meanders of the three mature rivers on the Elk Point, South Dakota, map.) At time of high water the river may break across the narrow peninsula of soft sediment enclosed by

the meander and so temporarily straighten its course, leaving the cut-off meander as a loop-shaped water body, called an *oxbow lake*. The bank of each oxbow lake is part of the old natural levees, so that in course of time the flood plain of a large river becomes covered with many ridges parallel to old oxbows that have dried away to swamps. (See Mound, Louisiana, and Little Rock, Arkansas, maps.) (Figure 109.)

Mature rivers are especially strong military barriers. They are the largest of true rivers; their open flood plains afford no concealment, except for forests. An assailant must cross both flood plain and river, impeded by the oxbows, swamps, and tributaries, and facing the danger of floods and of sudden changes of course. The defenders put their front trenches along the natural levee and their

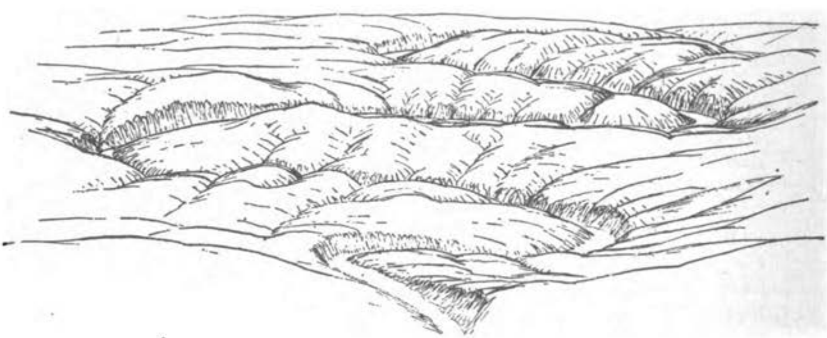

FIGURE 110. Sketch of the Potomac River near Pawpaw, Md. A rejuvenated river with deeply intrenched meandering course, narrow valley, and many tributaries. (Drawn by Frederick Morris.)

artillery if possible on the high land at the outer edge of the flood plain. In the invasion of Roumania the Danube formed a barrier more impassable than the Transylvanian Alps.

Braided rivers.—When a river passes from a highland to a plain its speed is checked. If it carried sediment in the highland it must deposit some of it along the course of the stream. So much may be deposited that the river becomes shallow and the water breaks up into many minor channels that separate and join again (p. 81). On the map such a river looks like braided hair. The braiding may develop within the mountains, especially in glaciated regions.

The Isonzo, Livenza, Tagliamento, and Piave rivers are braided rivers passing into meandering rivers in their lower reaches. Braided rivers are extremely formidable barriers in war time; their shifting gravel and sandbars, many and treacherously changing channels, total absence of cover for advancing troops, and liability to sudden torrential flooding place them in the first order of natural defenses. (See Anaheim, California, and Lexington, Nebraska, maps.)

Rejuvenated rivers.—If a country be uplifted by a movement of the earth's crust all the rivers will find their speed increased, and all will deepen their valleys, cutting narrow trenches as the land rises. A meandering river will cut a meandering gorge and will thus have the steep slides and narrow valley floor of a young river with the meanders and numerous tributaries of maturity. (Figure 110.) All the main rivers of northern France are such rejuvenated (made-young-again) rivers. In the first great battle of the war the winding trenches—the deeply entrenched meandering valleys of the Meuse and Sambre rivers—served as a system of trenches. The Somme, Aisne, Marne, and Meuse have somewhat widened their floors and are again becoming mature rivers. Along a typical rejuvenated river there is very scant room for roads, yet the country, cut by thousands of deep tributary valleys, is so difficult for traffic that the main arteries parallel the river. (See Figures 86 and 110.) See Brownsville, Pennsylvania, map, Harrisburg, Pennsylvania, map, and Pawpaw, Maryland, map.)

Drowned rivers.—If a coastal region is submerged the sea will fill the lower parts of nearby river valleys and their tributaries, converting them into broad bays with many branches. (Figure 80.) Chesapeake Bay, Hudson River and the mouth of the Seine are such drowned river valleys. Along the depressed north coast of Europe, submergence has occurred within historic times and the people of Holland, Belgium, and northern France have built dikes to keep out the sea. The drowned rivers are diked along each side, convering them into canals, and have seagates which are opened at low tide to let the water out. (See Nomini, Maryland, map.)

By cutting the dikes and opening the seagates the Allies have redrowned part of Belgium, thus barring the advance of the Germans.

INTERPRETATION OF UNDERGROUND STRUCTURE.

From a topographic map, which is primarily and almost exclusively concerned with the representation of surface facts and features, it is always possible to deduce some conclusions as to the kind and condition of the surface and the character and attitude of the underground rock. Structural features are discussed in Chapters I and VI. The present purpose is to show what structures in undisturbed rocks and in deformed rocks can be inferred from a study of topographic maps.

ROCK STRUCTURES IN GENERAL.

In a region of horizontally lying stratified rock, streams find themselves cutting the same rock stratum over a wide area. Their courses may therefore be lengthened by headward erosion with equal ease in all directions. The pattern of the resulting stream system will be

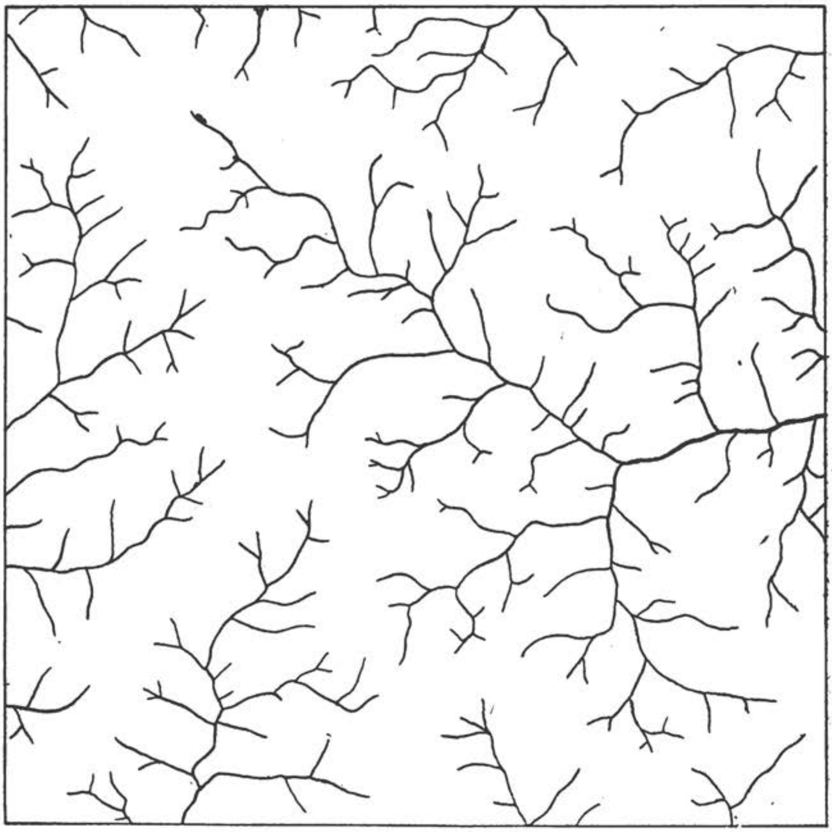

FIGURE 111. Map of part of the Barclay, Md., topographic sheet showing dendritic drainage.

like a tree with twigs and branches extending in all directions. (Figure 111.) But if the rocks are tilted so that the edges of the layers come to the surface in succession, then each rock stratum will form the surface over a zone which may be broad or narrow according to the steepness of the tilt of the rocks and the thickness of the rock stratum. Scarcely any two strata are of quite equal hardness, and it follows that the stream will encounter least resistance when cutting soft strata and most resistance upon the hard layers. Those streams which by chance were located upon soft strata become long, master streams to which short tributaries flow down from the hard strata. A rectangular pattern of drainage, called a *trellis* pattern, develops in such a country. In judging the structure of a country from its maps the stream pattern is one of the first things to be noted. (See Figure 72.)

REGIONS WITH ESSENTIALLY HORIZONTAL ROCKS.

Plains underlain by flat-lying rocks are indicated on topographic maps by treelike stream patterns and valleys of moderate depth. Such regions have broadly rolling surface, all parts of which are accessible. (Barclay, Maryland, map; Conde, South Dakota, map; and Sandy Hook, New Jersey, map.) The rock strata of some plains dip very gently. The surface of such plains is broken by steep slopes where successive layers come up to the surface (p. 172). If the rocks lie horizontally but the relief is great, with deeply incised valleys, the region is called a plateau.

Topographic maps of plains and plateaus show similar stream patterns, which indicate similar rock structure on plateaus. Hard rocks in a plateau may appear as cliffs and the softer layers as slopes. Where soft rocks are worn away from the flat surface of an underlying hard layer, the harder rock will appear as a nearly flat terrace. On a contour map crowded contours appearing at the same level at many places along the valley walls indicate cliff-like outcrops of hard rocks; more widely spaced contours indicate the sloping outcrops of softer rocks; and the absence of contours, just above a steep descent, indicates the surface of an exposed hard layer.

Stream dissection in a true plateau region may result in cutting off hills at the edge of the plateau. Such isolated hills are known as *outliers*. Small outliers are called *buttes;* flat-topped outliers of large area have received in America the name *mesas*. On the contour map outliers appear as small regions of closely crowded and completely closed contours, indicating an abrupt rise above the surrounding lowland to nearly or quite the height of a near-by plateau. From the butte at Ornes north of Verdun the Kaiser observed the unsuccessful attempt of the Brandenburgers to ascend the steep slope of the upland at Fort Douaumont. The mesa of the Chemin des Dames is an outlier of the Rheims-Soissons upland. Noyon is defended by two small mesas and the fortress of Laon, stubbornly held by the Germans, is a butte of limestone.

