WORKS OF

Dr. GEORGE P. MERRILL

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The Non-metallic Minerals.

Their Occurrence and Uses. Second Edition, Revised and Enlarged, 8vo, xii + 432 pages, 38 full-page plates, mostly half-tones, and 55 figures in the text. Cloth, $4.00.

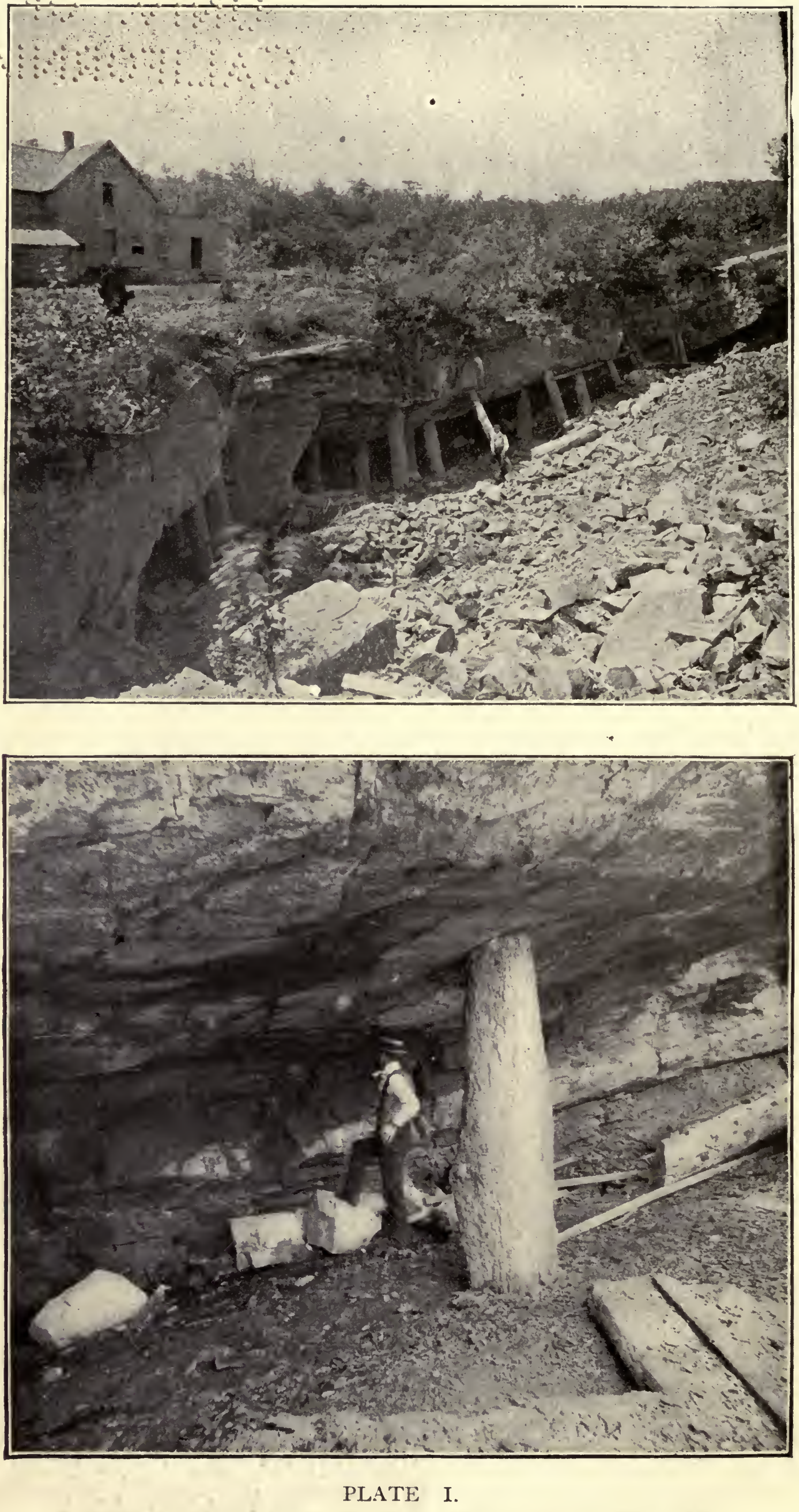

PLATE I.

Views in Graphite Mine near Hague, Warren County, New York.

[From photograph by C. D. Walcott.]

[*Frontispiece.*]

THE
NON-METALLIC MINERALS.

THEIR OCCURRENCE AND USES.

BY
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SECOND EDITION, REVISED
FIRST THOUSAND

NEW YORK:
JOHN WILEY & SONS.
LONDON: CHAPMAN & HALL, LIMITED.
1910

THE SCIENTIFIC PRESS
ROBERT DRUMMOND AND COMPANY
BROOKLYN, N. Y.

PREFACE TO THE SECOND EDITION.

THE first edition of this work was little more than a reprint of a handbook of the collections in Applied Geology in the U. S. National Museum. An attempt was there made, for the first time in America, to bring together widely scattered notes relating to many of the minor and little used minerals, it being felt that with the rapid development of the arts the time had come for a review, at least, of this branch of the mining industry, as well as a look into future possibilities, so far as the development of natural resources would permit. Since the work was written, much has been accomplished in the way of both study and exploitation, as will be evident to one who will peruse the voluminous publications of the U. S. Geological Survey and the columns of the trade and mining journals, and it is felt that the time has now arrived for putting the matter in a form more concise as well as more comprehensive. In doing this, the author has availed himself of the great mass of literature passing through his hands as Head Curator of the Department of Geology, as well as an experience of near thirty years in collecting, observing and arranging the materials under his care. He has drawn for information upon every available source, and has striven to give full credit therefor.

The name Non-Metallic, as used, it may be well to state, relates to the uses to which the various substances are put rather than to their true mineral nature. Otherwise expressed, the materials here described are considered with reference to their uses other than as sources of metals. In several instances, it is evident, the same material may be utilized for its metallic constituents as well, as is the case with the manganese oxides, but in such cases this phase of the subject is touched upon but lightly.

It should scarcely be necessary to state that in several instances, as those of cements, coals, phosphate, etc., the subject matter is so comprehensive that each might well demand a volume by itself. In these cases, summaries only are attempted and reference made to authentic treatises in the accompanying bibliographies.

TABLE OF CONTENTS AND SCHEME OF CLASSIFICATION.

I. The Elements:

II. Sulphides and arsenides:

III. Halides:

IV. Oxides:

IV. Oxides—*Continued:*

V. Carbonates:

VI. Silicates:

IV. Silicates—*Continued:*

PAGE

LIST OF ILLUSTRATIONS.

PLATES.

FIGURES IN TEXT

THE NON-METALLIC MINERALS,

EXCLUSIVE OF GEMS, BUILDING STONES, AND MARBLES.

I. THE ELEMENTS.

1. CARBON.

The numerous compounds of which carbon forms the chief constituent are widely variable in their physical properties and origin. As occurring in nature few of its members possess a definite chemical composition such as would constitute a true mineral species, and they must for the most part be looked upon as indefinite admixtures in which carbon, hydrogen, and oxygen play the more important rôles. For present purposes the entire group may be best considered under the heads of (1) The Pure Carbon series; (2) The Coal series, and (3) The Bitumen series, the distinctions being based mainly on the gradually increasing amounts of volatile hydrocarbons, a change which is accompanied by a variation in physical condition from the hardest of known minerals through plastic and liquid to gaseous forms. Here will be considered only the members of the pure carbon series, the others being discussed under the head of hydrocarbon compounds.

Diamond.—This mineral crystallizes in the isometric system, with a tendency toward octahedral forms, the crystals showing curved and striated surfaces. (Fig. 1.) The hardness is great, 10 of Dana's scale; the specific gravity varies from 3.1 in the carbonados to 3.5 in good clear crystals. The luster is adamantine; the colors, white or colorless, through yellow, red, orange, green, blue, brown to black. The transparent and highly refractive forms are of value as gems, and can best be discussed in works upon this subject. We have to do here rather with the rough, confused crystalline aggregates or rounded forms, translucent to opaque, which, though of no value as gems, are of the greatest utility in the arts. To such forms the name *black diamond*, *bort*, and *carbonado* are applied.

FIG. 1.—Diamond crystals; characteristic forms. [U. S. National Museum.]

Origin and occurrence.— The origin of the diamond has long been a matter of discussion. A small proportion of the diamonds of the world are found in alluvial deposits of gravel or sand. In the South African fields they occur in a so-called blue gravel, formed, according to Lewis, along the line of contact between an eruptive rock (peridotite) and highly carbonaceous shales. They were regarded by Lewis as originating through the crystallization of the carbon of the shales by the heat of the molten rock. De Launay states, however, that there is no necessary connection between the shales and the diamond, and shows with apparent conclusiveness that the latter occur often in a broken and fragmental condition, such as to indicate beyond doubt that they originated at greater depths and were brought upward as phenocrysts in the molten magma at the time of its intrusion. The primary origin of the diamonds he regards as through the crystallization, under great pressure, of the carbon contained in the basic magma in the form of metallic carbides.

The diamond-bearing rock, i.e., the true parent rock, is now very generally conceded to be the peridotite, and to which Lewis gave the name *kimberlite*.

The Brazilian diamonds come mainly from Minas Geraes and the

Paraguaca district, in the State of Bahia, where they are found in detrital material resulting from the breaking down of sedimentary metamorphic rocks. These rocks, as described by Branner,[1] belong to the Lavral series of Carboniferous formations, and consist of false-bedded pinkish red sandstone, conglomerate and quartzite. The washings yielding the diamonds are altogether along streams that flow over these beds or their detrital materials and there is apparently no doubt that they—and the quartzite in particular—represent the parent rock. Cases of finding of diamonds in the quartzite matrix have been reported, but apparently need authentication. There are no eruptive rocks in connection with the beds over the greater part of this district, and the diamonds, so far as yet determined, cannot be attributed to an igneous origin, Branner, however, notes the existence of considerable areas of serpentine (altered peridotite?) underlying the sedimentary series, and it is surmised as possible that such may have been the original source of the

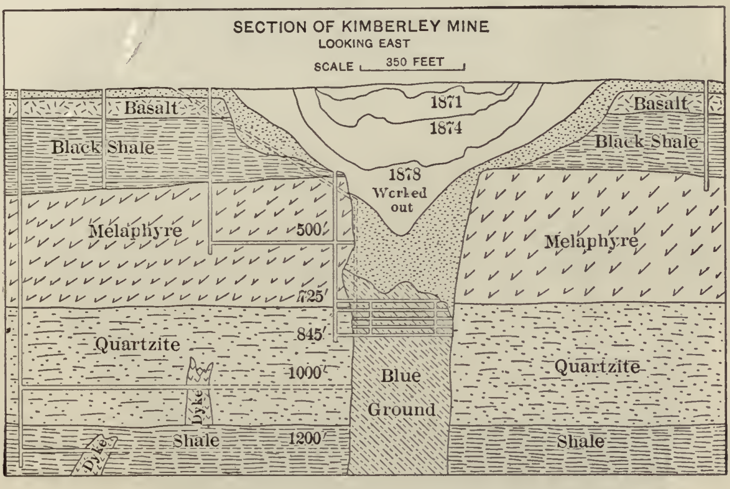

FIG. 2.—Section of Kimberley Diamond Mines.
[After Rennert.]

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[1] Engineering and Mining Journal, LXXXVII, 1909, p. 981.

diamonds themselves. The problem cannot be considered as yet solved.

According to Kunz,[1] 95 per cent of all diamonds at present obtained come from the Kimberly Mines, Griqua Land, west South Africa; of these, some 47 per cent are bort. The remainder come from Brazil, India, and Borneo. A few have been found in North America, the Ural Mountains, and New South Wales, but these countries are not recognized as regular and constant sources of supply. The Australian diamonds, it may be noted, have been found in igneous rocks, of the nature of diabase, or dolerite.[2] Recently

FIG. 3.—Largest Known Black Diamond. Weight 3150 carats.
[U. S. Geological Survey.]

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[1] Gems and Precious Stones, New York, 1890.

[2] Geol. Mag., Vol. VI, Nov., 1909, p. 492.

diamonds have been reported from near Murfreesboro, in Pike County, Arkansas, associated with peridotites under much the same conditions as in South Africa.

The largest known gem diamond is the Cullinan, found in 1905 in the Premier Mine, Transvaal, South Africa. This, before cutting, measured roughly 4×2½×2 inches and weighed 3,024¾ carats. The largest black diamond, or carbon, is that shown approximately natural size in Fig. 3. This was found in the Paraguaca district of Brazil in 1895, and weighed 3,078 carats.

Uses.—The material, aside from its use as a gem, owes its chief value to its great hardness, and is used as an abrading and cutting medium in cutting diamonds and other gems, glass, and hard materials in general, such as can not be worked by softer and cheaper substances.

With the introduction of machinery into mining and quarrying there has arisen a constant and growing demand for black diamonds, or bort, for the cutting edges of diamond drills, and to a less extent for teeth to diamond saws.

The crystallized diamond is not suitable for these purposes owing to its cleavage property. The best bort or carbonado comes, it is said, from Bahia, Brazil, where it is found as small, black pebbles in river gravels. The ordinary sizes used for drills weigh but from one-half to 1 carat, but in special cases pieces weighing from 4 to 6 carats are used. It is stated that the crowns of large drills, 10 inches in diameter, armed with the best grade of carbonado, are sometimes valued as high as $10,000.

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Graphite.—Graphite, plumbago, or black lead, as it is variously called, is a dark steel-gray to black lustrous mineral with a black streak, a hardness of but 1.2, and a specific gravity of from 2.25 to 2.27. The prevailing form of the mineral is scaly or broadly foliated, with a bright luster, but it is sometimes quite massive and columnar or earthy, with a dull coal-like luster.

Its most characteristic features are its softness, greasy feeling, and property of soiling everything with which it comes in contact. Molybdenite, the sulphide of molybdenum, is the only mineral with which it is likely to become confounded. This last, however, though very similar in general appearance, gives a streak with a slight greenish tinge, and when fused with soda before the blowpipe yields a sulphur reaction. Chemically, graphite is nearly pure carbon. The name black lead is therefore erroneous and misleading, but has become too firmly established to be easily eradicated.

The analyses given below show the composition of some of the purest natural graphites.

Locality.	Carbon.	Ash.	Volatile Matter.
Ceylon	98.817	0.280	0.90
Do	99.792	.05	.158
Buckingham, Canada	97.626	1.78	.594
Do	99.815	.076	.109

As mined the material is almost invariably contaminated by mechanically admixed impurities. Thus the Canadian material as mined yields from 22.38 to 30.51 per cent of graphite; the best Bavarian, 53.80 per cent. The grade of ore that can be economically worked naturally depends upon the character of the impurities and the extent and accessibility of the deposit. It is said[1] that deposits at Ticonderoga, New York, have been worked in which there was but 6 per cent of graphite.

Occurrence and origin.—Graphite occurs mainly in the older crystalline metamorphic rocks, both siliceous and calcareous, sometimes in the form of disseminated scales, as in the crystalline limestone of Essex County, New York, or in embedded masses, streaks, and lumps, often of such dimensions that single blocks of several hundred pounds weight are obtainable. It is also found in the form of true beds and veins.

The fact that the mineral is carbon, one of the constituents of

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[1] Engineering and Mining Journal, LXV, 1898, p. 256.

animal and vegetable life, has led many authorities to regard it, like coal, as of vegetable orgin. While this view is very plausible it can not, however, be regarded as in all cases proven.

That graphite may be formed independently of organic life is shown by its presence in cast iron, where, on cooling, it has crystallized out, in the form of bright metallic scales.

Carbon is also found in meteorites which are plainly of igneous origin, and which have thus far yielded no certain traces of either plant or animal remains. It is, however, a well-known fact that coal—itself of organic origin—has in some cases been converted into graphite through metamorphic agencies, and intermediate stages like the graphitic anthracite of Newport, Rhode Island, afford good illustrations of such transitions. Certain European authorities[1] have shown that amorphous carbonaceous particles in clay slates have been converted into graphite by the metamorphosing influence of intruded igneous rocks. Prof. J. S. Newberry described an occurrence of this nature in the coal fields of Sonora, Mexico,[2] as follows:

"All the western portion of this coal field seems to be much broken by trap dikes which have everywhere metamorphosed the coal and converted it into anthracite. At the locality examined the metamorphic action has been extreme, converting most of the coal into a brilliant but somewhat friable anthracite, containing 3 or 4 per cent of volatile matter. At an outcrop of one of the beds, however, the coal was found converted into graphite, which has a laminated structure, but is unctuous to the touch and marks paper like a lead pencil. The metamorphism is much more complete than at Newport (Rhode Island), furnishing the best example yet known to me of the conversion of a bed of coal into graphite."

In New York State and in Canada, graphite occurs in Laurentian rocks, both in beds and in veins, a portion of the latter being apparently true fissure veins and others shrinkage cracks or segregation veins which traverse in countless numbers the containing rocks. It is said[3] that in the Canadian regions the deposits occur generally in

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[1] Beck and Luzi, Berichte der Deutschen Chemischen Gesellschaft, 1891, p. 24.

[2] School of Mines Quarterly, VIII, 1887, p. 334.

[3] See On the Graphite of the Laurentian of Canada, by J. W. Dawson, Proceedings of the Geological Society of London, XXV, 1870, p. 112, and an article on Graphite by Prof. J. F. Kemp in The Mineral Industry, II, 1893, p. 335.

limestone or in their immediate vicinity, and that granular varieties of the rock often contain large crystalline plates of the mineral. At other times the mineral is so finely disseminated as to give a bluish-gray color to the limestone, and the distribution of the bands thus colored seems to mark the stratification of the rock. Further, the plumbago is not confined to the limestones; large crystalline scales of it are occasionally disseminated in pyroxene rock or pyrallolite, and sometimes in quartzite and in feldspathic rocks, or even in magnetic oxide of iron. In addition to these bedded forms, there are also true veins in which graphite occurs associated with calcite, quartz, orthoclase, or pyroxene, and either in disseminated scales, in detached masses, or in bands or layers separated from each other and from the wall rock by feldspar, pyroxene, and quartz. Kemp describes[1] the graphite deposit near Ticonderoga, New York, as in the form of a true fissure vein, cutting garnetiferous gneiss, which has an east and west strike. The vein at the "big mine" runs north 12° west, and dips 55° west. The vein filling is evidently orthoclase (or microcline) with quartz and biotite and pockets of calcite. Besides graphite, it contains tourmaline, apatite, pyrite, and sphene.

Walcott[2] describes the graphite at the mines 4 miles west of Hague, on Lake George, New York, as occurring in Algonkian rocks, and as probably of organic origin.

At the mines the alternating layers of graphite shale or schist form a bed varying from 3 to 13 feet in thickness. The outcrop may be traced for a mile or more. The garnetiferous sandstones form a strong ledge above and below the graphite bed. The appearance is that of a fossil coal bed, the alteration having changed the coal to graphite and the sandstone to indurated, garnetiferous, almost quartzitic forms. The character of the graphite bed is well shown in the accompanying plate (Pl. I), from a photograph taken in 1890. It is here a little over 9 feet in thickness and is formed of alternating layers of highly graphitic sandy shale and schist.

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[1] Preliminary Report on the Geology of Essex County, Contributions from the Geological Department of Columbia College, 1893, pp. 452, 453.

[2] Bulletin of the Geological Society of America, X, 1898, p. 227.

F. L. Hess describes[1] the graphite of Santa Maria, Mexico, as occurring in beds in sandstone which has been much folded and also intruded by granitic dikes. There are at least seven beds of varying thickness. The folding to which the enclosing sandstone has been subjected has in many instances so squeezed the yielding graphite as to form lenticular masses, in places upward of 20 feet in thickness which within a short distance may pinch out to mere knife-like edges. The wall rock of the mines, as may be surmised from the above, is mainly sandstone, though sometimes of granite. The graphite is wholly amorphous, but is said to be very pure. It would appear to owe its origin to the metamorphism of beds of coal through the intrusion of igneous rocks, as in the case described by Newberry.

According to J. Walther[2] the Ceylonese graphite occurs in coarsely foliated or stalky masses in veins in gneiss which, where mined, is decomposed to the condition of laterite. The veins are regarded as true fissures, and vary from 12 to 22 cm. (about 4¾ to 8¾ inches) in width.

The graphite of Northern Moravia occurs in gray to black crystalline granular Archæan limestone interbedded with amphibolites and muscovite gneiss, the limestone itself being often serpentinous, in this respect apparently resembling the graphitic portions of the ophicalcites of Essex County, New York. The material is quite impure, showing on the average but 53 per cent of carbon and 44 per cent of ash, the latter being made up largely of silica and iron oxide, with a little sulphur, magnesia, and alumina. This graphite is regarded as originating through the metamorphism of vegetable matter included in the original sediments, the agencies of metamorphism being both igneous intrusions and the heat and pressure incidental to the folding of the beds.[3]

As to so much of the graphite as occurs in beds there seems, then, little doubt as to its origin from plant remains which may be imagined to have existed in the form of seaweeds or to have been derived from diffused bituminous matter. The origin of the vein material is not so evident, though it seems probable that it is due

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[1] Engineering Magazine, XXXVIII, 1909, pp. 36–48.

[2] Records of the Geological Survey of India, XXIV, 1891, p. 42.

[3] Jahrbuch k. k. Geologische Reichsanstalt, 1897, XLVII, p. 21.

to the metamorphism of bituminous matter segregated into veins, like those of albertite in New Brunswick or of gilsonite, in Utah. Kemp states that the Ticonderoga graphite must have reached the fissure as some volatile or liquid hydrocarbon, such as petroleum, and become metamorphosed, in time, to its present state. Walther believes the Ceylon material to have originated by the reduction of carburetted vapors. (See also under origin of diamonds, p. 2.)

The total quantity of carbon in the form of graphite in the Laurentian rocks of Canada has been estimated by Dawson as equal to that in the form of coal in any similar areas of the Carboniferous system of Pennsylvania.

Sources.—The chief sources of the graphite of commerce are Austria and Ceylon. Other sources of commercial importance are Germany, Italy, Siberia, the United States, Canada and Mexico. The chief deposits of commercial value in the United States are at Ticonderoga, and Hague, N. Y., and Clay County, Alabama, where the material occurs in disseminated scales in a mica-free granite. An earthy, impure graphite, said to be suitable for foundry facings, is mined near Newport, Rhode Island. In Chester County, Pennsylvania, the material is mined from deposits in mica schist. Other American localities are: Bartow County, Georgia; Bloomingdale, New Jersey; Clintonville, New York; Wake County, North Carolina; Lehigh and Berks counties, Pennsylvania; Salt Sulphur Springs, West Virginia; St. Johns, Tooele County, Utah.

Near Centersville, Georgia, there is mined from open cuts a graphitic schist consisting essentially of from 5 to 10 per cent of amorphous graphite and talcose minerals, which presumably originated through the metamorphism of carbonaceous slates.

Graphite is a very common mineral in the Laurentian rocks of Canada. The most important known localities are north of the Ottawa River, in the townships of Buckingham, Lochaber, and Grenville. At Buckingham it is stated masses of graphite have been obtained weighing nearly 5,000 pounds. At Grenville the graphite occurs in a gangue consisting mainly of pyroxene, wollastonite, feldspar, and quartz, while the country rock is limestone.

Blocks of graphite have been obtained weighing from 700 to 1,500 pounds.[1]

Graphite is also found in Japan, Australia, New Zealand, Greenland, Guatemala, Germany, and in almost all the Austrian provinces, the most important and best known deposits being those of Kaiserberg at St. Michel, where there are five parallel beds occurring in a grayish-black graphite schist, the beds varying from a few inches to 6 yards. The only workable deposit in Germany is stated to be at Passau in Bavaria. The material occurs in a feldspathic gneiss, seeming to take the place of the mica. The beds have been worked chiefly by peasants for centuries, and the output used mainly for crucibles.[2]

Uses.—Graphite is used in the manufacture of "lead" pencils, lubricants, stove blacking, paints, refractory crucibles, and for foundry facings. In the manufacture of pencils only the purest and best varieties are used, and high grades only can be utilized for lubricants. For the other purposes mentioned impure materials can be made to answer. In the manufacture of the Dixon crucibles, a mixture of 50 per cent graphite, 33 per cent of clay, and 17 per cent of sand is used.

The low grade graphitic material obtained from graphitic schists, near Centersville, Georgia, is used as a "filler" in the manufacture of fertilizers, it being claimed for it that it prevents absorption of moisture, and incidental caking.

Preparation.—In nature graphite is usually associated with harder and heavier materials, which it is necessary to eliminate before the material is of value. In New York it is the custom to crush the rock in a battery of stamps, such as are used in gold milling, and then separate the graphite by washing, its lighter specific gravity permitting it to be floated off on water, while the heavy, injurious constituents are left behind. Mica, owing to its scaly form, can not be separated in this manner, and hence micaceous ores of the mineral are of little if any value.

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[1] Descriptive Catalogue of Economic Minerals of Canada, 1876, p. 122.

[2] The Journal of the Iron and Steel Institute, 1890, p. 739.

Prices.—The value of the mineral varies with its quality. In 1907 the crude lump was reported as worth $8 a ton and the pulverized $30.

The annual output as given [1] for the principal countries is as follows:

WORLD'S PRODUCTION OF GRAPHITE.

Year.	Austria.	Canada.	Mexico.	Germany.	India.	Italy.	United States.
	Metric tons.	Metric tons.	Metric tons.	Metric tons.	Metric tons.	Metric tons.	Metric tons.
1900......	33,663	1,743	2,561	9,248	1,858	9,720	1,862
1907......	40,425	525	3,202	4,033	2,472	9,260	2,080

Ceylon produced in 1906, 36,578 tons. Some 7,000,000 pounds of graphite are produced artificially by the International Graphite Company, at Niagara Falls, New York.

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Franz Kretschmer. The Graphite Deposits of Northern Moravia.

Transactions of the North of England Institute of Mining and Mechanical Engineering, XLVII, 1898, p. 87.

2. SULPHUR.

The color of this mineral when pure is yellow, sometimes brownish, reddish, or gray through impurities. Hardness, 1.5 to 2.5. Specific gravity, 2.05. Insoluble in water or acids. Luster resinous. It occurs native in beautiful crystals, or in massive, stalactitic and spheroidal forms. Once seen the mineral is as a rule readily recognized, and all possible doubts are set at rest by its ready burning with a faint bluish flame and giving the irritating odors of sulphurous anhydride. In nature it is often impure through the presence of clay and bituminous matters, and sometimes contains traces of selenium or tellurium.

Origin and mode of occurrence.—Sulphur deposits of such extent as to be of economic importance occur as a product of volcanic activity, or result from the alteration of beds of gypsum. On a smaller scale, and of interest from a purely mineralogical standpoint, are the occurrences of sulphur through the alteration of pyrite and other metallic sulphides.

As a product of volcanic action sulphur is formed through the oxidation of hydrogen sulphide (H_2S), which, together with steam and other vapors, is a common exhalation from volcanic vents and solfataras. Such deposits on a small scale may be seen incrusting fumaroles in the Roaring Mountain or associated with the sinter deposits of the Mammoth Hot Springs in the Yellowstone Park. It may also be produced through the mutual reaction of hydrogen sulphide (H_2S) on sulphuric anhydride (SO_2), the product being sulphur (S) and water (H_2O) as before. To these types belong the sulphur deposits of Utah, California, Nevada, and Alaska in the United States, as well as those of Mexico, Japan, Iceland, and other volcanic regions. Sulphur is derived from the sulphate of lime (gypsum or anhydrite) through the reducing action of organic matter. The sulphate, through the loss of its oxygen, becomes converted into a sulphide, which, through the carbonic acid in the air and water, becomes finally reduced to hydrogen sulphide with the formation of calcium carbonate.

According to Fuchs and De Launay[1] there is formed at the same time with the hydrogen sulphide, a polysulphide, which in its turn yields a precipitate of sulphur and carbonate of lime. The maximum amount of sulphur which would thus result from the decomposition of a given amount of gypsum is stated to be 24 per cent. This method of origin is illustrated in the celebrated deposit of Sicily, where the sulphur occurs partially disseminated through and partly interbedded with a blue-gray limestone. Beneath the sulphur beds as they now exist are found the remnants of the older gypseous beds, which through decomposition have yielded the materials for the lime and sulphur beds now overlying.

With these Sicilian sulphurs occur a number of beautiful secondary minerals, as celestite, calcite, aragonite, and selenite.

Sulphur derived directly from metallic sulphides is of little economic interest. Kemp states[2] that masses of pyrite in the calciferous strata on Lake Champlain may yield crusts of sulphur an inch or so thick, and it is not uncommon to find small crystals of the mineral resulting from the alteration of galena, as described by George H. Williams,[3] at the Mountain View (Maryland) lead mine.

The minute quantities of sulphur found in marine muds are regarded by J. Y. Buchanan[4] as due to the oxidation of metallic sulphides, which are themselves produced by the action of animal digestive secretions on preexisting sulphates, mainly of iron and manganese.

Localities. — The principal localities of sulphur known in the United States are, in alphabetical order: Alaska, California, Idaho,

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[1] Traité des Gîtes Minéraux et Métallifères, I, p. 259.

[2] The Mineral Industry, II, 1893, p. 585.

[3] Johns Hopkins University Circulars, X, 1891, p. 74.

[4] Proceedings of the Royal Society of Edinburgh, XVIII, 1890–91, p. 17.

Louisiana, Nevada, Texas, Utah, and Wyoming. With the possible exception of those of Louisiana, these may all be traced to a solfataric origin. The Alaskan deposits,[1] according to Dall, are best developed on the islands of Kadiak and Akutan. California deposits have in times past been worked at Clear Lake, in Modoc County, in Colusa County, in Tehama County, and in Napa County. The Louisiana deposits lie in strata of Quaternary Age, and are derived from gypsum. The following facts relative to this deposit are from Professor Kemp's paper, already alluded to:

Probably the richest and geographically the most accessible of the American localities is in the southwestern part of the State, 230 miles west of New Orleans and 12 miles from Lake Charles. The first hole which revealed sulphur was sunk in search of petroleum. While more or less bituminous matter was revealed by the drill, the great bed of sulphur is the main object of interest. A number of holes have since been put down with the results recorded below, leaving no doubt but that there is a very large body which awaits exploitation. The first explorations were made by the Louisiana Petroleum and Coal Oil Company. This was succeeded by the Calcasieu Sulphur and Mining Company. The Louisiana Sulphur Mining Company followed, and finally the American Sulphur Company. The records of 8 holes are appended. Nos. 1 and 2 are about 150 feet apart. Nos. 2, 3, and 4 were put down in 1886.

