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APPLIED GEOLOGY.

A TREATISE

ON THE
INDUSTRIAL RELATIONS OF GEOLOGICAL STRUCTURE;
AND ON THE
NATURE, OCCURRENCE, AND USES OF SUBSTANCES
DERIVED FROM GEOLOGICAL SOURCES.

BY
SAMUEL G. WILLIAMS,
PROFESSOR OF GENERAL AND ECONOMIC GEOLOGY
IN CORNELL UNIVERSITY.

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PREFACE.

So far as the author of this book has observed, no work has yet been published in this country which aims to give a connected and systematic view of the applications of geology to the various uses of mankind. A number of European and American treatises have appeared which limit themselves to special departments of applied geology, some of them discussing the modes of occurrence and distribution of metallic ores or mineral fuels; others treating of agriculture in its geological aspects, or dealing with the geological materials of chemical industries, or devoting themselves to building and ornamental stones, to mortars, or to gems. The work of D'Orbigny and Gente on geology applied to the arts and to agriculture, published more than a quarter of a century ago, is not only in a foreign language, but is now obviously incomplete; and the excellent treatise of Dr. Page, which reviews the entire field of applied geology, is naturally too much devoted to English and European materials and sources of supply to be wholly satisfactory to the American student.

Meanwhile an immense amount of work has been done in revealing the geological structure of the American Continent, and in making known its rich and varied resources—a work in which many independent investigators and explorers have added much of value to the information gained by the various State and national surveys. The knowledge thus acquired of the existence, the nature, the abundance, and the distribution of substances of practical utility, as well as of the important relations which are sustained by geological structure to human well-being and to the successful pursuit of many important callings, is scattered so widely in geological reports, in scientific and technical journals, and in the transactions of learned associations, as to be in a great measure inaccessible to the student and the practical man, unless a large library is at hand and abundant leisure to consult it. It seems evident, therefore, that there is need of a treatise such as this aims to be, which, avoiding minute detail, shall give a systematic and comprehensive account of the most important relations which geology sustains to human interests.

This book is written most largely from an American stand-point, yet care has been taken, in the case of all important substances, to give the chief foreign as well as the domestic sources whence they may be obtained, since those who may, it is hoped, consult its pages for business purposes, will naturally desire to know both where to look for their supplies and whence their sharpest competition is likely to come. With this view, also, tables of the annual production of many leading minerals have been carefully compiled from the most recent attainable data, and for these the excellent tables published by the "Engineering and Mining Journal" have furnished the largest part of the materials.

A work of this kind is in its very nature a discussion and arrangement of materials derived from various sources, and verified, so far as is practicable, by personal observation and inquiry. The author has endeavored to use the rich materials afforded to him with proper discrimination. If somewhat more space has been given to the chapters on "Agriculture," on "Materials of Construction," on "Mineral Fuels," and on "Ore Deposits" than to other topics, it will probably be conceded that the wide-reaching and important interests to which they relate will fully warrant this greater fullness of treatment. Where the works from which information has been most largely obtained were likely to be within the reach of those persons for whom this book is chiefly intended, they have been mentioned in the lists of works of reference appended to many of the chapters. This has necessarily precluded any specific mention of many valuable papers published in scientific journals and in the "Transactions of the American Institute of Mining Engineers," to which this book is indebted for many items of interest. For the arrangement of the seemingly heterogeneous materials of some of the later chapters, useful hints were derived from the "Geology of Canada," 1863, and from some features in the classification of the economic collection of the École des Mines in Paris. The author wishes also to acknowledge his indebtedness to the kindred works of D'Orbigny and Gente, and of Dr. Page, for many important suggestions, and to the first-named work especially for valuable aid in the preparation of the chapter on agriculture.

CORNELL UNIVERSITY, *October* 1, 1885.

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APPLIED GEOLOGY.

CHAPTER I.

INTRODUCTION — ROCK-FORMING MINERALS — CLASSIFICATION.

THE science of geology has both a theoretical and a practical side. Theoretically, it aims at an exhaustive study of the phenomena presented by the earth's crust, together with the order in time in which they originated, and the forces to whose combined or successive action they are due. It investigates the composition, the structure, the origin, and the arrangement of the earth's rocky masses. It strives to refer the present phenomena of the earth's crust to their appropriate causes. It reconstructs the history of the earth and of its successive inhabitants, using structure as its guide, and the present action of the unchanging forces of nature as its interpreter.

On the practical side, geology uses the knowledge of the earth's structure, and of the mode of occurrence and properties of its various products, to subserve human needs and promote human enjoyment. It guides the architect and the builder in the selection of fitting materials for construction—good building-stones, mortars, cements, and sands. It reveals to the agriculturist the origin of his soils, and points him to the cheapest and most effective means for correcting their defects. It teaches the civil engineer that the feasibility and expense of most of his important undertakings, the obstacles that he must overcome, and the aids of which he may avail himself, will depend in large measure on the geological structure of the region in which he must operate; and that he needs to take this into careful consideration, if he would guard against ruinous disasters, or almost equally ruinous miscalculations as to expense. It furnishes to the mining engineer the only available guide in his arduous calling, teaching him the nature and the modes of occurrence of those valuable substances for which he must seek, the laws to which they are subjected, and the irregularities and dislocations to which they are liable; and supplying him with those general principles, by applying which, he may make the technical experience gained in any one locality available under other and widely different circumstances. It aids the sanitarian in securing the two most subtile yet essential conditions of public health—pure air and wholesome water—both of which depend largely on circumstances purely geological.

Not only does practical geology hold such intimate relations with these very important interests, but, moreover, when we consider how large a proportion of the substances which civilized man utilizes for the supply of his multifarious wants is drawn from the bosom of the earth, we shall see how wide-reaching and vital are its connections with the very sources of human progress. Among these substances are the fuels that we burn; the materials that we use for illumination; the salt with which we preserve or season our food, and which becomes the basis of vast manufactures, some of whose products reach every family; the clays and sands that we fabricate into myriads of useful and ornamental forms, a number of which are found in every household, even the humblest; the ores that we smelt to provide ourselves with those implements by whose ever-widening use we are daily extending our mastery over the blind forces of nature; and, finally, but by no means least, those substances by which a cultured taste seeks for itself a refined pleasure—brilliant pigments, sparkling gems for jewelry, and handsome stones for domestic and architectural adornment. The withdrawal of any one of these classes of materials would seriously cripple human resources, and the lack of some of them would have made human advancement very difficult, if not impossible; for the stages of man's progress are well marked by the character of his pottery, and, better, by the nature and material of his implements.

It is but natural that a science which touches so vitally the interests of nearly all classes should attract the attention of enlightened governments; and we accordingly find that most civilized states have carried on to some extent geological surveys, which, while primarily revealing the geological structure of their domains, have also carefully sought out their various mineral resources. The publications of these surveys, giving an authoritative statement of the localities where valuable substances might be found, have naturally attracted capital to the development of such means of wealth, and have, doubtless, repaid manifold their cost by the increase in the taxable property of the communities that have carried them on. The two States of Ohio and Illinois published reports of their resources, beginning the one in 1870 and the other in 1866. The coal-trade alone of these two States increased from two and a half million tons each in 1870 to more than nine million tons each in 1882; and this industry in Illinois gave employment to 19,400 men and $8,230,000 capital. There is no good reason to doubt that this great increase in the coal-trade of those States was due in large measure to the reliable information furnished by their surveys.

Incidentally, also, such surveys have been of great service in discouraging misdirected and expensive explorations after substances not likely to be found in certain localities; for, second only in importance to the knowledge of what we may fairly expect to find in a given place is the certainty of what we ought not to expect to find. Large sums have been expended in New York by men unacquainted with its geological structure, in a futile search for coal in certain black, slaty rocks, holding geological positions such as have never yet furnished coal, nor are ever likely to do so. Any man would show himself ignorant indeed who should now undertake a search for coal in New York.

From what has already been said, it will be evident that at least an elementary knowledge of the earth's geological structure is essential as a guide in the intelligent prosecution of many great branches of industry. It will be necessary for our purpose, therefore, first to examine the most essential points of geological structure, and afterward to show their application to the various arts, drawing our materials as largely as possible from American sources.

Rocks: their Composition and Classification.

Geology deals with the rocks which form the earth's framework; and what is most essential to be known about rocks for our present purpose is—(1) their composition, i. e., the mineral substances which enter into them and impart to them most of their properties; (2) their texture and structure, or the characteristics which distinguish them both as rock-individuals and as rock-masses; (3) their origin, or the agencies through which they assumed their present form; (4) their mode of arrangement; and (5) the order in which they occur.

Rock-Forming Minerals.—Some careful examination of the rocks most commonly met with will prepare the observer to admit that all rocks, whatever their origin, are composed of mineral species; and, furthermore, that the minerals which play the chief part in their composition, and which most largely condition their use and durability, are comparatively few in number. These minerals, in particles varying greatly in size and regularity of form, aggregated in the most variable proportions, and consolidated by many different agencies to the most widely differing degrees of firmness, from mere incoherent masses of sand, to the hardest quartzite and the toughest trap, make up the chief bulk of the most important rocks of the globe. Ready acquaintance with them in their smallest discernible particles, and by their most obvious and easily-tested properties, is highly essential to the practical geologist. Chief among such minerals is quartz, with its most widely-disseminated compounds, viz.: the varieties of feldspar, mica, hornblende, and pyroxene, to which may be added talc, chlorite, and serpentine. Calcite and dolomite are the essential components of the various kinds of limestone and marble; while pyrite, though not largely present in rocks, should be known because of the injurious manner in which it affects their characters. The important ores and other minerals of economic use will be considered in other connections.

For a complete knowledge of these minerals, and others that will be mentioned in this treatise, the student should study the minerals themselves—all easy to be obtained—with the aid of some good treatise on mineralogy, Dana's "Manual of Mineralogy" being the best. The properties to which especial attention should be directed are, color and luster, hardness, cleavage and fracture, behavior with acids, and sometimes fusibility.

Quartz is readily distinguished by its glassy luster, its hardness, so great as not to be scratched by a knife, and by the fact that its fracture gives never flat but always curved surfaces (conchoidal fracture). It will scratch all the other minerals named above, being 7 on a scale of hardness beginning with talc, 1, easily impressed with the finger-nail, and ending with diamond, 10.

The hardest of the remaining minerals named as chief components of rocks, the **feldspars,** can be scratched with considerable difficulty by a knife, and their hardness is counted 6. Besides this, the feldspars can be split with flat, shining surfaces—cleavage—in two directions, making a right angle with each other in orthoclase, the most common kind, and in the other two important varieties, oligoclase and labradorite, varying but a few degrees from a right angle. The last two, in a good light, usually show on the face of easiest cleavage fine parallel lines, while orthoclase does not. The color of orthoclase and oligoclase varies from white to light red, while labradorite is usually gray or brown, with a beautiful internal reflection from smooth surfaces. Their luster differs somewhat from that of quartz, inclining to pearly. Their slightly inferior hardness and their flat cleavage surfaces usually make them easily distinguishable from quartz ; but if any doubt still remains, a thin, pointed splinter should be strongly heated with the blow-pipe. Any of the feldspars can be fused with more or less difficulty, while quartz can not.

The **micas** are readily distinguished by their very easy cleavage into thin, *elastic*, shining leaves. Muscovite mica is usually of light to brownish silvery colors, biotite black, and phlogopite of bronze-color. All are easily scratched with a knife.

Pyroxene, of which **augite** is the most abundant variety, and **hornblende,** as they are commonly found in rocks, are black, brown, or dark-green minerals, though some varieties are lighter green and white, a little more easily scratched than feldspar—their hardness being about 5.5—and more easily fused. Both cleave in two directions, making in pyroxene a little less than a right angle, and in hornblende a very obtuse angle of 124° 30′. Hence, when the angle of cleavage can be seen, the two minerals can be easily distinguished, otherwise not. It is helpful, however, to note that the cleavage of hornblende is easier than that of pyroxene, hence gives usually more complete surfaces and brighter luster; also that hornblende is frequently found associated in rocks with quartz and orthoclase, while augite, the most common form of pyroxene, is rarely so associated. Both are heavy minerals, and give more than usual weight to rocks in which they occur abundantly.

Calcite and **dolomite** are easily known by their ready cleavage in three directions, when crystallized, giving rise to a six-sided oblique-angled figure; by being easily cut with a knife—hardness 3 to 4; and by effervescing rapidly, from the escape of carbonic acid, with dilute hydrochloric acid. Their usual color is white. Dolomite is a little harder and a little heavier than calcite, and while calcite effervesces freely in cold acid, dolomite effervesces but slightly, if at all, until the acid is heated. Both are very important minerals, being, as has already been said, the essential constituents of all limestones and marbles.

Pyrite, or iron pyrites, is a mineral of metallic luster and light-yellow or golden color, whence it is often mistaken for gold—hence called "fool's gold"—but is readily distinguished from it by its great hardness, nearly equal to that of quartz, and by its giving when heated the odor of sulphur. It is little likely to be mistaken for any other mineral save copper pyrites, from which it may be distinguished by the fact that copper pyrites is much softer and its color is a deeper yellow.

Talc is a green, gray, or white mineral of pearly luster, so soft as readily to be scratched by the finger-nail, greasy to the touch, and usually of a scaly, foliated, or fibrous texture. Its softness and its soapy feel render it easy to be distinguished.

Chlorite, as it occurs forming a characteristic constituent of rocks, is usually a dark-green earthy mineral, but little harder than talc, and of a pearly luster when cleavable.

Serpentine is usually a massive though sometimes fibrous mineral, of an oily green color, sometimes red or nearly black, of greasy luster and slightly greasy feel, easily scratched with a knife, its hardness being about 3, and with a conchoid or splintery fracture.

To these materials of rocks should be added **clay,** an indefinite mixture of kaolin, which is a soft, unctuous substance resulting from the decomposition of feldspar, with varying amounts of quartz-sand often exceedingly fine, powdered feldspar, iron oxide, and occasionally other substances. It is plastic when wet, shrinks on drying or when strongly heated, and emits an earthy odor when breathed on. The rocks into which it enters are often described as *argillaceous* rocks, from the Latin name for clay: e. g., slate is an argillaceous rock, and a limestone containing a considerable amount of clay would be termed an argillaceous limestone. Also the following adjective terms are of frequent occurrence, viz.: *Quartzose* or *silicious*, applied to rocks containing quartz; *calcareous*, to those containing calcite; *ferruginous*, to those colored by iron oxide—usually red, yellow, or brown; and *arenaceous*, to those containing sand.

Rocks.—The minerals here described, with occasionally quite subordinate amounts of some other minerals, make up the rocks of chief economic importance. As constituents of rocks they are found, sometimes as crystals of usually imperfect outline, sometimes in the form of broken and worn grains, of sizes varying from those so minute as not to be perceptible to the unaided eye, to masses of considerable size. Hence, according to the condition of the composing substances, we may distinguish *crystalline* rocks and *fragmental*, or, as they may with equal propriety be termed, *sedimentary* rocks, because deposited from suspension or solution in water. The rocks of the latter class are found always arranged in layers or beds, and hence called stratified; while the crystalline rocks may occur either in beds more or less apparent, or without any signs of a bedded structure, when they may be termed massive. Stratified rocks, i. e., those having a layered structure, are much the most common, and examples of them may be studied in most localities where the rocks appear above the covering soil.

Sedimentary Rocks.—The sedimentary rocks are of three general kinds: (1) those formed from the worn fragments of pre-existing rocks, which may be called *mechanical* sediments, e. g., sandstones and shales; (2) those deposited from solution in water, or *chemical* sediments, as some limestones, many quartz rocks, and probably most beds of iron-ore; and (3) *organic* sediments, those formed from the worn and subsequently consolidated results of vegetable and animal growth, as most limestones and coal-beds. Beds of the second class are formed of welded and interlocked crystals, and have a degree of solidity equal to that of the composing mineral. Beds of the two remaining classes, though sometimes found as mere incoherent or slightly cohering masses like sand, gravel, and chalk, have more generally been consolidated by various means to a greater or less degree of hardness. The following are the chief means of consolidation:

Some rocks seem to be consolidated solely by the great and long-continued pressure of the overlying beds, causing the particles to adhere to each other, as is the case with many shales. When, as is often the case in sandstones, some finely-disseminated clay is present, making the contact among the sand-particles more complete, pressure gives the rock a greater degree of firmness. The presence of this clay can be detected by subsiding the finely-powdered rock in water, when the clay will remain long suspended, making the water turbid. A common means of consolidation is calcite, which has been introduced in solution, as in all sedimentary limestones and some sandstones. Its presence as a consolidating ingredient in rocks other than limestones can be readily detected by its effervescence with dilute acids. Silica consolidates many sandstones and conglomerates to a very high degree of hardness; and iron oxide is also a frequent means of consolidation, giving to rocks a red or yellow color. When red or yellow sandstones are pulverized and heated for a little time in strong hydrochloric acid, the cementing iron is dissolved, giving a deep yellow solution, and colorless grains of quartz remain.

Crystalline Rocks. — The crystalline rocks, other than the relatively small amounts of chemical sediments, are made up usually of imperfect crystals, sometimes of one mineral, but more commonly of two or more, welded, interlocked, or felted together to a mass as firm at least as the softest abundant constituent, unless a prevailing direction of some readily cleavable mineral like mica, talc, or hornblende, may dispose the rock to split more easily in certain directions. Some of these crystalline rocks have a more or less observable bedded character, often with foliation or schistose structure, and are generally believed to have once been ordinary sedimentary rocks, which, having been rendered somewhat plastic by heated water under enormous pressure, have crystallized in their present form. Hence they are termed *metamorphic* rocks, i. e., rocks which have been changed from their original condition. Other crystalline rocks show no signs of bedding whatever, their condition being probably due to a softening or fusion so complete as to have obliterated all traces of bedding, if they ever existed. In this condition they have often been thrust in among or through other rocks, emerging frequently at the surface. Where the subsequent cooling has proceeded at a very slow rate, and usually at very considerable depths, the resulting texture is coarsely and obviously crystalline; where the rate of cooling has been relatively rapid, the crystalline texture may be so fine and close as not to be apparent to the unaided eye, or the texture may in some cases be partly or entirely glass-like, i. e., vitreous. Rocks of this kind are termed *igneous* or *eruptive*, and those obviously crystalline are also frequently called *Plutonic* rocks, a term which implies the opinion that they were consolidated at great depths, and that our present opportunities for becoming acquainted with them are due to very great subsequent changes in the earth, in consequence of which they have become surface-rocks.

To give a connected view of what has just been said, a tabulated summary of rocks in general is here presented, classified according to origin, with their structure as rock-masses and the usual condition of their materials:

Classification on Origin.		Structure.	Condition of Materials.
Sedimentary	Mechanical, Chemical, Organic.	Stratified.	Fragmentary, sometimes crystalline.
Metamorphic.		Stratified.	Crystalline.
Igneous.		Massive.	Crystalline or vitreous.

Means of Consolidation:

1. Pressure.
2. Clay and pressure.
3. Silica.
4. Calcite.
5. Iron oxides.
6. Welding, interlocking, or felting of crystals.

Structure and Texture of Rocks.—By the **structure** of rocks is meant those characters which distinguish them as rock-masses, and which are usually best displayed on the large scale.

Most important of structural characters is **stratification,** which is the arrangement of rock-masses in tolerably parallel sheets or layers, varying in thickness from the fraction of an inch to several feet, and separating readily from each other. Layers of the same kind of rock lying together form a *stratum*, and alternations of different kinds of rock produce *strata* (plural of stratum). A stratum of some valuable material, e. g., coal, is frequently termed a seam or bed. Stratified rocks were undoubtedly formed in all usual cases by deposition of their materials from water, in precisely the same way that successive layers of mud and sand are being deposited now in seas, lakes, and rivers; and it is altogether probable that the division into layers is due to some considerable pause in the act of deposition, whereby the lower layer became somewhat compacted before the succeeding one was deposited; while the succession of strata marks changes in the conditions of deposit by which materials of different kinds came to be laid down.

The *massive* structure is contradistinguished from the stratified, and belongs to igneous rocks, or to those which have been so greatly changed from their original condition as to have lost all signs of bedding. The term massive is also used sometimes in contradistinction from lamination. *Lamination* is where rocks reveal the thin successive layers of which they are made up, either by some slight differences of color or texture in the several layers, or by splitting more readily on certain planes, usually parallel to the bedding. This structural character is a common one in sandstones, especially where they are argillaceous, and is occasionally seen in limestones. An excess of lamination in highly argillaceous rocks, causing them to split into thin, irregular, fragile slabs, constitutes the *shaly* structure.

Foliation, or the *schistose* structure, is a character of metamorphic *crystalline* rocks, analogous to lamination in the sedimentary series, and is due to the arrangement of the crystalline constituents in more or less definite planes, which often, no doubt, if not always, correspond to original planes of lamination, since these are likely to be the planes of easiest penetration and circulation for fluids. The *slaty* structure is one which belongs to argillaceous rocks that have been doubled up into folds, and so changed by intense pressure as to develop a tendency to cleave into *hard*, *even* slabs, in a direction at right angles to the pressure, and corresponding with the direction of the folds. The planes of cleavage rarely correspond with the original planes of lamination, though they may occasionally do so.

Joints are divisional planes in rocks, usually but not always nearly vertical, which divide the rocks of many regions into blocks that separate somewhat readily at these planes. These blocks, in regions of jointed structure, vary in width from an inch, or even less, to many feet, the main joints forming the faces of the cliffs and the back walls of the quarries; and where, as is frequently the case, there are two series of joints, cutting each other at nearly right angles, the weathered faces of the cliffs present a singular resemblance to regular piles of masonry. This structure is not confined to any one of the great classes of rocks that have been named, but may be found in all of them, occasionally even giving to massive rocks a false appearance of bedding. Practically considered, while the jointed structure greatly facilitates the operation of the quarryman, it also strictly limits the dimensions of the blocks that can be obtained.

The *columnar* structure often seen in volcanic rocks, especially the basalts, seems to be a variety of the jointed structure, in which, by the intersection of several jointing planes, the rock is divided into a series of rude pillars which are at right angles to the original cooling surfaces of the rock.

The *concretionary* structure is one which is displayed in some rocks by the collection of some mineral, notably silica, calcite, pyrite, or iron carbonate, into spherical, spheroidal, or irregular forms, e. g., the flinty nodules in chalk and limestone, the silicious balls in some sandstones, the calcareous and pyritous masses in some clay rocks, and the kidney-shaped masses of clay iron-stone.

By the **texture** of rocks is meant the internal arrangement of their constituents. The *granular* texture is displayed by rocks which are composed of worn grains or irregular crystals. These grains or crystals may vary from those of considerable size, giving a coarse-grained texture, to very minute ones, giving rise to the *compact* texture, as in many sedimentary limestones, and to the *aphanitic* or *crypto-crystalline* texture, as in some igneous rocks in which the really crystalline texture is revealed only by the microscope.

The term *granitoid* is applied to thoroughly crystalline rocks whose crystals are of approximately equal size, as in granite ; while the term *porphyritic* describes those which contain distinct crystals, notably of feldspar, imbedded usually in a very fine-grained base or ground-mass. The *vitreous* or glassy texture resembles artificial glass, and is found only in some eruptive rocks. The terms porous, fibrous, earthy, and vesicular, as applied to texture, hardly need explanation. Some eruptive rocks, originally vesicular, have had their rounded cavities subsequently filled by various minerals, giving rise to a variety of texture called the *amygdaloidal*, from the resemblance of many of the filled spaces to the almond, Latin *amygdala.*

CHAPTER II.

DESCRIPTION OF ROCKS.

Mechanical Sediments. — **Sand** is an unconsolidated mass of fine, worn grains of the harder minerals and crystalline rocks, in which quartz usually plays by far the largest and often the almost exclusive part, since it is the hardest and most enduring of the ordinary rock-forming minerals. Where the worn fragments range from the size of a pea to that of an egg, it is called gravel, still coarser gravel being sometimes termed shingle. Most sand contains particles of magnetic iron-ore, which can be detected by their clinging to a magnet. Sand, consolidated in any way, forms **sandstone.** In some sandstones pressure *seems* to be the sole consolidating agent, though doubtless a minute amount of silica cements the points of contact of the granules, producing a porous and often friable rock. The presence of a small amount of clay, forming a film which coats the grains of sand, or of a larger amount partially imbedding them, makes a firmer rock, often highly laminated—an argillaceous sandstone. Iron oxide, usually mingled more or less with clay, is a somewhat common cement, forming a red or yellow sandstone. When silica is the cementing material filling the spaces among the grains, it makes an exceedingly hard rock called a silicious sandstone; or where it occurs, as it usually does, among metamorphic rocks, it is called quartzite. Calcite is not often found as the chief cementing material of sandstones; but when it is present, it is readily recognized by its effervescence with acids. A sandstone which works equally well in all directions, without a tendency to split, is often called *freestone*—a name which is also sometimes applied to other rocks of like character. A thin-bedded laminated sandstone is a *flag-stone.* Coarse, rough-textured sandstones are often called *grits*—a term, however, not very definitely used.

A **conglomerate,** sometimes called pudding-stone, is formed of rounded pebbles, from the size of a pea to a foot or more in diameter, consolidated in any way, and with the spaces filled usually with cemented sand. Where the pebbles, instead of being rounded, are angular, the rock is called a *breccia.*

A **shale** is a highly laminated argillaceous rock, consolidated often by mere pressure, and so returning to mud when exposed for some time to the weather. Where it contains a considerable proportion of sand, it becomes an arenaceous shale, and so may graduate into an argillaceous sandstone.

Chemical Sediments.—These rocks deposited from solution in water by evaporation or cooling of the water, or by dissipation of the chemical agent that held them dissolved, although forming no great proportional amount of the rocks of the earth, still furnish several substances of great economical importance.

Calcareous deposits from water in which lime is held in solution by carbonic acid, when porous and friable, often incrusting twigs and leaves, are called *calcareous tufa;* when forming pendants from the roofs of caverns, and incrustations on their floors, are called *stalactites* and *stalagmites;* when forming compact beds, are named *travertine*, which, when banded with various colors, becomes *onyx marble;* and when composed largely of rounded concretionary grains, little larger than a mustard-seed, are termed *oölites.*

Gypsum is a sulphate of lime, which, when crystalline, is much softer than calcite, being easily scratched by the finger-nail, and cleaves easily in one direction, forming transparent, inelastic plates which quickly whiten when held in a flame. It forms considerable beds, or lenticular masses, which in some cases have been deposited by evaporation of the water that held the gypsum dissolved, and in others have been formed by a change of ordinary limestones through infiltration of sulphuric acid from sulphuretted springs. In the latter case, the gypsum forms a soft, earthy rock, usually of a gray color. When ground fine and heated, gypsum gives off much water, and leaves a powder that will *set* with water.

Salt occurs in beds or masses, sometimes of enormous thickness, which have doubtless been formed by the evaporation of inclosed bodies of sea-water. It is usually associated with beds of gypsum and of anhydrite—a mineral like gypsum, but containing no water.

The waters of some springs, especially in regions of volcanic disturbance, deposit silica, sometimes on the surface as hard, porous incrustations, called *silicious sinter*, as about hot springs and geysers; sometimes filling fissures in other rocks, forming common vein-stones that are connected with many valuable ore-deposits.

Iron-ores, which occur usually as beds associated with various other rocks, doubtless owe their origin to chemical deposition. *Siderite*, i. e., iron carbonate or spathic iron, occurs crystallized in the same form and with the same cleavage as calcite, but is somewhat harder and of considerably greater comparative weight—specific gravity—besides being of a brownish color; also, when heated in a test-tube, it turns black and becomes magnetic. When it occurs in kidney-shaped concretions, it is termed *kidney-ore* or *spherosiderite;* when mixed with clay, it is *clay iron-stone;* and when forming a black, bituminous, shaly mass, it is called *black-band.*

Limonite is an iron oxide containing some water, and forms masses of a fibrous or earthy texture, and of a color varying from brown to black; but its powder and the *streak* which it makes on an unglazed porcelain surface are of a dull yellow color. When heated in a test-tube, it yields steam which condenses in the upper part of the tube, and becomes magnetic, though not so before heating.

Hematite has the composition of limonite, but without water, and forms beds of a red, steel-gray, or black color, and of a texture varying from earthy or compact, to those mica-like, or to thin, tabular, very brilliant crystals. The streak and powder are of a dark cherry-red.

Magnetite is black, has a black streak and powder, and attracts the magnet strongly. It forms a crystalline, granular, or sometimes compact rock, of great weight, and is easily known by its magnetism and its black powder. The last three iron-ores form very heavy rocks, and, when crystalline or compact, are of about the hardness of feldspar, being scratched with some difficulty by a knife.

Organic Sediments.—These rocks, formed of the hard parts of very minute organisms, or of the remains of any organic growth ground up or macerated, and afterward consolidated either by pressure or by partial solution of their own substance, embrace all the coal-beds of the world, and all extensive deposits of limestone, besides those peculiar silicious deposits called tripoli.

The **limestones,** usually composed mainly of calcite, form beds of a drab, gray or blue color, sometimes red or black, and of a texture varying from earthy to subcrystalline or compact, which last are the most common. These rocks almost always contain a greater or less quantity of some impurity—iron, giving them a red color ; carbonaceous matter, making them dark ; or clay and silica, which are often found in such amounts that when the rock is burned for lime it will not slack with water, but when ground and mixed into mortar will set under water to a mass of great hardness, and is hence called *hydraulic lime*. Many limestones, besides calcite, contain also a considerable proportion of dolomite, or are made up almost wholly of dolomite. Such are called *magnesian limestones* or *dolomites*. *Chalk* is a very soft, earthy limestone, usually white, made up of the calcareous skeletons of very minute organisms. The limestones, when burned properly, lose their carbonic acid and become quicklime, which, on application of water, falls into a powder, i. e., slakes, with the evolution of considerable heat, which is greater in the case of the calcitic than in that of the dolomitic limes. Hence the former are called "hot limes," while the magnesian are termed "cool limes."

The limestones that are found associated with crystalline rocks have been metamorphosed by the action of heat, are of prevailing white or light colors, though often clouded or tinted by impurities, and are of a crystalline granular texture; sometimes of very fine grain, as in the best statuary and architectural marbles, sometimes coarse-grained. Any limestone which is susceptible of a fine polish is usually called a *marble*, the crystalline limestones furnishing probably the largest proportion of these. The crystalline limestones frequently contain certain disseminated minerals, forming mixtures, some of which are prized for ornamental purposes, like the verd-antique marble or ophiolite formed by the intermingling of calcite and serpentine.

Mineral coals are formed of former vegetable growths which have been more or less macerated, subjected to a peculiar, partially smothered decomposition, and consolidated by the pressure of the superincumbent rocks. A rude but convenient commercial classification of them is made according to the amount of volatile combustible matter that they contain. Those that contain little volatile matter, and hence are hard and lustrous, kindling with difficulty, and burning with but slight blue flame, no smoke, and intense heat, are called *anthracites*. *Semi-bituminous* coals are those that contain from ten to about eighteen or twenty per cent of volatile matter, and *bituminous* coals have a still higher percentage than this. Both these latter kinds kindle easily, and burn with a yellow flame and much smoke. Some of these coals soften while burning, and the pieces fuse together into a mass, which needs to be broken up to admit of ready burning—these are called *caking* coals; others do not soften while burning—such are the non-caking coals, named, from various qualities, splint or block coal, cherry coal, and cannel. The coals will be more fully considered in another place, and are mentioned here merely in their place as organic sediments.

Metamorphic or Stratified Crystalline Rocks.—A brief description only can here be given of the most widely disseminated and important species of metamorphic as also of massive crystalline rocks. Many of the varieties to which distinctive names are given by lithologists are not frequently met with, and are of little practical importance; it will not be expedient, therefore, to burden the attention of the student with them in a treatise like this.

As has already been said, the metamorphic rocks are those which are thought once to have been ordinary sedimentary rocks, and to owe their present crystalline condition to a more or less profound change caused by the agency of heat and moisture. They still show their original bedded structure with more or less distinctness, but the beds are invariably much disturbed, thrown out of their original nearly horizontal position, bent and folded, testifying to the action of enormous mechanical forces.

The most widely-diffused and most profoundly changed of these is *gneiss*, a foliated, crystalline compound of quartz, feldspar—usually orthoclase—and mica, the foliated arrangement of the minerals, sometimes very perfect, giving the rock a highly schistose structure, sometimes so indistinct as to make the mass difficult to distinguish from granite, which has the same composition, and which differs from gneiss only in the absence of all traces of bedding. Indeed, some masses of gneiss are believed by careful observers to be of eruptive origin, while it can hardly be doubted that some granite is only the extreme stage of metamorphism of rocks which once were stratified. Where hornblende replaces the mica of gneiss in whole or in part, we have *hornblendic* or *syenitic* gneiss.

Mica schist is a highly foliated rock composed of quartz and mica, the mica often highly prominent and enveloping the quartz, which is in irregular plates, knots, and seams; while in other cases the quartz predominates, the mica being present in only sufficient amount to give the mass a schistose structure. Where the mica almost wholly disappears, the rock still retaining the schistose structure, it is sometimes called *quartz schist*, which is therefore a rock consisting almost wholly of quartz, and showing a tendency to split into parallel layers.

A rock composed of grains of quartz, sometimes of considerable size, bound together by a silicious cement into a mass of flinty hardness, is called *quartzite*. It is a sandstone, metamorphosed by the infiltration of a silicious solution, or by the softening of the outlines of its grains, into a rock breaking with the characteristic glassy fracture of quartz, while its granular texture and bedded structure testify to its original condition.

A variety of mica schist, in which the quartz is usually in small amount, and the mica is a hydrous variety, i. e., containing water, is called by Dana *hydro-mica schist*. These schists have usually a grayish or greenish color, a pearly luster, and a greasy feel like talc, whence they are commonly called *talcose schist*. A true talcose schist is not a common rock. It is a foliated aggregate of scaly talc, with small amounts of quartz or feldspar, of whitish to greenish colors, and unctuous to the touch.

Chlorite schist is a foliated rock composed of chlorite and some quartz, with occasionally small amounts of other minerals. Its usual color is a dark green. It is commonly a soft rock, but sometimes the quartz, which usually occurs in scattered leaves or bunches, so interpenetrates and interlocks the entire mass as to give it a considerable degree of hardness.

Hornblende schist is a black or dark-green foliated rock, composed of dominant granular or fibrous hornblende, having a foliated arrangement, with minor quantities of quartz or feldspar. When the foliated structure is wanting, a rock of similar composition would be called *amphibolite* or hornblende rock.

Serpentine is a dark-green or reddish-brown rock, of compact texture and greasy feel. It is so soft as easily to be scratched by a knife. The mineral serpentine of which it is composed is probably, in all cases, a product of the metamorphism of other minerals or rocks. It usually occurs in irregular beds among metamorphic schists.

The Igneous or Massive Crystalline Rocks.—Most important of these is **granite,** already alluded to under gneiss. It is a compound of quartz, feldspar (mostly orthoclase), and mica ; feldspar is usually the predominant ingredient, of an impure white or reddish color, while mica is the least prominent. The quartz varies from white to smoky-brown in color, and may readily be distinguished by its fracture, hardness, and luster. The texture of granite varies from very fine-grained to one made up of crystals of considerable size, the crystals being interlocked, or welded together at their surfaces, so as to form a mass of great firmness. The mica in granite may be partially or entirely replaced by hornblende, giving rise to a usually darker-colored granite, called *syenitic granite.* Where the quartz disappears from a granitic rock it is called *minette* or mica trap ; where feldspar dies out we have *greisen*—a rock interesting only from its association with tin-ores ;

while the disappearance of mica gives rise to a rock called *aplite* and *pegmatite ;* or, if of foliated structure, *granulite.*

Felsite is an intimate mixture of feldspar with some quartz, of an exceedingly fine-grained—i. e., aphanitic or flinty—texture, and of a variety of colors, from yellowish to nearly black. It greatly resembles some quartz rocks, from which it may be distinguished by its slightly inferior hardness, its hardness being that of feldspar, and by the fact that in thin splinters it can be fused like feldspar before the blow-pipe, while quartz can not.

Syenite is a granular crystalline rock, composed of orthoclase and hornblende, the orthoclase predominating, and, from its usually being of a reddish color, giving the rock a prevailing red tint. Sometimes, however, feldspar of a lighter color occurs, yielding grayish syenites.

Trachyte is a grayish, or sometimes reddish or brownish, rough-textured compound, in which feldspar predominates, often showing glassy crystals, united with some hornblende or augite and dark mica, while magnetite is rarely absent. A trachytic rock of highly silicious character, and often displaying quartz-granules, but rarely containing hornblende, with a matrix usually very compact, or even enamel-like, is called *rhyolite* or *liparite.*

Diorite is a granular, dark-green, tough rock, composed of oligoclase feldspar and hornblende, with usually some magnetite. It differs from syenite in its kind of feldspar, in its usual range of color, and in being usually of finer texture.

Dolerite is a granular rock of gray to black colors, composed of labradorite feldspar and augite, with usually some magnetite. When it is exceedingly fine-grained and compact, it is called *basalt.* Basalt often contains grains of a bottle-green mineral called chrysolite. When dolerite contains chlorite, giving it a greenish color, it is often called *diabase.*

The rocks described above are by far the most widely distributed, and therefore most commonly met with; and with them have been named a few of less frequent occurrence, as exhibiting interesting variations of composition or structure.

Key for Approximate Determination of Rocks.*

The following brief key for rock determination, based on (1) texture, (2) hardness, and (3) structure and composition, may prove useful to the beginner:

1. Examine freshly broken, angular fragments with a lens.
    - *A*. Components not perceptible. See 2.
    - *B*. Components perceptible. See 4.
2. Test hardness of 1 *A* with a knife:
    - *a*. H 1 to 3½, easily scratched with a knife—sedimentary or decomposed:
        - a′—Very soft, earthy aspect, plastic when wet, Clay.
        - b′—Harder, in thin, irregular, fragile laminæ, Shale.
        - c′—*Cleaving* to thin firm plates, Slate.
        - d′—H 3, effervescing strongly with cold acid, Limestone.
        - e′—H 3 to 4, effervescing sluggishly with cold acid, rapidly with hot, Magnesian Limestone.
        - f′—H 2.5 to 3.5, usually green, somewhat soapy to the touch, not effervescing, Serpentine.
    - *b*. H 5 to 6, heavy, becomes black and magnetic by heat:
        - g′—Streak and powder yellowish brown, luster earthy to silky, Limonite.
        - h′—Streak and powder red, luster earthy to metallic, may be perceptibly crystalline, Hematite.
    - *c*. i′—Not scratched by knife, glassy luster, conchoid fracture, Quartz Rock.
        - j′—H 5 to 6, black or gray, often holds green grains of olivine, Basalt.
        - k′—H 6, fusible in thin splinters. See 3, or possibly, Felsite.

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* The idea of this key was suggested by Geikie's excellent "Text-Book of Geology."

3. 2 k′ may be glassy, when if—

l′—Of uniform texture, dark color, translucent on edges, of glassy aspect, Obsidian.

m′—Of pitchy aspect, various colors, slighty translucent, Pitchstone.

n′—Of rounded grains, of frequent concentric structure, in enamel matrix, Perlite.

n″—Of enamel-like matrix, often holding grains of mineral, especially quartz, Rhyolite.

NOTE.—The exact determination of hard, very fine-grained rocks usually requires microscopic and chemical examination.

4. Test hardness of 1 *B*.

o′—Soft, gray to white, crystalline to earthy, heated yields vapor and whitens, Gypsum.

p′—Easily scratched, effervesces readily with acid, Limestone.

q′—Slightly harder than p′, effervesces sluggishly with acid unless hot, Dolomite.

r′—H about 4, brown, effervesces with hot HCl, giving yellow solution, Siderite, etc.

s′—Of hard, rounded grains, chiefly quartz, cement various, Sandstone.

t′—Of hard, rounded, or angular pebbles, Conglomerate or Breccia.

u′—Of quartz-grains cemented by silica, fracture usually glassy, Quartzite.

v′—H 6, color and streak black, heavy, magnetic, Magnetite.

w′—H variable, schistose, with glistening surface, of mica and quartz, Mica Schist.

x′—Soft, color white to light green, soapy feel, schistose or massive, Talc.

y′—Easily scratched, dark green, slightly soapy, schistose, Chlorite Schist or Hydro-Mica Schist.

z′—Hard, greenish black, rather heavy, schistose, chiefly hornblende, Hornblende Schist.

a″—Hard, chiefly quartz, but schistose from a little mica, Quartz Schist.

b″—Scratched with difficulty, of interlocked or welded crystals. See 5.

5. Rocks of 4 b″ alternate with other crystalline rocks or show some foliated arrangement of their crystalline constituents—metamorphic. See 6.
Rocks of 4 b″ do not alternate, are massive, send branches into other rocks—igneous. See 7.
6. Composed of the following minerals, more or less distinctly foliated:
c″—Quartz, feldspar, and some mica, Gneiss.
d″—Quartz, feldspar, and hornblende (mica), Syenitic or Hornblendic Gneiss.
e″—Quartz, feldspar, and chlorite or talc, Protogine Gneiss.
f″—Quartz and orthoclase, often garnets, Granulite.
7. Rocks eruptive or intrusive, composed of—
g″—Quartz, feldspar, and mica, Granite.
h″—Quartz, feldspar, and hornblende (mica), Syenitic Granite.
i″—Orthoclase and hornblende, often red, Syenite.
j″—Oligoclase and hornblende, dark green or black, Diorite.
k″—Labradorite and augite, gray to black, Dolerite.
l″—Feldspar base and clear crystals of orthoclase, rough to the feel, Trachyte.
m″—Aphanitic base holding crystals of feldspar or quartz, Porphyry or Quartz Porphyry.

This key is intended only as a convenient aid to the student in finding the probable variety of rock with which he has to deal. His specimens should with this aid be carefully compared with descriptions in works on geology or lithology, and much critical study and comparison will be necessary to avoid the probability of error. It is well to be slow and painstaking at first, that one may be rapid later.

For a wider study of rocks, the student is referred to the following works: Von Cotta, "Rocks Classified and Described," translated by Lawrence; Geikie, "Text-Book of Geology," Book II; Dana, "Manual of Mineralogy and Lithology."

CHAPTER III.

ARRANGEMENT OF ROCK-MASSES.

ROCK-MASSES may be built up into the structure of the earth's crust in any one of three ways: First, and far the most widely diffused, as *stratified* rocks, or those occurring in nearly parallel beds of various thickness; second, as great *unstratified masses* like granite, exhibiting no signs of true bedded structure; and, third, as *included* or *vein-form* sheets, or masses of rock-material, differing from the inclosing rocks in composition or in structure, or in both respects, and occupying what were once apparently open fissures or cavities in these rocks.

Stratified Rocks.—The most striking character that marks the stratified rocks, and that from which they derive their name, is their occurrence in parallel sheets or strata piled one upon another to form masses often of vast thickness. These beds, when not metamorphic, usually contain indubitable evidences that they have been gradually and successively deposited in water, and mostly in the waters of the sea, in a manner exactly analogous to that in which beds of mud, sand, gravel, peat, and limestone are being accumulated at the present day. Most convincing of these evidences of formation in water is the frequent occurrence in the bedded rocks, at the most various depths, of the remains of animals, most commonly marine, and occasionally of plants, which often retain their structural characters in a high degree of perfection. Such traces of the former plants and animals of the globe are called **fossils**; and they not only give us some glimpses of the life-history of the usually remote periods during which the rock-materials were accumulated, but they also furnish valuable evidence of the conditions under which they were formed, whether in marshes, or in water, marine, brackish or fresh, clear or turbid, and at greater or less depths. It is obvious that of the beds thus superimposed on each other the lower will have been the earlier formed, while the overlying beds will be successively younger. Thus in stratified rocks whose normal position is obvious, or can by any means be made out, superposition is regarded as a reliable evidence of relative age. The several beds in any series of stratified rocks are usually separable from each other with little difficulty at their plane of junction, probably indicating that the lower bed had been somewhat consolidated before the materials of the succeeding one were deposited. A character peculiar to stratified rocks, because it results from successive deposition, is lamination, as already defined. It belongs more especially to the finer-grained sediments, like shales, fine-grained and somewhat argillaceous sandstones, and to some argillaceous limestones. Commonly the planes of lamination are parallel, or nearly so, to those of bedding; but in some rocks, especially sandstones, they may be diagonal to the bedding, giving rise to what is called false bedding or current bedding. Usually, but not invariably, rocks split more easily on the lamination than in other directions; and such rocks, when used in structures, should always be laid with their edges to the weather, as they will be more durable in that position.

When a stratified rock becomes metamorphic, lamination gives place to foliation, the planes of mineral arrangement, in most cases, probably following the original planes of deposition; or slaty cleavage takes the place of the original tendency to split on lamination planes, while the laminæ may still frequently be displayed in bands of different shades of color.

Position of Strata and Definition of Terms.—The original position of the beds of stratified rocks must have been nearly horizontal; but, as the result of the action of forces, for a discussion of which the student should refer to general treatises on geology, the strata in all metamorphic regions, and in many localities where the rocks have undergone no noteworthy transformation, are no longer horizontal, but are bent, doubled, and crumpled on the large scale, and often broken, with the fractured ends slipped past each other. The disturbances of strata, and the changes to which they have been subjected, give rise to the use of several terms, the meaning of which it is important to understand.

The **dip** of strata is the amount of their departure from a horizontal plane.

Where the dip is considerable, it is conveniently measured by means of an instrument called a clinometer, a convenient form of which is that of a foot-rule, two inches wide, folding to six inches, in one face of which is hung a delicate pendulum, swinging on the center of a graduated semicircle. (Fig. 1.)

This instrument held before the eye, and its lower edge made to agree in direction with the slope of the inclined rocks—or, better, set on its edge on a slip of board laid upon the rocks and shifted carefully about until the pendulum shows the greatest possible inclination—will give the *dip* of the strata with a good degree of accuracy.

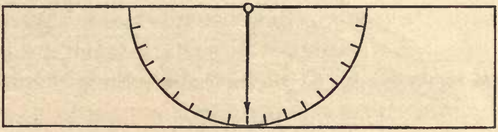

FIG. 1.

Where, however, the dip of the rocks is slight, as in much of New York, in western Pennsylvania, and in several Western States, it is found by ascertaining the height of some persistent stratum above a fixed plane like the sea-level, at several points where it appears in natural exposures, or is revealed in borings or excavations. The mutual distances of these points being found, the dip per mile and the direction of the dip can be ascertained. The *amount* and *direction* of dip are points of great practical as well as scientific importance, and should be carefully observed.

The **strike** of rocks is a direction at right angles with their dip, so that when the second is given the first may be known. For example: the dip of the rocks in a large part of New York is south, inclining a little west. Hence, the strike or the direction in which the rocks range across the State is nearly west; and it would be the same if the dip were in an exactly opposite direction, or to the north.

A **monoclinal** fold is one in which the strata dip in but a single direction. A common case in our Western Territories is that which is sketched in the following diagram, where horizontal strata are sharply folded up into a somewhat steep ridge, and then resume their original nearly horizontal position:

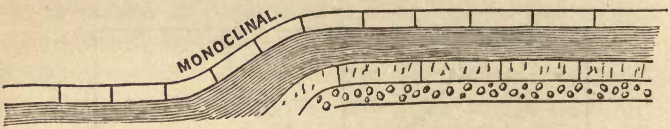

FIG. 2.

An **anticlinal** fold is one in which the strata dip away from an axis, forming an arch, as in Fig. 3, where *a* represents the axis of the fold from which the strata dip each way. A common occurrence with such folds is that the strata are broken at the axis, when the agencies of wear either plane down the fold to a level, its presence being indicated only by the opposite dip of the strata; or, where hard beds occupied the surface, the strata may be cut out along the axis, as indicated by the dotted line in Fig. 3, leaving two more or less marked ridges.

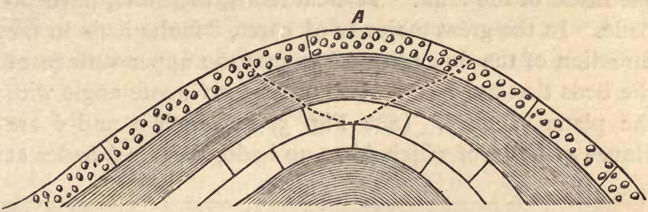

FIG. 3.—Anticlinal.

A **synclinal** fold is where the strata dip from opposite directions toward an axis, forming a trough, as in Fig. 4.

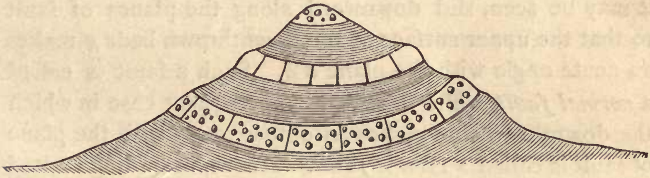

FIG. 4.—Synclinal.

In greatly disturbed regions, these folds are often so thickly set as to give the strata a crumpled appearance, visible even in hand specimens.

Frequently, also, not only in folded regions, but also in those in which the strata retain a nearly horizontal position, the strata are found to have been broken across, and the beds on one side of the break to have been dropped below those on the other, so that the two halves of the same bed no longer occupy the same plane. Such an occurrence is called a **fault**, and the faulted beds are said to be *thrown.* Thus we speak of the *downthrow* and the *upthrow.* The plane of fracture, though sometimes vertical, is usually inclined more or less from the vertical. The amount of this inclination from the vertical is called the **hade** of the fault. Vertical faults, therefore, have no hade. In the great majority of cases, "faults hade in the direction of the downthrow," so that the upper surface of the beds that have slid down makes an acute angle with the plane of fault. (See Fig. 5, in which *a* and *b* are planes of fault, of which *b* has no hade, while *a h* hades at an angle of 50° with the vertical.) The beds *c d e f* have it may be seen, slid downward along the planes of fault so that the upper surface of the downthrown beds *g* makes an acute angle with the plane *a h.* Such a fault is called a *normal fault*, while the much less frequent case in which the downthrow side makes an obtuse angle with the plane of fault is called a *reverse fault.* Hence, in mining faulted beds, like those of coal or iron, in the absence of other indications, the continuation of the bed is to be sought down the fault-plane when it slopes from the workings, and up it when it slopes toward the workings, as may be seen from the left side of Fig. 5. The walls of fault-fissures, when they consist of firm rocks, are often smoothed or glazed, and striated in the direction of movement. Such glazed surfaces are called *slickensides.*

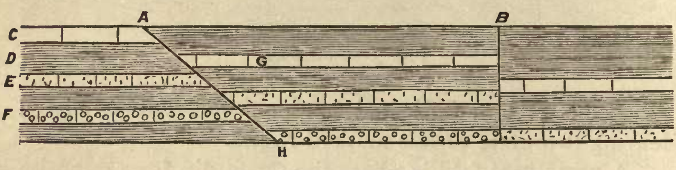

FIG. 5.—Faults.

Where strata are laid open to observation by the removal of loose materials, the point of appearance is called their **outcrop** or **basset.** Frequent places of outcrop are along the shores of bodies of water, or in the banks of deep-cut streams, or on the eroded sides and summits of hills and mountains.

Conformable strata are those which succeed each other in the regular and parallel order of superposition.

Unconformable strata are those in which (1) the overlying beds rest against the upturned and eroded surface of the lower beds, not agreeing with them in dip, as in Fig. 6; and (2) the overlying beds rest upon the much-eroded surface of the underlying ones, agreeing with them in dip, as in Fig. 7.

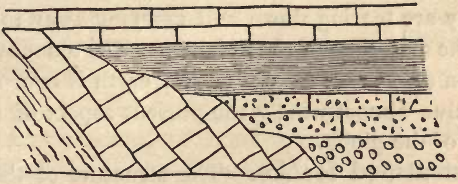

FIG. 6.—Unconformity by Upthrow.

In either case, "the base of the one set of beds rests in different places on different parts of the other set of beds." The first kind of unconformability is the more commonly observed, and doubtless always includes what is essential in the second, viz., the erosion or denudation of the lower beds, before the deposition of the upper ones. Unconformability testifies unmistakably to a considerable lapse of time, during which important physical changes occurred, including notable changes of level, as intervening between the periods of deposition of the two sets of beds.

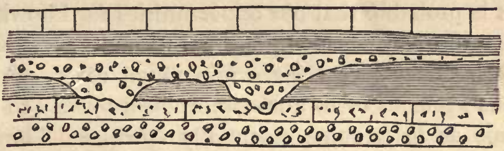

FIG. 7.—Unconformity by Erosion.

The term **denudation** is applied to the waste and wear of rocks by weathering and by the agencies of water and the atmosphere. (See Fig. 3 for illustration.) Denudation is a phenomenon which is going on constantly before our eyes, not more obviously in the tremendous rending and grinding action of the waves than in the silent activity of rivers, brooks, and rills, whose turbidity testifies that they are tearing down and carrying away to valley or ocean the materials of the uplands. The amount of denudation in all elevated parts of the earth is enormous, and to it is due almost wholly the present aspect of the land-surface of the globe.

Unstratified Rocks.—The structure of these rocks is massive, and, as their name implies, they show no signs of bedding or of successive accumulation, their only divisional planes, where they occur, being of a jointed character. Though it can hardly be doubted that unstratified rocks form the foundation on which all stratified rocks rest, yet they are of far less frequent occurrence as surface appearances than those of the stratified series; and it is probable that our opportunities for knowing them are due in many cases to great uplifts and enormous denudations. They owe their origin in all cases, perhaps, to igneous agencies or to a metamorphism pushed to such an extreme as to become essentially igneous. They occur, sometimes as great bosses, like granite, surrounded by other rocks into which they frequently send out arms; sometimes as the central portions of great mountain-chains, as in parts of the Sierra Nevadas and the Alps; sometimes as vast sheets of enormous thickness, as in portions of our Western plains; sometimes as great cake-like masses, called laccolites, thrust into the midst of stratified rocks and bulging them up into dome-like eminences, as in the Henry Mountains of Utah; and sometimes as great interbedded sheets overlaid by beds deposited apparently since they were poured out as lavas, as in the so-called melaphyre rocks of northern Michigan, whose amygdaloidal portions furnish in some cases rich repositories of native copper.

Included or Vein-like Rocks.—The masses here called *included* fill what, in the great majority of cases if not in all, appear once to have been open fissures or cavities in the inclosing rocks. In some cases the filling materials have evidently been introduced in a state of igneous fusion, such included masses being called **dikes.** In other cases the fissure or cavity has apparently been filled from solution in water or by sublimation, such inclusions, where they fill fissures of greater or less extent, being called **veins,** and, where they fill irregular cavities, being called by the German name **stöcke,** or stocks.

Dikes are usually nearly vertical in position, and have a more regular and wall-like form than veins, whence the name dike, signifying a wall. Indeed, irregular and branching fissures filled with material apparently injected in a plastic state are usually called veins rather than dikes, as in the case of granite veins. The fissures filled by dikes not unfrequently follow pretty closely for considerable distances the bedding planes of stratified rocks, giving to such dikes the appearance of beds. The rocks which form the walls of dikes have usually been metamorphosed to varying distances by the heat, common changes being consolidation, baking, and crystallization. The material of dikes is frequently fissured by joints, which pass often into a columnar structure, the columns being perpendicular to the walls. Dolerite with its varieties, basalt and diabase, is a common dike-forming rock, though some other varieties of igneous rocks are occasionally found forming dikes.

Some veins, usually in granite, gneiss, or the crystalline schists, are filled with material similar to that of the surrounding rock, though in a somewhat different crystalline state, often coarser; and their composing minerals were apparently separated from the inclosing rock to fill rents of small extent during the process of consolidation. Such are called veins of segregation.

True veins, called frequently mineral veins, fill what have once been open fissures of variable extent, both vertically and horizontally, some veins cutting the rocks to unknown depths, while others are quite shallow ; some being traceable for miles, while others die out in a few rods. The materials with which they are filled usually differ notably from the inclosing or country rock. They are usually of a crystalline granular texture, though often earthy from decomposition or other causes, and have often a banded structure of different minerals arranged parallel to the walls. They are frequently the repositories of valuable metallic ores, and hence they, as also stocks, will be more fully discussed in a subsequent chapter under the head of ore deposits.

Relative Age of Rocks.—Probably the most frequent question asked about rocks by persons little versed in geological science is with regard to the approximate age of certain strata, the marks of whose great antiquity have been so obvious as to impress even the casual observer. To this question it is not probable that any very satisfactory answer can ever be given. It can only be said, in a vague and general way, that the time embraced in the events to which geology testifies is very long even to those computations which would make it briefest. The *relative* age, however, of the stratified rocks can be made out with a good degree of certainty, not only for limited districts, but for all that portion of the globe which has been geologically explored ; and the various strata have been arranged in a series which expresses approximately the order of their appearance in time. This series has also been separated into larger and smaller subdivisions or groups, which, while based on certain interesting facts in their life-history or lithological constitution, are of vital importance as affording a means of ready reference for both scientific and economic purposes.

These groups of strata, which, if piled upon one another successively, would make a stupendous mountain-mass more than a hundred thousand feet in height, are nowhere found forming a complete and connected series; but rather, certain portions are found in one region, while other parts of the series must be studied in other and perhaps distant localities. The reasons for this fragmentary distribution may be briefly stated. They are (1) that during the vast periods of time embraced in geological history, the regions where rock-materials might be deposited have been slowly but constantly changing, by reason of fluctuations of level which have caused great and often repeated changes in the distribution of land and water. Thus, the areas where rocks were laid down have been repeatedly shifted from age to age, regions which had taken no part in rock-making, because they were dry land while certain series of rocks were deposited, subsequently changing places with former water areas, and becoming themselves the theatres of deposition.

To this may be added (2) the probability that many strata, once deposited in certain regions, have been entirely or partially removed by denudation in the course of subsequent changes.

The means by which an orderly arrangement of the members of a series so essentially fragmentary into a connected system has been effected are chiefly the following:

1. **Superposition.**—From what has already been said about the mode of formation of stratified rocks, it is obvious that the lowermost strata will have been first formed, while the overlying ones must be successively more recent. Hence, in any region where the natural succession of the strata has not been too much confused by uplifts and faults with subsequent denudation, the observed order of superposition of the strata, as studied in tolerably con-

tinuous outcrops, will give their relative age; and, if then some well-marked bed or stratum of this region can be positively recognized in some other locality where additional strata occur, the two series may be connected in the order of time, and ultimately the same mode of observation may be extended to include other and far more remote areas. Thus the observed order of superposition is not only a very valuable but wholly indispensable means of studying the relative age of strata. But it frequently happens that over wide spaces the succession of the strata can not be directly observed because they are covered by surface accumulations, or separated by bodies of water: how, then, shall we recognize strata already well studied in certain localities, when we come upon them in regions somewhat remote? Or, again, from what is apparently a completely continuous series of strata, whole groups of beds may be wanting from the causes mentioned above, without leaving anything to mark their absence: how, then, shall we be able to detect this absence, and to assign the strata that would make the series really complete? This recognition at distant localities of kindred strata, that is, those having like positions in similar series, this detection of groups missing from a seemingly consistent series is accomplished by a second and highly important means:

2. The **Use of Fossils.**—Throughout a very large portion of the time during which the stratified rocks have been accumulating, it is certain that forms of life have existed on our globe; and the fossil evidences of their existence have been preserved, to a very useful degree, in nearly all stratified rocks which are not metamorphic. Now, the various distinguishable stages in the great series of rocks, arranged in the order of their relative age, are characterized by the prevalence of certain forms of life, species or genera not found in other members of the series; or by certain groupings of forms which do not exist elsewhere

in like relations; so that by the careful comparative study of the fossils of localities separated from each other more or less widely, the rocks which contained them may be placed in their proper relative place in the chronological series. For figures and lists of the fossils which characterize the several members of the geological system, the student will do well to refer to some one of the excellent treatises on geology, like Dana's "Manual of Geology," Geikie's "Text-Book of Geology," Lyell's "Elementary Geology," or Le Conte's "Elements of Geology." Some examples of their use may be profitable. A large and peculiar family of crustaceans called Trilobites, because the body is divided lengthwise by depressions into three lobes (see Fig. 8), while found somewhat abundantly in the rocks below the coal-measures, has not yet been seen in any higher rock; and some of its genera, and nearly all its species, are limited in their range to certain sets of rocks: hence the family of Trilobites is characteristic of the rocks from the coal-measures downward; and its species, and in some cases genera, become distinguishing marks for the groups of rocks to which they are confined. So the Spirifer (see Fig. 9), an easily recognized genus of shells, which is confined to the strata from the Upper Silurian to the Lower Jurassic (rock groups presently to be mentioned), has well-marked species which are confined to the several groups of strata, and hence are used as landmarks for these groups, while the genus as a whole distinguishes all the rocks within the limits named.

FIG. 8.

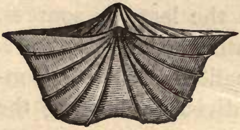

FIG. 9.

3. The **lithological characters** of strata, though in

many cases they furnish very unreliable marks for recognizing rocks, save within quite limited spaces, from the fact that they do not remain constant, but frequently change, so that within a comparatively short distance a conglomerate may be seen to pass into a sandstone and then to shade off even into a shale, yet in some cases, and especially among the older rocks, show such persistency as to make them very convenient guides for the rocks of certain districts. Thus, in central New York, a band of limestone called the Tully, usually not more than ten to fifteen feet thick, though occasionally rising to as much as twenty-five or thirty, is persistent in character over more than eighty miles from east to west, and furnishes a most valuable guide to the relative age of the rocks throughout its extent. So, likewise, in tracing coal-beds from one valley to another, use is made of certain somewhat persistent beds, usually of sandstone or limestone, as *key*-rocks, within tolerably regular distances above or below which the coal-beds are likely to be found. The availability of these key-rocks is greatly increased if, in addition to pretty uniform lithological characters, they also contain some well-marked distinguishing fossils; but, in any case, lithological characters, if carefully used within limited areas, are of great use in giving guesses at truth, to be afterward confirmed by other and more reliable evidence.

By the careful use of the three means just described, the relative ages of the stratified rocks are made out. By the use of characters derived from the last two sources, but chiefly from the second, the entire series of strata is also separated into greater and smaller groups, for convenience of reference, the larger divisions holding the same relative position and bearing the same names over the entire earth; while the smaller subdivisions, which usually differ widely in details in regions very remote from each other, are apt to receive in every country special names of local significance, and are afterward paralleled with each other, as far as possible, by a careful comparison of fossils. Thus the crystalline schists, which underlie all the fossiliferous stratified rocks, are generally termed Archæan; the fossiliferous rocks which succeed these, and which are characterized throughout by a profusion of invertebrate fossils, a few remains of fishes being found only in the upper beds, are called Silurian, and admit of a generally used division into Lower and Upper Silurian; the succeeding groups of strata, in which fishes of strange aspect are the dominant though by no means the most abundant forms of life, are called Devonian; to which succeeds the Carboniferous formation, characterized by the abundance of its coal-beds, and by the prevalence of land-plants belonging mostly to the highest cryptogams. Overlying the Carboniferous are found in many places great series of strata, which, with an abundance of other fossils, are characterized by the remains of reptiles, often of great size and uncouth forms. These rocks, termed usually Mesozoic, are susceptible of a threefold division, universally used, into Triassic, Jurassic, and Cretaceous periods. To the Mesozoic succeed the rocks called Tertiary or Cainozoic, which are characterized by the prevalence of mammals, forms of life which up to these rocks are represented only by a few very rare fragments, and in which the invertebrate remains have usually a strong resemblance to, and often identity with, creatures now living. Its widely recognized divisions are called Eocene, Miocene, and Pliocene. Lying upon the Tertiary deposits, where these occur, are found the more recent and usually unconsolidated surface materials, including drift-clays and bowlders, beach and terrace deposits, and other accumulations of kindred character, containing in some parts the remains of man or his works, and called Post-Tertiary or Quaternary.

The whole series of formations, from the top of the Archæan to the top of the Carboniferous, is usually called collectively the Palæozoic—i. e., the age of ancient life—because all the forms of life found in it resemble so remotely those now prevalent on the globe ; the term Mesozoic, applied to the succeeding rocks, signifying their approximation in forms of life to the existing state of things ; while the name Cainozoic (recent life), given to the Tertiary strata, is significant of the resemblance of its fossils to living species.

Subjoined is given, in tabulated form, the more comprehensive divisions just described, with the larger subdivisions, as recognized by American geologists :

Quaternary or Post-Tertiary,		Recent or terrace, Champlain, Glacial.
Tertiary or Cainozoic,		Pliocene, Miocene, Eocene.
Secondary or Mesozoic,		Cretaceous, Jurassic, Triassic.
Primary or Palæozoic,	Carboniferous,	Permian or Permo-carboniferous, Coal-measures, Sub-carboniferous or Lower Carboniferous.
	Devonian,	Catskill, Chemung, Hamilton, Corniferous, Oriskany.
	Upper Silurian,	Lower Helderberg, Salina, Niagara.
	Lower Silurian, including Cambrian or Primordial,	Hudson, Trenton, Canadian, Primordial, Potsdam most important.
Archæan,		Huronian, Laurentian.

Of a number of the divisions given, there are subdivisions of much local interest, for which, as well as for the European subdivisions, the student can, if he desires, consult the treatises mentioned on page 39. By the student familiar with German, the elaborate tables of European strata given in Credner's "Elemente der Geologie" can be consulted with advantage.

CHAPTER IV.

ECONOMIC RELATIONS OF GEOLOGICAL STRUCTURE.

HAVING now briefly considered those portions of structural geology which seem essential to the ready comprehension of what is to follow, let us consider how geological science may make men's practical endeavors more effective.

Economic geology may be defined to be that department of science which treats of the earth's structure and mineral products as they are related to the supply of human wants.

The economic geologist considers structure as it concerns the adaptability of rocks and strata for certain purposes, or as it is related to the occurrence and accessibility of valuable deposits. He regards rocks as in themselves fitted for certain uses, or as the probable repositories of useful materials. He is interested in the relative age of strata, and the means by which it may be determined, because it furnishes him an available guide to their possible desirable contents. He aims at an accurate and extended knowledge of those geological deposits which have practical utility. Nay, more: these deposits bear to each other practical and often very essential relations. Of these he takes careful note—for example, the proximity of metallic ores to the fuels and fluxes necessary for their beneficiation, or to the kindred ores with which they may profitably be mixed. Moreover, useful materials are valuable or valueless, according to their relations to the currents of human industry and to the means of profitable utilization. What value has an excellent quarry-stone, remote from transportation and from the great centers of construction? Of what present worth is an ore of moderate richness, at a long distance from the means of smelting or of easy concentration? What avails a rich placer deposit, without an abundant water-supply for its cheap separation? To such considerations, and others like these, little noted by the ordinary geological observer, the economic geologist must be keenly alive, for they are what constitute the relations of structure and products to the supply of human wants. Nor are these wants, as signified by demand, by any means constant. The progress of discovery or invention may change very greatly the economical estimate of a substance once little regarded. The naphtha and Seneca oil of thirty years ago are the petroleum of to-day. Iron pyrites has become a substance of great commercial importance, since its recent use as a source of sulphur in the manufacture of sulphuric acid. The ores of molybdenum and tungsten, till lately regarded only as interesting minerals, are now called to the attention of the United States geologists by their use as pigments; while all deposits of nickel have recently become of greatly increased interest since the wide use of this metal in electro-plating. Hence it is desirable that the economic geologist should always bear in mind "that, much as may already have been utilized, there are still many substances in the earth's crust which can be turned to account in the increasing requirements of modern civilization." (Page.)

Economic Relations of Geological Structure.— The economic bearings of geological structure are numerous, and of the most obvious importance. Structure, for example, conditions the relative accessibility of desirable substances; the facility with which they may be worked; the ease and consequent expense with which excavations and tunnels may be made, and their durability when finished; the reliability of the foundations of important engineering and architectural structures; the accessibility, the abundance, and the continued purity of deep-seated water-supplies; and not unfrequently the possibility of effective drainage.

Accessibility.—Among stratified rocks, it is obvious that their *dip* must exert a paramount influence on the accessibility of any particular bed from the surface. If the dip is slight, the depth below the surface of a bed will increase but slowly as we recede from the outcrop in the direction of dip; while, if the dip is considerable, the depth, and consequently the difficulty of access, increases rapidly. A dip of one degree carries the strata down ninety-two feet in a mile. The following table shows the descent for a surface-distance of one hundred rods for dips of from one to twenty degrees, and for every five degrees thereafter up to forty. It will be obvious that when we pass beyond the outcrop of a bed in the line of its ascent, this bed will disappear and give place to underlying beds:

Dip	1°	descent for	100 rods,	28.8	feet.
"	2°	"	"	57.6	"
"	3°	"	"	86.5	"
"	4°	"	"	115.4	"
"	5°	"	"	144.3	"
"	6°	"	"	173	"
"	7°	"	"	202.6	"
"	8°	"	"	232	"
"	9°	"	"	261.3	"
"	10°	"	"	291	"
"	11°	"	"	321.5	"
"	12°	"	"	350.7	"
"	13°	"	"	381	"
"	14°	"	"	411.4	"
"	15°	"	"	442	"

Dip	16°	descent	for 100 rods,	473	feet.
„	17°	„	„	504.5	„
„	18°	„	„	536	„
„	19°	„	„	568	„
„	20°	„	„	600.5	„
„	25°	„	„	769.4	„
„	30°	„	„	952.7	„
„	35°	„	„	1155.4	„
„	40°	„	„	1334.5	„

It may be seen from this table that even small dips make an important difference in accessibility at some distance from the outcrop, while dips of 5° and upward make necessary, before mining operations are begun, a careful estimate of the cost of sinking shafts, and the after perpetual expense of hoisting to the surface the water and the mineral which is the object of search. In all cases, therefore, where the dip of the rocks is known or can be ascertained, it needs to be taken into careful consideration in judging of the depth at which valuable deposits may be reached. In making this estimate also it should be remembered that the rate of deepening below a given plane is greatest directly down the dip, and diminishes each way from this line.

Faults also affect the accessibility of deposits relatively to our workings. They may bring the continuation of a bed nearer to the surface or remove it farther from the surface, or, bringing it within reach of denuding agencies, they may have caused it to be entirely removed. In even the most favorable cases, since they interrupt the continuity of beds, faults derange the underground approaches and means of transportation and increase the expenses of working.