On masses of granite or other firm crystalline rock of uniform structure a tree-like stream pattern and very rugged relief may develop as in a region of horizontally lying rocks, but terraces will be lacking and the cliffs will not recur at the same levels around the hills.

Plateaus with flat tops are uncommon. Parts of the Appalachian plateau developed on sedimentary rocks are carved into sharp ridges; on the other hand, the top of the Schwarzwald in Germany, a mass of crystalline rocks, is nearly level on top.

REGIONS WITH TILTED OR FOLDED ROCKS.

GENERAL FEATURES.

Trellis or rectangular stream patterns may result from tilting or folding of rock strata or from faulting that breaks bedded rocks and massive rocks into huge blocks and tilts them at various angles.

The angle of inclination of a tilted bed of rock is called the *dip*. A dip of 20° W. means that the strata plunge down into the earth westward at an angle of 20 degrees from the horizontal. (See Chapter I.) If the rocks are dipping westward, the upturned edges of the hard layers project out of the earth toward the eastward and there break off, forming a cliff facing eastward, and gentler slope facing westward. On a topographic map a hill formed of tilted strata will have crowded contours on the cliff side and more widely spaced contours on the side toward which the rock dips. If the dip be very steep (it may be vertical) both sides of the hill may be almost equally steep, but the long parallel lines of hills with parallel valleys between still proclaim bedded rocks. On the other hand, the beds may be tilted so slightly that a dip slope is not indicated on the map, for a single bed may cover hundreds or even thousands of square miles. In such a region the upland may have treelike drainage and resemble a plateau, while the lowland developed upon soft rock layers between the hard rock uplands may resemble a true plain with low relief and treelike drainage. But the dip is betrayed by the fact that the upland terminates in a more or less abrupt scarp looking down upon the lowland. (Figure 65.) Furthermore the streams that dissect the dip slope of the upland are longer and have gentler gradients than the streams descending the scarp.

In northeastern France from Laon and Mézières southward past

Epinal the strata dip very gently westward, giving a series of alternating uplands and lowlands. The uplands are plateau-like and are deeply dissected and difficult to traverse. Each upland ends in a ragged scarp, steep slope rather than cliffs, which face eastward against a German advance. The gentler westward-facing slopes are favorable for roads over which supplies may be brought. Of the four great fortified camps that defend the French frontier, three—Rheims, Verdun, Epinal—depend for their strategic value upon the uplands developed upon slightly tilted rocks. (See Figure 38.)

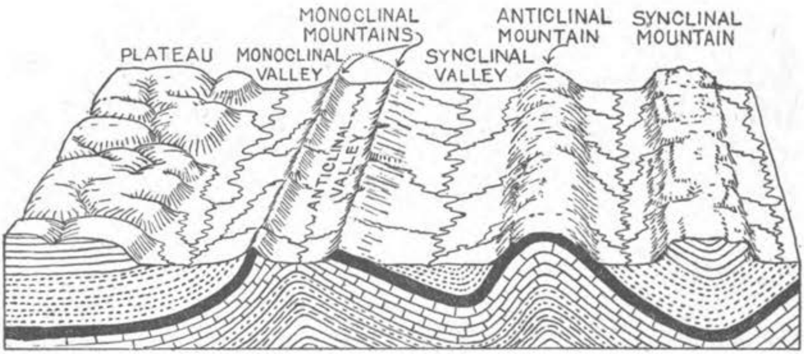

FIGURE 112. Diagram showing anticlinal, synclinal, and monoclinal mountains and valleys. (Drawn by Frederick Morris.)

The relation of tilted rocks to problems of water supply, drainage, and tunneling is discussed in Chapters I and V.

Rock strata may be folded and afterwards eroded to such an extent as to form an almost level plain, a *peneplain* (p. 182). Such a peneplain is formed by cutting off the upturned edges of the strata as with a giant scythe. The soft and hard rocks are worn to essentially the same level. When these regions of folded and beveled rocks are uplifted, the rejuvenated master rivers cut narrow gaps through the hard rocks, while their tributaries open broad valleys on the belts of soft rock. The hard rocks therefore become hills and the soft rocks valleys quite regardless of the original structures. (Figure 112.) Dependent only upon the hardness of the rock there may be developed synclinal or anticlinal mountains, synclinal or anticlinal valleys, and ridges and valleys in which all the strata dip in one direction. From the ridges the remnants of a level erosion surface may be seen.

PITCHING FOLDS.

All folds pitch or plunge gently downward into the earth and the eroded outcrop of a plunging fold forms a parabola or "hairpin curve" on the earth's surface. (Figure 113.) The pitch of a fold is the angle of inclination of the axis of the fold. (Figure 113.) A pitching anticline, beveled by erosion, outcrops in a parabola-shaped curve whose nose points in the same direction as the pitch. A pitching syncline similarly eroded forms a curving outcrop which points opposite to the direction of the pitch. (Hummelstown, Pennsylvania,

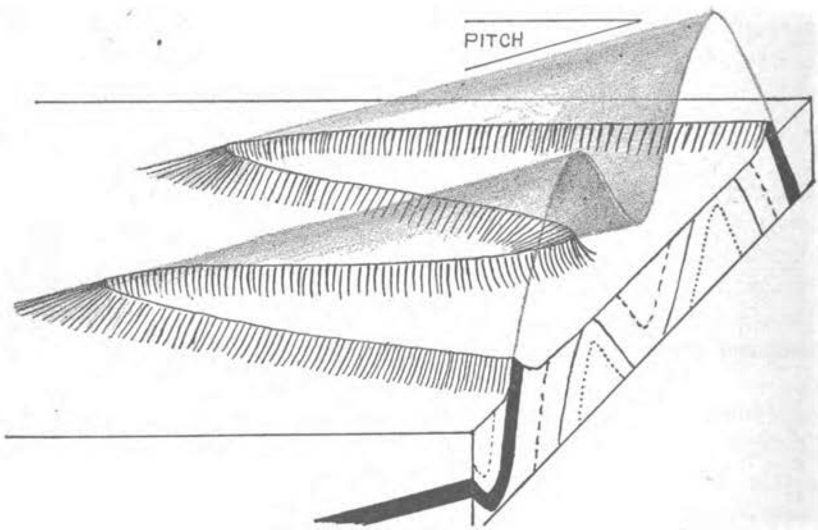

FIGURE 113. Diagram showing pitching folds. (Drawn by Frederick Morris.)

map; Harrisburg, Pennsylvania, map; New Bloomfield, Pennsylvania, map, to be used in combination; Lykens, Pennsylvania, map; Everett, Pennsylvania, map.)

During the process of erosion the soft layers are stripped off from the harder ones, exposing the surface of the folded hard layer along the axis of the fold. The slope downward along the pitch will be gentle, but the upward projecting edge of the hard stratum forms a cliff-like slope. For example, if the pitch of a fold is south an anticline erodes to a parabola pointing *south;* the gentle slope of the hard strata in the very axis of the parabola will face southward and the steep slope northward. A syncline erodes to a parabola pointing ***north*** with gentle slope facing southward and the steep slope northward, as in the anticline. The steep slope will be on the inside of the parabola in the anticline, and on the outside in the syncline. The gentle slope will be on the outside of the parabola in the anticline, and on the inside in the syncline. Figure 113 shows these relations and suggests how the arrangement of contours and streams enable one to determine the type of fold from a map. (Everett, Pennsylvania, map; Hollidaysburg, Pennsylvania, map.)

In strongly folded rocks like those of the Appalachians and the Jura Mountains the ridges form natural fortresses protecting natural highways in the soft rock valleys between. The river gaps cut through the hard rock ridges and form gateways. Mountains of folded rock are not at present included in the war zone, but if "military necessity" led Germany to violate Swiss neutrality, her troops might push through parallel valleys in the folded Jura Mountains and enter France through the gaps of the Doubs and other rivers to the rear of the great fortress of Belfort.

DOMES.

Strata may be up-arched into gentle domes, so that they dip into the earth in all directions outward from a center. (Figure 68.) The crest of the dome is the first part to be eroded away, thus exposing the lower strata. Each hard stratum, dipping outward, forms a cliff that faces inward. If the central rock is harder than the outer strata a dome mountain develops, that is, a mountain ringed by parallel circles of ridges and valleys and drained by radiating rivers descending the central dome and cutting their way through the ridges. If the central rock be softer than the outer strata it will weather away and form a basin overlooked by cliffs of the harder rock. The famous Saar coal basin in annexed Lorraine has this structure. With these principles in mind the structure of dome mountains may be determined from a topographic map. (Meeteetse, Wyoming, map; Oregon Basin, Wyoming, map.)

REGIONS WITH BLOCK FAULTING.

Both bedded rocks and crystalline massive rocks may be faulted, that is, split and tilted upward, or even shoved over one another for miles by great mountain-making forces (p. 31). In regions where the crust has been broken into great blocks which are tilted upward, the rock along the lines of break crushed by the movement of the faulting rock masses may be zones of weakness which the streams search out and erode into valleys. Streams may run along the foot of the fault block and others may be looked for lying more or less parallel to or branching from the main fault. (See Schroon Lake, New York, Thirteenth Lake, New York, or Indian Lake, New York, maps.)

Fault block regions may thus have a trellis drainage-pattern but without the long continuous ridges that tilting or folding of bedded rocks produce. As shown on a topographic map the mountain masses are short and blocklike and the valleys though somewhat parallel are not in line with each other as they are in regions underlain by bedded rocks.