RECORDS OF BORE-HOLES THAT HAVE PENETRATED THE SULPHUR BED.

Strata.	Original Well No. 1.	Granet's Wells.			Van Slooten's Well No. 5.	American Sulphur Company.		
		No. 2.	No. 3.	No. 4.		No. 6.	No. 7.	No. 8.
Clay, quicksand, and gravel...	333	344	426	332	345	350	370	499
Soft rock....................	110	84	70	138	91	95	72	44
Sulphur bed, 70 to 80 per cent.	108	112	119	45	110	125	126	52
Gypsum and sulphur.........	680	12	6	(*a*)	57	32	30	(*a*)
Depth of hole in feet......	1,231	552	621	525	603	602	598	596

a. Stopped in sulphur.

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[1] Alaska and its Resources, Boston, 1870.

Analyses from the large bed in holes No. 2 and No. 3 gave the following:

Depth.	Sulphur.	Depth.	Sulphur.
Hole No. 2.	Per cent.	Hole No. 3.	Per cent.
428 feet	62	503 feet	70
441 feet	70	533 feet	60
459 feet	80	549 feet	81
466 feet	83	552 feet	91
486 feet	90	604 feet	98
— feet	80		
— feet	75		
— feet	80		
540 feet	68		

The difficulties in development which have, however, been largely overcome, lie in the quicksands and gravel, which are wet and soft, and in the soft rock (hole 1), which yields sulphurous waters under a head, at the surface, of about 15 feet.

Sulphur deposits, supposedly due to the oxidation of sulphuretted hydrogen, occur over wide areas in northern El Paso and Reeves counties in Texas. The country rock is limestone and the sulphur wholly superficial and associated with gypsum or loosely consolidated detritus of the nature of sand and gravel.

Nevada.—The Nevada deposits occupy the craters of extinct hot springs near Humboldt House. These craters or cones are described by Russell [1] as situated on the open desert, above the surface of which they rise to a height of from 20 to 50 feet.

Nearly all of the cones are weathered and broken down, and are all extinct. The outer surface of the cones is composed of calcareous tufa and siliceous sinter, forming irregular imbricated sheets that slope away at a low angle from the orifice at the top. The interiors of these structures are filled with crystalline gypsum, which in at least two instances is impregnated with sulphur. One of the cones has been opened by a cut from the side in such a manner as to expose a good section of the material filling the interior, and a few tons of the sulphur and gypsum removed. The percentage of sulphur is small, and the economic importance of the deposit somewhat doubtful. The cone that has been opened is surrounded on all sides

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[1] Transactions of the New York Academy of Sciences, I, 1881–1882, p. 172.

by a large deposit of calcareous and siliceous material, thus forming a low dome or crater, with a base many times as great in diameter as the height of the deposit. These cones correspond in all their essential features with the structures that surround hot springs that are still active in various parts of the Great Basin, thus leaving no question as to their origin. They are situated within the basin of Lake Lahontan, and must have been formed and become extinct since the old lake evaporated away.

Sulphur is reported as occurring in the chemically formed deposits that surround Steamboat Springs, situated midway between Carson and Reno, Nevada, and in the Sweetwater Mountains, on the boundary between California and Nevada. The extent and geological relations of these last mentioned deposits are unknown.

Another illustration of deposits of the volcanic type is that furnished by the Rabbit-Hole Sulphur Mines. These are located in northwestern Nevada, on the eastern border of the Black Rock Desert, and derive their name from the Rabbit-Hole Springs, a few miles to the southward. The hills bordering on the east are mainly of rhyolite, with a narrow band of water-laid volcanic tuff along the immediate edge of the desert. At the mines the angular fragments of volcanic rock, have been cemented by opal and other siliceous infiltrations since their deposition, so that they now form brittle siliceous masses, with pebbles and fragments of older rocks scattered through them. In many places these porous tuffs and breccias are richly charged with sulphur, which fills all the interstices and sometimes lines large cavities with layers of crystals 5 or 6 feet in thickness. In the Rabbit-Hole District sulphur has been found in quantities for a distance of several miles along the border of the desert, but the distribution is irregular and uncertain, and is always superficial, so far as can be judged by the present openings. The sulphur has undoubtedly been derived from a deeply seated source, from which it has expelled by heat, and escaping upward along the lines of faulting, has been deposited in the cooler and higher rocks in which it is now found, though whether the deposition took place by direct sublimation or through the decomposition of hydrogen sulphide can not now be told with certainty. Judging from the siliceous material that cements the tuffs, it is evident that the porous rocks in which the sulphur is now found were penetrated by heated waters bearing silica in solution previous to the deposition of the sulphur. The mines occur in a narrow north-and-south belt along a line of ancient faulting which is one of the great structural features of the region. The absence of a recent fault-scarp, together with the fact that the mines are now cold and do not give off exhalations of gas or vapor, shows that the solfataric action has long been extinct, though at the Cove Creek Mines, mentioned below, the deposition is still in progress.

Utah.—Several sulphur deposits occur in central Utah, in and about Sulphurdale, a small mining camp some twenty miles north of Beaver. The best known of these are the Cove Creek beds, situated about four miles south of Cove Fort. The deposits have been exploited in an itinerant way for over thirty years, but their full extent is not as yet known. They have been described by G. Vom Rath,[1] A. F. Du Faur,[2] and W. T. Lee.[3]

The country is one of late Quaternary volcanic activity, and the sulphur, which is evidently due to the oxidation of exhalations of hydrogen sulphide, occurs filling the interstices of volcanic tuffs—in part rhyolitic—and in horizontal sheets, cracks and fissures in the same. The material occurs in all degrees of purity, that which is worked varying from 15 to 85 per cent sulphur. The average output of the region is given as about 1,000 tons. Vom Rath estimated the capacity of the Cove Creek deposit as some 1,300,000 tons.

Sicily.—Of the foreign localities of sulphur, the most noted at present are those of Sicily and Japan. The first-named deposits are described as occurring in Miocene strata involving, from below up, sandy marls with beds of salt, limy marls and lignite, gypsum and limestone impregnated with sulphur, black shales, and micaceous sands. Overlying all these is a white, marly Pliocene limestone, while below the Miocene is the Eocene nummulitic limestone. The sulphur is found in veinlets and sometimes in

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[1] Neues Jahrb. für Min. u. Pet., I, 1884, pp. 239–68.

[2] Transactions of the American Institute of Mining Engineers, XVI, 1888, pp. 33–35.

[3] Bulletin 315, 1904, U. S. Geological Survey, pp. 485–89.

larger masses, which ramify through the cellular limestone, as shown in Fig. 4.

FIG. 4.—Block of limestone (light) with alternating bands of sulphur (dark). Sicily. [U. S. National Museum.]

The yield in sulphur varies from 8 to 25 per cent, rarely running as high as 40 per cent. Below 8 per cent the rock can not be worked economically. More or less petroleum and bitumen are found in the mines. Barite and celestite sometimes accompany the sulphur.

The mining regions are in the southern central portion of the island; Girgenti and Larcara are the chief centers. The mines are distributed over an area of 160 to 170 kilometers (about 100 miles) from east to west, and 85 to 90 kilometers (55 miles) from north to south. They occur in groups around centers, partly because the sulphur-bearing stratum is not continuous, and partly because the sulphur indications are concealed by later deposits. The region is much faulted.

Japan.—The Japanese sulphur deposits are all of volcanic origin, and the Abosanobori Mine, in Kushiro village, Kawakami-gori, Kushiro Province, Hokkaido, may be taken as fairly typical. The mine is on a conical-shaped mountain of augite andesite which, on its northern side, is open and looks down upon a plain covered with lava, and is shut in by the walls of the old crater on the other sides. Sulphur is found in different parts of these walls in massive heaps, and sulphurous fumes still issue nearly everywhere about the mines. The ore as taken from the mines carries from 35 per cent to 90 per cent of sulphur, which is extracted by steam refining works at Hyocha, some 35 miles distant.[1]

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[1] The Mining Industry of Japan, by Wada Tsunashiro, 1893.

Other Japanese localities are: The Aroya Mines, at Onikobe village, Rikuzen Province, and the active volcano of Icvo-San, in Yezo.

In addition to these localities may be mentioned the following, in alphabetical order: Austria, Celebes, Egypt, France, Greece, Hawaii, Iceland, Italy, Mexico, New South Wales, New Zealand, Peru, Russia, Spain, and the West Indies.

Extraction and preparation.—Sulphur rarely occurs in nature in any quantity sufficiently pure for commercial purposes. In freeing it from its impurities three methods are employed: (1) Melting, (2) distillation, and (3) solution. In the first the ore is simply dry roasted at a low temperature or treated with superheated steam until the sulphur melts and runs off. The process is extremely wasteful. A process of fusion in a calcium chloride solution has come into use of late years, and bids fair to yield better results than either of the above. In the distillation process the ore is heated in iron retorts until the sulphur distills off and is condensed in chambers prepared for it. The product is mostly in the form of "flower of sulphur." The method is expensive, but the resultant sulphur very pure. In the third process mentioned the ore is treated with carbon disulphide, which dissolves out the sulphur and from which it is recovered by evaporation. This method, while giving good results, is also expensive and somewhat dangerous, owing to the explosive nature of the gases formed.[1]

Uses.—Sulphur is used mainly for the making of sulphuric acid, though small amounts are utilized in the manufacture of matches, for medicinal purposes, and in the making of gunpowder, fireworks, insecticides, for vulcanizing india rubber, etc. In the manufacture of sulphuric acid the sulphur is burned on a grate to sulphurous anhydride (SO_2) which is then conducted with a slight excess of air into large lead-lined chambers and mixed with steam and nitrous fumes, where the SO_2 is oxidized to the condition of SO_3 (sulphuric anhydride) and takes up water from the steam, forming H_2SO_4 (sulphuric acid). Ordinary roll sulphur is quoted in the current price-lists at from 1½ to 2½ cents per pound. (See also under iron pyrites, p. 32.)

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[1] The Mineral Industry, II, 1893, p. 600.

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3. ARSENIC.

This substance occurs native in the form of a brittle, tin-white metal, with a specific gravity of 5.6 to 5.7 and a hardness equal to 3.5 of the scale. On exposure it becomes dull black on the immediate surface. It is found, as a rule, in veins in the older crystalline rocks associated with antimony and ores of gold and silver. Some of the more celebrated localities for the mineral, as given by Dana, are the silver mines of Freiberg, Annaberg, Marienberg, and Schneeberg in Saxony; Joachimsthal in Bohemia; Andreasberg in the Harz; Kapnik and Orawitza in Hungary; Kongsberg in Norway; Zmeiv in Siberia; St. Maria aux Mines, Alsace; Mount Corna dei Darden, Italy; Chañarcillo, Chile; San Augustin, Hidalgo, Mexico, and New Zealand. In the United States it has been found at Haverhill, New Hampshire; Greenwood, Maine; near Leadville, Colorado; and on Watson Creek, Frozen River in British Columbia.

The arsenic of commerce is, however, rarely obtained from the native mineral, but is prepared by the ignition of arsenical pyrites ($FeAs_2$) or arsenical iron pyrites ($FeS_2,FeAs_2$). The white arsenic of commerce (arsenious acid, As_2O_3), though occurring sometimes native as arsenolite in the form of botryoidal and stalactitic crusts of a white or yellowish color, is, as a rule, obtained as a by-product in the metallurgical operations of extracting certain metals, particularly cobalt and nickel, from their ores. Such ores as Niccolite, a nickel arsenide ($NiAs$), Gersdorffite $NiAsS$), Rammelsbergite ($NiAs_2$), Smaltite ($CoAs_2$), Skutterudite ($CoAs_3$), Proustite (Ag_3AsS_3), and other arsenides and sulpharsenides on roasting give up their arsenic in the form of fumes, which are condensed in chambers prepared for this purpose.

Uses.—Arsenic is utilized in the form of arsenious acid (As_2O_3) in dyeing, calico printing, in the manufacture of various pigments, in arsenical soaps, in the preparation of other salts of arsenic, and as a preservative in museums, particularly for the skins of animals and birds. See further on p. 32.

II. SULPHIDES AND ARSENIDES.

1. REALGAR AND ORPIMENT.

Realgar is a monosulphide of arsenic, AsS, = arsenic, 70.1 per cent, sulphur, 29.9 per cent. Hardness, 1.5 to 2; brittle; specific gravity, 3.55; color, aurora-red to orange-yellow; luster, resinous; streak the color of the mineral. Orpiment, or auripigment as it is also called, is a trisulphide of arsenic of the formula As_2S_3, = arsenic, 61 per cent, sulphur, 39 per cent. Hardness and specific gravity essentially the same as realgar, with which it is commonly associated.

Occurrences.—Realgar and orpiment are very beautiful, though not abundant minerals which occur associated with ores of silver and lead in the various mining regions of Japan, Hungary, Bohemia, Transylvania, and Saxony. They have been reported in the United States in beds of sandy clay beneath lava in Iron County, Utah, and form the so-called "arsenical gold ore" of the Golden Gate Mine, Mercur, Tooele County, this same State, also in San Bernardino County, California; Douglas County, Oregon, and in minute quantities in the geyser waters of the Yellowstone National Park.

The realgar and orpiment of the Coyote mining district, Iron County, Utah, occur in a compact, sandy clay, occupying a horizontal seam or layer about 2 inches thick, not distinctly separated from the clay, but lying in its midst in lenticular and nodular masses. The bulk of the layer consists of realgar in divergent, bladed crystals, closely and confusedly aggregated, sometimes forming groups of brilliant crystalline facets in small cavities toward the center of the mass. The orpiment is closely associated with the realgar in the form of small and delicately fibrous crystalline rosettes and small spherical aggregations made up of fine radial crystals, and also in bright yellow, amorphous crusts in and around the mass of the realgar. Fine parallel seams of gypsum occur both above and below the layer, and the strata of arenaceous clays above for 30 feet or more are charged with soluble salts which exude and effloresce upon the surface of the bank, forming hard crusts. The whole appearance and association of the minerals indicates that they have been formed by aqueous infiltration since the deposition of the beds.[1]

Orpiment is said[2] to occur at Tajowa, near Neusohl, Hungary, as nodular masses and isolated crystals in clay or calcareous marl.

Uses.—Realgar is used mainly in pyrotechny, yielding a very brilliant white light when mixed with saltpeter and ignited. It is now artificially prepared by fusing together sulphur and arsenious acid.[3] Orpiment is used in dyeing and in preparation of a paste for removing hair from skins. According to the British consular reports there were exported from Baghdad in 1897, some 55,600 pounds of the mineral for use as a pigment. As with realgar, the mineral is now largely prepared artificially. The name orpiment is stated by Dana to be a corruption of *auripigment*, golden paint, in allusion to the color.

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The Mineral Industry, II, 1893, p. 25.

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[1] W. P. Blake, American Journal of Science, XXI, 1881, p. 219.

[2] H. A. Miers, Mineralogical Magazine, July, 1892, p. 24.

[3] Wagner's Chemical Technology, p. 87.

2. COBALT MINERALS.

Several minerals contain cobalt as one of their essential constituents in sufficient quantity to make them of value as ores. In other cases the cobalt exists in too small quantities to pay for working for this substance alone, and it is obtained as a by-product during the process of extraction of other metals, notably of nickel. The common cobalt-bearing minerals, together with their chemical composition, mode of occurrence, and other characteristics, are given below:

Cobaltite.— Cobaltine, or cobalt glance. This is a sulpharsenide of cobalt of the formula $CoAsS$, = sulphur, 19.3 per cent; arsenic, 45.2 per cent; cobalt, 35.5 per cent; hardness, 5.5, and specific gravity 6 to 6.3. The luster is metallic and color silver-white to reddish. When in crystals, commonly in cubes or pyritohedrons. Analysis of a massive variety from I, Siegen, Westphalia; II, Skutterud, Norway, and III and IV, Daschkessan, in the government of Elizabethpol, Caucasus, as given by various authorities, yielded results as below:

Constituents.	I.	II.	III.	IV.
Arsenic	45.31	43.46	35.97	31.73
Sulphur	19.35	20.08	....	....
Cobalt	33.71	33.10	17.90	17.55
Iron	1.63	3.23	1.44	9.85
Nickel	....	....	0.22	0.26
Undetermined	....	....	44.26	40.71

In Saxony the mineral occurs in lodes in gneiss and in which heavy spar (barite) forms the characteristic gangue. It is associated with other metallic sulphides, notably those of lead and copper. At Skutterud and Snarum, Norway, the cobaltiferous fahlbands, according to Phillips, "occur in crystalline rocks varying in character between gneiss and mica schists, but from the presence of hornblende they sometimes pass into hornblende schists; among the accessory minerals are garnet, tourmaline, and graphite. These schists, of which

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[1] Ore Deposits, by J. A. Phillips, p. 389.

the strike is north and south, and which have an almost perpendicular dip, contain fahlbands very similar in character to those of Kongsberg. The ores worked are cobalt glance, arsenical and ordinary pyrites, containing cobalt, skutterudite, magnetic iron pyrites, copper pyrites, molybdenite, and galena. Nickel ores do not accompany the ores of cobalt at this locality in any appreciable quantity. The principal fahlband is known to extend for a distance of about 6 miles, and is bounded on the east by a mass of diorite which protrudes into the fahlband, while extending from the diorite are small dikes or branches traversing it in a zigzag course. It is also intersected by dikes of coarse-grained granite which contain no ore, but which penetrate the diorite."

The Skutterud Mine in 1879 produced 7,700 tons of cobalt ore, which yielded 108 tons of cobalt concentrates containing from 10 to 11 per cent of cobalt, worth about £11,000.

At Daschkessan the ore occurs under a sheet of diabase, the cobaltite being in the wall rock of this sheet, which carries also garnets and copper pyrites. In 1887, 1,216 kilograms of the mineral were extracted; in 1888, 928 kilograms, and in 1889, 12,960 kilograms, besides some 3,000 kilograms of cobaltiferous matter obtained in treating the cobaltiferous copper ores.[1]

Smaltite.—This is essentially a cobalt diarsenide of the formula $CoAs_2$, = arsenic, 71.8 per cent; cobalt, 28.2 per cent; hardness, 5.5 to 6; specific gravity, 6.4 to 6.6. Color, white to steel-gray. Through the assumption of nickel the mineral passes by gradations into chloanthite.

Analyses of samples from (I) Schneeberg, Saxony, and (II) Gunnison County, Colorado, as given by Dana, yielded results as below

Constituents.	I.	II.
Arsenic	71.53	63.82
Sulphur	1.38	1.55
Cobalt	18.07	11.59
Iron	7.31	15.99
Nickel	1.02	Trace.
Copper	0.01	0.16

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[1] Annales des Mines, II, 1892, p. 503.

The mineral occurs like cobaltite in veins associated with other metallic arsenides and sulphides.

The name *safflorite* is given to a cobalt diarsenide closely resembling smaltite, but differing in being orthorhombic, rather than isometric in crystallization. The composition as given by Dana is quite variable, running from 61 per cent to 70 per cent arsenic, and 10 to 23 per cent cobalt, with 4 to 18 per cent of iron and smaller amounts of sulphur, copper, nickel, and bismuth. It is found associated with smaltite in various localities.

Skutterudite is the name given to a cobaltic arsenide of the formula $CoAs_3$, = arsenic, 79.3; cobalt, 20.7. It is of a tin-white color, varying to lead-gray, has a hardness of 6, and specific gravity of 6.72 to 6.86. It occurs associated with cobaltite, titanite, and hornblende in a vein in gneiss at Skutterud, Norway.

Glaucodot is a sulpharsenide of cobalt and iron of the formula (Co,Fe) AsS, = sulphur, 19.4 per cent; arsenic, 45.5 per cent; cobalt, 23.8 per cent; iron, 11.3 per cent. Color, grayish; hardness, 5; specific gravity, 5.9 to 6. Actual analysis of a Chilean variety yielded (according to Dana) As 43.2, S 20.21, Co 24.77, Fe 11.90. It is therefore essentially a ferriferous cobaltite, that is, a cobaltite in which a part of the cobalt has been replaced by iron. The mineral is found at Huasco, Chile, associated with cobaltite in a chloritic schist. The name *alloclasite* is given to a variety of glaucodot containing bismuth and answering to the formula Co(As,Bi)S. The composition as given is somewhat variable. Arsenic, 28 to 33 per cent; bismuth, 23 to 32 per cent; sulphur, 16 to 18 per cent; cobalt, 20 to 24 per cent; iron, 2.7 to 3.8 per cent. It is reported only from Orawitza, Hungary.

Linnæite is a sulphide of cobalt with the formula Co_3S_4, = sulphur, 42.1 per cent; cobalt, 57.9 per cent; a part of its cobalt is commonly replaced by nickel, giving rise to its variety *siegenite.* The mineral is brittle, of a pale steel-gray color, tarnishing red. Hardness, 5.5 and specific gravity, 4.8 to 5. When crystallized it is commonly in octahedrons. The following analyses of a nickel-bearing variety (*siegenite*) are quoted from Dana:

Constituents.	S.	CO.	Ni.	Fe.	Cu.
Müsen, Prussia..........	41.00	43.86	....	5.31	4.10
Mineral Hill, Maryland. .	39.70	25.69	29.56	1.96	2.23
Mine La Motte, Missouri.	41.54	21.34	30.53	3.37	Trace.

The mineral occurs in gneiss in Sweden; with barite and siderite a Müsen; in limestone with galena and dolomite at Mine La Motte, Missouri, and with sulphides of iron and copper in chloritic schists in Maryland.

Sychnodymite has the formula $(Co,Cu)_4S_5$, and yields sulphur, 40.64 per cent; copper, 18.98 per cent; cobalt, 35.79 per cent; nickel, 3.66 per cent; iron, 0.93 per cent. It is of a steel-gray color, metallic luster, and has a specific gravity of 4.75.

Erythrite or **cobalt bloom** is the name given to a hydrous cobalt arsenate of the formula $Co_3As_2O_8+8H_2O$, = arsenic pentoxide, 38.4 per cent; cobalt protoxide, 37.5 per cent, and water, 24.1 per cent. It occurs in globular and reniform shapes and earthy masses of a crimson to peach-red color associated with the arsenides and sulpharsenides mentioned above and from which it is derived by a process of oxidation. In Churchill County, Nevada, it occurs as a decomposition product of a cobalt-bearing niccolite. It is also found at the Kelsey Mine, Compton, in Los Angeles County, California; associated with cobaltite at Tambillo and at Huasco, Chile, and under similar conditions in various parts of Europe.

Asbolite or earthy cobalt, is a black and earthy ore of manganese (wad) which sometimes carries as high as 30 per cent of cobaltic oxide. It takes its name from the Greek *ασβολαινω*, to soil like soot. **Roselite** is an arsenate of lime, magnesia, and cobalt with the formula $(Ca,Co,Mg)_3As_2O_8,2H_2O$, = arsenic pentoxide, 51.4 per cent; lime, 28.1 per cent; cobalt protoxide, 12.5 per cent; water, 8 per cent. It is of a light to dark rose-red color; hardness, 3.5; specific gravity, 3.5 to 3.6, and vitreous luster. **Sphærocobaltite** is a cobalt protocarbonate of the formula $CoCO_3$, = carbon dioxide, 37.1 per cent; cobalt protoxide, 62.9 per cent. It is also of a rose-red color, varying to velvet-black. Hardness, 4, and specific gravity, 4.02 to 4.13. It occurs but sparingly, associated with roselite at Schneeberg in Saxony. **Remingtonite** is a hydrous carbonate the exact composition of which has not been ascertained. **Cobaltomenite** is a supposed selenide of cobalt. **Bieberite,** or cobalt vitriol, is a sulphate of the formula $CoSO_4 + 7H_2O$. The color is flesh to rose-red. It is soluble in water, has an astringent taste, and occurs in secondary stalactitic form. Pateraite is a possible molybdate of cobalt.

Aside from the possible sources mentioned above, cobalt occurs very constantly associated with the ores of nickel (niccolite, millerite, chloanthite, etc.), and is obtained as a by-product in smelting. Considerable quantities have thus from time to time been obtained from the Gap Mines of Pennsylvania, Mine La Motte, Missouri, and Lovelock, Nevada. Certain gold-copper mines in the Quartzburg district, Grant County, Oregon, are also producers. The nickel mines of New Caledonia are perhaps the most productive. The ore here, a silicate, carries some 3 per cent of cobalt protoxide.

A vein of cobalt ore near Gothic, Gunnison County, Colorado, is described as lying in granite, the gangue material being mainly calcite, throughout which was disseminated the ore in the form of smaltite. With it were associated erythrite, a small amount of iron pyrites, and native silver. An analysis of this ore yielded as below:

Cobalt	11.59
Iron	11.99
Arsenic	63.82
Silica	2.60
Lead	2.05
Sulphur	1.55
Bismuth	1.13
Copper	0.16
Nickel	Trace.
Silver	Trace.
	94.89

A cobalt ore, consisting of a mixture of glaucodot and erythrite, occurring near Carcoar Railway Station, New South Wales, has the composition given below:

Constituents.	I.	II.
Moisture	.120	2.180
Metallic arsenic	51.810	29.010
Metallic cobalt	10.447	13.830
Metallic nickel	.590	.390
Metallic iron	11.860	15.78
Alumina	....	Trace.
Metallic manganese	Nil.	Nil.
Metallic calcium	Nil.	.71
Magnesium	1.480	.22
Gold	Trace.	....
Silver	Trace.	....
Sulphur	1.520	11.24
Gangue (insoluble in acids)	22.078	26.31
Totals	99.905	99.67
Specific gravity	5.43	

According to the Annual Report, Department of Mines, for 1888, this ore occurs concentrated in irregular hollows and bunches, often intimately mixed with diorite in a line of fissure between an intrusive diorite and slate, the fissure running for some distance following the line of junction between the two rocks, and being presumably formed at the time of the extrusion of the diorite.

Other cobalt ores, carrying from 13 to 15 per cent of cobalt oxide, occur near Nina.[1]

Uses.—Cobalt is produced and sold in the form of oxide and used mainly as a coloring constituent in glass and earthern wares. Only some 200 tons are produced annually the world over. The market value of the material is variable, but averages about $2 a pound.

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3. ARSENOPYRITE; MISPICKEL; OR ARSENICAL PYRITES.

Composition.—Somewhat variable. Essentially a sulpharsenide of iron of the formula FeAsS, or FeS_2, $FeAs_2$, = arsenic, 46 per cent; sulphur, 19.7 per cent, and iron, 34.3 per cent. The name *danaite* is given to a cobaltiferous variety. The specific gravity of the mineral

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[1] Complete analyses of these are given in Catalogue of the New South Wales Exhibit, World's Columbian Exposition, Chicago, 1893, p. 330.

varies from 5.9 to 6.2. Hardness, 5.5 to 6. Colors, silver-white to steel-gray; streak, dark gray to black; luster, metallic. Brittle.

Occurrence and uses.—See under Löllingite.

4. LÖLLINGITE; LEUCOPYRITE.

The prismatic arsenical pyrites, or *leucopyrite*, is essentially a diarsenide of iron, with the formula $FeAs_2$, though usually contaminated with a little sulphur and not infrequently cobalt, bismuth, or antimony. It has a specific gravity of 7 to 7.4, hardness of 5 to 5.5, metallic luster, and silver-white to steel-gray color. Either löllingite or arsenopyrite can be readily recognized by the strong odor of garlic given off when roasted.

Occurrence and uses.—Arsenopyrite and löllingite both occur commonly in crystalline rocks and associated with other metallic arsenides and sulphides, and with ores of gold, silver, tin and lead. Mispickel is itself at times highly auriferous and forms a valuable ore of gold as in New South Wales, California and Alaska. Both minerals, often associated with the alteration product *scorodite*, occur in veins intersecting the older crystalline rocks in Orange, Putnam and Essex counties, New York. Near Kent, in Putnam County, the vein is in gneiss and consists of a white quartz gangue with varying proportions of the arsenide and iron pyrites. It has a northerly strike, and is in close proximity and runs parallel with a dike of basic igneous rock, though there is no apparent connection between the two. Hand-sorted samples of this ore yielded:

Constituents.	Per Cent.
Silica (SiO_2)	2.90
Iron, (Fe)	36.11
Copper, (Cu)	2.17
Sulphur, (S)	22.72
Arsenic, (As)	36.00
Total	99.90

Near Edenville and in other places in Orange County, arsenopyrite—associated with leucopyrite and the hydrous arsenate scorodite—occurs in crystalline limestone. Near Christiansburg, Montgomery County, Virginia, granular mispickel occurs intimately associated with iron pyrites in quartz schist.

That these arsenides could be utilized as sources of arsenic is apparent. As a matter of fact, however, a very large portion of the arsenic of commerce is obtained as a by-product in the smelting of arsenical ores of gold, silver, copper, etc., and still larger quantities might thus be obtained—more, indeed, than the market demands—did smelters arrange to condense and save the fumes from their smelters. It has been stated that from the stacks of the Washoe smelter (at Anaconda, Montana) there escaped during each day of August, 1905, some 57,270 pounds of arsenic;[1] in fact, that from this smelter alone the waste arsenic at that time exceeded six times the entire domestic output. In spite of these abundant sources of supply in the western mining regions, proximity to market and other advantages have favored a moderate development elsewhere. In Putnam County, New York, ore from a lode varying from 12 to 20 feet in width is mined and from it a product obtained averaging 25 per cent of metallic arsenic. Recent developments have also been made in the Virginia deposit noted. Aside from that of the white arsenic of the druggists the material appears in the market in form of a variety of salts and industrial preparations, as Sheep dip, Paris Green, London Purple, etc. Some 1,700 long tons of white arsenic were produced in this country in 1907 and 5,000 tons imported.

5. PYRITES.

Two forms of the disulphide of iron are common in nature. The first, known simply as pyrite or iron pyrites, occurs in sharply defined cubes and their crystallographic modifications, or in granular masses of a brassy-yellow color.