Great *uplifts* with subsequent *denudation* have likewise in many regions brought within easy reach deposits which must otherwise have remained utterly inaccessible. Indeed, it is reasonably certain that the great class of crystalline rocks with their valuable stores of building and ornamental stones, and the still more valuable veins of metallic ores which many of them inclose, have by this means alone been made accessible to man. In other cases the agencies of denudation, by excavating deep valleys in undisturbed and nearly horizontal strata, have, while sweeping utterly away great masses of valuable deposits, made the outcropping edges of the remainder easy of access and of drainage by tunnels driven into the hill-sides where they are found. Numerous examples of this kind may be found in mining for coal and iron-ores.

Relations of Structure to Facility of Extraction.—Useful substances, whether building-stones, mineral fuels, or ores, are extracted from their repositories either by open workings called quarries or by underground mining operations; and the ease with which these processes can be carried on, and the resulting materials reduced to merchantable dimensions, depends in an important measure on structural characters. In many cases the workings may be so arranged with reference to the dip of the strata as to clear themselves of water or to collect it where it can be most conveniently removed, while the handling of the materials is facilitated by a descending grade. The *bedded* and *jointed* structure of many rocks greatly aids the operations of the quarryman, enabling him, where there are two sets of joints at nearly right angles, to extract, with little waste of material, tolerably regular blocks of a size limited by the distance apart of the joints and the thickness of the beds. Where the bedding or the jointed structure, one or both, is wanting, recourse must be had to the laborious operations of channeling or drilling, with subsequent wedging or blasting, in the last case often with great waste of material. The jointed structure of coal, called the *cleat* or *face*, and the *end*, is of such importance that the workings must agree with it in direction. Where the beds are very thin, or the joints very closely set, the rock may be unfitted for any useful purpose, while the presence of a single system of joints at suitable distances may adapt a thick-bedded or massive rock for being extracted for large columns or for monoliths. The *laminated* or *schistose* structure of many rocks is an important aid in reducing them to proper dimensions. Availing himself of this, the workman, by repeated blows along the edges, causes thick masses to split parallel with the bedding, and thus with no great difficulty brings them to the thickness desired. The presence of *concretions* or of a concretionary tendency, as also of cross or current bedding, should be carefully noted, as they measurably or entirely unfit a rock for use.

Relations of Structure to Expense of Excavation, Tunneling, etc.—The ease and consequent expense with which excavations, tunnels, shafts, and other engineering works of like character can be accomplished, and their permanence when finished, will depend very largely on the nature and structure of the rock formations through which the works must be pushed ; and all estimates of expense should be based on the best attainable knowledge in these respects. The *hardness* of the rocks that must probably be penetrated ; their *firmness* or ability when cut through to sustain the pressure of the masses above and around them without artificial support; their *durability* in sides and roof when exposed to the atmosphere and weather; the *position* of beds, whether horizontal or highly inclined; and their *succession*, whether tolerably uniform or in alternations of firm beds with others that are friable or of ready disintegration; their *permeability*, whether close-grained and solid, or porous and seamed with fissures and joints, so as to make them ready water-ways—these and other considerations of like import are of vital interest in all undertakings of this character, and they present questions which can be satisfactorily answered only by a careful geological examination. Beds of hard, firm rocks with few or no joints will be difficult and expensive to penetrate ; but they will be self-supporting throughout and durable when finished, and in cuttings only a minimum of material needs to be removed. The first cost, therefore, is likely to be the only cost ; while incoherent strata of gravel and sand, though easy of excavation, require support at every step by expensive curbing or by arches of masonry, or, in cuttings, materials must be removed until the angle of rest is attained, so that the cost in the two cases may eventually prove not very unequal. Friable sandstones, fissile and easily decomposed shales, and not unfrequently the cut edges of highly inclined strata, will need proper support in both sides and roof, while fissured and porous water-bearing beds must have due provision made for carrying away the superfluous water, or must be masked by impervious walls.

The cutting of one of the most extensive tunnels in this country passed through many vicissitudes, and was ultimately completed only after years of delay, presumably through insufficient knowledge on the part of its projectors of the obstacles likely to be presented by the region through which it had to be driven, and consequent insufficient estimates of probable expense ; and the contractors for driving a tunnel to supply one of our great lake cities with water, meeting with an unsuspected waterway in the tough clay through which they were cutting, were forced to close the end of their workings by a strong bulkhead, and make an expensive *détour* to avoid the obstacle thus unexpectedly presented, yet which careful previous trials would probably have revealed. The history of many similar works would doubtless furnish additional illustrations of the importance of a knowledge of geological structure to those engaged in engineering enterprises of the kind here considered.

Foundations of Engineering and Architectural

Works.—It is evident that the stability of the foundations of engineering and architectural structures must depend entirely on their adaptation to the geological character of the underlying formations. If firm rock can be reached at reasonable depths, the best possible foundation is gained. Thick beds of tough and homogeneous clay also afford good foundations. But, where a great depth of loose, uncompacted materials is encountered, expensive preparations must be made to insure the stability of heavy structures. The great viaduct in Cleveland, constructed at a cost of more than two million dollars, was built across an alluvial flat, where immense sums had to be expended in deep excavations, driving close-set piles, and building up a substructure of grouting, before the piers of the bridge could be commenced. Every considerable town can furnish numerous examples, in the cracked and distorted walls of buildings, not always large nor heavy, of the need of using precautions proportioned to the native instability of the substratum on which the structure must rest. So, too, one occasionally sees important retaining walls yielding to the easily foreseen thrust of alternating beds of clay and quicksand, partly from insufficient attention to the character of the beds to be sustained, and partly from the lack of due provision for draining off the water which, in heavy rains, heightens manifold the natural instability of such deposits. In structures intended to hold or convey water, such as dams, reservoirs, and canals, minute attention is needed to the character and structure of the underlying beds. For such constructions, no substratum can be better than tough and compact clay, or close-textured and massive rocks, nor could anything well be worse than loose sands and gravel, or porous, fissured, and jointed rocks. In the first case, little care is needed, save to secure the requisite strength and thoroughness of work ; while in the second no precaution can be too great to remedy the innate defects of the foundation. Especially is this true when high dams are to be built, in which the pressure of a great column of water will heighten the permeability of the substratum and exaggerate its every defect, and where any defect unremedied is sure to lead to terrible disasters.

Structure and Water-Supply.—An abundant supply of wholesome water, free from risk of organic contamination, is of vital importance to individuals and communities; and it is a provision which the growth of population and its concentration on limited areas render every day more needful and more difficult. The usual sources of supply for families and small communities, aside from cisterns filled from roofs, are wholly geological in their nature, and depend for their character, their permanence, and their safety, on the structure of the region in which they are found. They are springs, wells dug or driven in drift or other surface accumulations, and artesians bored through drift or rock, often to very considerable depths, in which the water either overflows at the surface, or rises within easy reach of pumping apparatus. The term artesian is often confined to wells of this class that overflow, though with no very good reason; for it will presently be seen that what is really characteristic about wells of this kind is that they derive their water from sources deeper seated than usual, and that the origin of their supplies is not local, but more or less remote.

Springs.—These are sources of water arising from the underground circulation of the water that penetrates the earth from rain and snow. This water descends through the loose and porous materials until it meets with an impervious bed, usually of clay, along which it flows, until it gushes forth in a valley, or on the eroded edge of some hill. Such springs are liable to contamination from impurities on or near the surface into which their waters first sink; but, if the point of issuance is at a considerable distance, the impurities are likely to be removed, largely through the chemical agency of the air circulating in the permeable beds.

In Fig. 10, *a* and *b* are springs, represented as issuing on the side and at the base of the hill, at the junction of the sand and gravel beds 1 and 2 with the impenetrable clay-beds 4 and 5. The porous bed 3 is also a water-way, but does not produce a spring because the valley *c* is not eroded deep enough to intersect it. The water issuing at *a* is liable to contamination from any sources of impurities found between *a* and 4, and that at *b* from the area between 4 and 5; but the latter, having a greater distance to flow, would be surer to be freed from organic contaminations by the action of the air circulating in its bed. Both will be likely to take into solution portions of any soluble minerals, like lime or gypsum, which they may meet with in the beds through which they percolate; and, if such minerals occur in any considerable amount, the water of the springs will be *hard;* but, if little or no soluble minerals are met with, it will be *soft*—the terms hard and soft, applied to water, being used to describe the extent to which they are charged with or are free from dissolved minerals, with certain

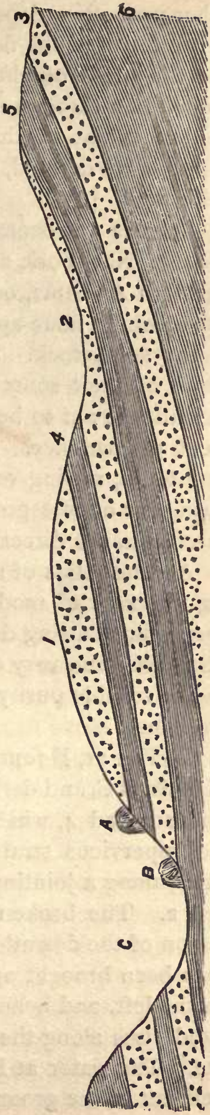

FIG. 10.—Illustration of Springs. (After Geikie.)

other properties dependent on this. The abundance and permanence of the flow of such springs will depend on (1) the thickness of their porous beds, (2) the freedom of percolation through these beds, dependent on their texture, (3) the extent of the gathering ground from which their supplies are derived, and (4) the amount of rainfall of the district.

Springs are occasionally met with, like those at Union Springs, New York, and the "Big Springs," so abundant in northern Alabama, one of which supplies Huntsville with water, which issue apparently from the mouths of caverns in the solid rock. Such springs, because of the great depth of their source and the extent of their gathering ground, are apt to be of very considerable volume and of great permanence. Also fissured rocks, such as jointed limestones, resting on impermeable strata, cause lines of springs or of wet ground on the sides of hills where they outcrop in the direction of their dip.

Another class of springs is found in many regions, rising in strata of moderate dip, along lines of fault or on open joints cutting down to porous, water-bearing strata. They are often very copious, and are usually both durable and of reliable purity. They are indeed a kind of natural artesians.

In Fig. 11, D represents a spring rising along the plane of fault, D C, and deriving its waters from the porous sandstones 2 and 4, which are inclosed above and below by the impervious strata 1, 3, 5, while B represents a spring rising along a jointing plane which penetrates to the porous bed 2. The broken ends of the water-bearing beds, by reason of the downthrow on the right of the faulting plane, have been brought opposite to strata not easily penetrated on the left, and hence the water with which they are saturated rises along the fault or joint from hydrostatic pressure. The water at B having but little head would merely well out of the ground, while that at D would be likely to gush out with considerable force, since its sources at 2 and 4 are elevated above the point of outflow. The force and abundance of outflow and the quality of the water will depend on the same circumstances as in the case of artesians presently to be described.

Wells.—The chief source of water-supply for domestic uses, for isolated dwellings, and small towns, where springs are not at hand, is found in wells, open excavations of varying depths, reaching either to some water-bearing stratum confined by impervious beds of clay, or to a common water-level of the district, below which all the beds are saturated with water. The depth of the well in either case will naturally depend on the depth below the surface of the general water-level, or of the special water-bearing stratum. In many localities the unconsolidated materials are of little depth, and do not carry water, so that the well-excavation, if it succeed at all, must be pushed through rock to some porous or open-jointed water-bearing stratum, the probability of reaching which within reasonable depth through means so expensive

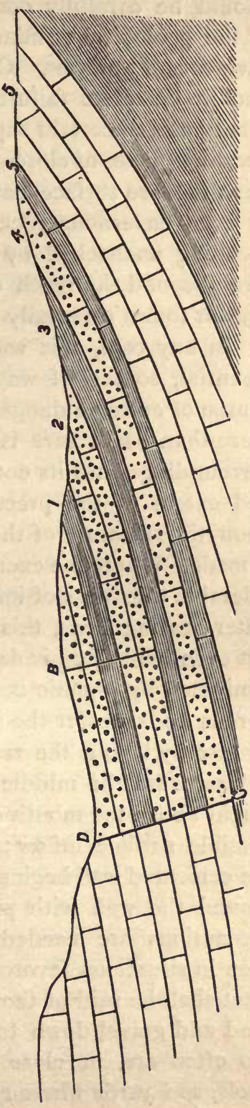

FIG. 11.—Illustration of Springs from Faults and Joints. (After Geikie).

should be carefully considered beforehand, in the light of the geological structure of the district as revealed in ravines and quarries. Otherwise, a costly excavation may end in complete failure, or be forced to depend on the scanty and uncertain supplies oozing from the joints and bedding-planes of close-grained rocks. In still other localities the loose surface materials rest immediately on fissured or even cavernous rocks, through which their water, descending unchecked by any impervious bed, are drained away beyond the reach of wells. Such are the so-called *dry lots* found especially in some limestone regions.

In any case, this widely used and convenient, if not essential, source of water-supply is liable to become a source of extreme danger to health, and even life, unless more than usual care is used as regards its location, its surroundings, and its construction, and unless the nature and extent of the precautions that are used are based upon the structure of the locality in which the excavation is made. Where the excavation has passed through a considerable thickness of impervious clay before reaching the water-bearing beds, this is highly favorable to security; but even here there is danger that the water may be contaminated by organic impurities leaching into it through porous beds nearer the surface. This should be guarded against by laying the retaining wall in hydraulic cement, at least from the middle of the clay-seam to a sufficient height above the mouth of the well to be secure from any possible surface inflow; special care being taken where the cemented wall begins in the clay to fill the entire space around the wall with puddled clay or cement. If such precautions are needed to insure safety from vitiation, even in situations favored by the underground structure, what shall be said of those wells excavated wholly through sand and gravel down to the water-level, located, as they too often are, in close proximity to house-drains, cesspools, and yards where animals are kept? In such cases an outbreak of certain too well-known types of disease, is usually only a question of time and of the power of human beings to resist poisonous influences. In all such localities it would be safer to obtain water for household purposes from well-constructed cisterns, into which the water should be admitted through a filter easily constructed with washed gravel, sand, and coarsely powdered charcoal ; but, if a well is to be dug, it should be carefully located as remote as possible from every probable source of contamination ; and, because of the extra hazard, special precautions should be used in the way of water-tight walls to secure filtration through as wide a space as possible. In a situation like that here described, and such are frequently to be found, even the degree of care here recommended may not secure perfect immunity ; less than this is sure to expose health and life to needless hazard. Nor should it be forgotten that the apparent purity and clearness of water afford no reliable criterion to its freedom from dangerous contamination. The germs of disease lurk unsuspected in many a bright and sparkling draught ; and it is to use very moderate language to say that a very considerable proportion of the ailments with which human beings are afflicted arise from the tainted waters which they drink. Indeed, in most long-settled, highly cultivated, and densely peopled districts, the soil becomes so saturated with organic substances that no comparatively shallow and open surface-wells can be considered safe.

Driven Wells.—These wells, made by driving down to a water-bearing bed an iron pipe shod with an iron point, and pierced with holes around the bottom to admit the water when it is reached, are practicable in unconsolidated beds of sand, gravel, and clay, where there are no bowlders to obstruct the driving; and present some great advantages over the usual open excavations, not only in the ease and rapidity with which they may be made, but in their freedom from risk of contamination from above, by the access of those surface-supplies of water which are liable to be loaded with organic impurities. If they reach to considerable depths, and in their descent pierce through beds of tough clay, the water that they furnish is likely to be excellent and reliable. In some of the southward-reaching valleys of the lakes of central New York, deeply filled as they are with stratified beds of unconsolidated materials, wells of this kind are often sunk to depths of from sixty to more than a hundred feet; and, in many cases, the structure of the containing beds causes them to overflow at the surface, sometimes with considerable force, constituting them veritable artesians. The water of these wells, though sometimes very slightly sulphurous, is excellent.

Driven wells are feasible only under the conditions mentioned in the first sentence of this paragraph; but there are large areas in the United States where such conditions are presented, and where the driven well would doubtless yield more wholesome water-supplies than those furnished by the common surface excavations. The chances that the water will overflow in any given case will depend on the conditions presently to be mentioned as conditioning the outflow from artesian borings.

Artesian Wells.—These wells are essentially borings, often of very great depth, which penetrate porous water-bearing strata of moderate dip, confined both above and below by other strata that are practically water-tight, the entire series of water-bearing and impervious beds outcropping at its elevated edge, often many miles distant from, and at a considerable elevation above, the points where borings are made. In some cases the series of water-bearing beds with their impervious cover form great basin-shaped depressions, around which their elevated edges outcrop on all sides, covered only by loose surface accumulations; but this kind of structure is by no means essential to success, provided only that the confined waters do not find easy egress at some point down the dip of the strata, or provided that the porous strata gradually change their character below the boring, as is frequently the case, and become practically water-tight.

In Fig. 12, which represents an ideal section across a basin-formed depression, 1, 2 is a water-bearing sandstone confined between impervious strata of shale, 4, 5, and 6, 7; and 3 is also a stratum of porous sandstone, which, near the center of the basin, thins out and becomes merged in the shale; while the dotted line C, D, marks the level of the opposite edges of the strata. It is evident that water entering at the outcropping edges 1, 2, and 3 of the porous beds, and filling them to saturation, will, at any points, as A and B, be subjected to a pressure equal to that of a column of water reaching from the dotted line to the top of the bed at that point; and that, if borings be extended to the water-bearing strata at these points, the water will overflow through them with a force proportioned to the height of the head above the mouth of the well. Should a boring be made at D through both water-bearing beds, the water in it would barely reach the surface, because its mouth would be on a level with the upper edges of the beds, while at A the water would be under a great head, and would issue with much force. At

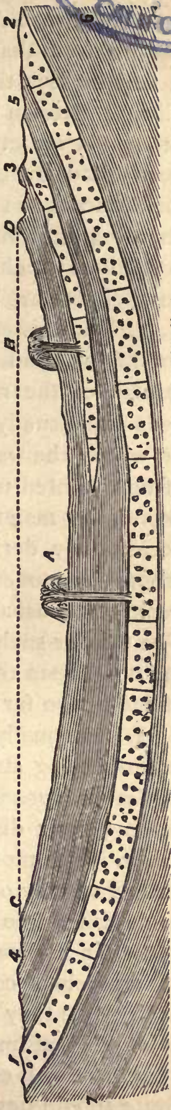

FIG. 12.—Illustration of Artesian Wells. (After Chamberlin.)

points between A and D, water would issue with a force varying from that at A to a mere quiet outflow. From this it may be seen that the possibility of obtaining water-supplies by artesian borings is entirely dependent on the larger geological structure of the region; and that this needs to be studied by the aid of the best attainable means, to make success in such necessarily expensive undertakings anything but a mere lucky chance. A brief review of the conditions which insure success will render this more obvious. These are:

1. The existence of porous strata to serve as collectors, conductors, and reservoirs of the water supplied by the rainfall of the region. The most reliable water-bearing beds are usually porous sandstones and conglomerates; or, where the water is derived from deep accumulations of uncemented materials, the same substances as sand and gravel, the materials of ancient beaches. Artesians may occasionally derive their supplies from fissured and cavernous limestones; but the chances of striking such *water-pockets* are usually too slight to encourage explorations. The thicker such beds are known to be in the region, and the more open their texture, the better will be the chances of success so far as this condition is concerned.

2. An equally essential condition of success is that the water-bearing strata should be covered and underlaid by *continuous*, *impervious* strata, confining the waters, and preventing their dissipation by percolation either above or below. The most reliable strata for this purpose are thick masses of clay or shale; though compact rocks of other kinds, when free from fissures, like some limestones, may, in certain regions, prove useful auxiliaries. The *continuity* of impervious cover throughout the entire extent of the beds, while they retain their character as water-ways, is a point of great importance.

3. A third essential condition is, that the series of strata should have a moderate dip from their outcrop to-

ward the point where the boring is proposed. A dip of one degree, as has been said on a former page, will carry the strata down about ninety-two feet in a mile, and one of two degrees one hundred and eighty-five feet per mile. Hence, any very considerable dip would, in no great distance from the outcrop, carry the strata beyond the reach of practical exploration. The table given on pages 46 and 47 will, where the dip is known, aid in estimating approximately the depth to which the boring must be carried. The inclination of the beds, as it may carry the outcrop of the water-bearing strata above the level of the well-mouth, will cause the water to overflow, or bring it within the reach of pumps. A deduction, however, of several feet for a distance of a number of miles, needs always to be made from the height to which the water might theoretically be expected to rise, on account of friction, and the resistance which even the most porous beds oppose to the free flow of water.

4. A consideration of much importance as regards the abundance of the water-supply that may be looked for from any porous beds, and one also which depends on the amount of dip, is the breadth of absorbing surface which these beds expose at their outcrop. The breadth of exposure on a level surface of beds one hundred feet thick, with a dip of one degree, would be a trifle more than a mile, and for two degrees dip, about half a mile, the breadth of surface exposure varying inversely as the dip. Hence a moderate degree of dip will give a greater extent of gathering-ground, or *area of catchment*, as it is often termed.

5. A fifth essential condition is, that there shall be no obstructions to a free flow *between* the site of the boring and the outcrop of the water-bearing beds. Such obstructions may be presented either by faults interrupting the continuity of the strata and rendering possible springs of the kind described in a preceding paragraph, or by dikes of volcanic origin cutting across the strata, and rendering

hopeless any flow below the obstruction, although success may be achieved above. Fig. 13, in which A represents a volcanic dike intersecting the water-bearing stratum B,

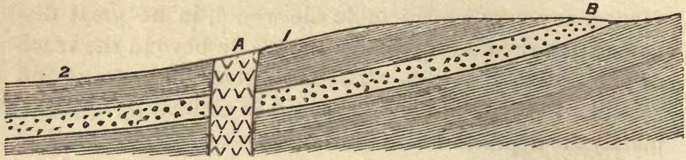

FIG. 13.—Illustrating effect of an Obstruction. (After Page.)

will illustrate the effect of this kind of obstruction. In this case, a boring between A and B, as at the point 1, would be likely to succeed, while one below A, as at 2, would be hopeless. Such obstructions, in regions where they are likely to occur, are usually not difficult to discover, and should be sufficient to deter men from undertakings that are sure to be futile.

6. The last consideration to be mentioned, which is meteorological rather than geological, has reference to the usual amount of rainfall which may be depended on to supply with water the gathering-ground of the porous strata. In large areas west of the Mississippi, the average rainfall is but small, yet it may be sufficient, under conditions otherwise favorable, to make artesian borings fairly successful; but in all the region east of the Mississippi the usual annual amount of rainfall is so abundant as to make the question of sufficient supply, under proper conditions, a reasonable certainty. A rainfall of thirty inches per annum, which is well within the average rainfall of the Eastern United States, would supply to the gathering-area of a hundred-foot stratum, dipping at an angle of one degree, 3,400 barrels of water a year for every foot in width across the outcrop; of which, if but one third is taken up by the stratum, upward of 1,100 barrels per year will be stored in every foot of its width. Hence the enormous

flow from some noted artesians need excite no surprise. An artesian well in the city of Louisville is said to yield 330,000 gallons every twenty-four hours from a depth of 2,086 feet; one in the city of Paris, the Grenelle well, discharges over half a million gallons per day, from a depth of 1,806 feet; while one, bored by a French engineer in the Sahara Desert, is said to have yielded at the outset 1,000 gallons per minute, or about 1,500,000 gallons per day.

The quality of the water yielded by such borings will naturally depend on the character of the strata which form the water-ways. In many cases it is very good; but in others the water derived from certain strata is found to be too heavily charged with mineral substances to be adapted for domestic use. It is usually difficult to predict the quality of the water that is likely to be obtained from a given set of beds; but a single test is commonly sufficient for a large district, for these deep-seated water-ways are apt to underlie extensive regions with strata of a tolerably uniform composition.

From what has been said of the structural characters which are essential conditions of the success of artesian wells, it may easily be understood that they should not be undertaken without a careful consideration of the geological character of the region. Much indispensable information may be gained with regard to the nature, thickness, order of succession, and dip of the strata, and the direction of their inclination, by consulting the geological reports and maps published by many of the States, and now being issued by the United States for the Western States and Territories. This, supplemented by such local observations as may be possible, will enable a careful person to form a judgment as to the probabilities of success in any given case. To enter upon such undertakings without such care would be to incur a great and needless hazard.

The student desiring larger information on the important subject of water-supply and artesian wells is referred to the "Reports of the Geological Survey of New Jersey" for 1876, 1882, and 1884, the last two of which are especially valuable; and to the first volume of the "Geological Survey of Wisconsin" (1873–'79), p. 689, from which Fig. 12 was copied: the second volume of the same report, pp. 149–171, has several interesting sections, showing the conditions under which artesian borings have succeeded in that State. Also the second "Report of the Geological Survey of Arkansas," pp. 52–67, has much of interest on this same topic; and notices of wells and borings may be found in many places in the "Final Reports of the Ohio Geological Survey."

Structure and Drainage.—The matter of effective drainage, so important for both sanitary and agricultural purposes, has also its geological aspects, though these may not in the majority of cases be the chief ones. The necessity for drainage, in not a few cases, arises from causes purely geological, and in many of these the evil may be remedied by means suggested by a knowledge of the geological structure. Fields rendered wet and cold by an impervious hard-pan may be found capable of amelioration by the mere use of the subsoil-plow, breaking through a thin crust to porous beds below. House-drainage on clay sites may be found practicable by sinking cess-pools to beds of sand and gravel beneath, in which case it is well to remember that the water-supply derived from neighboring wells will naturally be endangered. Districts may be rendered swampy and malarious by impervious strata at no great depth below the surface, where the topography of the region is not such as to offer outlets for drains. In some instances of this kind effectual relief has been found in the existence of deeper-seated porous or fissured strata, wells sunk to which have furnished the requisite outlets for drains. Still other districts have been made pestilent marshes by the presence of outcrops of rock or tough clay obstructing the natural drainage by streams, where the removal of such obstacles might reclaim to fertility large tracts of land, with immediate improvement of the health of the surrounding region. A work of this kind has recently been completed in New Jersey, while others are suggested—all justly regarded as legitimately belonging to the geological survey of the State. (See "Geological Reports of New Jersey" for 1869, 1870, 1877, and 1884.)

From what has been said in the preceding pages, it will be apparent that questions of geological structure are of deep concern to many prominent branches of human industry; and that in some matters of paramount importance they touch the interests of nearly every family. Other highly interesting relations of geological structure will be more appropriately treated of hereafter, when we come to consider the mode of occurrence of ore deposits.

CHAPTER V.

MATERIALS OF CONSTRUCTION.

AMONG the many useful substances which the earth's crust yields for the supply of human wants, the materials of construction may justly claim a leading place, both on account of their wide diffusion and their very general and highly important uses in both architectural and engineering structures. These, leaving out of view for the present iron, so largely used in modern structures, as rather an indirect than a direct geological contribution to the arts of construction, are the various kinds of building and ornamental stones, the brick clays, the mortars, and the cements.

Building-Stones.—The qualities which fit a building-stone for its various uses may be conveniently considered as belonging to two classes: (1) the *necessary* qualities, which are obviously strength and durability; and (2) the *desirable* ones, which are facility of working and beauty, whether of color, texture, or susceptibility of finish. Unless a rock has strength sufficient to endure any strains to which it may probably be subjected, and such powers of resistance to the usual agencies of decay as to enable it to withstand them for long periods under the conditions in which it is to be placed, it is wholly unfit for use in any important structure. When these essential qualities are assured, any properties which it may possess that will facilitate the work of reducing it to desirable forms will diminish largely the expenses of construction, while whatever may make it pleasing to the eye will greatly enhance its value for architectural purposes and for many ornamental uses.

1. Strength.—Let us first consider those properties on which the *strength* of stones depends. These are (1) *Closeness* and *compactness* of *texture*, in virtue of which all the grains of the stone being closely approximated touch each other at many points, and thus mutually sustain each other. Where such grains are large and loosely arranged, the tendency of strain is to press them more closely together, and so to tear them loose from their consolidating means, and when this is done the stone crumbles. (2) *Degree* and *means* of *consolidation*. The more completely the consolidating medium enwraps the particles of the stone and fills all the spaces among them, the stronger it will be. Some of the porous sandstones and earthy limestones have evidently but a small proportion of cementing material; a thin film of clay or of clay and iron oxide, a minute amount of silica or calcite at the points where the grains touch each other, seems to be all that holds them together; and, in the case of some friable rocks, it would seem that the particles are consolidated merely by the adhesion of their faces. Such rocks are not likely to have any great amount of strength, though some of them may be used for purposes where no considerable strength is required. Again, among the several consolidating materials, some like silica have greater inherent firmness than others, and this they are likely to impart to the stones which they cement. (3) *Hardness* and *cleavability* of *grains*. It is natural to expect, especially in the case of crystalline rocks whose grains are held in place by the interlocking or felting of the crystals, or by the welding together of their faces, that the intrinsic hardness of the grains and their susceptibility to cleavage will determine in a great degree the strength of the rocks. Moreover, where cleavable minerals are largely present, the smaller the size of the grains the more varied will be the direction which the planes of cleavage will be likely to have within a given compass, and the less the liability to yield to crushing from this cause. (4) *Direction* of *strain.* The great majority of bedded rocks offer a decidedly greater resistance to crushing when the strain is exerted in a direction at right angles to their planes of bedding; and the difference in the power of resistance to transverse or parallel strains is the greater the more distinctly laminated or foliated the rock is. This fact affords a good reason why such stones should always be laid on their natural bed. (5) *Elasticity.* The results of experiments recently published in the Geological Report of Indiana for 1881, indicate that where weight is to be sustained by stones with only the ends supported, as in the case of lintels and beams, *elasticity* is an important consideration, and that the elasticity of limestones is probably greater than that of sandstones or even of granite.

The strength of building-stones is determined by crushing cubes of a given size, usually of two inches edge, in a press which indicates the amount of force applied, and then reducing the result to terms of the force exerted on a square inch of surface. A table of the strength of several well-known building-stones, derived chiefly from the determinations of General Gillmore, is given below, with the percentage of water absorbed by each. Where the absorption is given as "very little," as in the marbles and granites, it is far below one per cent. The extremes of strength in the stones tested by General Gillmore are: for granites, from 9,500 pounds to 24,040 pounds; for marbles, from 7,612 pounds to 20,025 pounds; for limestones, from 3,450 pounds in a Caen freestone to 25,000 pounds; and for sandstones, from 4,250 pounds in a stone which absorbed nearly seven per cent of water to 17,250 pounds in No. 11 of the following table. It will be seen from

	Strength in pounds.	Water absorbed.	
1. Calcareous freestone, Caen, France.....	3,650	.052	Earthy texture.
2. Dolomitic limestone, Yorkshire, Eng....	5,219		Material of English Houses of Parliament, London.
3. Oölitic limestone, Bedford, Ind.... ...	11,750	.036	Material of Indiana Capitol.
4. Silicious limestone, Putnamville, Ind ..	11,750	.006	
5. Magnesian limestone, Greensburg, Ind.	16,875	.0085	
6. Marble, Italian.....................	11,250	very little.	
7. Marble, East Chester, N. Y...........	12,950	"	
8. Brown sandstone, Middletown, Conn...	5,550	.025	On edge, material of Trinity Church, Brooklyn, N. Y.
9. " " " "	6,950	.025	On bed.
10. " " Medina, N. Y.......	14,812	.018	On edge.
11. " " " "	17,250	.018	On bed.
12. " " Marquette, Mich....	7,275	.031	
13. Sandstone, Berea, Ohio...............	8,300	.05	
14. Sandstone, Amherst, Ohio.............	6,650	.052	
15. Whitish granite, City Point, Me.......	15,093	very little.	
16. Bluish-gray granite, Keene, N. H......	10,375	"	Used on inside of Capitol, Albany.
17. Dark granite, Quincy, Mass...........	17,750	"	
18. Gray " Westerly, R. I.	14,937	"	
19. Rose " Niantic, Conn...........	9,550	"	
20. Dark " Duluth, Minn...........	17,750	"	Called Gabbro.

Nos. 8, 9, 10, and 11 have their ultimate strength given for both edge and bed, showing a marked difference in strength according to the direction of pressure.

this table that, in the uncrystalline rocks, the limestones and sandstones, there is an obvious relation between the ultimate strength and the porosity as shown by amount of water absorbed, the more porous being generally the weakest, and where deviations from this occur they are probably due to differences in degree and means of consolidation.

2. **Durability.**—The durability of building-stones depends chiefly on certain assignable properties inherent in the rock ; but it is affected also in a very considerable degree by the conditions to which the stone is subjected. These are now to be considered. The inherent qualities which condition the durability of building-stones are the following : (1) *Sufficient consolidation.* This quality of a proper degree of firmness is a condition as well of durability as of strength. A slightly cemented stone, though sometimes a favorite for certain uses, because of the ease with which it may be worked, is peculiarly liable to mishaps in the somewhat rough usage to which stones in structures are likely to be subjected in the course of years. Accidental blows mar it or break fragments from its angles and edges ; slight inequalities of pressure cause it to crack and crumble ; and mere attrition, in places exposed to the contact of men and animals, or even to the force of wind-blown sand and dust, may slowly remove particles from its surface. All this, too, even though its lack of firm consolidation should not be correlated, as it is quite sure to be, with the lack of a second requisite of durability now to be mentioned. (2) *Density*, or *closeness* of *texture.* In a dense or compact stone, the cementing material, whatever it may be, is present in sufficient quantity to fill entirely the space between its grains ; or, if it is of crystalline character, its crystals are so interlocked as to leave no vacant spaces. Density is shown by the relative imperviousness of a stone to water, and from this arises its importance as a condition of durability. Water is the

chief medium through which the chemical agencies of decay in rocks gain access to their pores; and though probably no mineral substance is wholly impermeable to water, still, if the texture of a building-stone is close, the change from this cause will be very slow. The exclusion of water from the interior of a rock is even more important where the climate is liable to extreme cold, because of the violent rending effects due to the expansion of water in freezing. Water, in freezing, expands about nine per cent, with a force sufficient to tear asunder the grains of a stone within which it finds lodgment, and so causes its surface to crumble, or its laminæ to separate. Were it not that a marked degree of porosity in a stone promotes also rapid drying, and permits a considerable portion of the expansive force to be expended otherwise than in pushing apart the grains of the stone, the disaggregating effects arising from this cause would doubtless be greater and more rapid than they are; but, in any case, a very porous stone should have given undoubted proofs of durability before being used in important structures, where it must be exposed to the vicissitudes of a highly variable climate, like that of the Northern United States. (3) *Fineness* and *uniformity* in *size* of *grains.* It is undoubted that this quality exerts a decided influence upon the durability of building-stones; due, probably, in a considerable degree, to the weakening effect of large and irregular-sized grains which offer unequal resistance to pressure at different points; but it can hardly be doubted that, in a rock composed of two or more minerals, and exposed to great and sudden changes of temperature, the inequalities in the ratio of expansion of the constituent minerals must cause a tendency to disaggregation, which will be heightened by an increase in the size or in the inequality of the grains, and which will be likely to be reduced to a minimum when the grains are small and of uniform size. (4) *Freedom* from *injurious minerals.* It is obvious that the presence in a building-stone of any substance which is subject to decomposition when exposed to the weather, will seriously affect its durability. Of such substances pyrites is one of the most dangerous and yet widely diffused. Where it occurs lining seams, or in nodules and crystals of some size, its decomposition leaves unseemly holes and crevices, and gives the stone a disagreeable stain. Where it is disseminated in minute, almost imperceptible grains, it is often even more deleterious, since its ultimate decomposition produces a widespread disaggregation of the stone. So, too, iron carbonates and other protoxide compounds of iron are injurious to the rocks, chiefly bluish or greenish gray sandstones, in which they occur, through their tendency to pass to a higher state of oxidation. Many reddish and brown sandstones show little durability, and this is commonly attributed to the iron oxide, which acts as a coloring agent and also as a cement; though it is quite possible that the lack of durability may be due quite as much to the superabundant clayey matter which is apt to be also present in such rocks. Clay, which when present uniformly disseminated through a stone, to the amount of but a few hundredths of the mass, as in many limestones and sandstones, is rather beneficial than injurious, where it occurs in too great abundance, forming seams in sandstones or knots and irregular crevice-fillings in limestones, becomes a source of serious injury, not only by its own ready disintegration under atmospheric agencies, but also, through the tenacity with which it retains any water that it may take up, offering occasion for the destructive action of frost on the surrounding stone. Especially when a rock is somewhat porous, clayey matter, by its retentiveness for moisture, may become very destructive in severe climates, as has been suggested above in the case of brown sandstones.

But, besides those conditions affecting the durability of building-stones which are inherent in them, there are others which arise from the circumstances under which they are used in structures: (1) The great majority of the bedded rocks are most durable when laid upon their natural beds, that is, with their edges exposed. This is due, not merely to the fact that most such stones are thus laid in the position in which they are strongest, as has been stated in a preceding paragraph, but also to this, that the planes of bedding in rocks which are in any degree porous are naturally also the planes of easiest penetration for water. Hence, when they are set with the planes of bedding vertical, water soaks into them most freely, and the exposed surface is apt to show a disposition to crumble off in grains, or even, where they are distinctly laminated, to peel off in flakes, mostly from the effects of freezing; whereas, when laid with the edges exposed, they admit water much less readily. (2) Stones, when used in constructions, are doubtless much less affected by the solvent action of water than when they are in their native beds, for they are then no longer exposed to its constant permeation, and to the attacks of those chemical agents with which water is apt to become charged in passing through the soil. Yet it is believed, and apparently with good reason, that in great cities, the rains and fogs, charged with the sulphurous gases which the consumption of coal furnishes to the atmosphere, become active agents of destruction to some classes of building-stones, especially magnesian limestones. To this is attributed the rapid deterioration of the magnesian limestone used in constructing the new Houses of Parliament in London, a material which had endured for centuries in ancient structures, very little affected by the pure air of the country. (3) Again, building-stones, while conducting heat very slowly, are yet subject to expansion and contraction from variations of temperature. Experiments on the linear expansion of granite, limestone, and sandstone, conducted in 1832, under the direction of General Totten, the results of which were published in vol. xxii of "American Journal of Science," showed that a fine-grained granite varied .000004825 of its length for a change of 1° Fahr., that white, fine-grained, crystalline limestone from Sing Sing, N. Y., varied .000005668, and that a somewhat coarse-grained red sandstone from Chatham, Conn., varied .00000944, or nearly twice as much as granite. English experiments, quoted by Geikie in his "Text-Book of Geology," show that gray Aberdeen granite has nearly the same rate of variation (.00000438) as the above, and white Sicilian marble a somewhat greater rate (.00000613) than the above stone of the same class; while a Welsh slate varied .00000576 for 1° Fahr. Hence, in a climate of great and sudden variations of temperature, the difference of temperature and of consequent tension between the internal and external portions of a building-stone, and between its surfaces differently exposed to heat and cold, must subject it to a severe and often-recurring strain, to which it must eventually yield. Livingstone says, in his "Travels in South Africa," that the rocks in those tropical regions are exposed to so great variations of temperature between day and night, that fragments, varying in weight from a few ounces to upward of a hundred pounds, split and fly off. It can hardly be doubted that, in a climate like that of the Northern United States, this cause of dilapidation must seriously affect the ultimate durability of building-stones; and that, if the sandstone tested by General Totten shows even approximately the relative variation of sandstones under temperature changes, they may be expected to be most affected by this agency. Doubtless, also, those stones which possess the highest degree of elasticity, which has been referred to on a preceding page, may be expected to resist most successfully great extremes of heat and cold. The expansion and contraction of stones in structures naturally has an unfavorable effect on the tightness of joints and the adhesion of mortars and cements. Besides what has just been said, investigations prosecuted chiefly by German physicists on the ratios of expansion of several of the most important rock-forming minerals, like quartz, orthoclase, hornblende, and calcite,* have revealed in them marked differences in expansibility by heat, a fact which shows that the movements which must take place among the constituents of a rock composed of two or more minerals, when exposed to considerable variations of temperature, may be expected ultimately to lead to its gradual disaggregation. This fact will also explain the well-known tendency of granite, one of these composite rocks, to burst in pieces when exposed to the heat of conflagrations, though, in this case, something is probably due also to differences of temperature in different parts of the stone. (4) Prof. James Hall, in his excellent "Report on Building-Stones," calls attention also to the effects produced on stones by the growth of lichens in the small surface inequalities, thus affording a lodgment for dust, and detaining moisture to act slowly on the surface.

Beauty of Building and Ornamental Stones.—In the choice of stones designed for architectural uses, those qualities that please the eye naturally exert a great influence on the estimate in which they are held. Much depends, of course, on individual tastes, and something on the currents of fashion; but in the matter of color, the neutral tints, the grays, the buffs, and drabs, usually please longest; the reddish browns are also pleasing tints and largely sought after; but great care is needed in the selection of stone of this color, since experience has shown that it is liable to disintegrate from the influence of its cementing material. Dark colors give a heavy and somber appearance to buildings, which may be judiciously relieved by the use of light trimmings. White is glaring and painful to the eye in the blazing sunshine of American climates, and is besides apt to become soiled and dingy in the at-

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* "Constants of Nature," Part III, "Smithsonian Miscellaneous Publications."

mosphere of cities, especially if the stone is somewhat porous. This remark is also true of many neutral-tinted porous sandstones. In the selection of colors, it is also a matter of much interest, by the observation of long-exposed outcrops, to note the tint which the stone may be expected to acquire by weathering, since some stones which are pleasing when recently quarried, become, when long exposed, of a dead and disagreeable hue. Besides mere color, certain qualities of texture which adapt a stone to receive a fine finish, like some sandstones and earthy limestones, or to develop by polishing a beautiful surface or a pleasing variety of figures and colors, like some fossiliferous limestones, marbles, granites, and porphyries, place the stones which possess them in the category of ornamental materials; and some stones, like the highly esteemed Caen stone, may be judiciously chosen for purposes of interior decoration which would be perishable if exposed to the weather.

Facility of Working.—This is a quality of very considerable importance in a building-stone when it can be secured without a sacrifice of the *essentials* of sufficient strength and durability, for on this depends in a large degree the expense of construction. Indeed, the ultimate durability of important structures is not unfrequently overlooked in the effort to diminish present expense, and facility of working becomes a controlling rather than a subordinate consideration in determining the choice of a stone. The ease with which a stone may be wrought into desired forms depends: (1) On the hardness of its constituent minerals and the means by which they are cemented. Thus the granites and the silicious sandstones and limestones are, as a class, more difficult to dress than the nearly pure granular limestones and the sandstones of somewhat open texture, or those whose chief cementing material is a small amount of thoroughly disseminated clay. (2) A second condition, adapting a stone to the mode in which it is desirable that it should be worked, is often presented by its structure and mode of fracture. Thus, a laminated or foliated structure is a very important aid in reducing a stone to the desired thickness, to which if a tendency to a somewhat even cross-fracture be added, a hard stone may be dressed at reasonable expense. So, too, a conchoidal fracture facilitates the labor of the workman in dressing a stone for a rough-faced wall; while, where fine carving and delicate tracery are intended, the stone should be without brittleness, and should possess that complete homogeneity of both structure and texture which will adapt it to being cut with equal ease in any direction, and which is an essential character of the class called *freestones*, whether silicious or calcareous.

As is well known, all stones are more easily dressed when but recently removed from the quarry, as the surface hardens somewhat on exposure to the air, and in some cases in a very marked degree.

The manner in which a building-stone should be dressed is a matter chiefly technical, belonging to the architect and stone-cutter; but from one point of view it has a geological bearing, since upon it depend in a considerable degree the strength and durability of the stone. A mode of dressing which attacks the stone by blows directed against its face affects injuriously both its strength and durability. General Gillmore's experiments on the strength of granites showed that polished cubes were on an average twenty-five per cent stronger than cubes of the same stone that had been reduced to size by dressing; and experiments instituted in Indiana, on the oölitic limestone selected for the State Capitol, showed a difference of more than one third in strength and nearly one half in elasticity between sawed and tool-dressed stone. Nor should this seem surprising when we consider that any stone may be broken by repeated blows along a definite line. The effect of the blows directed against the stone is to weaken or destroy the cohesion of all the grains to which the jar is communicated. In like manner such blows crush the surface and measurably loosen the cementation of the stone for some distance inward, giving easier admission to water, and thus lessening its durability.

Selection of Building-Stones.—In the selection of a stone for construction, attention should be paid first of all to its *durability*, for, when this is made sure, sufficient strength will rarely be wanting. In the examination needful for this, while careful heed should be given to the qualities and conditions which have been enumerated as those on which durability depends, the most helpful and reliable indications may be obtained by observing the manner in which the stone has endured the weather in old structures, and especially its condition in its natural outcrops. If in these exposures the edges and angles of the stone remain sharp—if its surface shows no signs of flaking or crumbling, no cracks nor holes where pyrites or clay has lurked, nor dark stains from the change of iron compounds—it may be relied upon for structures if proper care is used to reject suspicious blocks ; but if a contrary state of things be revealed by such an examination, and if in old natural exposures the edges of the stone are furrowed by unequal weathering, while heaps of crumbled material are piled at the base of the cliff, the stone should be rejected. It is well to remember, however, in examining natural exposures, that some argillaceous sandstones, which are very durable if properly dried before being exposed to freezing, split up on their planes of lamination from the action of frost on their quarry-water in exposed cliffs, and that in their case the examination should be extended to determining whether the splitting reveals any gathering of the clay in seams.

As regards strength, a very large margin for safety is always allowed over the force needed to crush the stone, and it is probably very rare that a building-stone is subjected to even one twentieth of the load under which it would be likely to yield. The extreme pressure on stone in a wall fifty feet high is from fifty to sixty-five pounds per square inch. In a tower of stone two hundred feet in height, the strain at the base would be from two hundred to two hundred and fifty pounds per square inch, about one fourteenth the strength of the weakest stone given in the table on a preceding page.

Attention has already been directed to the error of selecting a stone for its beauty rather than for its durability. It should also be borne in mind that pleasing effects may be produced with a stone of a somber color by the judicious use of light-colored materials for trimmings, while even the more agreeable tints lose much of their effect if unrelieved by contrasting colors.

By attention to the suggestions already given, stone of a reasonable degree of facility in dressing may be secured in many localities ; and it is well to bear in mind that the harder kinds of rocks commonly produce their best effects in buildings when rough dressed, and so with a minimum of expense in working. When elaborate ornamentation is proposed, the question is usually one of fitness of materials rather than of expense.

After all, in the majority of cases where stone is used in constructions, local supplies must be the chief dependence, on account of the great expense of transportation ; and the suggestions here made are intended mainly to aid in the selection of the best materials from the supplies afforded by the rocks which may exist in the vicinity. Many stones also may do fairly well for cellars and foundations, where they are not exposed, which, from various causes, would not be durable if exposed to the weather ; and others may serve a useful purpose in rough constructions, like bridge-abutments, retaining walls, and underpinnings of farm-buildings, which from their coarseness of texture, their faults of color, or their hardness and irregular fracture, would be unsuited for a better class of structures. Indeed, many regions may furnish materials for these wide-reaching and very essential uses, which would yield none suitable for higher purposes.

North American Building-Stones.—A general idea of the *relative amounts* of the several classes of building-stones that are used in the United States from important quarries may be gained by observing the production reported in the census returns for 1880. The number of cubic feet of marketable stone reported was over 115,000,000. Of this, considerably more than a half, or 65,500,000 cubic feet, was limestone and marble ; a little less than 25,000,000, sandstone ; about 20,500,000, granite and other crystalline rocks of the same class ; while the slate product was somewhat more than 4,500,000 cubic feet. These amounts would be largely increased, could the local supplies derived from numerous small quarries be known ; but it is not likely that the relative amounts of the several stones would be materially changed. Hence it would seem that limestones and marbles are much more largely used than any other class of building-stone—a fact which is due, partly to their wide distribution, and partly to the comparative ease with which they may be dressed.

A general view may also be obtained of the *distribution* of building-stones of special value, by observing the States reporting the largest production of the several classes. Thus, in the production of limestones, Illinois leads in amount, followed by Ohio, Iowa, Indiana, Missouri, and Wisconsin, in the order named ; while Vermont, which stands twelfth in amount of product, leads the list in point of value, her product of about 1,200,000 cubic feet, chiefly marble, being worth somewhat more than the 13,000,000 cubic feet of Illinois limestone. In sandstone, Ohio ranks first in both amount and value, Pennsylvania second in amount, New York third, New Jersey fourth, and Connecticut fifth. In stones of the granite class, Massachusetts ranks first in amount and value of product, followed in order of value by Maine, Rhode Island, Connecticut, Virginia, and New Hampshire; while in the production of slate, Pennsylvania is foremost, yielding, with Vermont, over 83 per cent of the total product, minor amounts being supplied by Maine, New York, Maryland, and Virginia.

It will be seen from this that the production of granite, slate, and marble is chiefly confined to the Appalachian belt from Maine to Georgia—Colorado and California also producing small amounts; that the greatest limestone production is from the north central group of States; while the chief supplies of merchantable sandstones are, at present, derived from the region between these areas. A brief review of the geological distribution of the various classes of building-stones will not only reveal the reason for this grouping of productive areas, but will also be likely to suggest additional areas whence valuable building materials for both local use and commercial distribution may be derived, as the progress of settlement and the supply of easy means of transportation encourage their development.

Geological Position of Granitic Rocks.—The oldest rocks on this continent are found occupying much of British America, in a great V-shaped area with the point near the eastern end of Lake Ontario, extending into Labrador with its shorter branch, which covers most of the explored region north of the St. Lawrence, and with its longer branch skirting the north sides of Lakes Huron and Superior, and stretching away northward to the Arctic Ocean. From the point of the V, these rocks extend across the St. Lawrence at the Thousand Islands, and occupy a large area in northeastern New York—the well-known Adirondack wilderness. Rocks of similar character, but a portion of which are probably of somewhat later age, occupy parts of Nova Scotia and

New Brunswick, most of New England, the southeast corner of New York and northwestern New Jersey, and extend along the Appalachian range through Virginia, North and South Carolina, and Georgia, into eastern Alabama. These most ancient rocks also occupy a large part of northern Michigan, cover much of northern Wisconsin and Minnesota, and are extensively developed in the Rocky Mountains, the Wahsatch, the Sierra Nevada, and in many parts of the ranges of the Great Basin. This very ancient series of deposits, called the Archæan or Azoic, consists wholly of crystalline rocks of various kinds, arranged in rude beds, showing that they were once ordinary sediments which owe their present condition to metamorphism; and they have been penetrated in many places by vast masses of granite which have been thrust through them in a plastic state. Granitic rocks of several kinds form some of the series of beds also, as well as occasional crystalline limestones that furnish marbles. In the areas, chiefly Archæan, then, which have been described above, and in a few other limited exposures that have not been mentioned, but which lift themselves like islands from the midst of the newer rocks that surround them, and in these only, may we expect to find building-stones of the granitic class—the granites, the syenites, the gneisses, and the highly silicious schists. In several parts of these areas, rock of this class is now quarried in large amounts; in many others stone of fine quality and great beauty is known to exist, though not yet worked; and doubtless building-stone of equal merit will be found in many other localities not yet explored. Considerable amounts are already quarried in Colorado, and in California on the line of the Central Pacific Railroad. Besides our domestic supplies, considerable amounts are imported for monumental and ornamental uses, especially from Aberdeen and Peterhead in eastern Scotland. These rocks, composed of two or more of the minerals quartz, feldspar, hornblende, and mica, are as a class very durable, though some of them, in which feldspar is largely present and has microscopic pores, giving easier admission to water, weather somewhat rapidly. Pyrites should also be guarded against, in these as in other rocks, for it is sure to impair their durability. Where the constituents are very coarsely crystalline also, the rock is unfit for building purposes. Those granitic rocks which are composed of quartz and feldspar, or quartz, feldspar, and hornblende, with mica in small proportion, if present at all, and with the ingredients in small or moderate-sized grains, are the best. These rocks are harder than the other classes of building-stones; but most, and perhaps all of them, split with comparative readiness in one direction, called by the workmen the *rift*, and break most easily at right angles to the rift, thus making the dressing easier. They vary much in color, according to the color and proportions of their constituents, those composed chiefly of quartz and light-colored feldspars, with but little black mica, being of a gray or grayish-white color; those containing much reddish feldspar are reddish, and often very ornamental; while hornblende imparts to granites and syenite its own dark hue, as in some of the Quincy granites. Many of the granites are susceptible of a high polish, and are on this account considerably used for internal ornamentation in expensive buildings, as also for monumental purposes. Where the feldspar in a granite occurs in well-formed crystals of pleasing color, as in the so-called *shap* of Cumberland in England, it increases its value for ornamental purposes. Granites of this character can doubtless be obtained also at some localities in this country. Besides the silicious building-stones here described, trachyte, a volcanic rock composed chiefly of feldspar, is said to be used as a building-stone at Virginia City, in Nevada; and porphyry, another volcanic rock containing crystals of feldspar imbedded in a fine-grained matrix, chiefly of feldspar, with some hornblende or augite, though little suited for building, has long been used for ornamental purposes, for which some kinds have an ancient and deserved celebrity. Handsome porphyry is reported to be found in Grenville, Province of Ontario.

Geological Position and Localities of Marble and Slate.—Although the crystalline marbles and slates are chiefly derived from Silurian rocks, later in age than those from which the granitic building-stones are obtained, still their local distribution, and in some cases their geological position, is so closely related to these that they may conveniently be considered in this place. Excellent roofing-slates are quarried near Huron Bay, in northern Michigan, from rocks of the later Archæan, and others, it is said, in Minnesota, probably from rocks of the same age. Likewise the first "Annual Report on Mineral Statistics of Michigan, 1877–'78," states that desirable marbles may be obtained from the Archæan, not far from Marquette. So also the Archæan limestones of eastern Canada, at a number of localities, yield marbles suited for building and ornament, though these limestones are apt to be too much contaminated with various minerals, or too coarsely crystalline, to be desirable for such purposes. But the metamorphic rocks of the Lower Silurian, stretching along the east side of the Archæan in eastern Canada, Vermont, and southeastern New York, and along the same range in west Massachusetts and Connecticut, furnish the chief present supplies of handsome marbles for building and for ornamental uses; and in some localities the marble is veined with serpentine, making an esteemed ornamental stone called *verd-antique* marble. The serpentinous limestones of the Canadian Archæan can also yield supplies of this stone at some localities; while beautiful serpentines occur in Wake County, North Carolina, and in some of the western counties of that State. The Lower Silurian rocks of East Tennessee likewise yield highly esteemed marbles of various colors, which are exported chiefly from Hawkins and Knox Counties, though several other counties near the western base of the Appalachians can, it is said, furnish stone of equal beauty. The colored marbles for the interior decoration of the Capitol extension in Washington were obtained from Hawkins County, while that which was used in the construction of the building was dolomitic marble from Lee, Mass. Beautiful marbles are also reported from the western part of North Carolina, and a recent display (1883) of some of these in Boston attracted much attention.

Cleavable slates are obtained from argillaceous rocks that have been folded and subjected to great pressure, thus rendering them very compact, and developing in them a tendency to cleave at various angles with the original bedding-planes. The largest supplies are derived, as has already been stated, from Pennsylvania and Vermont. The slate region of eastern Pennsylvania is along the southeast base of the Appalachians, the chief quarries being in Lehigh and Northampton Counties, the adjacent part of New Jersey also furnishing some, and in Lancaster and York Counties. The remaining States mentioned before as furnishing slates yield them under similar geological conditions in regions where the rocks have been much disturbed and folded. It is quite probable that other localities of good roofing-slates will be found in the disturbed regions along the Appalachians, the Rocky Mountains, and the Sierra Nevadas. Indeed, slates are said to be already obtained in California near the base of the last-named range. The best British supplies of slate are obtained from the folded rocks of the Lower Silurian in northern Wales.

Slate should be susceptible of being split easily into thin, even plates; should be free from seams and strings of quartz, which interrupt the cleavage, and from crystals of pyrites, which would be likely to weather out, leaving holes, and should be so firmly compacted as to endure weathering without change. The softer cleavable beds, which, though sound, would not endure exposure to the weather, are wrought into school-slates and tablets.

Among the crystalline marbles, the very fine-grained and homogeneous kinds are the best, and have a high degree of durability, save possibly in moist climates. Those of coarse grain and friable texture, or those contaminated with foreign minerals, or containing soft spots of "talc-like mineral," are not only difficult to polish, but are apt to endure exposure to the weather badly. The older stones in cemeteries long occupied afford convenient opportunities for observing the behavior of marbles under exposure.

Besides the true marbles of crystalline texture, some compact limestones of pleasing and varied colors, frequently owing much of their beauty to sections of fossils contained in them, are polished and used for ornamental marbles. Of this kind is the marble from East Tennessee, mentioned above (Safford).

Besides our domestic supplies, considerable amounts of very fine marble are imported from Italy, chiefly from Carrara in the Apennines. Greece is also famous for fine statuary marble from the island of Paros, and from Mounts Pentelicus and Hymettus.

Sandstones and Limestones.—In studying the geological relations and topographical distribution of the two remaining and very important classes of building-stones, the sandstones and limestones, it will be helpful to remember that in the vicinity of the great Archæan regions, described in a preceding paragraph, which constituted the land areas of succeeding geological ages, and which directly or indirectly furnished the ground-up or dissolved materials of all later rocks, the chief strata are mechanical sediments—sandstones and shales—the limestone bands, important though they are, forming but subordinate parts of the great thickness of strata. On the other hand, the area now occupied by the great central group of States, from central Ohio westward into Kansas, seems to have been a vast interior sea of no great depth, in which chiefly limestones were formed through the agency of corals and other sea creatures; sandstones and shales being here but subordinate members in the series of strata. While, therefore, limestones furnish the chief building materials of the latter region, sandstones are the chief materials of the former—Ohio, which lies between the two, furnishing excellent varieties of both kinds of stone from her eastern and western sections, being the foremost producer of desirable sandstones, and second to but one State in amount of limestone quarried. In the first-named area, sandstone is furnished from several geological horizons, and at very numerous localities. The lowest unchanged formation, the Potsdam, affords much good stone of red and light gray colors, across the northern parts of New York and the adjacent portions of Canada; and it borders nearly the entire south shore of Lake Superior with sandstone of a brown color, which at Marquette, Mich., and Fond du Lac, Minn., is quarried, yielding an admired building-stone, and which will doubtless afford stone of equal quality at many other points along this shore. South of the Archæan, in central Wisconsin and Minnesota, this formation covers large areas, but furnishes little good building-stone, being usually too friable. The two succeeding periods offer, in parts of the Quebec and Hudson River groups, sandstones usually argillaceous, and suitable for flagging and for foundation-walls; the former chiefly in eastern Canada, the latter across New York from Oswego eastward. Next in ascending order, the Medina sandstone, along the south shore of Lake Ontario, yields, in one of its members, a usually hard but excellent sandstone of light gray and reddish-brown colors, which is largely quarried west of Rochester at Albion, Medina, Lockport, and other places, and is widely used both for buildings and for paving, promising great durability where carefully selected. The same geological formation in Canada, where it is called the "Gray Band," stretches across the Province of Ontario from Queenstown to Collingwood, and yields an excellent building-stone wherever it has been quarried. In the southern counties of New York, and in northern Pennsylvania, the Portage and Chemung groups yield, in many places and at various horizons, beds of dark gray, olive, and dark brown argillaceous sandstones, suitable for all ordinary building purposes, though of somewhat somber colors unless properly relieved by trimmings. Like all argillaceous sandstones, they need careful selection to avoid blocks containing seams of clay which soon disintegrate; but when properly selected, and *seasoned* before being exposed to frost, they give promise of great durability. The Sub-carboniferous yields, in parts of Pennsylvania and in eastern Ohio, beds of good sandstone, which in Ohio is the fine silicious freestone so largely quarried in the vicinity of Cleveland for ornamental building-stone, for grindstones, and for sawed flagging. It is easy to work, takes a fine surface, and is susceptible of delicate carving; and though very porous, seems, from its purely silicious character, to promise a good degree of durability. Along the Atlantic slope of the Appalachians, apparently filling long, narrow valleys formed by their folding, and running parallel with them, are found thick deposits of sandstone and shale of earlier Mesozoic age, in the Connecticut River Valley, and stretching across New Jersey, Pennsylvania, Virginia, and North Carolina. These deposits furnish, at many places, beds of a handsome brown freestone, easily worked, but not usually very durable. This freestone is largely quarried in Connecticut and New Jersey for use in New York and other cities. Deposits of similar and somewhat later age are extensively developed along the eastward side of the Rocky Mountains, in the so-called "hog-backs" of Colorado and Wyoming, where they are capable of furnishing excellent freestones of various agreeable shades of color. These freestones are already quarried at two or three points, notably at Morrison in the vicinity of Denver, for use in the public buildings of that city. California is also said to have, at several points, useful sandstones in the later geological formations, as well as an abundance of handsome marbles and limestones.

The precautions that should be observed in selecting sandstones for exposed parts of constructions are chiefly these: to choose the more purely silicious, and those of finer and closer texture; to avoid those containing pyrites, a large proportion of clayey matter, or seams of clay; to be suspicious of those in which a dark reddish coloring-matter is a principal means of consolidation; and, among porous sandstones, to select only those of proved durability, since, though some porous sandstones of purely silicious character are very durable, the durability of stone in general is inversely proportioned to its porosity.

Like the sandstones, the limestones, in the region bordering the Archæan, occur at certain geological horizons only, and even in the great central limestone area the stone which has been found to be adapted to the higher class of uses in construction is found mainly in a few geological formations. The lowest geological period which affords good limestones is the Canadian, which in its lowest group, called the Calciferous, furnishes in Minnesota the desirable stone quarried chiefly at Frontenac, Kasota, and Mankato, and in southeastern Missouri forms the magnesian limestone beds. The uppermost group of the same period, called the Chazy, furnishes a limestone which is quarried at many points in the northeast corner of New York and the adjacent parts of Canada, yielding an esteemed building-stone. The Trenton limestone, which extends across New York just north of the Mohawk River, and passes northwestward through Herkimer County into

St. Lawrence, is quarried at many places, yielding a gray and a dark-blue stone, and in eastern Canada it furnishes most of the building-stone used in Montreal and much of that which is used in Quebec. The limestones of the same formation, which occupy a large part of southern Wisconsin, are too much interlaminated with clay to yield much good building-stone ; but in Minnesota the upper beds are said to be free from clay-seams, and to be capable of furnishing reliable stone. The best limestones of Wisconsin are obtained from rocks of the Niagara period, which stretch along Lake Michigan in the eastern part of the State, and furnish an excellent building-stone at many points. Limestone of the same age is largely quarried in several parts of Illinois, furnishing the Joliet stone and Athens marble, in southeastern Indiana and in southwestern Ohio, yielding in the latter State the highly valued Dayton stone, as well as that obtained at Springfield and other places. The higher strata of this formation are also quarried in the western part of New York, at Lockport and other places; and, in the Province of Ontario, these beds, extending northwestward from Niagara Falls to Lake Huron, are capable of furnishing an excellent magnesian limestone at many points. In ascending order, the Lower Helderberg period is composed of limestones which have their chief development in eastern New York, where the lower members are quarried for local use from Schoharie County westward to Oneida County. The Corniferous limestone which succeeds this is of great extent and importance, stretching across New York from near Albany to Buffalo and thence across the Province of Ontario, and sending a branch down through the Lake Erie islands and central Ohio to a considerable distance south of Columbus, a second branch being found farther west in the same State. Throughout this wide extent it is quarried at many points for both building-stone and for lime, yielding, where free from quartz-nodules, with which some of its beds are thickly set, a strong and durable stone. This is the last of the limestones of the eastern division of States which is much used for building purposes. The Tully limestone of the upper part of the Hamilton period is confined to central New York, and can be used only for rough work, while the beds of limestone that occur in the coal-measures of Pennsylvania seem to be little used for construction. In the Western States it is different, for there the Sub-carboniferous limestones afford excellent building materials in Indiana, Illinois, Missouri, and Iowa, though in the last-named State the best supplies of building-stone are obtained from rocks of the Niagara period. In the Sub-carboniferous of Indiana, beds of highly esteemed oölitic limestone are largely quarried in several counties, extending from Montgomery County southward to Harrison, and this stone has been used in many important buildings, among which is the new State Capitol of Indiana. The same formation yields good building-stone at three different horizons in Illinois and at two in Missouri.

Although the limestones most highly esteemed and most widely used for construction in England, France, and southern Europe are obtained largely from formations younger than those named above, viz., the Permian, the Jurassic, and the earlier Tertiary, it is not known that any younger than the Carboniferous have yet been considerably used in this country.

In the ranges that have been described, limestones suitable for buildings can by no means be found in all places where the formations are exposed, for limestones, like other formations, are apt to present important differences at different exposures. In some places their bedding may be such as to unfit them for use ; in others their texture may expose them too much to the attacks of frost or to the solvent action of carbonated waters. Some are contaminated with pyrites, or contain so considerable a proportion of argillaceous matter as to impair their durability, while others contain clay in thin seams or irregular crevices, which, if it does not lead to their early decay, soon gives them a cracked and unsightly appearance. This seems to be more largely true of the gray sub-crystalline limestones. In other cases the strata may contain crystals and nodules of quartz, unfitting them for regular working; yet some silicious limestones in which the silica in fine particles is uniformly disseminated throughout the mass, though somewhat harder to dress, will doubtless be found possessed of desirable qualities in point of durability and strength. The points here mentioned are those that need to be carefully observed in choosing places for opening large quarries, and in selecting those seams that it is proposed to use for building purposes, while careful attention should always be given to the condition of all seams that have long been exposed to the elements. Of the limestone formations of North America, the Niagara and Corniferous appear to be the most generally useful over wide extents of country, the others being either limited in their range to certain regions, or presenting great differences of condition in sections remote from each other. Thus the more valuable Sub-carboniferous limestones are limited to the Western States, while the Trenton, which furnishes good building-stones in northern New York, in Canada, and in East Tennessee, is worthless in Ohio and Indiana, and of doubtful repute in Wisconsin, Minnesota, and Iowa.

Brick, Terra-Cotta, and Drain-Pipes.—These articles, so widely used for house construction, ornamentation, and drainage, are fabricated, as is well known, from clays possessing sufficient plasticity to permit of their being shaped in molds, and then burned in kilns to the requisite degree of hardness. Coarse clays, suited for bricks and drain-pipes, are widely distributed over our country. In the regions covered with drift deposits north of the parallel of 39°, they are found as large parts of these deposits, which, when free from stones, and from pebbles of limestone, can be used for brick-making. They are also found as a result of the weathering of shales, or of the disintegration of gneissose and other rocks, in the recent deposits of rivers and smaller streams, and in some lacustrine deposits formed when the lakes occupied a considerably higher level than at present as, for example, along the shores of Lake Michigan. Besides these wide-spread deposits, clays, some of which are adapted for much choicer uses, and which will be described in another connection, but the coarser of which make superior bricks, terra-cotta, and drain-pipes, are found in the Cretaceous deposits of New Jersey, Minnesota, and doubtless of some Western States and Territories; others may be found in the Tertiary deposits along the Atlantic coast and the Gulf of Mexico; while clays of great excellence may be obtained by the proper weathering of some of the *under-clays* of coal-beds, both of the coal-measures and of the Cretaceous deposits of Colorado, Wyoming, New Mexico, Montana, and some of the Pacific States and Territories. As may readily be inferred from the wide differences in origin of clays, they present also wide differences in composition and character. Essential ingredients in all of them are a sufficient proportion of kaolin, or true clay, to give them the requisite adhesiveness and plasticity, and of quartz sand to correct the tendency of clay when burned to excessive shrinking, warping, and cracking. The relative proportion of these ingredients may vary, however, within wide limits, and they are mingled besides with variable amounts of iron oxide, of the alkalies potash and soda, and of the alkaline earths lime and magnesia. The iron usually gives to bricks, as they are commonly burned, their well-known red color, by becoming the red oxide; but when a considerable proportion of lime and magnesia, or of these with potash, is present, these substances at a high temperature form with the iron and silica a compound which partially fuses, giving to the bricks a greater degree of solidity, and imparting to them the agreeable cream-color which is so favorably known in the so-called Milwaukee brick. As examples, both of the essential ingredients of clays and of their differences of composition, it may be said that the common brick-clays from the New Jersey Cretaceous contain about 45 per cent of kaolin, 30 per cent or more of sand, and 8 to 10 per cent of iron and the alkaline ingredients; that the ordinary clays of Wisconsin contain usually less than 25 per cent of kaolin, 60 per cent and upward of sand, and about 9 per cent of iron and alkaline substances, both these kinds of clay yielding red bricks; while the clay from which is fabricated the cream-colored Milwaukee brick has only about 20 per cent of kaolin, 4 per cent of iron oxide, and more than 40 per cent of lime, magnesia, and potash; this last clay being the more noteworthy because of the prevalent opinion that any considerable proportion of lime and potash is fatal to the excellence of a clay, whereas, in the use of this clay, the presence of these substances is counted a great advantage, not only as giving the bricks a greater solidity and an agreeable color, but as furnishing a reliable test of the thoroughness with which they have been burned; since, with insufficient burning, they have a red color, while the creamy tint appears only with a temperature that produces an incipient fusion. Brick clays are much improved by weathering. They are then *tempered* with a sufficient amount of clean, sharp sand, if the clay is deficient in this ingredient, ground in a pug-mill to secure uniformity of composition, and molded for burning either by hand or by a machine which is capable of shaping many thousands in a day. In the common mode of burning, a considerable portion of the product is apt to be unfit for use, partly from being overburned, and so glazed and cracked, and partly from being underburned, with the result of being weak and crumbling. In the Geological Report of New Jersey, for 1870, a perpetual kiln is figured and described, which appears to be ingeniously devised for securing uniformity of product with great economy of fuel. It is said to be capable of turning out from three to five millions of brick per year, at an expense for fuel of less than forty cents per thousand, waste coal being used for this purpose.

In the year 1880 over four thousand millions of common and pressed brick are reported to have been manufactured in the United States, the States which were foremost in that industry being New York, Pennsylvania, Ohio, Illinois, Indiana, New Jersey, Missouri, and Massachusetts. In the manufacture of drain-pipes Ohio leads, while New Jersey produces fully eighty per cent of all the terra-cotta. The manufacture of this last article requires the superior kind of refractory clay fitted for fire-brick, and a variety of colors is produced by the judicious admixture of clays having slightly different ingredients. Sewer-pipes are also made from the same kind of clay, both articles requiring to be burned at a high temperature.