The tilted blocks show a steep face at the line along which the splitting and elevation took place and a gentler slope downward away from the fault. The crest of the range lies at the top of the steep slope and near to the fault line. (Figures 76 and 77.) The Vosges and Schwarzwald mountains are typical fault blocks; their steep faces look down upon the flat Rhine Valley; their gentler slopes dip away from the Rhine. (Figure 78.) (Disaster, Nevada, map, Tonopah, Nevada, map, Schroon Lake, New York, map, Indian Lake, New York, map.)

INTERPRETATION OF LOOSE EARTH STRUCTURES.

ALLUVIAL FANS.

Alluvial fans are built by rivers issuing from mountains upon lowlands. They are low, cone-shaped heaps, steepest near the mouth of the valley, and sloping gently outward with ever-decreasing gradient. The fan built by the Tagliamento river, Italy, is a good example (Figure 114). On alluvial fans the contours bend outward in strong smooth convex curves like arcs of circles whose common center is just within the valley mouth as it opens from the mountains upon the lowland. The stream rushing out over this fan commonly breaks up into many distributing channels that spread the water widely, thus favoring the construction of a symmetrical cone (p. 192). The most fertile soil is near the foot of the fan, and here therefore the villages and farms are grouped. (Cucamonga, California, map.)

DELTAS.

Where a river empties into the sea or into a lake it drops its load of silt and may build up a delta, a flat-topped mound, rising to or just above the water level (p. 192). The topographic map shows numerous swamps and lakes and many distributing river branches on delta lands. These distributaries often overflow, building natural levees which form the highways on the delta. Contours are almost lacking unless a very small contour interval is used. (Forts, Louisiana, map; East Delta, Louisiana, map.)

TALUS.

At the foot of cliffs talus slopes of fallen fragments accumulate burying the foot of the cliff and in many places reaching far up the

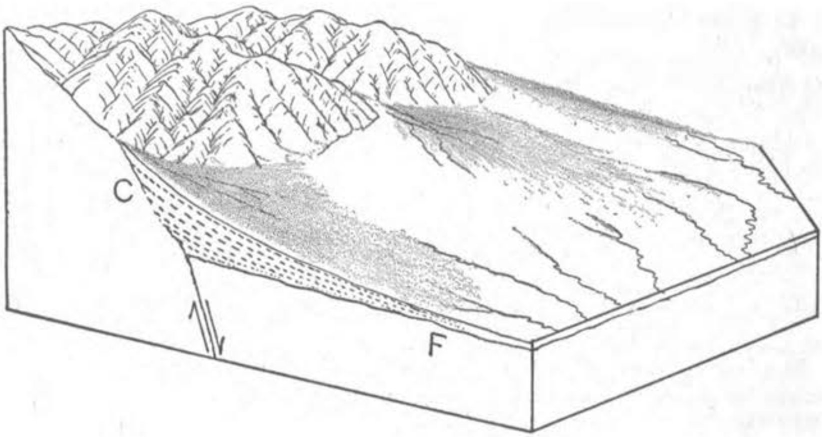

FIGURE 114. Diagram of alluvial cones, showing surface and underground structure. (Drawn by Frederick Morris.)

cliff face. The slope varies according to the size and shape of the fragments, being gentle where the fragments are soft or rounded and steep for hard angular blocks. The grade ranges from 12 degrees to over 30 degrees and is everywhere steepest near the cliff. On topographic maps the talus is shown as a series of contours parallel to the cliff. The contours appear farther apart as they descend and are indented at places where small stream gullies occur. Interpreting these contours to mean talus one expects a steep, difficult ascent with material ready to slip and roll and with the possibility of landslides. The foot of a high talus slope is an unsafe place to camp. (Figure 60 and p. 50.) (Chapter I.)

GLACIAL DRIFT FORMS.

Moraines.—During the glacial period great sheets of ice formed upon Europe and North America and spread slowly outward from the centers of accumulation. The sheet was thick enough to fill up river valleys and override mountains of medium height. The ice froze soil and boulders into its mass and carried them forward. When the ice melted, all of its contained debris was dumped on the surface of the ground (p. 15). At the edge of the ice sheet the material was deposited in roughly defined zones. These are the terminal moraines of the glacier. They consist of irregular mounds and hillocks and innumerable lakes and swamps as irregular as the hills. (See Figure 115.) (Minneapolis, Minnesota, map; Whitewater, Wisconsin, map; Staten Island, New York, map.)

In warfare the hills and hollows of a moraine give infinite combinations of shelter and advantageous domination. The loose earth is easy to trench, so that elaborate defenses can be rapidly constructed;

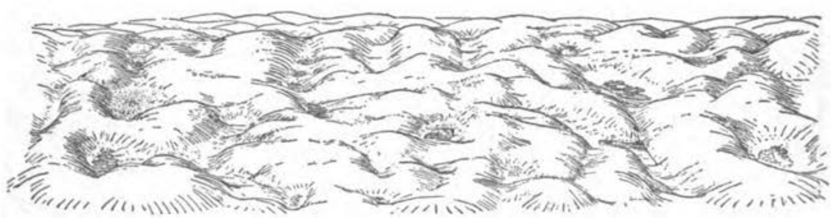

FIGURE 115. Bird's-eye view of about 2 square miles of terminal moraine. Lakes are shown by horizontal shading; swamps are dotted. (Drawn by Frederick Morris.)

advance over such a terrain is difficult and rapid retreat almost impossible. A belt of moraine country in East Prussia afforded a better protection to Germany than did the Carpathian Mountains to Austria, while Rennekampf's retreat through those lakes and swamps proved the ruin of his army.

Outwash plain.—Water from the melting ice washed gravel, sand, and silt out beyond the terminal moraine and built a series of broad, low alluvial fans called the *outwash plain.* These smooth stretches of sandy country make excellent camp-sites and airplane landing-fields. Camp Upton and Camp Mills have been built upon the outwash plain of Long Island. (Hempstead, New York, map.)

Drumlins.—The ancient glaciers like modern rivers became loaded at times with more material than they could carry and for many miles behind the terminal moraine deposited debris as they moved. And as a river builds sand bars in its bed, elongated in the direction of river flow, so the ice built smoothed ridges of glacial drift with their long axes parallel to the movement of the ice. Such elongated mounds of debris are known as *drumlins*. (Figure 116.) The map shows them as oval contoured hills, many of them twinned, that is, two or more lie side by side and share the same contours about their bases. Associated with drumlins are swamps and small lakes and irregular sluggish streams. Drumlins may have a core of rock; most of them are made of glacial drift, that is, clay, sand, and boulders commingled. (Weedsport, New York, map.)

Both within and behind the terminal moraine the melting ice formed streams which deposited sand and gravel in small irregular hillocks known as kames. In some places the stream carried its sediment into local lakes and built kames with flat tops and lobed front margin resembling deltas. Most kames are composed of well-washed, irregularly bedded gravel and are an important source of materials for road material and concrete aggregates. (See Chapter I.)

FIGURE 116. Sketch of a landscape showing drumlins with associated swamps and ponds. (Drawn by Frederick Morris.)

GLACIAL FEATURES IN MOUNTAINS.

Most high mountains have been carved by streams of ice. In some of them glaciers are still at work; in others, like the Vosges, the glaciers have disappeared. Ice carving has produced *matterhorn peaks, cirques* and *troughs* which are clearly expressed on topographic maps. (Figure 117.) Matterhorn peaks are shaped like hollow ground pyramids. Their contours bend inward on the sides of the pyramid, and sharply outward at the corners which are prolonged as high, narrow mountain walls called *arêtes*. In the Tyrol, the noun "wandt" is often compounded in local names of peaks, as Himmelwand and Hohewand, referring to their wall-like character. Mounts Cristallo, Pomagagnon, Nero, Adamello, and Pasubio are among the matterhorn peaks made famous by exploits of the Italian Alpini.

Cirque.—A cirque is a hollow, shaped like a Roman armchair. (Figure 117.) It is bowl-like, open in front, and its back and sides are formed by arêtes which rise like arms. In interpreting the map the cirque may be pictured as surrounded by bare, nearly smooth rock walls hundreds or even thousands feet high. Such walls present formidable obstacles, but some of them have been climbed by Alpini in their string-soled shoes. In the bowl of the cirque there is commonly a small round lake or tarn.