The second, identical in composition, crystallizes in the orthorhombic system, but is more common in concretionary, botryoidal, and stalactitic forms, which are of a dull grayish-yellow color. This form is known as marcasite or gray iron pyrites. Both forms have the

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[1] Journal of American Chemical Society, XIX, 1907.

chemical composition, FeS_2,=iron, 46.6 per cent and sulphur, 53.4 per cent.

The ore as mined is, however, never chemically pure, but contains admixtures of other metallic sulphides, besides, at times, considerable quantities of the precious metals. The following analyses[1] of materials from well-known sources will serve to show the general variation:

Constituents.	I.	II.	III.	IV.	V.	VI.	VII.
Sulphur	48.0	48.0	48.02	40.00	47.76	46.40	45.60
Iron	43.0	44.0	42.01	35.00	43.99	39.00	38.52
Copper	1.6	1.6	....	4.00	3.69	1.50	....
Zinc	1.5	1.5	....	....	0.24	....	6.00
Silica	5.0	3.7	7.60	20.00	1.99	9.25	8.70
Alumina	....	....	....	....	....	3.75	....
Arsenic	Trace.	....	....	Trace.	0.83	0.10	Trace.
Silver and gold	....	....	....	Trace.	Trace.	....	....
Lead	....	....	....	....	0.10	....	0.64

I. Milan, Coos County, New Hampshire; II. Rowe, Massachusetts; III. Louisa County, Virginia; IV. Sherbrooke, Canada; V. Rio Tinto, Spain; VI. near Lyons, France; VII. Westphalia, Germany.

Pyrite is sufficiently hard to scratch glass, and this, together with its color, crystalline form, and irregular fracture, is sufficient for its ready determination in most cases. Once known, it is thereafter readily recognized. Owing to its yellow color, the mineral has by ignorant persons been mistaken not infrequently for gold—which, however, it does not at all resemble—and has hence earned the not very flattering but quite appropriate name of "fool's gold." In certain cases, however, it carries the precious metals, and in many regions is sufficiently rich in gold to form a valuable ore.

Mode of occurrence and origin.—Pyrite is one of the most widely disseminated of minerals, both geologically and geographically, occurring in rocks of all kinds and of all ages the world over. It is found in the form of disseminated grains throughout the mass of a rock, or along the line of contact between basic eruptives and sedimentaries; as irregular and sporadic and concretionary masses in sedimentary rocks and modern sands and gravels; in the form of

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[1] Mineral Resources of the United States, 1883–1884, p. 877.

true fissure veins, and as interbedded, often lenticular masses, sometimes of immense size, lying conformably with the stratification (or foliation) of the inclosing rock. On the immediate surface the mineral is in most cases considerably altered by oxidation and hydration, forming the caps of gossan or limonite.

The origin of the mineral in the older crystalline rocks, as that of the rocks themselves, is not infrequently somewhat obscure. In sedimentary rocks it is undoubtedly due to the precipitation of the included ferruginous matter by sulphureted and deoxidizing solutions from decomposing animal and vegetable matter.

At the Stella mine, DeKalb Junction, St. Lawrence County, New York, the country rock is a light gray gneiss, the well-marked foliation showing a strike of N. 20° to 30° E., and dipping 20° to 30° to the northwest. It is probably a sheared igneous rock of pre-Cambrian age. At the mine the gneiss incloses a band of fine-grained, dark-colored schist 15 to 20 feet in width. This is also regarded as an altered igneous rock intrusive in the gneiss. The pyrite occurs in a series of overlapping lenses in this schist. These may vary from 200 to 250 feet in length, with an average thickness of 12 feet. The lump ore, as shipped, carries some 35 per cent of sulphur. The average mill ore carries but some 27 per cent, which amount is brought up to 44 or 45 per cent by careful concentration.

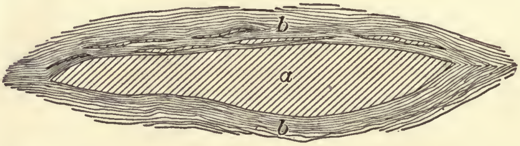

FIG. 5.—Plan of pyrite lens, Louisa County, Virginia. (*a*) Pyrite; (*b*) schist. [After Thos. Watson, Mineral Resources of Virginia.]

Pyrite outcroppings are found in Louisa and Prince William counties, Virginia, over an area some two miles in length. The ore occurs in the form of lenses (see Figs. 5 and 6), often of large size, in crystalline schists, the largest thus far reported in Louisa County being 700 feet in length with a maximum thickness of 60 feet, and in Prince William County, 1,000 feet in length with a width of 10 feet. They are stated [1] by Watson to conform in dip and strike with the schists, which in Louisa County is 60° to 65° to the southeast, and north 10° to 20° east; for Prince William County the dip is 25° to 55° to the northwest, the strike remaining the same. The contact between the ore bodies and the country rock is described as unusually sharp, though occasional gradations are met with. Thin layers of grayish white limestone often occur interlaminated with the schists and sometimes in close juxtaposition with the ore bodies.

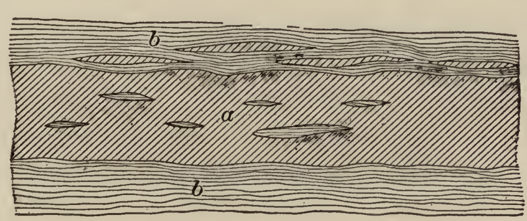

FIG. 6.—Section showing stringers of pyrite (*a*) interleaved with schist (*b*). [After Thos. Watson, Mineral Resources of Virginia.]

Dr. Watson is disposed to regard the pyrite as having originated through a process of replacement of some of these limestone bodies by sulphides.

The ore is massive and consists of fine, and, at times, very compact aggregates of granular pyrite. As mined it averages from 43 to 45 per cent sulphur.

At Rio Tinto, Spain,[2] the ore is described as occurring in immense masses several thousand feet in length, and from 300 to 800 feet in width, extending in depth to an unknown distance. The ore is very clean and massive, containing besides sulphur and iron only some 2 to 4 per cent of copper and traces of silver and gold. The material is mined wholly from open cuts and

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[1] Mineral Resources of Virginia, p. 190.

[2] A Visit to the Pyrites Mines of Spain, Eng. and Min. Jour., LVI, 1893, p. 498.

to a depth of some 400 feet. The country rock is described as of Silurian and Devonian schists, the ore occurring near contact with diorites.

Uses.—With the exception of the small amount utilized in the preparation of vermilion paints almost the sole value of the pyrite is for the manufacture of sulphuric acid and the sulphate of iron, known as green vitrol or copperas. In the process of making sulphuric acid the ore is roasted or burnt in specially designed ovens and furnaces until the mineral is decomposed, the sulphur fumes being caught and condensed in chambers prepared for the purpose. By the Glover and Gay-Lussac method from 280 to 290 parts of sulphuric acid of a density of 66° Baumé may be obtained for each 100 parts of sulphur in the ore, or about 2,565 pounds of acid to one ton (2,000 pounds) of average ore.

According to F. Stolba,[1] the so-called Bohemian fuming sulphuric acid is made from vitriol obtained from Silurian pyritiferous schists ("vitriolschiefer"). The method as given is as follows: Large masses of the schist, which consist essentially of a quartzose matrix containing pyrite, carbonaceous matter, and clay, are exposed to the weathering action of the atmosphere for three years. The products of oxidation so formed are ferrous sulphate and sulphuric acid, which latter acts energetically upon the clay, and finally aluminum sulphate and other sulphates are yielded. The ferrous sulphate at first formed becomes by oxidation ferric sulphate, which, together with the aluminum sulphate, is the principal product of the weathering of the vitriol slate. Ferrous sulphate remains only in small quantities. The next operation is lixiviation of the mass with water, after which the liquor obtained is concentrated to a density of 40° Baumé, and finally evaporated in pans until, on cooling, a crystalline cake of vitriol stone is obtained. The vitriol stone is now calcined in order to remove the greater part of its water. The resulting product, when heated to a very high temperature in clay retorts, yields sulphuric anhydride, and a residue, termed

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[1] Journal of the Society of Chemical Industry, V, 1886, p. 30.

colcothar, remains in the retorts. The composition of vitriol stone and colcothar will be seen from the following analyses:[1]

VITRIOL STONE.	
Fe_2O_3	20.07
Al_2O_3	4.67
FeO	0.64
MnO	Traces.
CaO	0.14
MgO	0.39
K_2O	0.07
Na_2O	0.05
CuO	0.10
SiO_2	0.10
P_2O_5	Traces.
SO_3	40.51
As	Traces.
H_2O	32.58=99.32

VITRIOL STONE.	
$Fe_2(SO_4)_3$	50.17
$Al_2(SO_4)_3$	11.94
$FeSO_4$	1.35
$MgSO_4$	1.17
$CaSO_4$	0.33
$CuSO_4$	0.20
K_2SO_4	0.13
Na_2SO_4	0.11
H_2SO_4	1.49
MnO, As, and P_2O_5	Traces.
SiO_2	9.10
H_2O	32.31=99.29

COLCOTHAR.			
Fe_2O_3	74.62	SO_3	5.17
Al_2O_3	12.53	SiO_2	1.17
MgO	3.23	CuO	0.20
CaO	0.82	H_2O	1.30=99.04

Pyrite on decomposing in the presence of moisture in the ground sometimes gives rise to an acid sulphate of iron. This may attack aluminous minerals when such are present, giving rise thus to solutions of sulphate of iron and alumina, which come to the surface as "alum springs," or, if no alumina is present, merely as iron or chalybeate springs, which are of more or less medicinal value. The presence of such sulphates in a soil is readily detected by the well-known astringent taste of green vitriol and alum, even where the quantity is not sufficient to appear as a distinct efflorescence. Impregnation of these salts in soils are by ignorant persons sometimes assumed to be of great medicinal value, and the writer has in mind a case in one of the Southern States, in which the aqueous leachings of such a soil were regularly bottled and sold as a specific for nearly all the ills to which the flesh is heir, though prescribed especially for flux, wounds, and ulcers. (See also under Alum, p. 350.)

In the manufacture of copperas the ore is broken into small pieces and thrown into piles over which water is allowed to drip slowly. A

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[1] The Geology of England and Wales, p. 279.

natural oxidation takes place, whereby the sulphide is transformed into a hydrated sulphate. The latter being soluble, runs off in solution in the water, which must be collected and evaporated in order to obtain the salt. Thus prepared the sulphate is used in dyeing, in the manufacture of writing-ink, as a preservative for wood, and as a disinfectant. It has also been used in the manufacture of certain brands of fertilizers.

The analysis given below show (1) the composition of fresh pyrite from the Coal Measures of Mercer County, Pennsylvania, and (2) and (3) that of two varieties of paint produced from it by calcination.[1]

Constituents.	I.	II.	III.
Bisulphide of iron	96.161	0.415	0.405
Bisulphide of copper	Trace.	....	....
Sesquioxide of iron	....	66.143	77.143
Alumina	.653	.697	.543
Protoxide of iron	....	6.300	5.142
Lime	.450	.160	.160
Magnesia	.140	.100	.100
Silica	.680	3.880	3.980
Sulphuric acid	....	13.110	7.334
Water and carbonaceous matter	....	9.195	5.194
Undetermined	1.916	....	....
Total	100.000	100.000	100.000

6. PYRRHOTITE: MAGNETIC PYRITES.

This form of iron sulphide differs from either of the pyrites just described not merely in the relative proportions of sulphur and iron, but in its bronze color and property of being attracted by the magnet. Moreover it does not show the cubic crystal forms of pyrite and indeed is rarely found in crystals at all.

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[1] Report M. M. Second Report of Progress in the Laboratory of the Survey at Harrisburg, Second Geological Survey of Pennsylvania, 1879, p. 374.

The content in sulphur (38 to 39 per cent) is too small to make it of immediate value in the manufacture of sulphuric acid. It is stated, however, that in certain cases, as at the Sudbury nickel mines where the mineral occurs so closely associated with ores of other metals as to necessitate a common treatment for all, the sulphurous fumes from the roasters can be economically condensed and utilized in the ordinary way. It is a safe prediction that in the not very distant future the mineral must be utilized as an ore of iron.

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7. MOLYBDENITE.

This is a disulphide of molybdenum having the formula MoS_2, = sulphur, 40 per cent; molybdenum, 60 per cent.

The mineral, like graphite, occurs in black, shining scales, sometimes hexagonal in outline and with a bright metallic luster. It is soft enough to be readily impressed with the thumb nail, and leaves a bluish-gray trace on paper. On procelain it leaves a lead-gray, slightly greenish streak. This faint greenish tinge, together with its property of giving a sulphur reaction when fused with soda, furnishes a ready means of distinguishing it from graphite, which it so closely resembles. Through alteration it sometimes passes over into molybdite or molybdic ocher, a straw-yellow to white ocherous mineral of the formula MoO_3, = oxygen, 33.3 per cent; molybdenum, 66.7 per cent.

Occurrence.—The mineral has a wide distribution, occurring in embedded masses and disseminated scales in granite, gneiss, syenite, crystalline schists, quartz, and granular limestone. It is found in Norway, Sweden, Russia, Saxony, Bohemia, Austria, France, Peru, Brazil, England, and Scotland, throughout the Appalachian region in the United States and Canada, and in various parts of the Rocky and Sierra Nevada Mountains. In Okanogan County, Washington, the mineral occurs in beautiful large flakes in an auriferous quartz vein transversing slates.

At Crown Point, in Chelan County, this same State, molybdenite occurs in a nearly horizontal quartz vein cutting a gray biotite granite, the mineral itself being in the form of crystals and flakes 20 mm. or more in diameter, and in small seams extending through the quartz in all directions.[1] In British Columbia it has been reported [2] as occurring in massive veins sometimes 8 inches in width. At Cooper, Washington County, Maine, the mineral is found in dikes of pegmatite cutting granite and also in the granite itself adjacent to the dikes. The pegmatites, in this instance are regarded as approximately contemporaneous with the granite, representing the latest crystallization of the granitic magma, and the molybdenum sulphide, an original constituent of the magma, crystallizing early during the process of cooling.[3]

On Quetachoo-Manicouagan Bay, on the north side of the Gulf of St. Lawrence, the mineral is reported [4] as occurring disseminated in a bed of quartz 6 inches thick, in the form of nodules from 1 to 3 inches in diameter, and in flakes which are sometimes 12 inches broad by ¼ inch in thickness. It is also found in the form of finely disseminated scales or small bunches among the iron ores of the Hude Mine at Stanhope, New Jersey, sometimes constituting as high as 2 per cent of the ore.

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[1] A. R. Crook, Bulletin Geological Society of America, XV, 1904, p. 283.

[2] Journal Canadian Mining Institute, VII, 1904, p. 164.

[3] G. O. Smith, Bulletin 26, U. S. Geological Survey, 1904, p. 198.

[4] Geology of Canada, 1863, p. 754.

Molybdenum is also a constituent of the mineral wulfenite, or molybdate of lead.

Uses.—The principal use to which molybdenite has as yet been put is in the preparation of molybdates for the chemical laboratory. It is stated that a fine blue pigment can be prepared from it, which it has been proposed to use as a substitute for indigo in dyeing silk, cotton, and linen. The metal molybdenum is produced but rarely, and only as a curiosity, and has a purely fictitious value. Up to the present time there has been no constant demand for the mineral nor regular source of supply.

8. PATRONITE: VANADIUM SULPHIDE.

The name *patronite* or *Rizo-patronita* has recently (1906) been applied to a peculiar amorphous asphaltic-appearing material, nearly black in color, breaking with a smooth to uneven and irregular fracture and which analyses show to be essentially a vanadium sulphide, though in nature almost universally admixed with silica, alumina, iron oxides and other impurities.

Composition.—The composition of the crude material as given by different authorities is as below:

Constituents.	I	II.	III.
SiO_2	10.88	6.88	22.22
Al_2O_3	3.85	2.00	8.32
Fe	2.45	2.92	1.98
V	16.08	19.53	15.36
MoO_3	0.50	0.18	....
S soluble in CS_2	6.55	4.50	41.81
S (combined)	54.06	54.29	
CaO	....	....	0.33
Moisture	Trace	1.90	....
Undetermined	5.63 [1]	....	9.88 [2]
	100.00	92.20 [3]	100.00

[1] Largely carbonaceous.

[2] Carbon.

[3] Contained also Ni, 1.87; C, 3.47; TiO_2, 1.53; Fe_2O_3, 0.20.

The formula for the minerals as suggested by these analyses is somewhat uncertain, but may be VS_4. With the patronite occurs an asphaltic compound, to which the name *Quisqueite* has been given; a coke-like material yielding some 86.63 per cent free carbon; a little free sulphur; an iron-nickel sulphide and the impurities noted in the analyses.

Occurrence.—Although vanadium-bearing hydrocarbons are not uncommon, material of the composition and character indicated has thus far been reported only from Minasragra, some 46 kilometers from Cerro de Pasco in Peru. The region is one occupied by Juratrias and Cretaceous shales, sandstones, and limestones dipping toward the northeast, much faulted and injected by dikes of trachyte, andesite, dolerite, diabase, and quartz porphyry. The entire vanadium-bearing deposit consists of a lens-shaped mass occupying one of the faults. The maximum width is some 28 feet and the length, so far as ascertained, 350 feet, with a strike N. 20° W., and dip of 75° W. This lens-shaped mass is composed mainly of three constituents, (1) quisqueite, a black, lustrous hydrocarbon of a hardness of 4.5 and specific gravity of 1.75; (2) a dull black, coke-like hydrocarbon

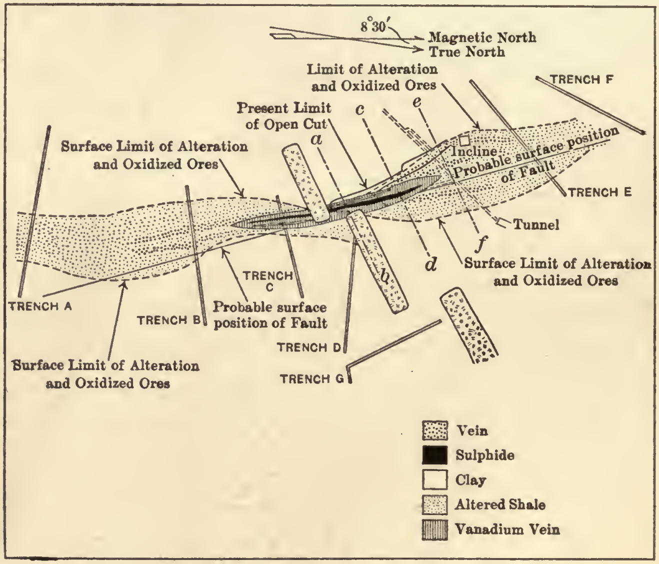

FIG. 7.—Map of La Quimira patronite area, Minasagra, Peru. [After D. F. Hewett, Bulletin American Institute of Mining Engineers, 1909.]

of a hardness of 4.5 and specific gravity of 2.4; and (3) the patronite. The relative position of these is shown in Fig. 7.

Origin.—No satisfactory explanation of this deposit is as yet at hand. Very probably the entire deposit may have been formed as have other asphaltic vein masses in Utah and elsewhere, i.e., the material was forced into the shales while in a plastic condition. It is conceivable, writes Hillebrand, that the injected material was originally homogeneous and that segregation took place subsequently.

Uses.—The material is roasted to drive off the volatile constituents and the residue used as a source of vanadium salts for metallurgical purposes.

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Journal American Chemical Society, XXIX, July, 1907.

III. HALIDES.

I. HALITE; SODIUM CHLORIDE; OR COMMON SALT.

Composition.—NaCl, = sodium, 60.6 per cent; chlorine, 39.4 per cent. The natural substance is nearly always more or less impure, as noted later. Hardness, 2.5; specific gravity, 2.1 to 2.6 per cent. Colorless or white when pure, but often yellowish or red or purplish from the presence of metallic oxides and organic matter. Readily soluble in cold water, and has a saline taste. Crystallizes in the isometric system, usually in cubes, rarely with octahedral modifications. The faces of the crystals (particularly when prepared artificially) are often cavernous or hopper-shaped. Sometimes occurs in fibrous forms, which it has been suggested are pseudomorphous after fibrous gypsum. Often found in the form of massive, crystalline granular aggregates commonly known as rock salt.

Sylvite, the chloride of potassium, sometimes occurs associated with halite, where it has formed under similar conditions. From halite it can be distinguished by its crystalline form, that of a combination of cube and octahedron (see Fig. 11), and more biting taste. Owing to its ready solubility it is rarely found in a state of nature. Bischofite, the chloride of magnesium, is still more soluble and practically unknown except in crystals artifically produced.

COMPOSITION OF SALT FROM VARIOUS LOCALITIES.

Varieties of Salt.	Chloride of Sodium.	Chloride of Calcium.	Chloride of Magnesium.	Sulphate of Calcium.	Sulphates of Magnesia and Soda.	Carbonates of Magnesia and Lime.	Alumina and Iron.	Residue.	Water.	Authorities.
Rock salt.										
Wieliczka, white	100	....	Tr.	....	....	....	....	....	....	Bischof.
Hall, in Tyrol	99.43	0.25	0.12	0.20	....	....	....	....	....	Do.
Stassfurt	94.57	....	0.97	0.89	....	....	1.12	2.23	0.22	Heine.
Ouled Kebbah, Algeria	98.53	0.93	0.57	....	....	....	....	....	....	Fournet.
Cheshire, England	99.32	....	0.02	0.46	....	....	....	....	....	G. H. Cook.
Holston, Virginia	99.55	Tr.	....	....	....	0.45	....	....	....	C. B. Hayden.
Petite Anse, Louisiana	98.88	Tr.	Tr.	0.79	....	....	....	....	0.33	Goessman.
Santo Domingo	98.33	....	0.04	1.48	....	....	....	0.01	0.07	Do.
Cardona, Spain	98.55	0.99	0.02	0.44	....	....	....	....	....	
Sea salt.										
Turks Island	96.76	....	0.14	1.56	0.64	....	....	....	0.90	G. H. Cook.
St. Martin's	97.21	....	0.26	0.54	0.24	....	....	....	1.75	Do.
St. Kitts	99.77	....	0.01	0.08	....	....	....	....	0.14	Do.
Curaçoa	99.85	....	0.03	0.12	....	....	....	....	....	Do.
Cadiz	95.76	....	0.57	0.75	0.48	....	....	....	2.44	Do.
Lisbon	94.17	....	1.11	0.49	1.39	....	....	....	2.84	Do.
Trapani, Sicily	96.78	....	0.49	0.41	0.68	....	....	....	1.64	Do.
Martha's Vineyard	94.91	....	0.24	1.42	0.19	....	....	....	3.24	Do.
Pacific coast (Union Pacific Salt Company)	98.435	....	....	....	0.365	....	....	....	1.20	Falkenan & Reese.
Salt from springs and lakes.										
Cheshire, England	96.36	0.01	0.02	1.17	....	....	....	....	2.44	Do.
Dienze, German Lorraine	97.39	....	....	1.02	0.89	....	....	....	0.50	Do.
Goderich, Ontario	97.03	0.01	0.03	1.43	....	....	....	....	1.50	Goessman.
Onondaga, New York	97.41	0.15	0.18	1.26	....	....	....	....	1.00	G. H. Cook.
Kanawha, West Virginia	91.31	1.26	0.43	....	....	....	....	....	7.00	Do.
Holston, Virginia	99.11	....	....	0.68	0.11	....	....	....	0.10	Do.
Saginaw, Michigan	92.97	1.09	0.50	0.33	....	....	....	0.01	5.10	Do.
Hocking Valley, Ohio	93.07	0.61	0.04	0.10	....	....	....	....	3.40	Goessman.
Pomeroy, Ohio	96.42	0.53	0.18	....	....	....	0.05	0.16	2.66	E. S. Wayne.
Nebraska	98.12	....	0.07	0.24	0.89	....	....	....	0.80	Goessman.
Kansas	93.06	....	0.24	1.12	0.18	....	....	....	4.80	Do.
Onondaga "factory filled"	98.28	....	....	0.91	0.09	....	....	0.12	0.60	Do.
Great Salt Lake	97.61	....	....	1.03	0.08	....	....	....	1.28	G. H. Cook.

Origin and occurrences.—Sodium in the form of chloride, to which is commonly given the simple name of salt is one of the most widely disseminated of natural substances, and not infrequently occurs in such quantities interstratified with other rocks as to assume proportions of geological importance. It is to the material occurring in this form that the name *rock salt* is commonly applied. As existing to-day the principal deposits of the world are a result of evaporation of seawaters or deposits from springs. In either case the ultimate source of the material was probably the same, the springs simply deriving their supply from pre-existing beds of marine origin. Inasmuch as seawaters carry in solution other salts than sodium chloride, so it happens that the beds of marine salt are almost invariably contaminated or interstratified with carbonates, chlorides, and sulphates of various substances which have been deposited in the inverse order of their solubilities as evaporation proceeded. The following list includes the more common associations: (1) carbonates of lime and magnesia in the form of limestones, marls, and dolomites; (2)

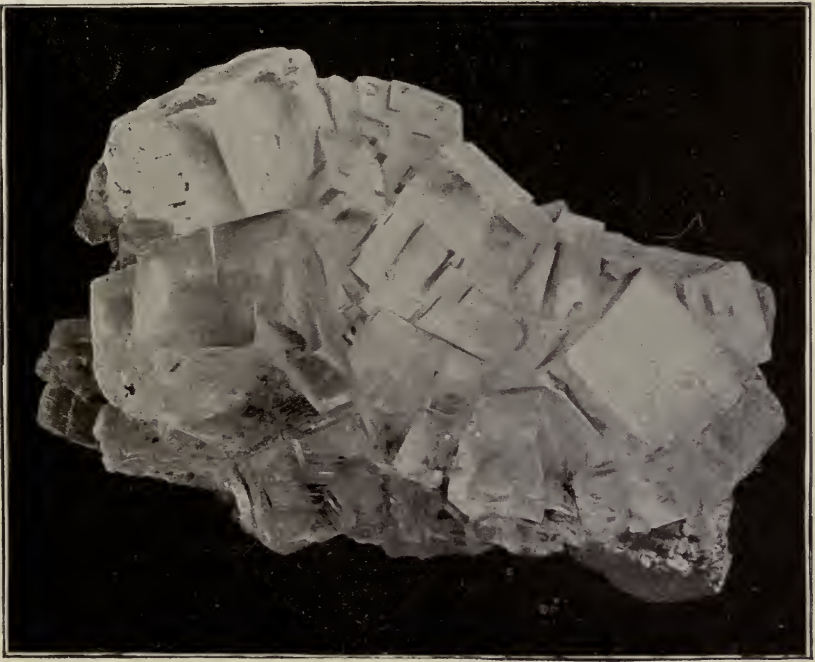

FIG. 8.—Cluster of halite crystals. Stassfurt, Germany.
[U. S. National Museum.]

sulphate of lime in the form of anhydrite and gypsum; (3) chloride of sodium, or common salt, and these followed in regular order by the sulphates of magnesia and soda (Epsom salt and Glauber's salt) and the chlorides of potassium and magnesium. These last are, however, so readily deliquescent that they are rarely found crystallized out in a state of nature, as above noted.

Such having been the method of formation, it is scarcely necessary to state that salt beds are not confined to strata of any one geological horizon, but are to be found wherever suitable circumstances have existed for the formation and preservation. The beds of New York State and of Canada and a part of those of Michigan lie among rocks of the Upper Silurian Age. They are regarded by Professor Newberry as the deposits of a great salt lake or sea that formerly occupied central and western New York, northern Pennsylvania, northeastern Ohio, and southern Ontario, and which he assumed to have been as large as Lake Huron, or possibly Lake Superior. A part of the Michigan beds, on the other hand, were laid down near the base of the Carboniferous series, as were also those of the Ohio Valley, and presumably those of Virginia, while those of Petite Anse, Louisiana, are of Cretaceous, or possibly Tertiary Age. The beds of the Western States and Territories are likewise of recent origin, many of them being still in process of formation.

The English beds at Cheshire, the source of the so-called "Liverpool" salt, are of Triassic Age, as are also those of Vic and Dieuze in France, Wurtemburg in Germany, and Salzburg in Austria, while those of Wieliczka in Austrian Poland, and of Parajd in Transylvania are Tertiary.

Salt is now manufactured from brines or mined as rock salt in fifteen States of the American Union. These, in the order of their apparent importance, are Michigan, New York, Kansas, California, Louisiana, Illinois, Utah, Ohio, West Virginia, Nevada, Pennsylvania, Virginia, Kentucky, Texas, and Wyoming. At one time Massachusetts was an important producer of salt from sea waters. The industry has, however, been gradually languishing, and may ere now be wholly extinct. In California salt is obtained largely from sea water, but also from salt lakes and salines. In Michigan, Ohio, the Virginias, Pennsylvania, and Kentucky salt is obtained from brines obtained from springs or by sinking wells into the salt-bearing strata, while in New York, Kansas, Louisiana, and the remaining States it is obtained both from brines and by mining as rock salt.

Of the foreign sources of rock salt the following districts are the most important: (1) The Carpathian Mountains, (2) the Austrian and Bavarian Alps, (3) Western Germany, (4) the Vosges, (5) Jura, (6) Spain, (7) the Pyrenees and the Celtiberian Mountains, and (8) Great Britain, while sea salt is an important product of Turks Island in the Bahamas, of the island of Sicily, and of Cadiz, Spain.

Space can here be devoted to details concerning but a few of these localities, preference naturally being given to those of the United States.

The beds of New York State, of Ontario, northern Pennsylvania, northeastern Ohio, and eastern Michigan all belong to the same geologic group—are the product of similar agencies. They have been penetrated in many places by wells, and from the results obtained one is enabled to form some idea of their extent and thickness. Below is given a summary of results obtained in boring a well to a depth of 1,517 feet at Goderich, Canada. Beginning at the surface, the rocks were passed through in the following order:

	Ft.	In.
1. Clay, gravel, marls, limestone, dolomite, and gypsum variously interstratified	997	0
2. First bed of rock salt	30	11
3. Dolomite with marls	32	1
4. Second bed of rock salt	25	4
5. Dolomite	6	10
6. Third bed of rock salt	34	10
7. Marl, dolomite, and anhydrite	80	7
8. Fourth bed of rock salt	15	5
9. Dolomite and anhydrite	7	0
10. Fifth bed of rock salt	13	6
11. Marl and anhydrite	135	6
12. Sixth bed of rock salt	6	0
13. Marl, dolomite, and anhydrite	132	0
Total thickness of formations passed through	1,517 feet.	
Total thickness of beds of salt	126 feet.	