Materials for Mortar.—The materials for the mortar to be used in various kinds of construction are sand, quicklime, and hydraulic cements, both natural and artificial. The type of a good sand for mortar-making is an aggregation of clean, sharply angular granules of *quartz*, of somewhat coarse texture; and the more closely a sand approximates to this type the better it is. In many sections an impure mixture of quartz sand with rounded grains of other substances and some clay is used, producing great annoyance by the crumbling of the mortar and the frequent fall of portions of the plastering of houses. It would be better, and in the end cheaper, to bring good sand from a considerable distance, rather than to use such inferior materials. Sands for mortar are found widely distributed in various superficial deposits along stream-courses, and on the shores of the ocean and other bodies of water, in the modified drift, in unconsolidated beds of Tertiary and Cretaceous age, and occasionally in the incoherent sandstones of much greater geological age. Quicklime for use in mortar is obtained by properly calcining in kilns any of the limestones and dolomites, whose general distribution has been given on a preceding page, and which are of a reasonable degree of purity ; i. e., which contain no more than six to eight per cent of silicious and earthy impurities. Doubtless, limestones less pure than this are frequently burned when nothing better can be obtained ; but it is obvious that the nearer a limestone is to absolute purity, the better it is for lime-making. A rough test of the purity of a limestone may be made by dissolving small fragments, chipped from various parts of the stone, in hydrochloric acid, applying a little heat if magnesian, and noting the nature and amount of the residue. This test can of course be made much more accurate if means can be had for weighing the stone fragments, and then weighing the filtered and dried residue. Quicklime obtained from ordinary limestone differs in some marked respects from that obtained from dolomites or highly magnesian limestones. The former, called *hot limes*, on the application of one third their volume of water, slack, i. e., fall rapidly into a fine, whitish powder, with great evolution of heat ; and when made into a paste with water, with which paste is thoroughly incorporated from three to five times its volume of clean, sharp sand, form a mortar which *sets* or hardens very quickly in the air. The latter, called *cool* limes, require less heat for their thorough calcination, slack less rapidly and with smaller evolution of heat, and form a mortar which sets more slowly, and so admits of more deliberate work on the part of the mason. While equally good with the other for all common uses of mortar, the dolomitic limes have evidently a special adaptation to the operations of the plasterer. Lime would undoubtedly make better mortar could it, after being slacked, be thoroughly covered from the air, and left for some months to ripen before being mixed. In this way, and with very coarse, angular sand, is said to have been made the mortar found in many ancient European structures, which rivals the firmness of the stones which it cements. A vast fragment of the old castle of Heidelberg, comprising nearly one half of one of the enormously thick towers, blown up by the French in 1688, still lies in the moat into which it slid, the entire mass firmly welded by the adhesion of its mortar, whose stony hardness seems unimpaired by an exposure of nearly two centuries. Our modern mortars, quickly made, can bear no comparison with such endurance as this. Indeed, in the removal or alteration of somewhat recent structures, the adhesion of the mortar too often opposes little resistance to the operations of the workmen, and not unfrequently, after the lapse of a few years, it crumbles spontaneously from between the stones which it was intended to cement.

In the selection of a limestone for calcination, after a sufficient degree of purity is assured, it is better to choose such beds as, without being friable, possess a somewhat granular and porous texture, since they burn to lime most easily and uniformly. The magnesian limestones have this constitution more generally than others, furnishing another reason for their selection where they are attainable. The Census Reports of 1880 show that lime suitable for mortar is found in greater or less abundance in every State and Territory of our Union, though it would appear that Oregon and Washington are least abundantly supplied.

While the mortars made from the kinds of lime just described, when immersed in water, remain soft and without cohesion, and gradually part with their lime by solution, that made from hydraulic limes and cements, either with or without admixture with sand, possesses the singular and valuable property of setting more or less quickly under water to a mass of stony hardness and great strength. Hence, in all constructions where moisture is to be withstood, as in damp foundations or submerged structures, the mortar should contain the latter kind of lime to the extent of at least half that which is used in the mixture, and in many cases the whole of it. This difference in behavior between common and hydraulic limes is due to an important difference in their composition. Common lime is burned from carbonate of lime or carbonate of lime and magnesia as nearly pure as can be obtained ; and the hardening of the mortar made from it is due in part to the re-formation of lime carbonate, in part to the crystallization of hydrate of lime upon the grains of sand, and probably in part to the slow formation, during ages, of lime silicate, in virtue of which a good mortar grows harder with age. Hydraulic lime, on the other hand, is burned from limestones notably impure, containing, as analyses show, from twenty to about fifty per cent of silica, alumina, and iron oxide ; it either does not slack at all with water, or slacks very slowly, and with great difficulty, needing, therefore, to be ground to a fine powder before being used ; and its hardening in mortar is due to a chemical combination of lime, or lime and magnesia, with silica and alumina, partially effected during the burning, and partially by the agency of water, forming hydrated silicates and aluminates of lime and magnesia, which are insoluble in water. The impure limestones suitable to yield hydraulic lime by proper burning naturally constitute, as General Gillmore remarks, transition beds between mechanical sediments like sandstones and shales, and the purer limestones; and in such geological positions they are usually found. From their nature as transition beds, also, and dependent as their properties are upon a due intermingling of substances from two very distinct sources, they possess, as might be supposed, but "little uniformity of composition over any wide areas, or through any considerable thickness of strata," and consequently need great care in selection, to secure stone which, when burned, will yield a good hydraulic lime. Indeed, some of the most reliable and highly esteemed materials of this class, like the celebrated Portland cement, are made artificially by burning a carefully proportioned and thoroughly incorporated mixture of clay and chalk. Where, however, natural stone can be found which, by proper care in selection and burning, will yield hydraulic limes and cements of good quality, it can be more cheaply obtained, and is good enough for all practical purposes. The United States, fortunately, has such limestones occurring at several different horizons, and of somewhat extensive distribution. The lowest of these horizons is in the Calciferous group, which at Utica in La Salle County, Ill., and at several points in Maryland and Virginia, furnishes hydraulic limes of satisfactory quality, and may be expected to do the same at points on the same range in eastern Pennsylvania. The Water-Lime group, at the base of the Lower Helderberg, with some kindred limestones belonging just beneath it in the geological series, furnishes nearly ninety per cent of all the hydraulic lime and cement produced in the United States, being largely burned in Ulster County, N. Y., furnishing the esteemed Rosendale cement, also in Oneida, Madison, Onondaga, and Erie Counties, and near Sandusky, in Ohio; while the well-known Louisville cement is obtained, according to Prof. James Hall, from beds of the Corniferous period belonging just above this in the geological series. A limited outcrop of rocks of the Hamilton period at Milwaukee, Wis., furnishes the Milwaukee cement. The St. Louis limestone, of the Sub-carboniferous, is said to give promise of possessing hydraulic properties at several points in Illinois; while impure limestones of the coal-measures furnish "Parker's cement" in Belmont County, O., and the "Johnstown cement" in Cambria County, Pa. A volume on "Mineral Resources of the United States," published by the United States Geological Survey in 1883, states that limestone suitable for hydraulic cements is found also in California, Oregon, and Washington Territory. The same work gives the United States production of cement for 1882 as about 3,250,000 barrels, of about 300 pounds each, of which New York is credited with 2,000,000 barrels, Ulster County alone furnishing over 1,500,000 barrels; the vicinity of Louisville, Ky., ranking second as a great producing center.

Works on building materials which students are recommended to consult.

"Tenth Census of the United States," Vol. X.
Prof. James Hall's "Report on Building-Stones."
Hull, "Building and Ornamental Stones of Great Britain," etc.
"Geology of Wisconsin, 1873-'79," Vol. I, Part III, chap. iv.
"Mineral Resources of the United States, 1883," p. 450, *et seq.*
Gillmore on "Limes, Hydraulic Cements, and Mortars."
Totten on "Mortars."
"Report on Clays of New Jersey," 1878.
"Geological Report of Minnesota," N. H. Winchell.

The student should also carefully consult the geological reports of his own State, by the aid of the index with which they are usually furnished.

CHAPTER VI.

RELATIONS OF GEOLOGY TO AGRICULTURE.

In the organization of the geological surveys of the various States, the advancement of agriculture has in nearly all cases been made one of the leading objects to be attained; yet it is doubtful whether the importance of the relations of geology to the tillage and improvement of the soil is fully realized, especially by those most immediately concerned. Questions as to the origin and distribution of soils; their character, and how it originated, and by what means it may be most cheaply improved; the means by which the reproduction of a proper arable surface may be made to keep pace with the natural processes of waste through tillage and other agencies; and the sources of supply and the proper use of mineral fertilizers to make good the necessary losses incurred in cropping—all involve considerations of a geological character, and it may easily be seen that they are of no secondary importance.

Those superficial portions of the unconsolidated surface-materials of the earth's crust, usually of but little depth, which are termed soils, with the subsoils extending to variable depths beneath them, are composed chiefly of exceedingly variable mixtures of sand and clay, with considerable proportions of vegetable mold and iron oxide, and usually smaller but very important amounts of lime, magnesia, the alkalies potash and soda, and phosphoric acid.

These soils and subsoils, like all other unconsolidated earthy materials, have originated from the *decay*, the *disaggregation*, and the *wear* of rocks once solid. Rocks decay through the chemical action on some of their constituents of water holding in solution carbonic acid and other chemical agents, which, penetrating deeply into their pores and crevices, unites with some of their components, and carries them away in solution, leaving the residue in an incoherent state. They are disaggregated, to some extent, by the roots of trees and vegetables, which insinuate themselves into their crannies and larger pores, and split them in pieces by progressive growth; but much more rapidly, in frosty latitudes, by the expansion in freezing of water, which is present in some amount in the substance of nearly all rocks. This agency of destruction, which has already been mentioned as a chief cause of dilapidation in building-stones, is a very efficient instrumentality in the formation and comminution of soils. Rocks are worn away and ground to powder by the friction of sand and of loose fragments of other rocks, dragged over them by moving water, or by blocks and sheets of ice, or which are swept along and dashed against them by the wind. These fragments of rock-materials, set in motion by any of the agencies that have been named, not only wear away the solid rocks, but also, by their mutual rubbing, grind each other down to an ever-increasing degree of fineness, until what were once large angular fragments become rounded pebbles, and ultimately fine mud or sand. Abundant examples of this mode of formation of the materials for soils may be seen, not only in the deep valleys and ravines that have thus been produced, but in the gullies filled with worn stones which every rain-storm is likely to make on cultivated slopes; and also in the rocks of some regions, which are worn and rounded, and even under-cut, by the agency of wind-swept sand.

The materials of soils and subsoils, originating in the ways described above, may in some cases occupy very nearly their original position, when their character will naturally be dependent largely on that of the underlying rocks; while in other cases they have been removed to greater or less distances from their place of origin, and so bear no relation whatever, in character or composition, to the rocks on which they rest. Considered, therefore, with reference to this circumstance only, we have *soils* of *disintegration*, or those owing their existence to the waste of rocks in place; and *soils* of *transportation*, whose materials have been brought to their present position by agencies such as ice and water from regions often quite remote. The soils of those portions of the eastern and central United States which lie south of the thirty-ninth parallel of latitude belong largely to the first class; while north of this parallel the soils are chiefly soils of transportation.

Soils of Disintegration.—Soils derived from the disintegration of sandstones are, as might be supposed, sandy, containing only those proportions of clay which were present in the original rock. These are frequently sufficient, in the argillaceous sandstones, to form a light sandy loam, lending itself easily to tillage, but apt to be less retentive than could be desired. Shales and soft slates form by weathering clay soils, which, where the rocks are pretty purely argillaceous, are heavy and undesirably compact, difficult to work, but highly retentive both of water and fertilizers. Where, however, shales contain a large proportion of sand, their disintegration produces either clay loams, or those very desirable soils called loams, in which the proportions of sand and clay are so happily adjusted as mutually to correct the defects arising from an excess of either; and which, while sufficiently easy of cultivation, are also properly retentive of all elements of fertility. The disintegration of limestones is due usually to the gradual solution and removal of the lime which forms their characteristic ingredient. Hence, the soil which arises from their destruction contains no very marked amount of lime, but is composed mostly of the original impurities of the rock, chiefly clay and iron, with sometimes silica, forming usually a reddish clay with rarely more than from one to five per cent of lime. Indeed, some shale soils contain a larger percentage of lime than those derived from the decomposition of limestones, probably because from their retentiveness they have not readily permitted it to be carried away in solution. Soils derived from the wear rather than the disintegration of limestones contain a larger proportion of lime in fine or coarse grains and pebbles; but these, from the manner of their formation, have been borne to some distance from their place of origin, and have usually been mingled with materials from other sources, to which they impart a useful modification. Soils derived from the disintegration of rocks of the granitic class owe whatever mineral elements of fertility they may possess to the decomposition of the feldspathic, micaceous, and hornblendic constituents of these rocks, which furnish a clayey matter retaining some of the alkaline, calcareous, and ferruginous ingredients of the original minerals; and this, mingled with the silica of the rock, may furnish, where the decomposition is unusually rapid, a soil of a good degree of fertility. More commonly, the native soil of granitic areas is thin and poor. On the contrary, the soils derived from the decomposition of the traps and other volcanic rocks are usually excellent, having a good texture and color, and being abundantly charged with the alkalies, lime, magnesia, and iron of the minerals entering into such rocks, with almost always favorable amounts of phosphoric acid.

Soils of Transportation.—Soils such as have just been described, which owe their leading characteristics to the nature of the underlying rocks and to the agencies to which these have been subjected, and which often at but little depth beneath the surface exhibit the same essential structural characters as the parent rock, into which they gradually merge by a diminution in the degree of disintegration, differ widely in origin, topographical position, and in some marked features of constitution, from the second kind of soils which have been called soils of transportation. The former, with some general exceptions presently to be noted, constitute the fundamental soils of our Southern and central range of States south of a line coinciding rudely with the thirty-ninth parallel of latitude. The latter cover, with few exceptions, those parts of the United States lying north of this limit and all of British America.

It will be obvious to any one who attentively considers the surface appearances presented by this latter region, that some widely operative and exceedingly powerful agency has, within a comparatively recent geological period, been active in shaping its surface features and in accumulating, mingling, and distributing the great irregular sheets of unconsolidated materials with which its rocks are more or less thickly covered. The thoughtful observer will note that the upper surface of the harder rocks exposed in quarrying or by the wash of rains is curiously smoothed and scored with fine parallel scratches, or sometimes with wider grooves usually running in a nearly north and south direction. His attention will be attracted by the great rudely rounded blocks of stone, sometimes of several tons weight, scattered here and there in the fields, which he can readily see are strangers to his vicinity, and which, if his geological knowledge permits, he may often recognize as similar to the rocky formations of regions far northward of that where they are now found. He will observe that thick sheets of blue and yellow clay, often thickly studded with blocks of stone, or irregularly alternating beds of sand and gravel and loam, or sometimes ridges of confusedly intermingled earth and stones, now rest on rocks of widely different character and of much *simpler constitu-*

tion than the materials which cover them. He may even learn from well-excavations, and deep borings in the valleys of rivers and streams, that many of these now flow scores of feet above their original rocky beds in channels cut in the unconsolidated materials with which they have by some agency been filled. These facts, and some others of similar import which he would probably observe, would be likely to suggest to him that the agent which produced them, whatever it may have been, proceeded from the north ; and that the loose superficial materials which now veil the rocks and fill deep the valleys, and whose fertile upper surface constitutes the soils, probably had their origin to the northward of their present locality. The only known agent that could have produced effects so great and so enormously wide-spread, planing and scoring rocks over areas hundreds of thousands of miles in extent, and transporting far from their birthplace great blocks of stone, is the power of a great, slowly-moving sheet of ice, such as that which now envelops a large part of Greenland ; and to such an agent these phenomena are now very generally ascribed. This vast ice-sheet, whose thickness, as judged by the heights which it overtopped, must have been many hundreds or even thousands of feet, enveloped and bore along with it all loose or projecting materials which it encountered or which dropped upon its surface ; and, armed with these, its under surface became a grinding instrument of enormous power, like a gigantic rasp, by which in its slow progress southward the surfaces of all underlying rocks were worn away and reduced to a fine rock paste, while the pre-existing valleys either were obliterated or were widened and deepened, according as their courses opposed or coincided with the direction of movement of the vast abrading mass. By this means were formed, during the unknown ages of duration of unusual cold called the glacial period, enormous amounts of what has not inaptly been called "rock-flour," which, when a warmer climate again prevailed and the ice-sheet slowly melted, was intermingled more or less completely with the other substances previously frozen into the glacial mass, and covered the surface with the raw materials of a soil of highly complex and varied constitution. With regard to these materials thus brought together it is obvious,—first, that, being the result not of *disintegration* but of *wear*, they must at the outset have contained the constituents of the parent rocks unchanged ; second, that, from the manner in which they were formed, substances from widely different sources were likely in most cases to be commingled, so that their composition might be expected usually to be more complex and variable than that of soils derived from rocks in place ; and, third, that they have no relationship to the rocks on which they at present repose other than that of mere accidental juxtaposition. The surface portions of these crude materials of soils have since their deposition been subjected to the usual atmospheric agencies of disintegration, which have broken up and comminuted in various degrees their coarser portions, have made soluble and subjected to the processes of plant-growth parts of their alkaline, calcareous, and phosphatic ingredients, and have mingled the whole with the organic residues derived from the decay of successive generations of plants, forming soils such as we now find them in areas not yet subjected to tillage. The subsoils have been subjected in a less degree to these atmospheric agencies, and retain more nearly their original constitution. They are likely, therefore, to be charged with a number of ingredients necessary to plant-growth, in greater abundance than the surface soils, and may, by proper mechanical treatment and by the action of certain natural agencies, restore to them elements of fertility of which they constantly tend to become exhausted, not only by the growth of crops, but also by that slow but incessant removal of the surface to which cultivated fields are subjected by the wash of rains. The most obvious mechanical means by which the proper renewal of the surface soil may be secured is deep tillage and subsoiling. By this means materials hitherto untouched are brought within reach of atmospheric influences which compel them to yield to agriculture any fertilizing principles they may possess. Among the natural agencies through which the subsoil appears to react beneficially upon the soil may be mentioned the capillary action of well-conditioned soils and earth-worms. The fine pores of a soil of proper texture not only furnish channels through which the rains sink into the earth, but also, when the surface has become dry, the deeper seated supplies of moisture ascend through their minute tubes by an action termed capillary to supply the losses occasioned by evaporation, bringing up with them in solution small but important amounts of fertilizing elements obtained from the subsoil which their evaporation leaves in the surface soil. Hence, after periods of drought, when this capillary action is more than usually active, the farmer frequently observes that his fields show more than usual fertility, due without doubt to this cause, which yet in ordinary seasons is constantly operating to augment the fertility of well-tilled lands. The humble earth-worms will, doubtless, seem to many a very insignificant agent in promoting the fertility and renewal of soils ; yet the careful observations of the distinguished naturalist, Charles Darwin, have left no room for doubt, not only that the active burrowing of their innumerable myriads plays a very important part in loosening the soil and making it readily accessible to atmospheric agencies of change, but also that their digestive action on the finer soil particles is a highly influential agency in the formation of vegetable mold, and in bringing to the surface some deeper seated elements of fertility contained in the subsoil.

Another kind of soils of transport, by no means confined to the region of glacial action that has just been described, but found covering areas of considerable extent in all regions, is that which finds its type and exemplar in "bottom-lands." These soils are due to the carrying power of flowing water, which in times of rain collects the wash of the uplands into rivulets, streams, and rivers, all rushing downward, turbid with the earthy matters with which their waters are loaded, until they reach the lowlands, where, when their flow is checked, they deposit first the coarser and then the finer materials that they have transported, gradually filling the hollows and coating the flood-plains of streams and rivers with a soil of exuberant fertility, and whose mass is augmented with every period of flood. Soils originating in this way are not confined wholly to lowlands and to the valleys of rivers and streams; but, especially in the glacial region, they may be found occupying apparently the ancient sites of vanished pools and lake-like expanses, which were probably formed by the waters of the great melting glacier.

It may thus be seen that our present arable soils owe their origin, their renovation, and much of their present condition, to the disintegration and wear of rocks; and that the means by which this work has been done are the chemical action of the atmosphere, and the mechanical force exerted by freezing water, and by moving water and ice. It is needful also to bear distinctly in mind that the mechanical agents, by their own unaided action, can not produce a fertile soil. Their efficiency is limited to their aid in reducing rock materials to a suitable degree of fineness, and there it ceases. But the plant-food, locked up in even the finest particles of rock, must be offered to plants in a soluble form before it can be used; to accomplish this solution, the co-operation of those native chemical agents contained in the atmosphere must be invoked. The mechanical agencies merely prepare the materials for the freer and more effective action of the real soil-makers, the chemical ones. Now, the agency of man, aided by such natural helpers as capillarity, the roots of deep-growing plants, and burrowing animals, is a mechanical one, and consists in putting the soils which he tills into the best possible condition for the action of the needed chemical agents. The more truly, then, he copies nature, and the more thoroughly he learns to accelerate the slow-moving operations which geological agencies effect, the more successful his labor is likely to prove. Deferring, then, for the present, any consideration of the fertilizing ingredients of soils, it may be profitable to direct our attention first to their nature and physical condition, and to consider how this may best be improved.

Nature and Amelioration of Soils.—The physical properties, in virtue of which a soil lends itself kindly to culture, are (1) easy *penetrability* to roots, to moisture, to air, and to fertilizers; (2) a sufficient *retentiveness* to prevent the ready escape of moisture and of fertilizing ingredients; and (3) readiness to absorb and utilize the solar warmth, for which last property *color* and *texture* are essential conditions, dark-colored and permeable soils and light-colored tenacious ones being the opposite extremes in this respect. These physical characters depend essentially on the relative proportions of three substances, viz., silicious *sand*, *clay*, accompanied usually with a notable amount of *iron oxide*, and those residues of organic decay which are termed *humus*. An undue preponderance of sand gives rise to a *light* soil easy of cultivation, and readily dried and warmed by the heat of the sun, but tending constantly to sterility from the ease with which it permits all soluble substances to be leached from it by the rains. A like excess of clay forms what is called a *heavy* soil, very tenacious, retentive in a high degree of moisture and fertilizers, and capable of giving a firm foothold to plants, but cold, impermeable, and difficult to till. Where humus preponderates, we have a peaty or turfy soil, which, when properly drained, is warmed and dried with wonderful rapidity, but which gives little support to plants, is apt to be *sour* from carbonic and other acids, and is usually deficient in some highly essential mineral elements of plant-food. So far as physical constitution is concerned, therefore, that soil is best "whose condition, equally removed from too great compactness and too great permeability, fits it to absorb and retain the due amount of moisture while giving easy exit to any overplus, to permit the ready access of air, and to absorb and utilize the warmth proper to its location." To judge from a comparison of many analyses, such a soil would contain from sixty to eighty-five per cent of sand, from ten to thirty per cent of clay and iron oxide, and from five to ten per cent of humus. Where a soil, from an excess of any component, does not naturally possess a proper texture, it stands in need of amelioration; and the means by which this may be best and most cheaply effected will naturally depend on the nature of its defect: it is also well to observe that amendments of the soil, i. e., beneficial changes in its condition and texture, should precede the application of manures, inasmuch as they prepare it in some cases to retain the fertilizing principles, and in all cases to derive the fullest benefits from their use.

An obvious means for improving sandy soils is mixture with clay to increase their retentiveness, and where this is found, as is sometimes the case, at no great depth in the subsoil, this improvement may be effected at no undue expense. Very great benefit may also be derived by treating such a soil with either variety of quicklime, or with clayey marls, either of which, while improving its texture, adds to it an important element of plant nutrition, in which such soils are apt to be deficient. The tillage of sandy soils should also be shallow, three inches in depth being probably quite sufficient, and every means should be used both to retain and increase any original solidity they may possess.

Turfy or peaty soils and swamp mucks contain a superabundance of humus, in virtue of which their materials may be profitably composted with manures, and used to improve other soils which are deficient in this ingredient. Mucky soils need first of all as careful drainage as is practicable, and then thorough treatment with quicklime and mixture with coarse, gravelly sand and animal manures.

Heavy clay soils need first of all thorough under-draining to remove the superfluous water with which they are apt to be clogged, and by which they are rendered both adhesive and difficult to be warmed. By the removal of this superabundant moisture, the texture of such soils is at once very materially improved. Their texture may then be further loosened and made more pulverulent by treatment with quicklime, by admixture with coal-ashes, or by burning portions of the surface in ridges or heaps with dried leaves and weeds or brush, and then mingling the burned portions with the remaining soil. Deep and rough plowing of heavy soils in the late autumn permits advantage to be taken of the powerful pulverizing action of winter frosts. It has also been suggested that, in the vicinity of iron-furnaces, their slags, previously rendered pulverulent by being run from the furnace into shallow pools of water, could be utilized advantageously for lightening the texture of heavy soils, adding to them also some elements of value in the compounds of lime and iron, and the small amounts of phosphorus which they contain. Doubtless the slags from the basic process, recently devised for the elimination of phosphorus from iron, containing as they do a considerable percentage of this element, will be found especially useful for this purpose, because of their unusual content of this valuable fertilizer.

Besides that proper physical condition which has just been described, with some of the means for its promotion, and which fits a soil to give suitable support to growing plants, to permit the easy spread of their roots in search

TABLE I.

	Ash, per cent.	Potash.	Soda.	Lime.	Magnesia.	Iron, etc.	Phosphoric acid.	Sulphuric acid.	Silica.	Carbonic acid.	Chlorine.
Wheat—straw......	.0527	18.	.61	4.50		0.33	4.08	.03	72.43		0.03
„ grain......	.013	28.49		1.49	12.17	0.15	57.31		0.33		
Rye—straw........	.036	16.73	.30	8.98	2.39	4.35	3.80	.81	63.89		0.81 NaCl.
„ grain........	.023	32.8	4.41	2.92	10.13	0.82	47.29	1.46	0.01		
Barley—straw......	.042	3.43	.92	10.56	1.45	3.05	1.14	2.25	75.55		1.41
„ grain......	.018	13.70	6.80	2.21	8.60	1.07	39.80	0.17	27.65		
Oats—straw.......	.051	22.8	4.07	7.29	4.58	1.41	1.94	2.15	54.25		1.60
„ grain.......	.04	12.90		3.70	7.70	1.30	14.90	1.00	53.30		0.55
Maize—stalk......	.04	9.60	28.60	8.30	6.60	0.80	17.10	0.70	27.00		1.50
„ kernels....	.01	32.50		1 40	16.20	0.30	44.90	2.80	1.40		0.20
Buckwheat—straw..	.041	7.21	1.44	33.08	9.16	1.60	0.40	0.18	3.57	40.35	0.96
„ grain..	.0192	8.70	20.14	6.66	10.38	1.05	50.07	2.16	0.69		
Peas—vines........	.0497	13.49	Carbonates and phosphates not determined.			0.50	10.72	4.94	7.81	51.86	4.63 NaCl.
„ grain.......	.03	35.50	2.50	10.10	11.90		30.10	4.70	1.50	0.50	1.30
Beans „	.032	38.40	12.27	5.90	9.03	0.11	31.34	2.47	0.44	0.35	0.35
Beets—root........	.0624	39.0	6.0	7.00	4.40	0.50	6.00	1.60	8.00	16.10	5.05
Turnips—root......	.076	26.60		14.63	11.96	2.84	41.68	0.77	1.32		
Potatoes—tubers...	.04	50.0	1.50	1.80	5.40	0.50	11.30	7.10	5.60	13.40	2.90
Tobacco—leaves...	.22	17.52	0.25	43.08	12.08	3.65	2.65	2.99	9.51		8.27 NaCl.
Hops—entire plant.	.0947	24.62	3.41	22.17	7.87	2.91	9.18	4.78	20.08		6.47

of nourishment, to favor a proper circulation of air, and to retain the moisture needed for plant-growth while yielding ready outflow to all excess, every fertile soil must possess also sufficient amounts of the inorganic substances and nitrogen which enter into the tissues of plants. What are the inorganic substances appropriated from the soil by the various cultivated plants can be learned from the analyses of their ashes, and a table of such analyses for a number of common plants, derived from French authorities, is given on the preceding page.

Tables of the mineral components of the above plants, derived from the ash analyses of Emil Wolff, may also be found in the Geological Report of Ohio for 1870, pages 366 and 367, which, while differing somewhat from the above in the relative proportions of some constituents, present no material differences in the substances themselves, and these, as they are present in some proportion, doubtless subject to considerable variations, in the tissues of all cultivated plants, are obviously essential to their growth and health. These substances must, with slight exceptions, be supplied by the soil ; and a very important part of scientific agriculture consists in knowing by what means to keep up in the soil a due amount of these important constituents, which would otherwise tend to exhaustion by successive cropping. Some of these, like silica and iron, need little attention, being present in sufficient amounts in nearly every soil, and being rendered readily available for plant-growth by natural causes. In many soils, lime and magnesia also are found in proportions sufficient to supply the needs of a long series of crops, while in others there is a deficiency of these substances. An average soil will give about two million pounds per acre, for a depth of eight inches. If, then, it contains one per cent of lime, this will make available with ordinary cultivation at least 20,000 pounds per acre. It will be seen, by reference to the table, that tobacco is the most exhaustive of lime among the common crops, containing about 9½ pounds per hundred of dried leaves, or 190 pounds per ton. It would require, therefore, one hundred crops of a ton per acre—much more than the usual crop—to exhaust this element from a soil containing one per cent. It is obvious that this is an extreme case for any soil ingredient. For an ordinary rotation of crops, one per cent of lime or magnesia in a soil would suffice for a long succession of crops. It may be observed that, among the cereals, lime predominates in the straw and magnesia in the grain. Hence the latter is likely to tend to more rapid exhaustion than the former, since, in good farming, the straw is mostly returned to the soil in the form of manure.

Of the mineral ingredients of soils, those that need most attention are phosphoric acid and the alkalies potash and soda, especially potash, which, as may be seen by the table, enters largely into most cultivated plants. It is justly thought, therefore, that phosphates, potash, and nitrogen are vital points in the art of fertilization ; and a high authority says, " A fertilizer may be considered complete when it contains lime, potash, lime phosphate, and a nitrogenous substance." Before considering the geological means which may be made available for keeping up the fertility of the soil, it will be well to examine a few analyses of soils of various kinds ; for, although questions are often raised as to their practical value, based on the local variability of soils, yet there can be no reasonable doubt that, when properly made after careful sampling, they may be of the greatest service to the agriculturist in revealing to him the capabilities of his soils and their needs.

The soil No. 3 of the Barrens is striking, from its deficiency in phosphoric acid, the alkalies, and organic matter; and its very small proportion of alumina, the basis of clay, shows it to be excessively leachy, whence, doubtless,

TABLE II.

	Organic matter, per cent.	Silica, per cent.	Alumina, per cent.	Iron oxide, per cent.	Lime, per cent.	Magnesia, per cent.	Potash, per cent.	Soda.	Phosphoric acid.	Sulphuric acid.
1. Prairie loam, Wisconsin............	4.24	79.59	4.17	8.16	1.30	1.04	.19	.49	.06	.03
2. Peaty soil, Wisconsin..............	21.40	64.49	4.80	5.74	1.62	.72	.14	.51	.12	.08
3. Sandy soil, Barrens, Wisconsin......	.80	94.08	.74	1.00	.64	.12				.37
4. Cape May, N. J., still good after 100 years' culture....................	2.59	87.51	3.45	2.88	.97	.75	.74	.14	.15	trace.
5. Shiloh, N. J., considered exhausted...	2.33	85.96	3.91	3.08	.24	.41	1.02		.10	.19
6. Subsoil, Fishing Creek, N. J........	1.76	87.47	7.94		.42	.65	.61		.13	.23
7. Prairie soil, Wood County, Ohio.....	9.18	66.40	16.40	2.03	2.05	1.67	1.75		.246	.05
8. Farm soil, " "	8.24	66.93	16.60	2.53	1.53	1.71	1.80		.329	
9. Black swamp soil, Wood County, O..	21.73	54.32	10.89	1.97	5.64	1.68	.54		.229	.185

its deficiencies originate. Soil No. 5 probably owes its exhaustion to its low proportion of organic matter and of lime. Nos. 7, 8, and 9 abound in fertilizing elements, but would be likely to need attention to their physical condition. No. 4, which is considered still good after a century of culture, though evidently not abounding in organic matter, has in eight inches of depth, on the moderate estimate of two million pounds to the acre—

Phosphoric acid,	3,000	pounds per acre.
Potash,	14,800	" "
Lime,	19,400	" "
Magnesia,	15,000	" "

Using now the table of ash analyses and per cent of ash given on a preceding page, it may be seen that a crop of twenty-five bushels of wheat = 1,500 pounds, if the straw, etc., equals fifty-six per cent of the crop, will take from the soil—

Phosphoric acid,	11.175	pounds	in grain	and	4.1	pounds	in straw.
Potash,	$5\frac{1}{2}$	"	"	"	18.1	"	"
Lime,	$\frac{3}{10}$	"	"	"	$4\frac{1}{2}$	"	"
Magnesia,	$2\frac{1}{3}$	"	"				

Several other crops draw much more of these ingredients from the soil. An estimate made in the "Geological Report of New Jersey," 1879, at page 116, of the amounts of important minerals withdrawn from the soil by a five years' rotation, of clover two years, and Indian corn, potatoes, and wheat, each one year, gives 581 pounds potash, 259 pounds lime, and 179 pounds phosphoric acid, of which, however, nearly all the lime, and considerably more than one half of the potash and phosphoric acid found in the clover, straw, corn-stalks, and potato-tops would, in careful farming, be retained on the estate and returned to the soil in the form of manure. The tables that have been given, and the specimen of computations that may be based on them, will serve to indicate the proportions of essential mineral elements that are found in various fertile soils, the approximate amounts that are certain to be withdrawn from them by various crops, and the importance of restoring to them in some form the fertilizing principles that have been withdrawn, to prevent a progressive exhaustion. An examination of Table I will show that, while lime preponderates over magnesia in the straw of the various cereals, the reverse is true for the grain; and when to this is added the fact that magnesia, from its great power of absorbing and retaining moisture, tends to give freshness to soils, it will suggest the expediency of testing magnesian quicklime on soils in which lime is deficient, despite the prejudice against it.

Geological Fertilizers.—Recalling now to mind the native composition of fertile soils, and that the constant tendency of the most judicious cultivation is to withdraw from them certain substances of capital importance, especially nitrogenous compounds, the phosphates, the alkalies potash and soda, as also lime and magnesia, it becomes a question of much importance what materials the earth's crust can supply to enhance the fertility of the soil without undue expense. Among these substances, one of the most widely distributed and cheaply available is peat, or swamp-muck. There are few localities in the Northern United States or Canada where it does not occur, and often in deposits of very considerable extent, in marshy spots, or at small depths beneath the surface, occupying the sites of former swamps and ponds. It not only improves the color of soils, making them more readily warmed, and their texture, rendering them more pulverulent and more retentive of moisture, but it also adds to them small but important amounts of alkalies, and often phosphoric acid, while by its decomposition it furnishes to growing plants supplies of nitrogen and carbonic acid; and it is claimed that it also absorbs ammonia from the air. It should be weathered in heaps for some months before being used; or, better, it may be composted in various ways. It may be composted with barn-yard manures, to which it not only adds its own fertilizing principles, but aids very materially in retaining the nitrogenous substances which might otherwise be dissipated in the process of fermentation. It is also composted with quicklime, or with lime and a small amount of salt, a good mixture being, it is said, a bushel of freshly slaked quicklime, or of lime slaked by brine, to twenty bushels of peat. "Experience has fully sustained its claims as a useful fertilizer, and chemical analysis shows that it contains the elements needed to stimulate the growth of farm-crops." ("Geology of New Jersey," 1868, p. 486.)

Another widely diffused mineral fertilizer, previously mentioned in another connection, is lime, which is already much used in agriculture, and is destined, doubtless, to a much wider application, with the spread of better methods of tillage. Not only those wide-reaching formations of calcitic and magnesian limestones, mentioned in the section on building materials, but also thinner and more locally developed seams, little regarded as building-stones, and somewhat too largely charged with impurities to be favorites for mortars, may furnish cheap local supplies for agricultural uses, benefiting the soil as well by the silicates and sulphates of lime developed in the burning, as by the caustic lime and magnesia which they furnish in their most finely divided and active form. These, as has already been remarked, make clay soils lighter and silicious ones more firm, lighten and sweeten damp and turfy soils, and contribute to the destruction of weeds and insects, while furnishing elements which analysis shows to be essential to the growth of most cultivated plants. Their efficiency in promoting the solution of other constituents of the soil is also, doubtless, very considerable. To derive the fullest benefits from their use, their application should usually be followed by that of organic manures.

Besides the use of quicklime as a fertilizer, a stimulant, and a solvent, benefit would doubtless be derived by many soils from the application of calcareous marls, where they may be obtained in the immediate neighborhood. Such marls may be found, usually in small ponds, in some portions of the Northern and Eastern States, where they are occasionally burned for lime ; but their original pulverulent condition permits their application to the soil in their raw or unburned state, where their action as a source of lime is more gradual and prolonged than that of caustic lime. Also, under many peat-beds is found a calcareous marl, formed of fresh-water shells, which may be advantageously used for the same purpose. Beds of calcareous marls of marine origin are extensively developed in the Cretaceous and Tertiary formations of the States bordering the Atlantic and the Gulf of Mexico, from New Jersey southward, which, besides their carbonate of lime, contain often important amounts of potash and phosphoric acid, and which are destined to be largely used in the regions where they occur.

Of greater importance, however, than these last-named marls are the greensand or glauconitic marls, which are found in similar geological formations and in the same regions, and which derive their chief value from the very important proportions of potash and phosphoric acid with which they are charged. These marls have been very largely used in New Jersey, where they abound in three beds of somewhat different properties ; and the effects that have followed from their use are thus strongly stated by Prof. Cook, "Geology of New Jersey," 1868, page 442 : "The marl which has been described in the preceding pages has been of incalculable value to the country in which it is found. It has raised it from the lowest stage of agricultural exhaustion to a high state of improvement. . . . Lands which in the old style of cultivation had to lie fallow, by the use of marl produce heavy crops of clover and grow rich while resting. Thousands of acres of land which had

TABLE III.

<table>
<tr><th></th><th>Phosphoric acid.</th><th>Potash.</th><th>Lime.</th><th>Magnesia.</th><th>Silicic acid.</th><th>Alumina.</th><th>Iron oxide.</th><th>Sulphuric acid.</th><th>Carbonic acid.</th></tr>
<tr><td>Red Bank, lower bed.............</td><td>1.14</td><td>3.65</td><td>9.07</td><td>1.50</td><td>38.70</td><td>10.20</td><td>18.63</td><td>.14</td><td>6.14</td></tr>
<tr><td>Holmdel, first quality, lower bed....</td><td>1.23</td><td></td><td>15.19
and carbonate
23.05</td><td></td><td>36.03</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Marlboro, ,, ...</td><td>1.14</td><td>4.47</td><td>7.79</td><td>1.21</td><td>38.70</td><td colspan="2">30.67</td><td>.31</td><td>6.12</td></tr>
<tr><td>Blue Ball, middle bed.............</td><td>1.04</td><td>6.98</td><td>0.48</td><td>3.79</td><td>54.11</td><td colspan="2">23.39</td><td>1.44</td><td></td></tr>
<tr><td>Pemberton, ,, ...</td><td>2.39</td><td>6.92</td><td>1.22</td><td>4.21</td><td>49.34</td><td colspan="2">27.07</td><td>0.13</td><td></td></tr>
<tr><td>Near Medford, ,, ...</td><td>1.79</td><td></td><td>1.90</td><td>3.05</td><td>47.00</td><td colspan="2">30.11</td><td></td><td></td></tr>
<tr><td>Shark River, upper bed ....</td><td>3.73</td><td>4.98</td><td>4.14</td><td>0.47</td><td>49.68</td><td colspan="2">28.71</td><td>2.44</td><td></td></tr>
<tr><td>Squankum, ,, ...</td><td>4.54</td><td>4.27</td><td>3.48</td><td>2.04</td><td>51.16</td><td>6.10</td><td>17.67</td><td>0.43</td><td></td></tr>
<tr><td>,, ,, ...</td><td>3.97</td><td>3.97</td><td>3.08</td><td>2.00</td><td>56.50</td><td>10.30</td><td>11.68</td><td></td><td></td></tr>
</table>

The water, ranging from 5½ to 10 per cent, has been omitted in this table.

been worn out and left in commons are now, by the use of this fertilizer, yielding crops of the finest quality. Instances are pointed out everywhere in the marl district, of farms which in former times would not support a family, but are now making their owners rich from their productiveness. Bare sands, by the application of marl, are made to grow clover, and then crops of corn, potatoes, and wheat." The work from which this is quoted gives, in the succeeding pages, an account of the mode of using this fertilizer and its results, which the student can profitably consult; as also Prof. Kerr's "Report on North Carolina Geology," 1875, in which will be found an account of the Tertiary calcareous marls of that State and their great value in agriculture. On page 121 are given a few analyses of greensand marls from New Jersey which may be found useful, those being selected which have been approved in use.

It will be observed that in all these marls phosphoric acid is present in considerable proportion, and to this substance much of their efficiency is ascribed. In many of them, also, potash is found in very considerable amounts, and there is no good reason to doubt that its liberation in the soluble form, in the course of the decompositions that go on in the soil, gradually furnishes to plants this important element in their nutrition. Of the silicic acid, a very considerable proportion exists in an easily soluble condition; and when it is considered how large a proportion of this substance is found in the stems of plants, the probable significance of this fact will be apparent. Doubtless, some other elements in these fertilizers, especially lime, aid in enhancing their value. The use of these marls in New Jersey is fully 100,000 tons per year, 1,080,000 tons having been dug in that State in 1882 for use and export; and it is certain that with the advancement of agriculture in the Southern seaboard and Gulf States, in which these and other marls are known to occur, they will be sought out and used with great benefit to agricultural interests; though, from the few analyses at present attainable, it would seem that the greensand marls are not there so rich in phosphoric acid and potash as those of the more northern localities.

A rich supply of the phosphates needed in agriculture is obtained from the region in the vicinity of Charleston, S. C., where it is estimated that nearly eight hundred square miles are underlaid more or less abundantly with phosphatic masses, of which twenty thousand acres are counted worth working with the present appliances for obtaining it. In this region, the phosphatic nodules are found along the courses and in the beds of streams, from which they are dredged, or underlying the surface at varying depths in a stratum which, according to Prof. Holmes, averages about fifteen inches in thickness. It is reported that, in 1883, 332,079 gross tons were produced, the rock being sold on a guarantee of containing not less than 55 per cent of lime phosphate, or about 25 per cent of phosphoric acid; and in the same year the shipments of manufactured fertilizers from Charleston are reported as amounting to 130,000 tons. These figures will give an idea of the vast extent to which the supply of this valuable fertilizer has already attained, from a source whose importance had not come to be understood so recently as 1868.

Another source of phosphoric acid which is rapidly attaining importance in this country is found in the mineral apatite, which occurs as beds and veins in rocks, chiefly of Archæan age. Deposits which may prove of economic importance occur at Bolton, Mass., and at Crown Point, N. Y., the latter of which is said to be extensive and has been mined to a limited extent. The deposits of greatest present importance are those found in Canada, in a region extending northeastwardly from near Kingston in Ontario, into Ottawa County, Province of Quebec. The deposits here occur in both beds and veins, of which the former afford the largest and purest supplies. The amount mined in 1883 reached, it is said, 23,000 tons of rock, containing from 75 to 85 per cent of lime phosphate. A small portion of this comes to the United States, but most of it is sent to England, where it is made available for agriculture by treatment with sulphuric acid.

Guano, also, which attains to the rank of a kind of geological deposit on certain islands off the coast of Peru, and to some extent of Africa, may properly be mentioned here. These deposits, formed from the droppings and remains of sea-fowls, during countless generations, in regions nearly rainless, are very rich in compounds of ammonia and phosphorus, and have for forty years been largely imported into Europe, and to some extent into this country, for use in agriculture. According to estimates made in 1873 of the amounts then remaining available, the supply is destined to speedy exhaustion, as at that time less than twenty years' supply could apparently be counted on.

A geological source of the nitrogen so needful for plant-growth may be found in the waste from the distillation of bituminous coal in gas-making and coking. Nearly all the bituminous coals of Ohio and Indiana which have been fully analyzed show a content of nitrogen amounting to an average of about one and a half per cent, and the same is doubtless true of other coals of this class. In the process of distillation this nitrogen is driven off in the form of ammonia, which may be converted into the sulphate or used to increase the ammonia in the compost-heap.

A mineral fertilizer very largely used as a top-dressing for various crops, especially clover and Indian corn, is ground gypsum, commonly known as land-plaster. This substance is a sulphate of lime, and there is a wide diversity of opinion as to the cause of the surprising results attending its use in many cases. The Atlantic seaboard States are supplied with it from Nova Scotia, where it is found in enormous beds in rocks of Lower Carboniferous age. New York has large deposits in rocks of the Salina period, ranging from Oneida County westward, near the line of the Erie Canal ; and it is quarried at many places and shipped to considerable distances, both ground and unground. Near Sandusky, O., it is obtained from rocks of the same age, and prepared both for agricultural use and for plaster of Paris. The great deposits in Michigan, along Saginaw Bay and near Grand Rapids, are found in rocks of the Lower Carboniferous ; and those at Fort Dodge, Io., are associated with rocks of the same age, these last deposits being of especial interest, because furnishing this fertilizer to an extensive region otherwise nearly destitute of it. Important beds of gypsum occur in two sections of Kansas, in the western part of Virginia on a branch of the Holston River, and in Pike County, Ark., while vast supplies of it are known to exist in the Triassic rocks of Texas. Great beds and lenticular masses of this substance, often of wonderful purity, are known to exist in nearly all the States and Territories of the far West, partly, as in Arizona, in rocks of the Carboniferous period, but chiefly in beds of the Triassic or of still later geological age. It will thus be seen that most sections of the United States and of the British Provinces are abundantly supplied with this mineral fertilizer, and that it occurs chiefly in rocks of the Salina, the Lower and Upper Carboniferous, and Triassic periods. The European deposits are found chiefly in the Permian and Triassic, some also occurring in the Eocene Tertiary. Besides their use as fertilizers, many of these gypsum deposits are of sufficient purity to be available for use in the arts as plaster of Paris, more particular mention of which will be made in another connection.

Common salt, also largely used as a fertilizer to supply to plants soda and chlorine, is very widely distributed over the United States and Canada, being obtained chiefly from brine-wells sunk in rocks of the Salina period, in western New York, largely at Syracuse and Warsaw, and at Goderich in the Province of Ontario; and in rocks of the Lower Carboniferous and Carboniferous periods in eastern Michigan, West Virginia, and the adjacent part of Ohio. Great deposits of rock-salt are found at Petit Anse in Louisiana, in materials of somewhat recent geological formation, and throughout the far Western and Pacific States and Territories abundant supplies await the development of those regions. In these latter regions are also found at several points mixtures of salt with sulphates and nitrates of potash and soda, affording substances which must ultimately become of great importance in agriculture as sources of nitrogen and potash. Similar crude salts are obtained for use in agriculture and for other purposes from South America in the rainless western regions; and crude salts of potash used in European and American agriculture are obtained from beds occurring in the Permian salt deposits of Stassfurt in Germany.

What have here been briefly enumerated and described are the chief fertilizers supplied to agriculture from geological sources, and the *judicious* use of which may be expected to increase largely the productive capacity of the soil. The beneficial effects of some of these are produced at once, and are quite limited in their duration, while others, acting more gradually, constitute a permanent improvement of the soil. Both of these classes of fertilizers may be used with advantage; but questions of expense incurred, as compared with benefits received and returns obtained, depend on many circumstances which belong rather to the science and art of agriculture than to applied geology.

Drainage and Subsoils.—The geological considerations which influence drainage, whether undertaken in the interests of agriculture, or for the promotion of healthful surroundings, or for the reclamation of waste lands, have already been suggested on page 64. They consist in the presence of a sufficient declivity to insure the easy passage of water through under-drains, and ultimately the free outflow of the collected waters of drainage, or, in the case of flat-lying districts, in the possible existence in the subsoil or underlying rocks of porous beds or fissured and jointed strata, which may serve as water-ways and afford an underground outlet to drains and cess-pools; or, on a larger scale, in the removal of geological barriers and obstructions caused by geological agencies, such as have converted tens of thousands of acres in central New York into the pestilent fen called the Montezuma Marsh. An example of the reclamation of a similar district by the removal of a barrier has recently been presented by the successful draining of the "Great Meadows" in Warren County, N. J., where an area of five thousand five hundred acres has been opened to cultivation, while the surrounding region has been freed from a fruitful breeding-place of malarial diseases. In all cases of difficult drainage examination should be made of the structure of what lies beneath the soil. Not unfrequently it may be found that the need of drainage arises from the presence of a comparatively thin crust of hard-pan, and that if this be broken up the difficulty will disappear. In a much greater proportion of cases than would be supposed, also, porous or fissured strata at no very considerable depths will furnish an easy outlet for both farm and house drains, promoting at the same time agricultural fertility and personal health and comfort. Prof. Emmons, in his report on New York agriculture, vol. i, calls marked attention to this too often neglected means of drainage. Such an examination can be easily and cheaply made, and, though it may not be needed for the purpose of facilitating drainage, it will reveal to the agriculturist the nature and resources of his subsoils, giving him information which is second in importance only to a knowledge of the capabilities and needs of the soil; for the subsoil may aggravate the defects of the arable surface by its tenacity or its permeability, or, on the other hand, it may furnish a ready means of remedying these defects by beneficial mixtures. Very frequently it will be found capable of restoring to the soil elements of fertility of which it may be measurably exhausted, or it may even be found to contain at no great depth unsuspected deposits of valuable fertilizers, as has been found true already in many sections of our country. Expedient as such careful examinations clearly are in all ordinary cases, their importance becomes especially great in regions where valuable fertilizers are known sometimes to occur, as well as in those where it may reasonably be suspected that deposits of valuable minerals like iron and coal may exist. It has frequently happened that estates have been sold merely for their value as farming-lands, from the mineral resources of which well-instructed investors have derived great wealth—wealth, too, which the former owners might have shared had they taken the pains to make or procure a proper examination of their lands. Scientific surveys made by governments can afford little benefit to those who permit themselves to be ignorant of their results, or who neglect to apply their teachings by such careful local examinations as they ought obviously to suggest.

Works which may profitably be consulted.

In general, the Geological and Agricultural Reports of one's own State. "Natural History of New York, Agriculture," vol i; "New Jersey Geological Report," 1868, pp. 378–500; and 1879, pp. 103–120; "Ohio Geological Report," 1870, pp 320–381 and pp. 452–459; "Second Geological Report of Arkansas," p. 42–54 and pp. 171–179, etc.; "Geological Report of North Carolina," 1875, pp. 162–217. The "Annual Report of New Jersey for 1870" also contains an account of the drainage of marshes. I have also been greatly indebted in the preparation of this chapter to the following French works: Meugy, "Geologie Appliquée à l'Agriculture," and D'Orbigny et Gente, "Geologie Appliquée aux Arts et à l'Agriculture."

CHAPTER VII.

RELATIONS OF GEOLOGY TO HEALTH.

Two highly essential conditions of health for both individuals and communities are supplied by wholesome water and pure air. Indeed, it can not be doubted that a large part of the diseases to which human beings are liable is due to the lack of one or both of these essentials. Both are very largely dependent on geological agencies, or on geological structure ; and hence it is proper that the important subject of sanitation should be considered here in its geological aspects.

The purely geological sources of water-supply have already been discussed in the chapter on springs, wells, and artesians, in which also were pointed out the dangers of contamination, and the precautions needed in some cases to secure a tolerable degree of purity. The importance of the subject is so great, however, that there is little danger of its being pressed too strongly upon public attention; since, even with the wide diffusion of information with regard to it, large numbers of people thoughtlessly persist in exposing both health and life to imminent risk by the use of readily obtainable water-supplies from sources peculiarly liable to contamination, while quite generally also showing a disposition to attribute the disorders resulting from this carelessness to some other than the real cause. Doubtless, a considerable portion of diseases incident to the settlement of some of our new territories could be avoided by the use of filtered rain-water; while in thickly settled villages and cities, the water of all wells, save those most favored by the underground structure, and most carefully guarded, can be used only at great risk to health. Even in the case of deep driven wells passing through thick beds of clay, a source of danger has recently been revealed, in the occasional corrosion of the iron tubing by foul superficial waters, which may thus gain unsuspected access to the domestic supply, suggesting the expediency of a frequent examination of these tubes, possibly by drawing up to view the portion that is exposed to risk of corrosion. In any use of the water from wells and from springs, save those from exceptionally deep-seated and remote sources, safety can be assured only by the exercise of intelligent care at the outset, and of constant vigilance afterward. So limited, however, is the supply from most of the geological sources, and so great is the risk of dangerous contamination in those most widely used, that nearly all large cities seek their water from other sources. Many, like Philadelphia and St. Louis, draw their supplies from the higher reaches of rivers on which they are situated, trusting to the purifying effects of atmospheric exposure to so far free the waters from the organic impurities with which they are more or less largely charged as to bring them within reasonable limits of safety; this source of supply being open to the obvious objection that, whatever may be the present condition of the water, it is sure to undergo a progressive deterioration from the growth of cities, villages, and manufactories on the upper course of the river, all of which will discharge their waste into it; not to speak of the important increase in amount of organic matter that must find its way into it from fields coming more widely into a high state of cultivation. Other cities, like Chicago and Cleveland, drive expensive tunnels far out beneath great bodies of fresh water, where the geological nature of the bottom makes this feasible, deriving thereby abundant and unobjectionable supplies. Still others, like New York, construct costly dams and reservoirs and aqueducts, to gather and bring water from distant, sparsely settled, and elevated districts; in which case many important circumstances need to be carefully weighed, some of which, and those of no minor importance, involve questions of geological structure. For not only is it necessary to consider the average amount of rainfall and the extent of gathering-ground, but also the geological character of the entire area becomes a matter of serious importance, since it is sure to influence the character of the water derived from it, and to condition both the feasibility and the expense of the dams that are to be constructed, and the ability of reservoirs to retain the water that may be collected into them. The water derived from a granitic area of catchment will differ greatly from that drawn from a limestone region, or from one underlaid with ferruginous sandstones and shales, and containing, it may be, considerable tracts of swampy ground. It is worthy of observation, also, that those districts which are likely to yield the most unobjectionable supplies of water are those least likely in the course of time to attract a numerous population, and thus to furnish an ultimate source of defilement. So, too, "the rocks of one glen may be retentive and eminently suited for a reservoir, while those of another may be so porous as to cause perpetual leakage; the rocks and springs of one tunneled aqueduct might be innocuous to the supply, while those of another might contaminate it with saline and metallic impurities." (Page's "Economic Geology.") It is evident, then, that the problem of wholesome water-supply is by no means a very simple one, requiring, in the case of small communities, the intelligent application of geological principles and precautions; while, where great numbers are to be provided for within small areas, it may tax the resources of the highest engineering ability, aided by no slight knowledge of structural geology.

The securing of pure and healthful atmospheric conditions is, in a very large degree, a matter of proper drainage. Malarious localities are usually wet or at least damp ones, those in which certain forms of vegetation flourish and decay, giving rise to unhealthful exhalations, to which any organic waste from neighboring dwellings adds a deeper taint. When the damp spot is dried, the wet or marshy tract drained of its superfluous water, the peculiar products of organic decomposition which cause disease cease after a time to be supplied, and the region becomes more salubrious. Drainage for sanitary purposes, as well as for agricultural improvement, depends in numerous cases on expedients suggested by facts of geological structure. According to the testimony of the Geological Survey of New Jersey ("Report" of 1880), the drainage of the Great Meadows in that State by the removal of a geological obstruction has been quite as marked a success for sanitation as for agriculture, as is shown in the striking decrease of malarial diseases in the surrounding region. This is but one of many instances that could be given, where the sanitary improvement of considerable tracts of "drowned lands" could be effected by the removal of geologically formed barriers to drainage. The reports of engineers show that the vast malarial region previously mentioned as the Montezuma Marshes, in central New York, owes its existence to such a barrier, and that its restoration to healthfulness can be effected only by the removal of this barrier. Of similar import is the necessity for sanitation, in grading portions of cities where great hollows occur surrounded by impervious barriers, of making sufficient provision for the under-drainage of these hollows before filling them up for building. Otherwise, even if unobjectionable materials are used in the filling, they are destined, through percolation from the streets and leakage from imperfect sewers, to become ultimately subterranean reservoirs of filth, the emanations from which can not but affect unfavorably the health of such localities. The sewerage systems of cities will always present some questions of geological significance. The course of the main sewers is naturally dictated by the slope of the ground, the opportunities for safe outlet, and, not unfrequently also, by the relative expense of excavation. Besides this, in some localities, the only desirable object may be the safe conveyance of sewage, while in others it may be highly desirable to provide also for the drainage of wet tracts; such considerations, in either case, controlling the choice of the materials with which the sewer should be constructed. In villages and small cities, where no general sewerage system is provided, the needful sanitary arrangements for dwellings must depend mainly upon supplying subterranean outlets through porous beds for superfluous or contaminated fluids. Where, from the nature of the underground structure, such drainage is not practicable, careful provision should be made for the frequent disinfection and proper discharge of impervious receptacles. When porous beds are made the outlets for house-drainage, it should always be borne in mind that any water-supplies derived from them will inevitably be contaminated. Sewage, however filtered and diluted, is not a fit beverage for human use. Numerous cases of severe and often fatal illness can, with a little care, be traced to this cause.

Should any one think that such careful provision for pure water and untainted air as has here been suggested is unnecessary, or too troublesome, it will be well to reflect that it accords with the uniform experience of civilized mankind; and that matters of such vital consequence as the health and happiness of human beings are too serious to be trusted to chance. All experience has shown that regions well drained and supplied with wholesome water are healthful ones; that cities kept properly clean and abundantly supplied with pure water show a diminished death-rate; that great epidemics, like cholera and yellow fever, either leave such cities and regions unscathed, or visit them with greatly mitigated violence, having their breeding-places in regions of filth, and confining their ravages chiefly to uncleanly and badly watered localities; and that diseases like diphtheria and typhoid fever can usually be traced to defective drainage and impure water.

CHAPTER VIII.

MINERAL FUELS.

Among all the mineral substances procured from the earth, the mineral fuels doubtless hold a foremost rank in importance, contesting even with iron for the supremacy in supplying the wants of civilized man. Indeed, the industrial rank of nations may be very accurately judged from the extent to which they utilize their fuel supplies. Great Britain, the United States, and Germany, the three foremost manufacturing nations, produce four fifths of the mineral fuels of the entire globe.

These highly important substances, whether anthracites, bituminous coals, lignites, or peat, are generally conceded to have resulted from a peculiar decomposition of vegetable tissues. There are a number of questions as to the particular mode in which these deposits originated, and the special forms and portions of vegetation that furnished their chief materials, which, although they are of much theoretical interest, are yet not of such practical importance to the student of economical geology as to claim our consideration here. It is sufficient for our present purpose to observe that the chief constituents of all vegetable tissue are carbon, oxygen, and hydrogen, with small proportions of nitrogen and some earthy substances. When these tissues decay or are burned with free access of air, their elements are dissipated in the form of carbonic acid and watery vapor, and ultimately nothing remains but an inorganic residue constituting the ash of the plants. When, however, vegetable substances undergo decay out of contact with the air, whether covered with earth or heaped together in wet places, and partly or wholly covered with water, the changes that take place in them are due mainly to chemical rearrangements that occur among their own elements. Of these, the oxygen unites with somewhat more than one third its own weight of carbon and with one eighth its weight of hydrogen to form carbonic acid and water. A portion of the hydrogen also unites with one third its weight of carbon to form marsh-gas, the fire-damp of coal-mines. The result of these several changes is that the *relative* amount of oxygen in the mass is diminished, while that of carbon, originally about one half of the whole, is increased; the color becomes darker, first brown, then nearly or quite black, from the increasing preponderance of coaly carbon, while the relative proportion of hydrogen is but slightly changed. The resulting substance, in the slow process of ages of this kind of change, passes through the condition of peat or brown coal, to become what is known as bituminous coal, or ultimately to be converted into anthracite, in some much-disturbed regions where probably heat accelerated the dissipation of most of the oxygen and hydrogen still remaining in the coal. That this process of chemical change is a gradual and protracted one, continuing even to the present day, is shown by the fact that marsh-gas and carbonic acid, or "choke-damp," are still eliminated from most coal-beds, and present some of the most dreaded dangers of coal-mining, against which careful provisions for ventilation, and the use of safety-lamps, do not always avail to prevent frightful casualties. Thus oxygen, useless as a fuel, is progressively eliminated, while the combustible elements, carbon and hydrogen, become ever more dominant, during the process by which coal is formed. By reference to the table of analyses given on a subsequent page, it may be seen that, in the course of this series of changes, the carbon, from being originally a little less than 50 per cent of the whole, becomes 60 per cent in well-formed peat, more than 66 per cent in brown coal, from 70 to more than 80 per cent in ordinary bituminous coal, and finally 90 per cent or more in anthracite; that the hydrogen, originally 6½ per cent, remains tolerably uniform in relative amount till the anthracites are reached, when it becomes, together with other volatile ingredients, not more than from 3 to 10 per cent, while oxygen diminishes from 43 per cent to an average of about 10 per cent in bituminous coals (a considerable portion of this being due to the presence of water), and to a much smaller amount in anthracite.

Now, these progressive changes in the relative proportions of the constituent elements are attended with considerable differences in the physical character of the successive products, and in their behavior when used as fuels. On these differences has been based a convenient practical classification of those variable substances called collectively mineral coals. This classification is primarily into *anthracite* and *bituminous* coal, the first of which neither softens nor swells in burning, yielding no smoke and little or no yellow flame, while the second softens and often swells in the fire, emitting much smoke and abundant yellow flame. These two great classes admit of a somewhat convenient subdivision, not always observed in practice, into *hard* and *semi-anthracites*, *semi-bituminous* and *bituminous coals*—a subdivision which is based on the relative proportion of volatile combustible substances contained in them, together with certain tolerably well-marked differences in their physical characters.

The *hard anthracites*, which usually contain less than 5 per cent of combustible gases, kindle with difficulty, and burn with an intense heat and little blue flame, have a more or less marked conchoidal fracture, a brilliant luster, and a specific gravity of from 1.5 to 1.8, being the heaviest and hardest of all coals.

The *semi-anthracites*, containing from 5 to 11 per cent of volatile combustible materials, kindle and burn more readily than the former class, giving a strong heat, often accompanied at first with a little yellow flame. They have a specific gravity of from 1.4 to 1.5 and sometimes more, are softer and less lustrous than the hard anthracites, and have usually an angular fracture with a tendency to break up while burning.

The *semi-bituminous* coals have from 12 to 20 per cent of volatile constituents and a specific gravity between 1.3 and 1.45, while the *bituminous* coals have more than 20 per cent of volatile matter, and their specific gravity is from 1.2 to 1.35, that of some of the Ohio coals being even more than 1.4, though the average gravity of this class of coals is less than 1.3. Both these kinds of coal liberate a part of their volatile matter, when heated, in the state of a dense oily liquid resembling bitumen, whence their name; they also emit a bituminous odor when burning. A further subdivision of the bituminous coals is made on physical characters of much economical importance, into *caking*, *cherry*, *splint* or *block*, and *cannel* coals.

The *caking* coals, when heated, soften greatly, and the fragments fuse together, or *agglutinate* into an adhesive mass, which is puffed up, by the gases liberated by the heat, into a hard and highly cellular substance called coke, consisting of the fixed carbon and mineral matters originally present in the coal. This property fits them to be used for the manufacture of coke, and for purposes where a "hollow fire" is desirable, as in blacksmithing, while rendering them much less convenient for domestic use.

The *cherry* coals, which owe their name to the beauty of their appearance, are usually highly lustrous but very brittle coals, which do not agglutinate when heated.

Their brittleness gives rise to a great amount of waste in mining and transportation, while their lack of adhesiveness when heated fits them for use as a domestic fuel.

The *splint* or *block* coals are hard, highly laminated, and difficult to be broken across, have a dull luster, and do not agglutinate when heated. Their properties adapt them especially for use in iron-smelting, for which they are largely utilized. They are often called *dry-burning* or *open-burning* coals, a name equally applicable to any of the non-agglutinating coals.

The *cannels*, of which Prof. H. D. Rogers proposed to make a distinct primary class under the name of hydrogenous coals, are characterized by their large proportion of volatile matter and their small amount of coke-like residue, their dull luster, their conchoidal or slaty fracture, and their tendency to split when burning with a crackling noise, somewhat like the chatter of a parrot, whence they are often called parrot-coals. They derive the name cannel (i. e., candle) coals from the readiness with which they take fire, and the cheerful flame with which they burn. This makes them favorites for use in open grates ; they are also largely used in making illuminating gas.

The *lignites* or *brown* coals are of much more recent geological origin, and usually much less completely carbonized, than those which have just been described. They are called lignites, because they frequently exhibit the woody structure of the plants from which they are derived, from the Latin word for wood, and brown coals, from their color or that of their powder. They burn readily without fusing, and emit a sooty smoke and a disagreeable smell. The lignites, as a class, contain a much larger proportion of water than other coals—a circumstance which greatly diminishes their value as fuel, since so large a portion of their heating power is wasted in converting into steam the water which they contain. The lignitic coals, which occupy vast areas in the western part of this continent, differ widely in quality. Some are hardly distinguishable in appearance or character from the true bituminous coals, having but a small per cent of water, and being sometimes capable of yielding a good coke; while others have a high per cent of water, often from 12 to 20 per cent, and crumble to a coarse powder when exposed to the air, being on both accounts very indifferent fuel.

It will be convenient, for purposes of reference, to resume in tabular form the classification of the mineral fuels, with the characters on which chiefly it is based, omitting for the present any consideration of peat:

Anthracites—do not soften; no smoke; little flame.	Hard anthracite—volatile to 5 per cent; sp. gr. 1.5 to 1.8; hard; lustrous; conchoidal fracture. Semi-anthracite—volatile 6 to 11 per cent; sp. gr. 1.4 to 1.5; less hard; luster dull; fracture angular.
Bituminous—soften; yield oily fluid; much smoke and flame.	Semi-bituminous—volatile 12 to 20 per cent; sp. gr. 1.3 to 1.45. Bituminous—volatile above 20 per cent; sp. gr. 1.2 to 1.4. Caking—agglutinates. Cherry—non-agglutinating; lustrous; brittle. Splint or block—non-agglutinating; dull; tough; laminated. Cannel—largely volatile; dull luster; conchoidal or slaty fracture.

Lignite—brown powder; usually contains much water; no fusion; sooty smoke; bad smell.

The following table of analyses, derived from various sources, is given to illustrate the composition of the various classes and kinds of mineral fuel; to which is added an average analysis of woody tissue derived from several different kinds of tissue. About one half of these are what are called *proximate analyses*, i. e., those giving only the percentages of fixed carbon, volatile constituents, and ash, with sometimes those also of water and sulphur. The re-

	Specific gravity.	Ash.	Water.	Fixed carbon.	Volatile.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.
1. Anthracite, Rhode Island	1.79	16.00		77.0	3.00					
2. ,, Beaver Meadow, Pa.	1.55	6.13		90.2	2.52					
3. ,, Neath Abbey, Wales		4.00		91.08	5.01					
4. ,, Mais Saize, France		8.50		83.30	7.50					
5. Semi-anthracite, Zerbe's Run, Pa.	1.40	6.11		84.25	7.31					
6. ,, ,, average of 11 analyses	1.40	6.69		83.99	9.45					
7. Semi-bituminous, New River, Va., coking		1.11	0.76	79.26	18.65					0.23
8. ,, ,, Blossburg, Pa.	1.32	10.77		73.11	15.27					0.85
9. Bituminous, Straitsville, O.	1.26	5.15	7.20	57.55	30.10	71.45	5.47	16.07	1.26	0.57
10. ,, Jackson County, O.	1.30	2.35	8.50	56.95	32.20	70.46	5.69	18.77	1.82	0.91
11. ,, block, Brier Hill, O.	1.26	1.45	2.47	64.25	31.83	78.99	5.92	11.50	1.58	0.56
12. ,, caking, Youghiogheny, Pa.	1.31	3.35	0.90	66.85	28.90	81.27	5.66	7.08	1.66	0.98
13. ,, Newcastle, England	1.25	3.22				80.03	5.08	9.91	0.98	0.78
14. ,, South Wales	1.32	5.52				80.70	5.66	4.38	1.35	2.39
15. ,, Derbyshire, England	1.27	2.40				79.85	4.84	10.96	1.23	0.72
16. Cannel, Flint Ridge, O.	1.43	13.20	2.60	44.0	40.20	70.42	6.50	6.89	1.65	1.34
17. ,, near Franklin, Pa.		17.68		29.54	52.78					
18. ,, Owsley County, Ky.	1.21	3.00		47.00	50.00					0.24
19. ,, Wigan, Lancashire	1.23	4.84				79.23	6.08	7.24	1.18	1.43
20. Brown coal, Bovey, England.		2.27				66.31	5.63	22.86	0.57	2.36
21. Lignitic coal, Bellemonte, Col.		2.00	20.00	58.70	19.30					
22. Woody tissue, average						49.00	6.50	43.20	1.30	

mainder are *ultimate* analyses, giving the percentage of all the elements; while five of them, taken from the "Geological Report of Ohio," 1870, combine both forms of analysis:

Geological Associations of Mineral Fuels.—The coals and lignites occur as beds of varying thickness, interstratified with other beds of sandstones, shales, fireclays, and occasionally limestones. The coal-beds, or seams, as they are frequently called, vary in thickness from the fraction of an inch to many feet. The Mammoth bed, in the Pennsylvania anthracite region, measures, at two points mentioned by Ashburner, one hundred and one hundred and fourteen feet, ranging between sixty and ninety feet over a large area in the Black Creek basin; while at St. Etienne, near Lyons, France, the main coal, according to Geikie, averages forty feet in thickness, and swells out occasionally to as much as one hundred and thirty feet. The main seam at Pictou, Nova Scotia, is about forty feet in thickness, and the Xaveri seam in Upper Silesia is, according to Credner, sixteen metres or over fifty-two feet thick. On the other hand, in every coal-region there are large numbers of very thin seams which are economically worthless, a thickness of three feet being usually considered as small as can be profitably worked by underground operations. Of the eighty or more seams found along the head of the Bay of Fundy, not more than four or five are workable. Southern Wales has twenty-three workable seams out of more than eighty. Southern Russia is said to have, on the river Donetz, as many as two hundred and twenty-five coal-seams, of which but forty-four are considered worth working; while of the one hundred and thirty-two seams in the Westphalian coal-field, near the Rhine, seventy-four are workable. These few examples, which could be greatly multiplied, will serve to show both the wide variations in thickness which coal-beds, like other strata, may assume, and also the extent to which they may alternate with other rocks in the series of strata or *measures* in which they occur. Very thick coal-seams, like some of those mentioned above, are by no means made up entirely of coal. They are nearly always separated, by seams of shaly matter or of very impure coal, into several subordinate layers or *benches*, which often differ considerably in character. Thus the Mammoth seam, where it is one hundred and fourteen feet thick, has eight feet of rock other than coal interlaminated with it ; and the Pictou main seam, where nearly forty feet thick, affords but about twenty-four feet of good coal, being interstratified with six bands of shale and ironstone or coarse impure coals.