Glacial trough.—Leading down from the cirque is a *glacial trough,* a flat-floored valley with extremely steep sides and a cross section like the letter U. (See Figure 79.) As shown on topographic maps

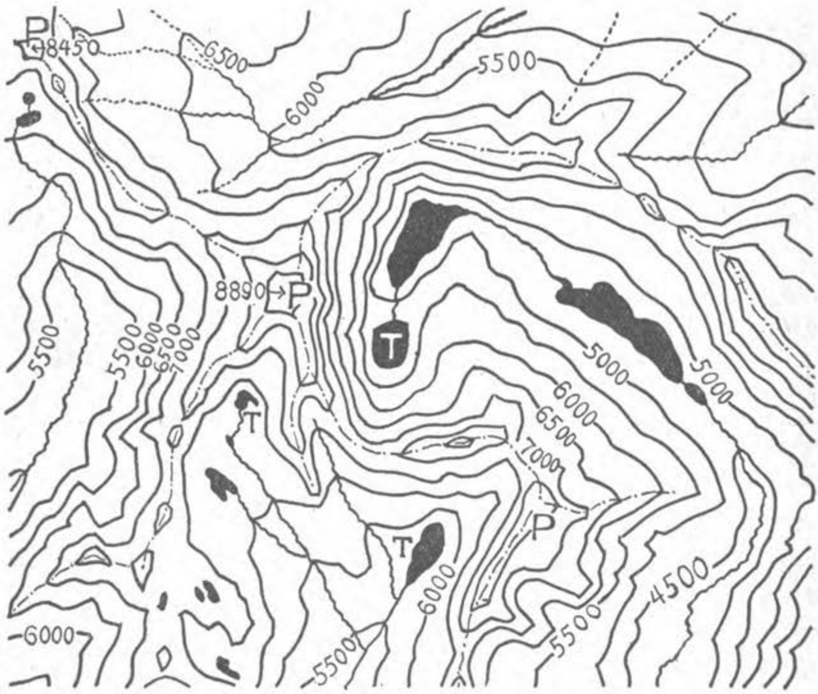

FIGURE 117. Map of Longfellow Peak, Mont. Contour interval, 500 feet. P = peak. T = tarn. — . — . — . = arête.

glacial troughs are remarkably straight, their walls are precipitous and their floors may include lakes. In the Tyrol some glacial troughs are more than a mile wide with walls rising almost sheer thousands of feet and are occupied by braided rivers. Some of these enormous valleys have received separate names. Thus the Brenta river flows through the Val Sugana and the trough of the Adige river is known as the Val Lagarina in the Trentino and the Vintschgau in the Tyrol.

Roads must ascend such valley walls by winding back and forth to reach the hanging tributary valleys, and to invade a glacial trough the assailant must gain control, not of the valley floor, but of the almost inaccessible upland on each side. In trying to overcome the difficulties of an Alpine terrain the Italians built serpentining roads up the sides of the troughs, harnessed the hanging-valley cascades to produce electric power, and crossed the U-shaped chasms by means of filori or teleferica, aerial railways.

PIEDMONT FORMS.

At the foot of great mountain ranges we find special combinations of land forms to which the general name Piedmont is given. One type of Piedmont forms is well developed in the war zone. On the Italian side of the Alps the mountains end abruptly and the plain begins with a series of alluvial fans. Braided rivers which lead out across the fans become meandering rivers upon the almost level plain below. In some places glaciers formerly extending down to the plain, and loop-moraines, some enclosing lakes, have been built out from the valleys, and moraine-hills rise above the fans. (Cucamonga, California, map; Anaheim, California, map.)

LIST OF TOPOGRAPHIC MAPS.

The following maps illustrate the types of land forms discussed in this chapter. The price of each map is ten cents, or six cents when ordered in lots of 100 or more. They may be obtained from the Director, U. S. Geological Survey, Washington, D. C.

Young rivers:
- Canyon, Yellowstone Park, Wyoming.
- Niagara Falls, New York, or Niagara Gorge, 1:12,000, 36 cents.

Mature rivers:
- Arapahoe, Kansas.
- Elk Point, South Dakota.
- Little Rock, Arkansas.

Flood plain studies:
- Donaldsonville, Louisiana.
- Mound, Louisiana.

Rejuvenated rivers:
- Brownsville, Pennsylvania.
- Harrisburg, Pennsylvania.
- Pawpaw, Maryland.

Drowned rivers:
- Wicomico, Maryland.

Braided rivers:
- Anaheim, California.
- Lexington, Nebraska.

Plains:
- Brandywine, Maryland.
- Barclay, Maryland.
- Conde, South Dakota (Young).
- Sandy Hook, New Jersey (Belted coastal).

Plateaus:
- New Berlin, New York.
- Oceania, West Virginia.

Inclined strata:
- Paterson, New Jersey.
- Fort Collins, Colorado (Steeply tilted).
- Schoharie, New York (Gently tilted).
- Niagara Falls, New York (Gently tilted).
- Sandy Hook, New Jersey (Gently tilted soft strata).
- Hanna, Wyoming.

Folded mountains:
- Chattanooga, Tennessee.
- Hummelstown, Pennsylvania. } To be used together.
- Harrisburg, Pennsylvania. } To be used together.
- New Bloomfield, Pennsylvania. } To be used together.
- Lykens, Pennsylvania.
- Everett, Pennsylvania.
- Little Rock, Arkansas.

Dome mountains:
- San Rafael, Utah.

Dome basins:
- Meeteetse, Wyoming.
- Oregon Basin, Wyoming.

Fault blocks:
- Ramapo, New York.
- Tonopah, Nevada.
- San Pedro, New Mexico.
- Schroon Lake, New York.
- Thirteenth Lake, New York.

Loose earth structures:

Alluvial cones:
- Cucamonga, California.

Deltas:
- East Delta, Louisiana.
- Forts, Louisiana.
- Gibson, Louisiana.

Glacial drift:
- Whitewater, Wisconsin.
- Minneapolis, Minnesota.

Staten Island, New York.
Weedsport, New York (Drumlins).

Alpine conditions:
Chief Mountain, Montana.
Cloud Peak, Wyoming.

Piedmont conditions:
Cucamonga, California.
Anaheim, California.

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Salisbury, R. D. Physiography, 770 pages. N. Y., Henry Holt. 1907. (Contains suggested exercises in map interpretation at end of each chapter. Processes are emphasized.)

SECTION III. MAP MAKING.

The use of topographic maps to interpret the character of the surface of the ground and the nature and structure of the underlying rock involves a knowledge of geology and therefore finds an appropriate place in a text book on military geology. The making of a topographic map, that is, making the necessary field surveys and drafting the map in the office, is a phase of civil engineering. It involves the use of mathematical formulae, of surveying instruments, and of methods of representing natural phenomena on plane surfaces. The topographer or topographic engineer is concerned primarily with measuring and recording land surfaces, rather than interpreting them. For these reasons map making is not included in the text on military geology.

Among the standard books on military mapping and military sketching are the following:

Barnes, J. B. Elements of Military Sketching and Map Reading. Van Nostrand. 75 cents.

Engineer Field Manual. War Department Professional Paper 29. Superintendent of Documents, Washington, D. C. $1.00.

Fulmer, J. J. Military Panoramic Sketching. Hudson. $1.00.

Grieves, Captain Loren C. Military Sketching and Map Reading. Army & Navy Coöperative Co., Washington, D. C. $1.00.

Sherrill, C. O. Military Topography for the Mobile Forces, etc. Banta Publishing Co., Menasha, Wis. $1.50. This work also appears in a three volume edition.

Spalding, G. R. Training Manual in Topography, Map Reading and Reconnaissance. U. S. War Department. Superintendent of Documents, Washington, D. C. 20 cents.

Sweeney, W. C. Sketching Methods. Hicks Judd Co., San Francisco. $1.00.

Stuart, E. R. Topographical Drawing. McGraw-Hill Co., New York. $2.00.

Topographic Instructions of the United States Geological Survey. Superintendent of Documents, Washington, D. C. 35 cents.

CHAPTER VIII.

ECONOMIC RELATIONS AND MILITARY USES OF MINERALS.

MINERALS and their products enter into almost every phase of the mechanical adjuncts of our modern civilization. In order to see how true this is it is only necessary to imagine the restrictions that would be imposed upon us if, for instance, our supply of iron or copper was completely cut off. Our dependence upon minerals is even greater in times of war. No nation could hope to carry on war under present conditions without abundant resources of certain essential mineral materials. The lack or the insufficient supply of certain metals would inevitably bring disaster. One thinks first of iron and steel, coal, copper, and the nitrates and sulphur used in making munitions, yet equally necessary is mica for wireless and other electrical insulation work; tungsten, vanadium, chromium, and manganese, necessary in making steel; platinum, necessary for chemical work in the manufacture of munitions; graphite, necessary for crucibles used to produce brass, crucible steel, and various alloys; and antimony to harden bullets. Consequently the military uses of minerals, the location of their deposits, the amounts available, the difficulties of their transportation, the possible development of substitutes if the supply is deficient—all these are vitally important subjects of study at the present time. The problems involved are exceedingly complex and present many unexpected ramifications. It may become necessary to find and develop new mineral deposits to meet the special war demands; to measure carefully the amounts and grades available in the ground; to take steps that will insure production of these substances; to solve problems of transportation and distribution created by the war; to see that commodities reach the industries that need them for war purposes; to ascertain the special needs of these industries; to see whether they are using the right materials to the best advantage; to see that the processes of smelting and manufacture are best adapted to the grades of material available; to procure as large a proportion as possible from domestic sources, thus avoiding the use of ships; to avoid the export of materials of which we are short and the import of materials of which we have enough; to consider not only the needs of ourselves but of our allies; so to plan the development of our domestic supplies as to interfere as little as possible with good international relations; to discriminate between the developments which are permanent and those which are merely war expedients; to see that all war expedients are properly considered in relation to taxes, international tariffs, and other government regulations; to keep in mind the interests of conservation, to the end that our mineral supplies may be used to best advantage, not only to ourselves, but to a world civilization.

It is becoming increasingly clear that military strategy and trade strategy have much to do with the nature and distribution of the raw mineral materials. It is more than a coincidence or accident that Germany's offensive moves have resulted in acquisitions of essential war minerals, as for instance, the iron and coal of northern France, the chromite and copper of the Balkans, the manganese, iron, and coal of southern Russia, the petroleum of Rumania. On the other hand, the return of Alsace-Lorraine to France would deprive Germany of her sole important iron supply. It is clear that in the peace compact questions of control and distribution of materials of this kind will play a large if not a dominant part. Already stock is being taken of the nature and distribution of the world's chief mineral supplies in order to determine the best means of using them, not only for national advancement but for the best good of civilization. It is clear, therefore, that, if we are to meet adequately and properly the war demands for minerals, there is a wide field for the application of geologic science in close coöperation with the sciences of metallurgy, political economy, finance, diplomacy, and even military strategy.