The section shows that the ancient sea or lagoon underwent at least six successive periods of desiccation, and especial attention is called to the remarkable regularity of the deposits. On the oldest sea bottom (13) the carbonates and sulphates of lime and magnesia were deposited first, being least soluble. Then followed the salt, and this order is repeated invariably. The other constituents mentioned as occurring in the waters of lakes and seas are not sufficiently abundant to show in the section, or owing to their ready solubility have been in large part removed since the beds were laid down. Chemical tests, however, reveal their presence in small but varying quantities.

Although salt was manufactured from the brine of springs, near Onondaga Lake, in New York, as early as 1788, and has been regularly manufactured from the brine of wells since 1798, it was not until subsequent to the discovery of extensive beds of rock salt in the Wyoming Valley, while boring for petroleum, that the mining of the material in this form became an established industry. In June, 1878, a bed of rock-salt 70 feet in thickness was found in the valley above mentioned, at a depth of 1,270 feet. Subsequently other borings in Wyoming, Genesee, and Livingston counties disclosed beds at varying depths. In 1885 the first shaft was sunk at Pifford by the Retsof Mining Company, the salt bed being found at a depth of 1,018 feet. Other shafts have since been sunk, the first about a mile west of the Retsof, the second about 2 miles south of Leroy, and the third at Livonia, in Livingston County. The salt when taken from the bed is of a gray color, due to the presence of clay, which renders solution and recrystallization necessary when designed for culinary purposes. The thickness of the beds and their depth are somewhat variable. The following figures are quoted from Dr. Engelhardt's report.[1] At Morrisville, in Madison County, it is 12 feet thick and at a depth of 1,259 feet; at Tully, in Onondaga County, it varies from 25 to 318 feet, at depths of from 974 to 1,465 feet. The seven beds found at Ithaca have a total thickness of 248 feet, the uppermost lying at a depth of 2,244 feet. In the Genesee Valley the beds vary in depth from 750 to 2,100 feet, and in thickness from 40 to 93 feet. In the Wyoming Valley the depth varies from 610 to 2,370 feet below the surface, and in thickness from 12 to 85 feet.[2]

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[1] The Mineral Industry, its Statistics and Trade for 1892, by R. P. Rothwell.

[2] For a very complete historical and geological account of these salt beds and the method of manufacture, see Bulletin No. 11, of the New York State Museum, 1893, by F. J. H. Merrill.

Ohio.—The first attempts at salt making in this State was made in 1798 with brines from salt springs in Jackson County. These, which became known as the Scioto Valley Works, were abandoned about 1818 owing to the discovery of richer brines in the Kanawha Valley and elsewhere. Drilling for salt began in the Muskingum Valley near Zanesville in 1817, and by 1833 the output of this valley alone amounted to 300,000 or 400,000 bushels annually. At the present date (1909) the principal works are in Meigs, Morgan, Franklin, Wayne, Medina, and Summit counties. During the years immediately following the Civil War there were thirteen furnaces in the State for the evaporation of brines. The number has gradually declined to five, owing to the cheaper production from wells in Michigan and New York. The densest of the Ohio brines come from the Berea Grits, but the amount is small; the so-called Big Salt Sand is the most prolific source. The wells vary in depth from 1,000 to 2,000 feet.[1]

Michigan.—The salt-producing areas of this State are, so far as now known, limited to the counties of Iosco, Bay, Midland, Gratiot, Saginaw, Huron, St. Clair, Manistee, and Mason, the beds of the Saginaw Valley lying in the so-called Napoleon sandstone, at the base of the Carboniferous. Professor Winchell has estimated this formation to cover an area of some 17,000 square miles within the State limits. The beds of the St. Clair Valley, on the other hand, are in upper Silurian strata, being presumably continuous with those of Canada. The manufacture of salt from brines procured from these beds began in the Saginaw Valley in 1860, and has since extended to the other regions mentioned. According to F. E. Engelhardt the rock-salt deposits in the Upper Silurian beds, with a thickness of 115 feet, were reached at Marine City, in St. Clair County, at a depth of 1,633 feet; at St. Clair, St. Clair County, at a depth of 1,635 feet, and with a thickness of 35 feet. At Caseville, in Huron County, the beds lie at a depth of 1,164 feet, and at Bay City, Saginaw Bay, at 2,085 feet, the salt beds being 115 feet in thickness. At Manistee the bed is 34 feet thick, lying 2,000 feet below the surface, while at Muskegon, in the Mason well, it was 50 feet thick at a depth of 2,200 feet.

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[1] Bulletin No. 8, Geological Survey of Ohio, 1906.

Kansas.—In this State the rock salt occurs in beds regarded as of Permian age, and has been reached by means of shafts in several counties in the southern and central part of the State. The following is a section of a shaft sunk in Kingman in 1888–89:

	Feet.
"Red-beds," red arenaceous, limestones, ferruginous clays, and clay shales with thin streaks of gray shales and bands of gypsum as satin spar	450
Gray or bluish "slate," with 2 feet of limestone at 500 feet	140
Red clay shale	4
Gray "slate," with occasional streaks of limestone, 2 to 8 inches thick, and some salt partings and satin spar with ferruginous stain	78
First rock salt, pure white	2
Shale and "slate," bluish, with vertical and other seams of salt, from 1 to 3 inches thick	26
Rock salt	4
Shales, with salt	11
Rock salt	7
Shale	3
Rock salt	3
Salt and shale, alternate thin seams	62
Rock salt	11
Shale	$1\frac{2}{12}$
Rock salt	5
Shales and limestone	8
Rock salt, bottom of it not reached	5
Total	820

Borings and shafts have also proven the existence of beds of salt in other parts of the State, as at Kanopolis, Lyons, Caldwell, Rago, Pratt, and Wilson. According to Dr. Robert Hays[1] it is safe to assume that beds of rock salt from 50 to 150 feet in thickness underlie fully half the area from the south line of the State to north of the Smoky River, an area from 20 to 50 miles in width. Although the mining of rock salt began in this region only in 1888, the annual output has already reached over 1,000,000 barrels.

Louisiana.—Salt in this State is derived from Petite Anse, a small island rising from the marshes on the southern coast and connected with the mainland by a causeway some 2 miles in length. According to E. W. Hilgard[2] the deposit is probably of Cretaceous Age, and presumably but a comparatively small residual mass

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[1] Geological and Mineral Resources of Kansas, 1893, p. 44.

[2] Smithsonian Contributions to Knowledge, XXIII. On the Geology of Lower Louisiana and the Salt Deposit on Petite Anse Island.

of beds once extending over a much larger area, but now lost through erosion. (See Fig. 10.) G. D. Harris,[1] however, regards them as deposits from springs ascending from deep-seated sources along lines of faults, the dome-shaped structure being due to the gradual forcing up of the deposit first formed by the crystallization of new material brought up by hydrostatic pressure from beneath.

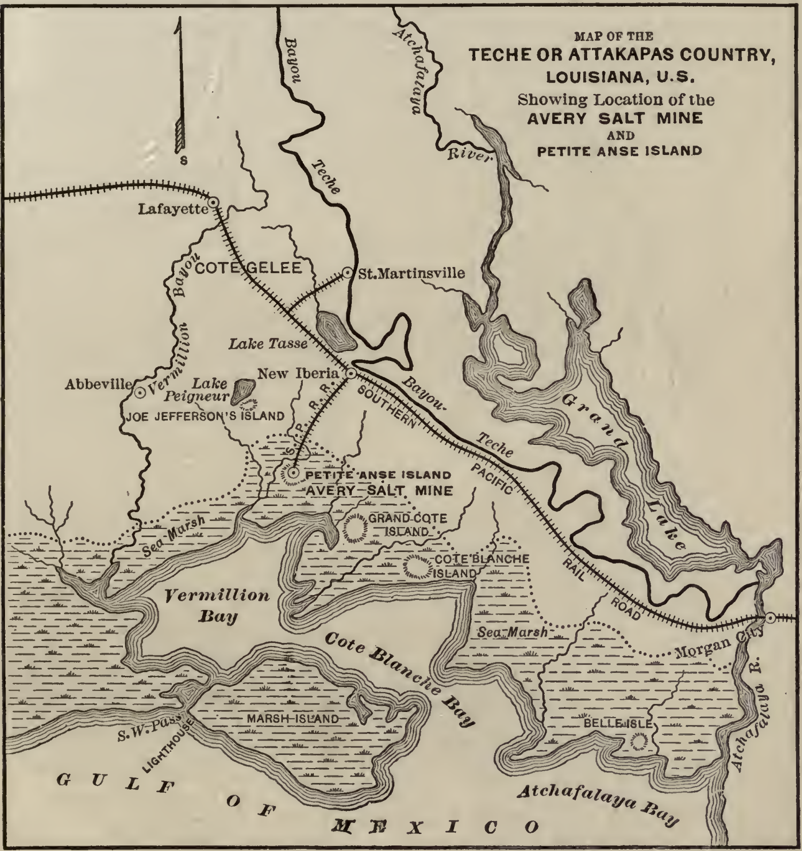

Fig. 9.—Map of Petite Anse, Louisiana.
[After Hilgard.]

Kentucky. — Salt in Kentucky is obtained from the brine of springs and wells in Carboniferous limestone. In Meade County brine accompanies the natural gas, the latter in some cases being

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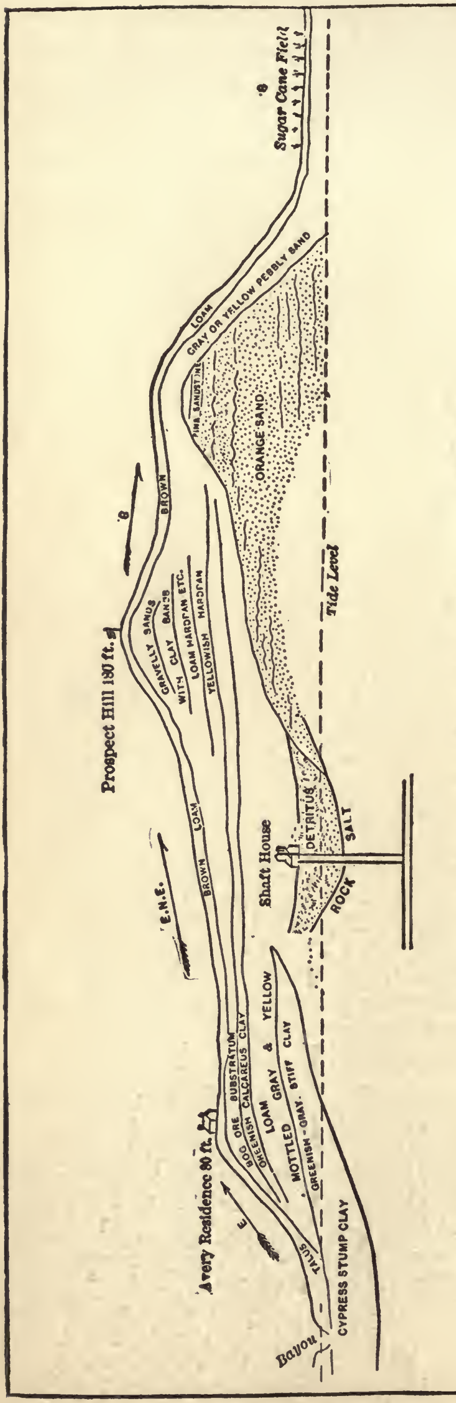
[1] Economic Geologist, IV, No. 1, 1909.



GEOLOGICAL SECTION OF PETITE ANSE ISLAND, LOUISIANA.

(Copied from Prof. E. W. Hilgard's Map.)

FIG. 10.

utilized as fuel for its evaporation. Springs in Webster County furnished salt for Indians long anterior to the occupancy of the county by whites, and fragments of their clay kettles and other utensils used in the work of evaporation are still occasionally found.

Texas.—The occurrences of salt are numerous and widespread. Along the coast are many lagoons and salt lakes, from which considerable quantities are taken annually. "Besides the lakes along the shores many others occur through western Texas, reaching to the New Mexico line, while northeast of these, in the Permian region, the constant recurrence of such names as Salt Fork, Salt Creek, etc., tell of the prevalence of similar conditions." In addition to the brines there are extensive beds of rock salt. That which is at present best developed is located in the vicinity of Colorado City, in Mitchell County. The bed was found at a depth of 850 feet, with a thickness of 140 feet. At the "Grand Saline" in Van Zandt County, a bed of rock salt over 300 feet in thickness was found at a depth of 225 feet.

England.—In England the salt occurs at Cheshire in two beds interstratified with marls and clays. The upper, with a thickness varying from 80 to 90 feet, lies at a depth of some 120 feet below the surface, and the second at a depth of 226 feet has a thickness varying between 96 and 117 feet. The accompanying general sections are from Davies' *Earthy and other Economic Minerals.*

DETAILED SECTION OF STRATA SUNK THROUGH AT WITTON, NEAR NORTHWICH, TO THE LOWER BED OF SALT.

		Ft.	In.
1.	Calcareous marl	15	0
2.	Indurated red clay	4	6
3.	Indurated blue clay and marl	7	0
4.	Argillaceous marl	1	0
5.	Indurated blue clay	1	0
6.	Red clay with sulphate of lime in irregular branches	4	0
7.	Indurated red clay with grains of sulphate of lime interspersed	4	0
8.	Indurated brown clay with sulphate of lime crystallized in irregular masses and in large proportions	12	0
9.	Indurated blue clay with laminæ of sulphate of lime	4	6
10.	Argillaceous marl	4	0
11.	Indurated brown clay laminated with sulphate of lime	3	0
12.	Indurated blue clay laminated with sulphate of lime	3	0
13.	Indurated red and blue clay	12	0
14.	Indurated brown clay with sand and sulphate of lime irregularly interspersed through it. The fresh water, at the rate of 360 gallons a minute, forced its way through this stratum	13	0
15.	Argillaceous marl	5	0
16.	Indurated blue clay with sand and grains of sulphate of lime	3	9
17.	Indurated brown clay as next above	15	0
18.	Blue clay as strata next above	1	6
19.	Brown clay as strata next above	7	0
20.	The top bed of rock salt	75	0
21.	Layers of indurated clay with veins of rock salt running through them	31	6
22.	Lower bed of rock salt	115	0
	Total	341	9

Poland.—At Wieliczka, in Austrian Poland, the salt occurs in massive beds stated to extend over an area some 20 by 500 miles, with a maximum thickness of 1,200 feet. At Parajd, in Transylvania, beds belonging to the same geological horizon are estimated to contain upward of 10,000,000,000,000 cubic feet of salt.

FIG. 11.—Cluster of sylvite crystals, showing characteristic cubo-octahedral forms. Stassfurt, Germany.
[U. S. National Museum.]

Germany.—One of the most remarkable deposits of the world, remarkable for its extent as well as for the variety of its products, is that of Stassfurt, in Prussian Saxony. On account of its unique character, as well as its commercial importance, being to-day the chief source of natural potash salts of the world, a little space may well be given here to a detailed description.[1]

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[1] Journal of the Society of Chemical Industry, II, 1883, pp. 146, 147.

Stassfurt is about 25 miles southwest of the city and fortress of Magdeburg, in Prussia. It lies in a plain intersected by the river Bode, which takes its rise in the Harz Mountains. The salt industry here is a very old one, dating back as far as the year 806. Previous to 1839 the salt was produced from brine pumped from wells sunk about 200 feet into the rock. The brine, in the course of time, became so weak that it was impossible to carry on the manufacture without loss. In 1839 the Prussian Government commenced boring with the object of discovering the whereabouts of the bed of rock salt from which the brine had been obtained. In 1843, seven years after the commencement of the borings, the top of the rock salt was reached at a depth of 256 meters. The boring was continued through another 325 meters into the rock salt without reaching the bottom of the layer. At this total depth of 581 meters the boring was suspended. On analyzing the brine obtained from the bore-hole, it was found to consist, in 100 parts by weight, of—

Sulphate of calcium	4.01
Chloride of potassium	2.24
Chloride of magnesium	19.43
Chloride of sodium	5.61

This result was not only unexpected, but disappointing, since the presence of chloride of magnesium in such quantities dispelled for the time all hopes of striking pure rock salt. The Government, however, guided by the opinions expressed by Dr. Karsten and Professor Marchand, to the effect that the presence of chloride of magnesium in such quantities was probably due to a deposit lying above the rock salt, determined to further investigate the matter, and in the year 1852 the first shaft was commenced, which after five years had penetrated, at a depth of 330 meters, into a bed of rock salt, passing on its way, at a depth of 256 meters, a bed of potash and magnesia salts of a thickness of 25 meters.

On referring to the section of the mines (Plate II) it will be seen that the lowest deposit of all consists of rock salt. The bore-hole was driven 381 meters into it without reaching the bottom of the layer. Its depth is therefore unknown. The black lines drawn through the rock-salt deposit represent thin layers of anhydrite 7 millimeters thick, and almost equidistant. The lines at the top of the rock salt represent thin layers of *Polyhallite*, the trisulphate of potash, magnesia, and lime. The deposit lying immediately on the bed of rock salt consists chiefly of the mineral *Kieserite*, a sulphate of magnesia. Still farther toward the surface the deposit consists of the double chloride of potassium and magnesium, known as *Carnallite*, mixed with sulphate of magnesia and rock salt. The deposit to the right, on the rise of the strata, consists of the double sulphate of potash and magnesia combined with one equivalent of chloride of magnesium, and intermingled with common salt to the extent of 40 per cent. The double sulphate is known as *Kainite* and is a secondary formation, resulting from the action of a limited quantity of water on a mixture of sulphate of magnesia and the double chloride of potassium and magnesium, as contained in the uppermost deposit previously spoken of.

Sixteen different minerals have been discovered in the Stassfurt deposits. They may be divided into primary and secondary formations. Those of primary formation are rock salt, Anhydrite, Polyhallite (K_2SO_4, $MgSO_4$, $2CaSO_4$, $2H_2O$) Kieserite ($MgSO_4$, H_2O), Carnallite ($KCl, MgCl_2$, $6H_2O$), Boracite ($2(Mg_3B_8O_{15})$, $MgCl_2$), and Douglasite ($2KCl, FeCl_2$, $2H_2O$). Those of secondary formation, resulting from the decomposition of the primary minerals are nine in number, namely: Kainite (K_2SO_4, $MgSO_4$, $MgCl_26H_2O$); Sylvite (KCl); Tachydrite ($CaCl_2$, $2 MgCl_2+12H_2O$); Bischofite ($MgCl_2$, $6H_2O$); Krugite (K_2SO_4, $MgSO_4$, $4CaSO_4$, $2H_2O$); Reichardtite ($MgSO_4$, $7H_2O$); Glauberite ($CaSO_4$, Na_2SO_4); Schönite (K_2SO_4, $MgSO_4$, $6H_2O$), and Astrakanite ($MgSO_4$, $4H_2O$). Only four of these minerals have any commercial value, namely: Carnallite, Kainite, Kieserite, and rock salt. The yield of boracite, which is found in nests in the Carnallite region of the mine, is too insignificant to be classed among those just mentioned.

In certains parts of the Carnallite region, the rock salt is found crystallized in the form of the cube and the octahedron, sometimes colored different shades of red and blue.

Methods of mining and manufacture.– In the manufacture of salt three principal methods are employed. The first, if, indeed, it

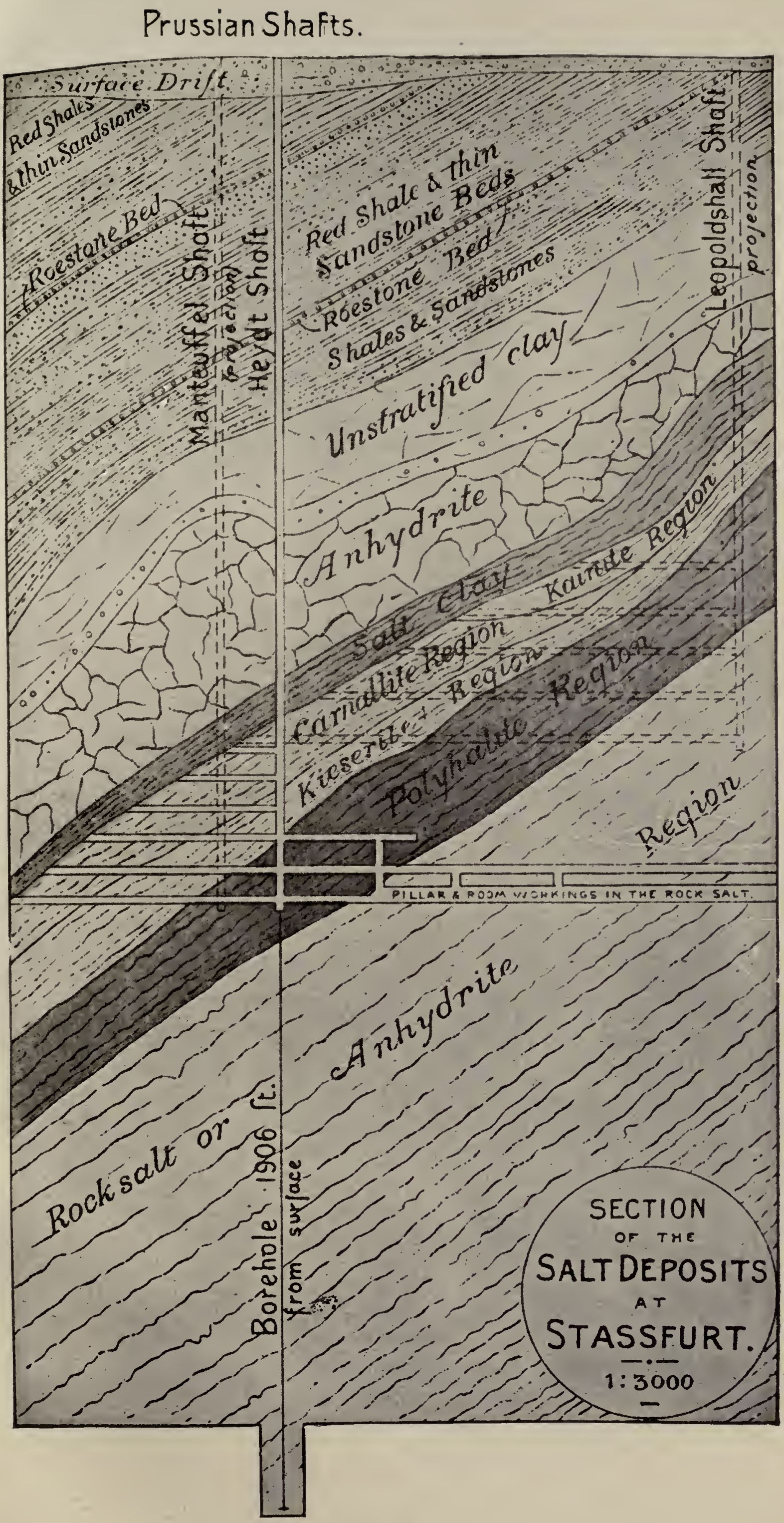

PLATE II.

Section of Salt Beds at Stassfurt, Germany.

[Trans. Edinburgh Geological Society. Vol. V, 1884.]

[*Facing page* 56.]

can be called manufacture, consists in mining the dry salt from an open quarry, as in the Rio Virgen and Barcelona deposits, or by means of subterranean galleries, the methods employed at Petite Anse and in Galacia.

At Petite Anse the method of mining and preparation, as given by Mr. R. A. Pomeroy,[1] is as follows:

Mining is done by means of galleries on two levels. There are 16 to 25 feet of earth above the salt deposit. The contour of the latter conforms nearly with that of the surface. The working shaft is 168 feet deep. The depth of the first level of floor is 90 feet; to the second, 70 feet farther. The remaining 8 feet are used for a dump. The galleries of the first level were run, on an average, 40 feet in width and 25 feet and upwards in height, leaving supporting pillars 40 feet in diameter.

The galleries of the second level are run 80 feet in width and 45 feet in height, leaving supporting pillars 60 feet in diameter. The lower pillars are so left that the weight of the upper ones rests upon them in part, if not wholly, with a thickness of at least 25 feet of salt rock between. Galleries aggregating nearly 1 mile in length have been run on the upper level and some 700 feet on the lower.

The salt as it comes from the mine is dumped into corrugated cast-iron rolls, which crush it. Next it goes into revolving screens, which take out the coarser lumps for "crushed salt" and let the fine stuff pass to the buhrstones. These grind the salt, and from them it goes to the pneumatic separators, which take out the dust and separate the market salt into various grades. Taking the dust out is essential to the production of a salt that will not harden, since the fine particles of dust deliquesce readily, and on drying cement the coarse particles together.

On the Colorado Desert the salt occurs in the form of a crust a foot or more in thickness, resting on a shallow lake of brine. This crust, which is covered with a thin layer of dust and sand blown over it from the surrounding desert, is cut away longitudinally, much

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[1] Transactions of the American Institute Mining Engineers, XVII, 1888, 1889, p. 111.

as ice is cut in the North. When loosened, the block, falling into the water beneath, is cleaned of its impurities, and is then thrown out on a platform to dry, after which it is ground and packed for market. In many parts of the arid West the salt is obtained merely by shoveling up the impure material deposited by the evaporation of salt lakes and marshes during seasons of drought. In this way is obtained a large share of the material used in chloridizing ores.

In the preparation of salt from sea water, solar evaporation alone is relied upon nearly altogether. This method, like the next to be mentioned, depends for its efficiency upon the fact already noted —that sea water holds in solution besides salt various other ingredients, which, owing to their varying degrees of solubility, are deposited at different stages of the concentration. In Barnstable County, Massachusetts, it was as follows: A series of wooden vats or tanks, with nearly vertical sides and about a foot in depth, is made from planks. These are set upon posts at different levels above the ground, and so arranged that the brine can be drawn from one to another by means of pipes. Into the first and highest of these tanks, known as the "long water room," the water was pumped directly from the bay or artificial pond by means of windmills, and there allowed to stand for a period of about ten days, or until all the sediment it may carry was deposited. Thence it was run through pipes to the second tank, or "short water room," where it remained exposed to evaporation for two or three days longer, when it was drawn off into the third vat, or "pickle room," where it stood until concentration had gone so far that the lime was deposited and a thin pellicle of salt began to form on the surface. It was then run into the fourth and last vat, where the final evaporation took place and the salt itself crystallized out. Care was requisite, however, lest the evaporation proceed too far, in which case sulphate of soda (Glauber's salt) and other injurious substances could also be deposited, and the quality of the sodium chloride thereby be greatly deteriorated.

As to the capabilities of works constructed as above, it may be said that during a dry season vats covering an area of 3,000 square feet would evaporate about 32,500 gallons of water, thus producing some 100 bushels of salt and 400 pounds of Glauber's salt. The moist climate of the Atlantic States, however, necessitates the roofing of the vats in such a manner that they can be protected or exposed as desired, thereby greatly increasing the cost of the plant. Sundry parts of the Pacific coast, on the other hand, owing to their almost entire freedom from rains during a large part of the year, are peculiarly adapted for the manufacture by solar evaporation. Hence, while the works on the Atlantic coast have nearly all been discontinued, there has been a corresponding growth in the West, and particularly in the region about San Francisco Bay.

The methods of procedure in the California works do not differ materially from that already given, excepting that no roofs are required over the vats, which are therefore made much larger. One of the principal establishments in Alameda County may be described as follows: The works are situated upon a low marsh, naturally covered by high tides. This has been divided, by means of piles driven into the mud and by earth embankments, into a series of seven vats or reservoirs, all but the last of which are upon the natural surface of the ground—that is, without wooden or other artificial bottoms. The entire area inclosed in the seven vats is about 600 acres, necessitating some 15 miles of levees. The season of manufacture lasts from May to October. At the beginning of the spring tides, which rise some 12 to 15 inches above the marsh level, the fifteen gates of reservoir No. 1, comprising some 300 acres, are opened and the waters of the bay allowed to flow in. In this great artificial salt lake the water is allowed to stand until all the mud and filth have become precipitated, which usually requires some two weeks. Then, by means of pumps driven by windmills, the water is driven from reservoir to reservoir as concentration continues, till finally the salt crystallizes out in No. 7, and the bittern is pumped back into the bay. The annual product of the works above described is about 2,000 tons.

A somewhat similar process is pursued in the manufacture of salt from inland lakes, as the Great Salt Lake, Utah.

The water is pumped from the lake into ponds prepared for its reception and situated above the level of the lake surface. In the first pond the mechanically suspended matters are left as sediment or scum, and the water passes into the second in a clear condition. The ponds cover upward of a thousand acres, and the drain channels leading from them aggregate 9 miles in length. The pumping continues through May, June, and July. A fair idea of the rate of evaporation in the thirsty atmosphere of the Great Basin may be gained from contemplating the fact that to supply the volume of water disappearing from the ponds by evaporation requires the action of the pumps 10 hours daily in June and July. This is equal to the carrying away of 8,400,000 gallons per day from the surface of the ponds.

"The 'salt harvest' begins in August, soon after the cessation of pumping, and continues till all is gathered, frequently extending into the spring months of the succeeding year. An average season yields a layer of salt 7 inches deep, which amount would be deposited from 49 inches of lake water. The density at which salt begins to deposit, as observed at the ponds and confirmed by laboratory experiments, is 1.2121, and that of the escaping mother liquors is 1.2345. The yield of salt is at the rate of 150 tons per inch per acre.[1]

Owing to the depth below the surface of the salt beds in Ohio, Michigan, and other inland States, the material is never mined as in the cases first mentioned, but is pumped to the surface as a brine and there evaporated by artificial heat. In the Warsaw Valley region the beds lie from 800 to 2,500 feet below the surface, and are reached by wells. These are bored from 5½ to 8 inches in diameter and are cased with iron pipes down to the salt. Inside the first pipe is then introduced a second 2 inches in diameter, with perforations for a few feet at its lower end, and which extends nearly, if not quite, to the bottom. Fresh water is then allowed to run from the surface down between the two pipes. This dissolves the salt, and forms a strong brine which, being heavier, sinks to the bottom of the well and is pumped up through the smaller or inner tube. At Syracuse the wells are not sunk into the salt bed itself, but into an ancient gravel deposit which is saturated with the brine. Here the introduction of water from the surface is done away with. In those cases, not at all uncommon, where the brine flows naturally to the surface in the form of a spring, pumping is of course dispensed with.