Besides the seams of coal, the rock series, constituting coal-measures, is made up of various alternations of sandstones, fire-clays, shales containing not unfrequently valuable deposits of clay ironstone, and, less frequently, strata of limestone. Occasionally, also, there occur in some regions seams of highly bituminous iron carbonate called *black-band* iron-ore, highly esteemed as a source of iron. The coal-seams are almost invariably found to be underlaid by a bed of *fire-clay*, or of clayey sandstone, varying from a few inches to several feet in thickness, and containing usually great numbers of fossil roots and curiously pitted stumps, called *stigmariæ*, which are evidently the remnants of a former vegetation that grew on them as soils. These *under-clays* are therefore generally believed to be the ancient dirt-beds from which sprang the vegetation that was transformed into coal. The under-clays are often found to be clays of such purity as to be capable, after being properly disintegrated by weathering, of being wrought into pottery, or molded into highly refractory fire-brick, whence their name of fire-clays. Their refractory character is, in all probability, due to the circumstance that the vegetation of the coal-beds withdrew from them those ingredients, like potash and lime, which cause clays to fuse at very high temperatures. (Newberry.)

Aside from the usual position of the under-clays, there is no fixed order of sequence of the strata which make up coal-measures; though it is very common to find a layer, sometimes quite thin, of bituminous shale, or very shaly coal filled with leaves and fragments of plants, resting immediately on the coal-seam. The nature of the strata which immediately overlie the coal is a matter of great practical importance, since upon it depend very much the ease and safety with which the coal may be mined. A roof of firm, thick-bedded sandstone greatly facilitates mining operations; while one of slippery and shivery shales is sure to cause difficulty and danger. Sandstones, however, sometimes present a curious danger of their own, in the form of what are called *coal-pipes*, the skeletons of ancient trunks of trees extending in a nearly vertical direction through the strata, the place of the bark being occupied by a tender film of coal, while that of the wood is filled with a solid column of sandstone. These, enlarging downward and generally destitute of branches, are easily dislodged, and in their fall crush whatever may be underneath, a peculiar example, as Lyell remarks, of the long-deferred action of gravity.

But though the various kinds of rocks which make up coal-measures in general present no settled order of relative arrangement, yet in any particular coal-field the leading strata, though often varying considerably in thickness, commonly show a surprising and very helpful degree of persistency in character and relative position. This is true, within limited areas, of some of the more important sandstone strata, but is more widely true of the leading seams of coal and limestone. For instance, Prof. H. D. Rogers estimates that the great Pittsburg seam of the Appalachian coal-field underlies an area of not less than fourteen thousand square miles, in a continuous sheet of varying thickness, some other coal-seams showing a similar constancy of position, though probably more limited in extent. In like manner, some of the limestones of the Pennsylvania coal series are recognized in similar positions in Ohio, where they are found persistent over large areas. Thus these persistent strata, whether of coal, of limestone, or sometimes of sandstone, become valuable standards of reference, or key-rocks, for determining the existence and the position of the useful rocks, which have been observed at some points to lie at a certain distance below or above them, due allowance being made for possible local changes in character and thickness of strata.

To illustrate what has been said as to the mode of occurrence and associates of coal-seams, and as to persistent strata, the following general section of the lower coal-measures of Ohio has been taken from the second volume of the Ohio Geological Report :

		Thickness in feet.
36.	Red and gray shales of barren measures......	
35.	Stillwater sandstone, often conglomerate.......	0 to 50
34.	Gray shale alternating with No. 35............	0 „ 50
33.	Buff limestone, ferruginous "mountain ore"....	0 „ 10
32.	Blackband iron-ore, often replacing No. 33....	0 „ 14
31.	Coal No. 7, "Cambridge," etc., seam..........	2 „ 7
30.	Fire-clay..................................	3 „ 5
29.	Limestone in eastern and southern counties....	0 „ 10
28.	Shale and sandstone........................	40 „ 50
27.	Coal No. 6 a, or "Norris" coal, sometimes with limestone over it..........................	0 „ 6
26.	Fire-clay..................................	3 „ 5
25.	Mahoning sandstone, often conglomerate......	0 „ 50
24.	Gray or black shale, alternating with No. 25....	5 „ 50
23.	Coal No. 6, "Straitsville" or "Big Vein" = Upper Freeport of Pennsylvania..........	3 „ 12
22.	Fire-clay..................................	3 „ 5
21.	Limestone in eastern counties = Freeport of Pennsylvania..........................	2 „ 8
21.	Gray or black shale, nodular iron-ore at base...	25 „ 50
20.	Coal No. 5, "Mineral Point," "Newberry" = "Lower Freeport" of Pennsylvania.....	2 „ 5
19.	Fire-clay, often non-plastic and excellent......	3 „ 6
18.	Shale and sandstone........................	20 „ 40

		Thickness in feet.		
17.	Limestone, " Putnam Hill " or " Gray ".......	2	to	8
16.	Coal No. 4, often double, " Flint Ridge cannel " = " Kittanning " of Pennsylvania..........	1	„	7
15.	Fire-clay....................	2	„	12
14.	Shale and sandstone, sometimes with coal 3 a..	20	„	90
13.	Blue limestone with iron-ore = Ferriferous of Pennsylvania.........................	2	„	6
12.	Coal No. 3, "Creek vein "..................	1	„	3
11.	Fire-clay, extensively used for pottery.........	5	„	15
10.	Shale and sandstone, " Tionesta " sandstone...	30	„	50
9.	Coal No. 2, generally thin, " Strawbridge " coal	1	„	5
8.	Fire-clay..........................	1	„	3
7.	Shale......................................	20	„	50
6.	Massillon sandstone.........................	20	„	80
5.	Gray shale..............................	5	„	40
4.	Coal No. 1, " Brier Hill," " Massillon "......	3	„	6
3.	Fire-clay....	3	„	5
2.	Sandstone and shale	10	„	50
1.	Conglomerate............................	—		—

The average thickness of the rocks in this section is about four hundred feet, and a considerable number of the strata included in it are recognized as identical with those holding corresponding positions in the lower coal series of Pennsylvania. In this series of four hundred feet of strata there is a maximum thickness of fifty-one feet of coal, with a probable average of about twenty-five feet or one foot of coal to sixteen feet of the measures. This is doubtless considerably above the average ratio of coal to rock. In the Pictou coal-field there is one foot of good coal to about twenty-six feet of poor coal and rock; in that of Illinois, one to twenty-five or thirty feet; in the Saarbrück area, the ratio is one to twenty-six; in that of Westphalia, one foot of workable coal to thirty-two feet of rock; and in the Southern Wales coal-basin, if the entire thickness of the Carboniferous rocks be considered, which is said to be twelve thousand feet, the ratio is about one to one hundred.

In nearly all cases, areas of coal-measures are basin-shaped—that is, they thin out on all sides as they approach their limits, and are surrounded by older rocks, somewhat like a picture set in a frame. They owe this form occasionally, it is probable, to the original form of the area in which they were deposited. This appears to be true of the great Appalachian coal-field as a whole, which seems to have been deposited in a long and shallow trough, inclosed on one side by land which now forms the crests of the Appalachians, and on the other by a low anticlinal ridge, extending through western Ohio and central Kentucky, the bottom of this trough having evidently been lowered by gradual subsidence to permit the deposition of the successive strata. In a case like this, the chief upper coal-seams would be likely to be more extended than those lower in the series, as is true of the Pittsburg seam. In much the greater number of instances, however, the basin-form is due to disturbances of position that have taken place since the rocks were deposited; the strata, by movements of the earth's crust, having been thrown into folds, sometimes wide and gentle, sometimes very abrupt; and when the crests of these folds have been removed by subsequent denudation, areas once continuous have been left as isolated, basin-shaped remnants. A striking illustration of this is presented in the sharply folded and denuded anthracite basins of Pennsylvania; while it is probable that the present separation of the coal areas of Illinois and Missouri is due to the denudation of a wide and gentle fold, cutting away the strata down to the rocks that underlie the coal. In these latter cases, the chief lower coal-beds would be likely to be most extended and continuous, the upper ones being largely swept away.

Geological Horizons of Mineral Fuels.—Although thin layers of carbonaceous matter are occasionally met with in rocks of Silurian and Devonian age, and even, as stated by Murchison, a small deposit of anthracite, from one to twelve feet thick, occurs in the Lower Silurian of Ireland, the material for which has apparently been derived from masses of sea-weeds, yet no beds of mineral fuel, of any considerable economic importance or reliability, have yet been found below that series of rocks which is called the Carboniferous, from the great prevalence in it of land-plants and beds of coal. The strata of the middle portion of this series are frequently called *the coal-measures* par excellence, because they furnish very much the largest part of the mineral fuel of the world, although coal-measures of great importance occur at several other geological horizons presently to be mentioned. The carboniferous rocks, omitting the upper or Permian portion, which is not coal-bearing and has little development on this continent, admit of the following subdivisions, recognizable in a general way in most American localities of these rocks, and nearly all of which, under various names, are found also in the European Carboniferous :

7. Upper barren measures—with thin coals ; Washington seam workable in West Virginia.

6. Upper productive measures—Pittsburg seam the chief, in Appalachian area.

5. Lower barren measures—Mahoning sandstone at base, with thin coals.

4. Lower productive coal-measures.

3. Millstone grit, or conglomerate.

2. Sub-conglomerate measures — coals of Arkansas ; Sharon coal of Pennsylvania ; lower or "edge coals" of Scotland ; coal horizon of Russia and northern Spain.

1. Sub-carboniferous limestone, etc.

The uppermost of these subdivisions is thought by Messrs. White and Fontaine to show Permian characters in West Virginia, where it contains a three-foot seam of coal, besides several thin seams.

The upper productive coal-measures (6) have their greatest economic importance in the Appalachian coal area, and in western Kentucky. The lower productive coal series is the most widely reliable of all, in both America and Europe; while the millstone grit, usually considered the base of the coal-bearing series, and hence sometimes called the *Farewell* rock, because when it is reached in mining the miners consider that they bid farewell to further hopes of coal, still has beneath it the coal-bearing rocks of Arkansas and northern Spain, most if not all those of Russia, and the lower or "edge coals" of Scotland.

Above the geological horizon of the Carboniferous, valuable measures of coal of the usual character are found in rocks of probable Triassic age, in central Virginia and North Carolina, and also in the Lower Oölite, a subdivision of the Jurassic, of Great Britain. Next in importance to the Carboniferous, on this continent, as a horizon of mineral fuel, is the rock series of probable Upper Cretaceous age, whose vast and wide-spread measures of lignitic coal are of so great importance to the development of the region lying west of the Missouri River.

Valuable deposits of brown coal are found in Europe in the Middle Tertiary, and are extensively utilized in Germany and Austria, but none of importance have yet been found in the Tertiary of North America. Thus the geological horizons of mineral fuels are:

7. Middle Tertiary—brown coals.
6. Upper Cretaceous—lignitic coals.
5. Lower Oölite in Great Britain—bituminous.
4. Triassic—bituminous chiefly.
3. Upper productive measures of Carboniferous.
2. Lower productive measures of Carboniferous.
1. Sub-conglomerate coal of Carboniferous.

Regions of Mineral Fuel.—The easternmost coal area of North America is that of northern Nova Scotia, east New Brunswick, and Cape Breton Island. It covers about eighteen thousand square miles, much of which seems likely to be of little value. There is a small area in

Rhode Island, extending a little way into Massachusetts, and containing about five hundred square miles, the coal of which is a very hard variety of anthracite. It is not largely worked, the product reported in 1882 being only ten thousand tons.

In the extent, variety, and excellence of its coal-beds, the Appalachian area surpasses any other on this continent, or indeed in the world. This vast coal-field, covering nearly fifty-nine thousand square miles, occupies a large part of western Pennsylvania and West Virginia, the western extremity of Maryland and Virginia, southeastern Ohio, the eastern part of Kentucky and Tennessee, and northern Alabama, with a corner of Georgia. The northeast extremity of this area furnishes the anthracite of Pennsylvania, the best in the world, in several detached basins carved out of the folds of the Alleghanies, and containing in all about four hundred and seventy square miles. In the Appalachian area, workable coal is obtained from all the coal-bearing horizons of the Carboniferous that have been enumerated, stretching from the Sharon subconglomerate seam in No. 2 of our section, p. 148, to the Washington seam in the upper barren measures, No. 7. The Pittsburg seam, so celebrated for its vast extent, its considerable thickness, and the superiority of its coal for coking purposes, is at the base of the upper productive measures, No. 6; while most of the coal of Ohio is obtained from the lower productive measures, No. 4.

The Illinois coal-field covers a large part of central and southern Illinois, the southwestern part of Indiana, and the western portion of Kentucky, occupying somewhat more than forty-seven thousand square miles. This area is producing large and rapidly increasing amounts of bituminous coals, chiefly from the lower productive measures, with some in Kentucky from the upper productive.

The largest in superficial extent of the Carboniferous coal areas is the Western one, occupying, it is estimated, seventy-nine thousand square miles, in southwestern Iowa, northern and western Missouri, eastern Kansas and Indian Territory, northern Texas, and western Arkansas. Over much of this area the coal-seams are thin, and the coal not of the best quality. The producing horizons are chiefly the sub-conglomerate measures in Arkansas, some of whose coals are semi-anthracites, and the lower productive measures in Missouri and Iowa. The largest production is from Iowa and Missouri, Kansas also furnishing nearly a million tons annually.

Besides these there is a rudely circular area in central Michigan, covering about six thousand seven hundred square miles with Carboniferous coal-measure rocks, about three hundred feet in maximum thickness, which contain, at several points, one seam three to four feet thick of bituminous coal, somewhat sulphurous, but considered a good fuel for steam purposes. The area seems not to be very promising for a large coal production.

The Triassic coal-fields of Virginia and North Carolina occupy four narrow, elongated basins running parallel with the Blue Ridge Mountains in the east central part of those States. These areas, although some of them have been long known, have been as yet but little developed. The one best known and most largely worked is in the near vicinity of Richmond, where one of its seams attains sometimes a thickness of forty feet. The coal is highly bituminous, as is also that of the other basins, save that of the Dan River in North Carolina, stretching into Virginia, which is shown by analyses to be semi-bituminous. The productive area of the several basins does not probably reach five hundred square miles.

The lignitic coal-fields of probable Upper Cretaceous age, in the far Western States and Territories, have not yet been sufficiently explored to give more than a vague approximation to their extent; but they are known to cover vast areas, especially in Colorado, Wyoming, Dakota, and

Montana. Those best known and most largely worked at present are those along the eastern base of the Rocky Mountains, through much of Colorado, and extending some distance into New Mexico; those along the Union Pacific Railway in southern Wyoming; those on the Weber River, and at other points, at no great distance from Salt Lake City in Utah; on Bellingham Bay and Puget Sound, in Washington Territory; and at Mount Diablo, near San Francisco, California. Several seams of superior anthracite and bituminous coal occur twenty-five miles southwest of Santa Fé, New Mexico.

Valuable deposits of anthracite and coking bituminous coal are found at Crested Butte, on the upper branches of the Gunnison River in Colorado, and are coming into extensive use; while near Durango, in the same State, and extending south into New Mexico, are enormous deposits of lignitic coal of excellent quality, some of the seams being said to range from twelve to near ninety feet in thickness. Valuable deposits occur also at Coos Bay in Oregon, and in Vancouver's Island. Rough estimates assign to the lignitic measures of Colorado about thirty thousand square miles of area, and to those of Wyoming twenty thousand square miles; but those which claim for Montana sixty thousand square miles, and for Dakota one hundred thousand square miles of coal-bearing territory, appear likely to be great overestimates.

As has already been remarked, the lignitic coals present very wide variations in character and value. Some, like parts of the seams of Crested Butte and Santa Fé, are anthracites, apparently equal in quality to those of Pennsylvania; others, like those of southern Colorado and adjacent parts of New Mexico, and part of those at Crested Butte, are coking coals which furnish a superior coke. Some, like those of Cañon City, Colorado, and part of those in Wyoming, are firm and open-burning, with a low per cent of water, much resembling "block-coal"; while many others have much water, and crumble readily on exposure, hence furnishing an inferior fuel. All kinds, with the increase of population and the growth of mining and other industries, are destined to be eagerly sought out, and to furnish supplies of inestimable value to a vast region otherwise scantily supplied with fuel. Six of the Western States and Territories had already, in 1882, a reported production of two million three hundred and fifty thousand gross tons, ranging from about one hundred and fifty thousand tons each in California and New Mexico, to nearly a million tons in Colorado, and two thirds as much in Wyoming.

Foreign Coal-Fields.—The chief coal areas of Europe are those of Great Britain, Belgium and France, Germany and Austria, southern Russia, and Spain. The coal-fields which have long given England its industrial supremacy occupy an area of less than twelve thousand square miles, and extend, in many separate basins, from South Wales, northeasterly through western England to the great Newcastle coal-field on the North Sea, with areas of sub-conglomerate coals in southern Scotland. All these areas of any considerable importance belong to the Carboniferous age, and the coal is mostly bituminous, with some valuable anthracite in South Wales.

The Belgian coal-field, of five hundred and eighteen square miles area, extends in a lengthened belt eastward from near Valenciennes, in France, to Aix-la-Chapelle; and its apparent eastern continuation across the Rhine forms the great Westphalian coal-field northeast of Düsseldorf.

The coal-fields of Germany, with an area of about eighteen hundred square miles, consist of several basins, mostly small in extent, the chief of which are those of Westphalia and Saarbrück, near the Rhine, Upper and Lower Silesia, and some small basins in Saxony. There are also important deposits of lignite in the Tertiary of North

Germany, some of them of great thickness. Austria has coal-fields and deposits of lignite of considerable extent in Bohemia.

Russia, which is credited with about thirty thousand square miles of coal territory, has a large portion of this in the more central provinces, supplied with but a few thin seams of inferior coal; its most valuable coal area being about eleven thousand square miles on the river Donetz, with one hundred and fourteen feet of workable coal, at the geological horizon of the millstone grit. (Credner and Murchison.)

The coal-fields of France aggregate two thousand and eighty-six square miles, in many isolated basins, scattered widely over its territory, some of which contain anthracite coal. Some of the more noteworthy are those of Valenciennes near the borders of Belgium, of Autun, and of St. Etienne, previously mentioned, in the southern part. In some of these basins the coal series occurs in the subconglomerate, but in most, at the usual horizon of the Carboniferous coal-measures.

The Spanish Peninsula has three thousand five hundred and one square miles of coal area, chiefly in the province of the Asturias, in the north part of the kingdom, and on the southern declivity of the Sierra Morena, both in rocks subordinate to the Carboniferous conglomerate.

India is reported to have about two thousand square miles of coal-fields, chiefly of Triassic age, and Japan five thousand square miles in the Tertiary. China is known to be exceptionally rich in coal, of Triassic or Lower Jurassic age, with some Carboniferous coal in the province of Hunan; but our knowledge of that country is too imperfect to permit any estimate of the area which bears coal-seams. The map published by Prof. Pumpelly, in the "Smithsonian Contributions," indicates the possibility that a very large portion of China proper is covered by rocks of the same age with those that bear valuable coal-seams at many known points. Further than this our knowledge does not extend. It is also reported that coal-beds, of Carboniferous, Jurassic, and Tertiary age, occur in Siberia.

True Carboniferous rocks with coal-seams are found in the eastern colonies of Australia, and especially in New South Wales, where there are said to be a number of beds of coal ranging from three to thirty feet in thickness. The following table, the materials for which are taken with slight change from the report on mineral resources of the United States, will give in compact form the probable areas of fossil fuels in the various countries, with their reported or estimated production in 1881:

	AREAS. Square miles.	PRODUCTION. Gross tons.
Great Britain	11,900	154,184,300
United States	191,994	76,679,491
Germany	1,770	61,540,475
France	2,086	19,909,057
Austria	1,800	19,000,000
Belgium	518	17,500,000
India	2,004	4,000,000
Russia	30,000?	3,255,000
Australia	24,840	1,775,224
Nova Scotia, etc.	18,000	1,124,270
Spain	3,501	800,000
Japan	5,000	800,000
Vancouver's Island	390	325,000
China	?	?
	293,803 *	360,892,817 †

The coal area of the United States, given above, does not include the lignitic coal-fields; but their product is included in the second column. The areas of United States coal-fields, known and estimated, are as follow:

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* Exclusive of China and Western America. † Exclusive of China.

New England area	500	square miles.	
Appalachian „	58,731	„	
Michigan „	6,700	„	
Illinois, etc. „	47,138	„	
Missouri, etc. „	78,430	„	
Virginia and N. Carolina area	495	„	= 191,994 sq. miles.
Colorado „	30,000?	„	
Wyoming „	20,000?	„	
Montana „	60,000?	„	
Dakota „	100,000?	„	= 210,000 sq. miles.

No guesses seem yet to have been hazarded as to the extent of coal lands in Washington, Oregon, California, Arizona, Utah, and New Mexico. It will probably be no exaggeration to concede to the entire lignitic coal area an extent of one hundred and seventy-five thousand square miles.

Impurities in Coal.—Besides their fuel constituents, carbon and hydrogen, all coals contain variable proportions of other substances. Some of these, like nitrogen and the mineral ingredients which constitute the ash, are inert, acting merely to diminish by so much the fuel value of the coal; some, like moisture and oxygen, which in combustion is removed as water, carry away a portion of the heat evolved, as the latent heat of steam; still others, like sulphur and phosphorus, are directly injurious to the fuel, both from evolving offensive gases in combustion, and from acting injuriously upon iron.

Ash.—The ash in good coals may range from not more than 1 per cent to 5 or 6 per cent, or somewhat more in anthracite. The ash of one hundred and fifty-two bituminous coals, examined in Ohio, averaged somewhat less than 5 per cent, ranging from .77 per cent to 17 per cent, ten of the samples yielding more than 10 per cent; while that of eighty-three bituminous coals, analyzed by the present Geological Survey of Pennsylvania, gave an average of 5.45 per cent, ranging from 1½ per cent to 19 per cent. It is probable that, in bituminous coals, ash not exceeding 5 per cent may be due almost wholly to the mineral constituents of the original woody tissue, but that much more than 5 per cent of ash would indicate the probable presence of foreign earthy matter, either disseminated, or occurring as thin laminæ of shale.

Anthracite coals, from their greater loss of the original constituents of woody tissue, in which loss the mineral constituents could obviously take no part, will naturally have a larger average of ash than the bituminous coals. Analyses of twenty-seven anthracites and semi-anthracites, recorded by the first Geological Survey of Pennsylvania, show an average of 6.13 per cent of ash; analyses of six, given in vol. M^2 of the second survey, show a 9 per cent average, ranging from 4½ to 14 per cent. Probably about 7 per cent would be a fair average for the ash in an anthracite free from foreign admixture.

Ash which contains any considerable proportion of iron, lime, and alkalies, is apt to cause serious difficulty, where high temperatures are required, from its tendency to fuse and form clinkers, which clog the grates and adhere to the fire-proof linings of stoves and furnaces. Coals which yield a white ash are less likely to give trouble of this kind, being nearly free from iron; while red-ash coals owe the color of their ash to a considerable amount of iron, and are liable to clinker.

Water and Oxygen.—The amount of water in various coals shows great variations, corresponding, doubtless, to the porosity of their texture. The average amount of water, shown by ninety-seven Pennsylvania bituminous coals, is about 1 per cent; by one hundred and twelve Missouri coals, is 3.4 per cent; by one hundred and fifty-nine Ohio coals, is 4.65 per cent; and by sixty-four Iowa coals, is 8.57 per cent. In combustion, both this water and the oxygen which is present to some extent in all coals must be driven off in the form of steam, diminishing proportionally the effective heat of the fuel.

Sulphur and Phosphorus.—These two directly injurious substances are present in variable proportions in almost every coal—phosphorus, the more deleterious of the two, in much the smaller proportion. Both generate offensive gases in combustion, and both act injuriously on iron, one tenth of one per cent of phosphorus present in iron causing it to be brittle when cold, or *cold short;* while the presence of sulphur in iron makes it brittle when hot, *red short*, and any marked amount of it in coal corrodes the iron-work of stoves, furnaces, and smoke-pipes, causing serious inconvenience and expense. Phosphorus is rarely present in the coals that have been examined with reference to it in Ohio and Pennsylvania, to the extent of .001 of the coal; usually its amount is much less than this, and it is quite probable that the recently devised basic process for eliminating it from iron will make its presence in coal a matter of small moment to iron-smelters; although for domestic use, where its products are liable to escape into inhabited rooms, even small amounts of it are objectionable. The amount of sulphur in coal rarely falls below a half of one per cent, an amount which is not seriously injurious; while it sometimes reaches as much as 6 or even 8 per cent, making the coal worthless for most ordinary uses. Analyses of eighty-two Pennsylvania bituminous coals show an average of 1.41 per cent of sulphur, ranging from .425 to 8.43 per cent; and of fifty-six Ohio coals a range from .11 to 6.19 per cent, giving an average of 1.9 per cent. The sulphur in coal exists in at least two different states, a considerable portion being combined with iron to form pyrites, or with lime as gypsum, while the remainder is in some obscure form of combination, as yet little understood. A portion of the sulphur can be eliminated by coking, but the proportion that can be so removed varies greatly in different coals, adapting them to different uses, as will be shown in a subsequent paragraph.

Fuel Value of Coals.—Although some valuable experimental investigations of the heating power of a considerable number of coals of different kinds, based on the number of pounds of water evaporated from the boiling-point by one pound each of the various coals, have been made for the United States Government by Prof. W. R. Johnson in 1842, and by General Meigs quite recently, yet the lack of any general series of experimental tests will make it convenient for the student to have at hand a theoretical method of reaching a tolerable approximation to the heating values of various fuels. Such a method is based on finding the sum of the heating powers of the two combustible constituents, carbon and hydrogen, of any coal, shown by its ultimate analysis, and subtracting from this sum the amount of heat wasted in driving off its oxygen in the form of steam. Experiments have shown that the complete combustion of one pound of carbon will heat 8,080 pounds of water 1° centigrade, and of one pound of hydrogen will produce a like effect on 34,462 pounds of water. The oxygen in the coal, during combustion, unites with one eighth its own weight of the hydrogen of the coal to form water, and the expulsion of this water requires 537° C. of heat per pound. Hence the formula for the theoretical heating power of any coal will be $C \times 8{,}080 + (H - \frac{1}{8}O) \times 34{,}462 - \frac{9}{8}O \times 537 =$ heating power, in which C, H, and O stand for the respective percentages of the carbon, hydrogen, and oxygen.

For example, coal 9 of the table on p. 141 contains in one pound .7145 of a pound of carbon and .0547 of a pound of hydrogen, of which .0201 will form with the .1607 of oxygen .1808 of a pound of water, leaving .0346 of hydrogen available as fuel. Hence $.7145 \times 8080 + .0346 \times 34{,}462 - .1808 \times 537 = 6868.45°$ C. for the theoretical heating power of this coal; and, since 537° C. of heat are required to convert one pound of water at the boiling-point to steam, this would *theoretically* evaporate

12.79 pounds of water. Similar computations may be made on any other coal of the table whose ultimate analysis is given. For example, No. 12 has a heating power of 8171.15°, sufficient to convert 15.21 pounds of boiling water to steam; and woody tissue, No. 22, has a heating power of 4077.3°, or an evaporative power of 7.56 pounds of water. The theoretical heating power of fuels can, however, by no means ever be attained in their practical use. Indeed, the loss of heat by conduction, by imperfect combustion, and by excess of air in the draft, is so great that it is rare that so much as two thirds of the absolute heating power is realized in practice, with even the best of appliances. The best results attained by Prof. Johnson were from five semi-bituminous coals, which evaporated each from 11 to 11.62 pounds of water per pound of fuel, equaling within a trifle the theoretical heating power of the *fixed carbon* alone. The highest result obtained by General Meigs was the evaporation of about ten pounds of water with one pound of fuel. Prof. Johnson was inclined to think, from the results of six closely agreeing tests, that the practical heating power of coals is no greater than that which is due to their carbon, an opinion in which Prof. H. D. Rogers concurs. Others think that the heating power of the *fixed carbon*, given by proximate analyses of coals, may afford a useful approximation: an examination, on this basis, of the table of forty-four coals given by Prof. Johnson, shows certainly some striking agreements, and some equally striking discrepancies. On the basis of the heating power of the fixed carbon only, the two coals, already used as examples, would have an evaporative power respectively of 8.66 and 10 pounds of water, or about two thirds of their theoretical heating power. It seems probable that two thirds of the theoretical result obtained by the formula given above will prove to be as convenient an approximation as can be gained.

Adaptation to Uses.—In selecting a coal for any of the multifarious purposes which fuel subserves, due regard being always had to relative cost and accessibility, it will usually be found that the combination of qualities possessed by the several classes of coals gives them special adaptations to certain uses for which they can be most economically employed. For all uses, except perhaps the coarsest, like the burning of lime and brick, it is essential that a coal shall be as free as possible from sulphur and phosphorus, as also from an undue amount of ash, especially of that kind which is liable to clinker at the temperature that must be maintained. For most purposes, also, it is highly desirable that coal should possess sufficient strength to bear handling and transportation without undue breakage and consequent waste, the caking coals being those in which breakage is of least consequence.

For domestic and kindred uses a coal should be non-agglutinating, free from sooty smoke and light ash, and of a high degree of heating power; and it should be capable of maintaining a steady combustion without too frequent attention. This combination of qualities is found in a high degree in the anthracites, and, for burning in close stoves and furnaces, no coal could be better. With proper appliances they are used also in open grates, the semi-anthracites being somewhat the better for this use, on account of their freer combustion. Cannel and open-burning bituminous coals are also adapted to open fires, the cannels being favorites for this use on account of their cheerful flame, despite their usual abundance of ash, and their somewhat low degree of heating power. These last-named species of coal, also, do not produce the unpleasant dryness in the atmosphere of rooms which is observable where anthracite is used in open grates.

For the generation of steam a coal should combine, with a high degree of evaporative power, the qualities of easy kindling and a free combustion. There should be no tendency to agglutinate, but rather to split up moderately in burning, thus exposing a larger surface to the fire; where the coal is to be used on long voyages, it is highly essential also that it should be susceptible of compact stowage—much steam-making power in little bulk—a property in which coals differ as much as 15 or 20 per cent. The semi-bituminous and free-burning anthracite coals are well adapted for steam purposes, the former class, according to the investigations of Prof. Johnson, excelling both in evaporative power and in capability of compact stowage; while Prof. H. D. Rogers inclines to give the preference to the latter class. Hard anthracite, and especially anthracite waste and slack, is also largely used for steam purposes where it is favored by cheap transportation.

For the use of blacksmiths, where a *hollow fire* is desirable, a pure agglutinating coal is employed; and this kind of coal is essential also for the manufacture of coke. For the last purpose the coal should have a high percentage of *fixed carbon*; and whatever sulphur it may contain should be, as far as possible, in that condition which renders it easy of elimination by heat. The operation of coking drives off the water, the volatile combustible matter, and the separable sulphur, leaving the fixed carbon and the ash as coke, which, in its best condition, is a hard, strong, and highly cellular substance of a silvery color.

Anthracite and open-burning bituminous coals are also largely used for iron-smelting, it being essential for this purpose that the coal should have sufficient strength to bear the weight of the charge without crushing, and that it should be free from injurious amounts of sulphur and phosphorus. Where dry-burning bituminous coal is used for smelting, it is freed from its volatile matter in the upper part of the furnace, the gases being drawn off by proper arrangements near the top of the stack, and used for heating the blast and for other fuel purposes.

For the manufacture of illuminating gas, a coal should have a high percentage of volatile combustible constituents, and any sulphur which it may contain should be, as far as possible, in that state in which it is not volatilized during distillation. A residue of good coke is also highly desirable. For this purpose, therefore, the fat, caking, bituminous coals are selected, with which cannel coal is sometimes mixed; this latter kind of coal, although very rich in volatile matter, yielding a residue of too inferior a character to be used profitably alone.

Although what has here been said may serve as useful suggestions to the student, in the selection of fuels best adapted to certain purposes, where such a selection is possible within reasonable limits of cost, yet it must always hold true that local supplies of mineral fuels, whatever their quality, must be the chief dependence of communities, because of their proximity to the consumer. Lignites, often of very inferior quality, are coming into increasing use in the western part of our continent; and the statistics of Germany and Austria show that more than 22,000,000 tons of this fuel are annually used in those countries for domestic and other purposes. Although peat is widely distributed in marshy places over the Northern United States and Canada, it has not yet been much used as fuel in this country, because of its high percentage of water and its objectionable odor, as well as because of the abundance and cheapness of coal. It is, however, largely used in Ireland, Scotland, and some parts of Germany; and it is said that more than 40,000,000 tons of this fuel are burned annually in Holland. It is prepared for use by cutting and drying, or by compressing it into bricks of convenient size. It has been suggested that its efficacy as fuel may be increased, and its disagreeable odor removed, by charring it like wood before burning. (Page.)

For the *natural gas*, which is coming into so large use very recently as a fuel, the student is referred to the succeeding chapter, where it is spoken of as the usual attendant of petroleum, although frequently found without this substance.

The student will do well to consult the geological manuals of Dana, Geikie, and Credner, Dawson's "Acadian Geology," the geological reports of the coal-producing States, and especially the second volume of Rogers's report on Pennsylvania, the volume on mineral resources of the United States, published by the Geological Survey in 1883, and Johnson's report on American coals.

CHAPTER IX.

GEOLOGICAL MATERIALS FOR ILLUMINATION.

CHIEF of the geologically furnished light-producers, at present, is *petroleum*, which, within the last quarter of a century, has attained a foremost place in point of cheapness and efficiency, to which must be added the bituminous shales and cannels, which yield illuminating oil by distillation, and ozocerite, or mineral wax, besides illuminating gas, which has already been mentioned as derived from bituminous coals.

What is known under the general name of petroleum, includes a series of hydrocarbon oils, varying widely in physical properties. Some are limpid fluids and may be burned for light without refining, while, with many intermediate grades, others are found viscid and even tar-like, having sufficient *body* to make excellent lubricators for machinery. Their color, by transmitted light, ranges from a light yellow, through orange and red, to a reddish brown so dense as to be translucent only in thin films, while, by reflected light, it passes from a light dusky to a dark green and to a black. Their gravity ranges from about 26° to 52° Beaumé. They differ as markedly in odor, also, as in other properties, some having a very disagreeable smell, while that of others is considered even pleasant.

Mode of Occurrence of Petroleum.—Petroleum is found at many points, issuing in small quantities from the earth in the form of springs; but, as a substance of economic importance, it is almost invariably found stored in deposits of porous rock, usually sandstones or conglomerates, which are incased above and below in practically impervious strata of shale or other clayey materials. The porous rock plays the part, in truth, of a vast sponge saturated in all its pores with petroleum and its usual accompaniment, combustible gases. It is obvious, then, that the storage capacity of such a bed will depend on its extent, its thickness, and its porosity. An oil-bearing sand-rock of considerable thickness, and of tolerably uniform and loose texture, is likely to yield largely, and to afford a good degree of certainty of success to the operator, while one of little thickness, or whose texture varies greatly in a vertical and horizontal direction, will be not only uncertain to reach at favorable points, but less likely to yield supplies of much durability. For example, the unusually thick and uniform sand-rock of Bradford, Pa., has given but a small percentage of unsuccessful ventures over a considerable area, and is still producing largely after a number of years of vigorous exploitation; while the territory along Oil Creek and the Alleghany River in western Pennsylvania, where the oil-bearing rocks occur in long and narrow belts, and are made up of irregular alternations of materials of highly variable texture, and often of no great thickness of porous rock, has afforded a large percentage of unproductive wells, and, while often producing largely, has in many localities been subject to early exhaustion. The impervious incasement is also highly essential, to retain within the sponge-like rock a substance so volatile as petroleum, and to prevent its dissipation. Where the oil-bearing rock is intersected by fissures which reach the surface, or is tilted so as to outcrop, much of its valuable contents is sure to have been lost. The idea, once somewhat prevalent, that the oil is stored in fissures, has been shown by developments to have little foundation in fact; and the oil-producer looks for success rather to a properly conditioned rock than to any fissures which may casually be encountered in boring. Where fissures occur locally in the rock they are helpful, not so much by increasing its storage capacity as by promoting a ready flow of its contents; and, in all cases, the operator produces them artificially, by shattering the oil-rock with explosives, to increase the extent of surface from which percolation may take place. Where favorable conditions are met with, of a porous storage-rock and an impervious incasement, the petroleum and its accompanying gas are usually found, at the outset, existing under enormous pressure, so that, when a fresh territory is first pierced with the drill, the oil frequently rises to the surface with great force, even from the depth of many hundred feet, producing flowing wells. A number of such wells in Pennsylvania have poured forth at first from two thousand to more than three thousand barrels of oil per day. As the pressure is relieved by the flow and by the sinking of additional wells, the rate of flow invariably diminishes, until ultimately the oil no longer reaches the surface, and resort must then be had to pumping. The question of the origin of this interesting substance is one which can by no means be considered to have been definitely settled as yet. It seems probable, however, that it has originated from accumulations of marine vegetation, and possibly, in some cases, also from animal substances, which, subjected during vast ages to a process of gradual change and distillation, have evolved fluids and gases that have slowly permeated the minute crevices of the overlying strata, until they have found final lodgment in the porous strata where they now occur.

The chief geological horizons from which petroleum is procured in paying quantities, leaving out of view those in which it has not yet proved of economic importance, are, first, the Corniferous, from which it is obtained in the western part of the Province of Ontario near Lake St. Clair; second, several different geological levels in the Upper Devonian of Pennsylvania and New York, of which that of Bradford and its vicinity is lowest, succeeded by that of the Warren and Forest County region, and this by that of Oil Creek and the Alleghany River; third, the Carboniferous, in which are found the usually heavy oils of West Virginia and the adjacent part of Ohio, with two other limited areas in northern and eastern Ohio; and, fourth, the Tertiary and possibly more recent deposits, in which occurs the petroleum of California, that east of the Carpathians in Galicia and Moldavia, that near Baku, on the Caspian Sea, and that on the Irrawaddy River, in Burmah, and on some of the coast islands of Burmah.

At the first of these horizons, near Lake St. Clair, some petroleum has been obtained from surface-wells, sunk in the drift materials overlying the limestones; but the chief supplies have been drawn from the Corniferous limestones themselves, which here vary from a close to an open texture, and are overlaid by about three hundred feet of shales. The oil is black, of an unpleasant odor, and of somewhat higher gravity than that of Pennsylvania, in comparison with which last region its production has always been small. Oil is also known to occur, near this horizon, in southern Kentucky and adjacent parts of Tennessee, but it has not yet been considerably produced in this section.

The Upper Devonian rocks of the Chemung and possibly of the Catskill period have, for many years, in western Pennsylvania and the adjacent part of New York, furnished by far the greatest supplies of petroleum known to exist, about five sixths of the world's supply being derived from this region. The petroleum is here obtained from a porous sand-rock, underlaid and covered by impervious shales. The oil territory which was first discovered and developed, occupying parts of several counties in western Pennsylvania, along Oil Creek and the Alleghany River, has given rise to the prevailing nomenclature of the oil-producers. Petroleum is here found in a triple group of white or gray, often loosely cemented, and porous sandstones and conglomerates, called respectively the *first*, *second*, and *third* sands, which are separated from each other by considerable beds of shaly rocks. This oil-bearing series has an average thickness of about three hundred and fifty feet, and is overlaid by about four hundred feet of soft, impervious shales. Still above these, in many places, are found beds of sandstones or conglomerates belonging to the Lower Carboniferous, and termed the first and second *mountain* sands, because they usually cap the highest hills. The oil-bearing sand-rocks are very variable in thickness, composition, and texture, and are sometimes split into benches by intercalations of shale, thus locally giving rise to more than three sand-rocks, while the series as a whole retains its usual thickness. The portions which produce oil are usually of but little width, often no great number of rods, though sometimes extending, with occasional interruptions, for some miles in the same general direction, bearing thus the character of deposits along an ancient shore-line. These lines of productiveness are the *oil-belts*. The lowermost, or third sand, is, in much the greater number of cases, the storage-rock ; and hence an oil-bearing rock is apt to be called the *third sand* by operators, even in regions of quite different structure. Where the third sand is wanting, as, for example, where the others overlap it, or where it is not porous, the second or the first sands may produce oil, but often of a different character from that usually found in the third sand. The usual third sand oil has a gravity of about 46° Beaumé, and is of a dark-green color by reflected light, while some of those from the higher sands are black, or have a reddish tint, or are of so high gravity as to fit them for lubricators rather than for illumination. The depth of the wells in this region varies from a few hundred feet to 1,600 or 1,800 feet, the deepest wells occurring in the southern part of the territory, toward which the strata have a gentle dip.

The celebrated Bradford region, in McKean County, Pennsylvania, with its continuation in New York, which has for a number of years produced so vast an amount of petroleum, has its storage-rock at a geological level fully a thousand feet below that which has just been described, and differs widely from it in general structure. The oil-bearing sand-rock is of a fine texture, tolerably compact, yet loosely cemented, and ranging in color from brown to a light gray, forming a storage-rock of an average thickness of perhaps forty-five feet, and varying so little in texture that over a producing territory of about one hundred and ten square miles not more than four per cent of the wells have proved unproductive. Above this stratum, which is called the third sand, lies a very thick mass of shaly rock with occasional sandy strata, among which the well-drillers number a first and second sand, following the traditions of the region first explored, to which this bears no structural resemblance. The average depth of the wells in this district ranges from 1,200 to about 2,000 feet, the deepest wells being found in its southwestern part. The cost of drilling and equipping a well 1,500 feet deep, in 1880, was estimated to be about $3,250.

The oil-producing horizon in Warren and Forest Counties, intermediate between that of Bradford and that of Oil Creek, has yielded productive wells in porous rocks, varying greatly in character and at different levels, the physical characters of the product being as variable as those of the conditions under which it occurs. Some of these oils are transparent, and of various reddish or amber tints, with a gravity of about 47° or 48°, while others are greenish and nearly opaque, with a gravity of 40°. A number of remarkable wells have been found in this region, several of which have started out with the astonishing daily production of from 2,000 to 3,000 barrels; but their activity has invariably been very short-lived, and as a class the wells of this district have shown little durability.

The oil district of West Virginia, extending into Washington County, Ohio, obtains its supplies from sandstones of Carboniferous age. The oil is said to occur in fissures on the site of gentle anticlinal axes. Its actual mode of occurrence probably does not differ materially from that which has been found to hold true on so extensive a scale in Pennsylvania. The oil is of greater gravity than that of Pennsylvania, ranging from 28° to 40° B., and the production has not been large, amounting in 1880 to about 220,000 barrels of 42 gallons, or about 600 barrels daily. The oil-producing territory of California occurs in two of its southwestern counties near the coast. In this region, large natural springs of petroleum with extensive sheets of asphaltum arising from its evaporation, have for many years been known to exist; the oil issuing from the outcropping edges of highly inclined bituminous strata of probable Tertiary age. The amount of oil obtained from borings in these strata has not hitherto met the sanguine expectations of the earlier explorers, apparently so well justified by the surface exudations. The estimated production of 1882 was about 70,000 barrels, or less than 200 barrels per day; though for a portion of that year a daily production of 500 barrels was claimed. From what are now known to be the usual conditions on which large supplies of petroleum seemingly depend, a great production can hardly be looked for from this district.

Of all the regions at present producing petroleum from the Tertiary or later deposits, that of Baku, on the Caspian Sea, is by far the most promising. Here, for many ages, a tract twenty-five miles long and a half-mile in width has yielded petroleum (naphtha) from a porous argillaceous sandstone of Tertiary age, the wells being usually not more than twenty-five feet deep. Recent careful explorations show, it is said, that the possible productive area may amount to as much as 1,260 square miles; and the active development now in progress resulted in a production, in 1882, of nearly 5,000,000 barrels, and in 1884 of about 6,700,000 barrels; from which it seems likely that this is destined to be a formidable competitor to the oil-regions of Pennsylvania. The petroleum of Baku is said to vary from a clear naphtha-like fluid to one of a yellowish-green and reddish-brown, with a gravity of from 26° to 36° B. It yields only about 33 per cent of illuminating oil, the residuum being burned for fuel.

The long-known petroleum of Burmah is obtained chiefly from wells of no considerable depth, in a soft greenish sandstone of late geological age, inclosed in impervious beds of sandy clay, near the Irrawaddy River. The productive territory is said to be less than a square mile in area, and the amount produced annually does not reach 1,000,000 barrels. Petroleum is also found in small quantities in springs on several islands off the west coast of Burmah. The Burmese product is of two kinds: one, which seems to resemble our "amber oil," is of light gravity and reddish color, and yields a high per cent of illuminating oil with little paraffine; the other is thick, of a greenish color and agreeable smell, and holds a large per cent of paraffine. The petroleum which is reported to exist in considerable quantities in deposits of Tertiary age north of the Carpathians does not seem as yet to have made any figure in the markets of the world. Of that which is said to have been long produced in China, little is known with certainty. Small quantities are also obtained in Japan, according to Prof. Lyman, from wells dug to no considerable depth.

The amount of petroleum produced in Pennsylvania and adjacent parts of New York, in 1882, was reported to be 30,053,500 barrels of forty-two gallons; and in June, 1883, the daily production was nearly 66,000 barrels, or at the rate of about 24,000,000 barrels yearly, a rate which was continued in 1884. It may thus be seen that the production of Pennsylvania is by far the greatest factor in the world's supply of this very useful commodity, that of the Caspian region ranking second.

How Oil-Wells are bored and operated.—In few branches of business have there been more remarkable improvements made, both in simplicity and effectiveness of work and in diminution of expense, than those which have been suggested by experience in drilling and operating oil-wells. This might naturally be expected, when we consider the great number of active and highly intelligent men who are engaged in a business involving more than usual risks, and in which the tendency to a constant diminution in the price of the product demands a corresponding diminution in the cost of production. Then, too, the number of these usually very deep borings has been enormous, being counted by the tens of thousands. The number of oil-wells producing simultaneously in the Pennsylvania region has sometimes been more than nineteen thousand; and the number of new wells in progress has not for many years fallen so low as a hundred, and has, not unfrequently, been more than four hundred. Hence, undertakings which thirty years ago would have been considered remarkable, have come to be matters of ordinary every-day business, and the means by which they could most easily be accomplished have demanded the attention of many clear-sighted men. At the outset, borings at first four inches and later five and a half inches in diameter were sunk to the oil-producing rock, no effort being made to shut off the water which entered the boring from porous rocks encountered in the strata that were penetrated. Hence the well, however deep, was always nearly full of water while the boring was in progress, causing serious inconveniences, not only by lessening the force of the drilling-tools, and by converting into fluid mud some of the softer shales to embarrass the drillers, but also by making it uncertain when an oil-bearing rock had really been reached, until the water-veins had been shut off and the well cleared of water by pumping. These and other difficulties eventually led to the adoption of the present form of boring, which seems admirably adapted to its purpose.

Where the loose surface materials are of considerable depth, a wrought-iron *drive-pipe*, of eight inches interior diameter, is forced down vertically to the bed-rock, in successive lengths of nine feet each; and an eight-inch hole is drilled through this pipe till it reaches the bottom of the lowest water-bearing stratum, when it is tapered gradually down to five and a half inches. Into this hole, an iron pipe of five and a half inches inside diameter, called the *casing*, screwed together in lengths, and surrounded at the bottom by a properly constructed collar, is lowered and firmly seated on the tapering shoulder prepared for it, thus shutting off all water from above. From this point downward the drilling, five and a half inches in diameter, is prosecuted *dry*, water being poured in from the top through the casing to moisten the powder produced by the drill, so that it may be removed as mud by an instrument called a *sand-pump*, which consists usually of a cylinder six to ten feet long of thin iron, provided at the bottom with a spindle-valve opening upward, and at the top with a bail by which it is attached to a stout rope of proper length. The usual drilling-tools are sixty-two feet long and weigh twenty-one hundred pounds. They consist of several parts screwed firmly together, and called, commencing from below, the *bit*, the *auger-stem*, the *jars*, the *sinker-bar*, and the *rope-socket*. The first named is the steel-edged chisel which cuts the rock, and is screwed above to the *auger-stem*, a bar of iron thirty feet in length. The *jars*, a highly important device, are two elongated steel-faced links with a play of thirteen inches, the lower link of which is screwed to the auger-stem, and aids in giving the downward or cutting blow, while the upper link attached to the *sinker-bar* aids the two upper members to give a sharp upward stroke to the tools on their ascent, by which the *bit* is loosened from the rock. The *rope-socket* is the upper member of the series, and is securely attached to the great rope-cable by which the string of tools is to be raised and lowered, and given motion in drilling. For the purpose of raising and lowering the drilling-tools, and of operating the well after it is completed, a stout, pyramidal framework about seventy-five feet in height, called a *derrick*, is erected over the site of the proposed well. At one side of this is set the steam-engine that furnishes the power, with the band-wheel and walking-beam by which the drilling-tools and other parts of the machinery are driven. At the top of the derrick is a stout pulley over which the drill-cable passes, and a little below a second pulley for the sand-pump rope. The end of the drill-cable opposite to that to which the tools are attached is coiled around a large cylindrical drum, called a *bull-wheel*, to which motion is given by the engine in raising the tools from the well: they will naturally descend by their own weight when permitted, the rate of their descent being controlled by a powerful brake applied to the bull-wheel. When the tools are lowered ready for drilling, they are connected with the end of the walking-beam by an arrangement called a *temper-screw*, the lower end of which is firmly clamped to the cable at the proper point. By this means, as the bit cuts deeper into the rock, the tools can be gradually lowered until the screw, about four feet long, is run out, when the tools must be raised and the well cleaned out with the sand-pump. When the oil-sand is reached, specimens of the *drillings* are taken for every *run*, and carefully preserved to serve as a guide in operating the well. In order to secure a perfectly cylindrical hole, the tools are rotated when in action, by means of a lever inserted in rings of the temper-screw.

A full description of the mode of drilling oil-wells, with working drawings, may be found by the student in Vol. I^3 of the "Second Geological Survey of Pennsylvania." It seemed fitting, however, to include, in a work of this character, this brief account of an operation so interesting even aside from oil-production, the improvements in which have reduced the cost of deep borings to about one fourth of what they were less than twenty years ago, while diminishing the time consumed in fully as great a ratio.

In the present mode of drilling a well dry, it can be ascertained, soon after the oil-rock has been penetrated, whether the well is likely to be successful. In case the show of oil and gas is satisfactory, the drilling-tools are removed, and the well is *tubed* with iron tubing of two inches diameter inside, screwed together in lengths until the bottom of the well is reached. The lower end of the tubing is provided with an *anchor*, made of a piece of perforated casing a few feet in length, to the top of which the working barrel is attached. The pump-rods, with a suitable valve at bottom, are next inserted into the tubing, being screwed together in lengths; the upper end of the pump-rod is attached to the walking-beam, and the operation of pumping oil begins. The oil passes to a tank by a side-pipe near the top of the tubing, while the gas, which is usually present, rises in the annular space between the tubing and casing, and is carried by another side-pipe to be burned as fuel under the boiler. In many cases, especially in the Bradford district, the oil is of such quality that the operation of pumping can be dispensed with, and the well compelled to flow by *heads*. This is effected by encircling the tubing, at a proper point above the oil-rock, with an annular valve called a *packer*, by which the space between the tubing and the walls of the well is closed gas-tight. The accumulating force of the oil and gas thus imprisoned below will then cause the well to flow periodically, or by *heads*.

Almost universally, before the well is tubed, the oil-producing rock is shattered by means of *torpedoes* charged with nitro-glycerine to facilitate the influx of oil. These torpedoes are simply tin shells, sometimes twenty to thirty feet long, and containing not unfrequently from thirty to sixty quarts of nitro-glycerine. These are lowered to their place by means of a wire, which is then unhooked and withdrawn, and the torpedo exploded by dropping a weight from above upon a detonating cap in its top. The commotion caused by so large an amount of this violent explosive can be more easily imagined than described. This operation is also frequently resorted to when the production of a well becomes greatly diminished, the tubing being withdrawn before the torpedo is used.

Refining.—The method of refining crude petroleum, to fit it for being burned in lamps, is based on the fact that the various ingredients of this highly complex substance have different boiling-points. Hence, by a process of fractional distillation at regulated temperatures, the more volatile ingredients, such as gasolene, naphtha, and benzine, which would render the oil dangerous to be burned in lamps, are first driven off, succeeded next by illuminating oil, and leaving behind in the still a tarry residue which may be further separated by distillation, leaving a final residue of coke. The illuminating oil is then further purified by agitation with sulphuric acid, by which a tarry substance is separated from it, and finally by agitation with water and an alkali to remove all traces of the acid. The average results obtained at a refinery in Titusville, Pa., treating petroleum of about 46° Beaumé, were given as the following:

Naphtha, etc	10	per cent.
Illuminating oil	75	„
Tarry residue	7	„
Gas and loss	8	„
Total	100	„

In a different mode of refining, a smaller proportion of illuminating oil is made, and the heavier products are separated as lubricators for machinery.

Uses.—Besides the well-known extensive use of petroleum for lighting purposes, the crude heavy oils are very valuable as lubricators for machinery. Several of its by-products are also largely used; as, for example, paraffine, which, besides entering into the manufacture of candles, has several other valuable applications; the so-called naphtha, which is used for mixing paints and varnishes, and as a solvent for resins and grease; while gasolene is employed as a carburetting agent in automatic gas-machines. Both crude petroleum and the residue from refining are also largely used as fuel in Russia.

For additional information with respect to petroleum, the student will do well to consult the "Second Geological Survey Reports of Pennsylvania," Vols. I, I^3, I^4, J, and R; the section on petroleum in "Mineral Resources of the United States," published by the United States Geological Survey in 1883; "Tenth Census of the United States," Vol. X; and the article "Petroleum" in Appletons' "American Cyclopædia." Valuable information may also be obtained from "Geology of Canada," 1863, and Vols. I, II, III of Ohio "Geological Reports," as well as from papers of Drs. Newberry and T. S. Hunt, on this and allied subjects.

To illustrate what has been said of the mode of occurrence of petroleum, the present mode of drilling and operating oil-wells, and the tools that are used in drilling, the following figures are appended.

Other Mineral Light-Producers.—Before the discovery and development of the great sources of natural rock oils, illuminating oils were produced to a consider-

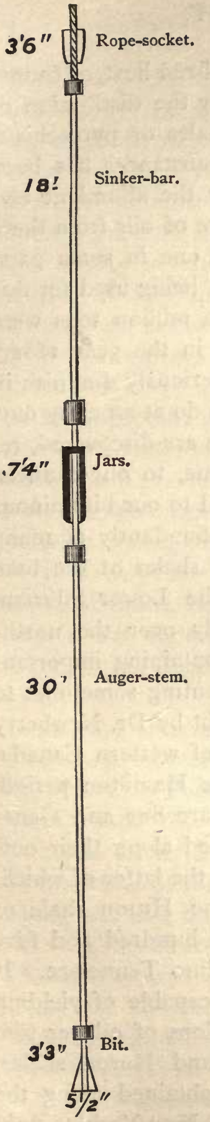

FIG. 14.—Drilling-tools. Total length, 61' 1"; weight, 2,100 lbs.; down stroke, 1,320 lbs.; upward stroke, 780 lbs.

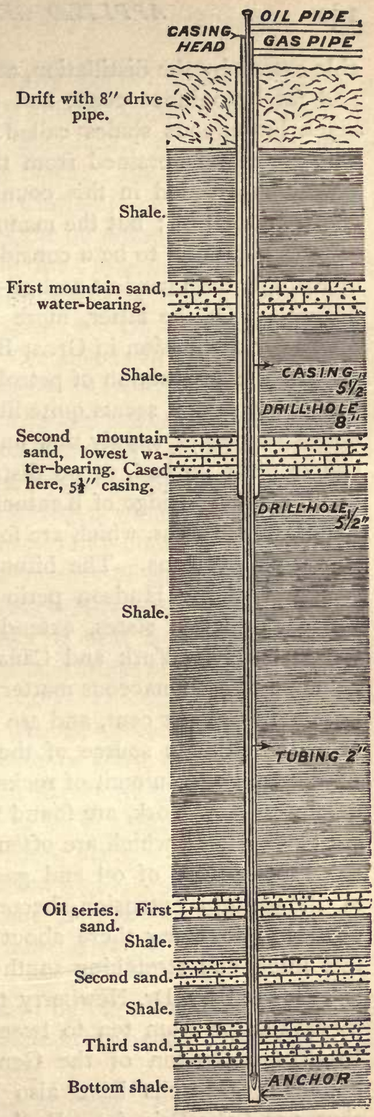

FIG. 15.—Ideal Section of Oil-Well, Oil Creek, Pa.

able extent by the distillation, at a dull-red heat, of cannel and fat bituminous coals, and also by the distillation of black bituminous shales called oil-shales or pyroschists. The use of oil obtained from these substances has been wholly superseded in this country by the abundant and cheap mineral oil; but the manufacture of oils from these sources continues to be a considerable one in some parts of Europe, both cannels and oil-shales being used for this purpose. Of the latter, more than a million tons were raised for distillation in Great Britain in the year 1882.* Should the production of petroleum seriously diminish in this country, as it seems quite likely to do at an early day, unless sources of supply now unknown are discovered, recourse must be had, at no distant time, to our cannels, like the Breckenridge of Kentucky, and to our bituminous shales, now useless, which are found abundantly at many geological horizons. The bituminous shales at the base of strata of the Hudson period in the Lower Silurian, called the Utica slates, extend widely over the northern part of New York and Canada, containing important amounts of carbonaceous matter, amounting sometimes to as much as 20 per cent, and are thought by Dr. Newberry to be the ultimate source of the oils of western Canada. At the base and summit of rocks of the Hamilton period, in central New York, are found the Marcellus and Genesee black shales, which are often marked along their outcrops by springs of oil and gas, and the latter of which, in its western extension, becomes the Huron shale of central Ohio, being there about three hundred and fifty feet thick, and stretching southward into Tennessee. It is estimated by Dr. Newberry to be capable of yielding by distillation from ten to twenty gallons of oil per ton. From the horizon of the Genesee and Huron shales, abundant gas-wells have also been obtained along the shores of Lake Erie, from Fredonia, in New York, to near

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* This amount was increased to 1,518,871 tons in 1884.

Cleveland, and also in Knox County, Ohio. The gas is utilized for heat and light, and, in Knox County, for making what is called "carbon-black," a substance nearly equal in value to ivory-black. Bituminous shales are found abundantly in the Carboniferous, as might be expected, since the source of the bituminous matter is doubtless largely vegetable; in the Triassic of Virginia and North Carolina, some of the strata of which are so highly bituminous as to be classed by O. J. Heinrich as the Oleiferous group; in the Cretaceous of Colorado and adjoining regions; and in the Tertiary rocks of western California, especially in Venturas and Santa Barbara Counties, from whose interbedded sandstones is derived the oil mentioned on a previous page. Most pyroschists contain also a considerable amount of nitrogen, which, by proper manipulation during distillation, can be obtained as ammonia.

In some of the earlier reports of the Geological Survey of Canada, Dr. T. Sterry Hunt has drawn attention also to our abundant beds of peat as a possible future source of oil, paraffine, gas, and other products, by distillation.

In 1877 an important deposit of ozocerite, or mineral wax, was discovered in southern Utah, this substance having previously been known chiefly from Moldavia, east of the Carpathians. It is of a wax-like appearance, and ranges in color from whitish to black. It is said to yield by fractional distillation from 8 to 10 per cent of illuminating oil, and 60 per cent of paraffine. Such are the chief light-producers of mineral origin. To recapitulate briefly, they are:

1. Gas and oil, obtained by the distillation of bituminous and cannel coals, bituminous shales, peat, and, to a small extent, from ozocerite.

2. Petroleum, occurring at present in porous or sometimes fissured storage-rocks, but having its probable deep-seated source in bituminous shales.

3. Natural gas, derived from oil-bearing rocks, and from wells sunk in bituminous shales.

4. Paraffine, obtained from ozocerite, and as a by-product in the refining of various bituminous substances.

CHAPTER X.

MODE OF OCCURRENCE OF METALLIFEROUS DEPOSITS.

On account of the very great importance of many of the metals in the arts and industries of civilized man, as well as of the difficulties and uncertainty that attend their discovery and exploitation, much attention has naturally been directed to the various combinations in which they occur, to the minerals with which they are found associated, and to the geological nature, structure, and origin of the deposits in which they are found.

As is pretty generally known, very few of the metals occur in nature in the metallic or uncombined state. In the vast majority of cases, they are found in chemical combination with some other element or elements, forming that class of mineral substances known as ores. These ores usually differ widely in appearance and properties from the metals which give them their value, and require to be subjected to some chemical process before the metal which they contain can be separated and utilized. Nor are the ores themselves usually found simple and unmixed. Almost universally they occur associated and intermingled with other mineral substances, which frequently make up the chief bulk of the metalliferous deposit, and from which they must be separated by processes sometimes mechanical, sometimes chemical. These associated minerals are known by the name of *gangues* or *vein-stones*. Again, although several of the metallic ores occur widely diffused in minute quantities in many rocks—as, for example, iron, traces of which may be found in nearly all rocks—still, to be of any economic importance, they must by some means have been concentrated in certain places into deposits of such richness as to admit of their profitable extraction. Such concentrations are called ore deposits, and to these various names are given, according to their structure and the geological conditions under which they occur.

Metallic Ores.—Of the metals possessing economic importance, gold and platinum are almost always found in the metallic state ; bismuth also most largely so ; and copper, which usually occurs in the state of ores, in one famous region is found in vast quantities as a native metal. Besides these, silver and mercury occasionally occur in the metallic state. Much the most widely diffused mineralizing agents of ores are *sulphur*, *oxygen*, and *carbonic acid*, to which are added in much smaller measure *silica*, *arsenic*, and *chlorine.* Most of the leading metals have compounds with sulphur, and in the case of several of the metals these sulphides form their chief ores. Pyrites, the iron sulphide, common as it is, and great as is its economic importance, can hardly be called a source of iron ; but the sulphides of silver, both alone and combined or associated with sulphides of lead, antimony, and arsenic, constitute a chief source of silver. So the sulphide of mercury (cinnabar), stibnite (the sulphide of antimony), and galena (the lead sulphide), are the main sources of these three metals ; while blende (the zinc sulphide) and the various sulphides of copper, or of copper combined with iron, are leading ores of their respective metals. Millerite, a nickel sulphide, is also a valuable ore ; and bismuthinite, the sulphide of bismuth, is said to be the source whence the United States are likely to derive their future supplies of this metal.

Among the oxide ores, those of iron have a foremost place, being, though not the sole, yet a leading source whence are derived the supplies of this most important metal. Tin is obtained almost wholly from its oxide, cassiterite. The most valuable ores of manganese are its oxides; and the brilliant compounds of chromium are wholly derived from chromite, an oxygen compound of chromium and iron. Zincite, the red oxide of zinc, found in New Jersey, is a valuable ore. Oxides of copper and of cobalt also occur, and are used wherever found as sources, the one of copper, and the other of smalt.

The important carbonate ores are those of iron, copper, lead, and zinc. The iron carbonate, called siderite, or spathic iron, whether pure or mingled with varying amounts of earthy or bituminous matters, as clay ironstone and black-band ore, are highly important ores of iron and largely utilized. Malachite (the copper carbonate), the lead carbonate (cerusite), and smithsonite (the carbonate of zinc), occur usually associated with other ores of their respective metals, notably the sulphides, have evidently been derived from them, and are valuable ores.

The silicate ores are those of zinc called calamine, of copper called chrysocolla, and several of nickel, all of which are employed as sources of their metals. Rhodonite, a manganese silicate, is also utilized somewhat in coloring glass and porcelain.

The only chloride ore of any importance is cerargyrite or horn-silver, which is a considerable source of silver. Arsenic forms several ores with nickel and cobalt which are important as sources of nickel and of the compounds of cobalt.

Besides these, ores, notably those of gold and silver, are sparingly met with in which tellurium is the mineralizing agent. These tellurides, variously combined, constituting the minerals sylvanite, hessite, petzite, nagyagite, and calaverite, are valuable ores of the precious metals in the few localities where they occur.

Ore Associations and Gangues.—Besides the comparatively simple ores that have been mentioned above, others of a much more complex character are frequently met with, formed by the union of two or more metals with the same mineralizing agent, or by the partial replacement of one element by another. Thus the most common ore of copper, chalcopyrite, is a double sulphide of iron and copper. Common ores of silver are sulphides of silver and antimony, or of silver and arsenic; and in the first, portions of the silver and antimony may be replaced by copper and arsenic. Cobalt and nickel also have arsenides and sulphides in which one metal may partially replace the other, forming double compounds; or antimony may partly replace arsenic in the nickel arsenides, giving rise to another form of complication. So in the mineral tetrahedrite, often called gray copper, which is a sulphide of copper and antimony, the copper may be partially replaced by iron and zinc, or by silver, forming a valuable ore of silver; while arsenic may take the place of a part of the antimony, giving rise to a highly complicated ore. Besides the complications of *composition* of which these few examples have been given, others arise from frequent *associations* of ores. Thus ores of silver are so frequently associated with those of lead that argentiferous lead-ores are a large source of silver, as in some of our great Western mining regions. Silver sulphide is found also with zinc sulphide, forming another often rich but somewhat troublesome ore, as in some of the mines about Georgetown, Colorado. So, too, the ores of lead and zinc are very often closely associated; iron pyrites is intermingled usually with more or less of copper pyrites, and *vice versa;* and manganese-ores occur with those of iron. Tin-ore is almost always associated with a mineral called wolfram; platinum, always native, is invariably alloyed with one or more of the rare metals iridium, palladium, rhodium, and osmium; and gold, likewise native, though alloyed with silver, is commonly associated with iron or copper pyrites, making its extraction difficult save where its associates have been removed by weathering. Only a few of the more common associations and combinations have here been mentioned by way of illustration. The student who desires to go more fully into this subject will find many more in special treatises on ore deposits like those of Grimm, Von Cotta, and J. A. Phillips.

Ores of metals thus composed and associated are in most cases arranged and disseminated in a considerable bulk of other minerals having no value as ores, and which are called *gangues*, or *vein-stones*. The most common of the gangues are quartz, calcite, baryte, often called heavy-spar, and fluor-spar. Sometimes the ore has little gangue, as is the case with some deposits of iron-ore; more commonly the gangue greatly surpasses the ore in amount. This is especially true in the case of ores of the precious metals, as can be readily understood when we reflect that an ore containing three hundred dollars' worth of silver per ton, which would be considered very rich, would have no more than one per cent of the metal, and that a gold-ore of the same value would contain only about one twentieth of one per cent, or about a pound in a ton. We call such deposits gold or silver deposits, because they contain enough of these metals or their ores to be worked with profit; when they might more justly be considered deposits of the gangue minerals slightly contaminated with gold or with silver ores. Proportions of these ores such as have been named, when viewed in the light of human enterprise, would be counted very rich and enormously profitable; but considered with reference to the relation that they bear to the mass of the rock, they are evidently but very minor accessories. The ratio which the ores of the base metals bear to their gangues must naturally be much greater than this, to bring them within the limits of profitable working; yet with these the question of profit is often dependent on some cheap and effective means of separating a large amount of worthless rock from a comparatively small amount of valuable material. For example, in the great Lake Superior copper-mines the native copper is mingled with from 85 to 99 per cent of worthless vein-stone, which, however, can be mostly separated by pulverizing the rock and washing it in suitable apparatus. Such a process of separation of ore from gangue is called *concentration*, and many very ingenious devices have been contrived for this purpose, descriptions of which may be found in technical works. They mostly depend upon the use of currents of water, but sometimes of air, whose velocity is so regulated as to sweep away the lighter materials, leaving the heavier behind. The greater the difference in *weight* of particles made nearly *equal in size*, the easier and more complete the separation can be made.

Geological Mode of Occurrence and Structure of Ore Deposits.—Ore deposits are unquestionably due to some process of concentration of substances, once widely and sparsely disseminated, or too deep-seated to be available for human use. In some cases the concentration has been due to mechanical agencies, by which rocks have been ground up, and their heavier and more unchangeable portions collected in favorable places; in some others it has been effected possibly by the agency of heat, which may have volatilized certain substances and forced them up from considerable depths in the form of vapor, to be condensed on cooling; but in the vast majority of cases the accumulation of ore deposits has been due to chemical solution, in which water has played a prominent and essential part. By this last means, particles widely diffused have been removed by solution from their parent rock, and have been carried away to be redeposited in fissures and cavities, or to fill the pores and cellules in rocks; or to react chemically with favorable portions of some rocks, chiefly limestones, and thus to replace them; or, through change or dissipation of their solvent, to be deposited in beds at the existing surface, either alone or mingled with other substances. The most important forms in which metalliferous deposits, thus originating, are found to occur, though variously grouped by different authors, may be conveniently tabulated as follows:

- 1. Stratified or bedded deposits........
  - *a.* Placers and other superficial deposits.
  - *b.* Deposits forming entire strata.
  - *c.* Deposits disseminated in strata.
  - *d.* Ores segregated from strata.
- 2. Impregnations.....
  - *e.* Infiltrations into beds.
  - *f.* Contact zones enriched from neighboring deposits.
- 3. Mass deposits.......
  - *g.* Gash-veins and caverns in limestone.
  - *h.* Quasi-veins or chambers.
  - *i.* Contact deposits.
  - *j.* Stockworks.
- 4. Veins.............
  - *k.* Segregated veins.
  - *l.* Fissure-veins
    - (1) Bedded veins.
    - (2) Cross-cutting veins.
    - (3) Contact veins.