Brief discussions of minerals of fundamental importance in relation to the war are given below.

MINERALS OF WHICH THE UNITED STATES HAS AN ADEQUATE SUPPLY OR EXPORTABLE SURPLUS.

The United States is well able to supply its normal and war needs of the great basic mineral commodities—iron, coal, oil, copper, sulphur, phosphates, aluminum, lead, zinc, gold, and silver. In fact, with regard to the entire list of some forty-five mineral products used in industries the United States is more nearly self-sustaining than any other country on the globe. If we may consider the supplies of Canada, Mexico, and Cuba as available to us this statement can be made even more sweeping. Any present shortages in this group of minerals are due mainly to temporary shortage of labor and transportation, of the kind which is affecting many other industries.

Of all the minerals named above we have a substantial exportable surplus in normal times and during the war; for special reasons it is still desirable to import supplementary quantities.

IRON.

The important uses of iron and steel for military and industrial purposes are so well known as to need no description here. Fortunately the United States has for a long time had a commanding position in the world's output of iron ores and still has immense reserves of these ores available. The United States produces nearly 50 per cent. of the iron units of all the iron ore mined in the world. Small quantities of iron ore, consisting of less than 5 per cent. of the domestic requirements, have been imported for various reasons. The cheap ocean transportation and nearness of supply makes the Cuban iron ore desirable for eastern seaboard furnaces, while special grades of iron ore not abundant in the United States are imported from Europe, Africa, and South America. During the war the overseas imports, except those from Cuba and a very small amount of low-phosphorous ore from Spain, have been discontinued. We are not only able to supply our own very great needs but can also in a considerable measure take care of those of our allies. Exports of the crude iron and steel products have increased from 1,000,000 tons in 1913 to nearly 6,000,000 tons in 1917, and exports of manufactured forms of the metal have also largely increased. England has large deposits of iron ore, but the most productive districts in France lie in the region now occupied by Germany. Italy has only small iron deposits. Germany has very rich districts in Alsace-Lorraine and is presumably also at present working the mines of northern France. The bulk of the ore mined in the United States comes from the Lake Superior region in the States of Minnesota, Michigan, and Wisconsin. New York, Alabama, and Tennessee also have important deposits. The chief ore in this country is hematite (ferric oxide, Fe_2O_3), but magnetite (ferrous-ferric oxide Fe_3O_4) and limonite (hydrous oxide, $2Fe_2O_3 . 3H_2O$) furnish small amounts.

A special problem has been created by the war demands for exceptionally low-phosphorous material for the manufacture of low-phosphorous pig iron used for certain ordnance and high-speed tool steel. Much of this material in the past came from Europe, part of it being the cinder derived from the burning of Spanish pyrite and the rest mainly Spanish low-phosphorous iron ore. The elimination of our imports of iron ore from Europe and the large reduction in our imports of Spanish pyrite have created a shortage in low-phosphorous iron which is being made up to a large extent by the development of domestic supplies, both from iron ore and from the burning of domestic pyrite.

COPPER.

Copper is extensively used in the form of wire, sheets, and tubes. A large amount, chiefly wire, is used as an electrical conductor. It is also much used in various alloys, such as brass (copper and zinc), bronze and bell metal (copper and tin or zinc), and nickel silver (copper, zinc, and nickel) and anti-friction alloys. The application of these various products to military uses is obvious.

In 1917 the United States produced over 60 per cent. of the world's total output and imported 18 per cent. additional. This means a control of about 80 per cent. of the entire copper business of the world. Our exports amounted to over 36 per cent. of the total world production in 1917, and this does not include the large amount of copper contained in brass or in more highly manufactured forms. Consequently, although we are entirely independent of foreign copper we must continue our copper business in undiminished volume to supply our ally customers, England, France, and Italy. This requires copper imports from South America and Cuba. The principal copper-producing States, named in the approximate order of their rank, are Arizona, Montana, Michigan, Utah, Nevada, Alaska and California. England and France also obtain important supplies from Africa, Australia, Japan and Spain. Germany has copper deposits, but their production is comparatively small and there have been for some time many indications of her apparent shortage in this metal.

While ship tonnage devoted to copper imports has been reduced during 1918, the total metallic copper imported during the year will be actually larger. This has been accomplished by eliminating overseas imports of copper ores except from Cuba and requiring that imports be confined to the more highly concentrated forms of copper. This restriction happens to coincide with the natural expansion of copper smelting (financed by American capital) in Peru and Chile. In 1919 this tendency will be even more marked.

The chief copper ores are chalcopyrite, $CuFeS_2$; bornite, Cu_5FeS_4; chalcocite, Cu_2S; tetrahedrite, $4Cu_2S.Sb_2S_3$; native copper, cuprite, Cu_2O; and malachite, $CuCO_3.Cu(OH)_2$.

LEAD.

The chief military use of lead is in the making of bullets and shot. Metallic lead is also used in the form of sheet, pipe, etc. It is a constituent of various alloys, such as solder (lead and tin), type metal (lead and antimony), low-fusing alloys (lead, bismuth, and tin). Lead in the form of the basic carbonate, known as white lead, is very valuable as a paint. There are many other ways in which lead and its compounds are used in various industries.

The production of lead in the United States in 1913 was about one-third of the world's output, but under the stimulation of war conditions this amount has increased about 50 per cent. Our resources are adequate to supply all demands. In normal times a large proportion of the lead we produced has been a by-product in the smelting of lead-silver ores. These ores have come chiefly from the States of Colorado, Idaho, and Utah. Lead ores occur in large amounts in the Mississippi Valley, locally alone but more commonly associated with zinc ores. The producing States in this section are Missouri, Kansas, Wisconsin, Illinois.

Many minerals contain sufficient lead to make them valuable as ores of the metal. The distinctly lead minerals, however, are few in number. The more important are: galena, PbS; cerussite, $PbCO_3$; and anglesite, $PbSO_4$.

ZINC.

Metallic zinc, or spelter, as it is called, is used chiefly for galvanizing iron and as an alloy with copper in brass. Both these products have many military applications. Zinc is used also in storage and telegraph batteries and, in the form of the oxide, or zinc white, as the basis of a very permanent white paint.

The production of zinc ores has increased more than 50 per cent. under the stimulation of war demands. The United States has ample deposits of this metal. The chief producing districts are in Missouri, Colorado, Montana, Idaho, Kansas, Wisconsin, and New Jersey. Germany has large zinc deposits and besides now controls the important Belgian districts.

The principal zinc minerals are sphalerite, ZnS; smithsonite, $ZnCO_3$; and calamine, $H_2(Zn_2O)SiO_4$. The following important ore minerals are found at Franklin, N. J.: zincite, ZnO; franklinite, $(Fe,Mn,Zn)O(Fe,Mn)_2O_3$; willemite, Zn_2SiO_4.

GOLD AND SILVER.

The United States occupies second place in the production of gold and first place in the production of silver. This country produces nearly one-fourth of the world output of gold under normal conditions. In the last two years the production has declined 15 per cent., and it is still falling at a faster rate than the production of the rest of the world. However, the United States may be considered to have an adequate supply of gold for its own use. The difficulty in increasing the selling price of gold to meet increased costs of production is having its effect on the gold output. The Allies produce over 90 per cent. of the world's gold, and Germany has less than 1 per cent. As the basis of value for all currency, it is necessary to extend gold reserves to keep up with the rapid expansion of other forms of currency.

Our situation with respect to silver is much stronger, as the output in the United States is almost one-half of the total world output. Including Canadian and Mexican production, the total production in North America equals nearly three-quarters of the entire silver output of the world.

MERCURY (QUICKSILVER).

The most important military use of mercury is in the manufacture of fulminate for caps to explode shells, cartridges, mines, etc. In normal times 30 to 40 per cent. of the mercury consumed in the United States was used for this purpose, but at present this proportion is largely increased. Other uses are in the amalgamation process for the extraction of gold and silver from their ores, in drugs (calomel, corrosive sublimate, etc.), in anti-fouling paint used on ships' bottoms, in thermometers, barometers, storage batteries, dental amalgam, etc.

The world's supply of mercury has come from a comparatively few localities, of which the chief ones are in Spain, Italy, Austria, and the United States. Our production comes mostly from California, with lesser amounts from Texas, Nevada, and Arizona. The production in 1917 was approximately 36,000 flasks (75 pounds) as compared with an average of 21,000 flasks before the war. The price has increased from $40 per flask in 1913 to $106 in 1917. The domestic production so far has not only proved ample for our needs, but we have had some surplus for export.

ALUMINUM.

Aluminum is a metal of great value because of its lightness, rigidity, and resistance to most acids. It is chiefly used in the construction of automobile bodies, airplanes, electrical cables, and utensils for chemical and household purposes. When its powder is mixed with ammonium nitrate it forms a very insensitive and stable explosive called "ammonal," used in mining and for certain shells. It is employed as a metallic paint. Its chief ore, bauxite, is used in the form of brick for furnace linings and in the manufacture of the artificial abrasive alundum and of various chemicals.

Although aluminum is one of the most common metals in the earth's crust, being a constituent of most silicates, of clay, etc., there are only a few minerals from which, with present methods, it can be easily and cheaply obtained. The United States and France possess the most valuable deposits of the chief ore, bauxite, $Al_2O_3.2H_2O$. Important deposits are located in Arkansas, Georgia, Alabama, and Tennessee. Before the war the United States was producing two-fifths of the world's output. Since then the domestic production has very greatly increased, and at the present time it is limited only by plant capacity. It will probably be necessary to import some bauxite from British and Dutch Guiana, in order to insure the expanded aluminum output which will later be established.