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[1] J. E. Talmage, Science, XIV, 1889, p. 445.

The methods of evaporation vary somewhat in detail. In New York the brine is run in a continuous stream in large pans some 130 feet long by 20 feet wide and 18 inches deep. As it evaporates the salt is deposited on the bottom, and, by means of long-handled scrapers, is drawn on the sloping sides of the pan. Here it is allowed to drain, and is afterwards taken to the storage bins for packing or grinding.[1] Salt thus produced, it should be noticed, is never so coarse as the so-called rock salt, or that which has formed by natural evaporation. In Michigan the brine from the wells is first stored in cisterns, whence it is drawn off into large shallow pans, known technically as "settlers," where it is heated by means of steam pipes to a temperature of 175°, until the point of saturation is reached. It is then drawn into a second series of pans, called "grainers," where it is heated to a temperature of 185°, until crystallization takes place.

The strength of brines, and therefore the quantity of water that must be evaporated to produce a given quantity of salt, varies greatly in different localities. At Syracuse the brine contains 15.35 per cent of salt; at the Saginaw Valley, 17.91 per cent; at Saltville, Virginia, 25.97 per cent; while Salt Lake contains 11.86 per cent, and the waters of San Francisco Bay but 2.37 per cent. The amount of impurities in the final product depends on the care exercised in process of manufacture, rapid boiling giving less satisfactory results than slower methods. The Syracuse salt has been found to contain 98.52 per cent sodium chloride; California Bay salt 98.43 per cent and 99.44 per cent; and Petite Anse 99.88 per cent. The impurities in these cases are nearly altogether chlorides and sulphates of lime and magnesia.

In many works, and particularly those of Michigan and Ohio, bromine is distilled and condensed from the bittern left from the crystallization of the salt. It is stated [2] that in some of the Ohio works the liquid remaining from the distillation of the bromine is run into a cistern and treated with lime. This neutralizes any acid

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[1] For details, see Salt and Gypsum Industries of New York, by Dr. F. J. H. Merrill, Bulletin No. 11, New York State Museum, 1893.

[2] Bulletin No. 8, Geological Survey of Ohio, 1906.

remaining from the bromine process. The liquid is then condensed by boiling in open pans, until calcium chloride separates out.

The Cheshire (England) salt beds are worked both by mining as rock salt and by pumping the brine. Formerly both upper and lower beds were mined, but flooding and falling in of the roofs caused the work to be discontinued on the upper beds. That now mined as rock salt comes wholly from the lower bed, and being impure is used mainly for agricultural purposes.

At Wieliczka the salt is likewise mined from galleries resembling in a general way those of a coal mine. These, according to Brehm,[1] begin at a depth of about 95 meters, forming several levels connected by stairways, the lowermost gallery being at a depth of 312 meters, or some 50 meters below sea level. These galleries have a total length of some 680 kilometers. They are connected with one another by means of eleven pits of which seven are utilized for hoisting purposes. The work goes on continually night and day the year through. The salt is cut out in the form of blocks, leaving huge chambers, the roof being sustained by means of large columns of salt left standing. The temperature within these chambers is very uniform, varying only between 10° and 15° C. The air is dry and healthful. The miners hew out of the salt statues of the saints, pyramids, and chandeliers. One chamber, called the Chapel of St. Antoine, with its altar, statues, columns, etc., is still in a condition of perfect preservation after a lapse of two centuries.

The output of salt in the United States for 1900 amounted to upwards of 20,000,000 barrels of 280 pounds each, of which 85 per cent was from mines and wells in New York, Michigan, and Kansas. For 1907 the output was 29,704,128 barrels, valued at $7,439,537. The annual output for the entire world amounts to upwards of 10,000,000 metric tons.

Uses.—The principal uses of salt have always been for culinary and preservative purposes. Aside from these, it is also used in certain metallurgical processes and in chemical manufacture, as in the preparation of the so-called soda ash (sodium carbonate), used

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[1] Marveilles de la Nature. La Terre, etc., p. 315.

in glass making, soap making, bleaching, etc., and in the preparation of sodium salts in general. Clear, transparent salt has been utilized in a few instances in optical and other research work.

2. FLUORITE.

This is a calcium fluoride, CaF_2, = fluorine, 48.9 per cent; calcium, 51.1 per cent. The most striking features of the mineral are its cubic crystallization, octahedral cleavage, and fine green, yellow, purple, violet, and sky-blue colors. White and red-brown varieties are also known. The mineral is translucent to transparent, and of a hardness somewhat greater than calcite (4 of Dana's scale).

Occurrence.—The mineral occurs, as a rule, in veins, in gneiss, the schists, limestones, and sandstones. It is also a common gangue of metallic ores, particularly those of lead and tin.

The principal American sources are Rosiclare, in southern Illinois, and on the opposite side of the Ohio River, in Kentucky, though deposits have been reported in Smith, Trousdale, and Wilson counties in Tennessee, and near Yuma, Arizona.

At Rosiclare the fluorspar occurs in what are regarded as true fissure veins varying from 4 to 40 or more feet in width in the Lower Carboniferous limestone. The original veins were, however, much smaller, the crevices having been enlarged by circulating waters, and the present great width being due to a partial replacement of the limestone.

On the hanging-wall side of the veins the fluorspar contents are not pure, and often contain fragments of the country rock. There is also no sharp contact of the vein with the wall. Near the foot-wall the fluorspar is often found in solid masses from 2 to 12 feet in thickness. With the fluorspar there is nearly always associated calcspar, galena, and sphalerite, and occasionally pyrite, chalcopyrite, and barite.

The depth to which the deposits extend has not been determined, but they have been worked to a depth of 200 feet without any apparent diminution in width of the vein, and Emmons regards it as reasonable to assume that they will extend as far down as the Trenton and Cambrian limestone.

At the Riley mine, in Crittenden County, Kentucky, the fluorite occurs as a vein filling a fault fissure between the St. Louis (sub-Carboniferous) limestone on the southeast, and the Birdsville quartzite on the northwest. The vein is some 3 to 4½ feet in width, striking N. 44° E. The southeastern wall, so far as exposed, consists of red residual clay and chert, with scattered blocks of the limestone. Toward the bottom of the shaft—some 75 feet, as shown in Fig. 12—is a strip of shale about 3 feet in thickness, apparently dragged in along the fault plane. The vein filling matter is mainly fluorite, with some white calcite and barite. Banding, parallel with the walls, is sometimes apparent. The fluorite of both Illinois and Kentucky is regarded as deposited from solutions, the material being originally a minor constituent of the deeper-lying limestone, whence it was leached by ascending thermal waters, the activity of which was excited by the intrusions of the neighboring peridotites.

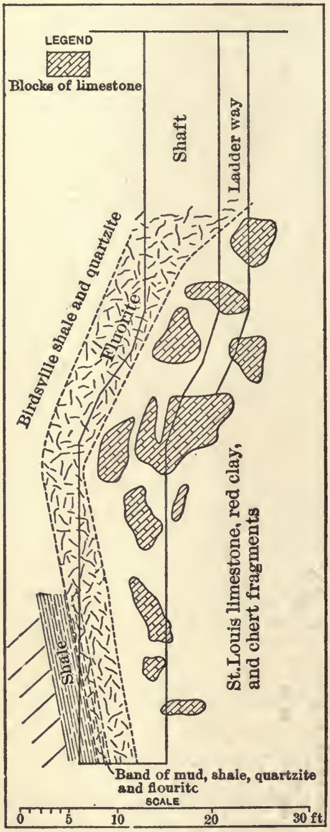

Fig. 12.—Section of fluorite vein, Chittenden County, Kentucky. [After W. S. I. Smith, Prof. Paper U. S. Geological Survey, No. 36.]

In both States the deposits are worked by means of shafts and drifts. As taken from the mine, the mineral is, in some cases, concentrated by a handcobbing machine and by the use of water-jigs, though in some cases it is shipped directly from the mine after having been simply washed. In a number of cases the lead and zinc ores commingled with the fluorite are saved as by-products.

Illinois and Kentucky are the principal sources of fluorspar as at present mined in America. The actual amount there existing is probably more than sufficient to supply the demand for many years to come. The average output at date of writing is between 40,000 and 50,000 tons, valued at from $5 to $10 per ton, according to quality.

Uses.—The material is used mainly as a flux for iron, in the manufacture of opalescent glass, and for the production of hydrofluoric acid.

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U. S. Geological Survey, Prof. Paper No. 36, 1905, pp. 107–207.

3. CRYOLITE.

Composition.—Na_3AlF_6, = aluminum, 12.8 per cent; sodium, 32.8 per cent; fluorine, 54.4 per cent. The mineral is, as a rule, of snow-white color, though sometimes reddish or brownish, rarely black, and coarsely crystalline granular, translucent to subtransparent. It has a hardness of 2.5; specific gravity of 2.9 to 3, and in thin splinters may be melted in the flame of a candle.

The name is from the Greek word *κρυος*, ice, in allusion to its translucency and ice-like appearance.

Mode of occurrence.—Cryolite occurs, as a secondary product, in the form of veins. It is rarely found in sufficient abundance to be of commercial value, the supply at present coming almost wholly from Evigtok in South Greenland. The country rock here is said to be granite, and the vein as described in 1866[1] was 150 feet in

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[1] Paul Quale, Report of Smithsonian Institution, 1866, p. 398.

greatest breadth, and was exposed for a distance of 600 feet. The principal mineral of the vein was cryolite, but quartz, siderite, galena, and chalcopyrite were constant accompaniments, irregularly distributed through the mass. In 1890 the mine as worked was described as elliptical in shape, 450 feet long by 150 feet wide, the pit being some 100 feet deep. The drills had penetrated 150 feet deeper and found cryolite all the way. Johnstrup, as quoted by Dana,[1] describes the cryolite as "limited to the granite; he distinguishes a central and a peripheral part; the former has an extent of 500 feet in length and 1,000 feet in breadth, and consists of cryolite chiefly, with quartz, siderite, galena, sphalerite, pyrite, chalcopyrite, and wolframite irregularly scattered through it. The peripheral portion forms a zone about the central mass of cryolite; the chief minerals are quartz, feldspar, and ivigtite, also fluorite, cassiterite, molybdenite, arsenopyrite, columbite. Its inner limit is rather sharply defined, though there intervenes a breccia-like portion consisting of the minerals of the outer zone inclosed in cryolite; beyond this it passes into the surrounding granite without distinct boundary."

Cryolite in limited quantity occurs at the southern base of Pike's Peak, in Colorado, and north and west of St. Peter's Dome. It is found in vein-like masses of quartz and microcline embedded in granite.

Uses.—The material has been utilized in the manufacture of soda, and sodium and aluminum salts, and to a small extent in the manufacture of glass and procelain ware. It is also used in the electrolytic processes of extracting aluminum from its ores, as now practiced.

The principal works utilizing the Greenland cryolite in chemical manufacture are, at time of writing, those of the Pennsylvania Salt Manufacturing Company at Natrona, Pennsylvania. From 5,000 to 10,000 tons are imported annually, valued at about $12 per ton.

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[1] System of Mineralogy, 1892, p. 167.

IV. OXIDES.

1. SILICA.

Quartz.—The mineral quartz, easily recognized by its insolubility in acids, glassy appearance, lack of cleavage, and hardness, which is such that it readily scratches glass, is one of the most common and widely disseminated of minerals. Chemically it is pure silica, of the formula SiO_2. It crystallizes in the hexagonal system with pyramidal terminations, and is one of the most attractive of minerals for the amateur collector. The common form is, however, massive, occurring in veins in the older crystalline rocks. Common sand is usually composed mainly of quartzose grains which, owing to their hardness and resistance to atmospheric chemical agencies, have withstood disintegration to the very last.

The terms *rose*, *milky*, and *smoky* are applied to quartzes which differ from the ordinary type only in tint, as indicated. Chalcedony is the name given to a somewhat horn-like, translucent or transparent form of silica occurring only as a secondary constituent in veins, or isolated concretionary masses, and in cavities in other rocks. Agate is a banded variety of chalcedony. The true onyx is similar to agate, except that the bands or layers of different colors lie in even planes. Jasper is a ferruginous, opaque chalcedony, sometimes used for ornamental purposes. Opal is an amorphous form of silica, containing somewhat variable amounts of water.

Quartz occurs as an essential constituent of granite, gneiss, mica schist, quartz porphyry, and liparite, and also as a secondary constituent in the form of veins, filling joints and cavities in rocks of all kinds and all ages.

Uses.—The finer clear grades of quartz were formerly used to some extent for spectacle lenses and optical work. Its main value is for abrading purposes, either as quartz sand or as sandpaper, and in the manufacture of pottery. For abrading purposes it is crushed and bolted, like emery and corundum, and brings a price barely sufficient to cover cost of handling and transportation. There is a remarkable variation in quartz as relates to its suitability for abrasive purposes, some varieties on crushing giving rise to sharp, splintery fragments possessing a high degree of cutting or abrading power, while others yield sands that are dull and of less value. As a rule the clear, glassy quartz will yield a sharper sand than the opaque and milky forms.

Ground quartz is used to some extent as a "filler" in paints, and as a scouring material in soaps. (See further under *Sand for glass making*, p. 419).

Flint is a chalcedonic variety of silica found in irregular nodular forms in beds of Cretaceous chalk. These nodules break with a conchoidal fracture and interiorly are brownish to black in color. By the aboriginal races the flints were utilized for the manufacture of knives and general cutting implements. Later they were used in the manufacture of gun-flints and the "flint and steel" for producing fire. At present they are used to some extent in the manufacture of porcelain, being calcined and ground to mix with the clay and give body to the ware. In this country the same purpose is accomplished by the use of quartz. Small round nodules of flint from Dieppe, France, are said to be used in the Trenton (New Jersey) pottery works for grinding clay by being placed in revolving vats of water and kaolin. All the flint now used in this country is imported either as ballast or as an accidental constituent of chalk.

As the material is worth but from $1 to $2 a ton delivered at Trenton, it may be readily understood that transportation is a rather serious item to be considered in developing home resources.

According to Mr. R. T. Hill, nodules of black flint occur in enormous quantities in the chalky limestones—the Caprina limestones—of Texas. Numerous localities are mentioned, the most accessible being near Austin, on the banks of the Colorado River.

Buhrstone, or burrstone, is the name given to a variety of chalcedonic silica, quite cavernous, and of a white to gray or slightly yellowish color. The cavernous structure is frequently due to the dissolving out of calcareous fossils. The rock is of chemical origin —that is, results from the precipitation of silica from solution, and presumably through the action of organic matter. In France the material occurs alternating with other unaltered Tertiary strata in the Paris basin. It is also reported in Eocene strata in South America, and in Burke and Screven counties along the Savannah River in eastern Georgia in the United States. The toughness of the rock, together with the numerous cavities, imparts a sharp cutting power such as renders it admirably adapted for millstones, and in years past material for this purpose has been sent out from French sources all over the civilized world.

Tripoli is the commercial name given to a peculiar porous rock associated with the Lower Carboniferous limestones of southwest Missouri, and regarded as having originated through the leaching out of the lime carbonate from a highly siliceous member of the series.[1] The rock is of a cream-white or slight pink cast, fine grained and homogeneous, with a distinct gritty feel, and, though soft, sufficiently tenacious to permit of its being used in the form of thin disks of considerable size for filtering purposes. According to Hovey [2] the deposit is known to underlie between 80 and 100 acres of land, in the form of a rude ellipse, with its longer diameter approximately north and south. From numerous prospect holes and borings it has been shown to have an average thickness of 15 feet, the main quarry of the present company showing a thickness of 8 feet. The following section is given from a well sunk in the northern part of the area:

	Feet.	
Earth	0 to	4
Tripoli	4	20
Stiff red clay	20	21½
Mixed chert, clay, and ocher	21½	40
Cherty limestone	40	93
Cherty limestone bearing galena	93	103
Limestone	103	128
Limestone bearing sphalerite and galena	128	136
Soft magnesian limestone	136	173

The tripoli is everywhere underlain by a relatively thin bed of stiff red clay, and also traversed in every direction by seams of the same material from 1 to 2 inches thick. These seams and other joints divide the rock into masses which vary in size up to 30 inches or more in diameter. Microscopic examinations as given by Hovey show the rock to contain no traces of organic remains, but to be made up of faintly doubly refracting chalcedonic particles from 0.01 to 0.03 millimeter in diameter. The chemical composition, as shown from analysis by Prof. W. H. Seaman, is as follows:

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[1] Bulletin No. 340, U. S. Geological Survey, 1908, p. 433.

[2] Scientific American Supplement, July 28, 1894, p. 15487.

Constituents.	Per Cent.
Silica (SiO_2)	98.100
Alumina (Al_2O_3)	0.240
Iron oxide (FeO and Fe_2O_3)	0.270
Lime (CaO)	0.184
Soda (Na_2O)	0.230
Water (ignition)	1.160
Organic matter	0.008
	100.192

The material boiled in a 10 per cent solution of caustic soda for three hours, yielded 7.28 per cent soluble silica.

Aside from its use as a filter the rock is crushed between buhrstones, bolted, and used as a polishing powder. To a small extent it has been used in the form of thin slabs for blotting purposes, for which it answers admirably, owing to its high absorptive property, but is somewhat objectionable on account of its dusty character. The view (Plate III) shows the character of a quarry of this material as now worked by the American Tripoli Company at Seneca, in Newton County.

Diatomaceous or *infusorial* **earth,** as it is sometimes wrongly called, is, when pure, a soft, pulverulent material, somewhat resembling chalk or kaolin in its physical properties, and of a white or yellowish or gray color. Chemically it is a variety of opal (see analyses on p. 72).

Origin and occurrence of deposits.—Certain aquatic forms and plant life known as diatoms, which are of microscopic dimensions only, have the power of secreting silica in the same manner as mollusks secrete carbonate of lime, forming thus their tests or shells. On the death of the plant the siliceous tests are left to accumulate on the bottom of the lakes, ponds, and pools in which they lived, forming in time beds of very considerable thickness, which, however, when compared with other rocks of the earth's crust, are really of insignificant proportions. Like many other low organisms the diatoms can adapt themselves to a wide range of conditions. They are wholly aquatic, but live in salt and fresh water and under widely varying conditions of depth and temperature. They may be found in living forms in almost any body of comparatively quiet water in the United States. The exploring steamer *Challenger* dredged

PLATE III.
Tripoli Mine, Seneca, Missouri.
[From photograph.]

[*Facing page 70.*]

them up in the Atlantic from depths varying from 1,260 to 1,975 fathoms, and from latitudes well toward the Antarctic Circle. Mr. Walter Weed, of the U. S. Geological Survey, has recently reported them as living in abundance in the warm marshes of the Yellowstone National Park, while Dr. Blake reported finding over 50 species in a spring in the Pueblo Valley, Nevada, which showed a temperature of 163° F.

Although beds of diatomaceous earth are still in process of formation, and in times past have been formed at various epochs, the Tertiary period appears for some reason to have been peculiarly fitted for the growth and preservation of these organisms, and all of the known beds of any importance, both in America and foreign countries, are of Tertiary Age. The best known of the foreign deposits is that of Bilin, in Bohemia. This is some 14 feet in thickness. When it is borne in mind that, according to the calculations of Ehrenberg, every cubic inch of this contains not less than 40,000,000 independent shells, one stands aghast at the mere thought of the myriads of these little forms which such a bed represents. Some of the deposits in the United States are, however, considerably larger than this. What is commonly known as the Richmond bed extends from Herring Bay, on the Chesapeake, Maryland, to Petersburg, Virginia, and perhaps beyond. This is in some places not less than 30 feet in thickness, though very impure. Near Drakesville, in New Jersey, there occurs a smaller deposit, covering only some 3 acres of territory to a depth of from 1 to 3 feet. Some of the largest deposits known are in the West. Near Socorro, in New Mexico, there is stated to be a deposit of fine quality which crops out in a single section some 6 feet in thickness for a distance of 1,500 feet.

Geologists of the fortieth-parallel survey reported abundant deposits in Nevada, one of which, in the railroad cutting west of Reno, showed a thickness not less than 300 feet, of a pure white, pale buff, or canary-yellow color. Along the Pitt River, in California, there is stated to be a bed extending not less than 16 miles, and in some places over 300 feet thick (see Plate IV). In the northern part of Santa Barbara County the earth occurs in quantities which are seemingly truly inexhaustible. In the region about Lompoc, south of the Santa Inez River, beds are exposed over an area of at least 3 square miles, and which have, in places, a thickness of several hundred feet.[1] Four miles west of Lompoc 1,000 feet in thickness of beds are exposed, and in the Burton Mesa the "pure diatomaceous earth" is stated to be 2,000 feet in thickness. Numerous other localities are mentioned where the material is almost equally abundant.[2] Near Linkville, Klamath County, Oregon, there occurs a deposit which has been traced for a distance of 10 miles, and shows along the Lost River a thickness of 40 feet. Beds are known also to occur in Idaho, near Seattle, in Washington, and doubtless many more yet remain to be discovered. A deposit of unknown extent, pure white color, and almost pulp-like consistency, has been worked in South Beddingham, Maine. Others of less purity occur near South Framington, Massachusetts, Lake Umbagog, New Hampshire, at Whitehead Lake, Herkimer County, New York, and at Grand Manan, New Brunswick.

Chemical composition.—As already intimated, this earth is of a siliceous nature, and samples from widely separated localities show remarkable uniformity in composition. Of the following analyses, No. I is from Lake Umbagog, New Hampshire, No. II from Morris County, New Jersey, and No. III from Pope's Creek, in Maryland. As will be noted, the silica percentage is nearly the same in all.

Constituents.	I.	II.	III.
Silica	80.53	80.66	81.53
Alumina	5.89	3.84	3.43
Iron oxides	1.03	....	3.34
Lime	0.35	0.58	2.61
Soda	....	....	1.43
Potash	....	....	1.16
Water and organic matter	12.03	14.01	6.04

The substance may therefore be regarded as a variety of opal.

Uses.—The main use of diatomaceous earth is for a polishing powder. It is, however, an excellent absorbent, and has been utilized to mix with nitroglycerine in the manufacture of dynamite. It has

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[1] A block of this material some 5 feet in diameter among the geological collections of the National Museum is reported as consisting of some 75 per cent of diatoms, and 25 per cent of sponge spicules and radiolaria. The most abundant forms among the diatoms are *Coscinodiscus robustus*, *Actinoptychus undulatus*, and *Ralfeii*, two species of *Raphoneus*, *Biddulphia aurita*, and an undetermined species of *Synedra*.

[2] Bulletin No. 315, U. S. Geological Survey, 1906, p. 438.

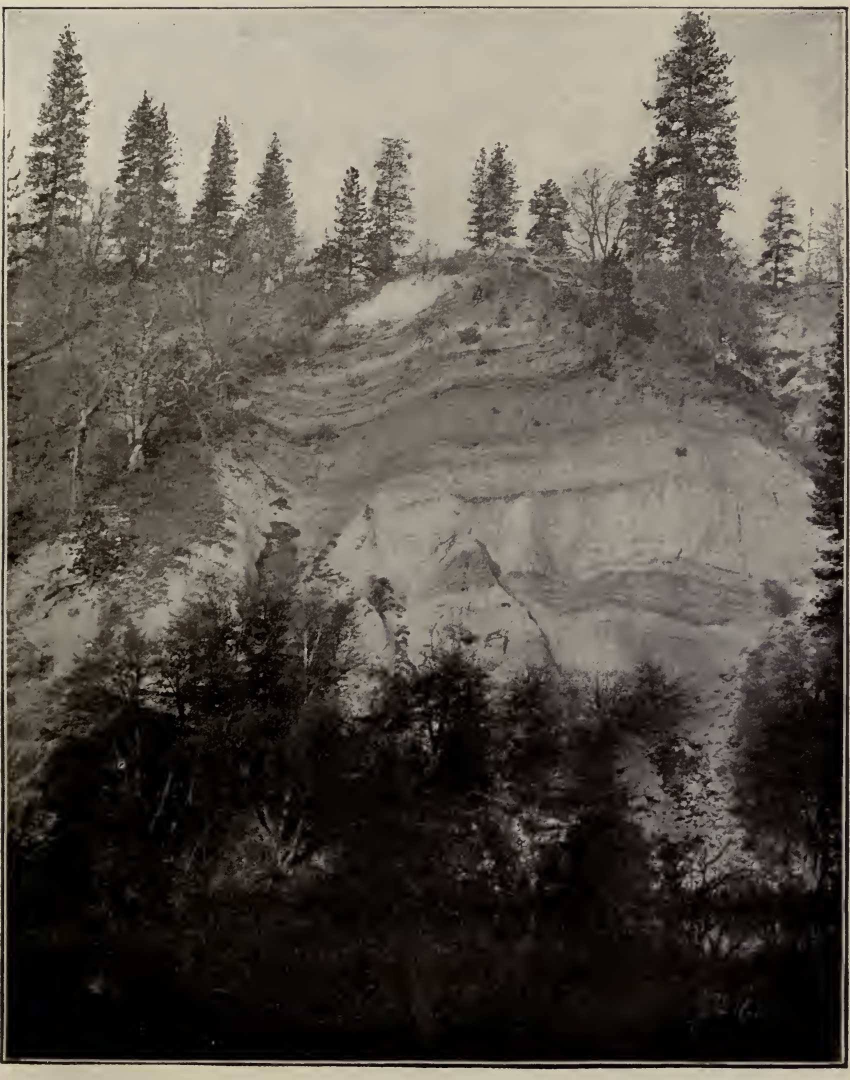

PLATE IV.

Bed of Diatom Earth, Great Bend of Pitt River, Shasta County, California.

[From photograph by J. S. Diller, U. S. Geological Survey.]

[*Facing page* 72.]

also been used to some extent in the preparation of the soluble silicate known as water glass, and still again as a non-conductive material for steam boilers, etc. The demand for the material is quite small, not nearly equal to the supply. The Maryland and Nevada deposits are the principal ones now worked. During the year 1897 the entire output was about 3,000 tons, valued at some $30,400.

2. CORUNDUM AND EMERY.

Corundum.—Composition, sesquioxide of aluminum, Al_2O_3, $=$oxygen, 47.1 per cent; aluminum, 52.9 per cent. In crystals often quite pure, but frequently occurring associated in crystalline granular masses with magnetic iron, and often more or less altered into a series of hydrated aluminous compounds, as damourite. The crystalline form of the mineral is hexagonal, or six-sided in outline, often with curved sides and square terminations, giving rise to roughly barrel-shaped forms, as shown in Fig. 13.

FIG. 13.—Corundum crystals, characteristic forms.
[U. S. National Museum.]

A prominent basal cleavage causes the crystals to break readily with smooth flat surfaces at right angles with the axis of elongation. The massive forms frequently show a nearly rectangular parting or pseudo-cleavage.

The most striking physical property of the mineral is its hardness, which is 9 of Dana's scale. In this respect it ranks then next to the diamond. The color varies from white through gray, brown, yellow, blue, pink, and red; luster, adamantine to vitreous; specific gravity, 3.95 to 4.1. The highly colored transparent red and blue forms are valuable as gems, and are known under the names of ruby and sapphire. The consideration of these forms is beyond the limits of this work.

Occurrence.—Although widespread as a mineral, corundum unmixed with a large proportion of magnetite (forming emery) has been found in comparatively few localities in sufficient abundance to be of commercial value. The most important deposits known in the United States are in southwestern North Carolina, the Laurel Creek region of northern Georgia, and central Montana. Within a few years corundum-bearing syenites, covering an area of many square miles, have been found in Renfrew, Hastings, and Halberton counties in Ontario, Canada.

According to Pratt, most of the corundum that has been mined in the United States for abrasive purposes has been obtained from the eastern part of the section, where it is associated with a long belt of basic magnesian rocks (peridotites) extending from Tallapoosa in east central Alabama, to Trenton, New Jersey, with disconnected outcrops north of New Jersey, as in Connecticut, Massachusetts, New Hampshire, and Maine. In the southern portion of this belt the peridotites have reached their greatest development, in some localities outcropping over an area of several hundred acres. At Webster, in Jackson County, North Carolina, the peridotite occurs intrusive in the hornblendic gneiss, the corundum occurring in greatest abundance at or near the line of contact between the two rocks. Associated with the corundum are nearly always at this locality a series of secondary minerals, including vermiculite, chlorite, and talcose, and serpentinous materials.

An ideal cross-section of one of the corundum contact veins at

Corundum Hill, in Macon County, is shown in Fig. 14, while a map of the country, showing the character of the surrounding rocks, is shown in Fig. 15. The mine at Corundum Hill has been until recently one of the most important in the country, and may be described in some detail as illustrating the mode of occurrence of the material. The formation here is a rather blunt, lens-shaped mass of peridotite (dunite) exposed over an area of about 10 acres. A number of veins have been worked, but, with the exception of the one marked "Shaft" on the map, they have soon pinched out.

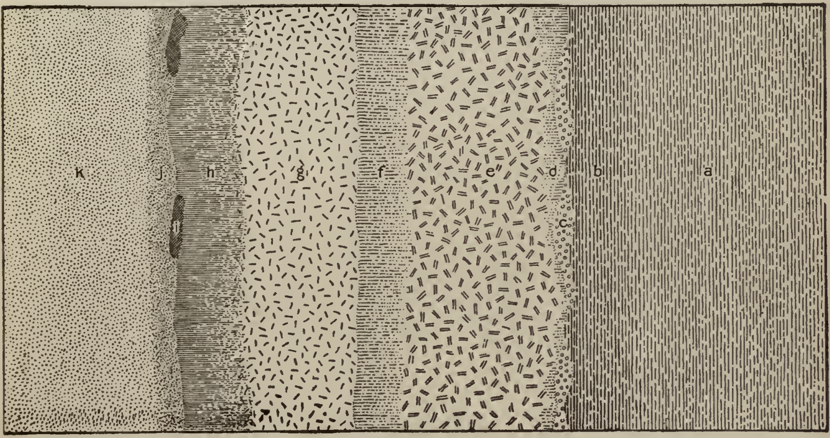

FIG. 14.—Ideal cross-section of a corundum contact vein at Corundum Hill Mine, North Carolina; *a*, fresh and unaltered gneiss; *b*, decayed gneiss; *c*, vermiculite; *d*, green chlorite; *e*, corundum-bearing zone; *f*, green chlorite; *g*, enstatite; *h*, talcose rock; *i*, clay; *j*, altered dunite; *k*, unaltered dunite.