1. **Stratified Deposits.**—Many valuable metalliferous deposits are found occurring in the form of beds, evidently deposited in most instances as sediments, but in at least one case, that will be mentioned, in sheets of volcanic rock interbedded with mechanical sediments. The bedded form of deposits is especially common with the ores of iron, though it is by no means confined to them. Usually the origin of the ores has been contemporaneous with that of the accompanying and inclosing rocks; where, however, it seems evident that it has been subsequent to that of the beds in which they are contained, they would properly be classed as impregnations. Bedded deposits have pretty definite limits above and below; their arrangement is parallel with that of other beds of the same series, whether the position of the series is horizontal or inclined; they have no special connection with other similar parallel

beds; and their valuable contents are in general more evenly distributed than is the case with other forms of ore deposits.

(*a*) **Placers.**—This important form of metalliferous deposits may, it would seem, be classed with beds, owing their origin as they do to the same kind of agencies by which mechanical sediments are formed, and when they come to be covered, as they sometimes are, by deposits of other materials, being considered and treated as beds. Placers originate from the disaggregation of other forms of ore deposits, and from the sorting of their materials by the action of running water. The substances which give them their value are of much greater specific gravity than the minerals with which they were originally associated, and are not affected by the usual agencies of change. Hence they retain their integrity, and are separated by the action of water from the lighter substances and from those which yield to disintegrating influences. Sometimes the valuable minerals remain nearly in their original position, and are merely separated in a greater or less degree from their accompanying rock. In much the more numerous and important cases, all the material of the disaggregated deposit is transported to some distance from its place of origin; the desirable substance, by reason of its greater gravity, is washed free from the lighter and finer rock, and is ultimately accumulated in the lower portions of a rude mass of the coarser rubbish, mingled usually with sand and in some places with "occasional beds of tenacious clay." The usual places of accumulation of placers are naturally at the base of declivities, in valleys, and in water-courses; and in the last case, the ancient water-course, now entirely filled with transported material, may long since have been abandoned by the stream to which its origin was due. These accumulations have in not a few cases been cemented to a solid mass, especially in their lower portions, by the infiltration of mineral waters, and some of the placers of the Pacific coast and of Australia have subsequently been covered by sheets of lava of great thickness. Placer deposits are sometimes hundreds of feet in thickness, and have a rudely stratified structure, marking undoubtedly periods of rapid and tumultuary deposition, alternating with others of more quiet action. The distribution of the valuable substance in such masses is by no means uniform. Being of high specific gravity, as has before been remarked, it naturally tends to the lowest point in the deposit, and is found most abundant on and near the *bed-rock*, the richest accumulations being found in holes, splits, and depressions of this rock, and at points where the current of the depositing stream had been arrested or suddenly changed by any cause. When several periods of deposition are superposed, several richer horizons or pay-streaks may occur, occupying each the lowest place in its own bed. The substances commonly found in placers are, besides precious stones, gold, platinum, tin oxide, and magnetite, all of them highly insensible to the usual agencies of change.

Although Von Cotta, in his excellent treatise on ore deposits, expresses a doubt whether placer deposits occur of earlier date than the Post-Tertiary, yet Dawson, in his "Acadian Geology," shows that gold-bearing placers are found in Nova Scotia at the base of the Lower Carboniferous as conglomerates deriving their materials from Silurian auriferous rocks; and in the vicinity of Deadwood, in the Black Hills, auriferous conglomerates of probable Primordial age occur, having all the characteristics of modern placers, both in the nature of the materials constituting the deposits, and in the distribution of the gold. ("Engineering and Mining Journal," 1882, p. 335.)

Besides placers, deposits of metallic ores of bedded structure occur, (*b*) forming the entire mass, or at least the greatly preponderating material of beds of considerable extent and thickness; such is the case with many very important deposits of iron-ore. Or (*c*) the metallic substance may be found disseminated more or less richly throughout certain beds; examples of which may be seen in the copper-bearing conglomerates of Lake Superior, and in the bituminous shale of Mansfeld, containing profitable amounts of ores of copper and silver. Lastly, ores may occur (*d*) as concretionary masses of variable size, in beds from whose remaining materials they have segregated themselves by virtue of the mutual attraction exerted by particles of a like kind; e. g., the kidney-shaped masses of clay ironstone occurring abundantly in some strata of the coal-measures.

The principal ores occurring in beds, besides gold, platinum, and cassiterite, mentioned as found in placers, are those of copper, lead, zinc, and iron, the last named of which, as a workable substance, occurs in this country almost exclusively in beds.

2. Impregnations.—Impregnations are deposits of ores found disseminated more or less richly in certain regions of rock, into which they have apparently been introduced *subsequently* to the origin of the containing rock. Their determining characters are their *subsequent origin*, and their usual lack of any *definite limits* other than the extent to which the rock containing them can be profitably extracted. They may occur (*e*) as infiltrations into pre-existing zones of rock, usually having the bedded structure, which from their porous or cellular texture, or from their fissured condition, have afforded access to metalliferous solutions or sublimations by which they have been enriched. Examples of this kind of impregnation are afforded by the deposits of Silver Reef, Utah, where several beds of Triassic sandstone inclosed in clay-slates contain profitable amounts of silver chloride and sulphides; by the deposits of copper glance in the Oscuras Mountains, in New Mexico, which occur impregnating conglomerates and decomposed argillaceous slates, and in some cases incrusting or replacing fossil plants and shells; by the Triassic sandstone of Commern in the Rhenish Province of Prussia, whose loose, fine-grained sandstone, according to Credner, sometimes nearly two hundred and fifty feet thick, is thickly strewed with grains of galena, constituting one of the most valuable lead deposits in Germany; and by the deposits of native copper in the Lake Superior region, which occur disseminated in sandstones and conglomerates, or filling the amygdaloidal cavities in great sheets of bedded volcanic rock. Impregnations of the kind here described are often by no means easy to be distinguished from true bedded deposits. The distinction, where it can clearly be made out, will depend upon observing how far all the attending circumstances point to *contemporaneous deposition*, or to *subsequent introduction*. The usually vague limits of such impregnations may either coincide in a general way with those of the beds in which they are found, or they may be confined chiefly to such portions of them as were most easily permeable to the enriching agency.

Besides these independently occurring impregnations, having no obvious connection with other accumulations of similar ores from which their materials may have been derived, others are found (*f*) closely dependent on other forms of ore deposit, to which they form a more or less enriched incasement or zone of contact. They may occur in the rock inclosing any of the other forms of deposit, whether beds, mass deposits, or veins. Their ores have in some cases, it is probable, been derived merely from the same source as those of the main deposit, with which in such case they would be contemporaneous; and, since the agency which formed the chief mass permeated also to some extent the surrounding rock, the ores of both would be quite likely to have a similar mineralogical character. In other cases, the enrichment of the surrounding rock has evidently been subsequent to the accumulation of the main deposit, and has been derived from it by decomposition and solution of some of its contents. Hence the impregnation in this case would be likely to hold its ores in mineral combinations somewhat differing from those of the parent mass.

3. **Mass Deposits.**—These deposits, called also by the German name Stöcke, are accumulations of ore of irregular form, but with somewhat clearly marked boundaries. The definiteness of their limits will usually serve to distinguish them from impregnations ; their great irregularity of form, and the limitation of their boundaries in all directions, separate them sufficiently from most veins; while they are distinguished from bedded deposits, both by their irregularity of form and position and by the fact that their ores are usually subsequent in origin to the incasing rocks, in which they either fill pre-existing cavities, or occupy tracts by virtue of a chemical replacement. In position these accumulations may coincide in their greater dimensions with the bedding of the inclosing rocks, or may be transverse to their bedding planes. In extent, they vary greatly, many of the lead-bearing *crevices* and *flats* of Illinois and Wisconsin being of no very considerable dimensions, while some of the mass deposits of argentiferous galena, etc., in our Western Territories, have yielded hundreds of thousands of dollars' worth of ore ; and one of the great deposits of cupriferous pyrites on the Rio Tinto, in southern Spain, was reported in 1883 to be in places more than thirteen hundred feet wide and six thousand feet in length. Indeed, their frequent great dimensions, their comparatively small distance from the surface, and the consequent ease with which they may be worked, afford some compensation for the uncertainty attending their exploration, and the certainty that, when their boundaries are reached, these isolated deposits will afford no reliable guide to anything beyond. Similar ore bodies may be likely to occur in the neighboring rocks,

either at the same or at a different geological level, but their lack of dependence on each other renders each an object of independent and often costly search.

These accumulations are often found filling partly or entirely cavernous spaces in limestones (*g*) which, when they have been formed by the widening of joints, are called often *gash-veins*, or, if by the partial or entire removal of beds, *flats*. Such are the lead deposits of Illinois and Wisconsin. The ores found in these cavernous spaces seem either to have been introduced from above, or to have been acquired by infiltration from the surrounding rocks. (*h*) Deposits of somewhat similar form, filling fissures and cavernous spaces in limestones that have been disturbed and thrown into inclined positions, and whose ores have, it seems highly probable, been brought in solution from below through fissures in the lower rock, may conveniently be called *quasi veins*, from the similarity of their position and of their probable mode of filling to that of fissure-veins. They are also called *chambers* by the distinguished geologist Dr. Newberry. The deposits of gold- and silver-bearing lead-ores of Eureka, Nev., are examples of this kind of mass deposit. (*i*) Ore accumulations frequently occur occupying spaces at the plane of contact between rocks of dissimilar character, and from this circumstance are called *contact deposits*. The celebrated deposits of rich argentiferous lead-ores of Leadville are of this character, occurring at the contact of porphyry with an underlying limestone. According to Emmons, these ore-masses are not fillings of pre-existing cavities, but have been formed by the replacement of the limestones by ore-bearing solutions penetrating them from the overlying porphyry. Accumulations thus originating are sometimes called *metamorphic* or *transformation* deposits. Contact deposits and flats which occupy a nearly horizontal position are frequently called *blanket-lodes*. (*j*) Stockworks are regions of rock so cut by a network of irregular, vein-like, ore-bearing fissures or sheets, that the entire mass must be mined out. An example of this kind of deposit is furnished by the Fresnillo mines, at Zacatecas, Mexico, which work an interlaced mass of fissures carrying ores of silver, with which also the inclosing rock is impregnated to varying distances from the stockwork.

It is well for the student to bear in mind that the distinction of these three classes of mineral deposits, viz., beds, impregnations, and mass deposits, is not always sharply drawn nor easily made. The extreme and well-marked forms will present no great difficulties; but not unfrequently they so approximate in characters that they are classed differently by different observers, and that the distinction among them, if it can be decisively made, will depend upon a careful study, not only of the circumstances under which they occur, but of the conditions in which they originated.

4. **Veins.**—Referring to what has already been said at page 35 for an account of vein-formed rocks in general, what follows here will be confined to a description of veins which carry metallic ores as an important portion of their contents. Such veins are frequently called *lodes*, although this term is sometimes loosely applied to ore deposits which are not, strictly speaking, veins. Metalliferous veins are sheets of mineral matter, differing usually somewhat markedly in mineralogical character from the inclosing or *country rock*, and filling pretty clearly defined fissures, or occupying definite structural planes therein. They tend to a vertical or highly inclined rather than to a horizontal position; differing in this respect, as well as in the subsequent origin of their contents, from bedded deposits, which originally, at least, must have been nearly horizontal, and whose ores were deposited as part of the continuous series of operations that formed the beds.

Segregated veins (*k*) are lenticular masses, chiefly of quartz, and sometimes of great dimensions, formed apparently by elimination of their materials from the surrounding metamorphic rocks, and by the concentration of these materials along certain planes of the bedding during the process of metamorphism. Gold is the chief valuable substance found in such veins, associated always with iron pyrites and sometimes with chalcopyrite, both of which may occur in sufficient abundance to be worth working, even if unaccompanied by gold. Of this kind are the quartz veins and lenticular masses of chalcopyrite with pyrites, which occur in the metamorphic schists of the Alleghany range from Georgia to Canada, and which in some places contain valuable amounts of gold and copper. On account of their conformity with the bedding of the accompanying rocks, they are often spoken of as beds, though apparently differing in mode of origination from true beds. Where they swell out to considerable dimensions also, they are indistinguishable from mass deposits, to which they are closely allied, and with which, doubtless, they might not inappropriately be classed.

Fissure-veins, or metalliferous lodes (*l*), are fissures of the earth's crust which have, subsequent to their formation, been filled with mineral substances of which metallic ores constitute a part. Such veins are often of very considerable length, being sometimes traceable for several thousand feet, or even for miles, in the same general direction, and it is highly probable that in many cases their extent is greater than can conveniently be traced. As to the depth to which they reach, it can only be said that it is greater than that to which the deepest human workings have yet been prosecuted, or indeed are likely, for practical reasons, ever to be prosecuted. Work on metallic lodes has been suspended, temporarily or finally, at various depths and for various reasons, but never, so far as known, from any real cessation of the vein in depth. The fissures occupied by the deposits now under consideration are doubtless fractures of the earth's crust, resulting from deep-seated causes, such as produce uplifts and other changes of level in rocks, earthquakes, and volcanic outbursts. Hence, veins are found chiefly in regions which have been subjected to powerful agencies of disturbance, regions rent by the throes of volcanic activity, regions of metamorphic rocks, mountain-regions, to whose larger structural lines they conform in direction. Also, the system of veins of any special region, made up of a number of separate veins, presents usually a rude but striking parallelism among its several members, as might be expected with fractures produced by the same disturbing cause, acting with a certain constancy of direction. Examples of this parallelism are presented by many vein-mining districts, as in the northwest coursing veins of Reese River, Nev., and the nearly east and west coursing veins of Gilpin County, Col. Sometimes a tendency to a radiate arrangement is observable in a system of veins.

It is obvious, however, that for the formation of a mineral vein mere fracture of the rocks is not sufficient. Doubtless many fractures have been made by movements in the earth's crust, the opposite sides of which have returned so nearly to their original position that no observable space has been left for future deposits. But extensive rock-fractures inevitably present a very uneven surface, as can easily be understood by observing, on a small scale, the irregular surface of a broken block of stone. If, then, the force which causes fracture causes also, as is very likely, some movement of the broken parts upon each other in any direction, it is easy to see that the fracture will present irregular open spaces, with the opposite walls resting upon each other at some points. The student can illustrate this clearly to himself by cutting a sheet of cardboard across irregularly, as was done for Fig. 16; or, better, by breaking a block of stone, and then moving the parts upon each other in any direction. Fig.

16 presents a section of such a fissure, which, by the movement of the upper part from *a* to *b*, presents the appearance *d*, while a movement from *a'* to *b'* gives the form *c*.

To such movements in their walls is doubtless attributable the striking irregularity in width which most fissure-veins present, varying from *bulges* of considerable width to a *pinch-out*, where the walls are separated from each other only by a seam of clay. In these faulting movements, the overhanging portion of the *country rock*, significantly called by miners the *hanging wall* of the vein, has usually slid downward on the underlying or *foot-wall* side.

Another means by which the walls of veins are held asunder, to be afterward filled with minerals and ores, is by the breaking off of fragments of the hanging wall, either by the shock that formed the fissure, or by gravity, and their sliding downward until they become wedged be-

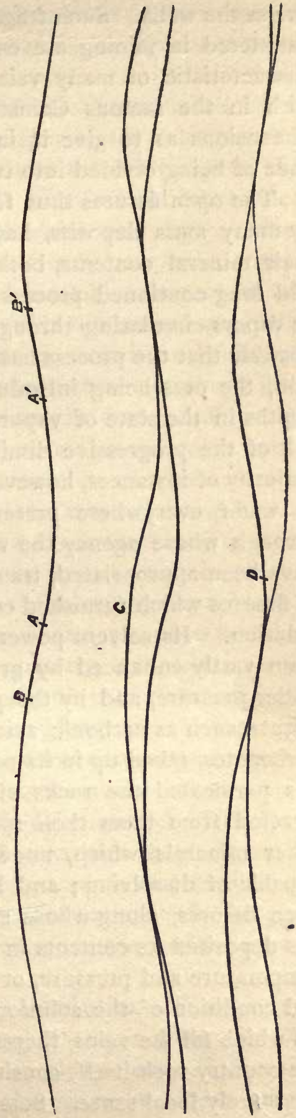

FIG. 16.—Irregularities of Width in Veins, resulting from Movement.

tween the walls. Such fragments of the country rock encountered in mining are called *horses* or *riders*, and are characteristic of many veins. Some of the horses met with in the famous Comstock vein were of such vast dimensions as to give it, in places, the delusive appearance of being divided into two veins.

The open fissures thus formed, as also those occupied by many mass deposits, have doubtless been filled with their mineral contents, both ores and gangues, by a slow and long-continued process of deposition from solutions or vapors circulating through them. In some cases it is possible that the process has been in part one of sublimation, the ores being introduced into the fissure at great depths in the state of vapor, and being deposited as a result of the progressive diminution of heat. In the great majority of instances, however, all the observed facts point to water, everywhere present in rocks, as the medium through whose agency the various vein-forming minerals have been appropriated, transported, and finally deposited in fissures which furnished convenient channels for its circulation. Its solvent power has doubtless in most cases been vastly enhanced by great elevation of temperature under pressure, and by the presence of various chemical agents, such as carbonic acid and alkaline sulphides and carbonates, taken up in its passage through the rocks. It has permeated the rocks often to vast depths; has abstracted from them their sparsely disseminated ores and other minerals which, under the circumstances, it was capable of dissolving; and has finally made its way into open fissures, along whose sides in its upward course it has deposited its contents in consequence of a decrease of temperature and pressure, or of some change in the chemical condition of the solution. The source of the minerals which fill the veins, therefore, is believed to be usually the country rock itself, considered in the wide rather than the merely local sense. Sometimes, indeed, the rocks immediately adjoining the present position of the ore deposits appear to have furnished the ores and gangues by lateral secretion, as is probably true of many vein-like mass deposits. But, in the case of true fissure-veins, all the circumstances point to the ascent of the solutions from great depths, and consequently to the derivation of their contents from the leaching of areas of the country rock of considerable extent in both width and depth. These deposits, therefore, are, as has already been said, concentrations, within a limited and available compass, of ores originally valueless from their wide dissemination. Much undoubtedly still remains to be done in investigating the chemistry of the process by which these seemingly insoluble substances have been brought into solution; but enough has already been done to render no longer doubtful the possibility of the translocation and concentration through aqueous solution of all the minerals found in veins and other ore deposits. It should also be borne in mind, in considering how ore deposits have been accumulated, that the present condition in which ores occur in veins is by no means always the same as that in which they were originally deposited. On the contrary, it is often apparent that important changes, not only of condition but also of location within the deposit itself, have taken place since their deposition. Thus the question that not unfrequently arises is, not how a given substance could have been dissolved, but what was the original form under which it was rendered soluble and brought to its present place, and by what means has it been made to assume its present state? Some examples of these transformations will be given hereafter, when we come to consider the surface appearances of ore deposits.

Arrangement of Vein Contents.—The mode of arrangement of the minerals with which veins are filled is quite variable. In some, especially those filled mostly with a single mineral, e. g., quartz, the structure is massive, any ores that are present being disseminated in granules often very fine, or in irregular lumps and threads. A common mode of arrangement, where the veins contain several minerals, is the *banded*, in which the different minerals, or sometimes different states of the same mineral, are arranged in more or less regular sheets parallel to the walls, and often showing duplicated or corresponding sheets on the opposite walls, as in Fig. 17, which exhibits a section of a copper-mine in Cornwall, from De La Beche's "Geological Observer," p. 659.

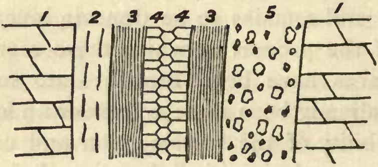

FIG. 17.—1, 1, Country Rock; 2, Massive Quartz; 3, 3, Agate-like Quartz; 4, 4, Quartz-Crystals or Combings; 5, Chalcopyrite.

Such a structure indicates that different conditions of deposition prevailed in the fissure at different times, or that solutions of a different character succeeded each other during the period in which it received its contents. In this mode of arrangement the valuable ore usually forms one or more of the successive bands of the vein commonly known by miners as *pay-streaks.* Where vacant spaces have been left in veins, usually along the plane of final closure, such spaces are called *vugs ;* or, where lined with crystals, as is apt to be the case, they are called *druses* or drusy cavities. Ores are often found lining such drusy cavities. Occasionally the vein structure is *brecciated*, i. e., the fissure has been filled with rounded or angular fragments of the country rock coated and cemented with the ore and gangue. This type of structure is presented by a few celebrated mines in our Western Territories. Besides the modes of occurrence mentioned above, it is common to find ores lining cracks and fissures of the vein-stone in the form of irregular strings, sheets, and incrustations.

The distribution of the ores in veins is apt to be very irregular, considerable portions of the vein being practically barren, or carrying ores of but low grade, while others present tracts of unusual richness. Such rich zones of ore are called *bonanzas*, or *ore-chimneys*. They are apt to occur in the wide portions of veins; either because width of fissure and consequent slower movement of ore-bearing solutions afforded unusually favorable conditions for deposition; or because, in the case of subsequent movement of the vein, crushing and fissuring its original contents, the wider parts offered favorable places for an after-concentration of ores within the vein itself. The Comstock vein of Nevada has afforded many remarkable examples of the alternation of wide tracts of barren rocks with ore-bearing zones, sometimes of great extent and astonishing productiveness, these bonanzas occurring in the wider parts of the vein. Also, there can be no doubt that the unequal distribution of ores in many veins is due in a great measure to the influence of the country rock; for where this differs in character in different parts of the fissure, some portions rather than others promote the deposition of ores, apparently from their greater roughness of surface, their readier conduction of heat, or their presenting conditions for a chemical reaction with the solutions circulating in the fissure. From these and other causes, veins usually present an irregularity in the distribution of their ores, as well as a heterogeneity of mineral composition, in somewhat marked contrast with any bedded deposits to which they may sometimes bear a close superficial resemblance.

Characteristic for deposits filling fissures are *branch-veins* or *leaders*, *horses*, and *selvages* or *fluccan*. *Branch-veins*, called also leaders and stringers, are small subsidiary veins diverging from the main vein, and leading some little distance into the country rock, where they may gradually die out. They have evidently been formed and filled by the same agencies as the main veins. Something akin to branches may occasionally occur in mass deposits which fill pre-existing cavities, but they can evidently not occur with beds, since these were deposited upon the underlying beds, and were subsequently covered by the accumulation of the overlying ones. *Horses* have already been mentioned as portions of the country rock, usually fragments of the hanging wall of inclined veins, which have broken off and slid down into the fissure, where they have subsequently been enveloped by the remaining contents. They occur in fissure-veins, and may occur in some mass deposits, but not in beds or impregnations. What is called *fluccan* or *selvage* is a sheet of earthy matter frequently found lining one or both walls of fissure-veins. It is caused sometimes by movements of the vein, which have ground up the materials along the walls; more frequently, doubtless, by the percolation of water along the walls, and the consequent decomposition of the adjacent rocks. Such decomposed sheets of rock are called by the miners *gouge*, because their softened condition renders them easy to be penetrated and gouged out by tools in mining operations. Where the selvage has been caused by movement, the adjacent rock usually presents a polished, glazed, and striated surface, termed *slickensides*, the striations bearing evidence of the direction of the movement. Appearances of this kind between the bands of a vein, and others presented by the structure of the vein contents, not unfrequently testify to the reopening of a vein after it has been filled, and the formation of a secondary fissure, which has subsequently been filled within the vein itself. Thus, in the section presented by Fig. 17 on a preceding page, the want of correspondence between the exterior bands 2 and 5 may possibly have resulted from reopenings of the vein-fissure. An undoubted illustration of a vein presenting several re-openings may be found by the student in Fig. 292, at page 658 of De La Beche's "Geological Observer," and another on page 48 of Phillips's "Treatise on Ore Deposits."

Veins occupy various positions with reference to the structural planes of the inclosing rock. Most frequently they are found cutting at various angles across the bedding of the country rock, where this is perceptible: e. g., *a*, Fig. 18, which incloses a horse (*e*).

Sometimes the vein-fissure has followed the contact-plane of unconformable rocks differing in character: e. g., *b*, Fig. 18. Such veins are called *contact-veins.* The Comstock is a contact-vein through a portion of its course. Finally, where the country rock is much inclined, the vein may be mainly parallel to the bedding, often making it difficult to determine whether it is really a fissure-vein or a bedded deposit: e. g., *c*, Fig. 18. In

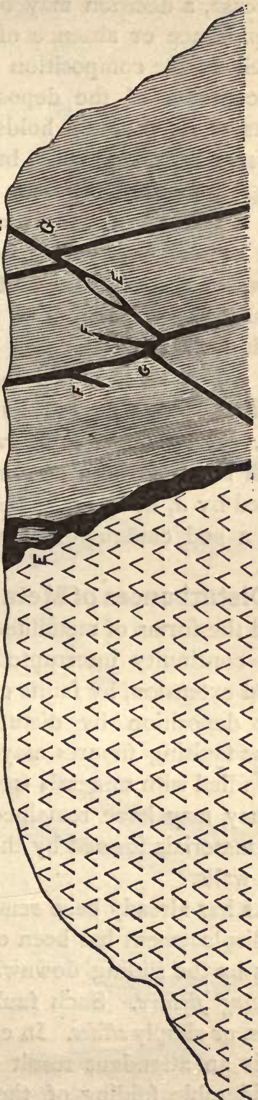

FIG. 18.—Ideal illustration of various kinds of Veins. *a*, Ordinary Vein; *b*, Contact Vein; *c*, Bedded Vein; *d*, Bed; *e*, *e*, Horses; *f*, *f*, Branches; *g*, Fault.

this case, a decision may often be reached by observing the presence or absence of *horses*, *stringers*, and *selvage*, as well as the composition and mode of arrangement of the contents of the deposit; by noting whether at all points of its course it holds the same position among the inclosing beds, or, rather, breaks across in places so as to occupy somewhat different planes at different points, as a vein is likely to do, but never a bed; and, finally, should it be crossed by other deposits, by observing whether it is *continuous* across these, and whether it causes any change in the relative position of their opposite parts, neither of which circumstances could be true of beds. The bedded vein, *c*, Fig. 18, is shown to be really a vein: (1) by having branches, *f f*; (2) by crossing the inclosing beds at *g*; (3) by faulting the vein, *a*; while the deposit, *d*, which is everywhere conformable to the bedding, and is faulted by *a*, is, so far as these circumstances show, probably a bed contemporaneous in origin with the country rock.

Disturbances of Metalliferous Deposits—Faults.—All the forms of metalliferous deposits are liable to have their continuity interrupted, either in depth or in horizontal extension, by faults caused by fissures formed since their deposition by disturbances of the earth's crust. These faulting fissures may themselves have subsequently been filled with minerals from solution, constituting veins; or they may have remained merely crevices, filled only with materials formed by the attrition or decomposition of their walls.

As has already been remarked in a preceding chapter, the displacement has been caused in the great majority of cases by the sliding downward of the *hanging wall* of the *faulting fissure*. Such faults are therefore called *normal* faults, or simply *slides*. In cases, however, where the faulting is an attendant result of powerful disturbances and considerable folding of the strata, examples may occur where the hanging-wall side of the faulting fissure has been thrust upward, producing a *reverse* fault, or *heave*.

In Fig. 19, representing faults of veins produced by fissures whose course is approximately parallel to that of the veins, 1, 2, and 3 illustrate normal faults, or slides, and 4, 5, and 6, heaves; 1 and 4 being caused by fissures dipping toward the veins, 2 and 5 by fissures dipping in the same direction as the vein at a lower angle, and 3 and 6 by fissures dipping with the vein at a steeper angle. A simple inspection of the figures will make it obvious that, in 1 and 6, the continuation of the vein may be found by a cross-cut from the interrupted end into the hanging wall of the vein in the direction of the arrows; that in 2 the cross-cut should be into the foot-wall of the vein; that in 3 and 5 a vertical shaft or *winze* should be sunk, and cross-cuts made in the direction of the hanging wall of the vein; while in 4 the vein would be found by a winze. The cases 1, 2, and 3 will be those most frequently met with. In the absence of any other means of infor-

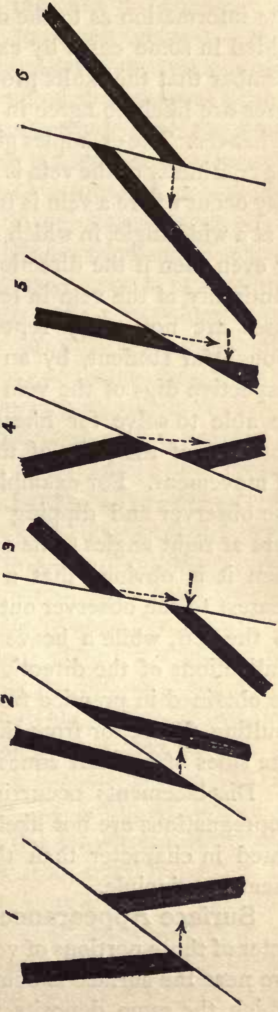

FIG. 19.

mation as to the direction of the faults of a new region, it is safest to assume at the outset that the faults, if any occur, are normal, and to act accordingly. When, however, definite information as to the direction of faulting has been obtained in some cases by exploration, then it is well to remember that the faults produced by the same *system* of fissures are likely to agree in direction, i. e., to be all slides or all heaves. The examples given above represent cases where the continuity of the vein is interrupted in depth. But cases may occur where a vein is faulted by a fissure striking across it at a wide angle, in which case, unless the vein be vertical, or even then if the direction of movement be oblique, the continuity of the vein in length will be interrupted. Such cases are not easily represented by diagrams; but the thoughtful student, by an attentive consideration of the respective dips of the vein and of the faulting fissure, will be able to solve for himself the problem of the relative positions of the parts of the vein with any given direction of movement. For example, suppose a vein, in a line with the observer and dipping to the right, to be cut by a fissure at right angles to its course, and dipping toward him; then it is obvious that a slide would throw the portion nearest to the observer out of line with the rest of the vein to the left, while a heave would displace it to the right. Indications of the direction of movement will be likely to be obtained in practice from striations of the walls of the faulting fissure, or from the relative positions on its opposite sides of peculiar zones or beds of rock.

Displacements occurring in beds, mass deposits, and impregnations are not likely to present cases more complicated in character than those of veins, or differing from them in principle.

Surface Appearance of Ore Deposits.—The character of those portions of veins and other ore deposits which are near the surface is commonly very different from that which the same deposits present at considerable depths.

This change of character, which is due to the action of the air, and of water charged with various chemical agents, is usually confined chiefly to the uppermost fifty or sixty feet; but not unfrequently, in the case of permeable and fissured deposits, it extends to much greater depths. "The general character of these altered outcrops consists in a disintegration and softening of the adjacent country rock, in the lack of sulphur compounds, and the prevalence of metallic oxides, salts of the metals, hydrates, carbonates, phosphates, arseniates, chlorides, etc., which often produce very striking colors; these change-products are also, mayhap, accompanied by the development of metallic copper and silver. In depth, these products of decomposition pass often very gradually into everywhere prevalent sulphides of the metals or into iron carbonate." (Von Cotta.) The superficial materials resulting from this change have received various names in different regions. In this country they are usually called *gossan*, a name derived from the mining districts of Cornwall; the Germans apply to them the significant name of the *iron hat*, and have an ancient rhyming rule which signifies that however good a vein may be, it will have an iron hat; while in Mexico and South America they are called *pacos*, *colorados* and *negrillos*. The nature of the change that occurs, and the special character which the altered outcrop is thus caused to assume, will naturally depend in every case on the original character of the contents of the deposit, both ores and gangues. Probably the most widely diffused and obvious change is the one which is signalized in the German and French name *iron hat*, applied to weathered deposits, and which originates in the conversion of the widely disseminated compounds of iron, notably pyrites, into the hydrated peroxide, giving to the mass a reddish or yellowish-brown color, and in some cases making it to a certain depth an available source of iron. Thus the outcrops of copper deposits present usually a mass of spongy iron oxide mingled with the original veinstone, and showing few if any traces of copper, which has been changed from the original sulphide to the soluble sulphate (blue vitriol) and washed away. This may be succeeded below by a rich zone of copper oxides and carbonate with metallic copper, and finally by the unchanged sulphides of copper and iron. The copper veins of Ducktown, Tenn., illustrated by Safford in his "Geology of Tennessee," and also by Le Conte in his "Elements of Geology," will afford a good example of this kind of transformation.

Deposits of lead and zinc are in like manner found changed to the carbonates of those metals, cerusite and smithsonite, sometimes inclosing cores of the original galena or blende but partially transformed; and where pyrites was originally mingled with the ores, the carbonates are reddened or intimately mixed with spongy oxide of iron, as is the case with the argentiferous carbonates of Leadville and Eureka. The superficial portions of silver deposits are apt to contain the precious metal in the form of native silver or of the chloride, mingled sometimes with the bromide and iodide, succeeded at greater depths by the usual compounds of silver with sulphur, antimony, and arsenic.

Auriferous quartz veins, containing, as they usually do, disseminated iron pyrites or chalcopyrite, present at the surface masses of rusty cellular quartz from which the pyrites has been removed, leaving the rock stained with iron oxide, and containing the threads and grains of gold in a state such that it may easily be obtained by crushing and amalgamation. At no great depth, the unaltered form of the vein is met with, in which the gold is so associated with the metallic sulphides as to be by no means so easily and completely secured.

It is obvious that a knowledge of the surface appearances usually presented by the ore deposits of any region is of very great importance to those engaged in searching for such deposits in *that region;* yet it would be a great error to suppose that inferences derived from the examination of the deposits in any one district can be safely treated as unerring guides in the exploration of all others. For example, however true it may usually be that the outcrops of gold-veins are indicated by iron-stained and cellular quartz, and however expedient it may be to follow up and test carefully any such indications in a district that is known to be gold-bearing, yet the converse of the proposition is by no means true, that every outcrop of rusty cellular quartz is probable evidence of the existence of gold; for such appearances occur in many places where no gold has ever been found. To an important extent, every mineral region is likely to present distinctive characters of its own; and general statements as to the effects of atmospheric and aqueous agencies upon ore deposits need to be supplemented by a careful study of the special modifications that are liable to be met with in any particular district, from differences, it may be, in the nature of the minerals with which the ores may be associated, or in that of the substances with which the permeating water may be charged.

General Distribution of Ore Deposits.—Since, as has already been remarked, ore deposits seem in all cases to be concentrations, under favorable conditions, of substances once widely disseminated in rocks, it is obvious that they are most likely to be found in localities where the conditions for such a concentration have been presented. Such favorable conditions are most likely to be found in regions cut by ancient eruptive rocks, since they bespeak the former activity of forces that would produce fractures and fissures, and would furnish the heat essential for the solution of many substances found in ore deposits; in regions of fractured, folded, and altered rocks, mountainous regions, because in them also fissures would be likely to be opened, the circulation of fluids facilitated, and heat generated by the intense exertions of mechanical force; in regions of rocks of great geological antiquity, rather than in those of more modern date, because the more ancient rocks, by reason of their age, have been longer exposed to occasions for the action of those slow-working and protracted agencies by which ore deposits have doubtless been most largely produced, and because, to effect the solution and deposition of many highly refractory substances frequently found in veins, masses, and impregnations, the action of water at a very elevated temperature must be requisite, needing the concurrence of heat with the pressure of a great thickness of covering rock, a circumstance which implies not only relative antiquity in the rocks which were the deep-seated theatre of such action and deposition, but also the lapse of vast periods of time during which these deeply placed rocks were elevated and laid open to human search by an enormous denudation; whence also mountain-regions, whose rounded forms and comparatively slight elevation above the general surface show that their very roots have been exposed by wear, are likely to be more favorable than those whose rugged and elevated peaks testify to a briefer exposure to elemental waste.

It will thus be seen that conditions favoring the accumulation of ore deposits are presented (1) by great disturbances of the earth's crust by which fissures may be produced, heat generated, and circulation promoted; (2) by heat, such as initiates, accompanies, and succeeds outbursts of volcanic activity; (3) by original depth of action and consequent pressure, through which the solvent possibilities of heated waters are enormously increased; and (4) by great lapse of time during which the repeated and protracted action of agencies seemingly feeble may produce important accumulations, which may subsequently be brought within reach of human explorations by great uplifts and denudation.

The regions, therefore, in which the great majority of valuable ore deposits are found are (1) those which are in close proximity to eruptive rocks, especially those of somewhat ancient date; (2) mountainous regions, more particularly those whose low and rounded outlines show that large portions of their original bulk have been removed by denudation; and (3) regions of rocks geologically ancient, the more recent formations containing usually little of value besides iron-ore. It has been observed also that regions where rocks of very dissimilar character are found in contact are favorable to the accumulation of ore deposits, hence contact deposits, whether from their liability to separate and form fissures as the result of disturbances, or from their presenting planes of easy percolation to metallic solutions, or from some favoring circumstances of the wall-rocks.

It should by no means be inferred that regions like those here enumerated are likely in every case to furnish valuable ores in some portion of their extent; but only that ore deposits occur mainly in such connections and much more rarely elsewhere. It is well also to bear in mind that the conditions which have produced one *discovered* ore deposit in a region are quite likely to have produced others also which are apt to bear to this some definite relation of kind, position, or direction.

Prospecting.—What has been said as to the general distribution of ore deposits may be useful to the observer at the outset in directing him to the kind of localities which are likely to reward his search. Its proper application will depend, as may be seen, upon some knowledge of the geological structure of the region, and a preliminary acquaintance with the general character of its rocks. Without these, any first discovery of valuable minerals would be due merely to a lucky accident, as indeed most first discoveries have probably been. In the absence of other sources of information, traces of ancient workings may prove useful guides to the explorer, indications such as would be given by old pits not yet wholly obliterated, and heaps of *débris* whose weathered contents may afford some hints of what explorations would be likely to reveal. Such ancient workings of the aboriginal inhabitants of the country have led, it is said, to the discovery of some of the copper-mines of Lake Superior, and of the best mica deposits of North Carolina. Mere local traditions of the occurrence of minerals, however, when unsupported by perceptible traces of former workings, are notoriously unreliable.

In districts where there is a strong probability of the existence of ores, useful indications to aid in their search may be gained in several ways : from peculiarities of vegetation, since many ore deposits exert a special influence on the vegetation along their course ; from the contents or the depositions of springs issuing from the hidden courses of veins, etc. ; or from some marked features of the topography, such as sharp, narrow ridges marking the outcrop of veins harder than the country rock, or linear hollows suggesting the presence of those made up of materials softer and more easily decomposed than the inclosing walls. The best and most helpful aid is furnished, however, by the *débris* arising from the disintegration and wear of ore deposits, which is likely to be found strewed along stream-courses and slopes below the outcrop of the parent formation. Such transported materials, called usually *shode-stones*, or in our Western mining regions more commonly *float*, will naturally present the surface appearances of the deposits from which they were derived, such as cellular iron-stained quartz and the like. These float minerals, indicating the possible proximity of an ore deposit, are traced carefully upward along stream-beds or slopes, to the point beyond which they are no longer found; and at this point further search is made for the originating deposit by trenches or pits excavated to the underlying rock. Should this examination reveal the probable presence of a vein or some other form of mineral deposit, more extended explorations are made by means of pits and shafts, to determine its direction, extent, and character; and these explorations are accompanied by assays, which, if made upon samples fairly taken, may indicate the possible value of the deposit, and whether it is likely to justify extended working.

Circumstances which condition the Value of Ore Deposits.—Sound business discretion will naturally dictate that the work of exploration should be pushed far enough to reveal the real nature and probable abundance of the valuable mineral, in both depth and extent, and that the conditions on which the present and prospective value of such a deposit must depend should be carefully considered, before the necessarily costly preparations for extensive mining and for the beneficiation of the product should be undertaken.

A primary consideration in determining the value of an ore deposit will, of course, be the relative amount of the valuable metallic substance which the ore mass contains. Where the ore is intimately mingled with the gangue, the value should be estimated on the basis of the entire mass that must be subjected to the processes of concentration and reduction. When, however, the ore is found concentrated into a somewhat definite *pay-streak,* or in a narrow vein, while the value of the ore may be estimated on this same basis, careful consideration should be given to the fact that with the ore a sufficient amount of barren rock must be taken down to give room for convenient mining operations, usually three feet or more in width, increasing by so much the cost of getting the really valuable ore. The value of ores of the precious metals is usually stated as so many dollars or so many ounces per ton; thus, an eighty-dollar ore is one containing that value of gold or silver in a ton. Sometimes the value of low-grade gold-rock is given as so much per cord, the cord being approximately eight tons. In the case of the less valuable metals, like mercury, copper, lead, and iron, the percentage which the metal bears to the ore mass is given. It is obvious that to attain even an approximately reliable estimate of the average value of a deposit, the samples that are subjected to assay should fairly represent what must be treated as ores; otherwise, all further calculations must be mere wild guess-work, as indeed too many estimates of the prospects of new mines are apt to be. Reasonably fair samples can be obtained only by some systematic operation which will exclude entirely the chance for even an unintentional selection, such as by taking shovelfuls indiscriminately from many parts of a well-mixed ore-pile, breaking this material into small fragments, heaping it up, and subjecting it to successive quarterings, until a specimen of convenient bulk is obtained for the assayer. Before, however, a final decision is reached, a *mill test* should be made, by hauling several tons of what is to be considered ore to the most convenient reduction-works, and finding what it will yield to this practical test.

Second only in importance to the relative amount of metal in the ore mass is the state in which it occurs: whether native, and obtainable by a process merely of crushing and washing, like the copper-rock of Lake Superior; or *free milling*, like some ores of gold and silver, which after crushing yield their metallic contents mostly to amalgamation, with little accessory treatment; or in some simple form of combination from which the metal may be liberated by a process involving few operations, like galena and iron oxide; or involved in such complications with other substances as to require an intricate and costly series of operations for its beneficiation; whether also, in case the ore is intimately mingled with so much gangue as to reduce it below the limits of profit, it is in such physical condition, and bears such relations of gravity to the gangue, as to admit of easy concentration, and whether in such case there is a sufficient supply of water for the purpose. It is easy to see that, if one ore costs ten dollars per ton more for reduction than another, it needs to be ten dollars richer to pay ; and that if fifty dollars' worth of ore disseminated through ten tons of vein-stone can, with but little loss, be concentrated into one ton worth nearly fifty dollars, it may, if the process of concentration is made cheap enough by abundant water, become valuable when it would otherwise be valueless.

The question of ready and cheap transportation is also one of vital importance. Remote regions, difficult of access, can utilize at first only their richest ores, those whose value is so concentrated as to bear heavy transportation charges and still leave a margin for profit. Every improvement in the means of communication, every reduction in the charges for carriage, will render available ores of lower and still lower grade, and will bring the products of such regions nearer in value to more favored localities. Many districts in our own country of well-known promise have their mining industries still hampered by the difficulties and cost of transportation. For what avail mines capable of producing an abundance of ores of fair nominal value, all of which and even more may be consumed by the charges for mining, reduction, and excessively dear transportation ?

The probable expense of working the deposit also needs the most attentive consideration, depending as it does on several circumstances, such as the cost of labor; the hardness of the rock that is to be dealt with; the structure of the deposit, whether likely to need much or little support for roof or walls, and whether the timber for this purpose is at hand; the cost of food, tools, and mining appliances in general; and the cost of the power that must be used for hoisting ores, and for handling the water that is likely to be encountered. All these elements of inevitable expense must vary greatly, as may readily be seen, with the circumstances of different localities, and must be carefully estimated in view of such circumstances, if one would avoid the risk of unprofitable undertakings.

Finally, the relation which the particular metal that is to be produced is likely to bear to the supply of human wants, as indicated by the state of the market for that metal, needs to be taken into account. For example, a deposit of copper which, in view of all the considerations above enumerated, would seem likely to yield a good profit when the metal is selling at sixteen cents per pound, might be found to promise no margin of profit with copper selling at fourteen cents or less.

The practical importance of the considerations given above, and the frequency with which some of them are overlooked, sometimes intentionally, by promoters of mining enterprises, will justify a brief abstract of the chief conditions on which depends the value of ore deposits:

1. On the relative amount of metal in what must be treated as ore, needing—
   - *a.* Fair sampling to secure a reliable estimate of the average value.
   - *b.* Due consideration of the amount of dead rock to be handled in securing the ore.
2. On the nature of the combination in which the metal occurs; often also on susceptibility to concentration.
3. On situation with respect to cheap transportation.
4. On the cost of exploitation, which includes a consideration of—
   - *a.* The cost of labor.
   - *b.* The hardness of the rock to be mined.
   - *c.* The structure of the deposit as regards the need of costly support.
   - *d.* The cost of food, tools, mining supplies, etc.
   - *e.* The cost of power for hoisting and pumping.

5. On the relations to the supply of human wants, indicated by current price.

Erroneous Ideas regarding Ore Deposits.—There are prevalent among persons engaged in mining a number of false or only partially justified notions, arising partly from an imperfect knowledge of the true character of ore deposits, partly from a tendency to too wide generalization in formulating as general laws applicable to all mining regions the results of an experience gained in some limited district whose conditions were possibly largely peculiar to itself. As these ideas in many cases tend to foster too sanguine expectations, and to encourage too hazardous ventures without proper examination, while in others they may unduly discourage careful investigation, they deserve to be briefly stated and discussed in a work of practical character, as this aims to be.

1. A somewhat prevalent idea of this kind is, that fissure-veins are likely to increase in width as they descend. From what has already been said as to the manner in which open fissures are formed, partly by a faulting movement of walls of irregular contour, partly by the aid of detached masses of the country rock, it may be seen that this idea is likely to be baseless. Veins may be expected to vary greatly in width, passing from a mere narrow clay seam in one place, to a bulge of considerable width in another. If now at the *present surface*, resulting always from denudation, the vein happens to be encountered at a narrow point, it will naturally widen for a time, sometimes to a considerable depth, before again contracting; if, however, it should be struck at a wider portion, the contrary may be true. The idea has probably sprung from men's disposition to believe easily what they strongly desire, coupled with the well-known tendency to permit a single success to blot out the remembrance of many failures.

2. Somewhat closely akin to this error is the notion that

fissure-veins grow richer in depth. This may have arisen from the fact that where the products of the decomposition of the ores are soluble, as in the case of copper and silver, the outcropping portions of the veins are impoverished, and their true character does not appear until the weathered portions are passed. When, however, the metallic substance is itself unchangeable, e. g., gold, the outcropping portion may be not only relatively richer, but also much more easily reduced than the unweathered part of the vein; so that it may very well happen that a mine which "pays from the grass-roots" may pay nowhere else, for the reason that the sparsely distributed metal may be so involved with other substances in the unchanged vein as not to yield itself to any cheap method of beneficiation. Veins, where found in their natural condition in depth, are likely, as has been stated on a former page, to have their chief value collected in richer zones alternating with tracts of ground practically barren, the richer zones being met with more commonly in the wider parts of the vein. It will therefore be a mere accident dependent upon denudation, whether the vein shall be struck in a richer or poorer portion of its extent. The opinion, once current on high geological authority, that gold has been accumulated in paying quantities only in the superficial portions of veins, is probably entertained by very few persons at present, since mining investigations have shown that it was based on incomplete data.

3. Another current opinion, viz., that certain directions of strike in veins are decisive indications of their possible value, and its modification ascribing certain specialties of course and form to veins of certain metals, may furnish good illustrations of too sweeping generalizations. It is undoubtedly true that, within given regions, the courses of veins, and also of other forms of deposit that have been greatly disturbed, are likely to have a tolerably definite direction, conforming themselves, indeed, in a general way,

to the prevailing structural lines of the region due to uplifts, as if related to them in origin, as they doubtless are. The error, then, is not in expecting certain prevailing directions in the courses of deposits in a given region, but in looking to find the same in *all* regions, without regard to that which conditions their direction, viz., the structural characters produced by upheaval. Still more, it is to be considered that it is merely the *existence* of the fissure that is due to the causes which control its direction, and not the *nature* of *its contents*, whether or not they shall be metalliferous, or what ores they shall contain. The filling of the fissure is a subsequent process, and is due to a quite different agency. For the forces which produced all the fissures of any region of fissure-veins, and which hence controlled their direction, were *mechanical*, and thus totally different from the *chemical* agencies which filled them, and so conditioned the nature of their contents. The same kind of mechanical forces, exerted in the same region at a subsequent period and in a somewhat different direction, may produce a second set of fissures varying in direction from the first, and which, if filled by solutions of a different kind, may form veins containing the ores of a different metal. To this cause is due the fact that veins of the same region which course differently are apt to have unlike metallic contents. Yet veins of similar ores in distinct mining regions which have different structural features may have widely different courses, because their *courses*, and not their *contents*, are conditioned by such structural causes.

4. The sentiment in favor of some kinds of country rock, as likely to be favorable to richness in deposits, and against others as likely to be unfavorable, is not without justification so long as it is restricted to districts in which such influences have been observed. There is no reason to doubt that from several causes, some of which have been briefly mentioned on a preceding page, the country

rock does exert an influence on the deposition of the contents of veins. *What* influence, however, is a matter which needs to be carefully studied in each region for itself, and not to be hastily inferred of any region because of observations made in a different one. For it is to be borne in mind that the nature of the solutions circulating in fissures must have been an influential factor in determining the deposition of ores upon one kind of wall-rock rather than upon another, the interaction between the two varying with the nature of the solution ; also, that the relative composition of rock species is to a great extent variable and indefinite, so that one is liable, while using the same rock *name*, to be dealing with rocks that, from the difference in the relative amounts of their constituents, might be likely to exert notably different influences on ore deposition.*

5. Finally, it may be well to mention in this connection the prejudice, common among men engaged in mining, in favor of fissure-veins, and against some other forms of ore deposits. It is true that a fissure-vein whose average richness gives evidence of being satisfactory, has the great advantage of affording such promise of continuance as to justify large expenditures for its proper development, but coupled with the certainty that the cost of both exploration and extraction must increase greatly as depth is attained. Other forms of deposit are, however, not without their compensating advantages. Mass deposits, for example, though of very uncertain extent and duration, are frequently of vast dimensions, and their uncertainty is fortunately counterbalanced, as Rossiter W. Raymond remarks, not only by this circumstance, but also by " their comparative small depth and the consequent ease and cheapness of extraction and of exploration." As a matter of fact, very large portions of our mineral wealth are derived from deposits other than fissure-veins. Not to mention the vast stores of iron-ore obtained from beds, it is

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* Von Cotta, " Erzlagerstätten."

enough to allude, for a few examples out of many, to the gold derived from placers; the copper from the deposits of Lake Superior, whether they be called beds or impregnations; and the silver and lead from the mass deposits and *quasi* veins of Leadville and Eureka. Hence, it is well for men interested in mining enterprises to cherish no prejudices for or against particular forms of deposit, but to endeavor, by the wise adaptation of methods to the special deposits in hand, to extract from them the greatest attainable profit, which is the true purpose of all intelligent mining.

The student will do well to consult, for further information with regard to ore deposits, "A Treatise on Ore Deposits," J. A. Phillips; De La Beche, "Geological Observer"; R. W. Raymond, chapter on ore deposits in "United States Report on Mineral Resources," 1870; Burat, "Geologie Appliqué"; and Von Cotta, "Erzlagerstätten," Part I; also papers on ore deposits by Dr. J. S. Newberry.

CHAPTER XI.

IRON.

IRON may justly claim the foremost place among the metals, from the indispensable relations which it bears to most forms of human industry. The sources from which it is obtained commercially are the oxide ores and the carbonates, viz., magnetite, hematite, limonite, spathic ore or siderite, clay iron-stone, and black-band. Richest among these is *magnetite*, which when pure contains a little more than 72 per cent of metallic iron. It is highly magnetic, yields a black powder and a black streak on unglazed porcelain,and is so hard as to be scratched with difficulty by a knife. It is often crystalline granular, the faces of the crystals being triangular when perfect. *Hematite* when pure contains 70 per cent of iron. It is not usually magnetic, though sometimes it slightly affects the magnetic needle, and its powder and streak are of a dark red. It varies much in appearance, being sometimes hard and of a steely metallic luster, when it is called specular ore; often constituting a reddish ochreous mass of an earthy texture; occasionally composed of black, shining, mica-like scales, and hence called micaceous ore; and sometimes made up of red, oölitic grains. *Limonite* differs from hematite in being hydrated (combined with water), and so containing a smaller percentage of metallic iron—about 60 per cent—and in yielding a brown powder and streak. It is often found in stalactitic and semi-concretionary forms, with a smooth and shining surface, and a fibrous, often radiated, internal structure. The pure iron carbonate called *siderite* or *spathic* iron-ore, which contains about 48 per cent of metallic iron, is a sparry mineral of brownish color, and of an easy, threefold rhombohedral cleavage, in which it closely resembles calcite and dolomite, from which its cleavage angles differ but little. When strongly heated, it decrepitates, turns black, and becomes magnetic; and when heated in hydrochloric acid, it dissolves with effervescence, yielding a yellow solution. In its impure forms it occurs abundantly in certain shaly strata of coal-regions, mingled with a considerable proportion of earthy matter, forming beds of *clay iron-stone*, or collected into kidney-shaped concretions disseminated through the beds, when it is called *kidney-ore;* or sometimes it is found mingled with much bituminous matter forming black, shaly-looking seams called *black-band.* These impure carbonates, though not so rich in iron as several other ores, by reason of their close proximity to fuels and fluxes, and of the ease with which they are reduced, are a large and valuable source of iron.

Mode of Occurrence.—Although iron-ores are sometimes found filling fissures and irregular cavities, their usual mode of occurrence in this country is in bedded deposits, whether disseminated in the beds like the kidney-ores, or forming nearly the entire bulk of strata which are not unfrequently of great dimensions. Where the strata with which they are associated have been greatly altered and thrown into highly inclined positions, the ore-beds have much the appearance of veins and are often so called; but there is little reason to doubt that they are really beds, often of lenticular shape, formed as part of the regular series of events by which the strata in which they are inclosed were accumulated. Many of the limonites seem to have arisen from the transformation or disintegration of other kinds of iron-bearing strata, and occupy somewhat ill-defined positions, yet related to those of the probable parent deposits.

Geological and Topographical Distribution.—Though small amounts of iron-ores may be found in nearly every geological position, still their occurrence in workable quantities is chiefly confined to a comparatively few geological horizons. Of these horizons in this country, the Archæan is much the most prolific in excellent ores, magnetite and hematite. From this horizon come the ores, so largely worked, and furnishing more than half the iron of the United States, of the Lake Superior region, of northeast New York and adjacent Canada, of northwest New Jersey, and of the celebrated Iron Mountain region of southeast Missouri. Enormous beds of iron-ore occur also in this horizon in southern Utah, and along the Appalachian range south of New Jersey, especially in North Carolina.

From the horizon of the Lower Silurian Potsdam and Calciferous are derived most of the valuable deposits of limonite which occur along the Appalachain range from New York and Connecticut to Alabama, and which are largely worked for local use at many points along this range, in New York, Pennsylvania, western Virginia, East Tennessee, and Alabama.

The horizon of the Clinton Group of the Upper Silurian affords a singularly persistent seam of oölitic hematite, which extends with some interruptions from central New York through Pennsylvania, etc., into Alabama, and ranges in thickness from one foot to a maximum of twelve or more feet. Above this horizon little of value is found until the Carboniferous is reached, where beds of clay iron-stone, kidney-ore, and black-band, are met with in most coal-regions, furnishing large local supplies of ores which are destined to become of increasing value with the rapid growth of the iron industry on this continent. Ores of this same character are also found associated with the coal-beds of Triassic and Cretaceous age in the United States, and much of the iron-ore of France, according to Lebour, is derived from the Jurassic and Lower Cretaceous. A famous iron horizon occurs in the Middle Lias (Jurassic period) of Great Britain, where a clay carbonate in the so-called Cleveland District, Yorkshire, yields nearly one tenth of the iron of the world from an ore averaging 30 to 35 per cent of iron.

Besides the iron regions mentioned above, the United States is known to possess rich deposits in the Rocky Mountain region and on the Pacific slope, though they are still undeveloped save to a limited extent in Colorado and Oregon. The magnetite deposits of southern Utah are said to be very extensive. Besides our native supplies of ore, considerable amounts are yearly imported, chiefly from the island of Elba, from Algiers, and from Spain, which last country is reported to mine annually for export about four million tons of iron-ore.

Other highly important foreign regions of iron production, besides those that have been named, are those of the coal districts of Great Britain; those of Germany, which raise her to the third place as an iron-producer; those in the ancient crystalline rocks of Sweden and Norway; and that of Luxembourg, which supplies much of the iron-ore smelted in Belgium. It is also recently reported that southeast Cuba, through American enterprise and capital, is likely soon to become a considerable producer of iron-ores.

In the case of a substance so abundant and widely diffused as iron-ore, its economic importance must largely depend on (1) its proximity to the fuels and fluxes needed for its reduction to the metallic state, (2) its freedom from injurious ingredients not readily removed in smelting, and (3) the percentage of iron which it is capable of yielding. The fuels used for its reduction are anthracite and dry-burning bituminous coals, coke, and charcoal; while limestone is the flux most largely employed for removing in the form of slag the usual silicious and clayey impurities. Nearness to the prime necessaries may bring into early use comparatively lean ore deposits ; while even richer ones, less favorably located, may wait long for development. Where, therefore, abundant iron-ores of reasonable richness are found in convenient proximity to good fuels and limestone, there prosperous centers of iron production are likely to arise, and transportation facilities to be furnished. To such fortunate concurrences is largely due the supremacy in iron production of Great Britain, where the ores most largely utilized are only moderately rich. Many localities in our own country afford examples of a similar character, which are likely to be considerably multiplied in the near future.

Where abundant and cheap fuel and limestone are not at hand, an iron-ore needs usually to be both pure and rich to warrant distant transportation. The most troublesome impurities in iron-ores are sulphur and phosphorus, neither of which is easily eliminated from the iron in the process of smelting, and both of which necessitate increased expense for even their partial removal. A small amount of sulphur in iron causes it to be "red-short," i. e., brittle and difficult to work at a red heat ; while more than a tenth of one per cent of phosphorus makes it "cold-short," or brittle when cold, thus unfitting it for many uses where great strength is required, and rendering it wholly unsuitable for the manufacture of steel. Where ores are sufficiently free from these injurious accessories, and are capable of yielding 60 per cent or more of pig-iron, they may be profitably transported to smelting centers at considerable distances. Hence the Archæan ores of New York, Missouri, and of the Lake Superior region, are largely carried for reduction to Pennsylvania, Ohio, and Illinois ; while the rich and pure ores of Spain and Elba are brought by cheap ocean-carriage to be mixed with other ores in iron for various steel-making processes. A recently devised modification of the Bessemer process, which, by the use of a basic lining for the converter, consisting essentially of some mineral rich in magnesia, frees iron from phosphorus, promises to make available for the highest uses ores otherwise unobjectionable, but held in bad repute because of their large amount of phosphorus.

According to a somewhat careful estimate of the iron production of 1882—

The production of	the world was	20,656,184 tons gross or metric ;
„	Great Britain,	8,493,287 gross tons ;
„	United States,	4,623,323 ,,
„	Germany,	2,945,007 metric tons—

these three leading producers having, therefore, furnished somewhat more than sixteen million tons, or nearly four fifths of the product of the world. The steel product for the same year was given as 6,307,756 tons, of which Great Britain produced 2,259,649 tons and the United States 1,736,692 tons, these two nations together producing nearly two thirds of the steel of the world.

These figures will serve to give some idea, not only of the vast proportions of the industries for which iron-ores furnish the basis, but also of the countries which, by a fortunate combination of circumstances, seem to be best adapted to be leaders in those industries.

The rapid growth of the iron industry in the United States may be seen when it is considered that in 1854 the entire product was 656,445 gross tons, and that it rose in twenty-six years to 3,835,191 gross tons in 1880. Among the States of the Union, Pennsylvania is foremost in production, from causes that may easily be inferred, yielding in 1882 more than 47 per cent of the entire product of the United States, with Ohio, New York, and Illinois holding second, third, and fourth rank ; while Michigan, New Jersey, Tennessee, Missouri, and Alabama each produced 100,000 or more gross tons.

The **uses** of iron and steel may justly be said to be coextensive with civilized industry. Some of its leading uses only can here be indicated, viz., in constructing and operating railways, for rails, bridges, and rolling-stock; in ship-building; in architecture, for pillars, girders, and multifarious other purposes; in tools and machinery for both agricultural and manufacturing uses; in pipes for the conveyance of water and petroleum, and in tanks for storage; in stoves, furnaces, and boilers; and in wire for fencing and for lines of telegraph.

The works to which the diligent student might refer for more complete information with regard to the ores of this important metal are very numerous. He will do well to consult the Geological Reports of Missouri, Michigan, and Wisconsin, and those of the States along the great Appalachian range, from Canada and New York to Alabama, some or all of which may be within his reach. Many valuable papers on this subject may also be found in the volumes of "Transactions of the American Institute of Mining Engineers." The "Statistics and History of Iron and Steel," in the "Report of the Tenth Census of the United States," and the article "Iron," in the "Mineral Resources of the United States," published by the Geological Survey, 1883, should be consulted; also Wright's "Reports on Mineral Statistics of Michigan," for 1877–'78, 1880–'82; and Phillips's "Treatise on Ore Deposits."

CHAPTER XII.

COPPER.

THE chief sources whence are derived the supplies of this metal of great and growing importance in the arts, are the native metal, and the sulphides, chalcopyrite, bornite, and chalcocite. These yield more than seven eighths of the world's supply of copper, the sulphides furnishing fully three fourths, while native copper affords somewhat more than a seventh, mostly from the Lake Superior region. The remainder is supplied by the carbonates, malachite and azurite, and by the red and black oxides formed by the transformation of other ores, with minor amounts from the silicate, chrysocolla, and tetrahedrite or gray copper. Metallic copper and all its common ores yield with no great difficulty to the knife, having a hardness varying from about three to four; they are also soluble with more or less ease in nitric acid, giving green or blue solutions, into which, if a clean knife-blade be dipped, it will soon be covered with a red coating of copper.

The native metal is easily distinguished by its well-known red color, its bright metallic luster, and the flexibility of a thin shaving cut off with a knife.

Chalcopyrite, its most common ore, somewhat resembles iron pyrites, with which it is often associated, but is easily distinguished by its greatly inferior hardness, and by its deeper shade of yellow, with a tint verging on green. It is a double sulphide of copper and iron, and yields, when pure, about 34 per cent of copper.

Bornite, called usually *variegated copper pyrites* and *erubescite*, is also a sulphide of iron and copper of somewhat variable composition, carrying from 55 per cent to more than 60 per cent of copper. Its color varies from red to brown, and it easily tarnishes on exposure, taking the variegated colors from which it derives its common name.

Chalcocite, or *copper glance*, is of a dark, lead-gray color, with usually a blue or green tarnish, and is somewhat softer than the two preceding ores, with which it is often associated. It is a simple sulphide of copper, and contains nearly 80 per cent of the metal. These three sulphides of copper give fumes of sulphur when heated on charcoal, and when dissolved in nitric acid, with heat if necessary, leave a residue of sulphur.

Malachite is a light-green carbonate of copper, holding nearly 57 per cent of the metal ; and *azurite* is a blue carbonate, with about 55 per cent of copper. Their hardness is about four, and when dissolved in nitric acid they effervesce from the escape of carbonic acid. They are easily distinguished by these characters and that of their solution. When malachite occurs in thick, compact incrustations, showing delicate bands of color, as in some of the Siberian mines, it is considerably used as an ornamental material in inlaid work.

The black oxide of copper, called *tenorite*, and the deep red oxide, called *cuprite* and *tile ore*, or, when it occurs in crystals, *ruby copper*, are both minerals of high specific gravity, and contain respectively, when pure, 80 and 88 per cent of the metal. Both dissolve in nitric acid, and, when heated with the blow-pipe on charcoal, yield a malleable globule of copper. These oxides are often found in some abundance in the middle and lower zones of the decomposed parts of copper veins, and are valuable sources of the metal. Large, rounded masses of tenorite, streaked with green, were found, at an early day, in considerable abundance in the Lake Superior copper regions.

Chrysocolla, a bright bluish-green silicate of copper, which contains, when pure, about 36 per cent of copper, is found in sufficient amount in some of our Western copper regions to be a valued source of copper. It has nearly the same hardness as malachite, for which it is often mistaken; but its shade of color is noticeably different, and it does not, like malachite, effervesce with nitric acid.

Tetrahedrite, called usually *gray copper*, from its prevailing color, is a complex sulphide of copper and antimony, with commonly some other metals, notably silver. It occurs somewhat abundantly in some of the mines of the Rocky Mountain region, where it is valued rather as a source of silver than of copper.

Mode of Occurrence.—Copper or its ores occurs in all the great classes of metalliferous deposits that have been described in a preceding section: (1) It is found in veins intersecting the older rocks, or forming lenticular deposits in certain planes of their highly inclined bedding, as at many points along the Appalachian Mountains, at the Bruce and other mines on the north shore of Lake Huron, at the mines like the Cliff on Keweenaw Point, which have become famous from the enormous masses of native copper which they have yielded, and in the very rich district around Butte City in Montana. (2) It occurs in mass deposits, as along the base of the Sierra Nevada in California, in the Harz Mountains at Goslar, and in the enormous deposits in southwest Spain on the Rio Tinto, in all of which localities the copper ore is mingled with large proportions of pyrites. The very rich copper deposits of Globe, Arizona, and of the Copper Queen, seem also to be of this character, though the ores are widely different. (3) It occurs disseminated in beds, as in the deposits of

Ste. Genevieve County, Mo., which are in two beds of Lower Silurian limestone, at several points in the Lower Silurian beds of Canada, which have not yet risen to great commercial importance, and in the famous copper slate of the Harz Mountains, which, in the vicinity of Mansfeld, yields so large a portion of the copper of Germany from a seam of but inconsiderable thickness. (4) It is found in impregnations, as in the rich deposits of native copper, disseminated in amygdaloids and conglomerates, on Keweenaw Point, in northern Michigan; in the oxide and carbonate ores which enrich enormous zones in beds of felsitic rock, on the boundaries of Arizona and New Mexico, near the Gila River; and in the beds of conglomerate and underlying slate, impregnated with copper sulphides and oxide, in the Oscuras Mountains of central New Mexico. Thus far, in this country, the deposits which have here been classed as veins and impregnations have been much the most largely worked, and with the greatest profit, though important amounts are also produced from the other two classes of deposit.

Geological and Topographical Distribution.—Although workable deposits of copper are sometimes found in formations as late as the Permian, as at Mansfeld, and in the possibly younger beds of the Oscuras Mountains, yet they are most largely accumulated in the ancient crystalline or eruptive rocks of the Archæan and in the often much-disturbed and altered beds of the earlier Silurian.

The most notable copper region in North America is that of the southern shore of Lake Superior, in the northern peninsula of Michigan. The copper here occurs in the native state, in a very thick series of interbedded volcanic rocks, sandstones, and conglomerates, of probably later Archæan age, though they are thought by some excellent geologists to belong to the Cambrian. The metal is found partly in fissure-veins, in which the copper has been met with largely in masses, sometimes of enormous size, several having been discovered which weighed from two hundred to nearly five hundred tons; partly as one of the minerals filling amygdaloidal cavities in the volcanic rocks, some of the irregularly shaped masses here also attaining considerable dimensions; and partly disseminated in conglomerates, in which it constitutes a portion of the cementing material. The fissure-veins are no longer so productive as they once were, the great masses being now unfrequently found, so that the product depends chiefly on the copper disseminated in lumps, strings, and grains in the vein-rock. The largest part of the product is derived from the amygdaloids, in which, besides the fine grains and strings of metal with lumps of a few pounds in weight, irregular masses weighing more than a ton are sometimes encountered, filling large scoriaceous cavities in the ancient lava-beds; and from the cupriferous conglomerates, in which one great mine, the Calumet and Hecla, produces considerably more than half the copper of the region from a conglomerate impregnated with about five per cent of the metal. The amygdaloids are more easily worked than the conglomerates, and their average of metal varies from about three per cent in the Quincy mine to 0.72 per cent in the Atlantic. The process of extraction consists in freeing the lumps and masses, as far as possible, from the accompanying minerals, by steam-hammers, rock-breakers, and stamps, stamping the finer copper and gangue to a coarse powder, and washing away the waste rock in jigs and buddles, and then smelting the lumps, masses, and washed grains to rid them of the remaining gangue in the form of slag.

Second in the list of copper-producers is the region immediately around Butte City, Montana, which in 1882 produced over four thousand gross tons of metal from rich sulphide-ores, yielding also usually valuable amounts of silver, and in 1884 reached a production of over eighteen thousand gross tons.

Ranking third in amount of metal produced since 1883 are the copper-producing districts of Arizona, at present three in number. The Clifton district is in the southeast part of the Territory, on the Gila River, near the boundary-line of New Mexico. The ores, mostly carbonates and oxides, are said to occur in enormous zones in vertical beds of felsite rock, and to average fifteen per cent of copper in a gangue of manganese and iron oxides. The Copper Queen mine at Bisbee is the largest producer in Arizona, having a very rich body of carbonates and oxides in limestone with, it is said, some native copper, and copper glance in the deeper workings. A block of this ore, weighing three tons, recently sent to the Museum of Cornell University by Prof. W. P. Blake, is made up chiefly of malachite intermingled with black oxide of manganese and calcite. The Globe District, in Gila County, though situated badly in regard to transportation, is yet producing largely in several mines, the ores of all which are carbonates and oxides, containing also small amounts of the precious metals. The Old Dominion mine, in this district, is said to yield annually more than two thousand net tons of copper. Besides these chief producing centers there are some other promising mines in this remote Territory, of which the Peabody, in Cochise County, a little north of the famous Tombstone region, is stated ("Report of the Director of the Mint for 1882") to be producing at the rate of eighteen hundred tons per year, from an ore carrying a high percentage of gold and some silver. In 1884 the estimated yield of Arizona was 11,920 gross tons of copper.

Colorado produces considerable amounts of copper, solely as a secondary product from ores worked chiefly for their gold and silver. Most of this is from the mines of Gilpin County, west of Denver, with smaller amounts from the San Juan region, and from a locality near Cañon City. New Mexico, though not yet producing more than four or five hundred tons per year, is known to have very rich deposits in not less than six counties, many of the mines carrying also important amounts of the precious metals. Wyoming, in 1883, increased its copper product about twelve-fold, producing nearly six hundred tons from mines on the Platte River, ninety miles north of Cheyenne. The ores are rich carbonates and cuprite. Vermont has long had a steady production from low-grade pyritiferous ores, chiefly in Orange County. Besides these main producing regions, promising deposits are known to exist and have been considerably worked in many places along the Appalachian range, chiefly in western Virginia, the northwest part of North Carolina at Ore Knob, and at Ducktown in southeast Tennessee; as well as in California, Nevada, Utah, Ste. Genevieve County, Missouri, and in Maine.