MOLYBDENUM.

Molybdenum is used in making steel alloys. It is a substitute for tungsten: for some purposes a given quantity of tungsten can be replaced by half as much molybdenum. Molybdenum steel is used for high-speed tools, armor plate, projectiles, etc. There are other minor uses of the metal.

The total world production is small, but the United States leads. Molybdenum ores are found in Arizona and Colorado, and our production could be considerably increased if necessary. In 1917 we produced about 175 tons of the metal, valued at $350,000. Most of this was shipped abroad, where its use is more general than with us. The two most important molybdenum minerals are molybdenite, MoS_2; and wulfenite, $PbMoO_4$.

MAGNESIUM.

Magnesium is the lightest metal known that remains at all stable under atmospheric conditions. Its use has materially increased since the war began, mainly owing to its value in shrapnel shells, aerial bombs, and rockets. The combustion of the powdered metal produces a dense white cloud by day and a brilliant white light at night. For this reason it is used in observing the bursting point of shells and for lighting the battlefield at night. When alloyed with aluminum it produces a metal for use in airplanes that is lighter, stronger, tougher, and harder than pure aluminum.

Before the war magnesium was manufactured chiefly in Germany. Since then an amount sufficient for present needs has been produced in the United States. There are numerous sources of supply for the raw materials from which the metal is obtained, but at present the salt brines of Michigan and the deposits of magnesite are the most important.

SULPHUR.

Sulphur is used both in the form of the element and as sulphuric acid. The element is used in the manufacture of rubber, gunpowder, paper, and matches, in the preparation of wood pulp, and in many chemical processes. Sulphuric acid is one of the most essential materials used in the manufacture of high explosives. It is necessary in the manufacture of fertilizers from phosphate rock, the refining of petroleum, the production of aniline dyes, etc. Until recently most of the sulphur used in the United States was imported, largely from Sicily and Japan, but important deposits have been discovered in Louisiana and Texas, which are now producing on a large scale, with the result that the United States is now producing over three-fourths of the world's sulphur and is entirely independent of outside supplies of sulphur-bearing raw materials, including pyrite. Imports of sulphur have ceased. Exports to Canada continue large. In return we receive a large tonnage of pyrite.

Sulphuric acid is produced by the oxidation of various metallic sulphides or by the burning of sulphur itself. The sulphide most commonly used is iron pyrite, FeS_2, but the acid can also be obtained from the fumes derived from the smelting of various other sulphide ores. An unlimited supply is available from smelters in the United States, the problem being simply one of the installation of the proper plants and their subsequent profitable utilization under peace conditions.

PHOSPHATES.

Phosphate minerals furnish an important ingredient of fertilizers. In normal times the United States was producing three-sevenths of the world's output. Notable deposits of phosphate rock, essentially calcium phosphate in composition, are found in the southern Atlantic

States, the chief producing districts being in Florida, Tennessee, and South Carolina. Enormous reserve deposits are known in the Western States. Our exported surplus in 1913 was 44 per cent. of our output. Since that date exports have been greatly reduced, because the phosphate industry has everywhere been depressed by the war. In 1917 they amounted to 6 per cent. of our output. Potentially the exportable surplus is as large as ever. Next to the largest supply is in French North Africa. Several islands east of Australia with various political relations have been dominated by Japan since the war. The Central Powers in Europe depend on slags from Lorraine iron ore for their domestic supply of phosphate.

FLUORITE (FLUORSPAR).

Fluorite is a calcium fluoride, CaF_2, which is used in various ways but chiefly as a flux in the smelting of copper, lead, and iron and in the manufacture of steel. The United States produces practically all it uses, but under war conditions the amount consumed has materially increased and there has been some difficulty in keeping the production up to the demand. The chief producing districts are in Illinois and Kentucky; smaller deposits occur in Colorado, New Hampshire, and Arizona.

MAGNESITE.

Magnesite is a mineral having the composition of magnesium carbonate, $MgCO_3$. When calcined at high temperatures it produces a very dense, fire-resisting, and chemically inactive substance. It is used chiefly in the manufacture of refractory linings for steel and other furnaces. It is also used in the making of a cement for sanitary flooring in office buildings, hospitals, ship decks, and railroad cars.

Before the war the United States produced only a few thousand tons of this mineral annually, chiefly from California, and imported the remainder, largely from Austria-Hungary and Greece. During the last few years the California deposits have been actively developed and new ones opened in Washington, so that in 1917 we produced 90 per cent. of our needs, although the amount consumed was twice that of pre-war times.

CORUNDUM AND EMERY.

Under the above head may be included all abrasive materials, both natural and artificial. Corundum is an oxide of aluminum, Al_2O_3, which because of its great hardness and superior toughness is used as a grinding and polishing material. Under the name emery are included various grades of corundum and mixtures of this mineral with other materials, the iron oxide, magnetite, being often included. The chief artificial abrasives are carborundum, composed of carbon and silicon, SiC, made from coke and sand, and alundum, which has the same composition as corundum itself. These materials are used in grinding, rough dressing, shaping, and polishing metals, particularly steel, and glass. In this way they enter into the manufacture of numberless articles of military equipment. Besides manufacturing the artificial abrasives in large quantities the United States produces corundum and emery from various localities. The best deposits are in New York, North Carolina, and Virginia. Before the war the better grades of these materials were imported.

COAL.

The annual coal production of the United States now constitutes over 40 per cent. of the world's total and is twice as much as the production in any other country. The coal of the United States has not so greatly entered into foreign commerce as that of England, or even that of Germany, for most of that which we have mined has been consumed at home or in Canada. Our exports by sea have been only 4 per cent. of the world's sea-borne coal and have gone principally to South America. Our imports are very small and come wholly from Canadian fields that happen to be convenient to some parts of the country. With the increase in our shipping and the prospects of greater foreign trade, it can be assumed that the United States will obtain a much larger proportion of the world's coal trade after the war. The loss of the principal coal mines of France by the German offensive, the lack of coal supplies in Italy, and the lack of shipping and labor to supply the deficiency from England have been important factors in the war. Germany also occupies important Russian coal fields.

PETROLEUM.

Over 60 per cent. of the petroleum thus far produced in the world has come from the United States, and the present production is fairly constant at 65 per cent. of the total—that is, nearly two thirds of the world's oil business is done in the United States. The only other countries producing more than 3 per cent. of the world's total are Russia and Mexico. The recent decline in Russia is balanced in large part by the rapid increase in Mexico. Germany's acquisition of southern Russia and Rumania has temporarily solved the problem of her oil supply.

The exports of oil consist mostly of refined products. They amount to about 15 per cent. of the world's total and show normally some increase from year to year. We manage to supply the needs of our allies, with the help of Mexican production. The imports are about 4 per cent. of the world's total and come largely from Mexico, for refining in the United States. These are likely to increase rapidly for a time. There are prospects also of rapid developments in the northern part of South America.

ASPHALT.

Asphalt is used in road making, in protective paints, roofing, calking ships, etc. Of the total natural asphalt we required before the war about two-thirds was imported, principally from Trinidad and Venezuela. This importation in 1918 was reduced 50 per cent., mainly by cutting down the use of asphalt but partly by the substitution of manufactured asphalt and other domestic road-making materials for natural asphalt. After the war presumably the importation of natural asphalt will be resumed because of its desirable qualities.

Manufactured asphalts, made chiefly from Californian and Mexican oils, are adequate in quantity to meet all asphalt requirements, though their production makes heavy drafts on our supply of fuel oil.

OTHER MINERALS.

Other minerals which can be fully supplied by the United States and Canada are still imported in part from western Europe as ballast and backhaul. These are chalk, fuller's earth, mineral waters, pumice, salt, building stone, talc, and soapstone. High-grade clay and flint pebbles could be supplied with more difficulty but are also obtained from Europe as ballast and backhaul.

MINERALS FOR WHICH THE DEMAND MUST CONTINUE TO BE MET BY OVERSEAS IMPORTS.

There are comparatively few necessary minerals which from present indications we must continue indefinitely to obtain mainly from foreign sources.

TIN.

The chief military uses of tin are in making alloy bronze, tin plate, and cans for the preservation of food products. There are numerous other uses not directly concerned with war needs, and for many of them other materials may be used as substitutes.

Only one-tenth of 1 per cent. of the tin consumed in the United States is supplied from domestic sources, and there are no indications that this percentage can be considerably improved. Deposits in North and South Carolina have been worked, but at present the principal district is on the York peninsula, 100 miles northwest of Nome, Alaska. The United States, however, has consumed about 40 per cent. of the world's output of the metal. The rigorous conservation program in consumption now being carried out by the War Industries Board will result in saving perhaps 25 per cent. of our consumption, but this saving will be more than absorbed by increased demands. The imports have come chiefly from the Straits Settlements, England, the Dutch East Indies, and Bolivia. Recently a reduction plant has been built in New Jersey to handle Bolivian ores. The only important ore of tin is cassiterite, SnO_2, which contains 78.6 per cent. of tin.

ANTIMONY.

An alloy of lead with six to sixteen per cent. of antimony is used in making bullets for small arms and shrapnel. The antimony gives a hardness to the lead that causes it to retain its shape under the effects of explosion. Antimony sulphide is used in certain smoke bombs and in the primers of shells and cartridges. Antimony is an ingredient of type metal and in anti-friction metal for bearings for machinery, etc. Red antimony sulphides are used in vulcanizing and coloring red rubber, also in paints.