[U. S. Geological Survey.]

Most of the mining has been done on the south side of this formation, as described by Pratt, by means of open cuts, and later by tunnels. Plate V shows the entrance to this tunnel, with the peridotite on the left and the gneiss on the right beyond the cut. For nearly the whole distance of the southern boundary of the dunite formation a cut has been made, following the contour of the hill. This is sometimes wholly within the gneiss, and at other times wholly within the peridotite, and again cutting directly across the contact. The tunnels are all to the left of the cut, and have encountered corundum almost continuously for a distance of 1,280 feet.[1]

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[1] These mines have now (1909) been for several years abandoned.

The materials collected from the mines at Corundum Hill are in the forms known as *block*, *crystal*, and *sand* ores. The meaning of the terms is obvious. A small amount of garnet is occasionally found associated with the corundum in the vein along the southern contact.

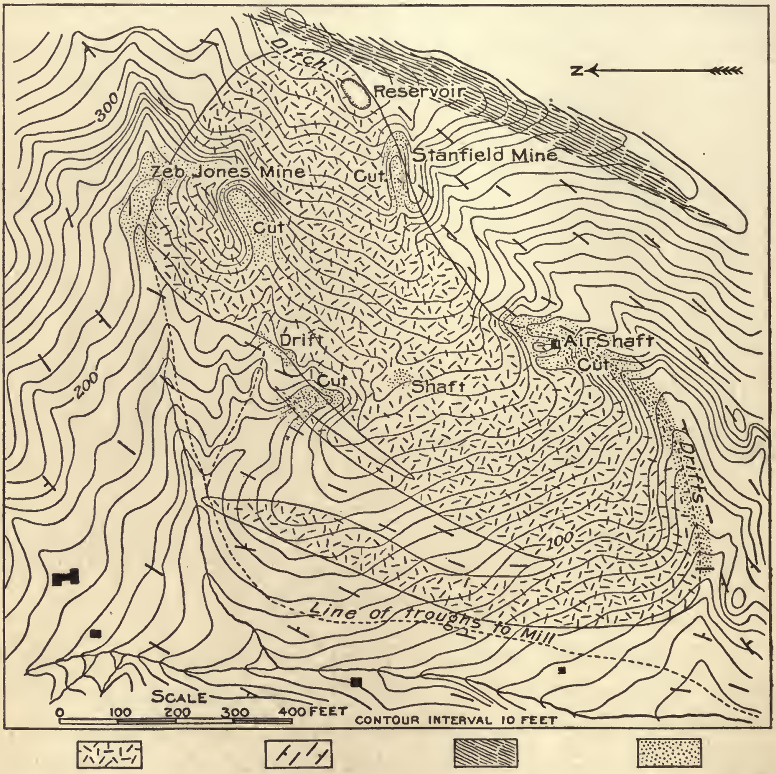

FIG. 15.—Map of peridotite formation at Corundum Hill, Macon County, N. C. [U. S. Geological Survey.]

At what is known as the Buck Creek, or Cullakeenee Mine, about 20 miles southwest of Franklin in this same county, corundum is found associated with a compact mass of peridotite, covering about three-quarters of a square mile, forming the largest mass that is known in the Appalachian belt. A topographic map of this area, showing the association of the various rocks, is shown in Fig. 16.

PLATE V.

Vein between Peridotite and Gneiss, Corundum Hill, Macon County, North Carolina.
[After J. H. Pratt, Bulletin No. 180, U. S. Geological Survey.]

[*Facing page* 76.]

The vein here is described as differing from most of the corundum veins in the peridotite rocks in that it is composed essentially of plagioclase feldspar, and hornblende, which bear a relation to each other similar to that of the feldspar, quartz, and mica in pegmatite dikes. There is an abundance of ore at this mine, but it has been as yet unexploited, owing to difficulty of transportation.

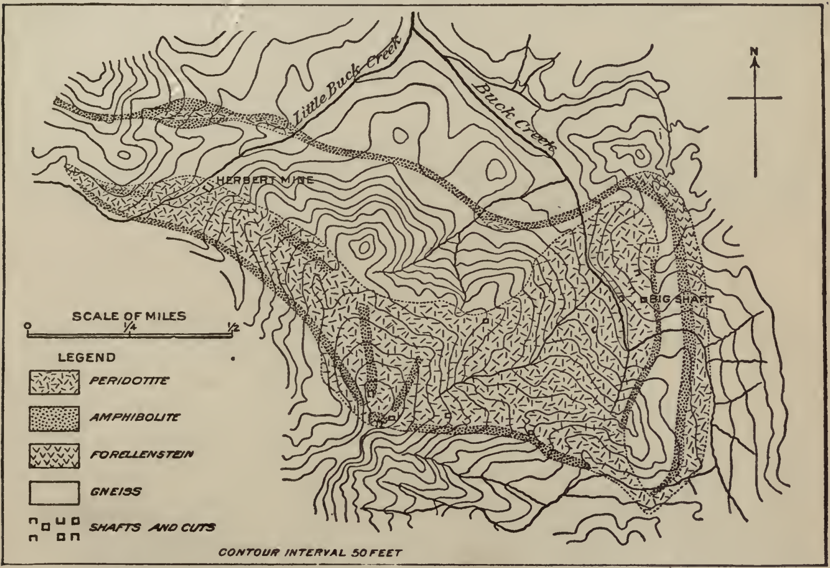

Fig. 16.—Map of the Buck Creek peridotite area, showing the relation of the amphibolite dikes.
[U. S. Geological Survey.]

At Laurel Creek, in Georgia, on what is known as Pine Mountain, in Rabun County, there is a large outcrop of peridotite covering several hundred acres, along the contact of which with the gneiss large deposits of corundum have been found. Fig. 17 shows the relation of the gneiss and the peridotite. The formation here occupies two small hills, which, on account of their rough and barren nature—a feature characteristic of regions occupied by iron magnesian rocks—offer a sharp contrast to the surrounding country. A large open cut on the east side of the formation follows, for the most part, along the contact to a depth of some 200 feet. (Plate 6, Fig. 1.) At its lower end this cut encounters what is known as the Big or Dunite Vein of massive corundum, the cut having followed on a contact vein of crystallized corundum. Although this vein is near the contact of the peridotite with the gneiss, it is separated from the same by a band of peridotite and a small vein of sand corundum. This has been one of the most famous mines in the country, and has furnished ore of an exceptionally high grade.

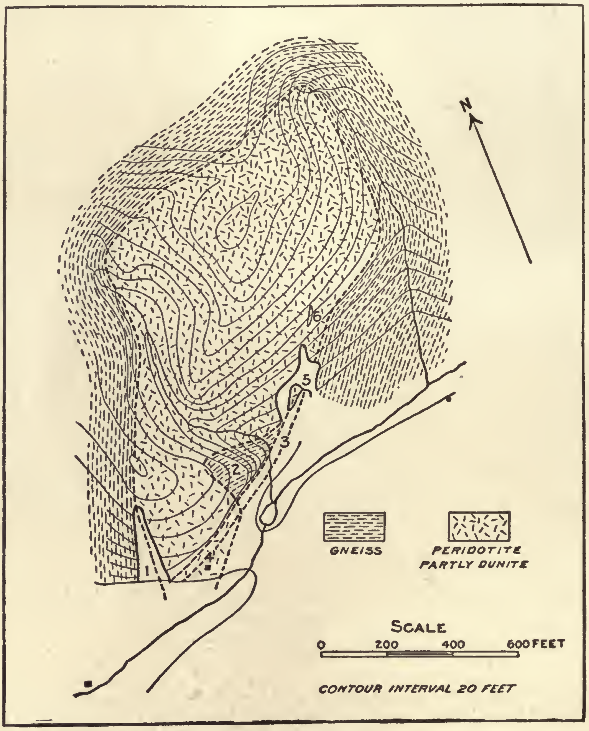

FIG. 17.—Map of the peridotite formation at Laurel Creek, Rabun County, Georgia. [U. S. Geological Survey.]

A large part of the corundum that has been found in Montana is of the sapphire variety, and is used as gem material. Hence its consideration belongs properly to a treatise on gems. But at one locality, not far from Bozeman, in Gallatin County, corundum, in well-defined hexagonal crystals, of all sizes up to 10 millimeters in diameter and 20 to 30 millimeters in length, has been found in considerable quantity in an igneous rock composed essentially of orthoclase feldspar, corundum, and biotite. The rock has at times

Fig. 1.—Corundum Vein at Laurel Creek, Georgia.
[After J. H. Pratt, Bulletin No. 180, U. S. Geological Survey.]

Fig. 2.—Bauxite Bed, Saline County, Arkansas.
[From photograph by C. W. Hayes, U. S. Geological Survey.]

PLATE VI.

[*Facing page* 78.]

a somewhat gneissic structure, and in these portions the corundum is found in a more or less finely divided condition, and in other portions, where the rock has a pegmatitic character, the corundum is coarsely crystallized and surrounded by orthoclase. The percentage of corundum is quite large. The colors vary from bluish gray to almost colorless.

Near the entrance of Yogo Gulch, in Fergus County, in this same State, feldspathic igneous rocks allied to the minettes have been found carrying sapphires. The rock occurs in the form of two parallel dikes about 800 feet apart, which can be followed for over a mile in a nearly east-and-west course, their general width being from 6 to 20 feet. The rock, which is much decomposed on the surface, has a dark gray, decidedly basic appearance, and is very tough. The sapphires are mainly of some shade of blue, and occur in the form of sharp, distinct crystals. The material is used wholly for gem purposes.

In Ontario, Canada, the corundum occurs as a primary constituent of syenite, the rocks varying from a normal syenite to a nepheline syenite and a mica syenite, the mineral being most abundantly developed in the normal syenite. The rocks occur as dikes cutting through the gneisses, the corundum existing in such abundance as to average perhaps 12 per cent of the entire mass, and in crystals of all sizes up to 50 millimeters in diameter. The principal areas thus far discovered, as shown in the accompanying map (Fig. 18), occupy an area some 75 miles in length extending from Renfrew County westerly through Hastings into Haliburton, with smaller areas in Peterborough and Frontenac counties.

The corundum deposits of India have been described by T. H. Holland.[1] The mineral here occurs in a matrix of deep flesh-colored feldspar, which is in bands or lenticular masses and has associated with it often a considerable portion of sillimanite, rutile, spinel, and mica.

Corundum in what is apparently commercial quantities has been reported in the ranges near Mts. Painter and Pitts in South Australia. The mineral occurs in the form of segregation lumps,

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[1] Geology of India, Part III, Economic Geology.

rough hexagonal crystals and irregular shaped masses disseminated throughout a schistose metamorphic rock consisting mainly of black mica.

Origin.—The origin of the corundum in the occurrences above noted can be in part surmised from the descriptions which have been given. It is evident that, in the majority of cases, such result from the direct crystallization of aluminum oxide from a molten magma.

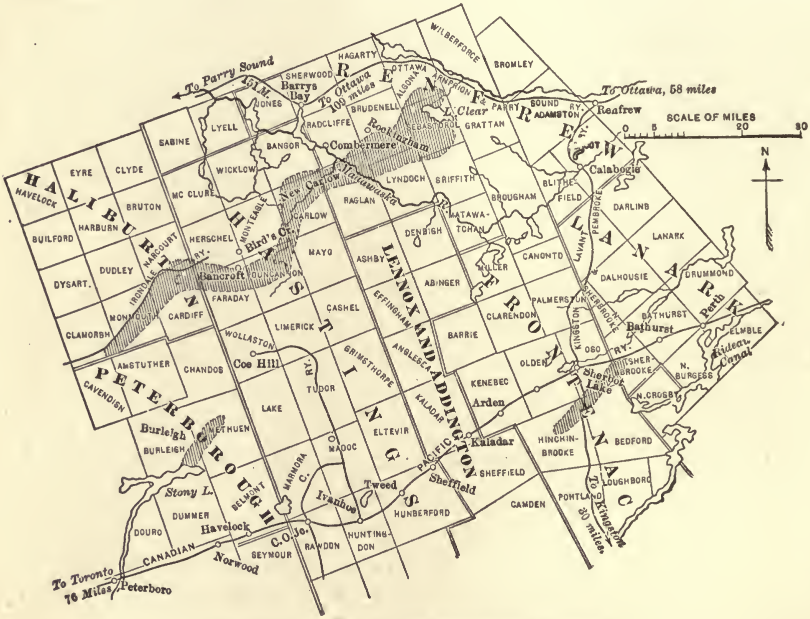

FIG. 18.—Map of corundum areas of Canada.

Experimental work by Morozewicz[1] has shown that from supersaturated alumina-silicate magmas deficient in the alkalies, lime, magnesia, and iron, the alumina may all separate out as corundum. With increasing amounts of the alkalies and lime, the feldspars, in varying proportions, may appear. The presence of magnesia and iron is likely to give rise to minerals of the spinel group, as well. These results are all in accord with Montana, North Carolina and Canadian occurrences and may probably be considered as final.

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[1] Tschermak's Min. u. Petr. Mittheil., XVIII, 1898.

The sapphires occurring in the basic rock from Yogo Gulch, Montana, are regarded by Pirsson[1] as of pyrogenic origin, that is, as resulting from the direct crystallization of the oxide, which has in this case been derived from aluminous material dissolved from shales by the molten rock during its intrusion. It seems most probable that the Indian corundum, even including the ruby of Burmah, is of secondary origin—a result of metamorphism.

Emery.—The rock emery takes its name from Cape *Emeri*, on the island of Naxos, where it occurs in great abundance. Mineralogically it has been regarded by various authorities as either a mechanical admixture of corundum and magnetic iron ore or as simply a massive iron spinel—hercynite. So far as the Naxos emery is concerned, the first view in undoubtedly correct, the two minerals occurring in about the proportion of two parts of corundum to one of magnetite and other minerals. Physically emery is a massive, nearly opaque, dark-gray to blue black or black material, with a specific gravity of 4 and hardness of 8, Dana's scale, breaking with a tolerably regular fracture, and always more or less magnetic.

Chemically the material is quite variable. Below are the results of analyses by Dr. J. Lawrence Smith, from whose papers on the subject these notes are partially compiled.

Localities.	Alumina.	Iron.[2]	Lime.	Silica.	Water.
Kulah	61.05	27.15	1.30	9.63	2.00
	63.50	33.25	0.92	1.61	1.90
Samos	70.10	22.21	0.62	4.00	2.10
Gumuch	60.10	33.20	0.48	1.80	5.62
	77.82	8.62	1.80	8.13	3.11
Nicaria	71.06	20.32	1.40	4.12	2.53
	75.12	13.06	0.72	6.88	3.10
Ephesus	60.10	33.20	0.48	1.80	5.62
Chester, Massachusetts	44.01	50.21	....	3.13	
	50.02	44.11	....	3.25	
	51.92	42.25	....	5.46	
	74.22	19.31	....	5.48	
	84.02	9.63	....	4.81	

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[1] American Journal of Science, Vol. IV, 1894, p. 42.

[2] It is stated that the American Plate Glass companies, while accepting an emery carrying as high as 60 per cent Fe_2O_3, will not accept this in the form of an artificial admixture of corundum and magnetite. It must be the natural, crystalline admixture.

Geologically emery, like corundum, belongs to the older crystalline rocks. In Asia Minor it occurs in angular or rounded masses from the size of a pea to those of several tons weight, embedded in a blue-gray or white crystalline limestone, which overlies micaceous or hornblendic schists, gneisses, and granites. Superficial decomposition has, as a rule, removed more or less of the more soluble portions of the limestone, leaving the emery nodules in a red ferruginous soil. With the emery are associated other aluminous minerals as mentioned below.

According to Tschermak[1] the Naxos emery occurs mostly in the form of an iron-gray, scaly to schistose, rarely massive, aggregate consisting essentially of magnetite and corundum, the latter mineral being in excess. In addition to these two minerals occur hematite and limonite, as alteration products of the magnetite. Margarite, muscovite, biotite, tourmaline, chloritoid, diaspore, disthene, staurolite, and rutile occur as common accessories; rarely are found spinel, vesuvianite, and pyrite. Under the microscope he finds the emery rock to show the corundum in rounded granules and sometimes well-defined crystals with hexagonal outlines, particularly in cases where single individuals are embedded in the iron ores. (Plate VII, Fig. 2.) In many cases, as in the emery of Krenino and Pesulas, the granules are partially colored blue by a pigment sometimes irregularly and sometimes zonally distributed. The corundum grains, which vary in size between 0.05 mm. and 0.52 mm. (averaging about 0.22 mm.), are very rich in inclosures of the iron ores, largely magnetite in the form of small, rounded granules. The quantity of these is so great as at times to render the mineral quite opaque, though at times of such dust-like fineness as to be translucent and of a brownish color. The larger corundums are often injected with elongated, parallel-lying clusters or groups of the iron ores, as shown in Fig. 3, of the plate from Tschermak's paper, and are surrounded by borders of very minute zircons. The iron ore, as noted above, is principally magnetite, but which, by hydration and oxidation, has given rise to abundant limonite. The magnetites are in the form of rounded granules and dust-like particles, and also at

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[1] Mineralogische und Petrographische Mittheilungen, XIV, 1894, p. 313.

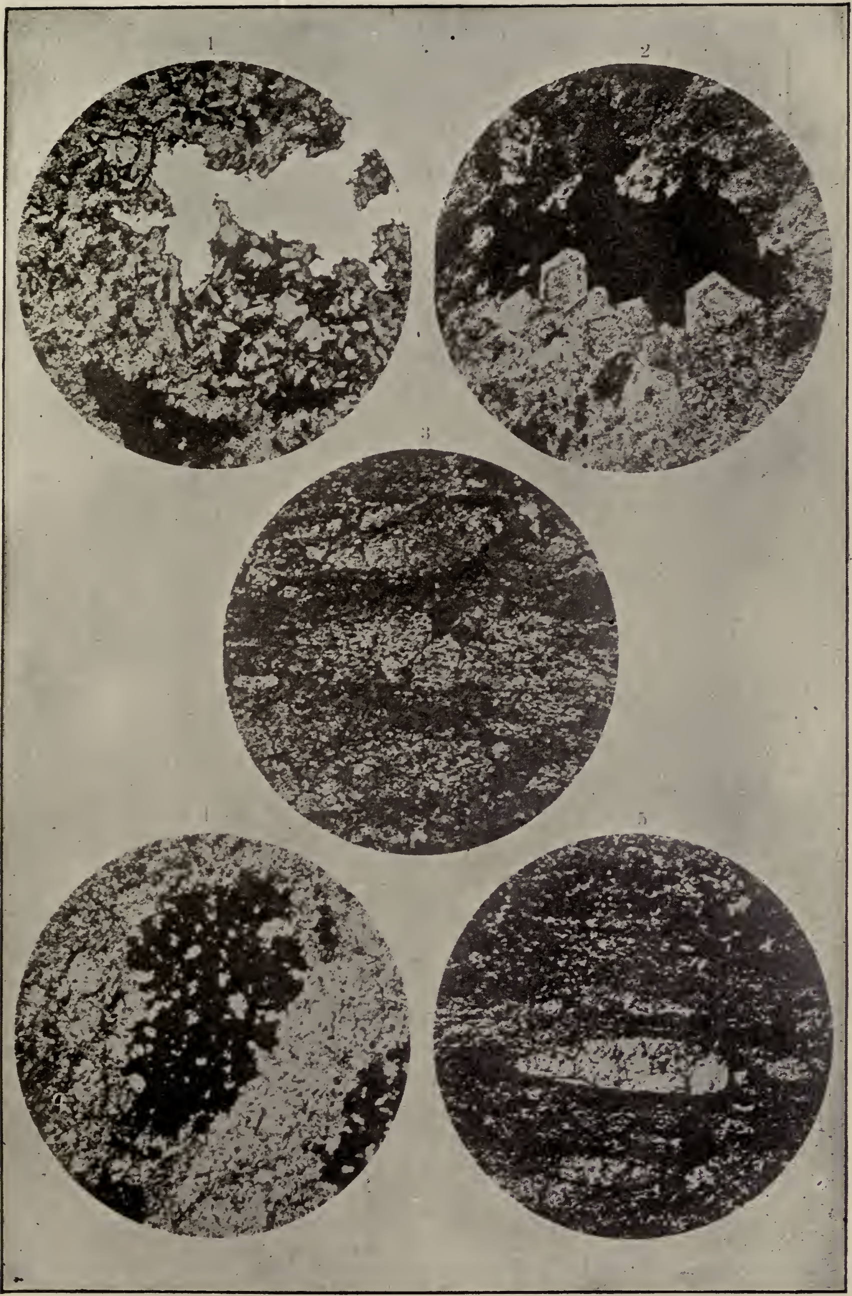

PLATE VII.
Microstructure of Emery.
[After Tschermak, Min. u. Pet. Mittheil., XIV, Part IV.]

[*Facing page* 82.]

times in well-defined octahedrons. In their turn the magnetites also inclose particles of corundum very much as the metallic iron of meteorites of the pallasite group inclose the olivines, and as shown in Fig. 4 of the plate.

The following account of these deposits and the method of working is by A. Gobantz:[1]

Naxos, the largest of the Cyclades Islands, is remarkable as being one of the few localities in the world producing emery on a large scale; the deposits, which are of an irregularly bedded or lenticular form, being mostly concentrated on the mountains at the northern end of the islands, the most important ones being in the immediate vicinity of the village of Bothris. The island is principally made up of Archæan rocks, divisible into gneiss and schist formations, the latter consisting of mica schists alternating with crystalline limestones. The lenticular masses of emery, which are quite variable in size, ranging in length from a few feet to upward of 100 yards and in maximum thickness from 5 to 50 yards, are closely associated with the limestones, and, as they follow their undulations, they vary greatly in position, lying at all kinds of slope, from horizontal to nearly vertical. Seventeen different deposits have been discovered and worked at different times. These range over considerable heights from 180 to 700 meters above sea-level, the largest working, that of Malia, being one of the lowest. This important deposit covers an area of more than 30,000 square meters, extending for about 500 meters in length with a height of more than 50 meters. This was worked during the Turkish occupation, and it has supplied fully one-half of all the emery exported since the formation of the Greek Kingdom. The highest quality of mineral is obtained from two comparatively thin but extensive deposits at Aspalanthropo and Kakoryakos, which are 435 meters above the sea-level. The mineral is stratified in thin bands from 1 to 2 feet in thickness, crossed by two other systems of divisional planes, so that it breaks into nearly cubical blocks in the working. The floor of the deposit is invariably

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[1] Oesterreichische Zeitschrift für Berg- und Hüttenwesen, XLII, p. 143. Abstract in the Minutes and Proceedings of the Institute of Civil Engineers, CXVII, pp. 466–468.

crystalline limestone, and the roof a loosely crystalline dolomite covered by mica schist. The underlying limestones are often penetrated by dikes of tourmaline granite, which probably have some intimate connection with the origin of the emery beds above them.

The working of the deposits is conducted in an extremely primitive fashion. The rock is first broken by fire-setting. A piece of ground about 5 feet broad is cleared from loose material, and a pile of brushwood heaped against it and lighted. This burns out in about twenty-four or thirty hours, when water is thrown upon the heated rock to chill it and develop fractures along the secondary divisional planes in the mass of emery, and so facilitate the breaking up and removal of the material. Sometimes a crack is opened out by inserting a dynamite cartridge, but the regular use of explosives is impossible as, owing to the hardness of the mineral, it can not be bored with steel tools.

The only deposits of emery at present worked in the United States occur on what are known as North and South Mountains, near Chester, in Hampden County, Massachusetts, and Peekskill in Westchester County, New York. The Chester deposits were first described by Dr. C. T. Jackson (in 1864) and developed by Dr. H. S. Lucas, the material being at first regarded as mainly magnetite and worked as an iron ore.

The vicissitudes of the operations here, like those of the chromite deposits near Baltimore, form one of the interesting chapters in the history of mining operations in the United States, but which can not be here touched upon.

The deposits have been frequently described, as noted in the bibliography, the facts which are here given being derived mainly from the recent works of B. K. Emerson and J. H. Pratt. The country rock is schistose epidotic-amphibolite of doubtful origin, but which Pratt thinks may be an altered eruptive. The emery-bearing veins conform in a general way with the winding of the schist, and have a strike of approximately north 20° east, south 20° west, dipping to the eastward at an angle of some 70°. As first shown, where cut by the Westfield River, the vein is very narrow, but widens rapidly to the north, attaining a width of 17 feet, of which some 10 feet are emery, the remainder being mainly magnetite. The vein, or bed, cuts through both North and South Mountains, and has been traced a distance of some 5 miles, though the emery is not continuous for the entire distance. It can, however, be traced by means of streaks of chlorite (corundophillite) which almost invariably accompany it. Other characteristic associates are the above noted margarite and magnetite, talc, and black tourmaline, the vein material itself being described as a chloritic magnetite containing in abundance bronze-colored grains of emery and, along the borders of the thicker portion of the main vein and of the eastern vein, a considerable quantity of brown-black tourmaline in delicate stellate forms. The part of the vein rich in emery shows the material in the form of a dark gray, nearly black massive rock, throughout which the corundum is disseminated in the form of small crystals, sometimes 5 to 15 millimeters in diameter and of a rich bronze color.

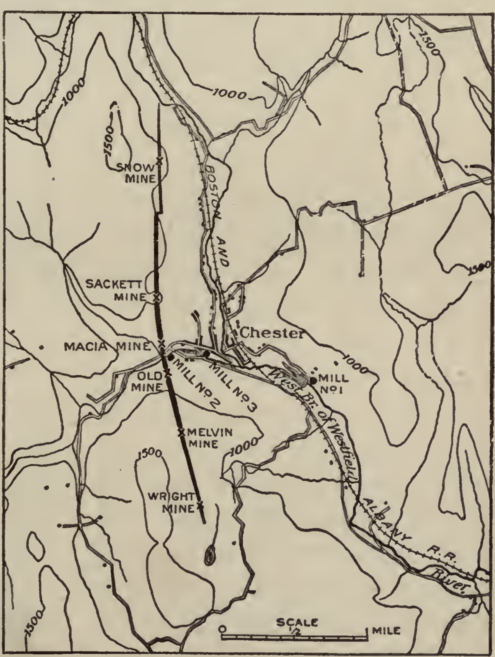

FIG. 19.—Map showing location of emery deposits at Chester, Massachusetts. [U. S. Geological Survey.]

Six mines have from time to time been opened on this deposit, as shown in Fig. 19. At the Melvin Mine the vein varies from 6 to 16 feet in width. A cross-section of the Old Mine is given in Fig. 20. The limits of the deposit as given by Emerson are: Length, 4 miles; depth, 750 feet (above the level of the brook), and with an average width of 4 feet.

The origin of this ore has, naturally, been a matter of some speculation. Emerson regards it as most probable that the emery-magnetite material was originally a deposit of limonite, which was formed by the replacement of limestone, and into which alumina was carried by infiltrating solutions and deposited as allophane and gibbsite, ultimately altered into corundum and magnetite by metamorphism. Pratt, on the other hand, regards the amphibolite as probably an altered eruptive rock, and argues that the magnetite and corundum are both segregations of basic materials from the igneous magma, i.e., are products of magmatic differentiation.

The Peekskill emery occurs in the form of a hard, dark gray to nearly black rock which the microscope has shown to consist essentially of corundum, spinel, and magnetite, the first named in varying proportions up to 50 per cent of the mass. It is associated in the form of lenses and

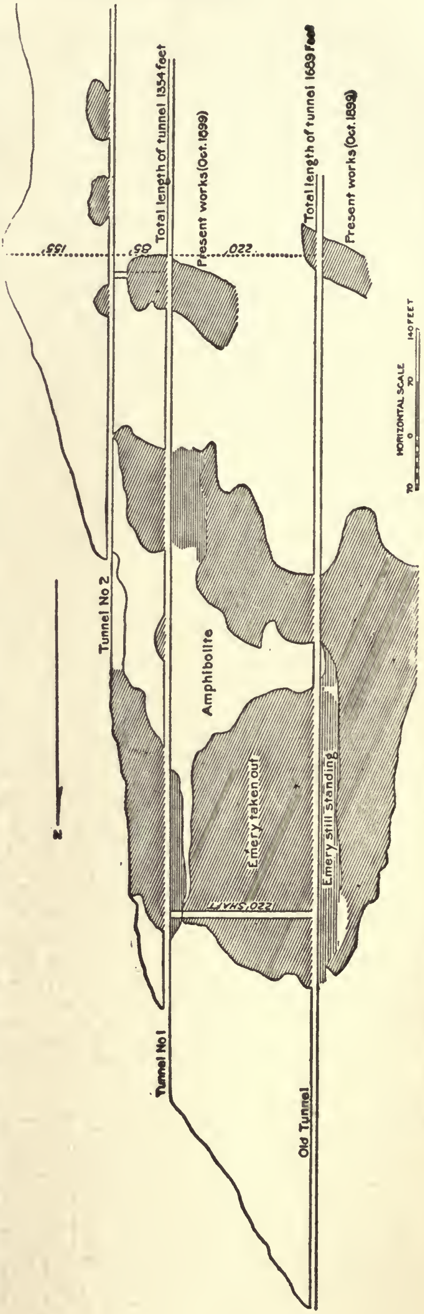

FIG. 20.—Cross-section of Old Mine, showing the amount of emery taken out prior to April, 1899. [U. S. Geological Survey.]

bands, with intrusive rocks—gabbros—from which it was doubtless derived by a process of magmatic segregation. The extent of the individual deposits is very irregular and unreliable. The mines are all open cuts located on natural outcrops, the yield from any one opening being rarely over 100 tons and frequently much less. The annual output is but 500 to 700 tons, and the material regarded commercially as inferior to that of Naxos, but well adapted for emery wheels and like purposes.

Sources.—The chief foreign commercial sources of emery are those of Gumuch-dagh, between Ephesus and the ancient Tralles: Kulah, and near the river Hermes in Asia Minor; and the island of Naxos, whence it is quarried and shipped from Smyrna, in part as ballast, to all parts of the world. The chief commercial source in the United States, or indeed, in North America, is Chester, Massachusetts, and Peekskill, New York, as above noted. The island of Naxos is stated to have for several centuries furnished almost exclusively the emery used in the arts, the material being chiefly obtained from loose masses in the soil. The mining at Kulah and Gumuch-dagh was begun about 1847, and at Nicaria in 1850.