Other North American deposits of copper are found in the southeast part of Cuba, near Santiago de Cuba, which formerly yielded annually as high as thirty thousand tons of eighteen-per-cent ore; and in the British dominions, on the north shores of Lakes Superior and Huron, in southern Quebec, and in Newfoundland. Judging from the statistics of production, these are rather regions of promise than of present vigorous working, with the exception of Newfoundland, which in 1883 is credited with a product of ten hundred and fifty-three tons from two localities, and of Capelton, in the southern part of Quebec, which annually sends to the United States a large amount of cupriferous pyrites to be used in the manufacture of sulphuric acid, from which is extracted about four hundred and fifty tons of copper.

Under the existing conditions of production, arising from large output and low prices of copper, the chief North American centers of growth for this industry for the immediate future seem likely to be those of Lake Superior, Arizona, Butte, with probably Wyoming, New Mexico, and

Newfoundland, and those sections in which, like Colorado, the production of copper is made an accessory to the extraction of the precious metals, or to the manufacture of sulphuric acid.

Of the foreign producers of copper on a large scale, Chili, with Bolivia, still ranks foremost, although the production of Chili has greatly diminished in recent years, while Spain and Portugal have risen to almost equal rank. The product of Spain is obtained from enormous mass deposits of copper-bearing pyrites near the Rio Tinto, in the extreme southern part of the peninsula, and extending into adjacent Portugal. These great deposits, called mass deposits (Stöcke) by Von Cotta, are pronounced fissure-veins in a recent account by a French engineer ("Engineering and Mining Journal," November 17, 1883), and yield an average of about three per cent of copper.

Next to Spain, as a producer of copper, is Germany, whose largest product by far is derived from the beds of Mansfeld, before mentioned, the residue coming from cupriferous pyrites, mainly from great mass deposits in the Harz Mountains. Australia also furnishes large amounts, chiefly from the divisions of South Australia and New South Wales.

England, once a large producer of copper-ores, has maintained her supremacy in the copper industry mainly by large importations of ores, cupriferous pyrites, and partially reduced copper, from Spain, South America, the Cape of Good Hope, Australia, and some other countries, her own once famous mines in Cornwall, Devon, Anglesea, etc., yielding little more than three thousand tons annually.

The following table of the product for 1883, recently compiled in London, partly from estimates, will give an idea of the most important sources of supply. In this the German product has been corrected from more recent statistics, as also that of the Cape of Good Hope. France, which in 1882 produced 3,627 tons, is for some reason omitted from this table:

	Tons.
United States	52,080
Chili and Bolivia	44,349
Spain and Portugal	43,655
Germany	18,205 *
Australia	12,000
Cape of Good Hope	5,175
Venezuela	4,018
Norway and Sweden	3,430
England	3,000
Russia	3,000
Japan	2,800
Italy	1,600
Newfoundland	1,053
Hungary	1,000
Algiers	600
Austria	500
Mexico	489
Peru	395
Canada	329
Argentine Republic	293
Total	197,971

A table of production of the various parts of the United States in 1882, prepared by the United States Geological Survey, will show the distribution of our own product. It is reduced to gross tons of 2,240 pounds:

	Tons.
Lake Superior region	25,439 †
Arizona	8,025
Montana, Butte	4,044
Colorado	667
Vermont	564
New Mexico	389
California	369
Utah	271
Southern States	180
Nevada	156

* Of which 17,501 was from Mansfeld.

† Calumet and Hecla mine, 14,309 tons.

	Tons.
Missouri	132
Maine	130
Wyoming	45
Pyrites, mostly Canadian	446
From desilverizers	56
Total	40,913

The increase in 1883 was due mostly to the first three regions in the list and to Wyoming, and in 1884 the estimated product of the United States was 64,831 gross tons.

Uses of Copper.—The uses of copper are numerous and important. Among these is its employment for sheathing the hulls of wooden ships; in wire, in the various appliances connected with the widely and rapidly developing applications of electricity; in the fashioning of many articles for domestic uses, and also for manufacturing purposes, such as boilers and evaporating-pans for sugar-works and stills for distilleries; as one of the elements in some forms of galvanic battery; and as a chief component in several alloys very largely used in the arts, such as brass for many parts of machinery and for numerous other uses, and bronze for cannon, bells, and statuary. It has also a considerable use as an essential or subsidiary ingredient in alloys for coins, and for the manufacture of various ornaments. Besides this, several of its salts are largely used in the arts, such as the sulphate, called blue vitriol or blue-stone, the acetate, known as verdigris, and the brilliant though dangerous green pigments formed by its combinations with arsenic.

Works to be consulted.

"Mineral Resources of the United States," 1882, article "Copper"; Von Cotta, "Erzlagerstätten," Part II, for Europe; Geological Reports of Michigan, Missouri, Tennessee, and North Carolina; Geological Report of Canada, 1863; "Third Annual Report of the United States Geological Survey"—Irving's Report; Wright's "Reports on Mineral Statistics of Michigan," 1877-'78, 1880, 1882; Phillips, "Treatise on Ore Deposits."

CHAPTER XIII.

LEAD AND ZINC.

Lead.—Lead was smelted in the United States as early at least as 1825, but during nearly half a century from that date, down to the close of 1872, with wide fluctuations in the amount of production, the annual output had never exceeded 27,000 gross tons. Since that date, the discovery of rich stores of argentiferous lead-ores in Colorado, Nevada, Utah, and some other Western regions, has swelled our production of lead, mainly as an accessory to the extraction of silver, to five-fold its former amount, and we now rank foremost among producers of this metal.

The sources from which lead is derived are the sulphide (galena) and the carbonate, with minor amounts from the sulphate, which is often associated with galena as a product of its transformation by atmospheric agencies, as is also the carbonate.

All these ores yield easily to the knife, their hardness not exceeding 3; they are of high specific gravity, and are easily fused by the blow-pipe, being reduced to a malleable bead of lead, with the exception of the sulphate, which requires the addition of soda for its reduction.

Galena, the fundamental and most common ore, occurs in granular or in cubical crystals, has an easy cubical cleavage, a lead-gray color, and a brilliant metallic luster, and contains 86 per cent of lead. The carbonate, *cerus-*

site, which contains 77 per cent of lead, is usually white or gray in color, occurs massive or in right rhombic prisms, its crystals have a brilliant luster, and it dissolves with effervescence in nitric acid. *Anglesite*, the lead sulphate, holding about 68 per cent of lead, occurs massive or granular, and is of white or gray color, and bright, resinous luster. It melts very easily, but yields a bead of lead only by the addition of soda carbonate ; and it does not effervesce with acids, by which characters it may be distinguished from the carbonate.

Nature of Deposits and Chief Geological Horizons.—Ores of lead occur (1) most largely in mass deposits in limestone formations, filling irregular cavities formed by the enlargement of joints, or extending between beds, or occurring at the plane of contact of limestone with some rock of dissimilar character. Of this kind are the deposits of Eureka district, Nevada, of southeast Missouri, of the Galena district of Illinois and Wisconsin, and of Wythe County, Virginia, occurring in limestone of Lower Silurian age ; and those of Leadville, and of southwest Missouri and adjacent Kansas, in limestone of the Carboniferous.

(2) They are found disseminated in beds, as, e. g., in beds of Lower Silurian limestone in East Tennessee (Safford) ; and near Commern, in the Rhenish Province of Prussia, where they impregnate abundantly thick beds of loose white sandstone of Triassic age, constituting the richest lead deposits of Germany.

(3) They occur in veins cutting strata of different kinds, but productive chiefly in limestone, between whose beds, or at their contact planes, they not unfrequently form also *flat deposits* connected with the fissures, as in northern England, in Derbyshire, and in the two northern counties of Wales.

(4) They are also met with in veins, usually more or less argentiferous, cutting ancient crystalline formations,

as at Georgetown and in the San Juan region, Colorado, at Freiberg in Saxony, and in Cornwall.

The chief lead-bearing geological horizons of this country and of England are the Lower Silurian and the Carboniferous, with some in crystalline formations; the same appears to be true also for Spain ; while in Germany, lead is derived mostly from Triassic rocks. Limestone appears to be a rock which is especially favorable to the deposition of ores of lead. These ores are usually associated with more or less of silver, sometimes in proportions too minute to be separated with profit, but not unfrequently the silver contents equal or surpass in value the lead with which they are blended.

Chief American Centers of Production.—Of the lead production of the United States more than 43 per cent is credited to Colorado, in which State its extraction is wholly accessory to that of silver; and the larger portion of the product is derived from the famous region about Leadville. The ore masses are found here chiefly at the contact of a limestone of Lower Carboniferous age with overlying masses of porphyry, and, according to Emmons, they owe their origin to a replacement of the substance of the magnesian limestones by silver-lead solutions which were derived from the overlying eruptive rocks. The ores are argentiferous lead sulphide and carbonate in a gangue of ferruginous silica and clay. Besides the Leadville region, the silver-lead veins around Georgetown and in the San Juan region, cutting Archæan rocks, afford considerable amounts of lead.

Next in production to Colorado is Utah, 60 per cent of whose product in 1882 was derived from the Horn Silver mine in Beaver County, most of the residue coming from the region around Salt Lake City. Here, also, as in all the Rocky Mountain region, the extraction of lead is an accessory to that of the precious metals, the value of which usually equals or surpasses that of the lead.

The mines of Eureka district, in Eureka County, yield nearly all the lead of Nevada, the reported product varying from about 8,000 to 28,000 gross tons per annum. The ores here, which are chiefly carbonate of lead in a highly ferruginous gangue, carrying 20 to 30 per cent of lead with a high value in gold and silver, occupy great chambers in a magnesian limestone of Lower Silurian age. The inclosing limestone is tilted up at a considerable angle, and bears evidence of great compression, in consequence of which it is much fractured and crushed, so that the ore masses, in their mode of introduction and after-concentration, seem to have a considerable resemblance to fissure-veins. They therefore belong to that variety of mass deposits which in a preceding chapter has been described as "*quasi* veins," i. e., those which, while mass deposits in mode of occurrence, are allied to true veins in having derived their ores from some deep-seated source rather than from local concentrations.

The State of Missouri, which is an important producer of lead, has two geological horizons of lead-bearing strata. A very considerable area in the southeast portion of the State, with some of the central counties, has deposits of lead-ores in Lower Silurian limestones, partly occurring in mass deposits, partly disseminated in certain of the beds, according to Prof. Brodhead. The deposits, however, which are at present most largely worked, are those occurring in *crevices* and *flats*, true mass deposits, in the Lower Carboniferous limestones of the southwest part of the State, about Joplin and Granby, and extending into adjacent Kansas. The ores here are associated with important amounts of zinc ores, but contain only insignificant proportions of silver.

In the Galena district of Illinois, Wisconsin, and Iowa, lead-ores, associated with zinc but poor in silver, are found in vertical crevices formed by the widening of the joints of the Lower Silurian limestone in which they occur, or sometimes in flats between the beds of the limestone. This region does not appear to be a large producer at present.

Besides these well-known and most largely productive districts, most of the States and Territories of the Rocky Mountain division are reported to have promising deposits of lead-ores, though little worked as yet, unless where they contain paying amounts of the precious metals. This is especially true of Montana and of the Wood River region in Idaho, from both of which a considerable production of argentiferous lead was reported in 1882. In Wythe County, Va., also, large bodies of sulphide and carbonate of lead, associated with ores of zinc, are known to exist and have been somewhat worked, in limestone of Lower Silurian age; and they need only good facilities for transportation to build up a prosperous center of metallic production.

The lead product of the United States for 1882, which was considerably increased in 1883, was reported to be 120,832 gross tons, distributed as follows:

	Tons.
Colorado	52,360
Utah	26,786
Missouri, Kansas, Illinois, etc	25,906 *
Nevada	7,670
Idaho	4,450
Montana	3,660
Total	120,832

The foremost foreign producers of lead are Spain, Germany, and England, with minor amounts from Austria, Greece, Italy, and France. Of these, Spain is much the largest producer.

The lead-producing regions of this kingdom are in the provinces of Murcia and Almeria on the southeast coast near Cartagena, and about Linares, in the province of Jaen, a little farther inland, on the head-waters of the Guadalquiver. The district about Linares is said to yield

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* Less than one tenth from Illinois and Wisconsin.

nearly two thirds of the lead, but it is poor in silver; while the coast deposits about Cartagena, which, according to Von Cotta, are *veins* of galena and blende, cutting Silurian limestones and slates, contain profitable amounts of the precious metals.

The large lead product of Germany is derived from Commern, in the Rhine Province; from Upper Silesia, where it is subordinate to a very large output of zinc; from the Harz Mountains, Nassau, and Freiberg. At Commern, according to Credner, the galena is found richly impregnating a friable white sandstone of Triassic age, which attains sometimes a thickness of eighty metres, or more than two hundred and sixty feet. In Upper Silesia, according to the same author, the associated ores of lead and zinc occur in mass deposits in a dolomitic limestone of the Muschelkalk (Triassic).

England has also a large but somewhat decreasing production, chiefly from Alston Moor, from Derbyshire, and from Flintshire and Denbighshire in North Wales, with some from other localities.

The following table of the lead production of the world, from the latest attainable statistics, will afford a good idea of the most important lead-producing countries. The amounts are given in gross tons for England and the United States; for the Continental states of Europe they are supposed to be metric tons of 2,204½ pounds:

	Tons.
United States, 1883	129,722
Spain, „	123,000
Germany, „	89,767
England, 1882	50,328
Austria, „	11,899 *
Greece, 1881	11,700 †
Italy, 1873	15,500 ‡
France, 1882	8,067
Total	439,983

* Partly litharge. † Amount exported. ‡ Sardinia.

Chief Uses of Lead.—The very great increase in the production of lead within the past ten years has doubtless been attended by a corresponding increase in its use. It is employed in the arts, in the form of metal, in a number of important alloys, and in several chemical combinations. As metal, it is used in sheets for covering roofs, for lining sulphuric-acid chambers in chemical works, and for condensing-pans and cisterns, and for lining tea-chests. It has a large use in pipes for the conveyance of water and gas. Coated with a thin film of tin, as tin-foil, it has a large and increasing use for linings and wrappers of many articles for culinary and other purposes. Its alloys with tin, bismuth, and antimony are used as soft solder and pewter, and for type and stereotype metal. Either alone, or slightly alloyed with arsenic, it is used for bullets and shot. White lead, an artificial carbonate, the chromate, or chrome-yellow, and red lead, are largely used as pigments; both litharge and red lead enter into the composition of the most brilliant kinds of glass; and the acetate, called also sugar of lead, is largely used in the arts and in medicine.

Books of reference.

"Geological Reports of Missouri"; "Geological Reports of Illinois," Vol. I; "Geological Report of Wisconsin," Vols. II and IV; "First Geological Report of Iowa," Vol. I, Part I; "Second Geological Report of the United States"—Emmons on Leadville; "Mineral Resources of the United States," 1882; Wallace, "Laws which Regulate the Deposition of Lead-Ores in Veins"; Phillips, "Treatise on Ore Deposits."

Zinc.—The ores from which zinc is extracted are the sulphide, called *blende*, *smithsonite*, the carbonate, and *calamine*, a silicate of zinc; besides which, in a New Jersey locality, three minerals, which are rare elsewhere, occur abundantly and constitute valuable ores of the metal, viz., the red oxide *zincite*, *willemite* another silicate, and *franklinite*.

The most widely diffused ore is that popularly known as *blende*, or *black-jack*, but whose scientific name is sphalerite, and which contains 67 per cent of zinc. It occurs commonly massive, but sometimes in crystals; has an easy cleavage, is of a variety of colors, the more common ones being yellow, brown, and black, with a resinous luster; and its hardness is that of dolomite, yielding with no great difficulty to the knife. It is infusible before the blow-pipe on charcoal; but, when strongly heated, it yields fumes of zinc oxide which coat the coal with a yellow film that becomes white when cold; and in nitric acid it dissolves, giving the disagreeable odor of sulphuretted hydrogen.

The carbonate, *smithsonite*, which results from the weathering of the sulphide, contains about 52 per cent of zinc, and occurs usually in dirty-white or brownish masses, crusts, or stalactites, which when crystalline have a pearly luster. It is harder than blende, being somewhat difficult to scratch; it dissolves in nitric acid with effervescence, and before the blow-pipe behaves like blende. This ore is the "dry bone" of Western miners.

Calamine, the common zinc silicate, called Galmei by the Germans, contains about 54 per cent of the metal, and occurs usually in whitish masses or crusts, but sometimes in rhombic prisms with a pearly luster. Its hardness is intermediate between that of blende and smithsonite; and it dissolves in hot sulphuric acid, the solution becoming jelly-like when cold.

Zincite, the native oxide of zinc, containing 80 per cent of the metal, is of a deep-red color, very easy cleavage, and brilliant luster, and is found usually in cleavable, foliated masses. It is infusible before the blow-pipe, but gives a zinc film like blende on coal, and, when heated with borax, yields a yellow glass. It dissolves in nitric acid, and its hardness is a little greater than that of blende.

Willemite, a second zinc silicate containing 58 per cent of zinc, occurs usually massive, but sometimes in rhombohedral crystals. It has various colors, as yellow, green, red, and yellowish brown, and, with soda on charcoal, it gives a zinc film before the blow-pipe. It dissolves in hydrochloric acid, yielding a jelly of silica, like calamine.

Franklinite, a complex compound of oxides of iron, manganese, and about 17 per cent of zinc, greatly resembles magnetite in form, color, magnetism, and hardness; but its streak is reddish brown, and before the blow-pipe on charcoal with soda it yields a film of zinc.

Mode of Occurrence.—In their mode of occurrence and geological horizons, the ores of zinc present no marked differences from those of lead, with which, in the majority of cases, they are intimately associated. Thus, in the lead regions of Missouri, and of the Galena district, forming mass deposits occupying flats or irregular fissures discontinuous in depth, in limestones of the Lower Silurian and Lower Carboniferous, the two sets of ores are found associated; and in the Galena district, as shown by Chamberlin, in tolerably equal amounts, though with a tendency to occupy somewhat different levels; while in deposits of similar character in Lower Silurian limestone near Bethlehem, Pa., the zinc-ores are remarkably free from lead. In the veins, often following faulting fissures, productive chiefly in Lower Carboniferous limestones, of North Wales, Derbyshire, and northern England, the two ores are also frequently found associated. In the silver-bearing veins cutting Archæan rocks about Georgetown, Col., zinc blende is a frequent large constituent of the ore, making a mixture from which it is difficult to extract the silver without great loss by volatilization; and the remarkable deposits of franklinite, zincite, and willemite, near Franklin, N. J., in Archæan limestones, form part of the series of highly metamorphosed and greatly disturbed beds of that region. These few examples will serve to show that, although the ores of zinc and lead are not always found together, their modes of occurrence are yet strikingly similar, even when they form distinct and separate deposits.

American Centers of Production of Zinc Ores.—The Lower Carboniferous lead region of southwestern Missouri and adjacent Kansas, mentioned in the previous section, is at present the foremost producer of rich zinc-ores in the United States, it being estimated to yield fully two thirds of the zinc which we produce. The ores are blende, with considerable amounts of calamine. The zinc deposits of eastern Missouri, covering, in connection with lead, copper, and nickel, a considerable area in portions of ten counties, and once yielding a considerable supply of ores, are said to be doing little at present.

The zinc-ores of the Galena district, blende and smithsonite, according to Chamberlin are proving fully equal in amount to those of lead, and show a marked tendency to accumulation in the limestone crevices at lower levels than the galena with which they mingle in the middle zones of deposit. Here, as in Missouri, in the earlier periods of mining, they were thrown on the waste-heaps as worthless "black-jack" and "dry bone," but have later been collected as the basis of a prosperous industry.

The ores of zinc with lead occurring in eastern Tennessee, in the Lower Silurian (Knox dolomite), are reported to be worked for zinc near Knoxville. Passing northeastward from this point, we meet with the zinc deposits of Wythe County, Va., and of Lehigh County, Pa., both in strata of the same geological age as the Knoxville deposits. According to C. R. Boyd (Institute of Mining Engineers, June, 1883), the ores of Wythe County are carbonate and sulphide of zinc, remarkably free from lead, occurring in great mass deposits in dolomite, and yield a zinc of exceptional purity. The deposits in Lehigh County, near Bethlehem, are not worked at present. The ores, blende with the results of its transformation, smithsonite and calamine, occur in crevices, sometimes parallel, sometimes perpendicular, to the bedding of greatly disturbed and fractured magnesian limestones, and seem to belong to the variety of mass deposits which have been described as "quasi-veins."

The unique deposits of franklinite, zincite, and willemite, in Essex County, N. J., in the vicinity of Franklin, are found in Archæan limestone, in beds conformable to the highly inclined and crystalline strata of the region. They are of great dimensions, and furnish important supplies of ore for the manufacture of a high grade of metal, and also of white zinc oxide and spiegeleisen. The regions above described are at present the only important producers of zinc-ores in North America.

Foreign Zinc-producing Regions.—Among foreign producers of zinc, Prussia ranks easily foremost, her mines in Upper Silesia, in the Rhenish Province, and Westphalia, yielding more than two fifths of the zinc of the entire world. The famous zinc district of Upper Silesia, which yields annually about seventy thousand metric tons of the metal, obtains its ores, chiefly calamine with minor amounts of blende, from mass deposits in a dolomitic limestone of Triassic age; while in the Rhenish district and Westphalia the ore is blende with but a small proportion of calamine, in irregular deposits in the Devonian or Lower Carboniferous limestone, which is chiefly dolomitic. The very large product of Belgium is derived in but small measure from its native ores. According to the latest returns available, less than 12 per cent of the zinc-ores smelted in that country came from Belgian mines, which resemble in character and horizon those of the Rhine Province; the residue being imported from Greece, Sardinia, Spain, Sweden, Germany, and France, most largely from the two regions first named. England is a considerable producer of zinc from her lead regions in Wales, northern England, Cornwall, and Devonshire.

Besides these countries, France, Spain, Austria and Poland, Greece and Italy, yield important amounts; France, as appears from Von Cotta's description, chiefly from veins in crystalline and eruptive rocks; and Spain partly from the lead district near Cartagena, mentioned in the preceding section, and partly from the province of Santander, on the northern coast, where large mass deposits and impregnations (?) occur in Cretaceous strata between dolomite and clay slate, which yield nearly two thirds of the zinc of Spain.

The zinc product of the world, according to the latest available data, approximates 290,000 gross or metric tons, distributed as follows:

		Tons.
Prussia,	1883	116,644
Belgium,	,,	78,220
United States,	,,	29,747 *
England,	,,	27,661 †
France,	1882	18,325
Spain,	1881	7,032
Austria,	1882	4,791
Poland,	1883	3,783
Total		286,203

Zinc is used in sheets as a covering for roofs, as a lining for various receptacles, and as a protection for floors and walls against the heat of stoves. It has a very important use in most forms of galvanic battery. It is very largely used for coating sheet-iron and wire for fencing to protect them from rust, a process which is called *galvanizing*. A single manufactory in this country is said to use more than three thousand tons annually for galvanizing fence-wire. Several of its alloys, like brass, Mosaic gold, German silver, hard solder, and Babbitt's metal, are largely used in the arts. Among its compounds, zinc-white is a highly valued paint, zinc sulphate is used in medicine and

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* And 9,000 gross tons zinc oxide.

† Estimated.

in the arts, and zinc chloride is employed in the process called Burnettizing, for the preservation of timber, as also for a disinfectant.

As works of reference, most of those mentioned under lead may be consulted with profit, to which should be added "Geology of New Jersey," published in 1868.

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CHAPTER XIV.

TIN AND MERCURY.

Tin.—Although a sulphide of tin is occasionally met with, the only ore that seems to be relied upon as a source of the metal is *cassiterite*, an oxide which contains 78⅗ per cent of tin. It is a brown or black mineral of brilliant luster when in crystals, and is of nearly the hardness of quartz. It is infusible by the blow-pipe on charcoal, but, if soda be added, it yields a white, malleable bead of tin. It is found sometimes crystallized in modified square prisms and octahedrons, but more commonly massive, in grains, lumps, and kidney-shaped masses, which, when they have a concentric and radiated structure, are called *wood tin*, or *toad's-eye* tin.

Mode of Occurrence and American Localities.—Tin-ore occurs (*a*) disseminated in bunches and grains in veins cutting ancient crystalline rocks like granite, gneiss, micaceous and hydro-micaceous schists, and is often associated with a peculiar kind of granitic rock called *greisen*, composed of quartz and mica without feldspar. It is accompanied by a great number of minerals, like pyrite, chalcopyrite, albite feldspar, tourmaline, and wolfram. (*b*) From its hardness and unalterability by atmospheric agencies, cassiterite is one of the ores which is found largely accumulated in *placer* deposits, in the neighborhood of tin-veins, from whose denudation it has been accumulated in favorable localities; and it is said that a large proportion of the tin product is still obtained from this source. Hence the name *stream-tin*, since these tin placers are often called *streams.*

Tin-ore has not been found hitherto in quantities of economic importance in North America, although a number of localities, apparently of great promise, have been discovered within the last few years which seem likely soon to give both the United States and Mexico a rank among producers of tin. Quite recently, Prof. W. P. Blake has reported the occurrence of tin-stone in the Black Hills of Dakota. It is there found both in placers and in irregular bunches and seams in veins of coarse granite, associated in some places with greisen, and in others in a greisen-like rock of albite and mica.

Tin is reported as occurring in very promising deposits in two of the southern counties of California, ores from San Bernardino County giving an analysis of about 60 per cent of the metal. In Clay County, Ala., deposits of tin-stone have been opened and worked to some extent since 1881. The ore here occurs disseminated in grains in vertical beds of gneiss, interstratified with micaceous and chloritic schists. Six beds of the tin-bearing gneiss are said to occur, some of them yielding an average of 1½ per cent of the oxide. Tin-ores are said also to have been discovered at King's Mountain in North Carolina, and at several other points in the United States, but whether in quantities sufficient to justify mining, is still to be shown.

Mexico is reported to have deposits of cassiterite of great extent and high promise in the States of Durango and Chihuahua, but they are as yet very little worked, and have not apparently added anything to the supply of the world. From South America, Bolivia yields annually about one thousand metric tons, and the States of Colombia are said also to produce small amounts.

Foreign Producers.—The chief supplies of tin are from three regions, viz., from Cornwall, England; from

Banca and Billiton, in the Straits of Malacca, hence called Banca tin and Straits tin; and from the eastern part of Australia, chiefly from New South Wales, with some from adjacent Queensland and Victoria. The tin deposits of Cornwall have been worked for many ages, the earliest workings extending back, it is supposed, some centuries before the Christian era. The ore is still obtained to some extent from placers, but chiefly from veins in ancient crystalline rocks. The Australian deposits, which in New South Wales are found over an area of 8,500 square miles, occur in narrow veins, irregularly disseminated in bunches, grains, and seams, and associated with quartz, feldspar, *greisen*, and chlorite, the country rock being, like that of Cornwall, granite and crystalline schists. The largest supplies are obtained, however, from extensive placer deposits derived from the disintegration and wash of the veins. The latest government report gives the product of New South Wales for 1883 as 9,125 gross tons of tin and its equivalent in ore, and the chief hindrance to making the output much greater evidently arises from the frequent defective supply of water to wash the ore-bearing gravels. Some of these placer deposits are of very considerable depth, occupying the sites of ancient water-courses, and are covered with masses of basalt, presenting a striking resemblance to the deep gold placers of California. The large supplies of Banca and Billiton are said to be derived chiefly from placers, which yield annually about eight thousand tons. Besides these, small amounts of tin are produced in Germany and Bohemia, from deposits similar to those of Cornwall, the product of the two regions amounting together to one hundred and thirty-six tons in 1882.

The entire product of the world for 1881 is said to have been 38,123 gross tons.

The statistics of production, so far as they could be obtained, are as follow:

		Tons.
England, 1882		9,158
New South Wales, 1883		9,125¼
Banca and Billiton	about	8,000
Bolivia, 1881		1,000
Germany, 1882 (from Saxony)		102
Austria „ (from Bohemia)		34

Tin, used somewhat in castings, is much more extensively employed as a coating for other metals, as, for example, iron in the widely used tin-plate, copper in many vessels for culinary purposes, and lead in the so-called tin-foil. Its alloys, chiefly with copper, but somewhat with lead and bismuth, are numerous and important. Among them are bronze, bell-metal, gun-metal, britannia, pewter, soft solder, Babbitt's metal, and the amalgam with mercury for coating mirrors, besides several others.

Several of its compounds also have important uses in the arts. Tin oxide is used for enamels, as a coating for razor-strops, and for giving a fine polish to some ornamental stones; the chlorides have valuable applications in dyeing and calico-printing; and the bisulphide, under the name of *bronze-powder*, is considerably used for ornamental purposes.

Mercury.—Although mercury or quicksilver is not unfrequently found native in small quantities, the only source of it which is of economic importance is *cinnabar*, the sulphide, which contains when pure about 87 per cent of the metal. This ore is of a bright red or brownish red color and scarlet streak; is of high gravity, about 9, and is easily scratched, its hardness being less than that of calcite. Before the blow-pipe it is easily dissipated in vapor, leaving no residue save the substances with which it may be mingled.

Mode of Occurrence and Localities.—Its mode of occurrence in all the great producing regions, three in number, is the same, viz., as an impregnation, either from solution or from vapor, in certain porous or fissured beds of tilted and sometimes metamorphosed stratified rocks. The three regions, however, while agreeing in the character of the deposits, contain them in rocks of widely different geological age; the Spanish deposits being inclosed in Silurian strata, the Austrian in rocks of the Lower Triassic, and the Californian in strata not older than the Cretaceous.

The production of mercury in the United States, which is now nearly one half the entire product of the world, is confined wholly to the vicinity of the Coast Range in California. In this region, at least eight counties, ranging from Fresno on the south to Trinity County on the north, are known to contain workable deposits of cinnabar. The richest deposits that have been opened hitherto are those of New Almaden, in Santa Clara County, while important supplies are also derived from Napa, Lake, Sonoma, and Fresno Counties, the mines in other sections seeming to depend for their working upon favorable prices for quicksilver. The inclosing strata in the entire region are usually serpentine, and sandstones and shales, the last-named rocks being sometimes much metamorphosed, in other cases wholly unchanged, and in some localities containing fossils of probable Tertiary age. The cinnabar occurs in irregular deposits, impregnating in some cases talcose, argillaceous, and jaspery slates; in others, sandstone; while in others, quartzites and opaline quartz form the gangue. The average contents of metal in the New Almaden mine are said to be about 3⅓ per cent, and the average cost of production in well-conducted mines is said by Wagoner to be 27½ cents per pound. Throughout the region, irregular deposits of chromic iron are said to be as constant as cinnabar. As an indication of the location of the mines whose product is at present the most important, the following table is given for the fiscal year ending June 30, 1883; it is stated in flasks of 76½ pounds:

	Flasks.
New Almaden (Santa Clara County)	28,753
Napa Consolidated (Napa County)	6,351
Great Western (Lake County)	4,514
Sulphur Bank ,,	4,053
Reddington ,,	2,555
Great Eastern (Sonoma County)	2,673
New Idria (Fresno County)	1,720
Other mines	671
Total	51,290

The famous Spanish quicksilver mines of Almaden, northeast of the city of Cordova, have been wrought for many centuries, having been known, it is said, to the ancient inhabitants of the peninsula before the time of the Roman occupation. The ore deposits here occur in vertical Silurian strata of sandstone, quartzite, and bituminous schist, with hard sandstone and limestone which do not contain ores. The cinnabar, in a compact or earthy condition, is found, in the largest mine, impregnating a gray sandstone to such a degree that the mass may yield as much as 25 per cent of mercury, and leave as a residue when distilled only loose sand. In other cases the impregnated beds are of quartzite, creviced with fissures running in all directions, into which the cinnabar has penetrated, forming sometimes also great masses, with occasional cavities containing metallic mercury. That these deposits are really impregnations, and not bedded veins, as they have sometimes been considered from the presence of a *selvage*, seems to be conclusively shown by the fact that the original planes of stratification of the beds are often perceptible in the midst of the deposits. The chief mine in 1851 was already 1,050 feet in depth, and the width which had been mined out at the 800-foot level was said to be 67 feet. No ores are treated here which carry less than two per cent of mercury, and the cost of production is not more than twenty cents per pound.

The quicksilver-mines of Idria are in Carniola, in the southern part of Austria, not far from the Adriatic Sea, and have been worked since the latter part of the fifteenth century. They occur in greatly inclined strata of Triassic age, impregnating black bituminous schists, or forming contact deposits between dolomites and slates, or filling transverse fissures in dolomite and limestone. The workings have now reached the depth of 950 feet, and the ore-bearing rock is found to grow richer as greater depth is gained, confirming the opinion that the cinnabar has been derived from a deep-lying source by infiltration or sublimation. The ores of the Idrian mines are reported to average about 1.6 per cent of mercury, and the annual production is much smaller than in the other two regions.

Besides these three chief sources of supply, comparatively insignificant amounts of mercury are obtained from Italy and other parts of Europe; but the total supply estimated to be received from these scattered localities is of little importance, as may be seen from the following statistics of the world's production in the year 1882. In this table the product is given in flasks, of which those of the United States, as has already been said, contain 76.5 pounds of mercury, while those of Spain and Austria hold 76.07 pounds. The amounts are also given in a second column in metric tons of 2,204.6 pounds:

PRODUCTION OF MERCURY IN 1882.

	Flasks.	Metric tons.
United States	52,372	1,830
Spain	45,921	1,630
Austria	11,853	409
Italy, etc., estimated	2,000	69
Total	112,506	3,938

California, therefore, furnished about 46½ per cent of the mercury of the world, and the New Almaden mine alone fully 25 per cent.

Uses of Mercury.—The largest uses to which mercury is applied are in the extraction of gold and silver, and in the preparation of the brilliant pigment vermilion. From the valuable property which this fluid metal possesses, of readily forming alloys, called amalgams, with the precious metals at ordinary temperatures, it has become indispensable in the processes by which these metals are cheaply extracted from ores of too low grade to be smelted with profit; and about 45 per cent of all mercury is used for amalgamation. A still larger proportion of the product is employed in the manufacture of vermilion, the artificial sulphide of mercury, used as a pigment.

Other important applications of mercury are found in the making of mirrors and philosophical and meteorological instruments, such as barometers and thermometers, in the manufacture of fulminates for percussion caps, and of various preparations for medical use, as well as in a process for preserving timber from decay, called kyanizing.

Works of reference.

"Geological Report of California," Whitney, Vol. I; J. Ross Browne, "Report on Mineral Resources of the United States," 1867, p. 170; R. W. Raymond, "Report on Mineral Resources of the United States," 1873, p. 18; Williams, "Report on Mineral Resources of the United States," 1883; "Engineering and Mining Journal," Nos. for December 24, 1881, and October 7 and December 23, 1882; Von Cotta, "Ore Deposits," Part II, pp. 248 and 455 of German edition; Phillips, "Treatise on Ore Deposits."

CHAPTER XV.

SILVER.

THIS, which is counted one of the two precious metals, and which in all ages of the world has been held in high estimation and largely used for coinage and for articles of luxury and ornamentation, is found native in small amounts in most great regions where it is mined, when it is easily distinguished by its pure white color, often with a dark superficial tarnish, by the ease with which it may be cut and its brilliant luster on a cut surface, and by its solution in nitric acid, from which it may readily be precipitated by a clean slip of copper, yielding a coating of silver, or by a solution of common salt, yielding a white chloride of silver which soon becomes discolored on exposure to light. More commonly it is found in various combinations with other substances, forming ores of silver. Those most largely met with are its combination with sulphur, called *argentite ;* with sulphur and antimony, forming *stephanite* and *pyrargyrite ;* with sulphur and arsenic, called *proustite ;* with chlorine, called *cerargyrite*, or horn-silver; and with sulphur, antimony, and lead, called *freieslebenite*, a mineral found as an ore in the mines of Guadalajara in Spain. It also frequently replaces a part of the copper in *tetrahedrite*, or gray copper, thus making it a valuable ore of silver, as has been mentioned in the chapter on copper. In many of our Western mines, also, it is largely obtained from its associations with ores of lead and with zinc blende.

All these ores of silver are so soft as to be easily cut with a knife, and have a specific gravity varying from 5½ to 7½; all melt with little difficulty before the blow-pipe, emitting fumes of sulphur, antimony, arsenic, or chlorine, and yielding a bead of silver, either alone or by addition of soda carbonate; and all, save *cerargyrite*, dissolve in nitric acid with precipitation of any sulphur, antimony, and arsenic that may be present, and the silver may be deposited from this solution on a clean slip of copper, or may be precipitated as chloride by salt water. These ores may be distinguished from each other—*argentite*, or *silver glance*, by its dark lead-color and lustrous streak, its malleability and sectility, and its yielding a silver bead by heat on charcoal without soda; *stephanite*, or *brittle silver*, by its black color and streak; *pyrargyrite*, by its usual dark-red though sometimes black color, and its *red* streak, from which it takes its common name of ruby silver; *proustite*, also called ruby, or light-red silver-ore, by its light-red color and the odor of garlic which it emits when heated; *freieslebenite*, by its steel-like color, and its yielding when heated on coal a globule of silver-lead, from which the lead may be burned off by heating with the blow-pipe on a little cup of bone-ash, leaving a bead of silver, an operation which is termed *cupellation;* and *cerargyrite*, called usually horn-silver, by its looking and cutting somewhat like horn, and by its emitting peculiar pungent fumes when heated on charcoal, and yielding a bead of silver without soda. When pure, argentite contains 87 per cent of silver, stephanite 69 per cent, pyrargyrite 59 per cent, proustite 65 per cent, freieslebenite about 24 per cent, and cerargyrite 75 per cent. Argentiferous galena requires no special description. Its silver contents may be ascertained by *cupelling* the silver-lead globules obtained by heating on charcoal.

When it is considered that an ore-mass containing one thousand dollars' worth of silver per ton would hold no more than a thousand ounces avoirdupois per gross ton of rock, or about three per cent of silver, and that such an ore-mass would be counted very rich, while one yielding one half of one per cent, if abundant, would be worked with enormous profit, it will be obvious to the student that the ores of silver, described above, can not usually be expected to occur in pure and easily determinable masses of considerable size, but rather as strings, thin seams, and stains disseminated in a comparatively large bulk of gangue rock, most commonly quartz or calcite, where its determination as a *silver-ore*, and as to the amount which it may yield per ton, will often be easier and of greater economic importance than any exact answer to the question of precisely *what* silver-ores are present in the mass. For this reason the description of the most common silver-ores has here been made chiefly as general as possible, embracing those characters which are common to them all, as in this form it will be more likely to be generally useful to the practical man. For more complete descriptions, and for desirable additions to the few specific characters here given, the student can refer to any good manual of mineralogy like Dana's.

Mode of Occurrence of Silver Deposits.—The forms of deposit in which workable silver-ores are found are various, including most, if not all, the chief classes of deposit described in a preceding chapter. They occur in veins, cutting granitoid rocks, and crystalline schists of the Archæan, as in the Reese River region of Nevada, in the Atlanta and associated lodes of Salmon River, Idaho, in the mines about Georgetown, Col., and in those of Kongsberg, Norway, and Freiberg, Saxony. Some of the greatest silver-veins of the world are incased in or associated with volcanic rocks of Tertiary age, called variously *andesite*, *propylite*, and sometimes *diorite*, e. g., the celebrated Comstock vein of Nevada, the Veta Grande of Zacatecas, and some others in Mexico, and those of Felsobanya and Schemnitz in Hungary.

It occurs in impregnations, as in the Triassic sandstones of Silver Reef, in southwestern Utah, and in the joints and bedding planes of Devonian limestones of the White Pine region, Nevada. Associated with ores of lead, it is found in mass deposits and *quasi*-veins, as at Leadville, in many mining districts of New Mexico, and at Eureka, Nev. It forms flat deposits, connected in origin with mineralized dikes of eruptive nature, of which character, according to W. P. Blake, are the silver deposits of Tombstone in southern Arizona. Finally, as an example of silver in beds, may be cited the copper schists of Mansfeld, which, besides affording much of the copper of Germany, yield also important amounts of silver. An interesting occurrence of silver may also be noted here, viz., that in the regions of native copper on Lake Superior, where the two native metals are not unfrequently found forming parts of the same lump, and thoroughly welded together without being alloyed.

Regions producing Silver.—Of the vast silver production of North America, derived almost entirely from the United States and Mexico, it may be said in a general way that, with comparatively trivial exceptions, it is obtained from the great mountainous region of the western part of the continent, comprised between the Front range of the Rocky Mountains on the east, and the Cascade and Sierra Nevada ranges on the west, with their southern extension into Mexico. The only exceptions worthy of note are the product of Dakota, which might without great violence be included in the first, and that of the Appalachian range mostly from North Carolina, and of Canada, the three together amounting to little more than three hundred thousand dollars in value in a product of more than seventy-five million dollars. A similar statement may also be made with regard to the silver production of South America, second only to that of the United States and Mexico, which is derived from the Andes and their western slope.

Within the great mountain-region indicated above, the

United States has much the largest silver production of any country in the world. Of the eleven States and Territories included within its limits, all save Wyoming, Oregon, and Washington, in 1882 yielded amounts of silver valued at eight hundred thousand dollars or more. The State ranking highest in silver production in that year was Colorado, whose sixteen and a half million dollars' worth of silver was derived most largely from three chief districts: that of which Leadville may be considered the center, including Lake County and small portions of Summit, Gunnison, Eagle, and Chaffee; Clear Creek County, of which Georgetown is the center; and the San Juan region, including portions of about six very rugged and mountainous counties, whose chief centers seem to be Silverton and Ouray. Besides these chief regions, Boulder, Custer, Gilpin, and Park Counties yield important amounts. The mines of these four counties are chiefly in veins, and the vein system in all of them yields gold as well as silver; that of Gilpin County, in particular, affording six times as much gold as silver. The two great mines of Custer County, the Bassick and the Bull Domingo, present features worthy of mention, since their gangue is a kind of breccia of the country rock, carrying the ores of gold and silver of the first, and of silver of the second named mine, as a cementing incrustation of the blocks of stone; while the ore-bearing fissure of the Bassick has the character of a chimney of unknown depth but limited extent, giving rise to the theory that it is the pipe of an ancient hot spring.

Next in value of silver output to Colorado is Arizona, in which the noted Tombstone region, in the southernmost county of the Territory, yields fully two thirds of its silver; while Pinal County, chiefly through the Silver King mine; Gila County, so rich in copper; Yavapai, Yuma, and Pinal Counties are also important producers. The large silver product of Utah may conveniently be said to be derived from three chief districts, of which what may be called the Salt Lake district, since its mines use Salt Lake City as a center or are in convenient proximity to it, includes Salt Lake and Tooele Counties and the Tintic district of Juab County, the ores of which are mostly treated near Salt Lake; as also Summit County, in which the very rich Ontario mine produces yearly about two million four hundred thousand dollars in silver. In the Frisco district of Beaver County, the Horn Silver mine is much the largest producer; and the Harrisburg or Silver Reef district, in the very southernmost part of the territory, yields about nine hundred thousand dollars a year from its unique reefs of sandstone permeated with ores of silver.

Nevada, so short a time ago the foremost State in silver production, mainly from the Comstock mines, the Eureka and Reese River districts, and from Esmeralda and White Pine Counties, has during the past few years sunk to the fourth place, the great diminution in the yield of the Comstock mines not having been compensated by a corresponding increase elsewhere. Besides the regions named above, Elko, Lincoln, and Nye Counties are important producers of silver.

Of the silver produced in Montana, about five sixths are reported to come from the near vicinity of Butte City, the remaining sixth being made up mostly by three counties, Beaver Head, Deer Lodge, and Jefferson, which surround it, in the western portion of the Territory.

The silver of Idaho, amounting to about two million dollars per year, is derived almost wholly from the three counties of Custer, Alturas, and Owyhee: in the first, from the region on the head-waters of the Salmon River; in Alturas, from the Atlanta vein and the Wood River region, these districts being in near proximity to each other; while the mining districts of Owyhee County are in the southwest corner of the Territory, in the vicinity of Silver City. Most of the silver of New Mexico so far has been derived from mines along the Mimbres, or Black range, and the Socorro Mountains, in portions of Grant, Doña Aña, and Socorro Counties, in the southwest part of the Territory; and that of California from the Sierra Nevada Mountains, chiefly on their eastern declivity. The annexed table of the silver product of the United States in 1882 will aid the student to gain a clearer idea of its relative distribution from the preceding brief description. The values are reckoned on the coinage estimate of silver, viz., $\$1.29\frac{29}{100}$ per ounce, troy. As the selling price of uncoined silver during that year was not more on the average than $1.11 per ounce, troy, the *real* value of the total is given also at that rate.

Colorado	$16,500,000
Arizona	7,500,000
Utah	6,800,000
Nevada	6,750,000
Montana	4,370,000
Idaho	2,000,000
New Mexico	1,800,000
California	845,000
Oregon	35,000
Dakota	175,000
North Carolina	25,000
Total	$46,800,000, or

$40,179,440 value at $1.11 per ounce troy.

Foreign Silver Regions.—In amount of silver produced, Mexico is second only to her neighboring republic, the United States. Some of the mines, like those of Guanajuato and Zacatecas, have been long known, having been opened even before the time of the Spanish conquest, and, though worked fitfully and without system, have yielded enormous quantities of the precious metal. In more recent times many of them have fallen into the hands of English and American capitalists, and with improved methods are yielding regularly and largely. These silver deposits, chiefly veins, or, as at Fresnillo, stockworks accompanied by impregnations, follow the line of the Cordilleras from Tasco, south of the city of Mexico, as far northward at least as Batopilas in the southwest corner of Chihuahua. The foremost silver-producing States are Guanajuato and Zacatecas, both of which have famous mines, as the Valencian in Guanajuato and those of Zacatecas, Sombrerete, Fresnillo, Pachuco, and Real del Monte in Zacatecas. Besides these States, silver in important amounts is obtained from Queretaro, and from parts of Jalisco, Durango, and Chihuahua. The Mexican yield of silver in 1883 is reported to have been more than twenty-nine million five hundred thousand dollars. The deposit of Silver Islet, on the north shore of Lake Superior, which has yielded three million dollars' worth of the metal, mostly from native silver in a vein cutting Archæan schists and dikes, is no longer a considerable producer; and its companion veins, if any exist, have not yet been discovered on the mainland.

The silver of South America is derived mainly from Bolivia and Chili, with much smaller amounts from Colombia and the Argentine Republic, Peru not being named in a recent list of silver-producing countries published by the Director of the United States Mint, although in 1880 its average annual product was given as 79,365 kilogrammes =$3,298,410, mostly from Cerro de Pasco. These silver deposits, as has already been said, are in the Andes Mountains, and on their Pacific slope. The mines of Potosi in Bolivia have been long celebrated, but are now greatly surpassed by those of Huanchaca and Colquechacq, west and north from it. The most important mines of Chili are in the regions near Copiapo and Iquique, a port belonging until recently to Peru.

The large silver product of Germany is derived mostly, it is said, from the vicinity of Freiberg, from the Harz, and from Mansfeld where it is an accessory to the production of copper. The silver mines of the Austrian Empire are in the Tyrol, and on the slopes of the Carpathians at Schemnitz, Kremnitz, and Felsobanya in Hungary, and in Transylvania. Spain produces a considerable amount of silver from the mines of Hiendelencia in the province of Guadalajara, northeast of Madrid, as also from the argentiferous lead deposits on the southeast coast in the vicinity of Cartagena and in the northeast part of the province of Almeria. The product of Norway from Kongsberg, of Russia from its Siberian provinces, and of Japan, are none of them so much as four hundred thousand dollars per annum. The silver of Japan, according to Prof. Lyman, of the University of Tokio, is derived from argentite, antimonial sulphides, and native silver, which occur mostly in veins, though sometimes in irregular mass deposits in volcanic rocks. The production of Japan was formerly much more considerable than at present.

A table of the production of the precious metals throughout the world for the year 1883, prepared by the Director of the United States Mint, has recently been published, and the table below is a copy of that portion of this which relates to silver:

	Weight in kilogrammes.	Mint value.
United States	1,111,457	$46,200,000
Mexico	711,347	29,568,576
Colombia	18,283	760,000
Bolivia	384,923	16,000,000
Chili	128,106	5,325,000
Argentine Republic	10,109	420,225
Canada	1,641	68,205
Russia	7,781	323,427
Austro-Hungary	48,708	2,024,645
Germany	230,694	9,589,300
Norway	5,645	234,645
Sweden	1,582	65,800
Turkey	2,164	89,916
Italy	432	17,949
Spain	74,500	3,096,220
Japan	8,488	353,825
Australia	1,924	80,000
Total	2,747,784	$114,217,733

The silver product of the world, therefore, was 2,747$\frac{784}{1000}$ metric tons. The mint value given in the table is \$1.29$\frac{29}{100}$ per ounce troy, which equals \$41.56 per kilogramme. As the average market rate of silver during 1883 was \$1.10 per ounce troy, a deduction of 14.92 per cent should be applied to the above, making the *real value* \$97,176,447.

The enormous increase in the production of silver since 1860, resulting from the discovery of our Western deposits and from the more thorough working of the Mexican mines, and which has, since the year 1872, increased the annual output fully 80 per cent, has produced the effect that might naturally be anticipated for silver, as for any other metal, of diminishing its value in comparison with gold and with all salable commodities. It already interferes seriously with its availability for its largest use, viz., in coinage, rendering necessary a resort to artificial and arbitrary expedients for the continuance of its use at a rate of estimation which was fixed in times when the metal was much less abundant; and it threatens, unless a great falling off in production soon occurs, or unless new and wider avenues for its employment are soon opened, to force a fundamental revision in the ideas of coinage, with the abandonment of any serious attempt to fix its relative estimate with the less abundant metal, gold, which is so generally made the standard of value by commercial nations.

Uses of Silver.—The uses of silver have always been determined by the beauty of the metal, by its rarity in comparison with other metals save gold, and by its unalterability by the ordinary agencies of change which so soon affect most other metals. From these circumstances it has for ages been dedicated to coinage, and to the fabrication of articles of luxury and ornament, articles which in a measure bespeak the wealth and importance of their possessors. For these uses, it is always alloyed with a certain proportion of copper, usually from 7½ to 25 per cent, to increase its hardness and durability. Besides these chief uses, silver is also largely employed in plating other metals and alloys, either by applying to them a thin sheet of silver, or more commonly by depositing the metal from solution upon the objects to be plated by the galvanic current. Some of the compounds of silver also have a very considerable use in photography, in surgery, and in the plating of mirrors.

A table of the uses of silver in the arts, for other purposes than coinage, will be given in connection with gold in the chapter on gold.

Works of reference.

Clarence King, "Geological, etc., Survey of the Fortieth Parallel," Vol. III; "Sutro Tunnel Report"—Von Richthofen's description of the Comstock lode; "Geology of the Comstock Lode and Washoe District," G. F. Becker, United States Geological Survey; "Second Annual Report of the Director of the United States Geological Survey"; Raymond's "Reports on the Mineral Resources of the United States," from 1869 to 1876; "Reports of the Directors of the United States Mint"; Von Cotta, "Erzlagerstätten," Part II, for Europe; Phillips, "Treatise on Ore Deposits."

CHAPTER XVI.

GOLD.

This, the more highly valued of the two precious metals, is found very widely distributed over the earth, but usually in traces so minute as to be economically valueless. It is only when it has been accumulated in rock deposits, in proportions varying from a considerable fraction of an ounce to a number of ounces per ton of rock, or when, by the disaggregation of the containing rocks, it has undergone a process of concentration in the channels of ancient or modern stream-courses, that it becomes an object of other than theoretical interest. Gold is rarely found forming ores, properly so called, although its common associations with iron and copper pyrites, and with some other minerals, are often conveniently called ores. It usually occurs in the metallic state, almost always alloyed with more or less of silver and occasionally with other metals. When it is in visible particles it is readily distinguished by its yellow color, its luster, its malleability, and by the ease with which it may be cut with a knife. The only minerals which are liable to be mistaken for it are iron and copper pyrites, which somewhat resemble it in color, but in no other respect, since both are harder, pyrites very much so; both crumble instead of flatten under the hammer, and, though copper pyrites can be cut with no great difficulty, it yields a greenish powder instead of a flexible metallic shaving like gold. When heated strongly with the blow-pipe, also, gold melts to a brilliant globule on coal, while both of the minerals in question yield fumes of sulphur. Besides its usual occurrence as native metal, true ores of gold are sometimes met with which are compounds of tellurium with gold, either alone, as in *calaverite*, or with silver, as in *sylvanite* and *petzite*, or with lead, as in *nagyagite*. These minerals, which are usually mineralogical rarities rather than sources of the precious metals, have been found in sufficient abundance to become valuable ores at a few localities in our Western mining regions, notably in the region around Gold Hill in Boulder County, Col., where mines, like the Red Cloud, Cold Spring, Keystone, and Smuggler, have yielded considerable amounts; and in the Bassick mine, Custer County, Col., where the tellurides occur in some of the incrustations which cement the breccia-like gangue.

Mode of Occurrence of Gold.—Gold is found in both *original* and *secondary* deposits, the original deposits being the veins and beds, or impregnations in which it was originally accumulated by various agencies; and the secondary those which have resulted from the disintegration of the first, and the concentration of their heavy auriferous contents by running water, in the channels and accumulations of streams, usually in their lowest parts and in their hollows and eddies, and which are called alluvial deposits, or *placers*.

Gold-bearing *veins* occur cutting granite and other crystalline or eruptive rocks, as in the veins of Gilpin County, Col., and some of those of California; or following mostly the planes of bedding of highly inclined schists, of which kind are the veins of Nova Scotia and many of those of the Appalachian range and of the Sierra Nevada. In these veins quartz is the usual gangue, in which the gold is disseminated in minute grains, films, and strings, usually associated with pyrites, arsenical pyrites, and chalcopyrite, and not unfrequently with some galena and blende. In the upper and exposed portions of such veins, these sulphides have been weathered out, leaving the quartz cellular and rusty and the gold free, so that it is easily obtained by crushing the rock and amalgamating with mercury; but where the sulphides are not decomposed, the gold is so incased in them that but little of it can be obtained by such simple methods, and the ores are called *rebellious.* In some veins, as in the Comstock, the Atlanta lode in Idaho, the *quasi*-veins of the Eureka district, Nev., and in the veins of Kremnitz in Hungary, gold is found associated with silver, forming a considerable part of the value of the ore body. This is notably the case in those unfrequent instances where the ores are tellurides, as in the regions named in a preceding paragraph, and in the veins of Nagyag, in Transylvania. Besides its occurrence in veins, gold is also found disseminated in beds of talcose, chloritic, and micaceous schists, or in lenticular segregations parallel with their bedding planes. Deposits of this kind have yielded important amounts of gold, for example, at King's Mountain and Gold Hill in North Carolina. (Kerr.) Workable amounts of gold are also sometimes found as impregnated zones of the country rock of veins. The greenstone walls of the vein of Kremnitz are impregnated for some distance with valuable amounts of gold; and the schists which incase some of the quartz-veins of California contain gold, possibly derived from the veins.

But, important as are these original and primary deposits of gold, and destined as they doubtless are to become in the future even more important, yet the secondary deposits, or placers, have in all time been the source of much the largest part of the gold, and continue to be a very large source, although the output from veins is increasing. Of the enormous gold product of our Pacific coast fully nine tenths, it is said, has been derived from placers; most of the gold of South America is from the same kind of deposits, as is also two fifths of the product of Victoria, in Australia, and a much larger proportion of that from the more northern provinces of the east coast of that island; the large product of New Zealand is mostly from placers; and nearly all of that from Russia, from the Siberian side of the Ural Mountains, is likewise from a similar source. In Australia, as well as in California, many of the older and deeper placer deposits have been covered by thick sheets of volcanic rocks, forming what are called "deep placers," from which the auriferous gravel is extracted by subterranean workings, similar to those by which coal-beds are worked. Gold, as it occurs in placers, offers some signal advantages to those engaged in obtaining it. By the agencies of disintegration and transportation, through which the placers have originated, the metal has been freed from entangling alliances with the sulphides with which it is so commonly associated, and is presented in the state most favorable for being seized upon by the mercury which is used for its collection. Again, the gold, which in many of its original deposits was in amounts too minute and insignificant to justify even the least expensive efforts at extraction, has been mostly separated from its containing rocks and concentrated into deposits where it may be profitably worked. A third and very important advantage is the facility with which enormous amounts of these superficial accumulations can be handled, and their valuable contents extracted, by modern hydraulic methods, where the requisite conditions can be obtained, of sufficient slope of surface and an abundant supply of water under great head. Streams of water of from four to nine inches diameter, and under a head due to a descent of from one hundred to more than four hundred feet, directed against a bank of auriferous gravel, unless its parts are very firmly cemented, tear down and disaggregate the materials with great rapidity, and send them rushing tumultuously through long *sluices*, where the gold is caught by mercury distributed in the stone or iron *riffles* with which the bottoms are paved. In this way gravels which contain but ten to twenty cents' worth of gold per cubic yard can be profitably worked. In placer deposits only are occasionally found those exceptionally large masses of gold, called *nuggets*, which weigh from a few ounces or pounds to one hundred and fifty pounds and even more. Nuggets of considerable size have been met with in our Southern Atlantic States and in California, but the greatest masses of this kind have been found in Australia, one of which weighed over one hundred and forty-six pounds, another nearly one hundred and eighty-three pounds, and two others weighed respectively one hundred and thirty-five and ninety-two pounds. The largest reported from the United States was from North Carolina, and weighed twenty-eight pounds avoirdupois, or a trifle more than thirty-four pounds troy. Since bunches of this size have, it is claimed, not yet been met with in undecomposed veins, and since the gold of nuggets is usually considerably purer than that in veins, it seems possible that the nuggets may be due to some process of gradual solution and subsequent precipitation of the gold *within the placers*, as has been maintained by Prof. T. Eggleston ; an opinion which has, however, been strongly opposed by Dr. Newberry, in an article on the "Genesis and Distribution of Gold," in which an explanation of the origin of nuggets is given, wholly consonant with the generally accepted theory of the formation of placers.

Regions of Gold Production.—About 93 per cent of the gold of the world is derived from four great regions of production, viz., the mountainous western section of the United States from the meridian of the Black Hills westward; the Australian region, consisting of the eastern part of Australia, with Tasmania and New Zealand ; the Russian gold region of Siberia ; and the two northern divisions of South America, Colombia and Venezuela. If to these be added the product of Africa, the Austrian Empire, Mexico, Canada, and Brazil, little more than $1,000,000 worth per year remains to be credited to the rest of the world.

The following table of the gold product of the United States for 1882, from the report of the Director of the Mint, will afford a fair idea of our gold-yielding regions, and of their relative importance:

GOLD PRODUCTION OF THE UNITED STATES IN 1882.

1. California	$16,800,000
2. Colorado	3,360,000
3. Dakota	3,300,000
4. Montana	2,550,000
5. Nevada	2,000,000
6. Idaho	1,500,000
7. Arizona	1,065,000
8. Oregon	830,000
9. Georgia	250,000
10. Utah	190,000
11. North Carolina	190,000
12. New Mexico	150,000
13. Alaska	150,000
14. Washington	120,000
15. South Carolina	25,000
16. Virginia	15,000
17. Wyoming	5,000
Total	$32,500,000

From this table it may be seen that the Southern Appalachian States, which, up to the time of the discovery of gold in California in 1848, were our sole producers of gold, but which after that time came to be little regarded, are again showing much activity and are yielding a creditable output, aggregating in 1882 $480,000 in value, mostly from Georgia and North Carolina. The large product of California, more than one half that of the entire United States, is credited to no less than thirty-two counties, but is obtained chiefly from the Sierras and their Pacific slope, Nevada and Mono Counties taking the lead, while Amador, Plumas, and Sierra Counties have each a product of more than $1,000,000. Nearly one half the product of

Colorado is from Gilpin County, with large amounts also from Lake, Boulder, Clear Creek, Custer, and Rio Grande Counties, eight others of the mountain counties aiding to swell the total. The gold of Dakota is derived from the Black Hills region in the southwest part of the Territory, most largely from mines working the enormous belt of low-grade rock in Lawrence County, but with considerable amounts also from placers, and from the peculiar *fossil placer* of Lower Silurian age which was mentioned in the chapter on ore deposits, and which is here called *cement.* The gold of Nevada is derived mostly from the Comstock and Eureka district mines, the first group of mines yielding gold and silver in tolerably equal proportions, and the second producing gold, silver, and lead. The localization of the gold product of the remaining gold-producing sections can not be profitably attempted, since the production in those new regions is subject to great fluctuations, from the discovery of new mines and the partial abandonment of older locations by a population intent on rapid gain. Placers of small extent become exhausted and the course of production drifts elsewhere; or the weathered portions of the veins in a newly-discovered territory are hastily worked out by simple appliances, and then the locality is measurably abandoned, awaiting the advent of capital for its more complete and systematic development; or rumors of a rich *strike* elsewhere may cause an almost total exodus of that adventurous class who are the pioneers of all new mining regions. From these various causes the production of gold in several promising sections has not yet sufficiently settled about great centers to make it safe to note them definitely.

An estimate of the gold production of the world for the year 1883 has recently been published by the Director of the Mint, which, with a slight rearrangement, to bring together regions which are contiguous, is given below, with weight and values:

	Kilogrammes.	Value.	
United States.....	45,140	$30,000,000	$31,909,639 for North America.
Mexico...........	1,438	955,639	
Canada...........	1,435	954,000	
Colombia.........	5,802	3,856,000	$8,140,499 for South America.
Venezuela...	5,022	3,338,058	
Argentine Republic	118	78,546	
Brazil............	952	632,520	
Bolivia...........	109	72,375	
Chili.....	245	163,000	
Africa............	3,000	1,993,800	$28,613,880 for Southern Hemisphere and Japan.
Australia, etc......	39,873	26,500,000	
Japan.............	181	120,080	
Russia............	35,913	23,867,935	$25,363,883 for Europe.
Austro-Hungary...	1,638	1,088,615	
Germany.........	457	303,722	
Italy.............	109	72,375	
Sweden...........	37	24,590	
Turkey...........	10	6,646	
Total........	141,479	$94,027,901	

From this table it appears that the total annual product of gold is about 141½ metric tons, worth, at $664.62 per kilogramme, $94,027,901; and that North America produces over a third of this, chiefly from the Rocky Mountain division of the United States, with nearly a million dollars' worth each from the Pacific slope of Mexico and from Canada. The gold of Canada is derived from the quartz-veins on the Atlantic side of Nova Scotia, and from veins and placers in Quebec, not far from the United States boundary; promising veins of gold-bearing pyrites also occur in the township of Marmora, Hastings County, Ontario, and gold is obtained from placers in British Columbia. Next to the gold product of North America ranks that of the Australian provinces, from the quartz-veins and placers of the four eastern divisions of Australia, of which Victoria is the largest producer, from Tasmania and from New Zealand, whose placers yield several million dollars' worth annually. The Orange Free State of South Africa exhibited at Philadelphia in

1876 a rich collection of gold nuggets gathered from its "golden sands"; and more recently rich placers have been opened in the Transvaal, from which, and from the longer known placers of the east and west coast, the gold of Africa is derived. The best known sources of the large gold product of Russia are the placers and occasional veins of the Urals, chiefly on the eastern slope; and the gold of the Austrian Empire is derived almost wholly from Hungary, from veins on the lower declivities of the Carpathians and their outliers, ranging from Schemnitz and Kremnitz in the north, around to the region called the Banat in the south. The gold of Colombia and Venezuela is derived mostly from placers, the attempts at working veins having, it is said, not been satisfactory; and the production of Brazil, according to recent reports, is obtained mostly from five mines, one of which, the St. John del Rey, yields fully seven eighths of the entire amount.

Uses of Gold.—The uses of gold, like those of silver, have from the earliest periods been based on its intrinsic beauty, rarity, and unchangeability by chemical agencies, and have been for coinage and articles of luxury. In recent years it has had also a considerable use for pens and dental supplies, as well as for coating less valuable metals. For coinage and most other purposes it is alloyed with copper or silver to increase its hardness, the standard of fineness for coin in this country being nine tenths gold, and in England eleven twelfths. For other purposes the amount of alloy varies widely. The report of the Director of the Mint for the year ending June 30, 1884, gives a table of the uses of gold and silver for purposes other than coinage during the fiscal year, based on a wide correspondence with manufacturers; from which it appears that in the United States alone nearly fourteen and a half million dollars' worth of gold, and more than five and a half million dollars' worth of silver, was so used. This table is here given:

	Gold.	Silver.
Watch-cases	$3,598,308	$1,845,599
Watch-chains	827,000	23,544
Jewelry and watches	7,905,163	1,098,220
Plate	528,868	2,066,294
Leaf	1,084,824	46,883
Pens	145,924	6,730
Spectacles	215,428	23,782
Instruments	5,199	13,990
Dental supplies	37,912	6,738
Supplies for watchmakers, etc.	79,227	8,331
Chemicals	31,611	416,419
Total	$14,459,464	$5,556,530

TABLE OF VALUE OF FINE GOLD.

Per ounce, troy	$20.6718.
Per pound, troy	248.06.
Per ounce, avoirdupois	18.84⅛.
Per pound, avoirdupois	301.46.
Per kilogramme	664.628.

Modes of Extraction of Gold.—Although the extraction of gold from the gold-bearing rock is an operation which belongs rather to the metallurgist than to the geologist, yet the great general interest which attaches to this, the most highly valued of the precious metals, will render not inappropriate a brief sketch of the two most common modes of extraction. The mode of getting gold in the large way from placers by hydraulic methods has already been outlined, and needs no repetition. Where gold occurs in rock material not intimately associated with sulphides, as in some quartz-veins and talcoid schists, or in the decomposed outcroppings of deposits, it is reduced to a fine powder or *pulp* with water in stamp-mills, and the gold *caught* on copper plates coated with mercury, and arranged partly inside the stamp-boxes, partly on an inclined platform over which the pulp flows after leaving the battery. At proper intervals of time the amalgam of gold is scraped from the plates, and, after being cleaned, the volatile mercury is distilled off from the gold by heating in iron retorts. When, however, the gold is involved in sulphides like pyrites and arsenical pyrite, and so becomes what is called *rebellious* instead of *free-milling*, it is first crushed to powder in a stamp-mill or otherwise, in which operation any free gold may be caught as in free-milling if thought desirable; second, concentrated, i. e., freed from gangue by washing in gigs, buddles, or vanners; third, roasted, to free the sulphides from sulphur and reduce them to oxides, thus liberating the gold from its entanglements; and, fourth, the gold is amalgamated, or, *better*, reduced to the form of the soluble chloride of gold, by treating the moistened pulp with chlorine gas in a suitable vessel, an operation which can be greatly hastened by keeping the pulp in motion, and introducing the chlorine under considerable pressure (Mears's process); when, fifth, the chloride is leached from the pulp with water, and the gold precipitated as a powder by adding a solution of iron sulphate. When the gold is associated with valuable amounts of copper, a much more complicated process of smelting and separation of the metals is resorted to, for which any one interested in such matters will need to refer to treatises on metallurgy.

Works of reference.

Besides the works mentioned under silver, most of which are applicable also to gold, the student will do well to consult Whitney's "Treatise on the Auriferous Gravels of California"; Dawson's "Acadian Geology"; the Geological Reports of Canada for 1863 and 1870–'71; "Geological Reports of North Carolina," Emmons, 1856, and Kerr, 1875; and also numerous papers in "Transactions of American Institute of Mining Engineers." Many other works might easily be named, but some of the above are most likely to be accessible to the diligent student.

CHAPTER XVII.

PLATINUM AND OTHER METALS.

Platinum.—This metal, whose singular infusibility and indifference to nearly all chemical reagents, combined with its remarkable ductility and its malleability, make it an object of great importance in the arts, is always found in the metallic state, and usually alloyed with iron and certain rare metals, of which the most common are iridium and osmium. It has never yet been found in any other than placer deposits, in which it usually occurs in flattened grains, readily distinguished by their infusibility and malleability, and their great specific gravity. Nuggets of considerable size are also occasionally met with, the largest of which, according to Phillips, weighed twenty-two pounds troy. Although the original deposits from whose destruction the platinum has been supplied to placers have never yet been discovered, still, according to Von Cotta, its occasional occurrence with chromic iron in bits of serpentine, point to veins of that mineral as the source of the metal. Although platina was first discovered in Colombia in 1735, and has since been found at several points in Brazil, it does not appear that South America adds any important amount to the small product of the world. Nearly the whole supply is derived from placers on the east slope of the Urals in Russia, the product of 1881 amounting to 6,798 pounds avoirdupois. Besides this, Borneo is said to furnish about five hundred pounds a year, and in 1882 the United States yielded about thirteen and three fourths pounds avoirdupois. The entire product of the world does not probably exceed four net tons per year. Discoveries of small quantities of platinum have repeatedly been announced from various localities of the United States, especially in the gold placers of California, and recently in the Wood River region of Idaho; but nothing of economic importance has yet come to light, although the demand for the metal to be used in the arts constantly exceeds the meager supply. It is quite possible that a careful examination of the placer deposits of California might reveal a much greater abundance of this metal than has been suspected hitherto. Indeed, operations directed to securing gold from auriferous sands, by washing and amalgamation, would be very little likely to detect platinum, which does not amalgamate. If the idea of Von Cotta and also of Prof. W. P. Blake is well founded, that the mother rock of platinum is serpentine, the most promising localities in which to search in California will be those alluvial deposits which have been formed from the *débris* of the serpentinous rocks of the Coast Range.

The **uses** of platinum are based on its infusibility, its resistance to most chemical agents, and its ductility. It is used in chemical manufactories for the large stills in which the ultimate concentration of sulphuric acid is effected; in numerous forms of chemical apparatus, as crucibles and evaporating dishes, and as foil, wire, and the tips of forceps to support objects in blow-pipe operations; as one of the elements in the most powerful form of galvanic battery; in fine wire for incandescent lighting by electricity, and for forming the cutting edge of a number of surgical instruments—the wire, when in use, being heated to whiteness by a galvanic current, and searing as it cuts so as to prevent the effusion of blood. Platinum is used somewhat for medals and ornaments, for dentists' supplies, and in porcelain-painting, to give a steel-like color to objects, and it was once used in Russia for coinage. Its uses would doubtless be much extended did the supply of the metal permit.