Until recently all the antimony produced in the United States came from antimonial lead, a by-product of the smelting of certain lead and silver ores. Under the stimulation of war prices (the price of antimony has risen from a normal rate of 7 cents per pound to as high as 50 cents) small deposits of pure antimony have been opened, chiefly in Nevada and California, but at present about nine-tenths of the antimony we consume has to be imported. Large stocks in hand make it possible to reduce importations in 1918 about 45 per cent., and further reduction in overseas imports seems possible for 1919.

Metallic antimony is imported chiefly from China. Smaller amounts of antimony ore come from the same source and also from Bolivia and Mexico. Germany probably has an adequate supply of this metal. The only important direct source of the metal is the mineral stibnite, Sb_2S_3.

TUNGSTEN.

Tungsten is a metal which is used chiefly in the form of an alloy with iron in producing high-speed tool steel. An alloy with 5 to 8 per cent. of tungsten makes steel hard and tough, and tools made from it retain their cutting edge much longer and hold their temper at greater heats. The metal is also used to a smaller extent as filaments in electric lights and as a substitute for platinum in electrical contacts.

Tungsten minerals are produced in the United States chiefly from Boulder County, Colorado, and the Atolia district in California. Other deposits are in Arizona and Nevada. In 1917 the United States produced about two-thirds of its total consumption, the remainder being imported from Bolivia, Peru, and eastern Asia. The United States demand for 1918 has increased 50 per cent. over 1917. There are possibilities of domestic production sufficient to meet future demands. There also is a possibility that the demand for tungsten may be partly met by the larger use of molybdenum, of which we have abundant supplies. There are two important tungsten minerals: wolframite, $(Fe,Mn)WO_4$, and scheelite, $CaWO_4$.

VANADIUM.

Vanadium is an important ingredient of certain steels. These alloys are used for tool steels, also in cast steel where special toughness is desired and in locomotive and automobile frames.

Vanadium ores are found in Colorado and Utah, and from these deposits at present more than 500 tons of the metal is produced annually. This production could be materially increased if necessary. The largest vanadium deposit in the world is in Peru, and the United States has heretofore imported most of the vanadium it has used from this source. Transportation difficulties have reduced the amount obtained from Peru and made it desirable to develop our own deposits. Germany has no known ore supply of this metal available. The merchant submarine *Deutschland* carried 15 tons of ferro-vanadium on one of its homeward trips.

The important vanadium ores are roscoelite, a complex silicate containing a small amount of vanadium; carnotite, a uranium-vanadium mineral of uncertain composition; and vanadanite, $Pb_4(PbCl)(VO_4)_3$. The chief mineral of the Peruvian deposit is patronite, an impure vanadium sulphide.

PLATINUM.

The most essential war need for platinum is as a contact material to promote chemical reactions in the manufacture of the sulphuric and nitric acids used in making munitions. It is also necessary for utensils in chemical laboratories and manufacturing plants. The only platinum mineral of importance is the native metal itself. This is very rare and has been found in workable deposits in only a few localities. While small amounts of platinum are available from various sources in the United States, chiefly from California and Oregon, the indications are that no essential part of our demand can be met from domestic supplies. The great bulk of the world's supply has been obtained from placer deposits in Siberia and on the eastern slope of the Ural Mountains, Russia. Colombia produces annually a small amount, which has recently been considerably increased, and constitutes the nearest available source. Since the war began the production of platinum in Russia has materially decreased and its importation into the United States has practically ceased.

MICA (ISINGLASS).

Mica is valuable because of its perfect cleavage, transparency, elasticity, non-conductivity of heat and electricity, resistance to decomposition, and non-inflammability. It is used mostly as an insulating material in the manufacture of electrical apparatus. Ground mica is used in the preparation of lubricants, for boiler and pipe coverings, in paints, for glazing, and in the manufacture of rubber goods.

The United States produces about 40 per cent. of its total consumption of sheet mica. This comes chiefly from New Hampshire, North Carolina, and South Dakota. While our domestic production of mica is very large, we do not produce enough of the highest-grade clear mica to supply the war demands for electric insulation, wireless telegraphy, spark plugs, etc. One-half of the highest-grade clear mica that we require still comes from India, and a small but increasing amount comes from Brazil. The government has commandeered imported mica.

Although there are a number of minerals that belong to the Mica group, only one, muscovite, a potassium-aluminum silicate, has any extended use.

CRYOLITE.

Cryolite, Na_3AlF_6, which occurs in commercial deposits only in Greenland, is essential for the production of aluminum. About 50 per cent. of the output is used for this purpose. For the manufacture of opaque white glass, in the enameling of iron ware, and for a flux in the manufacture of white Portland cement there are domestic substitutes for cryolite, and importation of it for these purposes has been stopped.

MONAZITE.

Monazite is used principally for gas mantles, spark lighters, and luminous paints. Importation of monazite from India and Brazil has been cut down 20 per cent. by reduction in requirements and agreement with the importers. There is as yet little domestic production of monazite, but there are indications of increase in the future.

MINERALS NORMALLY IMPORTED BY SEA WHICH IN THE FUTURE CAN BE LARGELY PRODUCED FROM DOMESTIC SOURCES IF IT SEEMS DESIRABLE.

A number of essential mineral commodities which have formerly been largely imported from overseas are being developed in this country to such an extent as to make us nearly if not quite independent of foreign sources under ordinary peace conditions. Exceptional war demands for nitrate and a few other minerals require a large importation during the period of the war, after which importation will not be needed.

The campaign to develop these minerals from domestic sources has been so successful as to raise questions as to how far it is desirable to go in this direction, in view of our future world relations. The result has been accomplished by various expedients, such as the mining of low-grade ores at high cost and substitutions and economies in manufacture and use. While it may become possible for us to do without importations of such minerals, this independence will be attained only at high expense and will mean the too rapid exhaustion of our limited supplies of these minerals. It is therefore essential for our national well-being to ascertain clearly the nature and extent of our dependence on foreign sources and to see that in the great changes the world is now undergoing these channels of supply shall remain open to us. If this is done, war regulation of the temporary phases of our domestic mineral industries should be framed accordingly.

MANGANESE.

Manganese is of essential military importance because of its use in practically all steel. All high-grade steel contains on the average one-half of 1 per cent. of manganese, and in certain steel the amount runs up to 10 or 12 per cent. The manganese serves as a deoxidizer, destroying any iron oxide dissolved in the steel, as a conveyer of the proper amount of carbon necessary for the steel, and also to impart to it certain other essential qualities. Other metals may be used to perform certain of these functions, but no single metal can completely take its place. The manganese is introduced into the steel in the form of iron alloys, the chief being *ferromanganese,* which contains about 6 to 7 per cent. of carbon and 80 per cent. of manganese, and *spiegeleisen,* which contains from 4 to 5 per cent. of carbon and 15 to 20 per cent. of manganese. Spiegeleisen can be made from various low-grade ores, but ferromanganese can be conveniently made only from exceptionally pure deposits. It is reported that because of the diminishing supply of manganese in Germany the steel from which the lining of its cannon tubes is now made is of inferior quality and more quickly worn out. Other uses for manganese and manganese ores are in the manufacture of dry cells, glass, hydrochloric acid, and bleaching powders. The ores of manganese are chiefly oxides, the two most abundant being pyrolusite, MnO_2, and manganite, $Mn_2O_3.H_2O$.

The United States has produced considerable amounts of low-grade ores suitable for making the alloy spiegeleisen. These have largely come from manganese-bearing iron ores found in the Lake Superior iron-ore districts and from the iron-manganese residuum obtained from the smelting of the New Jersey zinc ores. In normal times 99 per cent. of the high-grade ore from which ferromanganese could be made has been imported. Because of ship shortage in 1918 and consequent diversion of domestic production, the proportion of overseas importation (except from Cuba) will be reduced to about 55 per cent. The number of manganese producers in the United States has increased in a year from 75 to 325. It is estimated that in 1919, by the systematic development of domestic ores and changes in practice adapted to the average lower grade of these ores, only 10 per cent. of our total supplies will be needed from overseas deposits outside of Cuba. In other words, under the stimulation of war conditions we have practically become self-supporting in regard to manganese.

There is no question that if necessary the importation of manganese from Brazil can soon be completely eliminated, but this brings up problems as to our relations with Brazil, both during and after the war, use of our ships after the war, and the expense to which we shall go in developing lower-grade supplies which if movement between countries were free could not be worked at a profit except with a high protective tariff or bonus.

CHROMIUM.

Chromium is used as the metal, in various chemical combinations and in the form of its most abundant ore, chromite, $FeO.Cr_2O_3$. The metal is used chiefly in the form of *ferrochromium,* an iron alloy containing 60 per cent. chromium, which is used in the manufacture of many steels, particularly those used for projectiles, armor plate, gun linings, high-speed tools, automobile axles and springs, locomotive frames and springs, and in general where steel parts must stand hard usage. The mineral chromite is used in the manufacture of refractory brick for the lining of metallurgic furnaces. Various chromium compounds are used as pigments, such as chrome-green and chrome-yellow, as oxidizing agents, in tanning leather, etc.

The deposits of chromium ore in the United States are small and of low grade. The most important localities are in California. In 1913 less than 1 per cent. of our supplies came from domestic production, the remainder overseas, mainly from New Caldeonia and Rhodesia. In 1918 40 per cent. will be domestic, 15 per cent. will come from Canada and Cuba, and overseas importation from New Caledonia, Rhodesia, and Brazil will be reduced to 45 per cent. The indications are that supplies of overseas imports can be further reduced in 1919. This result has been accomplished by increase of production in California, Canada, and Cuba, by economies introduced in the steel, paint, leather, and chemical industries, by the use of lower grades, by the recovery of chromium from certain slags not heretofore used, and in other ways.

NITRATES.