Uses.—In preparing for use, the mineral, after being dug from the soil or blasted from the parent ledge, is pulverized and bolted in various grades, from the finest flour to a coarse sand, the excess of magnetite, where such exists, being extracted by means of an electromagnet. The commercial prices vary according to grade from 3 to 10 cents a pound.

The chief uses of both emery and corundum, as is well known, are in the form of powder by plate-glass manufacturers, lapidaries, and stone workers; as emery paper, or in the form of solid disks made from the crushed and bolted mineral and cement, known commercially as emery wheels. The great toughness and superior cutting power of these wheels render them of service in grinding glass, metals, and other hard substances, where the natural stone is quite inefficient.

An "emery" recently put upon the market consists of an artificial admixture of Canadian corundum and magnetite. The cutting power of the mixture is less than that of the natural emery, where the two substances are so closely intercrystallized, and among those who know, it will rarely be accepted as an equivalent.

(See further under Grind- and Whetstones, p. 400.)

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3. BAUXITE.

Composition.—$Al_2O_3.2H_2O$, =alumina, 73.9 per cent; water, 26.1 per cent. Commonly impure through the presence of iron oxides, silica, lime, and magnesia. Color, white or gray when pure, but yellowish, brown, or red through impurities. Specific gravity, 2.55; structure, massive, or earthy and clay-like. According to Hayes[1] the bauxites of the Southern United States show considerable variety in physical appearance, though generally having a pronounced pisolitic structure. The individual pisolites vary in size from a

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[1] The Geological Relations of the Southern Appalachian Bauxite Deposits. Transactions of the American Institute of Mining Engineers, XXIV, 1894, pp. 250–251

fraction of a millimeter to 3 or 4 centimeters in diameter, although most commonly the diameter is from 3 to 5 millimeters. The matrix in which they are embedded is generally more compact and also lighter in color. The larger pisolites are composed of numerous concentric shells, separated by less compact substance or even open cavities, and their interior portions readily crumble to a soft powder.

In thin sections the ore is seen to be made up of amorphous flocculent grains. The matrix in which the pisolites are embedded may be composed of this flocculent material segregated in an irregulary globular form or in compact oölites, with sharply defined outlines. Or both forms may be present, the compact oölites being embedded in a matrix composed of the less definite bodies. In some cases the interstices between the oölites are filled either wholly or in part with silica, apparently a secondary deposition.

The pisolites also show considerable diversity in structure. In some cases they are composed of the same flocculent grains as the surrounding matrix, from which they are separated by a thin shell of slightly denser material. This sometimes shows a number of sharply defined concentric rings, and is then distinctly separated from the matrix and the interior portion of the pisolite. The latter is also sometimes composed of imperfectly defined globular masses, and in other cases of compact, uniform, and but slightly granular substance. It is always filled with cracks, which are regularly radial and concentric, in proportion as the interior substance has a uniform texture. Branching from the larger cracks, which, as a rule, are partially filled with quartz, very minute cracks penetrate the intervening portions. Thus the pisolites appear to have lost a portion of their substance, so that it no longer fills the space within the outer shell, but has shrunk and formed the radial cracks. No analyses have been made of the different portions of the pisolites or of the pisolites and matrix separately, and it is impossible to say whether any differences in chemical composition exist. It may be that some soluble constituent has been removed from the interior of the pisolites, but it is more probable that the shrinking observed is due wholly to desiccation.

Scattered throughout the ground mass are occasional fragments of pisolites, whose irregular outlines have been covered to varying depths by a deposit of the same material as forms the concentric shells, and thus have been restored to spherical or oval forms.

The following table will serve to show the wide range of composition of bauxites from various sources:

COMPOSITION OF BAUXITES FROM VARIOUS LOCALITIES.

Localities.	SiO_2.	TiO_2.	Al_2O_3.	Fe_2O_3.	(ign) H_2O.	(100°) H_2O.	P_2O_5.	Analyst.
1. Baux, France:								
a. Compact variety.....	2.8	3.1	57.6	25.3	10.8		......	Deville.
b. Pisiform.	4.8	3.2	55.4	24.8	11.6		......	Do.
c. Hard and compact calcareous paste....	......	......	30.3	34.9	22.1		......	Do.
2. Calabres, France.........	2.0	1.6	33.2	48.8	8.6		......	Do.
3. Thoronet, France, red variety...............	0.30	3.40	69.30	22.90	14.10		......	
4. Villeveyrac, Hérault, France, white variety..	2.20	4.00	76.90	.10	15.80		......	
5. Wochein, Germany.......	6.29	......	64.24	2.40	25.74		.46	Lill.
6. Langsdorf, Germany:								
a. Brownish red........	5.14	......	50.85	14.36	27.03	1.35	.48	Lang.
b. Light red..	10.27	......	49.02	12.90	25.88	.93	.38	Do.
7. Vogelsberg, Germany.....	1.10	3.20	50.92	15.70	27.75	.85	......	Liebreich.
8. Cherokee Co., Alabama. ..	37.87	......	39.44	2.27	12.80	9.20	......	Dr. Wm. B. Phillips.
9. Jacksonville, Calhoun Co., Alabama	18.67	......	45.94	11.86	21.20	1.40	......	Do.
a. Red...............	7.73	......	47.52	19.95	23.57		......	Do.
b. White.............	23.72	......	41.38	.85	23.72		......	Do
c. Red...............	10.25	2.53	41.00	25.25	20.43	.65	Trace.	W. F. Hillebrand.
d. White.	21.08	2.52	48.92	2.14	23.41	.45	Trace	Do.
10. Floyd Co., Georgia......	2.80	3.52	52.21	13.50	27.72		......	Nichols.
11. Do.................	......	3.60	57.25	3.21	......	......	......	Do.
12. Do.................	2.30	3.55	56.88	1.49	......	......	.07	Do.
13. Barnsley estate, Dinwood Station, Georgia, No. 7..	1.98	2.38	61.25	1.82	31.43			Prof. H. C. White
14. Pulaski Co., Arkansas:								
a. Black..............	10.13	......	55.59	6.08	28.99		......	
b. Do...............	11.48	......	57.62	1.83	28.63		......	
c. Do...............	2.00	3.50	62.05	1.66	30.31	......	......	
d. Red...............	4.89	......	46.40	22.15	26.68		......	
e. Do...............	3.34	......	58.60	9.11	28.63		......	
f. Do...............	10.38	3.50	55.64	1.95	27.62	.....	......	
g. Do...............	16.76	3.50	51.90	3.16	24.86	......	......	

No. 1.—Contains also 0.4 $CaCO_3$. No. 2.—0.2 $CaCO_3$. No. 3.—12.7 $CaCO_3$. No. 5.—22.90 $FeO + Fe_2O_3$. No. 6.—0.10 $FeO + Fe_2O_3$. No. 7.—0.85 CaO 0.38 MgO, 0.20 SO_3. No. 8.—0.35 FeO, 0.41 CaO, 0.11 MgO, 0.09 K_2O, 0.17 Na_2O, trace CO_2. No. 9.—FeO not det., 0.62 CaO, trace MgO, 0.11 K_2O, 0.20 Na_2O, 0.26 CO_2. No. 10.—0.80 CaO, 0.16 MgO.

Origin and mode of occurrence.—The mineral received its name from the village of Baux (or Beaux[1]) in Southern France, where a highly ferriferous, pisolitic variety was first found and described by Berthier in 1821. The origin of the mineral, both here and elsewhere, has been a matter of considerable discussion. The following notes

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[1] Hence the *au* should receive the sound of long o, and not that of the au in our word *haul.*

relative to the foreign occurrences are from a paper by R. L. Packard:[1]

The geological occurrence of the bauxite of Baux was studied by H. Coquand[2] who describes the mineral as of three varieties, pisolitic, compact, and earthy. The pisolitic variety occurs in highly tilted beds alternating with limestones, sandstones, and clays, belonging to the Upper Cretaceous period, and in pockets or cavities in the limestone. The limestone containing the bauxite and that adjacent thereto is also pisolitic, some nodules being as large as the fist. The pisolitic bauxite has sometimes a calcareous cement, and at others is included in a paste of the compact mineral. Coquand supposed that the alumina and iron oxide composing the bauxite were brought to the ancient lake bed in which the lacustrine limestone was formed, by mineral springs, which, discharging in the bottom of the lake, allowed the alumina and iron oxide to be distributed with the other sediments. In some cases the discharge occurred on land, and the deposit then formed isolated patches. Sometimes the highly ferriferous mineral predominates over the aluminous (white), at others diaspore is found enveloping the red mineral, while in other cases it is mixed with it, predominating largely and sometimes manganese peroxide replaces ferric oxide.

M. Angé[3] describes the bauxite of Var and Hérault and gives analyses. In the red mineral of Var druses occur with white bauxite running as high as 85 per cent Al_2O_3, and 15 per cent H_2O, corresponding to the formula $Al_2O_3+H_2O$. He refers with apparent approval to the prevailing theory of the formation of bauxite, according to which solutions of the chlorides of aluminum and iron in contact with carbonate of lime undergo double decomposition, forming alumina, iron oxide, and calcium chloride. Other deposits in the south of France, in Ireland, Austria, and Italy, seem to him to confirm this view, because they also rest upon or are associated with limestone. The bauxite deposit in Puy de Dôme can not, however, be explained by this theory, because it is not associated with limestone, but rests directly upon gneiss and is partly covered by basalt. The

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[1] Mineral Resources of the United States, 1891, p. 148.

[2] Bulletin de la Société Géologique de France, XXVIII, 1871, p. 98.

[3] Bulletin de la Société Géologique de France, XVI, 1888, p. 345.

geological sketch map of the deposit near Madriat, Puy de Dôme, shows gneiss, basalt, with uncovered bauxite largely predominating, and patches of Miocene clay, while a geological section of the deposit near Villeveyrac, Hérault, shows the bed of bauxite conformably following the flexures of the limestone formation when covered by more recent beds, and when exposed and denuded occupying cavities and pockets in the limestone. This occurrence is substantially the same as that of the neighboring Baux. M. Angé agrees with M. Coquand in attributing the bauxite to geyserian origin, but uses as an illustration of the contemporaneous formation of bauxite the deposits from the geysers of the Yellowstone Park, which is evidently due to a misunderstanding. No petrographical examination of the bauxite of Puy de Dôme was made nor any attempt to trace a genetic relation between the latter and the accompanying basalt. The occurrence is, however, noteworthy, and an examination might show that it is another instance of the direct derivation of bauxite from basalt, which is maintained somewhat imperfectly in the two following instances.

Lang[1] describes the bauxite in Ober-Hessen, as found in the fields in rounded masses up to the size of a man's head, embedded in a clay colored with iron oxide. The chemical composition and petrographical examination seems to show that it is a decomposition product of basalt. The process he explains as follows: By the weathering of the plagioclase feldspars, augite, and olivine, nearly all the silica had been removed, together with the greater part of the lime and magnesia; the iron had been oxidized and hydrate of alumina formed. The residue of the silica had crystallized as quartz in the pores of the mineral.

A more detailed account of the derivation of bauxite from basalt is given in an inaugural dissertation by A. Liebreich.[2] The localities described are the southern slope of the Westerwald near Mühlbach, Hadamar, in the neighborhood of lesser Steinheim, near Hanau, and especially the western slope of the Vogelsberg, Germany. Chemical analyses show certain differences in the composition of samples from

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[1] Berichte der Deutschen Chemischen Gesellschaft, XVII, 1884, p. 2892.

[2] Abstracted in the Chemisches _entralblatt, 1892, p. 94.

different places, the smaller amount of water in the French bauxite causing him to refer it to diaspore, while the Vogelsberg mineral is probably gibbsite (hydrargillite). The Vogelsberg bauxite occurs in scattered lumps or small masses, partly on the surface and partly embedded in a grayish-white to reddish-brown clay, which contains masses of basaltic iron ore and fragments of more or less weathered basalt itself. Although the latter was associated intimately with the bauxite, a direct and close connection of the two could not be found, but an examination of thin sections of the Vogelsberg bauxite showed that most specimens still possessed a basaltic (anamesite) structure, which enabled the author to determine the former constituents with more or less certainty. Lath-shaped portions representing altered plagioclase feldspars filled with a yellowish substance preponderated. Filling the spaces between these were cloudy, yellow, brown, and black transparent masses which had evidently taken the place of the former augite. Laths and plates of titanic iron, often fractured, were commonly present, and the contours of altered olivine could be clearly made out. The basalt of the neighborhood showed a structure fully corresponding with the bauxite. Olivine and titanic iron oxide were found in the clay by washing. The basaltic iron ore also showed the same structure.

But two localities in the United States have thus far yielded bauxite in commercial quantities. These are in Arkansas and the Coosa Valley of Georgia and Alabama.

According to Branner the Arkansas beds occur near the railway in the vicinity of Little Rock, Pulaski County, and near Benton, Saline County. The exposures vary in size from one to twenty or more acres, and aggregate something over a square mile. This does not, in all probability, include the total area covered by bauxite in the counties mentioned, for the method of occurrence of the deposits leads to the supposition that there are others as yet undiscovered.

Like all bauxite, the Arkansas material varies more or less in color and in chemical composition. At a few places it is so charged with iron that attempts have been made to mine it for iron ore. Some of the samples from these pits assay over 50 per cent of metallic iron. This ferruginous kind is exceptional, however. From the dark-red varieties it grades through the browns and yellows to pearl-gray, cream colored and milky white, the pinks, browns, and grays being the more abundant. Some of the white varieties have the chemical composition of kaolin, while the red, brown, and gray have but little silica and iron, and a high percentage of alumina. The analyses given on page 91 show the composition of this bauxite as compared with that of other localities.

According to C. W. Hayes[1] the bauxite of the Bryant district in Saline County is a decomposition product, in place, of nepheline syenite. The bauxite bed is described as resting directly upon a kaolinized type of the syenite (locally known as chimney rock), and overlaid by Tertiary sands and gravels. The thickness of the bed over a large part of the district is from 10 to 15 feet, though in places reaching a maximum of 40 feet. Both the underlying kaolinized rock and the overlying Tertiary sands and gravels are more easily eroded than the bauxite and hence the latter, where erosion is well advanced, is apt to stand out in the form of a low ridge. Two distinct types of ore are recognized in this district, (1) granitic and (2) pisolitic. The first mentioned lies next to the kaolinized syenite, is of a yellowish-gray color, a spongy structure and is quite free from any trace of pisolites, showing, on the contrary, distinct traces of of the crystalline ("granitic") structure of the original syenite, in which the nepheline and orthoclase have been preserved only in form of skeletons of alumina. Original cleavage surfaces of these minerals can even at times be detected, though more frequently the structure is quite obliterated. This type of ore occurs also in the form of well-rounded boulders from 2 or 3 inches to 2 feet in diameter. Such are surrounded by a dense structureless shell or crust from $\frac{1}{2}$ to $\frac{3}{4}$ of an inch in thickness, but within which the material resumes the normal, spongy form. Both portions have essentially the same composition. The boulders were presumably simply waterworn masses of the syenite. Dr. Hayes regards this form of the bauxite as in every case derived directly from the syenite by the decomposition of the feldspar and nepheline (elaeolite), and the removal in solution of the silica, lime and alkalies. The second class of ore mentioned—the pisolitic—forms the upper part of the bauxite bed,

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[1] Twenty-first Annual Report, U. S. Geological Survey, 1899–1900, Part. III, p. 446.

or sometimes constitutes the entire bed, resting directly upon the kaolin. There is a well-marked gradation in the character of the ore from one part of the district to another, the one sometimes prevailing and sometimes the other.

The origin of the two types, as here associated, has not been satisfactorily worked out, though possibly that of the pisolitic type offers the fewest difficulties. After a discussion of the various possibilities, Dr. Hayes sums up the matter as follows:

"The syenite of the bauxite region was intruded under a light cover of Paleozoic rocks. These were subjected to rapid erosion and the surface of the syenite was exposed. Either its subjacent portions retained a considerable portion of their original heat, or a fresh supply of heat was furnished by renewed intrusions or dynamic disturbances. The region was then covered by a body of water probably cut off from the sea, and salt, or highly alkaline. The alkaline waters by some means gained access to the heated portions of the syenite and dissolved its minerals. The heated waters returned to the surface heavily charged with the constituents of the syenite in solution. They were still efficient solvents, however, and acted upon the syenite at the surface, removing most of the silica, along with the lime and the alkalies, but leaving the alumina and depositing in place of the constituents removed about as much, or more, alumina as the rock originally contained. Some of the alumina brought to the surface in solution was deposited by this metasomatic process, replacing a part of the silica removed from the syenite, but a larger part was thrown down as a gelatinous precipitate on the bottom of the water body and somewhat evenly distributed over the undulating syenite surface, at the same time acquiring the pisolitic structure and becoming mingled with the boulders of aluminized syenite. Most of the spring exits were in the immediate vicinity of the syenite areas, so that there the water was most strongly impregnated with the various salts in solution and hence precipitation of the alumina was most rapid. Wherever the ascending solutions found their way to the surface by an isolated conduit through the Tertiary sediment already deposited, a local deposit of greater or less extent was formed. The precipitation of the alumina must have taken place almost immediately after the solution emerged

PLATE VIII.
Church Bauxite Bank, Showing Method of Mining.
[From a photograph by C. W. Hayes, U. S. Geological Survey.]

[*Facing page* 94.]

from the conduit, otherwise the bauxite would have been much more widely disseminated, or even entirely dissipated in the surrounding sediments."

As stated above, and as acknowledged by Dr. Hayes, this theory is not altogether satisfactory, far less so, in fact, than that proposed for the formation of the deposit in Georgia and Alabama. The chief difficulty lies in the finding of a satisfactory solvent for the original aluminous silicate and a cause for the rapid precipitation of the alumina, when once in solution.

The Georgia and Alabama deposits, according to Hayes, are found irregularly distributed within a narrow belt of country extending from Adairsville, Georgia, southwestward, a distance of 60 miles, to the vicinity of Jacksonville, Alabama. The only points at which it has been worked on a commercial scale are at Hermitage furnace, 5 miles north of Rome, Georgia, near Six Mile Station, south of Rome, and in the dike district near Rock Run, Alabama. (See Fig. 21.) The oldest rocks of the region are of Cambrian Age, and are subdivided on lithologic grounds into two formations, the Rome sandstone below and the Connasauga shale above. The former consists of 700 to 1,000 feet of thin-bedded purple, yellow, and white sandstone and sandy shales. The Connasauga formation is between 2,000 and 3,000 feet in thickness. It consists at the base of fine aluminous shales; the upper portion is more calcareous, and locally passes into heavy beds of blue seamy limestone.

Above the shale is the Knox dolomite. It consists of from 3,000 to 4,000 feet of gray, semicrystalline, siliceous dolomite. The silica is usually segregated in nodules and beds of chert. These, in the process of weathering, remain upon the surface, and with the other insoluble constituents form a heavy, residual mantle a hundred feet or more in thickness covering all the outcrops of the formation. It is associated with these residual materials that the extensive deposits of limonite and bauxite are found. The geological structure of the region is complicated, and for its details the present reader is referred to Dr. Hayes's original paper.

The bauxite deposits in the Rock Run district are regarded as typical for the entire region, and are described as follows:

Four bodies of the ore were being worked in 1893 on a considerable scale, and all show practically the same form. The southernmost of the four, called the Taylor bank, is located 3½ miles northeast of Rock Run, near the western base of Indian Mountain. (See Fig. 21). Although the heavy mantle of residual material effectually conceals the underlying rocks, the ore appears to be exactly upon the faulted contact between the narrow belt of Knox dolomite on the northwest and the sandy shales and quartzites of Indian Mountain on the southeast. It is covered by three or four feet of red sandy clay, in which numerous fragments of quartzite are embedded. The ore-body is an irregularly oval mass, about 40 by 80 feet in size. Its contact with the surrounding residual clay, wherever it could be observed, appears to be sharp and distinct, and, about the greater

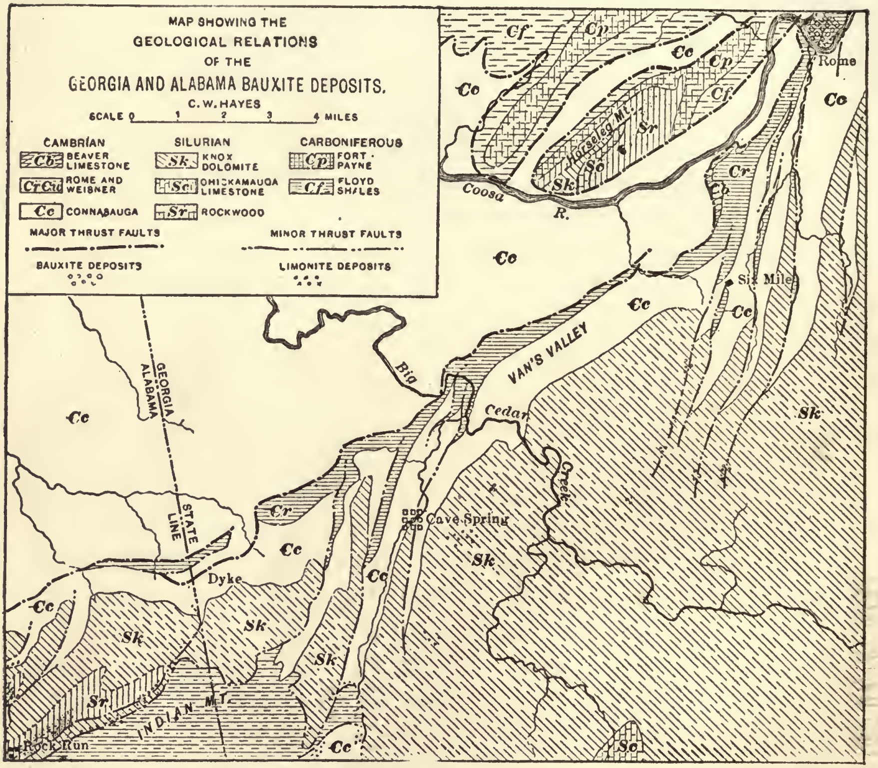

FIG. 21.
[After C. W. Hayes, U. S. Geological Survey.]

portion of its circumference, very nearly vertical. A certain amount of bedding is observable, although no trace can be detected in the surrounding residual material. Upon the northwestern or down-hill side of the ore-body this bedding is very distinct. Layers of differently colored and differently textured ore alternate in regular beds, a few inches in thickness, and above these are thinner beds of chocolate and red material, probably containing considerable kaolin. These beds have a steep dip, somewhat greater than the slope of the hillside, but in the same direction. They are not simply inclined planes, however, but are curved, so as to form a steeply pitching trough. With increasing distance from the ore-body the lamination becomes less distinct, and the beds pass gradually into a homogeneous mottled clay. The accompanying section, Fig. 22, shows these relations of the ore and residual mantle.

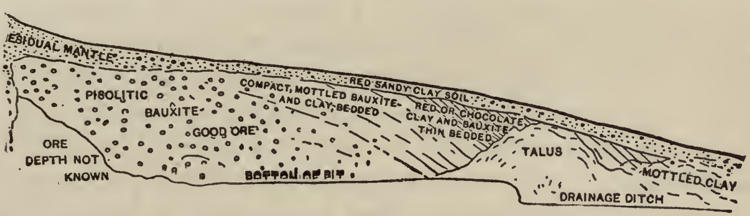

FIG. 22.—Section showing the relation of bauxite to mantle of residual clay in Georgia. [After C. W. Hayes, U. S. Geological Survey.]

At the Dyke bank (see Fig. 21), about a mile northeast of the one above described, the stratification is well shown in portions of the deposit. Beds of yellow and gray, fine-grained material alternate with others of pisolitic ore. The beds dip at an angle of about 40,° and are curved so as to form a steep trough. The compact material also shows distinct cross-bedding, both primary and secondary planes dipping in the same direction.

In the Gain's Hill bank, about 250 yards north of the Dyke bank, the ore-body shows a more regularly oval form than in most of the other deposits, and is also somewhat dome-shaped, swelling out laterally from the surface downward, as far as the working has progressed.

Although some of the workings have gone to a considerable depth (in a few cases 50 feet or more), the bottom of the ore-body has not been reached in any case. The ore varies in composition with depth, but not in a uniform manner, nor more than do different portions at the same depth. The deepest pits have not gone below the base of the surrounding residual mantle, so that no observations have yet been made with regard to the relations between the ore and the country rock; and nothing has yet been observed which warrants the conclusion that the ore, if followed to sufficient depth, will be found interbedded with the underlying formations, or even that it will be found occupying cavities in the limestone—although the latter is quite possible.

Concerning the origin of these deposits it is stated that no eruptive rocks, either ancient or modern, are found in the vicinity, nor are there any rocks in this region which, by weathering, could yield bauxite as a residual product. Hence, any satisfactory explanation must give the source from which the material was derived, the means by which it was transported, and the process of its local accumulation.

The ore is associated with the Knox dolomite or with calcareous sandy shales immediately overlying the dolomite. The Connasauga formation, consisting of 2,000 feet or more of aluminous shales, invariably underlies the dolomite at greater or less distance beneath the ore-bearing regions, and is probably the source from which the alumina was derived.

The region has been profoundly faulted. Undoubtedly the dislocations of the strata generated a large amount of heat. The fractures facilitated the circulation of water, and for considerable periods the region was probably the seat of many thermal springs which it is reasonable to suppose were the agents by which the alumina salt was brought to the surface.

The oxygen contained in the meteoric waters percolating at great depths through the fractured strata would readily oxidize the sulphides disseminated in the aluminous shales. Sulphates would thus be formed, the most abundant of which was ferrous sulphate. Some sulphate of aluminum must also have been formed, together with the double sulphate of potassium and aluminum, especially in the absence of sufficient potash to form alum with the whole.

In its passage from the underlying shales through several thousand feet of dolomite the heated water would become highly charged with lime, in addition to the ferrous and aluminous salts already in solution. But calcium carbonate reacts upon aluminum sulphate, forming a gelatinous or flocculent precipitate which consists of aluminum hydroxide and the basic sulphate. This reaction may have taken place at great depth and the resulting flocculent precipitate been brought to the surface in suspension. From analogy with pisolitic sinter and travertine now forming, such conditions would appear to be highly favorable for the production of the structures actually found in the bauxite. The precipitate was apparently collected in globular masses by the motion of the ascending water, and constant changes in position permitted these to be coated with successive layers of more compact material. Finally, after having received many such coatings, the pisolites were deposited on the borders of the basin, and the interstices filled by minute oölites formed in a similar manner or by the flocculent precipitate itself. Slight differences in the conditions prevailing in the several springs, such as concentration and relative proportion of the various salts in solution, also temperature and flow of the water, would produce the variation in the character of the ore observed at different points.

A small portion of the ferrous sulphate was oxidized and precipitated along with the bauxite, but the greater part was carried some distance from the springs and slowly oxidized, forming the widespread deposits of limonite in this region.

Pittman describes highly ferriferous bauxite covering several square miles of territory in the Innverell and Emmaville districts of New South Wales. The material occurs "capping small hills, and in many cases surrounding points of eruption."

"It is clearly," he says, "of volcanic origin, and while in some cases it appears to consist of volcanic ash, in others in may have been derived from the decomposition of basalt *in situ.*" The analyses quoted show it to run from 30 to 60 per cent of alumina; 2 to 42 per cent of iron oxide; 6 to 32 per cent of water, and equally varying proportions of silica and minor impurities.[1]

Uses.—The better-known use of bauxite is as an ore of aluminum, for which purpose it lies beyond the scope of the present work.

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[1] Mineral Resources of N. S. Wales, by E. F. Pittman, 1901.

It may, however, be well to state that before the aluminum can be satisfactorily extracted the ore is purified by chemical processes. The principal use aside from this is for the manufacture of alums and other aluminum salts such as are used in baking powders and dyes. It is believed that the mineral, owing to its highly refractive qualities, will be utilized in the manufacture of fire-brick and crucibles. An alumino-ferric cake, a by-product obtained in the purifying process, is claimed as of value for sanitary and deodorizing purposes. The price of the crude ore varies greatly, according to purity. The average price for the past few years has been about $5 a ton.

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4. DIASPORE.

This is a hydrous oxide of aluminum corresponding to the formula Al_2O_3,H_2O, = alumina, 85 per cent; water, 15 per cent; hardness, 6.5 to 7. It is a whitish, grayish sometimes brownish or yellowish mineral, occurring in the form of thin flattened or acicular crystals and also foliated, massive, and in thin plates or rarely stalactitic. It is transparent to subtranslucent, and sometimes shows violet-blue colors when looked at in one direction, or reddish-blue or asparagus-green in others. Luster, vitreous or pearly.

Occurrence.—The mineral commonly occurs with corundum and emery in dolomite and granular limestone or crystalline schists. In the United States it occurs in large plates in connection with the emery rock at Chester, Massachusetts.

Uses.—See under Gibbsite.

5. GIBBSITE; HYDRARGILLITE.

This is also, like diaspore, a hydrous oxide of aluminum, corresponding to the formula $Al_2O_3,3H_2O$, = alumina, 65.4 per cent; water, 34.6 per cent. The mineral is of a whitish, grayish, or greenish color, sometimes reddish through impurities, and occurs in flattened, hexagonal crystals, or in stalactitic and mammillary and incrusting surfaces. Its occurrence is similar to that of diaspore.

It has been shown that the so-called laterite of the Seyschellian Islands in the Indian Ocean is a mixture of quartz, iron oxides and hydrargyllite. Whether or not the last named is in such form as to be of economic value is not yet apparent.

Uses.—Neither diaspore nor gibbsite have as yet been found in sufficient quantities to be of economic importance. Should they be so found, their value as a source of alumina is easily apparent.

6. OCHER.

The term ocher as commonly used applies to earthy and pulverulent forms of the minerals hematite and limonite, but which are almost invariably more or less impure through the presence of other metallic oxides and argillaceous matter. In nature the material rarely occurs in a suitable condition for immediate use, but needs first to be prepared by washing and grinding, and perhaps roasting.