Nickel and Cobalt.—Nickel, which, from its wider applications and its valuable properties, has within a comparatively recent period come to be a metal of increasing economic interest, is derived from ore compounds with sulphur, arsenic, and silica, in which it is very commonly associated with cobalt, forming a considerable group of minerals, of which the most common are *millerite*, a yellow sulphide in needle-like crystals or wool-like bunches; *siegenite*, a steel-gray sulphide of nickel and cobalt; *niccolite*, or copper nickel, a copper-colored arsenide; and silicates of an apple-green color, which have recently been found in so considerable quantities and of such exceptional purity on the island of New Caledonia as seriously to affect the price of the metal. The ore from which the largest supplies have always been obtained is magnetic iron pyrites, containing nickel, with which some of the other nickel compounds are often associated. Although ores of nickel occur at numerous localities in the United States and Canada, mostly in ancient crystalline rock, and often associated with serpentine, as on the north shore of Lakes Superior and Huron, at Oxford in Quebec, and Chatham, Conn., its extraction has been attended with success only at the Lancaster Gap mines in Pennsylvania, which have yielded in some years fully one fifth the nickel of the world from arsenical pyrites and millerite averaging not more than two per cent of the metal; and at Mine La Motte, in southeastern Missouri, where its extraction was subsidiary to the production of lead. Besides these localities, deposits said to be of great promise occur in Churchill County, Nev., and in Douglas County, Ore., in which last region the ores are green silicates, resembling in grade and purity those of New Caledonia. Near Schneeberg, in Saxony, are mines which have been wrought for more than two centuries, yielding nickel, cobalt, bismuth, and arsenic, and which still furnish most of the important production of Germany. The silicate ores of New Caledonia, which yield a nearly pure metal more easily than any others known, are mostly shipped to France, of which the island is a penal colony. Although the ores of nickel occur usually in veins, in Mine La Motte, mentioned above, they are found in a thin seam of slate associated with the lead-bearing Lower Silurian limestones of that region, or coating the seams of galena.

The entire amount of nickel produced in 1877 was estimated at 550 metric tons. No complete statistics of nickel production are attainable ; but that of the United States in 1882 was 125 metric tons, and that of Germany for the same year was 121 metric tons, France yielding 30 metric tons. The chief uses of nickel are for the alloy called German silver, for minor coinage, and for electroplating, for each of which uses the demand is very considerable. German silver, which is an alloy of copper and zinc with one third or less of nickel, is largely used for fabricating many domestic implements and wares, which are then electro-plated with silver. An alloy of 25 per cent of nickel with 75 per cent of copper is used in the United States coinage for three and five cent pieces, and one containing 12 per cent of nickel for pieces of one cent. Nickel alloys are used also in Germany and Belgium for minor coinage. For the electro-plating of many instruments, articles of domestic use, portions of stoves and machinery, nickel is peculiarly adapted by reason of its hardness, its difficulty of fusion, its resistance to rust, and its susceptibility to a high polish ; and its use for this purpose is very large and rapidly increasing. By a recently devised process, it is possible to make nickel-coated iron-plate, which, for the manufacture of cooking utensils that are to be subjected to heat, has several striking advantages over tin-plate.

Of **cobalt**, whose ores occur very commonly associated with those of nickel, it is sufficient to say that it is produced in small amounts in the United States at the two nickel-producing localities; that it has at present no use as a metal; and that it is employed to give a blue color to glass, porcelain, and earthenware, in the form of the black oxide, and of smalt, which is a silicated oxide made by fusing cobalt oxide with glass, or with quartz sand and potash. The production of cobalt oxide at the works of Lancaster Gap mine in 1882 was 11,653 pounds.

Besides the metals already described, there are several others which are of considerable economic interest, whether from the valuable properties that they impart to certain alloys, like antimony and bismuth; or from their adaptation to certain special uses, like magnesium and aluminium, which last metal awaits only cheaper processes of extraction to be largely used; or from the large use of some of their compounds in the arts, like manganese, chromium, and arsenic.

Antimony has already been mentioned as a common mineralizing agent in ores of silver; but the usual source of the metal is the sulphide *stibnite*, a soft, lead-gray, and easily fusible mineral, occurring in rhombic prisms of easy cleavage, or in radiating needles, as also massive; and readily distinguished by these characters as well as by being dissipated into a white vapor with an odor of sulphur before the blow-pipe on charcoal. It occurs most commonly in veins in crystalline rocks, and the largest deposits yet found in the United States are those near Battle Mountain in the Humboldt region of Nevada, and in Kern County, Cal. These deposits are said to be of great importance, and have been worked to some extent, though difficulties arising from distance from markets and from easy transportation have not hitherto made their exploitation profitable. Besides these, promising deposits are reported to exist in Sevier County, Ark. Valuable foreign sources of supply occur in Germany, Hungary, France, Spain, Borneo, and in New South Wales. From its ready fusibility, the ore is easily separated from its gangue by heat. It is used in alloys, as type and stereotype metal, and in britannia; and some of its compounds are used in medicine, in orange and yellow pigments, and in pyrotechny for Bengal fire.

Bismuth occurs native, associated often with ores of cobalt and silver in veins inclosed in crystalline rocks, as also in the form of a sulphide called *bismuthinite*, and as an impure oxide called bismuth ochre. The chief supplies are derived from Schneeberg, Saxony, the German product of 1881 being reported as fifty-six metric tons; from Bolivia, the value of whose product for the same year is reported at $61,189; and from South Australia. Deposits of some importance are said also to exist in Utah, in Boulder and La Plata Counties, Col., and near Golden, in the same State. Its uses are somewhat limited, being chiefly in compounding fusible alloys, soft solder, and britannia; in the preparation of pearl-powder, and of mordants for calico-printing, and in coloring glass and porcelain.

Magnesium is very widely diffused as a constituent of several common rock-forming minerals; but the sources whence the metal is obtained are the mineral carnallite, a double chloride of magnesium and potassium occurring associated with the salt deposits of Stassfurt in Germany, and magnesite, a magnesian carbonate which is associated with serpentine, and which to obtain the metal is converted to a double chloride of magnesium and sodium by dissolving in hydrochloric acid and adding a solution of common salt. The metal is obtained from either of these double chlorides by fusing with metallic sodium and fluorspar. It is rolled into thin ribbons or made into wire, and in this form burned in a proper lamp, giving a light of exceeding brilliancy for use in signaling. It is also used in filings for pyrotechny.

Aluminium is a recent addition to the list of metals, but its remarkable characters promise to render it highly useful in the arts as soon as processes shall be devised by which it may be liberated from its combinations within reasonable limits of cost. It is a white metal of singular lightness, its specific gravity being only about one third that of iron; it is malleable and very tenacious, and unalterable by atmospheric agencies; and its alloy with copper, called aluminium bronze, is of a golden yellow color, very hard and malleable, and of a tensile strength which is said to be greater than that of Bessemer steel. The compounds of this metal with silica are some of the most widely distributed constituents of rocks, and kaolin, the essential constituent of clays, is a hydrous silicate of alumina; but it has not yet been found practicable to obtain the metal from its silicated compounds. The sources from which it is obtained are bauxite, a hydrous oxide of aluminium and iron containing but a trifling amount of silica, found abundantly in France, and cryolite, a double fluoride of aluminium and sodium, which is brought from Greenland. Bauxite is first converted into a chloride of sodium and aluminium, and then the latter compound is fused with metallic sodium and a flux, thus liberating the metal; while cryolite can be fused direct with sodium. A process is said recently to have been devised in Philadelphia by which the reduction of the metal will be very greatly cheapened by dispensing with the use of sodium, and reducing the cost of preparing the aluminium compound; and, if it proves successful, this interesting metal will soon be largely used in the fabrication of engineering and other instruments, and for various other purposes where strength combined with lightness is desirable. The French production of aluminium in 1882 was 2,349 kilogrammes.*

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* While this work is going through the press, it is announced that

Chromium.—This metal is of little economic importance as a metal, having merely a limited application in the manufacture of what is called chrome-steel; but its brilliant colored compounds are largely used in the arts as pigments and in calico-printing; and they have also a limited use in galvanic batteries. The source whence it is derived is the mineral chromite, or chromic iron, a hard, black, feebly magnetic compound of chromium and iron oxides, which contains when pure about 68 per cent of chromic sesquioxide, but rarely has more than 60 per cent. This mineral occurs usually in beds or veins of serpentine in crystalline rocks, as along the eastern base of the Appalachians, and in the Coast Range of California, at favorable localities in which it is found in great abundance. It was formerly derived wholly from Wood's Mine, Lancaster County, Pa., and the adjacent parts of Maryland not far from Baltimore. Lancaster County is said to have yielded ninety-five thousand tons of the ore, averaging 48 per cent of the oxide. The supplies from these localities are said to be now mostly superseded by the richer ores of California, which are drawn most largely from mines in San Luis Obispo County, and from Placer County near Auburn, rich deposits being also known to exist in several other counties. By appropriate treatment, this ore is converted into bichromate of potash, the basis of all chrome pigments.

Manganese.—The direct uses of this metal are in alloys with iron, called spiegeleisen, or ferro-manganese, according to the percentage of manganese which they contain, and which are largely used in the manufacture of steel; and in an alloy with copper called manganese bronze, which from its hardness is well fitted for bearings in heavy machinery. The iron alloys are obtained by smelting manganiferous ores of iron, procured mostly

Messrs. E. H. and A. H. Cowles, of Cleveland, O., have perfected a process by which the manufacture of aluminium bronze will be much cheapened.

from Germany and southern Spain, the American ores being too commonly contaminated with phosphorus to be used for this purpose. Several native compounds occur in considerable abundance, chiefly oxides, which are black, a rose-red carbonate, and a lighter red silicate; but that which is most used in the arts is *pyrolusite*, a tolerably soft black dioxide of manganese (MnO_2), whose impure mixture with iron oxide, called *wad*, is also employed for some of its uses. These oxides are found in the Atlantic States from Maryland to Georgia, the purest being obtained from Bartow County, Ga., and the Virginia deposits being next in value, Augusta County yielding fully one half of the product of Virginia, from a single mine. Promising deposits occur also on the Pacific coast, the one best known being on an island in the Bay of San Francisco. Deposits of this mineral should contain at least 60 per cent of the oxide to justify their exploitation. Pyrolusite is largely employed in the arts for the liberation of chlorine and the manufacture of bleaching-powder, in the preparation of varnish and "boiled oil," and in glass-making to discharge the green tints which iron imparts. It is also used in glazing and painting pottery, and in glass-staining, and to some extent with potassium chlorate in making oxygen. The permanganate of potash has likewise a large use as a disinfectant.

Arsenic.—This metal, so widely known by reason of the deadly nature of all its compounds, is but little used in the metallic state. It enters into a few alloys, the chief of which is with lead to give it greater hardness in the manufacture of shot. Its compounds are, however, considerably used for various purposes. The yellow sulphide, called orpiment, or king's yellow, the red sulphide realgar, and the arsenite of copper, called Scheele's green, are used as pigments, realgar being also used in pyrotechny and for signaling purposes as an ingredient in "white Indian fire"; the oxide is used in glass-making and for the preservation of natural history specimens; and some of the compounds enter into pharmaceutical preparations. Arsenic occurs in the crystalline rocks, forming important ores with silver, nickel, and cobalt; and its compound with sulphur and iron called *mispickel*, or arsenical iron pyrites, a hard, silver-white, and brittle mineral which yields an odor like garlic when heated, is found abundantly in many places associated with ores of silver, copper, and other metals, as at Freiberg, and with ores of tin, as in Cornwall. From this last mineral chiefly, and from the ores of nickel and cobalt, it is obtained for commercial purposes in the form of the well-known white arsenic, by roasting the ores and condensing the arsenic in chambers and flues. It is made mostly in Germany, and in Cornwall and Devon. The ores from which it is obtained exist also in sufficient abundance at various points in regions of crystalline rocks in the United States.

Iridium, which is found sparingly associated with platinum, has a limited but important use, based on its extreme hardness, in wire draw-plates and knife-edges for balances, in the nibs of gold and stylographic pens, and in the contact-points of telegraph instruments. It is said, also, to be used somewhat in porcelain-painting to give a black color. Its chief source is *iridosmine*, an alloy of iridium with osmium and one or more other rare metals of the same class, which is found not only in the Urals, but also in the gold placers of California and Oregon, where its weight, which equals that of gold, renders it easy to be recovered, so that this region now yields important supplies. The value of pure iridium is nearly that of gold, the iridosmine selling at from twenty-five to sixty dollars per pound troy, according to the percentage of the metal which it contains.

Besides these metals, a few others, whose ores are of somewhat unfrequent occurrence, but which are utilized in the arts for special purposes, deserve brief mention here.

Molybdenum, in the form of molybdenite, a mineral which resembles graphite, but is easily distinguished from it by yielding sulphur by heat, has been found at several localities in the Eastern States, and is said to occur in some abundance in Gunnison County, Col., and in Utah. It is used to give a blue color to pottery. *Uranium*, also used in porcelain-painting for yellow and black colors, has been found as the mineral pitchblende at the Wood mine near Central City, Col., and also near Denver. Its chief supplies are, however, derived from Bohemia. *Tungsten* is obtained from wolfram, a compound of tungsten, iron, and manganese, found as a somewhat frequent associate of the tin-ores of Cornwall and of Saxony. It has been found in small quantities in Maine, Connecticut, North Carolina, Missouri, and Nevada, and is quite likely to be met with in the tin region of the Black Hills. Tungsten has in recent years come into use for making a special grade of steel, which is of extreme hardness without being very brittle, and which is therefore adapted to the manufacture of tools for turning and planing iron. Some of its soluble compounds are used to a small extent in calico-printing, and other compounds are of excellent promise as valuable pigments.

In this necessarily condensed treatment of the metals, their mineralogical and geological mode of occurrence, the regions where they are most largely obtained, and their leading uses, no attempt has been made to do more than to give the student such information as may serve as a guide to his active efforts or to his more extended researches in special directions. It is hoped that it may also prove helpful to the practical man, not only by indicating the most promising sources of materials for his technical pursuits, but also by pointing him to regions whence he may look for the most effective competition in his business. To these ends the leading foreign deposits have been noted, as well as those which are found in our own country; and the extent and importance of both sources of supply and competition have been suggested by the tables of production, which have been compiled from the latest statistics and estimates that have come to hand in Government reports and technical journals. A number of rare metals have been entirely omitted, while the metals of the alkalies and alkaline earths, which, with a single exception, have no technical use as metals, will be treated in their appropriate place under their most important native compounds.

CHAPTER XVIII.

SUBSTANCES ADAPTED TO CHEMICAL MANUFACTURES OR USE.

THE earth's crust affords a considerable number of substances whose applications are chiefly of a chemical character, or which form the basis of extensive chemical manufactures before they attain the varied forms in which they may most completely supply human wants. Some few of the substances which may most conveniently be discussed under this head, besides their chemical applications, have also direct uses in their native condition, like salt and sulphur; some, like the fluxes, are used either to remove unwelcome ingredients in the form of a liquid slag in metallurgical operations, or to give a fine exterior finish to pottery; while some, like pyrites and niter, may furnish the initiative to series of chemical operations resulting in a number of useful products. It may also with propriety be stated here, once for all, that some mineral substances are of varied utility, and might with equal fitness be considered under any one of two or more different classes of applications. Such substances will receive whatever general discussion may seem desirable in the first class in which they may occur; and any subsequent mention of them will imply an acquaintance with their previous treatment.

Pyrites.—Pyrites, so called from the Greek word for *fire*, because its hardness is such as to enable it to strike fire with steel, is a sulphide of iron, FeS_2, containing, when pure, 53.3 per cent of sulphur. It is found frequently in cubic crystals of a light yellow color and brilliant metallic luster, gives a black streak on porcelain, is very hard though brittle, and emits when heated the odor of sulphur, yielding finally a black magnetic globule. Although a compound of iron, it was not described among the ores of iron, because it is not directly used as a source of that metal, though the residues from its treatment for chemical purposes are in recent years coming into use for making certain grades of iron and steel. Pyrites, in small quantities, is very widely disseminated in rocks of all ages, and, by the readiness with which it oxidizes when exposed to the weather, it constitutes one of the most active agents in their decay; but, to be of any economic importance, it needs to occur in deposits of great dimensions, and reasonably free from admixture with other minerals save chalcopyrite, with which it is usually associated.

The workable deposits of pyrites occur in great beds, swelling out often to dimensions so vast as to be considered mass deposits, and intercalated mostly in crystalline schists, which in this country at least seem to be of Archæan age. Deposits of this kind are found along the eastern slope of the Appalachians from eastern Alabama to New Hampshire and Maine. Along this range mines have been opened at Capelton in the Eastern Townships of Quebec, at Milan in New Hampshire, Stafford in Vermont, Rowe in Massachusetts, and at Tolersville in Louisa County, Va. From the Canadian locality about forty thousand tons are sent yearly to the United States. The deposits at Milan, which have been proved for more than nine hundred feet in length, are from eight to more than forty feet thick; and those of Tolersville, according to a recent account, are capable of yielding easily one thousand tons daily. The pyrites from all these localities contains valuable amounts of copper, and all are claimed to be remarkably free from arsenic, a deleterious ingredient which is rarely entirely absent from pyrites deposits, and whose presence in any considerable proportions seriously impairs the value of the mineral for some of its foremost uses. Besides these deposits, which are favorably situated with regard to transportation, others of the greatest promise are known to exist within the Appalachian region which are still untouched from lack of a market. The State geologist of Alabama reports extensive deposits of cupriferous pyrites in Clay County; and, according to C. R. Boyd, in the western part of Carroll County, Va., occurs a body of pyrites in talcose schists, which has an average length of ten miles with an average width of thirty-three feet, and which contains an average of two and a half per cent of copper and 45 per cent of sulphur.

Large as are our American deposits of pyrites, they sink into comparative insignificance in comparison with some of the enormous masses which are found in Sweden, Spain, and Germany. The greatest of these are the deposits of Rio Tinto in southwestern Spain, extending west into Portugal. Here are worked two vast beds or veins in highly disturbed and metamorphosed schists, associated with quartz porphyry, which are thought to be of Permian age. The southern vein, which is from three hundred to four hundred feet in width, is opened for sixteen hundred feet of its length, and is known to be at least twenty-five hundred feet in length, while the northern vein is much more enormous, being fully six thousand feet long, and swelling in places to a width of from thirteen hundred to sixteen hundred feet. The pyrites from these immense deposits contains highly important amounts of copper, a recent analysis of the export material showing 3.69 per cent of copper, with 47.76 per cent of sulphur, but contaminated by nearly one per cent of *arsenic*. The Spanish output of pyrites in 1881 was nearly a million and a half tons, and it has greatly increased since that date;

and the large amount of copper directly and incidentally derived from these deposits is a highly important factor in determining the present low prices of that metal.

At Goslar, in the Harz Mountains, in a region of Devonian limestone and slate, occurs an enormous mass deposit of cupriferous pyrites, which, as described by Von Cotta, has a known length of eighteen hundred feet, with a width of three hundred and fifty feet, and sends a considerable branch into the hanging wall, showing that it can not be considered a *bed*, although in other respects its position is conformable with the stratification of the inclosing rocks. The pyrites of this deposit contains *arsenic* and *lead*, with small amounts of several other metals. The German output of pyrites in 1883 was 148,700 metric tons.

At Fahlun, in Sweden, a great irregular mass deposit of copper-bearing pyrites, with numerous outliers, is met with in schists and gneiss of Archæan age. Portions of this deposit contain also *lead* and zinc. Also at Agordo, in the Tyrolese Alps, occurs a considerable mass deposit of pyrites, varying in width from twelve to two hundred and fifty feet, in a country rock of talcose and clay slate, with the bedding of which it conforms.

Uses of Pyrites.—The foremost use of pyrites is as a cheap source of sulphur in the manufacture of sulphuric acid, and it has within the past twenty-five years rapidly replaced native sulphur in this very important industry. For this purpose, the pyrites is burned in properly constructed combustion-chambers, the sulphur being eliminated in the form of sulphurous acid ; and it is said that some of the arrangements for this purpose are so effective as to leave less than one per cent of sulphur in the iron of the residue. After burning, the copper in the pyrites is extracted by a leaching process, and the residual somewhat sulphurous iron oxide can then be used as a source of certain grades of iron, and for some other purposes.

The characters which best adapt pyrites for the use of acid manufacturers are the following: (1) A high percentage of sulphur. As has already been stated, absolutely pure pyrites contains about 53 per cent of sulphur; but most of the mineral in commercial quantities holds varying amounts of quartz and other substances, which diminish the percentage of sulphur by so much. The Spanish pyrites contains, according to the analysis alluded to above, about 2¼ per cent of silica and lime, and a little less than 48 per cent of sulphur. It has recently been stated that pyrites capable of yielding 45 per cent of sulphur is worth about seven dollars per ton for acid-making. (2) Freedom from arsenic, antimony, and lead, the first of which substances unfits the acid containing it for many of its uses, while the second and third promote the fusion of the pyrites while burning, and so hinder the complete elimination of its sulphur. Arsenic, while especially common in pyrites, is also especially objectionable, and, in the foregoing account of the great deposits, its presence or absence where *known* has been mentioned for this reason. (3) Readiness to part with the contained sulphur, in which different lots of pyrites show considerable differences; partly in consequence of the physical condition of the mineral, that which is more granular and porous presenting a larger surface for the combustion of the sulphur; partly from differences of fusibility, arising from the presence or absence of minerals that are liable to act as fluxes at the temperature which is employed; partly, also, from the presence of sulphur compounds which retain their sulphur with considerable tenacity, like copper, the presence of which, while adding to the selling value of the pyrites in one direction, diminishes, to a certain extent, its value to the acid-maker as a source of sulphur, since it prevents its complete elimination. (4) It is desirable that pyrites for acid-making should not have a tendency to crumble readily in mining and handling, since this produces a great amount of "fines," rendering necessary special arrangements for its burning. (5) Pyrites sometimes contains water mechanically inclosed, rendering it liable to decrepitate violently while burning—a troublesome character, which detracts from its value. (6) As was suggested above, the presence of a considerable proportion of copper adds much to the value of pyrites, since it becomes a source of copper as well as of sulphur. The copper is paid for, on analysis, in addition to the *obtainable* sulphur; or else, in some cases, the residues, after burning, are returned to the seller. It can hardly be expected that all these desirable characters will concur in every lot of pyrites that is worth extracting. That will be the best which has the greatest number of excellences, and those most essential. With a careful examination of fair average samples of pyrites as regards these requisites, the probable value of any great body of pyrites well located for cheap transportation to markets can be closely approximated. The extent and importance of the chemical industries to which pyrites furnishes the initiative can not be better stated than by quoting from the "Geology of Canada," 1863, p. 746: "In order to give some idea of the great importance of iron pyrites and of its products in a manufacturing point of view, it must be said that sulphuric acid, which is now for the most part manufactured from pyrites, is the agent used for decomposing common salt for the manufacture of soda in its various forms of soda-ash, carbonate of soda, and caustic soda. From this decomposition is also obtained hydrochloric acid; this is used in the manufacture of chlorine, and of bleaching-powder or chloride of lime, which are indispensable in the bleaching of cotton, linen, and of the materials for paper. Besides this, the manufactures of soap and glass, and many other chemical products, are dependent upon the soda thus obtained. The sulphuric acid is also used for the manufacture of nitric acid, of superphosphate of lime, of alum, and many other products, all of which are generally manufactured in the vicinity of sulphuric acid and alkali works."

Besides its use in the manufacture of sulphuric acid, pyrites is largely utilized in making iron sulphate or copperas, to be employed in dyeing fabrics black and as a disinfectant. Incidental to this process, sulphur is sometimes extracted for the market from the pyrites, by heating the mineral in retorts to drive off about one third of the sulphur, which is condensed. The pyrites, partially roasted in this way or merely in heaps, or quite as frequently without preliminary roasting, is piled on tight floors under a shed-cover, moistened with water, and left to the action of the atmosphere, by the agency of which it is oxidized to iron sulphate; this is then leached out with water, and the solution, properly concentrated by boiling, is left to deposit the copperas in crystals.

Sulphur.—As will already have been observed in the preceding chapters, the compounds of sulphur with the metals constitute a highly important and widely diffused class of metallic ores called sulphides or sulphurets, and from some of these a part of the sulphur can be obtained by a process of distillation, as in the case of iron pyrites. As a commercial article, however, it is more largely obtained from deposits in gypsum, bituminous marl, and limestone, or from volcanic regions, where it is found uncombined, filling fissures and cavities, and mingled usually with varying amounts of earthy substances, from which it is easily separated by melting in large kettles; the sulphur melts at a temperature a little above that of boiling water, the impurities settle to the bottom or are skimmed out, and the sulphur, in a tolerably pure condition, is then ladled out into molds. A simpler mode of separation is by setting fire to the sulphurous earth in heaps or kilns, when the heat generated by the combustion of a portion of the sulphur melts the rest, which flows off and is caught; or it can be obtained much purer by distilling off the sulphur from the earthy mass in iron or earthenware retorts. The source of the sulphur in these deposits is doubtless from the decomposition of earthy or metallic sulphides and sulphates, in some cases possibly by heat, but in most by the agency of water and oxygen or organic matter, giving rise to sulphur springs which deposit their sulphur by the action of atmospheric oxygen. The largest supplies of sulphur, for both Europe and the United States, are derived from Sicily, where the deposits are found in foliated gypsum, bituminous marls, and limestones of Tertiary age. These deposits contain from 20 to 40 per cent of sulphur, of which they yield somewhat more than half to the usual processes of extraction. The United States imported in 1880 more than 100,000 tons of sulphur, nearly all from Sicily, and it is said that Europe derives nearly nine tenths of its sulphur from the same region. Important deposits also occur in Italy and Poland. Iceland contains rich but undeveloped deposits of sulphur, and it is found in most volcanic regions. In the United States, sulphur has hitherto been obtained from native deposits only in California and Nevada, though deposits of great promise are known to exist at Cove Creek in western Utah, in New Mexico, in the Yellowstone region, and near Evanston, in Wyoming. The deposits of Cove Creek, and those of Rabbit Hole in northwestern Nevada, are said to be in regions of comparatively recent volcanic activity, occupying in the first case the sites of not yet extinct *solfataras*, and either filling fissures in the rocks or impregnating and cementing tufas.

Sulphur has several important and extensive uses, foremost among which is its employment in the manufacture of sulphuric acid. Until within a very few years, all the acid made in this country was manufactured from sulphur, chiefly Sicilian; and although it is now being slowly superseded for this purpose by pyrites, on account of the greater cheapness of the latter substance, still, for many uses where perfect freedom from arsenic is required, acid made from sulphur is sure to be preferred. Some of our Western sulphur deposits, however, are said not to be wholly free from arsenic, a fact which indicates that such deposits were derived from sublimation in which case arsenic from its volatility would accompany sulphur, rather than from elimination from the water of sulphur springs. Other large uses of sulphur are in the making of gunpowder, in the manufacture of matches, for which its ready inflammability adapts it, in the vulcanizing of rubber and gutta-percha, in bleaching straw and woolen goods, and as a cementing material between iron and stone. It is used in the manufacture of vermilion, an artificial sulphide of mercury; of mosaic gold or bronze powder, a bisulphide of tin, and of several other useful compounds; has some important pharmaceutical applications, and the sulphurous-acid gas generated by its combustion is a very valuable disinfectant.

Salt.—This useful and indeed indispensable substance occurs in nature in two states—either (1) in solution, as in the waters of the ocean, and of salt lakes and ponds, or in those of salt springs and wells, the waters of which derive their salt from subterraneous masses, or from percolating through clays and marls in which salt is disseminated; or (2) in irregular beds and masses of rock-salt, which are sometimes of enormous dimensions, and from which the salt is obtained by regular mining operations. From whichever source derived, salt, which, as is generally known, is a chloride of sodium, is never absolutely pure, but holds variable amounts of sulphates of lime, magnesia, and soda, chlorides of calcium and magnesium and sometimes of potassium, with usually a little iron carbonate, and often, in the case of rock-salt, some finely disseminated clay. The salt of this country has hitherto been derived almost entirely from the evaporation of natural brines, like those of Syracuse, N. Y., and of the region around Saginaw Bay, Mich., by solar or artificial heat; or from the solar evaporation of sea-water in salt-pits at favorable points, as in California; while a very considerable portion of the European supply has for ages been drawn from beds of rock-salt, the famous mines of Wieliczka, near Cracow, in Polish Austria, having, it is said, been worked since the eleventh century.

A pure saturated brine contains at ordinary temperatures about 25.7 per cent of salt, and the strength of brines is usually tested by an instrument called a salometer, an areometer graduated from 0°, the point to which it sinks in pure water, to 100° for the point at which it stands in a pure saturated brine. A degree of the salometer answers, therefore, to about one fourth per cent of salt in a *pure* solution; while a degree of the ordinary hydrometer of Beaumé corresponds very nearly to 1 per cent of salt, if the brine is pure. Sea-water contains 2.6 per cent of salt, and nearly 1 per cent more of other saline ingredients; the brines of Syracuse hold from 14 to about 18 per cent of salt; those of Michigan, from 15 to nearly 20 per cent; those of Goderich, Ontario, from 20 to 24 per cent; and the weaker brines of West Virginia and Ohio, about 10 per cent.

Beds or deposits of rock-salt occur associated with beds of gypsum, marls, and clays, and sometimes, as at Goderich, of porous dolomites. They have in all probability originated from the desiccation of salt lakes, or of sea-borders cut off from the main body of water by barriers which were occasionally overleaped by the outside waters, thus adding new supplies to be concentrated by evaporation. In the process of concentration such waters would naturally first deposit their least soluble ingredient, gypsum or anhydrite, which is always present in sea-water, and afterward, with increasing concentration, their salt; while earthy substances, washed from the adjacent lands, furnished the solid impurities and the materials for the interstratified beds of marls and clays. Every fresh influx of sea-water will give occasion for a new deposition of gypsum to be interlaminated with the salt; while the more soluble sulphates and chlorides of magnesium and potash become greater in amount in closed basins, like that of the Dead Sea at present, and may ultimately, under favorable circumstances, on the final drying up of the area, form deposits of carnallite, sylvite, kainite, etc., like those of Stassfurt in Germany, and in the eastern Carpathians, which will be mentioned in subsequent sections. Some of the deposits of salt thus formed are of vast dimensions. Probably the most amazing yet known is that at Sperenberg, south of the city of Berlin, which, according to Roth and Credner, has been explored by boring nearly four thousand feet without penetrating to its base. That of Wieliczka is said to be in places not less than fourteen hundred metres thick.

Salt deposits are by no means limited to any special members of the geological series. On the contrary, they are found in rocks of various geological ages, from the Upper Silurian to the present time. Yet, aside from the deposits which are now accumulating in closed basins and lagoons, there are recognized on both continents geological horizons which are especially rich in salt. Thus, in North America, a group of Upper Silurian rocks has been appropriately called the Salina, because of its salt-bearing character; along it are ranged the great salt-works of Syracuse, the two recently discovered salt-beds of Wyoming County, thirty and seventy-five feet thick, from which a nearly saturated brine is drawn, and the deposits around Goderich, on Lake Huron, consisting of six salt-beds of an aggregate thickness of one hundred and twenty-six feet, some of which are of unusual purity, besides salt-wells at many other points, the brine of which is not strong enough to be worked with profit under the existing conditions of production. A second profitable salt horizon is that of the Lower Carboniferous up to the base of the coal-measures, which yields the brines of the Saginaw region in Michigan, and those of Ohio and West Virginia near the Ohio River. The great mass of extraordinarily pure salt at Petit Anse in Vermilion Bay, southern Louisiana, which has been explored to the depth of one hundred and sixty-five feet without reaching the bottom, is said by Hilgard to be of probable Cretaceous age. In Europe the Triassic is often called the Saliferous system, on account of the rich deposits of rock-salt that occur in it at several different horizons; in England, at Northwich in Cheshire, and in Germany at Vic and Dieuze in Lorraine, on the upper Neckar in Würtemberg, and at a number of other points. Yet the rocks of the Permian period might with nearly equal propriety be counted a saliferous system, since in them occur the enormous deposits of Stassfurt and Sperenberg, which have already been mentioned, as well as those of the government of Perm in eastern Russia, and those of the Kirghiz Steppe near the Caspian Sea; while in the Tertiary are found the celebrated deposits of Wieliczka, and those occurring along both sides of the Carpathians to Wallachia and Transylvania; as also, quite probably, those of Cardona, in the Pyrenees of northeast Spain, which are thought by some to belong to the Cretaceous period.

Besides the chief salt-producing centers in the United States that have been mentioned above, the great Western region, extending from the Rocky Mountains to the Pacific coast, is abundantly supplied with salt at many points, from salt lakes, pools, and marshes, and surface incrustations overlaying beds of salt of unknown depth, and which occupy apparently the sites of ancient salt lakes long since dried up. Nevada, in particular, abounds in salt deposits of these various kinds. Near Columbus, Esmeralda County, a salt-field of nearly fifty square miles is found; on the

Rio Virgen, in Lincoln County, are said to occur enormous masses of rock-salt with an outcrop of not less than twenty-five miles; and several other counties have supplies almost equally abundant, while every State and Territory in this region may draw sufficient supplies of this needful substance from sources existing within its own limits.

In 1882 the United States produced 801,547 gross tons of salt, of which 71 per cent was furnished by the Saginaw region and Syracuse; about 18 per cent more by West Virginia and Ohio, in nearly equal proportions, while most of the residue was derived from California, Pennsylvania, Utah, Virginia, Louisiana, and Nevada. In the same year the reported product of Great Britain was 2,135,499 gross tons, and that of Germany 322,422 metric tons of *rock-salt*, her production from salt-works in 1881 having also been 456,958 tons. The product of Russia in 1874 was 769,000 tons, 54,630 tons of which was rock-salt; and that of Austria, for the same year, was 249,521 tons, of which 81,081 tons was rock-salt.

The largest use to which salt is applied is doubtless for household purposes, in the seasoning of food and the preservation of provisions. This use among civilized nations is everywhere large, varying with the habits of the people from about ten to more than thirty pounds per capita. It is estimated that the people of the United States consume in this way about thirty-two pounds per person; and, if this estimate is correct, our production, large as it is, is mostly consumed for this single use. Another large use of salt is in chemical manufactures, as a source of soda by the Leblanc process, or by the recently devised ammonia process; as a source of hydrochloric acid incidental to the Leblanc process; and, directly or indirectly, for the liberation of chlorine in the manufacture of chloride of lime, to be used for bleaching purposes and as a disinfectant. Large amounts are used, also, in the metallurgy of silver, as a chloridizing agent preparatory to amalgamation; in the manufacture of pottery as a glaze; and as a fertilizer in agriculture.

For additional information on the occurrence of salt, and the mode of extraction from brines, the student is referred to "Natural History of New York," Beck's "Mineralogy"; "Geological Report of Michigan," Vol. III; T. Sterry Hunt's articles on salt in the "Geological Survey Reports of Canada" for 1866, 1866–1869, and 1876–'77; "Mineral Resources of the United States," 1883; Credner, "Geologie," pp. 45 and 291; Hoffman, "Chemische Industrie," and Ure's "Dictionary of Arts," etc.

Alkalies from Geological Sources.—The ultimate source of the alkalies potash and soda, save such portions as may always have been present in oceanic waters, is doubtless to be found in the decomposition of the rock-forming minerals which contain them, chiefly feldspars and micas. From these they have passed partly into soils, from which they are withdrawn by plants in the processes of growth; and a very important portion of the potash of commerce is still obtained from leaching the ashes of plants and evaporating the solution. Still larger portions of these soluble substances have been carried into great bodies of water, like the ocean and inland seas and lakes; and, on the final desiccation of isolated bodies of such waters, have formed deposits of salts of potash, soda, and magnesia overlying salt-beds, as at Stassfurt, Kaluscz in eastern Hungary, and Maman in Persia; or, in arid regions, like those of northern Chili and adjacent Peru, and portions of our great Western basin region, have formed extensive alkali flats impregnated with carbonates, sulphates, and sometimes nitrates of soda, occupying the sites of former inland seas, portions of which in some cases still remain, forming lakelets of intensely alkaline water.

Of the potash salts, the nitrate, called niter or saltpeter, is spontaneously generated in the soil of a number of hot regions like India, Persia, Arabia, and Egypt, doubtless by the action of organic matter on the *débris* of feldspathic rocks ; as also on the earth floors of some caves in our Western States. India formerly yielded the largest supplies ; but, during recent years, a chief source of the salts of potash has been the vast deposits overlying the beds of rock-salt near Stassfurt in Germany. Here a series of beds, several hundred feet in thickness, is made up of alternating layers of rock-salt and hydrous sulphates and chlorides of potash, soda, magnesia, and lime, called kainite, carnallite, sylvite, kieserite, and polyhalite. These are largely extracted and sent into commerce. Sylvite, which is the chloride of potassium, is readily converted into saltpeter by the agency of soda nitrate, yielding nitrate of potash and common salt. In 1882 Germany produced 141,272 metric tons of kainite, which is a complex compound of potassium and magnesium sulphate, magnesium chloride, and water, and 1,063,592 metric tons of other potash compounds. These are utilized as fertilizers, and in the manufacture of the various valuable compounds of potash. The occurrence of these desirable deposits of potash minerals, in connection with the upper beds of salt deposits in several foreign localities, suggests the expediency of a careful examination of what overlies any beds of rock-salt that may be found in our own country, to see whether similar sources of potash and magnesia may not possibly be discovered here. The numerous uses of potash compounds, in the manufacture of gunpowder, matches, soap, glass, saleratus, alum, and nitric acid, in photography and dyeing, in galvanic gilding and silvering, and in medicine, are familiar to most persons. The United States imported in 1882 5,225 net tons of saltpeter, which is said to have been obtained mostly from India.

As has already been said, in treating of pyrites and of salt, the compounds of soda are very largely manufactured from common salt. But, besides this, the nitrate, carbonate, and sulphate of soda occur native in very important deposits in several arid regions, where they occupy usually the dry basins of former bodies of saline waters, the shrunken remnants of which sometimes remain as alkaline pools and lakelets. Probably the most noteworthy of these deposits are those of Chili and Peru, of Central Asia, and of several portions of the great basin region in the Western United States. The *salinas* of Chili and Peru extend over several degrees of latitude in that rainless region, and in many places the soil is richly impregnated to the depth of several feet with various salts of soda, magnesia, and lime, of which the nitrate of soda, often called Chili saltpeter, is a considerable constituent. The nitrate, with some of the other more soluble substances, is leached from the soil, the solution evaporated, and the crude salt exported, to be used as a fertilizer, and in the manufacture of nitric and sulphuric acids and nitrate of potash. Among the most notable of the numerous saline deposits and lakes of the Great Basin, impregnated more or less richly with the carbonate and sulphate of soda, and in some places with the nitrate, together with common salt and compounds of magnesia, are, first those of Humboldt County and Churchill County, Nev., in what is called the Forty-Mile Desert, the first of which has valuable amounts of nitrate of soda, and the second, in a depressed basin of several acres in area, is said to be filled to the depth of ten feet or more with nearly pure carbonate of soda divided into layers by thin seams of clay ; second, those reported from San Bernardino County, Cal., and the southern border of New Mexico, containing nitrate of soda ; third, those of Carbon County, Wyo., where, sixty-five miles north of Rawlins, a lake of three hundred acres area is said to hold in solution about 10 per cent of soda sulphate and carbonate, while a lakelet three and a half acres in extent which receives its overflow is filled with solid carbonate to more than six feet in depth, a number of other soda lakes being also found about Independence Rock in the same region ; and, fourth, the soda lake at Morrison, near Denver, Col., the sulphate of soda from which is said to be coming into use in Denver for glass-making. It is highly probable that the thorough examination of this vast region will reveal the presence of many valuable deposits of the alkalies not at present known. A recent geological reconnaissance of southern central Oregon, made by Mr. J. C. Russell, the results of which are published in the recently issued Fourth Report of the Director of the United States Geological Survey, has shown that the waters of two considerable lakes in that region, Lakes Sumner and Abert, are "strong solutions of potash and soda salts," an analysis of the water of the last-named lake revealing the presence of two per cent of *potash* compounds and a little salt, the origin of which Mr. Russell attributes to the decomposition of the feldspars in the surrounding volcanic rocks.

Besides the uses of soda compounds that have already been incidentally mentioned, they are largely employed as detergents in households and in bleaching establishments, in the manufacture of hard soaps and of glass, in cookery for raising bread and cake, in medicine and photography, and in some metallurgical operations as a solvent of silver salts.

Borax.—This substance, which is largely used in the arts for several important purposes, is a biborate of soda, which occurs native in several localities, and is also obtained by treatment of native boracic acid, and of ulexite or boronatrocalcite, a double borate of lime and soda, found in rounded masses made up of white, silky radiating fibers. These compounds, with some others of little commercial importance, are found dissolved in the waters or crystallized in the mud of the margins and bottoms of closed and greatly shrunken saline lakes, or forming incrustations, mingled with other salts and earthy matters, in marshes which are dry during a portion of the year; or issuing in the water of hot springs in a few volcanic districts. For a long time it was brought to Europe in an impure form called *tincal*, from Thibet, where it was found in the borders of a saline lake, and the process of refining was long kept secret by the Dutch and Venetians. Supplies of tincal were also obtained from Nepaul, in India, and from Ceylon. Later, it was made largely from the boracic acid which issues with steam from the hot springs of the lagoons of Tuscany. To these sources are now added the rainless region of Chili, in the vicinity of Iquique, where boronatrocalcite is found in large quantities, and the borax lakes and marshes of Nevada and California. Large deposits of borates have also recently been discovered near the Sea of Marmora in Asiatic Turkey. The first locality in the United States where borax was discovered was in a small saline lakelet, very near Clear Lake, in Lake County, Cal., where it occurred in crystals enveloped in the gelatinous mud and underlying clay of the bottom. Hot springs in the vicinity were also found to contain boracic acid. For a number of years, a considerable amount of borax was derived from this lake, but it seems now to be superseded by richer or more accessible localities. The largest amount of borax produced in this country at present is derived from the borax marshes near Columbus, in the southeast part of Esmeralda County, Nev. It occurs here in extensive salines or marshes, called Teel's Marsh, and Fish Lake, Columbus, and Rhodes Marshes. These are all in oval alkaline flats, occupying closed basins, which are dry during a portion of the year, but in the wet season have shallow pools in their lowest parts. The borax occurs forming incrustations mingled with salt, soda, and earthy substances, from which it is freed by dissolving it with the aid of steam, and then crystallizing it. A considerable amount of the double borate of lime and soda is also found in these marshes in the usual white fibrous balls. In 1882 nearly half the borax produced in the United States was derived from Teel's Marsh, a considerable quantity being also obtained from Fish Lake Marsh. Similar borax deposits occur in Slate Range Marsh, San Bernardino County, Cal., from which a large amount of borax is obtained; and very promising deposits are reported also to occur in Inyo County, about one hundred miles northward from the last. The output of borax in the United States for 1884 was 3,500 tons of 2,000 pounds. The result of the late discoveries of borax has been to reduce the wholesale price to about thirteen cents per pound, which is not more than two fifths of the price that formerly prevailed.

The largest uses of borax are based upon its property of dissolving the oxides of many of the metals at a high temperature, and forming with them a kind of glass, which, in a number of cases, has characteristic colors. Hence it is used as a flux in refining metals; by iron and steel workers in welding, to preserve the surfaces of the metal clean from oxide during the operation; by braziers and jewelers in soldering; by enamelers; and by chemists, as a most valuable reagent in blow-pipe operations. It is an essential ingredient in all artificial gems; is a component of some varnishes and fine toilet soaps; and is said to enter into some kinds of glass. Considerable amounts are also used as a detergent for household purposes, by packers in preserving meats, and in some medicinal applications.

The student will gain some additional information about borax from "Mineral Resources of the United States" for 1867, p. 178, which contains an account of the first discovery of borax in the United States, by the discoverer; "Mineral Resources of the United States," 1883; Ure's "Dictionary of Arts," etc.; and Watt's "Dictionary of Chemistry."

Alum.—This well-known substance is a hydrous double sulphate of potash, soda, or ammonia, with alumina, the base of clay. It is sparingly found native as an efflorescence on rocks, where it originates from the weathering of pyritous clays containing potash, but is more commonly manufactured from pyritous shales, called *alum-shales*, or from *alunite*, an insoluble sulphate of potash and alumina, called commonly alum-stone. The latter occurs in rocks of volcanic regions, where it probably originates from the action of sulphurous vapors on feldspars containing potash. It is a somewhat rare substance, but is found in quantities of commercial importance at Tolfa near Rome, and at two or three localities in Hungary, where it forms considerable beds. The mineral is carefully calcined to avoid fusion and loss of sulphur, then kept moist in heaps, and left to the action of the weather, by which it is disintegrated, with the development of soluble alum. This is leached out and crystallized, forming opaque cubes; and, under the name of Roman alum, derived from the chief locality whence it is obtained, it is preferred to other alums for some uses. By far the most abundant material for the manufacture of alum is afforded by the *alum-shales*. Those best adapted to the purpose of alum-making are pyritous clay rocks, in which coaly matter is disseminated, thus affording readier access to the air, by which the decomposition of the pyrites is effected. The decomposition of the pyrites, accelerated usually by the long-continued application of a low degree of heat in extensive piles, converts the alumina of the clay into sulphate of alumina, which is leached out, concentrated, and converted into alum by the addition of a proper amount of sulphate or chloride of potash or ammonia. The sulphate of alumina for this purpose is also largely made by treating with sulphuric acid calcined clays which are as free as possible from lime and iron oxide. For this use, the excellent clays which abound in the Cretaceous beds of New Jersey are admirably adapted; and there can be no doubt that pyritous shales, adapted to alum-making, can be found in many portions of our own country, especially in the coal and lignite regions, from which they are mostly extracted in Europe, though it has recently been stated that most of the clays used in the United States for alum-making are imported. It has also been proposed to manufacture alum from the greensand which abounds in the Cretaceous of New Jersey, by treating the gently ignited greensand with sulphuric acid, the greensand furnishing the requisite potash and alumina.

On account of the strong affinity of its aluminous base for organic coloring-matters, alum is largely used as a mordant in dyeing, and by manufacturers of what are called *lakes*, which are compounds of organic coloring principles with alumina, of which madder lake, and the brilliant cochineal lake called carmine, are familiar examples. It is also used in clarifying liquors, in some processes of tanning skins, in medicine as an astringent, in pastes for paper, and in small amounts by bakers for whitening and raising bread.

Besides the substances applicable to chemical manufacture or use that have already been described, some mention should also be made in this connection of *magnesia*, *strontia*, and *titanium*. Magnesia will require some mention in the chapter on refractory materials; but, besides the use based on its resistance to heat, are others of a chemical nature. The sulphate, which is much used in medicine under the name of Epsom salt, is found native at Stassfurt as the mineral kieserite, and is also obtained from the residues after extraction of potash from some other Stassfurt salts. It is said to be used as a cheap substitute for sulphuric acid in the preparation of *blanc fixe*, a white pigment obtained by the precipitation of chloride of barium, and also in the manufacture of *pearl-white*, to be used in paper-making. Epsom salt and magnesia alba can also be manufactured from magnesite, a carbonate of magnesia, much resembling calcite and dolomite in color and cleavage, but containing no lime, besides being somewhat harder and more sluggish in its effervescence with acids. It occurs in considerable beds in the Lower Silurian rocks of Bolton and Sutton in Quebec, near the boundary-line of Vermont, where it is associated with beds of dolomite, steatite, and serpentine, and in one locality with argillite ; and it will doubtless be discovered in similar associations elsewhere, whenever an active demand for it shall arise.

Strontia, the almost sole use of which has been heretofore in pyrotechny in the form of the nitrate for making red fire, is recently coming into a greatly increased demand, since it has been found that it can be utilized in recovering sugar from the "*melasse*," which has hitherto occasioned great loss in making beet-sugar. The two minerals in which it occurs in economically important amounts are *strontianite*, the carbonate, and a sulphate called *celestite* (Latin *cœlum*), from its frequent *sky-blue* tint. They are both heavy minerals, their specific gravity being from 3.6 to 4 ; both are quite brittle, and both give a bright-red colored flame when heated before the blowpipe. Like other carbonates, strontianite effervesces with acids, and by this it may readily be distinguished from celestite. These two minerals are sparingly distributed, being found in nests and crevices, most commonly in limestones, in the United States and Canada, but sometimes also in sandstone and clay, or associated with gypsum. They have been found in the Lower Silurian limestones of Manitoulin Islands, somewhat abundantly at Kingston, and on the Ottawa River in Canada, as also in Jefferson County, N. Y. ; and in Upper Silurian limestone near Schoharie and Lockport, N. Y., in Blair and Mifflin Counties, Pa., and on Strontian and Put-in Bay Islands, Ohio, where celestite is more than usually abundant. Strontianite is obtained from Argyleshire in Scotland, where it was first discovered, and somewhat abundantly in Westphalia, where it occurs in veins or shrinkage cracks in Cretaceous clays; while Sicily is much the most considerable producer of celestite, exporting, it is said, about four thousand tons annually. For its new use, in the manufacture of beet-sugar, caustic strontia is obtained from strontianite by heating it to redness to expel the carbonic acid. This, when boiled with "melasse," forms a compound with the sugar from which the strontia is separated by carbonic acid, leaving the sugar to be dissolved and crystallized. On account of its infusibility, caustic strontia is also utilized in making *tuyères* for blast-furnaces. The nitrate of strontia, for use in pyrotechny, is obtained by treating strontianite with nitric acid, or by heating celestite, mixed with charcoal, to a high temperature, and then treating with nitric acid the sulphide of strontia thus formed.

The compounds of *titanium*, which are now considerably used in the manufacture of artificial teeth and in porcelain-painting, are probably destined to a greatly increased use in the manufacture by various chemical means of a number of brilliant and permanent pigments. It is found abundantly, in the form of *ilmenite*, or titanic iron, in the Archæan rocks of Canada and Norway, where it bears a great resemblance to magnetite, being, however, very little magnetic It occurs also in crystalline rocks as titanic acid, forming the minerals *rutile* and *brookite*.

CHAPTER XIX.

FICTILE MATERIALS.

THE arts of the potter and the glass-maker afford a striking exemplification of what human skill can accomplish by a dexterous use of the properties of substances which in their original condition are among the most common and least valued objects. What could be more dissimilar to the magnificent creations of porcelain and of glass which, in varied forms, deck the tables and adorn the mansions of the rich, and which are objects of eager desire to princes, or even to the humbler wares which spread the board and minister to the modest wants of the poor laborer, than heaps of clay and sand, of lime and feldspar, with bins of soda, potash, salt, and borax, and a few metallic oxides? Yet the former are but the latter, mingled by knowledge bought by generations of experience, fashioned by skill and taste, and subjected to a treatment adapted to develop to the utmost their latent capabilities. The art of shaping rude vessels from clay and hardening them by fire is one which has been practiced in the infancy of civilization; but the highest and most refined developments of this art tax to the utmost the scientific resources and the cultivated taste of the most enlightened nations.

A number of the substances used as materials for the manufacture of porcelain, earthenwares, and glass, have already been described, as regards their geological occurrence, in the preceding pages. Such are potash, soda, and lime, used as fluxes in glass-making and in glazes for pottery; such is oxide of lead, used as a flux for flint-glass and in many glazes; such are the oxides and a few other compounds of the metals employed in glass-staining and porcelain-painting; such is salt, used as a glaze for stoneware, and borax, used also in some glazes, and as a partial substitute for silica in some fine sorts of glass and artificial gems. Of the remaining substances, including *clay*, *silica*, *feldspar*, *granulite*, *steatite*, and *baryta*, all of which are used more or less largely in one or both of these arts, *clay* is of the greatest interest, since it forms the basis of all pottery-wares, and has also some other highly important applications. This substance is a highly variable mixture of kaolin, the mineral on which its valuable properties depend, with silica, iron, lime, magnesia, the alkalies potash and soda, and often a small amount of mica and partially decomposed feldspar. In blue and black clays, organic matter is also present, and disappears on burning, leaving the clay white. Kaolin is a usually white and unctuous hydrous silicate of alumina, which contains in round numbers 46 per cent of silica, 40 per cent of alumina, and 14 per cent of water. From this it will be seen that two and a half times the alumina given in the analysis of a clay will show the amount of kaolin that enters into its composition. In some of the best clays this mineral is much the largest ingredient, but small proportions of other substances being mingled with it; while in others it may constitute considerably less than half of the aggregate, to which, nevertheless, it gives its essential characters. Kaolin, then, is the *essential* ingredient of every true clay, and by itself constitutes a clay of the finest quality; all other ingredients are non-essential accessories, and in some cases injurious ones, rendering the clay unfit for its highest uses. The most invariable accompaniment of kaolin in clay is free silica, occurring in the form of sand intimately mingled with the mass, and varying in amount from a mere fraction of one per cent to more than fifty per cent of the whole. This silica, though sometimes in grains of moderate size, frequently exists in the state of an almost impalpable powder or dust, yet showing itself under the microscope as minute angular particles of white, transparent quartz. The quartz in clay to be used for pottery can hardly be considered as anything but a diluent of the clay. Indeed, for the purposes of the potter, rich or *fat* clays need to be mingled with finely comminuted silica, in preparation for their use. By itself in a clay, it is inert, acting, however, physically to counteract the tendency to shrinkage and the production of checks and cracks which kaolin alone exhibits when subjected to great heat. When, however, vitrifiable bases, like potash, soda, and lime, are present in the clay, the readiness of finely divided silica to form with them fusible compounds at a high temperature causes that slight incipient fusion which gives rise to the hardness and strength of the productions of the potter. Some one or all of the three bases that have just been named, but potash much the most generally, are found in nearly all clays, but usually in small quantities in the best. It seems quite probable that these alkaline substances which analysis reveals, and which produce their effect on the fusibility of the clayey mass, are due, in some cases at least, to partially decomposed feldspar, and sometimes to mica present in the clay. Both of these minerals contain potash, and feldspar usually contains some soda and lime also. Feldspar in clays occurs in small, sandy particles. Mica, from the ready flotation of its minute laminæ, is little likely to be found in clays which are somewhat remote from their place of origin, and which have possibly been worked over more than once by transporting agencies before resting in their present beds. The most undesirable contamination of clays for potter's use is iron, which in some of its forms, as oxide, carbonate, or sulphide, seems never to be wholly absent from any clay. Sometimes its proportions sink to not more than a fifth of one per cent; more frequently, however, it is present to the extent of two or three per cent or even more, unfitting the clay for any save the coarsest and most common wares, since it imparts to them yellow, red, or brown colors, according to its amount and the degree of heat to which the articles are subjected. The following table of analyses of a few approved pottery clays will give a fair idea of their composition, and of the extent to which the various ingredients other than kaolin may be present without proving seriously detrimental. The titanic acid, which will be observed to be present in several of the clays, especially those from New Jersey, seems to be wholly inert, producing no appreciable effect on their properties. Following the excellent arrangement of analyses given in the New Jersey Report on Clay Deposits, and in the Ohio Report on Economic Geology, the kaolin-forming compounds, the inert substances, and the compounds which promote fusibility, with their respective amounts, are placed in separate groups. It may here be said that, for their finest uses, clays are *washed* by mixing them thoroughly with water, and then allowing the creamy liquid in which the clay will remain long suspended to flow off into settling-vats where the clay is deposited. By this means the coarser and heavier impurities are easily separated.

The properties of clays which are of chief interest to the potter are *plasticity*, and a *tendency* to *shrink* at a high temperature. Most clays which are used by potters when properly moistened are tenacious and pasty, and are susceptible of being easily shaped into any desirable form in molds or on the potter's wheel. The forms thus made harden considerably on drying, and when heated to a high temperature assume the stony consistency which is familiar to every one in earthenware and porcelain. This

	Combined silica.	Alumina.	Water.	Kaolin constituents.	Sand.	Titanic acid.	Inert constituents.	Potash.	Soda.	Lime.	Magnesia.	Iron oxide.	Fluxing constituents.
1. Ware clay, Woodbridge, N. J.....	44.64	38.75	13.05	96.44	0.81	1.32	2.13	0.17			0.11	1.15	1.43
2. Select paper clay, S. Amboy, N. J.	44.39	39.48	14.17	98.04	0.20	1.06	1.26	0.25				0.45	0.70
3. White clay, Middlesex Co., N. J..	46.11	35.56	14.89	96.56	0.51	1.46	1.97	0.12				1.38	1.50
4. Stoneware clay, " "	29.29	21.17	6.72	57.18	37.93	1.00	38.93	1.81	0.18		0.22	1.68	3.89
5. China clay, Lawrence Co., Ind.....	40.10	36.35	22.60	99.05	0.40		0.40	0.14			0.13	0.15	0.42
6. Potter's clay, Pope Co., Ill........	34.70	31.34	12.00	78.04	12.30		12.30	0.79	0.16		0.10	0.16	1.21
7. Yellow-ware clay, Liverpool, O....	42.28	24.12	7.77	74.17	18.02	1.20	19.22	2.42		0.59	0.68	1.46	5.15
8. China clay, Cornwall, England...	28.40	24.11	7.20	59.71	37.80	0.20	38.00	0.96				0.79	1.75
9. Best Belgian clay, Ardennes	36.69	34.78	10.73	82.20	9.95		9.95	0.41		0.68	0.41	1.80	3.30
10. Fire clay, Golden, Col..........	52.41	32.21	14.05		With combined silica.			0.61		0.20	0.06	0.66	1.53

valuable property of plasticity belongs solely to the kaolin of the clay ; and plastic clays, rich in alumina, admit the addition of a considerable amount of fine sand without any material diminution of their plasticity. The plasticity of clays is doubtless dependent in part on the water held in chemical combination by the kaolin, since, when this water is driven off by a red heat, plasticity is permanently lost, and can not be restored by any treatment of the stony product with water. That it is by no means due wholly to the combined water, however, is shown by the fact that some highly valued porcelain clays or kaolins are but slightly plastic. An example of this is presented by the clay of which the beautiful Sèvres porcelain is made, which, when prepared for use, is so little tenacious as to require a quite special and expensive mode of handling in shaping the articles which are fashioned from it, a fact to which the high price of this porcelain is in a great measure due. Prof. George H. Cook, in his report on the clay deposits of New Jersey, has shown that very probably the plasticity of kaolin is largely due to a minute subdivision of the crystalline plates and bundles of which the mineral is originally composed, since recognizable crystals of kaolin are found, by microscopic examination, to abound in clays which are deficient in this property, while they are absent, or nearly so, from highly plastic clays.

The shrinkage of clays, when subjected to great heat, is a character quite as remarkable as their plasticity. This arises partly, no doubt, from the expulsion of water ; but that this is not the only cause, is shown by the fact that the clay continues to contract with an increase of temperature, even after the water has been entirely expelled. On this fact was based the pyrometer of Wedgwood, which attempted to measure very elevated temperatures by the degree of contraction which they produced in rods of clay ; an attempt which was not entirely successful, on account of irregularities in the contraction of clays when exposed to long-continued heat. Highly aluminous or *fat* clays shrink the most by heat, while very sandy or *lean* clays shrink less or not at all. Hence, to counteract the excessive shrinkage of fat clays, which is apt to cause irregularities and cracks in the wares when burned, they are *tempered* by mixing them intimately, before molding, with a proper amount of finely divided silica, or with thoroughly burned and pulverized clay.

Clays originate doubtless from the decomposition of feldspathic rocks, such as granites, gneisses, and porphyries. The feldspars, from whose decomposition kaolin is derived, are orthoclase, albite, and oligoclase, albite being the most readily attacked by the agencies of decay, but orthoclase, from its greater abundance, being the most important source. These minerals, which are silicates of alumina, with potash, soda, and lime, when exposed to the action of carbonic acid and water, slowly lose their alkaline constituents and some of their silica, take in water, and so are ultimately converted to kaolin. When kaolin is found on the place of its origin, it is naturally associated with the quartz and mica, which are the remaining constituents of granite and gneiss; or, with quartz alone, when it is derived from the variety of granite called *aplite* or *graphic* granite, which contains little or no mica. Such clays are usually deficient in plasticity, probably from the undisturbed crystalline condition of their kaolin. Of this kind are apparently the porcelain clays of China, from which the names kaolin and china clay have been derived; that of Saint Yrieix-la-Perche, not far from Limoges, which is the basis of the French manufacture of porcelain; that of Saxony, from which Dresden porcelain is made; and the china clay of the granite district of Cornwall. The Chinese kaolin and that of Cornwall, according to Ure, have more plasticity than that of France and Germany. On account of the slowness with which kaolin subsides in water, with which it readily forms a milky mixture, and of the consequent ease with which it may be transported to long distances from the place of its origin, much the largest portion which is formed is washed away from its parent rock, and deposited in low grounds or in bodies of water, forming often considerable beds, like those found so abundantly in parts of New Jersey, and those which constitute the under-clays of many coal-beds. These translocated clays, as a result of their transportation by moving water, have usually been freed from most of their mica, and from their free silica, save that which existed in a state of fine subdivision. They are also commonly highly plastic, although those which have been much solidified by pressure need to be softened by weathering before they exhibit this character. These clays are occasionally of such purity as to be adapted to the finest uses in the manufacture of porcelain; such, however, are found in but few localities. Clays, adapted to the manufacture of the more common articles of white and ornamented stoneware, are more abundantly distributed, while others, which are too much contaminated with iron for this purpose, are used for making jars, jugs, and many other articles of a coarser kind.

Pottery clays are known to occur at many points in the Archæan districts along the Appalachian range, from New England to Georgia, and they are dug to a limited extent in several localities. These are all surface deposits of geologically recent origin, and some of them may be found suitable for porcelain-making. Clay deposits, suitable for common wares, are reported at a number of points in the far West, and are said to be utilized to some extent; but none of the very best quality, apparently, have yet been found, unless the clay of Golden, Col., given in analysis No. 10, on a preceding page, should prove to be one. The clay deposits most largely wrought in this country hitherto are of Cretaceous and Carboniferous age. The Cretaceous clays of New Jersey, chiefly in

Middlesex County, are abundant, and of qualities fitting them for various uses. The excellent pottery clays are not only largely sent to other States, but are the basis of a very important manufacture of wares of various kinds at Trenton, Jersey City, and Elizabeth, New Jersey producing nearly three fifths of the pottery wares that are made in the United States. It can hardly be doubted that some of the New Jersey clays may be used for the manufacture of the best porcelain. Some of the under-clays of the lower coal-measures, in several of the coal-producing States, are suited to the manufacture of pottery. They have been most largely utilized for this purpose at Liverpool, O., on the Ohio River, and at two or three other localities in the same State, where they are mixed with clays from other regions, Ohio ranking next to New Jersey in the amount of wares produced. At Huron, Ind., and at other points in Lawrence County and also in Owen County, noted deposits of kaolin called *indianaite* occur, an analysis of which, showing an unusual proportion of water, has been given on a preceding page. This clay is used at Indianapolis for making encaustic tiles of the highest grade of excellence, and at various points in the United States in the manufacture of fine qualities of white ware; and it seems to be suitable for the very highest uses of the potter. No attempt has here been made to enumerate the many promising localities of pottery clays which are known to exist in the United States, but which have not as yet been much developed. It is certain, however, that clays adapted to the more common uses are widely distributed, while it is probable that here, as in all other countries, kaolins suitable for the manufacture of fine porcelain will be found to be rare. Any mention of fire-clays has been purposely deferred to a succeeding chapter; and those coarser clays, which are so widely used for brick-making and similar purposes, have already been described in treating of building materials.

The materials on which is based the vast English manufacture of pottery and porcelain in Staffordshire are derived from the southwest counties of Cornwall, Devon, and Dorset, in which are found extensive deposits of excellent clays and kaolin.

Although clay is the basis of pottery, several other minerals are mingled with it to form the pastes that are employed for the various kinds of ware. Of these, silica has the most universal use, being mingled with the clays in proper proportions to correct their tendency to too great and irregular shrinkage in burning. This may be obtained in the state of clean silicious sand, or of flint, found disseminated in chalk and other limestone rocks; or of massive quartz, from veins of this mineral occurring in regions of granitic rocks and silicious schists, such as the Archæan areas described in treating of building-stones. From whatever source derived, the silica is ground to a very fine powder before it is used, and the massive forms are frequently calcined before grinding, to render them more brittle. This finely divided silex is not only mingled intimately with the clay which forms the body of the ware, but also enters into most of those vitrifiable mixtures which are used as glazes. Both silex and pure clay or kaolin, however, are wholly infusible at the temperature attained in porcelain-kilns. Hence, to impart to the clay mixture a tendency to that incipient vitrifaction which increases the strength of the more common wares, and gives to fine porcelain the translucency which is so much admired, minerals like feldspar, lime, and crystallized gypsum, are added, which at high temperatures form with silica fusible compounds. The Chinese use for their porcelain a mixture of kaolin with a silicious feldspar called *petuntse*, which mixture requires an exceedingly high temperature for its vitrifaction. The standard mixture for Sèvres porcelain is, according to Ure, 59 per cent of silica, 35.2 per cent of alumina, 2.2 per cent of potash, and 3.3 per cent of lime, which may be formed by mingling kaolin with proper proportions of feldspar, flint, and chalk. The English "tender porcelain" is composed of clay and flint, with bone-dust, and sometimes potash, as a vitrifying agent; and in Wedgwood-ware, baryta is used as a flux for the clay. The feldspar which is used in these mixtures, to add the needful alkalies, is to be sought, as might be expected, in regions of coarsely crystalline granitic rocks. That which is used in this country seems to be obtained mostly from near Middletown and Portland, Conn., and from middle Virginia; but numerous other localities are known in the New England and Atlantic seaboard States, where it can be found abundantly.

The glazes which give to wares their impermeability, and their smooth and often brilliant finish, are various mixtures of flint, feldspar, ground glass, lead oxide, borax, potash, soda, and lime. From among these substances, various manufacturers compound for their wares glazes which experience teaches them to be most suitable for their purposes, the glazes being artificial glasses, sometimes transparent, sometimes opaque, which coat the wares to heighten their beauty, or sometimes to conceal their defects. Some porcelain has a glaze of feldspar only. Many coarser articles of pottery are glazed by merely throwing salt into the kiln among them at the proper stage of the baking; the salt is decomposed by the heat, and its soda forms a fusible glaze with the silica and alumina of the surface of the wares.

The colors which are used for the ornamentation of pottery are mostly oxides of the metals, with a few chlorides and chromates. These are mingled or fused with proper fluxes, ground fine, and applied to the wares before their final burning in a medium of gum-water, or of some volatile oil. The colors are in some cases fused into the glaze of the wares, and in others they are laid on under the glaze and show through its transparent substance. The oxides, which are chiefly used for painting porcelain and other wares, are those of cobalt, iron, copper, antimony, uranium, nickel, manganese, chromium, tin, and titanium, with chlorides of gold, silver, and platinum, and a few chromates. By a proper treatment of these substances and their fluxes, the skillful porcelain-painter attains as complete a mastery over the effects that he desires to produce with these coloring materials that must pass through the fire before showing their real nature, as the artist who paints on canvas with ordinary pigments.

Glass.—It may be stated in a general way that this beautiful, transparent, and impervious substance, which plays so large a part in the comforts, conveniences, and elegancies of civilized life, is a double silicate of potash or soda and lime or lead. Its foremost materials are therefore silica, the alkaline substances, and lead oxide. In some of the finer kinds of glass, boracic acid takes the place of a portion of the silica. To correct the effects of impurities in these materials, a little niter is commonly used, as also small amounts of arsenic, and of black oxide of manganese, which, from its purifying effects, is often called *glass soap*. The geological occurrence of most of these substances has already been described elsewhere. The silica, which constitutes the largest ingredient in all varieties of glass, was formerly prepared for the finer kinds by calcining and grinding flint, from which is derived the name of *flint* or *crystal* glass, applied to the very dense, lustrous, and highly refracting double silicate of potash and lead. It has, however, been found that, in somewhat numerous localities, sand may be obtained of sufficient purity to be used for all the purposes of glass-making. For all except the coarser varieties of glass a tolerably fine, angular, white sand is needed, free from earthy impurities, and especially from iron, which gives to glass a green tint. In some localities, sea-sands are found of sufficient purity for any purpose. Thus the English manufacturers obtain much of their sand from the Isle of Wight, and from points on the coast of Norfolk and of Holland. In southern New Jersey a large number of glass-houses obtain an inexhaustible supply from a bed of Tertiary sand more than ninety feet thick, and of very considerable extent, much of which is so pure as to require no washing before being made into window-glass. The glass-works in central New York obtain a good sand for window-glass from the modified drift around Oneida Lake. In four counties of central and southern Indiana great deposits of pure white sand and slightly indurated sandstone occur, from which an approved quality of plate-glass is manufactured. Besides such deposits of incoherent sands of Tertiary age and of recent origin, which are pure enough for glass-making, white silicious sandstones are occasionally met with in much more ancient rocks, which are so friable as to be readily reduced to sand, and are then used for the manufacture of glass. Notable among these is the St. Peter's sandstone of the Lower Silurian, which occupies considerable areas in Missouri, Minnesota, and Wisconsin, and in La Salle County, Ill. At many of its exposures, it occurs as a clean white sandstone, remarkably free from impurities, and so friable as to be readily extracted from its beds by pick and shovel. A considerable manufacture of glass is already based upon this sand, and its use seems destined to be greatly increased. The Potsdam sandstone, which occupies the lowest horizon of the Lower Silurian, also occurs of sufficient purity to afford a good material for glass, in portions of northern New York, Canada, and Wisconsin. A few only of the more noteworthy exposures of sands which have been proved by use to be sufficiently pure for the manufacture of the better grades of glass have here been mentioned. Many others will doubtless be eventually brought into use within our broad domains; but it will easily be conceived that, though sand is a very widely and abundantly distributed substance, yet that which is of the high degree of purity needed for the manufacture of fine white glass is by no means common. For the making of bottle-glass, in which purity of color is not required, inferior sands are largely utilized. For this last purpose a rock called *granulite* has recently come into quite extensive use in Saxony and in southern England. Granulite, though sometimes granular, is usually a schistose rock composed of alternating layers of quartz and feldspar, with little or no mica, and is usually of a white color, so that it is called by the Germans *weiss-stein*, or white stone. The Saxon granulite contains from 70 to 80 per cent of silica, with a considerable per cent of potash in its feldspar, and less than one per cent of iron; and, when melted with the addition of sufficient lime to secure perfect fusion, makes a pale-green bottle-glass, at about two fifths of the usual cost for this article. Rock of this character, or that which will serve the same purpose, viz., granite free from mica and containing but a minimum amount of iron, may doubtless be found in the Archæan areas of Canada and New England, as well as elsewhere, and where met with it will afford excellent opportunities for the profitable investment of capital. The Saxon production from this source is said to have reached twenty-two million bottles in 1880, and to have increased rapidly since that time. It has recently been proposed to use this glass for gas and water pipes and other large castings, and, should this idea be carried out successfully, deposits of granulite and graphic granite, favorably located with respect to transportation, will naturally assume great economic importance.