Nitrogen in the form of soluble nitrates is used largely as a fertilizer. In the form of nitric acid it is absolutely essential for the manufacture of most high explosives besides being necessary for many important branches of chemical industry. The only extensive source of natural nitrates in the world consists in the deposits of soda niter (sodium nitrate), known commonly as Chile saltpeter, that occur in the desert regions of northern Chile. No deposits of any importance are known in the United States. Germany, long ago, realizing that in case of war she would probably be shut off from the importation of nitrates from Chile, developed a process by which nitrogen could be extracted from the air, four-fifths of which consists of this element. Another process made available the nitrogen contained in the ammonia that is formed as a by-product in the manufacture of illuminating gas and of coke from coal. Meanwhile the amount of nitrates imported into the United States from Chile has grown from less than 500,000 tons in 1912 to a much larger tonnage in 1918 and has required the use of more than 200 ships. For 1919 the demand will be larger. A small part of this demand will be supplied by nitrogen-fixation and coal-distillation plants. Shipping is inadequate to take care of the remainder, but even if shipping were available, it is questionable whether this amount, together with the amounts needed by the Allies, could be supplied from production in Chile. It is therefore necessary to provide for additional domestic supplies. Domestic development of these supplies is more expensive than building ships, but the limitation of shipping capacity makes it necessary to undertake domestic development regardless of cost.

POTASH.

Approximately 95 per cent. of the potash salts we consume is used for agricultural fertilizers. The remainder is used in various chemical industries, chiefly in gunpowder, in meat preservatives, in the manufacture of glass, soap, and matches, and in the cyanide process for the recovery of gold and silver from their ores. For many purposes other materials may be substituted, but potash salts are essential in fertilizers.

The world's chief supply of potash salts has come from Germany. The imports of potash salts into the United States fell from over 1,000,000 tons in 1912 to 12,000 tons in 1916. The price of the chief salts have in consequence risen from $35 or $40 per ton up to $450 per ton. Germany has long believed that her possession of these rich potash deposits gives her a trump card that she expects to play in the discussion of peace terms. It is interesting to note that substantial parts of the potash resources controlled by Germany are in Alsace and in Poland. It is therefore a very vital problem for this country and her Allies to develop independent sources of this necessary material. In this connection the potash deposits in Spain are of interest.

A great amount of experimental work has already been done looking to the development of such new sources of supply, but the domestic production in 1917 was only about 10 per cent. of our normal needs. Production for 1918 shows an increase. Some of the new sources are: potash from brines in Nebraska; the deposits of various alkali minerals found in the old dried-up lake beds of Nevada and California; the kelp beds found along the Pacific coast; by-products from cement kilns and blast furnaces and from organic waste materials such as molasses residue, wood ashes, wool scourings, and the waste from distilleries; deposits of alunite (a sulphate of aluminum and potash) in Utah; and various potash-bearing silicate rocks. The domestic production of potash is taking care of the really established needs for mixed fertilizers to such an extent that there is now no crisis as regards potash supply, though prices are about ten times the pre-war prices. It is clear that if necessary the United States can in the future be nearly if not entirely independent of German potash, but at some expense and trouble. Independence would involve a substantial tariff or bonus.

PYRITE.

Pyrite is the source of sulphur for sulphuric acid, which is essential to munitions and fertilizers. Before the war domestic sources supplied 25 per cent. of the domestic demand, and imports, mainly from Spain, 75 per cent. In 1918 the domestic production will supply about 50 per cent. and importation 50 per cent. The development of the domestic supplies will make it unnecessary to import any pyrite in 1919, except from Canada, though some may be imported because of backhaul and ballast considerations. Reduction in imports has been made possible by heavy drafts on our unique deposits of native sulphur in Texas and Louisiana, stimulation of domestic pyrite mining, and the recovery of pyrite from the mining of coal. Here again there is no question that the country is and can remain self-supporting in regard to its pyrite supplies, but this independence has been achieved in some degree through the use of materials which under ordinary conditions of world commerce could not compete with pyrite from Spain. Pyrite is produced mostly in Virginia, California and New York but workable deposits exist in a number of other states. (See "Sulphur.")

GRAPHITE.

Graphite is used in war mainly for the crucibles required in the production of crucible steel, brass, bronze, and other alloys and metals. For this purpose only crystalline graphite, known as flake graphite, is suitable, and as no satisfactory substitute is known, graphite becomes of vital importance in time of war. Amorphous graphite is used in foundry facings, gray paints, lubricants, electrodes, polishes, pencils, etc.

Before the war 70 per cent. of our total consumption was met by importation from Ceylon and Madagascar, 17 per cent. from Canada and Mexico, and 12 per cent. from domestic sources, principally New York, Pennsylvania, and Alabama. In 1918 importation had been reduced 60 per cent., and it is estimated in 1919 that our required imports will be still less. This decrease has been accomplished largely by drawing on large stocks of foreign graphite that were already in this country. However, there are considerable domestic supplies which can and will be drawn upon. In the manufacture of crucibles about 25 per cent. of domestic and 75 per cent. of foreign graphite has been used. Better cleaning and standardization of the domestic product will make it possible in the future to rely mainly on domestic grades.

MINERAL IMPORTS NEEDED FROM NORTH AND SOUTH AMERICA.

CANADA.

The United States is dependent on Canada for almost all of its nickel supply and for a part of its asbestos.

Nickel.—The principal use for nickel is as a steel-hardening metal. A great many steels contain nickel, usually in amounts ranging from 2 to 4 per cent. Nickel steel is tougher, more elastic and shock resistant, and less liable to oxidation than ordinary steel. Such steels are used in the manufacture of armor plate and large-caliber guns, for structural work in bridges, engine forgings, marine shafting, automobile axles, etc. An alloy with copper, the so-called Monel metal, is used by the Navy for propeller blades and for valves in high-pressure steam systems. Other uses of the metal are in coinage and for various utensils and in nickel plating. It is a constituent of the alloy known as German silver.

Important deposits of nickel ore are few in number. The two most productive are at Sudbury, Ontario, Canada, and in New Caledonia. The United States has a few low-grade deposits of nickel ore and produces annually about 1,000,000 pounds of the metal, most of it as a by-product in the electrolytic refining of copper. The domestic consumption at the present time is in the neighborhood of 50,000,000 pounds, most of which comes from the Canadian deposits. A great part of the Canadian ore is smelted to a sulphide matte in Canada, and this material is then brought into the United States for refining at Constable Hook, N. J.

There are a number of sulphide and related minerals that serve as ores of nickel. The more important are pyrrhotite, FeS, which in many places carries nickel; pentlandite (FeNi)S; millerite, NiS; and niccolite, NiAs. Some nickel silicates of uncertain composition are found occasionally.

Asbestos.—Asbestos is a fibrous mineral which on account of its non-conductivity of heat is useful as a fire-proofing and heat-insulating material. Canada leads the world in the production of asbestos, the mines being located at Thetford, Province of Quebec, just north of the Vermont border. While the United States has deposits of asbestos in Georgia, Arizona, and California it derives by far the greater part of its supply from this district in Canada.

Practically all commercial asbestos is obtained from the fibrous variety of the mineral serpentine, a magnesium silicate, though other fibrous minerals would serve the same purpose.

Other minerals.—We need from Canada also talc and chromite. There is no other mineral commodity available in Canada, with the possible exception of cobalt, which cannot be supplied mainly from the United States if necessary, but it is convenient and economical to draw on Canada for supplementary supplies of pyrite, iron ore, gypsum, arsenic, copper, mica, magnesite, and graphite.

MEXICO.

The single great resource of Mexico which we can use to the best advantage is oil. The cutting off of oil supplies from Mexico under war conditions would result in serious embarrassment, not only to ourselves but to the other Allies. In peace times the demand is not quite so urgent. Mexico has many other mineral commodities which the United States uses to good advantage, such as copper, gold, silver, asphalt, arsenic, graphite, magnesite, lead, zinc, and antimony. There are indications that antimony may be largely developed in Mexico. If so, this will be the nearest source of supply for the United States.

CUBA.

Cuba has large supplies of iron ore, manganese, chromite, copper, and pyrite, all of which can be used to advantage in the United States. It is especially important that the importation of chromite and manganese be encouraged to the maximum extent during the war, in order to save longer hauls.

CENTRAL AMERICA.

The mineral resources of Central America are still in rather a low state of development. Of the mineral supplies we now import from that region, manganese and chromite are probably the most necessary for our use.

SOUTH AMERICA.

During the war it is essential that we continue to receive supplies of nitrate and copper from Chile; antimony, tin, and tungsten from Bolivia; manganese, mica and monazite from Brazil; and copper, tungsten, and vanadium from Peru. There are pending developments in platinum in Colombia which may go far to make us independent of other overseas sources. After the war the number of commodities needed from South America can be somewhat reduced, if necessary, if we regard simply our own requirements.

MINERAL SUPPLIES OF GERMANY AND AUSTRIA.

Within the original boundaries of the Central Empires there are adequate supplies of coal, iron, zinc and potash. Areas occupied by the German troops contain sufficient supplies of manganese, chromite, and oil, and a partly adequate supply of phosphate. There is a shortage of most other minerals. If the original boundaries are restored Germany will be dependent on outside sources for practically all mineral supplies except coal, iron, zinc, and potash. If Alsace-Lorraine is returned to France Germany will be without an iron supply and will lose a fraction of her potash. It is clear that she will make every effort to retain the important supplies she has acquired in southern Russia and the Balkans, and that she will cede Alsace-Lorraine only after complete defeat.

INDEX.

A.

B.

C.

D.

E.

F.

G.

H.

I.

J.

K.

L.

M.

N.

O.

P.

Q.

R.

S.

T.

U.

V.

W.

Z.

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