The substances which are used for coloring glass, like those employed in porcelain-painting, are metallic oxides and a few other compounds of the metals, all of which, it need hardly be said, are obtained from geological sources. Thus the white opaque glass called enamel derives its color and opacity from the oxide of tin; a blue color is given by the oxide of cobalt, green by oxide of copper, yellow by chromate of lead and by silver chloride, and other colors by similar means. Without at all entering into the technicalities of glass-making, it may appropriately be said here, in illustration of the geological origin of its materials, that the chief varieties of glass are compounded of the following ingredients:

Common bottle-glass, of silica, alumina, soda, and lime; Bohemian glass, of silica, potash, and lime; crown-glass, of silica, potash or soda, and lime; window-glass and mirror-plate, of silica, soda, and lime; crystal and flint glass, of silica, potash, and lead oxide; strass for artificial gems, of silica and boracic acid, potash, and lead oxide.

The differences of quality are due to the relative purity of the ingredients, the proportions in which they are compounded, and the skill and care with which they are treated.

For additional information with regard to materials for the manufacture of pottery and glass, the student is referred to the following works: Ure's "Dictionary of Arts," etc., articles on clays, glass, and pottery; "Geology of New Jersey," 1868; the "New Jersey Report on Clay Deposits," 1878; and "Ohio Geological Report," Vol. V, chap. ix.

CHAPTER XX.

REFRACTORY SUBSTANCES.

FOR numerous and highly important purposes among civilized nations, materials are required which will endure very high degrees of heat without injury; and every improvement whereby more elevated temperatures are secured by the skillful use of fuel, renders the need of such refractory substances more imperative. It is necessary only to direct attention to the furnaces used for various metallurgical operations, and especially those in which iron and steel are to be treated; the kilns in which pottery is baked and the materials of glass are fused; the *seggars*, or fire-proof boxes, in which earthenware and porcelain are exposed to the heat of the kiln; the large pots or crucibles in which the ingredients of glass, and metals like copper, silver, and steel, are melted; and the linings of Bessemer converters, in which molten iron is to be subjected to ebullition by the action of a current of air to burn out its impurities—to indicate the variety and importance of the uses for which refractory substances are required, and the fierce heats which they are called upon to endure without softening. All these substances are minerals which enter into the composition of rocks, and are therefore derived from geological sources.

Foremost in importance among these is *fire-clay*, both from its great infusibility, and from the readiness with which it may be fashioned into convenient forms. This clay does not differ from the pottery clays described in the preceding chapter in any respect save in its greater necessary freedom from the fluxing ingredients, potash, soda, lime, magnesia, and iron oxide. The presence of any considerable proportion of these fluxes in a clay, to the extent, for example, of two or three per cent, injuriously affects its heat-resisting properties; and the combination of two or more of them proves more detrimental than a like amount of any one, because the compound silicates are more fusible than the simple ones. The more completely a clay is composed of kaolin, or of kaolin and silicious sand, the more refractory it is likely to show itself, since both these substances are wholly infusible at the temperatures attained in industrial operations. This may be seen by examining the following analyses of several of the most celebrated fire-clays of this country and of Europe. They are arranged in the order of their resistance to an extreme fire-test, made by exposing small triangular prisms of each with *sharp edges*, for a half-hour, to a heat in which platinum was melted. Exposed to this heat, some of the clays retained their sharp edges; others, while retaining the sharpness of their edges, were more or less blistered or distorted; in others, the edges were rounded and fused, and a number melted. This series of tests was undertaken by the Geological Survey of New Jersey, and its results and methods are published in the annual report of that State for 1880. On this was founded a tentative division of the clays into seven classes, according to their relative refractoriness; and to this classification the numbers in the first column refer. The analyses of the same clays have been selected from those given in the New Jersey report on clay deposits, to which reference has been made before. Neither soda nor lime appears in any of these analyses.

As all these clays are well esteemed for their resistance to heat, it may be assumed that the amount of the flux-

	Class.	Combined silica.	Alumina.	Water.	Kaolin constituents.	Sand.	Titanic acid.	Inert constituents.	Potash.	Magnesia.	Iron oxide.	Fluxing constituents.
1. H. Cutter and Son, fire-clay, Woodbridge, N. J.	1	44.22	38.08	14.10	96.40	1.11	1.32	2.43	0.15	0.11	0.91	1.17
2. A. Hall and Sons, fire-clay, Woodbridge, N. J.	1	42.05	35.83	12.20	90.08	5.70	1.10	6.80	0.44	0.11	0.77	1.32
3. Evens mine, crude clay, Missouri	2	43.93	40.09	13.80	97.82	0.60		0.60	0.20		0.88	1.08
4. Bollene fire-clay, France	2	38.20	28.19	10.50	76.89	14.95	1.15	16.10	0.40		2.76	3.16
5. Sorée, fine clay, Belgium	3	41.70	33.50	10.65	85.85	8.20		8.20	1.40		2.05	3.45
6. Garnkirk No. 1 fire-clay, Scotland	4	44.35	35.30	13.70	93.35	1.30	0.95	2.25	0.75		1.60	2.35
7. Mineral Point fire-clay, Johnstown, Pa.	4	44.95	38.84	12.50	96.29	0.30	1.55	1.85	0.35		0.91	1.26
8. Glenboig Star fire-clay, Scotland	5	30.40	24.68	9.00	64.08	31.05	1.10	32.15	0.20	0.10	1.67	1.97
9. Stourbridge glass-pot clay, England	6	30.50	22.52	8.30	61.32	33.65	1.00	34.65	0.50		1.43	1.93
10. Fire-clay, Winchester, Illinois	7	23.15	17.08	6.30	46.53	46.70	0.90	47.60	1.10	0.28	3.47	4.85
11. Coblentz glass-pot clay, Germany	7	18.35	15.66	6.84	40.85	53.03	1.20	54.23	0.63	0.28	1.19	2.10

ing ingredients in a fire-clay can not safely exceed what is found in these, especially as one of the clays which occupies the lowest class contains the most of the fluxes. When it is considered, also, that in these tests pure rock-crystal was melted, a reason will be found why the four clays that contained the most free silica rank lowest in this list. It would be difficult to assign reasons for some other differences in refractoriness shown by the clays in the table, as, for example, why clay No. 7 should not have been as refractory as Nos. 2 and 3, unless it is to be found in the texture and density of the clays.

Aside from the very superior fire-clays obtained from the Cretaceous clay deposits of New Jersey, the great bulk of the refractory clays of Europe and the United States are derived from the under-clays of coal-beds—not only those of the coal-measures proper, but also, as in several of our Western Territories, those bearing similar relations to the lignitic coals of the Upper Cretaceous. These under-clays doubtless owe their freedom from alkaline constituents to the fact that, having once been *soils* which sustained a luxuriant vegetation, these substances have largely been withdrawn from them by the processes of plant-growth. When first dug, they are hard and stony, but can be softened and rendered somewhat plastic by sufficient weathering. Frequently, however, they are merely ground fine with water, mixed with a proper amount of previously burned and pulverized fire-clay called *calcine*, and sufficient sandy, plastic clay to serve as a *bond*, and then molded and burned for fire-brick, glass-pots, retorts for gas and zinc works, terra-cotta wares, chimney-tops, and many other articles which are either to be exposed to high temperatures, or which need to be fired strongly to secure the characters desired.

Dinas or *silicious bricks*, which are employed where an excessive temperature is attained, as in the melting-chamber of regenerative furnaces, in which ordinary fire-brick does not endure well, were originally made from a silicious rock locally called *clay*, though containing about 97 per cent of silica, occurring in the Carboniferous strata of South Wales. This rock was disaggregated and mixed with a small portion of lime to serve as a cement, then molded and burned at a high heat for several days. At the high temperature employed, the lime combines with an equivalent amount of silica to form a refractory silicate which binds the whole together. Similar bricks are now made from any pure silicious rock, which is ground and mixed with about one per cent of milk of lime to form a *bond* for the mass when burned. The silicious rock employed for this purpose should be free from iron and mica. Silicious bricks expand somewhat when heated, and so keep the parts of the furnace tight.

The substance called *ganister*, used as a refractory lining for Bessemer converters, is a very fine-grained and tough sandstone, or quartzite, containing a certain amount of finely disseminated aluminous matter. When this is ground fine and mixed with water, the contained alumina acts as a sufficient bond. Rock for this purpose is obtained in England from a silicious under-clay of the coal-measures at several points, the best being found in the vicinity of Sheffield. A rock of a similar character is found in the Archæan strata in the immediate vicinity of Marquette, Mich., where a thin-bedded and ripple-marked quartzite is quarried to a considerable extent for this use. Any pure silicious rock, ground to a fine powder and mixed with a proper amount of good fire-clay, is said to answer well in place of ganister.

What are called *fire-stones* are usually silicious sandstones, which should be free especially from iron, and from mica the potash in which renders it a fluxing ingredient. Fire-stones may be found by careful examination and trial in many localities, where their cheapness makes them a reasonably good material for many purposes, as for the hearths of furnaces and fireplaces, and for the construction of kilns, though their use is now largely superseded by that of fire-brick. Where used, it is hardly necessary to say that they should be thoroughly dried before being subjected to heat.

For a number of purposes bricks are very desirable which shall combine with the ability to endure unchanged all ordinary degrees of temperature, very feeble conductivity for heat, and much less specific weight than common fire-brick. Such materials, called *floating bricks*, because they are lighter than water, are made from an infusorial earth called "fossil meal," composed of the microscopic skeletons of silicious organisms, and forming a whitish earthy mass, very light, and resembling chalk in appearance, but yielding no effervescence with acids. This substance, mingled with a small amount of clay, may be made into bricks which weigh less than one fifth as much as ordinary bricks, which resist heat well, and which when red-hot at one end are not perceptibly warm at the other. An earth of this kind is abundant in Tuscany ; and it is probable that the Tertiary infusorial earth which occurs in a bed thirty feet thick near Richmond, Va., and in a still thicker deposit at Monterey, Cal., is adapted to this use.

Graphite or *plumbago*, under the name of black-lead, is familiar to every one from its wide use in lead-pencils. It is a soft, black mineral, of a greasy feel and metallic luster, and easily gives a lead-gray mark on paper, on which account it is used in the manufacture of pencil-leads. Aside from the impurities with which it is often contaminated, it is pure carbon, having the same composition as the diamond, to which in other respects it is so unlike ; and it is in all probability the ultimate stage in the series of changes which vegetable matter undergoes, passing through the conditions of peat, lignite, and mineral coal, to end in graphite, which is not only infusible, but also incombustible under the conditions which are presented in the industrial use of heat. It is usually found in quantities of economic importance only in the most ancient crystalline rocks, associated frequently with limestones, and also with gneiss and schistose rocks. In these it occurs, either disseminated more or less abundantly in certain horizons of the rock, or forming pockets and nests, or filling vein-like fissures with mineral of a high degree of purity. It is met with at many points in the Archæan region, extending from the Province of Quebec, in Canada, through New York, New Jersey, etc., to North Carolina and Alabama; but in most of the localities it is either too sparingly disseminated to pay for its extraction, or is of such physical character as not to admit of cheap separation from its impurities. It has been mined to some extent at Bloomingdale, N. J., Bucks County, Pa., and Sturbridge, Mass., being found in graphitic gneiss; but the chief place in the United States where it is mined at present is near Ticonderoga, N. Y., where it is obtained from a graphitic schist, about fifteen feet thick, and containing from 8 to 15 per cent of disseminated graphite. This locality yielded two hundred net tons of graphite in 1882, the remainder of the United States producing only twelve tons. In Ottawa County, Quebec, extensive deposits occur in the Laurentian limestones, containing in some localities 20 to 30 per cent of disseminated graphite. Fissure-veins are also found here, which yield a very pure mineral, but it is said to be usually in quite limited amounts. Graphite deposits have also been worked at intervals in the Archæan rocks near St. John, New Brunswick, and it is reported to occur in graphitic schists in the Archæan area of northern Michigan, as also in some of the Western Territories. The Island of Ceylon furnishes it in immense vein deposits of singular purity at Travancore, and from these the largest supplies of the world are derived, although Austria and Bavaria produce annually from 15,000 to 18,000 metric tons. The rocks in which available graphite is most likely to be found are, therefore, those of Archæan age, though small amounts occur in strata as late as the coal-measures. The famous deposit of Borrowdale in England, which is now no longer worked, occurs in veins in interbedded trap; and its product was once sold at from $8 to $12 per pound, for the manufacture of pencils, extraordinary precautions being taken to prevent theft. The present price of graphite is from $25 to $200 per ton, according to its purity and fineness.

The properties on which depend the important uses of graphite in the arts are its infusibility, its unchangeableness in the air, even when exposed to high heat, its soft, unctuous texture, its ready conduction of electricity, and its graphic quality, from which is derived its name graphite, from the Greek *grapho*, I write. Of these, its infusibility properly concerns us in this place; but, for the sake of completeness, its leading uses may be briefly enumerated here, although some of them belong properly in the succeeding chapter, where they will be referred to. Fully one third of all the graphite that is produced is used for refractory articles, such as small furnaces, nozzles and stoppers for the Bessemer process, and crucibles for melting steel, silver, copper, and brass. For these purposes it should be free from lime and iron oxide, with which it is liable to be contaminated; since, for such uses, it must be intimately mingled with a proper proportion of fire-clay to give it strength, and the silica of the clay would form fusible compounds with iron and lime. Other large uses of graphite are for stove-polish, to protect iron articles from rust, and for foundry-facings, two fifths of the product being employed for these purposes, an additional amount being also used for glazing powder and shot. A fourth highly important and increasing use is for the lubrication of heavy machinery, in which it is employed in the state of a fine powder, and in various patent greases. Its use in pencil-leads is familiar to every one, besides which it is considerably employed in electrotyping and for several minor purposes.

Although caustic *lime* is one of the most infusible as well as most easily obtained of known substances, it is not capable of being used in the large way as a refractory material, because of the readiness with which it absorbs water from the air and then crumbles to powder. It is, however, used for constructing the small furnaces and crucibles in which platinum is melted and refined by the heat of the oxyhydrogen blow-pipe flame, a small but quite important use. Caustic *magnesia* is also highly infusible, and in Germany is converted into a very refractory brick, being cheaply obtained from the waste liquors of the Stassfurt salts described in a preceding chapter, by precipitation from its chloride by milk of lime, or by subjecting the chloride to the action of an oxidizing flame and superheated steam. A cheap and effective mode of utilizing in the large way the refractory properties of a combination of these two alkaline earths has recently been devised, whereby the lime produced by calcining strongly a somewhat silicious dolomite is made into a paste with pitch, and then molded into bricks, or used directly as a refractory lining for Bessemer converters. By gradual heating, the pitch is burned out, and the refractory earths are left in the shape required. This is the so-called "basic lining," by the agency of which a considerable percentage of phosphorus may be eliminated from iron, rendering available, for steel-making purposes, iron hitherto wholly unfit for this use. Magnesian limestones, suitable for this purpose, are widely distributed among the geological formations, and need no special mention in this connection. It is said by Bloxam, on the authority of Gilchrist, that the best composition of a magnesian lime for the basic process is, lime, 52 per cent; magnesia, 36 per cent; silica, 8 per cent; alumina and iron, 4 per cent.

Steatite, called commonly *soapstone* or *potstone*, is a soft, compact, gray or greenish form of talc, and derives its name soapstone from its soapy feel. In composition, it is a hydrous silicate of magnesia, and is highly infusible, on which account it is considerably used as a fire-stone in hearths, stoves, and furnaces, and for register borders and pipe-holes, as also in gas-jets and in several articles for household purposes. It is found in the ancient crystalline rocks of the Atlantic border States, and is quarried chiefly in Vermont and New Hampshire, though similar deposits are known to occur in several other States.

Mica and Asbestus.—The leading uses of these two minerals are based upon their infusibility, coupled in the one case with toughness and great transparency, and in the other with a highly fibrous texture and a very slight conductivity for heat. The only desirable variety of mica is *muscovite*, in large transparent crystals, free from irregularities and accessory minerals. Such crystals occur chiefly in veins of exceedingly coarse-grained granite, and, as might naturally be expected, they are to be sought for chiefly in regions of Archæan rocks, as along the Appalachian range, and in the vicinity of the Rocky Mountains and the Sierra Nevadas. The chief production of mica has hitherto been from western North Carolina, and from the Black Hills, near Deadwood. In North Carolina, according to the Geological Report of that State in 1875, the mica occurs in veins of coarse granite with walls of gneiss, in which are found rude crystals of mica weighing from thirty to fifty pounds, and in a few instances even as much as a thousand pounds, affording, occasionally, sheets three feet across. The most profitable workings here are on the sites of pits and galleries of some ancient race of men. Similar ancient workings are reported by Prof. Smith to exist at various points of eastern Alabama, giving promise of merchantable mica in that State. The mica from the Black Hills is reported to be of very fine quality, and plates of large size are sometimes produced. "The main ledge is said to be fourteen feet wide, and to consist of a central mass of feldspar and 'porphyry,' with a casing of mica which varies in width from three to four feet on each side. The country rock is granite." Mica is produced also in Maine and New Hampshire; and a company with large capital is reported to have been lately formed in Marquette to develop a promising mica property in northern Michigan, and another in Chaffee County, Col., for a like purpose. It is well to bear in mind that it has been observed in North Carolina that, wherever hornblendic rocks or chloritic schists form the walls of the mica-bearing veins, the mica is apt to be badly specked with magnetite. The chief use of mica is for the transparent plates of stoves and furnaces, and for lanterns, some of the larger plates being also occasionally utilized in surveyors' instruments in the place of glass. Finely pulverized mica is also used as an absorbent of nitroglycerine in one variety of high explosives, and likewise as a finish for wall-papers, and for some other ornamental purposes. The price of sheet-mica varies at present from twenty-five cents to five dollars per pound, according to size and quality, exceptionally large and fine sheets bringing even a higher price.

Asbestus affords a curious example of a mineral whose leading properties have been known for many centuries, and have caused it to be somewhat used by the ancients for incombustible fabrics, which were objects of curiosity rather than of practical utility; yet whose important industrial capabilities have been neglected until very recent years. It is a fibrous form of several minerals, like hornblende, pyroxene, and serpentine, is of a white, light green, or brownish color, and is practically infusible by the heat of ordinary fires. The most valuable kinds occur in long, silky, parallel fibers, which are strong and flexible, and capable of being spun like flax by proper machinery, and woven into fabrics that are incombustible. Hence its name, which is a Greek word applied to the mineral with reference to this property. Other varieties, in which the fibers interlace so as to form a kind of natural felt, are called *mountain leather* and *mountain cork*, while the fine, silky, fibrous variety is sometimes called *amianthus*, from a Greek word meaning *unpolluted*, because the fabrics woven from it, when soiled, may be readily cleansed by passing them through fire. To be of any considerable economic importance, asbestus needs to have length and fineness of fiber, combined with toughness and flexibility. These qualities are often lacking in mineral which has a promising appearance, the fiber being short, or brittle and harsh to the touch, making a substance of little or no value. Hence the expediency, when a new deposit is discovered, of having the mineral carefully tested in respect to these qualities, before incurring any considerable expense in working it. Asbestus is found in regions of crystalline rocks, most commonly associated with serpentine, occupying vein-like crevices which are of uncertain and usually quite limited extent, causing great difficulty in mining it with profit. The finest is produced in the Italian Alps and in Corsica; but a considerable amount of asbestus of good quality is obtained from the Province of Quebec, from several of our Atlantic seaboard States, ranging from New York to Georgia, and from some of the far Western States, especially California. Doubtless more diligent search within our great areas of crystalline rocks, stimulated by the rapidly growing demand for this mineral, will result in many new discoveries, some of which may yield an article equal in quality to the best Italian.

The uses of asbestus are based upon its fibrous texture, its resistance to fire, and its very feeble conduction of heat and electricity. It is most largely used for packing the joints and working parts of steam-machinery; for covering boilers and steam-pipes to prevent loss of heat by radiation; and as a fire-proof lining for floors and ceilings, and for the walls of wooden buildings. For some of these purposes it is spun into yarn by the aid of special machinery, or woven into sheets and tape, with the addition, for some uses, of India-rubber; for others, it is felted and pressed into sheets of a kind of paper called *mill-board*, of any required thickness. In this latter form it is used also as an insulator in dynamos. It is woven into fire-proof cloth for the drop-curtains of theatres, for furnace-men's aprons and leggings, and for other similar purposes; and it has been proposed to construct from such cloth light fire-proof shields to protect firemen from the heat of conflagrations. Twisted into cord and rope it may be used for fire-escapes, since it has great tensile strength. It has long had a limited use in incombustible wicks for lamps, for which it is admirably adapted. It is also used for making fire-proof cements and paints. There is no reason to doubt that, with the probable increase in the production and diminution in cost of this useful mineral, there will be a large increase in its industrial applications in the immediate future.

The United States production of asbestus in 1882 was reported to be twelve hundred tons, and its average value at the mines about thirty dollars per ton, varying from fifteen to sixty dollars, according to quality, exceptionally fine mineral commanding much higher prices than these.

With reference to the substances treated of in this chapter, the student can profitably consult the following works, to which many others might easily be added: Bloxam on Metals—the chapter on "Refractory Materials"; "New Jersey Report on Clay Deposits," 1878, and Annual Report for 1880; "Ohio Geological Report," Vol. V; "Geological Report of North Carolina," 1875; "Geology of Canada," 1863, section vi of chapter xxi; "Mineral Resources of the United States," 1883; also any good encyclopædia; and the files of the "Engineering and Mining Journal," by the aid of its excellent indexes.

CHAPTER XXI.

MATERIALS OF PHYSICAL APPLICATION.

A VERY considerable number of purposes, some of which are sufficiently common and consequently of a high degree of importance, are subserved by substances of geological origin by reason of their possession of certain physical properties, as texture, hardness, and color; little previous preparation, and that of a purely mechanical nature, being necessary to adapt them for their uses. Such are the substances which are used for mending roads and improving streets and walks; for grinding various kinds of grain as well as many minerals; for giving a keen edge to cutting instruments, and for imparting a fine polish to wood, stone, and metals; for drawing purposes, and for the cheap and rapid reproduction of pictures; for diminishing friction; for making molds for castings in metal; and for some other uses of analogous character. The mere enumeration of these utilities is sufficient to show how nearly some of them touch the comforts and conveniences of civilized man; how much others affect the efficiency of his efforts; and how intimately still others concern his opportunities for refinement.

Materials for Roads and Walks.—The commercial rank and the industrial advancement of any community are pretty fairly expressed in the excellence of its means of communication, not merely by lines of railway, but also by those more numerous and highly important avenues of travel and intercommunication which afford ready access to every hamlet and every home. The improvement of country roads is usually effected by the judicious use of those materials which are most easily accessible in any given locality. In very many regions, deposits of gravel, the accumulations of streams, and sometimes of the ocean, or the relics of the glacial age, afford a convenient means of improvement, which, from the usual hard and silicious nature of the pebbles, is both cheap and durable, making, with due preparation of the foundations, and by proper arrangement of the coarser and finer portions, excellent and enduring roadways. In some few localities where gravel is not found, ledges of conglomerate, not too closely cemented, may be accessible, which, at some slight cost for crushing, may afford excellent material for roads. In other cases, silicious limestones of the vicinity, crushed by rock-breakers, or broken to proper sizes with hammers, are used for road purposes, needing occasional renewal on account of the comparative softness of the stone. Harder and more enduring material is afforded by the hornstone and chert, which occur at most of the exposures of the largely quarried Corniferous limestone across the State of New York and westward, and which are found accompanying some of the limestones of the Lower Carboniferous age in the Western States. In regions of crystalline formations, rocks of the granite class—quartzites, felstones, tough porphyries, and still tougher traps—may be made available for road-metal. All these rocks, of hard and tough character, can be most cheaply reduced to sizes proper for macadamizing roads by means of rock-crushers driven by steam or water power; and though the first cost of the roads constructed from such materials may be somewhat large, yet their convenience and durability, when once properly made, will more than compensate for the original outlay. In European countries, permanent roadways are constructed from all the substances that have here been enumerated; their use is increasing in the more thickly settled portions of our own country; and there can be no doubt that, ere long, a people so progressive and so practical as ours will become impatient at the too often wretched condition of our roads, and will seek, in durable rock materials, for a permanent means of improvement. The need of previous careful drainage, and the preparation of a suitable foundation for a road, before using any of these materials, has not been insisted on here, because it is a matter which belongs rather to the road-engineer than to the geologist.

For those streets of cities and large towns which are devoted chiefly to residences, and which are little used for transportation, macadamized roadways, properly constructed of materials such as have already been mentioned, present the advantage of being comparatively noiseless—an advantage which may compensate in a good degree for their liability to dust in dry weather. But for streets which are much used as thoroughfares for heavy traffic, the road materials need to be employed in larger and more solid forms, to secure stability under stress. For this purpose, rectangular blocks of hard and tough varieties of stone are used, arranged in courses, such width of the blocks being best as affords the most convenient hold for the feet of horses. A number of kinds of rock are well adapted to this use, such as granites, hard sandstones, quartz schist, felstone, trap, and porphyry. The granites most suitable for pavements are those of medium fineness of grain, in which quartz rather than feldspar is a dominant ingredient, or those into which hornblende enters in a considerable amount, those being naturally selected in which a somewhat easy *rift* in certain directions facilitates their reduction to proper shapes. Quartz schists, or those highly silicious mica schists in which the mica is barely in sufficient amount to impart a schistose structure, may be wrought with ease into good paving-blocks. Felstone is also sometimes used for pavements where its structure admits of easy working. These three kinds of paving materials may be obtained in those regions of Archæan rocks which were described in the chapter on building-stones, and which have since been several times mentioned. In a number of our Northern cities, of which Rochester, Buffalo, and Cleveland are examples, a silicious sandstone obtained from the lower member of the Niagara period in western New York, and called the Medina sandstone, from one of the villages where it is largely quarried, is extensively used for pavements, and is found excellent for this purpose. In the region about Medina and Albion it is a hard, well-cemented sandstone of extraordinary strength, susceptible of being wrought without much difficulty into convenient blocks, and of sharp grit, so that it shows little tendency to become smooth by wear. In the northeast part of New York, also, very hard silicious sandstones occur in strata of the Potsdam period, which are admirably suited for use in paving. In the immediate neighborhood of New York city, at many points in Connecticut and New Jersey, and in elongated belts of strata which stretch parallel to the Atlantic border even to the boundary of South Carolina, occur dikes of basaltic trap-rock which has a very extensive use for paving-blocks. It is a hard, heavy, and very tough rock, and makes pavements of unsurpassed durability; but its tendency to become smooth and slippery by wear renders it expedient to shape it into narrower blocks than those which are commonly used. It is perhaps needless to say that only those portions of the trap-rock are fitted for this use whose structure admits of their being easily split into the required forms.

It will be seen, therefore, that for all purposes of road construction, a rock needs to be *hard*, that it may endure wear; *tough*, that it may not easily yield to blows; of such *structure* as to admit of being wrought without too great expense; and, if possible, of such *texture* as to remain somewhat rough in use.

The qualities which are desired in a material for the construction of sidewalks, and for some other kindred uses, are evenness of surface, closeness of texture to resist the penetration of moisture, and a sufficient degree of hardness to withstand the kind of wear to which it is to be subjected. The ability to secure slabs of different dimensions and thickness, to adapt them to use under a variety of circumstances, is also very desirable. These qualities are well combined in what are called *flag-stones*, which are even-bedded and somewhat argillaceous sandstones, occurring in sheets of from two to eight inches in thickness, associated with shales and thicker bedded sandstones. Such flagging is largely quarried in beds of the upper part of the Hamilton period and of the Lower Chemung (Portage group), near the Hudson River, in Ulster and Greene Counties; at the south end of Cayuga Lake near Ithaca, in strata of the Chemung period; in the northern part of Wyoming County, Pa., in strata which are referred by the Pennsylvania geologists to the lower part of the Catskill period; and near Warren, Ohio, in beds of the Lower Carboniferous (Waverly group). Where such flagstones can not be obtained without too great expense, resort is often had to thin-bedded or easily divided rocks of other kinds. Thus, thin-bedded limestones are sometimes applied to this purpose, though the surface is liable to be somewhat uneven, and to become dangerously smooth by use. In northern Ohio, soft sandstones, of Lower Carboniferous age, are split or sawed into slabs of proper thickness, which, although somewhat porous and liable to wear, make very handsome walks. In many localities, sidewalks and sometimes roadways are constructed from a concrete of fine gravel, pulverized limestone, and asphaltum, or of sand and hydraulic cement, which, when properly made, are very good.

Asphaltum, for this purpose, is obtained chiefly from the Island of Trinidad, and some also from Santa Barbara County, Cal., which is used on the Pacific coast. The tar from gas-works serves as a fair substitute for asphaltum for this use. Many of the streets of Paris are paved with a calcareous asphalt, obtained from Val de Travers and elsewhere in Switzerland; and this substance is also imported into the United States to a considerable extent, to be used in sidewalks and for coating roofs. The Geological Report of Canada for 1880–'82 announces the discovery, on the Athabasca River, of a bituminous sand-rock, which is probably suitable for walks and water-proofing. It is worthy of consideration whether a valuable application of such water-proof concretes could not be made in the pavements of cities, especially on streets devoted to residences, by using them as an impervious cement between the paving-blocks, thus preventing, at least in a measure, the unhealthful emanations which arise in warm weather from the putrefaction of organic matters, while at the same time guarding against displacements by the action of frost.

This enumeration of some of the leading geological substances which are utilized for roads and walks may serve as an indication of those physical properties of rocks and minerals which best adapt them to such uses, and may guide the inquirer to still other substances in his own neighborhood that may be employed for a like purpose.

Abrasives.—What are here classed as abrasives are those rocks and minerals which, by reason of their intrinsic hardness, or of certain grades of hardness and texture, are used for sharpening all kinds of edge-tools, for triturating grain and minerals, for polishing wood, stone, and metals, and for rock-drills. These are, with a single exception, wide-reaching as well as important uses, affecting the convenience and efficiency of many arts and trades, and some of them concerning every household. And foremost among these in treatment as in importance may justly be placed those substances used to give a keen edge to cutting instruments, the grindstones and whetstones; for, not to speak of the many occupations which owe much of their efficiency to the excellence and variety of their edge-tools, there are few individuals who do not find daily occasion to use such articles as knives and scissors.

A better description could not well be given of the conditions which must combine to make a good grindstone-rock than that of Dr. Dawson, in his "Acadian Geology," p. 154: "These grindstones have been formed from beds of sand, deposited in such a manner that the grains are of nearly uniform fineness, and they have been cemented together with just sufficient firmness to give cohesion to the stone, and yet to permit its particles to be gradually rubbed off by the contact of steel. A piece of grindstone may appear to be a very simple matter, but it is very rarely that rocks are so constituted as perfectly to fulfill these conditions." The infrequency of occurrence here spoken of is well exemplified in this country and Canada, which, in all their vast area, have as yet developed but three or possibly four regions in which occur strata of the proper quality to yield first-rate grindstones: one, near the head of the Bay of Fundy in Nova Scotia; a second, in northern Ohio, near and west of Cleveland; and a third, at Point au Barques in Michigan. These are all in strata of the Carboniferous age, and mostly in its lower portion; though one of the two geological horizons which yield grindstones in Nova Scotia lies above the productive coal-seams. Besides these localities, what is called the "Gray Band," in the lower portion of strata of the Niagara period (Medina group), in the Province of Ontario, Canada, is said at some points to present the characters requisite to make grindstones of good quality.

It is interesting to observe that in England, also, most of the rock which is used for grindstones is derived from the grits of the Carboniferous age. Of this age are the grindstones quarried near Newcastle and Sheffield, as also in Yorkshire and Staffordshire, and at a few other localities. It would seem that in this age, more frequently than in the others, conditions were presented favorable for the formation of an even-grained, homogeneous sand-rock, not too closely cemented.

Rock suitable for the manufacture of whetstones and hones is composed of some very hard mineral, like quartz, and occasionally garnet, in the condition of fine, even grains, cemented to a firm mass. If the grains are somewhat coarse, the stone cuts down instruments rapidly, but gives a coarse edge. In the best honestones for delicate instruments, the grain is almost imperceptibly fine. The finer-grained and stronger portions of grindstone-rock are wrought into a coarser kind of whetstones for sharpening farm implements and other tools, in which a fine, smooth edge is not required. Stones of similar character but tougher fiber are made from mica schists or slates which contain, thoroughly disseminated, a large proportion of fine-grained silica. Such is the rock which is manufactured into whetstones in the southern part of Quebec on Lake Memphremagog, at Bridgewater, Vt., and doubtless at other points in regions of mica slates. Whetstones for finer uses are made from varieties of very fine-grained silicious slates called *novaculites*, some of the most valued among which are nearly pure quartz in an excessively minute state of division, and cemented by silica. Such is the Arkansas or Ouachita oilstone obtained at the Hot Springs of Arkansas, which, according to two different analyses, contains from 98 to 99½ per cent of silica. This rock is of the age of the Lower Carboniferous, and, according to Dr. Owen, it owes its snowy whiteness and its impalpably fine grain to the long-continued action of hot silicious waters. The finest of these stones are known to the trade as Arkansas oilstones, while those of somewhat coarser grain are sold at much cheaper rates as Ouachita stones. The Turkish oilstones are also highly esteemed, their grain being slightly less fine than that of the best Arkansas stone. The very superior yellow Belgian hone-stones owe their fine quality to microscopic garnets set in a garnet paste.

For the grinding of grain, almost any hard, tough, sharp-grained rock will serve fairly well, and several kinds of rock of this character have been and still are employed locally for this purpose, some of which have even more than a local use. Thus, tough, coarse-grained gneisses, and some firmly cemented conglomerates, are so employed. A white, hard, sharp-grained sandstone, of sub-Carboniferous age, found at Peninsula, O., is used near where it is found, and also sent elsewhere, for preparing oatmeal and for pearling barley, for which purposes it appears to be specially fitted. A basaltic lava, found in Germany, is used for millstones, especially for grinding minerals, because of its peculiarities of texture. The rock, however, which is most suitable for millstones of any yet known, is a highly cellular quartz-rock called *buhrstone*. That which has the highest reputation, and is most largely used, is obtained from the vicinity of Paris, France, from rocks of earlier Tertiary age. It is of fresh-water origin—indeed, often contains great numbers of silicified fresh-water shells, and in the best portions the cellular spaces occupy more than one third the bulk of the stone. Its superiority is due to its cellular structure and its hardness. The stone is cut into blocks of proper form, which are fitted together and held to their place by iron bands to form millstones. Rock of similar character, and in strata of about the same geological age, is found also in South Carolina, Georgia, and Alabama. The use of millstones in making flour has been, to a considerable extent, superseded in large flouring establishments by that of iron rollers; but for other purposes, and in most small mills, there is likely to be always a wide demand for stones to be used in grinding. There will be needed here no more than an allusion to the use of stone in heavy wheels for pulverizing clays, quartz, and other minerals as well as ores, and for some pulping purposes; and the much ruder use of heavy stone blocks, dragged round and round on a pavement of stone, for grinding ores in the *arrastra*.

For the rapid grinding, cutting, drilling, and polishing of the harder rocks and minerals and of steel, resort is had to the hardest of known minerals, the *diamond* and *corundum*, or to the impure and somewhat less hard but tougher variety of the latter mineral called *emery*. The diamond, because of its rarity and great cost, is confined to special uses. Small crystals and angular fragments are firmly cemented into handles to be used in cutting and ruling glass, in drilling and cutting rubies, sapphires, and some other gems, and for the fine dressing of millstones. Diamond drills, used for prospecting mineral deposits and veins at considerable depths, are made by cementing small diamonds around the edge of a hollow cylinder of steel. This, being swiftly revolved by machinery, not only cuts rapidly through rocks, but also enables the miner to bring up from various depths a solid cylindrical core of rock for examination. For this purpose, black diamonds, not suited for jewelry, are used, called *borts*, *carbons*, or *carbonados*. They are procured, it is said, chiefly from the Brazilian diamond regions. Other diamonds of inferior quality are used for the other purposes that have been named, or crushed to fine powder to be used for cutting and polishing the harder gems and the diamond itself.

The mineral *corundum*, which is inferior only to the diamond in hardness, in the condition of transparent crystals of various colors furnishes the gems sapphire, ruby, emerald, etc. That which is used as an abrasive is most commonly gray and imperfectly transparent, and is of no value as a gem. It has been found in the Appalachian region of the United States at many localities, the most important of which are in Clay and Macon Counties, N. C., and Chester County, Pa. Masses of corundum are said to have been found in Clay County, N. C., weighing from three to six hundred pounds, associated with the olivine rock of that region. It is estimated that about five hundred tons are produced annually by the United States. *Emery*, which is an impure form of corundum contaminated with varying amounts of iron oxide, whence it derives its dark color, is obtained chiefly from near Smyrna, in Asia Minor, where it occurs in considerable masses, and from the island of Naxos. It has also been mined at Chester, Mass. Both corundum and emery are pulverized to a powder of different degrees of fineness for different purposes, and sold, under the name of emery, for polishing glass and the harder kinds of stone and metals, a large part of the price at which it is sold being due to the labor of reducing to fine powder minerals of such hardness. The powder of emery, though not so hard as that of pure corundum, and hence not abrading so rapidly, is said to be less brittle and so more durable. What are called emery-wheels, so largely used in machine-shops for grinding and polishing iron and steel, are made by mixing powdered emery into a paste with water-glass, fire-clay, or some other cementing material, then molding into the proper shape and baking. Emery-paper is made by cementing emery-powder to stout paper with glue. Sand-paper, to be used for polishing wood, is made in like manner from sharp quartz sand.

Sand is also largely used as an abrasive in sawing and rubbing to a smooth surface marble and sandstone. Other mineral substances, which are utilized for polishing wood and stone, bone and ivory, as also metallic articles, are *pumice* and *tripoli.* Pumice is a light, porous, felspathic lava which is brought chiefly from the neighborhood of Mount Vesuvius and the Lipari Islands, but is said to occur abundantly also in San Francisco County, Cal. Tripoli is a silicious, infusorial earth of very fine grain which is found near Richmond, Va., and Monterey, Cal., as also in Nevada and at a number of foreign localities. Tripoli has also been somewhat used as an absorbent of nitro-glycerine in making dynamite.

Graphic Materials.—What have been thus grouped in this place are those geological substances which, by reason of their texture, softness, color, and some other properties, are used with no other than a mechanical preparation for making, or for receiving and transferring, drawings and writings. As is well known, great improvements have been made within the present century in the adaptation of means for these purposes, whereby the multiplication of writings and of works of art has been greatly facilitated and cheapened, to the great advantage of business, while bringing within the reach of all classes of people better means for cultivating a refined taste, and for the illustration of subjects otherwise difficult of comprehension. Some portion of this improvement has been due to the discovery, or adaptation and preparation, of geological substances, such as graphite, chalk, steatite, and lithographic limestone. *Graphite*, the mode of occurrence and localities of which have been given in the preceding chapter, has long been used in pencils for drawing and writing, being sawed into slender prisms from blocks of granular graphite ; and for this use that of Borrowdale, England, had a special value, being pure and of granular texture. Now, however, purified graphite, in a fine state of division, is either compressed into solid masses by hydrostatic pressure, to be afterward sawed into pencil "leads," or else mingled into a paste with certain proportions of the finest clay, run into molds, dried, and heated to such temperatures as are needful to secure the degrees of hardness which are requisite for different purposes. *Chalk*, so largely used in crayons for school and other purposes, is a soft, white, earthy limestone, composed of the calcareous skeletons of microscopic organisms. This forms nearly the uppermost deposit of rocks of the Cretaceous period in southern England and northern France, where it covers considerable areas. Because of its peculiar soft and friable condition it is easily pulverized and molded into proper shapes, either alone or mingled with various coloring ingredients. Its physical condition fits it also to be used in some porcelain mixtures, and to be mingled with a proper proportion of clay for burning into hydraulic cements. The so-called *red chalk*, used for graphic purposes, is an argillaceous ochre, i. e., a soft, earthy form of red iron oxide mingled intimately with clay, which occurs in regions of iron-ores. The massive granular form of talc, called *steatite* and soapstone (see preceding chapter), is used, under the name of French chalk, for marking on cloth, and in crayons for drawing in fine white lines on a dark ground ; and *pyrophyllite*, a soft, aluminous silicate, closely resembling talc in its light colors, its softness, and its greasy feel, is much used for slate-pencils. The latter occurs in the Archæan slates of Georgia and both Carolinas, and near Little Rock, Ark.

The very important graphic material known as *lithographic limestone* is a very fine-grained, compact, and perfectly homogeneous limestone, of conchoid fracture, and usually of a pale-gray or yellowish tint, and having a sufficient degree of porosity to slightly absorb water and oil. On the smoothed or finely granulated surface of such a stone, drawings are executed with a properly prepared *greasy* pigment, called lithographic chalk and lithographic ink, or such drawings may be transferred to it from specially prepared paper. The stone absorbs the greasy drawing material sufficiently to retain it firmly, and, if it now be moistened with water, all except the greasy portions absorb the water and become wet. A roller charged with the oily printer's ink, passed over the moistened stone, will now *wet* only the greasy lines of the drawing, which may then be printed from as from an engraving. Limestones possessed of this peculiar combination of characters are very rarely met with. Hitherto they have been obtained wholly from certain thin-bedded limestones of the upper part of the Jurassic period at Solenhofen, Bavaria, a locality famous also for the remarkably preserved fossils which it affords. Limestone of the required quality is, however, reported to occur in strata of the Trenton period in Marmora, Hastings County, Ontario, and in a yellowish dolomite of the Salina period on the Saugeen River in Bruce County, of the same province. It is said, also, that lithographic limestones in small slabs may be obtained at some localities in the Lower Carboniferous limestone of Missouri, portions of which, however, are apt to show spots of different texture, and so to be worthless.

Pigments.—A great majority of the pigments that are in common use are derived from the metals by chemical processes, and hence have already been mentioned in their proper places among the useful applications of the metals from which they are derived. Such, for example, are the various pigments manufactured from lead, zinc, chromium, mercury, arsenic, antimony, copper, and cobalt. Besides these, however, there are some other substances which, with no other than a mechanical preparation, are used as cheap pigments. Thus, *graphite*, so largely utilized for other purposes that have been mentioned before, is also somewhat used as a black paint. Finely pulverized *chalk*, under the name of *whiting* and *Spanish white*, is used as a white or tinted wash for walls; and caustic lime is also widely employed for the same purpose. Besides these substances, which have already been described in other connections, *ochre*, *umber*, and *barytes* have a large use as pigments. *Ochre* is a soft, pulverulent form of hydrated peroxide of iron, mingled usually with more or less considerable proportions of clay, silica, and organic matter, and affording various shades of yellow, red, and brown. It occurs in deposits of various geological ages, and often as superficial accumulations of recent periods. Thus, the softer earthy portions of some hematite beds are ground and used as pigments, called *iron paints*. The ochre deposits of Great Britain are found chiefly at the base of the Cretaceous system, while the extensive beds of ochre along the St. Lawrence in Canada are superficial deposits which, in some cases, are interstratified with peat, and have been accumulated by the solvent action on iron compounds of organic acids resulting from vegetable decomposition, and the subsequent deposition of the iron oxide by atmospheric oxidation. Ochre is procured also from the muddy ferruginous waters pumped from mines. Its color may be greatly modified by calcination, thus driving off its water of hydration. Beds of red and reddish-brown clay-rocks, colored by iron oxide, are also ground and used as a cheap paint. *Umber* is a soft, earthy variety of ochre, which is colored brown by oxide of manganese, and becomes reddish brown by calcination. It occurs usually in crystalline rocks, and is brought mostly from the island of Cyprus. It is found, also, at a few localities in Great Britain, and is said to be produced to some extent in this country.

The mineral *barytes*, called also *heavy spar*, because of its great specific gravity, is a white crystalline or massive sulphate of baryta, of about the same hardness as calcite, and is fusible by the blow-pipe, giving a green color to the flame. On account of its great weight, it is little liable to be mistaken for any other white mineral save celestite, which has nearly the same weight and hardness ; and from this, the color imparted to the blow-pipe flame readily distinguishes it, that of celestite being a bright red. It occurs commonly as a vein-stone, especially in veins of lead and copper. It is found in workable quantities at quite a number of localities in North America; as in the copper veins on the north shore of Lake Superior; in the central Missouri lead region, especially in Miller and Morgan Counties; in several counties of East Tennessee, being worked in some; and in Wythe, Smyth, and Campbell Counties, Va., a single mine in the county last named being reported to be able to produce a hundred tons per day. Considerable amounts are produced also in Pennsylvania and Maine. The largest production is from Missouri and Virginia; Connecticut grinds also a large amount of barytes imported from Germany. About twenty-five thousand tons a year are mined in the United States, of which much the largest part is used for mixing with white lead and zinc white, in the preparation of white paint. This employment of barytes is commonly considered an adulteration, and manufacturers do not seem eager to publish the fact of its use; yet, when properly prepared, it produces a good opaque white color, which is not, like lead, liable to discoloration from sulphuretted hydrogen.

Lubricators. — The mineral substances which are most largely employed for diminishing friction in machinery, viz., *graphite* and the heavy varieties of petroleum, have already been mentioned in other connections as fitted for this use. The foliated varieties of *talc*, when free from needles and grains of the harder minerals, are also used to a considerable extent in lubricating compositions. This last-named mineral, which, like soapstone, its massive form from which it is distinguished commercially, occurs in crystalline schists, is found in several of the States of the Atlantic border—most largely in Georgia, Pennsylvania, New York, and Vermont. The fibrous form of this mineral, which is found in considerable quantities near Gouverneur, N. Y., is quite largely mined and ground for pulp to be used in paper-making. It may readily be judged that only the fibrous variety could be used for this purpose, since only this has any staple to form a felt; and the St. Lawrence mineral may, it is said, enter into printing paper to the extent of twenty per cent, or even more. Talc has also a quite extensive use in soap-making, and in dressing skins and leather, these various applications rendering it a mineral of considerable economic importance. In the "Geological Report on the Midland Counties of North Carolina," 1856, Prof. Emmons speaks of a valuable *anti-friction* hornstone as abounding in several counties of that State. This rock, probably a felstone, since it graduated into porphyry, was of flinty aspect and very fine and compact texture, and was highly valued locally as a bearing for the axles of heavy wheels. From its fine texture and great hardness, this distinguished geologist pronounced it to be fitted to take the same part in diminishing the friction of heavy machinery that rubies play in the works of watches.

Molding-Sand.—This substance, which is of so much importance for foundry use, is an intimate mixture of quartz sand with just sufficient proportions of clay and ochre to enable it to retain the form given by the pattern, and to withstand in founding the current of molten metal without displacement. If the proportions of the cohesive substance are too small, even if the mold retains its form before it is used, it is apt to *wash*, i. e., to be swept away in places by the flowing metal, and so to cause irregularities in the casting, or to ruin it wholly. If, on the other hand, there is more clay than is needed, it is *burned* in the founding, and forms a crust on the casting which is somewhat troublesome to remove. A good sand for molder's use should contain about 92 per cent of fine quartz sand, 6 per cent of clay, and 2 per cent of iron oxide. The fineness and delicacy of the impression that can be given will depend on the fineness of the sand that is present in the molding mixture. For some very fine castings, an artificial mixture is prepared by calcining loamy sand, grinding it very fine, and adding some substance to impart the necessary adhesiveness. Good molding-sand is of a yellow color, soils the fingers when dry, and when damp, if grasped in the hand, it retains a delicate impression of the fingers. It occurs in superficial deposits, usually of no great thickness, and is liable to great variations in quality at points little removed from each other. Molding-sand is by no means of common occurrence, and the foundries of very considerable sections of country are often obliged to depend for their supplies on material brought from a distance. Saratoga County, N. Y., furnishes a molding-sand of fine reputation and of various qualities fitted for special purposes, which is transported to long distances. Good sand for this purpose is found at some localities in New Jersey, from which supplies are sent to the Southern seaboard States. Tompkins County, N. Y., has a fair quality of sand which supplies the local demand for ordinary foundry uses. For some purposes, as for large castings in bronze, molding-sand is even imported from Europe. For the facing of molds, called *foundry facings*, graphite is largely used, as has already been said. A cheaper facing, and one which, for some purposes at least, is less liable to *wash*, is afforded by hydraulic lime.

CHAPTER XXII.

ORNAMENTAL STONES AND GEMS.

A TREATISE which is intended to present any just view of the contributions which geology makes to the supply of the multifarious wants of mankind, can not omit some account of those substances which, while not ministering to man's necessities, nor promoting his comfort, nor increasing the efficiency of his efforts, are nevertheless strongly desired by him as a gratification to his tastes, as the expression of his wealth and social consequence, or as fitted to be fashioned into the most permanent monuments of his culture and refinement; objects which, though not necessary, are yet essential, because without them something would be lacking for the complete satisfaction of his many-sided nature. Man loves beauty and craves ornament, and all that ministers to this sentiment and craving is more elevating in its tendency than what satisfies merely his bodily wants. Many of the substances which are drawn from geological sources lend themselves to these higher wants of mankind by their durability, combined with their beauty, their brilliancy of color or of luster, and often their rarity. Several of them are found in considerable abundance, and a great part of the estimation in which they are held is due to their adaptation to the purposes of refined and artistic workmanship. Such are the *ornamental stones*, the objects wrought from which usually far surpass the raw material in value. Others add to beauty of color and brilliancy of luster a greater or less degree of hardness and of rarity, and, while gratifying the taste of their possessor, become in a certain degree badges of his wealth and importance. Such are the *gems*, a large part of whose value is usually intrinsic, i. e., dependent in but a minor degree on excellence of workmanship.

Ornamental Stones.—On account of the hardness and unalterability of the mineral, the various forms of *quartz* have, for many centuries, been used for ornamental purposes. The transparent varieties were fashioned by the ancients into crystal cups and vases, and set in jewelry. Its use for most such purposes is now largely superseded by that of the finer kinds of glass, which are more brilliant and cheaply formed, but more liable to be marred in use because of their inferior hardness. Clear white quartz has a considerable use in lenses and for spectacles; and under such names as Rhine-stone and California diamond, quartz is still quite largely cut and polished for cheap jewelry, that which is of a clear yellow color figuring as false topaz, and that of a smoky tint as Cairngorm-stone. The purple variety of quartz called amethyst, when transparent crystals of sufficient size and proper depth of color are met with, is cut for valuable jewelry. Much, however, that is sold under these various names is artificial, being made from strass. Handsome crystals and clusters of crystals of quartz are held in some estimation as household ornaments. Fine specimens for this purpose are found at the Hot Springs of Arkansas, and in Herkimer County, N. Y.; as also frequently in regions of Archæan rocks. The most valued amethysts are brought from India, Ceylon, Siberia, and Brazil; and they are found also on Keweenaw Point, and in some of the Eastern States, but seldom good enough for jewelry. The massive translucent varieties of quartz with waxy luster, and especially those which present alternating bands and spots of different colors and shades of color, due to impurities introduced during the successive deposition of the layers from silicated waters, make very handsome ornamental stones, and are wrought into a variety of beautiful objects, such as vases, cups, boxes, necklaces, seals, buttons, knife-handles, and small columns for cabinets; or they are merely cut and polished to display their spots and bands of color, and used for mantel and cabinet ornaments. Varieties of milky and bluish tints are called *chalcedony*, abundant in geodes in Iowa and Illinois; of bright, rich red, *carnelian*, brought from the East Indies; of concentric and often zigzag bands of color, *agates*, found on Lake Superior; of smoky tints, containing moss-like figures in metallic oxides, *moss-agates*, occurring in the Rocky Mountain region; and of flat, parallel layers of white and black or brownish shades, *onyx* and *sardonyx*. These last are the materials in which are cut miniature articles of sculpture called cameos, in which the alternation of layers of different colors is dexterously made to heighten the effect, and in the art of cutting which the ancients had attained as great skill as is displayed by modern artists. The opaque red, yellow, and green variety of quartz, called *jasper*, when it occurs in bands of different colors, is valued for ornaments like vases, handles, boxes, and small cabinets, and especially for mosaics and inlaid work. Handsome varieties are found in Calaveras County, Cal.; Graham County, Kan.; near Troy, N. Y.; and at Chester, Mass.

Some of the varieties of feldspar also afford ornamental material. Thus *sunstone*, a yellowish or grayish feldspar, containing minute scales of mica, and *moonstone*, a milky opalescent feldspar with pearly reflections, are cut for jewelry; and *labradorite*, a dark-gray or brown feldspar, which when polished often presents a beautiful play of bright bluish and greenish colors from internal reflections, is a handsome material for ornamental uses. The last-named mineral is obtained of good quality from Labrador, whence its name, being also found in northern New York; while the first two occur in Amelia County, Va., and Delaware County, Pa. Moonstone is brought also from Ceylon, and sunstone from Norway. The feldspars used for ornament occur in regions of crystalline rocks. The tough, heavy, compact, and translucent stone, called *nephrite* and *jade*, of green and blue colors, obtained from China, India, Siberia, Alaska, and New Zealand, is used for making carved ornaments, for which purpose it has long been held in high estimation by the Chinese. *Lapis lazuli*, a mineral usually compact and of rich blue color, occurring in the ancient crystalline rocks of Persia, China, Siberia, and Thibet, furnishes a valued material for objects of luxury, like vases, rich mosaics, and the inlaid work of costly furniture, besides being used in jewelry. When powdered, it becomes the costly blue pigment, *ultramarine*, which is now, however, prepared artificially at much smaller expense than that from the native mineral.

The use of *malachite*, the green banded carbonate of copper, in magnificent inlaid furniture, has already been mentioned in the chapter on copper. It is a common ore of copper in our Southwest Territories; but large concretionary masses, fit to be cut for ornamental uses, are not often met with, the Ural Mountains being still the chief source of supply for such purposes.

The fluoride of calcium, called *fluor-spar* and *Derbyshire spar*, which occurs both massive and crystalline as a vein-stone in many veins, especially those of lead, when transparent, and of fine colors, such as green, purple, and red, is sometimes wrought into ornamental articles, like vases, snuff-boxes, and candlesticks. Derbyshire, England, affords a handsome blue fluorite, whence the mineral has derived one of its common names. Fluorite fit for ornamental uses is said to be found in Hardin County, Ill., and in Colorado. The chief use of the mineral, however, is for a flux in metallurgical operations, and as a glaze for pottery. A hard, compact, and lustrous variety of brown coal, which admits of a high polish, is used on this account, and because of its black color, for personal ornaments, especially mourning jewelry, under the name of *jet.* It occurs abundantly in El Paso County, Col., and at some localities in Texas ; also in England (Whitby being a celebrated locality), in France, and in Spain. Like the lignites and brown coals, jet occurs in the later geological deposits, the Tertiary and Upper Cretaceous ; and like these, also, it is very *light* when compared with other minerals, by which character it may easily be distinguished from its imitations made of glass.

Another very light mineral substance, largely used for small ornamental objects, is *amber*, a transparent fossil resin of yellow and orange colors, frequently inclosing insects. It occurs in irregular lumps in the Tertiary beds of several European and Asiatic localities, and on the Atlantic borders of Massachusetts and New Jersey ; but much the most important source of supply is the Baltic coast, chiefly of Prussia, where it is washed out of its containing strata and thrown on the shore by the action of the waves. It is manufactured into ornaments for the person, such as ear-pendants, bracelets, necklaces, and brooches, and into boxes, mouth-pieces for pipes, and handles for canes and paper-knives. As its weight is less than half that of an equal bulk of glass, this character, as well as its softness, affords an easy means of distinguishing it from imitations.

The ornamental employment of *marbles* in the interior decoration of houses has already been mentioned under building-stones ; but, aside from this, a large use of marbles of fine texture and pleasing and varied colors is made in the ornamentation of articles of furniture and in sculpture, one of the noblest of the fine arts. For the latter purpose marble is required which is of fine and even texture, free from any foreign minerals, and of a pure and uniform white color. Such marble is of rare occurrence, and hence the celebrity of some of the marbles of Italy and Greece, those of Carrara and Paros. What is called *onyx marble* is a translucent stalagmite, prettily banded with different light shades, and obtainable in masses of considerable size. It is a beautiful material for ornamental purposes, and may be wrought into many pleasing objects. Attention has recently been called to it by large specimens from Algiers and Mexico, exhibited at some of the World's Expositions. *Alabaster*, a compact, translucent variety of gypsum, and *verd-antique* marble, a rock composed of green serpentine and white calcite, are also used in ornamental work.

Mention should also be made here of the *porphyries*, hard and tough varieties of rock, made up of a very fine-textured felspathic base inclosing well-defined crystals, usually of feldspar. Where the base and inclosed crystals are of pleasing and finely contrasted colors, as dark red, green, and white, this rock, from its susceptibility to high polish, has in all ages been an admired material for ornamental objects, such as vases, caskets, columns, parts of furniture, and handles of knives. The antique red and green porphyries have an ancient celebrity. As porphyry is of volcanic origin, its geological position is naturally in dikes; and material suitable for ornamental uses is more likely to occur in those which cut rocks of great geological antiquity.

Gems.—The minerals which, from their transparent brilliancy, their beauty of color, and their hardness, coupled with their rarity, are held in esteem as gems are but few in number, not more than a dozen in all. They are the diamond, corundum, spinel, topaz, beryl, zircon, garnet, tourmaline, spodumene, turquoise, and opal, some even of these holding but a doubtful place in a list of gems, although occasional examples of uncommon size and beauty sell at a considerable price. Of these, only the transparent varieties, and those of pleasing and uniform colors, have any considerable value as gems, some others being utilized on account of their hardness, like the black diamond and bort, and the gray and black corundum, or being valued merely as mineralogical specimens. With the exception of the opal, which occurs in nests and veins in volcanic rocks like the rhyolites, all the gems have their birthplace in the ancient crystalline rocks, although several are most commonly met with in alluvial deposits formed from the ground-up and assorted *débris* of such rocks. Where used as gems, all are transparent save turquoise, which is opaque, and opal, which is usually merely translucent. They range in hardness from the diamond and corundum, which scratch all other minerals, to opal and turquoise, which may be scratched by quartz ; all but the last two can therefore be easily distinguished from their glass imitations by their superior hardness, since that of the brilliant variety of glass called *strass* or *paste*, from which imitation gems are made, is not more than 5 on the scale of hardness, while that of the softest gems is 6, and of quartz 7. Hardness is essential in gems, since, though entailing greater expense in cutting, it preserves their colors and polish undimmed for ages. A few of the gems are colorless, like the diamond, and occasionally the topaz and zircon; but most of them present various clear shades of red, green, blue, and yellow ; and some of them, like corundum and beryl, afford gems of several different colors which bear different names. The *carat*, in which the weight of many precious stones is reckoned, is a conventional weight, equal, according to Ure, to about 3.88 grains troy, although sometimes used as no more than 3.1 grains. Gems are cut, according to their nature and shape, in four different styles, of which the *brilliant* consists of a truncated double pyramid, the truncated ends being octagons, and the sides made up of a combination of triangular and rhomboid or pentagonal facets; the *rose* cut has a flat base surmounted by a pyramidal dome, made up usually of twenty-four triangular facets; the *table* has a rectangular face and beveled edges; and the *en cabochon* cut has a flat base and smooth, rounded dome.

As is well known, the *diamond* is the most highly valued of the gems. This mineral, which is pure crystallized carbon, the same element which in other conditions constitutes charcoal and graphite, is the hardest of all known substances, readily scratching every other mineral and being scratched by none. The peculiar charm of the diamond lies in its singular brilliancy of luster, in which it as far surpasses all other gems as it does in hardness, and which depends on the great refractive and dispersive power that it exerts on the rays of light. The diamond is usually colorless, but has not unfrequently a slight tinge of color, of which yellow is the most common and least esteemed. A diamond of the first water is perfectly transparent and colorless, and free from spots or flaws, those of clear green and rose tints being also very highly prized. Diamonds are occasionally found of considerable size: the largest from South Africa weighed 308 carats, the largest from Brazil 254½ carats, and one is mentioned from India which is said to have weighed originally 900 carats. Those weighing more than twenty carats are rarely met with, the vast majority of those found being much smaller than this; and they lose, on the average, about one half their weight in cutting and polishing—operations which can be performed only by the aid of the powder of the diamond itself. The diamond has very rarely been found in any other than alluvial deposits made up probably of the *débris* of its original rocky matrix; so that there has been much conjecture as to the nature of the formations in which it originated. In Brazil it is found in a peculiar rounded gravel of milky quartz, associated with coarse ferruginous sand, called by the miners *cascalho*. This may have been derived from a ferruginous conglomerate, or, more probably, it is thought, from a laminated and sometimes slightly flexible quartzite called itacolumite, which belongs to the ancient crystalline series of that country. In India, where its mode of occurrence is said to be similar to that in Brazil, a French geologist, M. Chaper, has recently found the diamond *in situ*, associated with corundum, in a matrix of rose-colored pegmatite, a variety of granite, the granitic rocks in the vicinity of the gems being traversed by veins of feldspar and epidotiferous quartz; thus we have reliable information of one mode of original occurrence of this gem, if not the only one. The great diamond-producing regions of the world are three in number, viz., the southern part of Hindostan, Brazil, and South Africa. The diamond region of the Indian Peninsula has been known from a remote antiquity, and from it have been derived most of the famous diamonds which are among the crown jewels of European sovereigns. The Brazilian diamond-fields are chiefly in the provinces of Minas-Geraes and Bahia, north of Rio Janeiro, though gems are found also in Parana, Goyaz, and Matto-Grosso. The black diamonds, or *carbonados*, mentioned in the preceding chapter, are found in Bahia. The Brazilian product is said to amount to from forty to fifty pounds troy per annum. The latest discovered and most prolific region is that of Griqualand and the Orange Free State in South Africa, of which Kimberley is the center, and which has been known only since 1867. The workings here extend to the depth of some hundreds of feet, and the value of the product for 1881 is said to have been about $22,000,000. Besides these chief regions, diamonds are found in the Ural Mountains and in Borneo, and a few isolated occurrences have been noted in the United States—in Georgia, North Carolina, Virginia, and California.

Corundum, which ranks next to the diamond in hardness, is pure crystallized alumina, and, when occurring in transparent crystals of pure colors, yields gems which rank next to the diamond in value, and which receive different names in jewelry according to the colors that they present. Thus, the transparent blue corundum is called *sapphire;* the red, *oriental ruby;* the green, *oriental emerald;* the violet, *oriental amethyst;* and the yellow, *oriental topaz*—white stones also occurring which have passed for diamonds. While the original matrix of these gems, like that of ordinary corundum, is in crystalline rocks, they are most frequently found in alluvial deposits. The finest stones are obtained mostly from the East Indies, some being found also in Saxony, Bohemia, and France. Gems of the corundum species are found occasionally in North Carolina; also in southern Colorado, New Mexico, and Arizona, in sand with garnets.

The *spinel* is a mineral composed of alumina and magnesia, with usually a little iron, is in hardness next below corundum, by which it may be scratched, and when used as a gem is of a fine rosy red color, though green and violet tints also occur. This gem, which is called by jewelers *spinel ruby* and *balas ruby*, is obtained chiefly from Siam and Ceylon, where it occurs in crystalline rocks, but mostly in alluvial deposits derived from their wear. Spinel is also found in Sussex County, N. J., and Orange County, N. Y., sometimes in crystals of large size, but rarely if ever fit for jewelry.

The *topaz*, which is a silicate of alumina containing a considerable proportion of fluorine, occurs in rhombic prisms with perfect cleavage across the prism, has a hardness about equal to that of spinel, and its color is most commonly yellow, but sometimes green, blue, and white. Like the other gems, it occurs in crystalline rocks, or in their *débris.* Those used in jewelry are mostly brought from Siberia, Kamchatka, and Brazil; it is found also in Saxony and Bohemia, in Arizona and New Mexico, and on Pike's Peak; the last-named locality, which has recently been discovered, gives promise, it is said, of yielding a light-blue topaz which will be valuable for gems—colorless and pellucid crystals being also found.

Beryl, a silicate of alumina and glucina, which occurs in six-sided prisms, sometimes of great size, in the crystalline rocks of some of the Eastern States, when transparent and of fine colors affords the valuable green gem, *emerald*, the sea-green or bluish *aqua marine*, and the yellow or light-green beryl. Its hardness is somewhat less than that of the spinel and topaz, by which it may be scratched. Crystals fit for jewelry are sometimes found in New England and in Alexander County, N. C., but the emerald and aqua marine are mostly obtained from New Granada, Brazil, Hindostan, and Siberia.

Zircon, the silicate of zirconia, transparent red crystals of which constitute the gem called *hyacinth*, and colorless or smoky ones, the *jargoon*, although found in crystalline rocks at several localities in North Carolina, New York, and New England, has not yet afforded any valuable gems in the United States. These are derived from Ceylon, which furnishes so many other gems, from Siberia, Greenland, and some European localities. The hardness of zircon is about the same as that of beryl, and exceeds that of quartz.

The *garnet*, which is a silicate of quite variable composition, is of about the same hardness as quartz; and though of quite common occurrence in mica schist, hornblende schist, and some other crystalline rocks, still, clear red crystals of proper size are held in some estimation as gems. Stones of the finest quality are found in southern Colorado, New Mexico, and Arizona, excellent ones being also obtained from Greenland and Ceylon. It is usually cut in thin tables, or low, rounded forms.

The *tourmaline* is a variable compound of silica, alumina, and boracic acid, with several other substances. It occurs in prisms, usually black, of three, six, nine, or twelve sides, with a low, three-sided pyramidal end, has about the same hardness as quartz, and is found as a common accessory of various ancient crystalline rocks. It is occasionally met with in transparent crystals of clear yellow, green, blue, and pink colors, when it becomes a gem of considerable value. Fine yellow gems of this mineral are obtained from Ceylon, and sold often as topaz. Paris, in Oxford County, Me., is a celebrated locality for tourmaline gems of various colors, yielding, it is said, more than two thousand dollars' worth per year; and two or three other localities in the vicinity of Paris give promise of yielding similar gem-stones.

Hiddenite, or lithia emerald, a variety of spodumene, and composed of silica, alumina, and lithia, is a gem recently discovered at Stony Point, Alexander County, N. C., where it occurs in small open pockets in gneiss-rock, associated with emeralds and several other crystallized minerals. The most valued gems are of a brilliant grass-green color, those of light-green and yellow colors as well as colorless being also found, but held in less esteem. According to its discoverer, the gem has a brilliant cleavage, and is somewhat harder than the emerald. The locality is being diligently explored for the mineral, which is in good demand for cabinet specimens as well as for gems.

Turquoise is a hydrous phosphate of alumina, opaque, of a delicate blue or bluish-green color, due to copper, and of a hardness inferior to that of quartz. Despite its inferior hardness and opacity, it has long been held in esteem as a gem, because of its pleasing color and the beautiful combinations that it makes when cut with a smooth, rounded surface and set with diamonds or pearls. It occurs in small, rounded masses, or in thin veinlets traversing eruptive or crystalline rocks. The best has for ages been obtained from Khorassan, a province of Persia. Attention has recently been called to two localities of this mineral that were largely worked by the ancient Mexicans, among whom, at the time of the Spanish conquest, it was highly prized as a gem under the name of *chalchihuitl*, or chalchuite. One of these localities, showing old workings of vast extent, is in the Los Cerillos Mountains, twenty miles southeast of Santa Fé, and the other in Cochise County, Arizona. The mineral at both these localities is bluish green. It has also been found at a locality in southern Nevada of a rich blue color, disseminated in grains in a hard sandstone, which is polished and makes a beautiful mottled stone for jewelry.

Opal is a peculiar, massive, uncrystalline form of quartz, containing a variable proportion of water, somewhat softer than crystalline quartz, by which it may be scratched, and also of a lower specific gravity, its weight rarely exceeding 2.2 that of water, while that of quartz is about 2.65. When used as a gem it is translucent, and usually of a milky color, and presents a vivid, iridescent play of colors, due to internal reflections with decomposition of the luminous rays, by microscopic laminæ. (Zirkel, "Die mikroskopische Beschaffenheit der Mineralien," etc., p. 116.) To this charming opalescence, which is best displayed when the gem is cut with a smooth convex surface, it owes the high estimation in which it was held by the ancients not less than by modern nations. It occurs in small nests and thin veins traversing certain volcanic rocks. The precious opal, and the *girasol*, or *fire opal*, have not yet been found fit for jewelry in the United States. They are obtained from Hungary, Honduras, and Mexico, and to some extent from the Faroe Islands.

Besides the minerals here briefly described as precious stones, some others are occasionally used in jewelry, for example, chrysoberyl, kyanite, idocrase, and chrysolite; of which it will be sufficient to say that the first named, which nearly equals corundum in hardness, is a valuable gem in the rare cases when it is transparent and free from flaws; and that chrysolite is in some demand because of its olive-green tint.

Although most of the gems are by nature singularly indestructible, still, from the comparative unfrequency of the occurrence of stones suitable for gems of the first quality, it may be doubted whether the increase in the supply more than keeps pace with the increase in wealth and luxury, and with the consequent disposition to acquire precious stones. Even the recent large increase in the supply of diamonds, resulting from the discoveries in South Africa, does not appear yet to have produced any perceptible effect in diminishing their price as gems. The demand for several of the precious stones is indeed subject to the caprices of fashion, like that for most things which are objects of taste and preference rather than of necessity. Hence occur temporary fluctuations in their price, which bear little or no relation to variations of supply. Yet, on the whole, these minor fluctuations serve but to accentuate more sharply the fixedness and constancy of the passion for the more indestructible gems, showing how unchangeable is the principle of human nature in which it has its roots.

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