Various varietal names are applied to the ochers, according to their natural colors or sources. The original "Indian red" was a red argillaceous ocher, with a purplish tinge, found on the island of Ormuz, in the Persian Gulf. A large part of the pigment of this name is now prepared artificially from iron pyrites. Umber is a gray, brown, or reddish variety containing manganese oxides and clay. It derives its name from Umbria, in Italy, where material of this nature was first utilized. Sienna is a highly argillaceous variety, also from Italy, near Sienna.

The natural colors of the ochers are dependent on the degree of hydration and oxidation of material and the kind and amount of impurities. In a general way the hematites are of a deep red color, while the limonites are yellow or brown. Either color is liable to shade variations, according to amount and kind of impurities. The colors are intensified, or otherwise varied, by roasting.

Artificial ochers are produced by roasting iron pyrites (sulphide of iron) or an artificial sulphate (green vitriol). (See under Pyrite.) The materials known commercially as *rouge*, *crocus*, and *Indian red* are quite pure ferric oxide, prepared by roasting pyrite or by other artificial means.

COMPOSITION OF OCHERS IN THEIR NATURAL CONDITION.

Natural Color.	Locality.	Fe_2O_3.	Al_2O_3.	SiO_2.	H_2O.	Alks.
Yellow	Marksville, Page Co., Virginia	39.0	1.50	33.0	11.5	0.5
Red	Rawlins, Wyoming	90.2	....	Insol. 7.2	.....	1.2
Yellow-brown	Hancock, Berks Co., Pennsylvania	*a* 36.67	50.00		10.60	.....
Deep brown	Anne Arundel Co., Maryland	19.67	76.57		2.60	.....
Deep red-brown	Northampton Co., Pennsylvania	*b* 42.45	30.58		11.85	.....
Gray	Northampton Co., Pennsylvania	*c* 12.20	74.10		5.23	.....
Dark brown	Brandon, Vermont	*d* 52.92	32.88		14.62	.....
	Montgomery Co., Alabama	*a* 10.57	69.30		7.40	.....
Light yellow	Cartersville, Georgia	*b* 55.84	32.20		12.00	.....

a. A part of the iron in a ferrous condition.
b. Contains also some manganese.
c. Iron exists mainly in a ferrous condition.
d. Contains much manganese.

COMPOSITION OF MANUFACTURED MINERAL PAINTS.

Variety.	Fe_2O_3.	Al_2O_3.	SiO_2.	H_2O.	P_2O_3, MnO, CaO.
Lowe's metallic paint *a*	78.87	3.29	11.96	5.07	0.80
Rossie red paint *b*	60.50	5.63	18.00	0.33	$CaCo_3$ 15.66
Light brown paint *c*	77.26	7.00	13.84	0.06	1.84
Brown-purple paint *d*	93.68	3.06	3.20	S. and loss. 0.06	....

a. Made from red fossiliferous ores mined at Atalla, Alabama, and Ooltewah, Tennessee.

b. Made by Iron Clad Paint Company, of Cleveland, Ohio, from ore mined in Wayne County, New York.

c. From ore mined at Lake Superior, Michigan.

d. Ore from Jackson Mine, Michigan.

A "blue ocher," formed by the decomposition of the Utica shales in Lehigh County, Pennsylvania, has the following composition:

Constituents.	Per Cent.
Ignition (water and carbon)	9.10
Quartz	44.50
Combined silica	26.25
Alumina with traces of ferric oxide	17.95
Magnesia	0.94
Alkalies, etc	1.26
	100.00

A second variety, from 1½ miles northwest of Breinigsville, and which was sold as a yellow ocher, yielded:

Silica, 60.53; alumina, 17.40; ferric oxide, 9.27; lime, 0.08; magnesia, 1.92; water, 5.51; alkalies, 5.27.

Origin and mode of occurrence.—These vary greatly. In some cases deposits of this nature are formed by springs. Such result from the leaching out from the rocks, by carbonated waters, of iron in the protoxide condition, and its subsequent deposition as a hydrated sesquioxide. In other cases they are residual products formed by the removal, by solution, of the lime carbonates of calcareous rocks, leaving their insoluble residues—the clay and iron oxides—in the form of a red, yellow, or brown ocherous clay. Again, they may result from the decomposition (oxidation) of beds of pyrite (iron disulphide) and from the decomposition of beds of hematite, and by the disintegration of the more compact forms of limonite. Still again, they may result from the decomposition of schists and other rocks rich in iron-bearing silicate minerals. The yellow ochers of the Little Catoctin Mountains, near Leesburg, Virginia, are thus stated to be residual products from the decomposition of hydromica or damourite schists.

An extensive deposit, or line of deposits, of yellow ocher near Cartersville, Georgia, is described as occurring in the form of extremely irregularly branching veins intersecting a shattered quartzite of Cambrian age. The veins often expand into bodies of considerable size, and when the ocher is removed, rooms 6 to 10 feet in diameter are sometimes left, connected by narrow, winding passages. The contact between the ocher and quartzite is never sharp, but there is a gradual transition from one to the other. "The quartzite first becomes stained a light yellow and loses its compact, close-grained texture. This phase passes into a second, in which the rock is perceptibly porous, having a rough fracture and a harsh feel, and containing enough ocher to soil the fingers. In the next phase the ocher preponderates, but is held together by a more or less continuous skeleton of silica, although it can be readily removed with a pick. The final stage in the transition is the soft yellow ocher, filling the veins, which crumbles on drying, and contains only a small proportion of silica in the form of sand grains." An examination with the microscope seems to point unmistakably to an origin through a chemical replacement of the silica of the quartzite by the iron oxide, as has been shown by Van Hise to have taken place in the case of the hematite ores of the Lake Superior region. The chemistry of the process is not, however, quite clear. The rocks are faulted, and may at some time have been permeated by heated solutions. Water from the surface rocks containing in solution iron carbonate or other ferrous salt, penetrating downward through the shattered quartzite, would meet with oxidizing solutions, and the iron would be precipitated as limonite, and in this particular case in an ocherous form. Thus far the reaction is not difficult to understand, but to account for the removal of the silica is not so easy. The heated solutions from below, perhaps alkaline, may have been instrumental in bringing it about, and perhaps also the carbonic acid liberated during the process of oxidation.[1]

A paint ore found near Lehigh Gap, Carbon County, Pennsylvania, though not properly an ocher, may be described here for want of a better place. The raw material is a dull shaly or slaty rock, of a dark gray color, sandy texture, and quite hard, and if descriptions are correct is probably an arenaceous siderite or carbonate of iron.

According to C. E. Hesse[2] the paint bed is of unknown extent except so far as indicated by outcrops along the southern border of Carbon County, about 27 miles north of Bethlehem, where it occurs in a well-defined ridge of Oriskany sandstone. Along the outcrop the beds are covered by a cap of clay and by the decomposed portion of the Marcellus slate. Beginning with this slate the measures occur in the following descending order:

a. Hydraulic cement (probably Upper Helderberg), very hard and compact.

b. Blue clay, about 6 inches thick.

c. Paint ore, varying from 6 inches to 6 feet in thickness.

d. Yellow clay, 6 feet thick.

e. Oriskany sandstone, forming the crest and southern side of the ridge. It is extremely friable, and disintegrates so readily that it is worked for sand at many points. (See Fig. 23.)

The paint bed is not continuous throughout its extent. It is faulted at several places; sometimes it is pinched out to a few inches, and again increases in width to 6 feet. The ore is bluish gray, resembling limestone, and is very hard and compact. The bed is of a lighter tint, however, in the upper than in the lower part, and this is probably due to its containing more hydraulic cement

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[1] Hayes and Eckel, Contributions to Economic Geology, Bulletin No. 213, Series A, Economic Geology, XXIV, U. S. Geological Survey, 1902, pp. 427–432. See also Bulletin No. 13, Geological Survey of Georgia, 1906.

[2] Transactions of the American Institute of Mining Engineers, XIX, 1891, p. 321.

in the upper strata. The paint ore contains partings of clay and slate at various places. At the Rutherford shaft there are five bands of ore alternating with clay and slate, as follows: Sandstone (hanging wall), clay, ore, slate, ore, clay, ore, slate, ore, cement, slate (foot wall). These partings, however, are not continuous, but pinch out, leaving the ore without the admixture of clay and slate. Near the outcrop the bed becomes brown hematite, due to the leaching out of the lime and to complete oxidation. Occasionally streaks of hematite are interleaved with the paint ore. In driving up the breasts toward the outcrop the ore is found at the top in rounded, partially oxidized, and weathered masses, called "bombshells," covered with iron oxide and surrounded by a bluish clay. In large pieces the ore shows a decided cleavage.

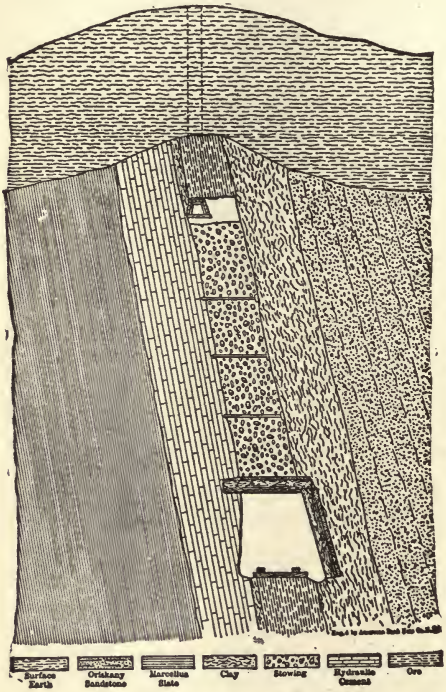

FIG. 23.—Section across the bed, Rutherford and Barclay Mine.
[After C. E. Hesse.]

Some of the mines of Clinton iron ore (hematite) in New York State, and the hematite ores of St. Lawrence County, are used in paint manufacture, as are also ferruginous shales and slates. The green, brown and blue shales occurring in the Chemung formation in Cattaraugus County have thus been utilized as well as the red shale occurring at the base of the Salina formation in Herkimer County. The utility of the material depends, naturally, upon the amount of iron contained by it and the facility with which it can be reduced to a gritless powder. Even the red roofing slates of Washington County find a limited application along these lines.

A mineral paint mined on Porter Creek, near Healdsburg, Sonoma County, California, is said[1] to consist of hematite and silicate of iron in the form of a compact mass lying between hornblendic rock, actinolite, and mica schist on the one side and rotten serpentine on the other. The vein has a north-of-east course, and is some 60 feet in width. The material is mined from a tunnel, crushed, ground between buhrstones, and bolted, making a paint fit for mixing with oils or japan.

Preparation.—As already intimated, only a small portion of the ocher is used in its natural condition, it being first roasted and then ground, the grinding being either "dry" or in oil. The roasting deepens the color to a degree dependent upon the length of time the ore is exposed. Yellows are converted into browns and reds, and the ocher rendered less hydrous at the same time. The crude ore as mined is not infrequently separated from the coarser or heavier impurities by a process of washing in running water, whereby the ocher, in a state of suspension, is drawn off into vats, where it is allowed to settle, the water decanted, and the sediment made up into bricks and dried, when it is ready for grinding.

The method pursued at Caldbeck Falls, in Cumberland, England, is as follows, the ocher occurring here in a vein in granite and admixed with quartz:[2]

"The umber is brought down by an overhead tramway and passed through a hopper into a wash barrel consisting of a cylinder formed of parallel bars one-eighth of an inch apart, having a perforated pipe conveying water, for its axis. By this means the umber is washed through, the quartz being retained; the former then passes to an edge-runner, the casing of which is of sufficient depth to allow of the submersion of the rollers. The rate of revolution is about 14 to the minute, and the finer floating particles flow into the drag mill. The bed of this mill is a single block of granite, and over it

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[1] Twelfth Annual Report of the State Mineralogist, 1894, p. 406.

[2] Journal of the Society of Chemical Industry, October, 1890, p. 953.

the four buhrstone blocks are dragged; the finer 'floating' particles of umber pass to a second mill of the same kind, then through a brass wire sieve (to remove particles of peat and heather that have been floating throughout the process) to settling tanks, composed of brickwork lined with cement. After settling for four hours four-fifths of the water is drawn off, and the umber, now of the consistency of slurry, filter-pressed and dried. It has the following composition:

Constituents.	Per Cent.
Ferric oxide	47.14
Manganese dioxide	11.17
Cupric oxide	3.23
Alumina	7.66
Lime	Trace
Magnesia	Trace
Silica	24.70
Combined water	6.18
	100.08

In this form it is put upon the market.

At the Lehigh Gap Mines the ore, as it comes from the mines, is free from refuse, great care having been taken to separate slate and clay from it in the working places. It is hauled in wagons to kilns, which are situated on a hillside for convenience in charging. The platform upon which the ore is dumped is built from the top of the kiln to the side of the hill. The ore is first spalled to fist size and freed from slate, and is then carried in buggies to the charging hole of the kiln.

The kiln works continuously, calcined ore being withdrawn and fresh charges made without interruption. The ore is subjected for forty-eight hours to the heat, which expels the moisture, sulphur, and carbon dioxide. About 1½ tons of calcined ore are withdrawn every three hours during the day. The outside of the lumps of calcined ore has a light-brown color, while the interior shows upon fracture a darker brown. Great care is necessary to regulate the heat so that the ore is not overburnt. When this happens the product has a black, scoriaceous appearance, and is unfit for the manufacture of metallic paint, as it is extremely hard to grind.

The calcined ore is carried from the kiln in wagons to the mill, where it is broken to the size of grains of corn in a rotating crusher. The broken ore is carried by elevators to the stock bins at the top of the building, and thence by shutes to the hopper of the mills, which grind it to the necessary degree of fineness. Elevators again carry it to the packing machine by a spout, and it is packed into barrels holding 500, 300, or 100 pounds each.

Uses.—The ochers are among the most widespread and readily accessible of coloring materials, and have been used by savage and civilized people, both ancient and modern. The war paint of the American Indian was not infrequently an ocher mixed with oil or grease. According to William J. Russell,[1] the pigments used by the Egyptians and others since the earliest times were of hematite, and mostly of an oölitic variety, apparently closely corresponding to the Clinton hematites of New York State. As tested, such were found to contain from 79.11 to 81.34 per cent ferric oxide.

The ochers are now used mainly in the manufacture of paints for exteriors, as of buildings, the rolling stock of railways, bridges, and metal roofing. They are also used as a pigment for coloring mortars, and in the manufacture of linoleums and oilcloths. Mixed with a certain proportion of oxide of manganese, the ochers have been used to produce desirable colors in earthenware. The Caldbeck Falls material noted is said to be utilized, in addition to the purposes mentioned, for the coloring of various kinds of brown paper.

The raw ocher (that is, ocher not roasted), of a light-yellow color, was at one time in great demand, particularly throughout New England, for painting floors.

The value of the prepared material is but a few cents a pound.

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[1] Nature, XLIX, 1894, p. 374.

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CONRAD E. HESSE. The Paint Ore Mines at Lehigh Gap.

Transactions of the American Institute of Mining Engineers, XIX, 1890, p. 321.

C. W. HAYES and E. C. ECKEL. Occurrence and Development of Ocher Deposits in the Cartersville District, Georgia.

Bulletin No. 213, Series A, Economic Geology, XXIV, U. S. Geol. Survey, 1902.

7. ILMENITE; MENACCANITE; OR TITANIC IRON.

Composition.—$FeTiO_3$, = oxygen, 31.6 per cent; titanium, 31.6 per cent; iron, 36.8 per cent; hardness, 5 to 6; specific gravity, 4.5 to 5; color, iron-black with a submetallic luster and streak; opaque. Differs from magnetite, which it somewhat resembles, by its crystalline form and by its influencing but slightly the magnetic needle.

Mode of occurrence.—Its common form is massive, or in thin plates or laminæ, or as small granules, sometimes disseminated through the mass of rock or loose in the sand. In microscopic forms it is a common constituent of eruptive rocks, both acid and basic. Not infrequently it occurs in large masses, closely resembling magnetic iron ore. In the parish of St. Urbian, Bay St. Paul, Province of Quebec, Canada, is such a bed, stated to be 90 feet in thickness and to have been traced, with some interruptions, for a mile. The bed is in anorthite feldspar rock of Laurentian age. The ore is quite pure, and carries some 48.6 per cent titanic acid. At Kragerö, in Norway, the mineral occurs in the form of veins in diorite. In Virginia it is found in granular masses, containing apatite.

Uses.—The mineral has as yet proved of little economic importance. It is stated that the presence of titanium has an important bearing upon the qualities of iron and steel, but as such it is beyond the scope of this work. As long ago as 1846 an attempt was made to use a ferrocyanide of titanium as a green paint in place of the poisonous arsenical greens. Later (1861) other patents were granted in England for titanium pigments. A deep-blue enamel, resembling the smalt prepared with the oxide of cobalt, has also been prepared from it, but as yet the mineral, though abundant and cheap, has practically no economic use. In the course of time it will probably be utilized in the manufacture of titanium steel.

8. RUTILE.

Composition and general properties.—This mineral is a titanium oxide, having the formula TiO_2, = oxygen, 40 per cent, and titanium, 60 per cent. The hardness is 6 to 6.5; specific gravity, 4.18 to 4.25; luster, metallic adamantine, opaque as a rule, rarely transparent; color, reddish brown to red, rarely yellowish, blue, or black; streak, pale brown. The mineral crystallizes in the tetragonal system, and is commonly found in prismatic forms longitudinally striated, and often in geniculate or knee-shaped twins. Not infrequently it occurs in the form of fine thread-like or acicular crystals penetrating quartz. It is insoluble in acids and infusible before the blowpipe.

Brookite and octahedrite have the same composition and essentially the same physical properties and mode of occurrence.

Mode of occurrence.—Rutile occurs mainly in the older crystalline granitic rocks, schists, and gneisses, but is also found in metamorphic limestones and dolomites, sometimes in the mass of the rock itself, or in the quartz of veins. Being so nearly indestructible under natural conditions, it gradually accumulates in the débris resulting from rock decomposition, and is hence not an uncommon constituent of auriferous sands.

Localities.—Some of the better-known localities are the apatite deposits of Kragerö, in Norway; Yrieux, near Limoges, in France; the Ural Mountains; and the Appalachian regions of the United States. Graves Mountain, Georgia; Randolph County, Alabama, and the Magnet Cove region of Arkansas are celebrated localities.

Near Roseland, Nelson County, Virginia, rutile is found disseminated a coarsely crystalline quartz feldspathic rock of evident igneous origin. The mineral occurs mainly in the form of small granules of all sizes up to 2 or 3 millimeters in diameter, which are sometimes disseminated with remarkable uniformity throughout the feldspathic ground-mass or again segregated in the quartz; rarely pieces of several pounds' weight have been found loose in the soil. The rock is remarkably free from other minerals than those mentioned, and there is a complete absence of titaniferous iron or heavy constituents such as would render difficult a separation of the rutile by the ordinary gravimetric methods.

The ore is mined from open cuts, stamped and concentrated on the premises, the yield varying from 5 to 25 per cent of rutile concentrates in the form of a beautiful resinous red-brown sand.

Uses.—Much attention has of late been paid by metallurgists to the question of the influence of titanium on cast iron and steel. The consensus of opinion at date of writing is apparently to the effect that such is beneficial. According to A. J. Rossi cast iron may be improved in both transverse and tensile strength from 20 to 30 per cent by the addition of small amounts of titaniferous alloys. Quite similar results follow its use in steel. Small amounts of titanium are also used in the manufacture of artificial teeth and of porcelain ware, in both cases serving as a pigment. It is also used in dyeing leathers and in the preparation of the "carbons" used in electric lights.

Until the establishment of the mill at Roseland, Virginia, some 200 to 300 pounds only of rutile were annually produced in the United States, and 40,000 to 90,000 pounds in Norway, the average value being about 10 cents per pound. The Virginia works are capable of producing from 1,000 to 2,000 pounds per day.

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Engineering and Mining Journal, March 8, 1902.
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9. CHROMITE.

Chromite is a mineral of the spinel group, and of the theoretical formula FeO,Cr_2O_3. This equals a percentage of chromic oxide of 68 per cent, but the natural mineral has often alumina and ferric iron replacing a part of the chromium, so that 50 per cent chromic oxide more nearly represents the general average. The ordinary demand, it may be stated, is for an ore carrying 45 per cent and upward of chromic acid.

The analyses given on the next page will serve to show the varying character of the mineral.

COMPOSITION OF CHROMITE FROM VARIOUS LOCALITIES.

Location.	Constituents.								
	Al_2O_3.	MgO.	Cr_2O_3.	Fe_2O_3.	FeO.	SiO_2.	CaO.	Miscellaneous.	Total.
Near Athens, Greece	20.80	11.78	9.80	2.72	7.00	4.85	5.50	$FeCO_3$, 37.75	100.20
Bare Hills, Baltimore, Maryland	13.002	......	39.514	36.004	......	10.596	......	......	99.116
Price's Creek, Yancey County, North Carolina	7.15	4.42	59.20	......	25.02	3.20	......	MnO, 0.92	99.91
Franklin, Macon County, North Carolina	22.41	15.67	44.15	5.78	11.76	......	......	......	99.77
Wilmington, Delaware	6.66	2.06	45.50	......	42.78	3.00	......	......	100.00
Black Lake, Canada	11.35	2.62	51.18	......	19.80	7.48	0.40	......	92.85
Bolton, Canada	3.20	15.03	45.90	......	35.68	......	......	......	99.81
Ekaterinburg, Russia	6.77	13.40	49.49	......	23.27	7.07	......	......	100.00
Western Transvaal, South Africa	17.23	9.94	37.03	0.71	23.95	7.63	2.00	MnO_2, 6.16	99.65
Chester County, Pennsylvania	9.723	......	51.562	35.14	......	2.901	......	MnO, trace.	99.326
Monterey County, California	2.18	12.29	52.12	15.24	......	12.12	5.65	......	99.60
Lancaster County, Pennsylvania	5.75	9.39	55.14	......	28.88	......	......	......	99.16
Do	0.86	9.89	56.55	......	30.23	......	......	......	97.53
Urals	......	5.04	64.00	......	......	1.03	......	Al_2O_3+FeO, 29.33	99.40
		6.15	62.25	......	......	0.95	......	" 30.05	99.40

Chromite, like magnetic iron, is black in color and of a metallic luster, but differs in being less readily if at all attracted by the magnet. On a piece of ground glass or white unglazed porcelain it leaves a brown mark, and fused with borax before the blowpipe it gives a green bead.

Occurrence and origin.—Chromite is a common constituent in the form of disseminated granules of basic eruptive rocks belonging to the peridotite and pyroxenite groups and in the serpentinous and talcose rocks which result from their alteration. It is never found in true veins or beds, though sometimes in segregated, nodular masses somewhat simulating veins on casual inspection. The more common form, as noted above, is that of small masses and detached granules, which, when freed from the inclosing rock, form the ore known as chrome sand.

It is stated by J. H. Pratt, that in North Carolina chromite occurs under conditions very similar to those of corundum, i.e., at and near the line of contact between the intrusive peridotites and gneissic rocks. It is thought probable by Pratt that the mineral was held in solution in the molten magma at the time of its intrusion into the country rock. Such a magma, he states[1] would be like a saturated liquid, and as it began to cool the minerals would crystallize, not according to their fusibility, but according to their solubility in the molten material. The more basic minerals (in this case chromite) being, according to the general law of cooling and crystallizing magmas, the least soluble, would be the first to separate out. These early crystallizations would naturally take place near the line of contact of the eruptive material with the previously solidified rocks, since cooling would be here first manifested. Convection currents would tend to bring new supplies of material and hence the deposits would become enriched. F. Cirkel[2] reports a wide variation in the character of the deposits in Canada, no two being alike. In some cases the ore occurs in disseminated granules and in others in lenses or pocket-shaped deposits as knolls or kidney-shaped accumulations, distributed through cracks in solid serpentine, or segregated and in contact with intrusions of granitic rock. This author, however,

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[1] Transactions of the Am. Inst. of Mining Engineers, XXIX, 1899 (1900), p. 25.

[2] Report on Chrome Iron Ore Deposits in the Eastern Townships of Quebec. Ottawa, 1909.

FIG. 1.—Segregation Veins of Chrome Iron, near Rustenburg, South Africa.
[From Trans. Geological Society of South Africa.]

FIG. 2.—Open Cut Manganese Mine, Crimora, Virginia.
[After Thos. Watson, Mineral Resources of Virginia.]

PLATE IX.

[*Facing page* 116.]

finds nothing to support an oft-repeated assertion to the effect that all of the commercially important deposits lie along the contact of the serpentine with the granite or other rocks; in fact, some of the larger deposits are far removed from such contacts.

In the Transvaal, South Africa, the deposits occur associated with igneous rocks rich in hypersthene and poor in plagioclase feldspars. They occur in what are described as fairly well-defined bedded veins with dip and strike roughly analogous to that of the neighboring sedimentary beds, the thickness of the veins varying from 5 feet downward, and usually maintaining a fairly uniform width for some distance. The following section is given showing the occurrence at Mooihoek:

	Ft.	In.
1. Fine-grained friable weathered dark greenish noritic rock, rich in rhombic pyroxene with scattered chromite grains	0	0
2. Chrome iron vein composed of dark almost black granular ore	1	0
3. Fine-grained granular dirty greenish hypersthenite	2	4
4. Black fine-grained friable granular chrome-iron ore with small lighter-colored irregular patches	4	6
5. Dark granular slightly greenish hypersthenite identical with No. 3	2	6
6. Vein of black powdery chrome-iron ore closely resembling No. 4	4	6
7. Granular hypersthenite with scattered grains of chromite.		

It will thus be seen that there are three separate sheets of the chrome ore with a collective thickness of about 10 feet. The presence in the country rock of scattered grains of chromite shows, however, that the deposits are not in true veins, but evidently segregations out of the molten magma, as in Canada and North Carolina. In all of these cases it is evident that the chromite deposits are to be considered as original and not due to the alteration of the peridotite into serpentine. Baumgärtel,[1] it is true, describes secondary chromites originating through the decomposition of chromiferous diopsides in Bosnian peridotites, but there is nothing to show that such secondary deposits ever occur of such magnitude as to be of commercial importance.

The principal domestic sources of chromium are at present Del Norte, San Luis Obispo, Shasta and Placer counties in California, though formerly mines in Lancaster County, Pennsylvania, and the Bare Hills region near Baltimore were very productive. The American supply of material is to-day derived very largely from Canadian sources, the distribution of the mines being coincident

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[1] Tschermak's Min. u. Petr. Mittheil., XXIII, 1904, p. 393.

with that of the Cambrian serpentines, from which is derived the asbestos and which occur in a belt extending from Southern Vermont to Gaspe in the Province of Quebec. Along the course of this belt chromite exists at several points, and many attempts have been made at mining, but in most instances the mineral has been found in too small a quantity to be of commercial value. The most important field is in what is known as the Thetford Black Lake area, and especially in the township of Coleraine. The deposits are of an exceedingly irregular character, having no definite form and no tendency to adhere to dimensions in special directions and apparently have no relation to each other. Masses of ore have been found varying up to 50 or 75 feet in greatest diameter.

On account of the irregular character of the deposits there has always been, and presumably always will be a considerable amount of uncertainty in mining and little dependence can be placed upon surface indications. The quality of ore that can be worked to commercial advantage is naturally widely variable. Cirkel states that in the Canadian area a rock must yield at least 20 per cent of chromite in order to be utilized.

Chrome ore is also found in Newfoundland; the Russian Urals; in Asia Minor and European Turkey, and in Macedonia; in Australia, New Zealand and New Caledonia, in all cases so far as known the deposits occurring in peridotite or serpentine.

Uses.—Chromium is used in the production of the pigments chrome-yellow, orange, and green, and in the manufacture of bichromate of potash for calico printing and certain forms of electric batteries. A small amount is also used in the production of what is known as chrome steel.

Chrome-ore linings for reverberatory furnaces have been successfully adopted in French, German, and Russian steel works. The bottom and walls of the furnace are lined with the ore in large blocks, united by a cement formed by two parts of ore finely ground, and one part of lime as free from silica as possible.

The best composition used for lining reverberatory furnaces is found to be from 36 to 40 per cent of chromic oxide, 18 to 22 per cent of clay, 9 to 10 per cent of magnesia, and at most 5 per cent of silica.[1]

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[1] Journal of the Iron and Steel Institute, 1895, pp. 506, 507. Abstract from L'Echo des Mines, XXI, p. 584.

Chromite has been also successfully used as a hearth-lining for copper-smelting purposes.

"The chrome industry in America originated in the discovery in 1827 of chrome ore in the serpentine of the Bare Hills region, some 6 miles north of Baltimore, Maryland. Mr. Isaac Tyson, Jr., began the manufacture of 'chrome-yellow' from this material in Baltimore, in 1828. Finding that the chrome ore was always confined to serpentine, Mr. Tyson began a systematic examination of the serpentine areas of Maryland, which could be easily traced by the barren character of the soil which they produce. A narrow belt of serpentine extends across Montgomery County, and while chrome ore is occasionally found in it, nothing of economic importance has ever been discovered in Maryland south of the areas known as 'Soldiers' Delight' and 'Bare Hills.' Northeastward, however, the deposits become much richer. The region near Jarrettsville was productive, and thence the serpentine was traced to the State line in Cecil County. Near Rock Springs the serpentine turns and follows the State line eastward for 15 miles. On the Wood farm, half a mile north of the State line and 5 miles north of Rising Sun, in Cecil County, Mr. Tyson discovered in 1833 a chromite deposit, which proved to be the richest ever found in America. This property was at once purchased and the mine opened. At the surface it was 30 feet long and 6 feet wide, and the ore so pure that each 10 cubic feet produced a ton of chrome ore, averaging 54 per cent of chrome oxide. The ore was hauled 12 miles by wagon to Port Deposit, and shipped thence by water to Baltimore and Liverpool. At a depth of 20 feet the vein narrowed somewhat, but immediately broadened out again to a length of 120 feet and a width of from 10 to 30 feet. The Wood Mine was worked almost continuously from 1828 to 1881, except between the years 1868 and 1873. During that time it produced over 100,000 tons of ore and reached a depth of 600 feet.

"Between 1828 and 1850 Baltimore supplied most of the chrome ore consumed by the world; the remainder came from the serpentine deposits and platinum washings of the Urals. The ore was at first shipped to England. After 1850 the foreign demand for Baltimore ore declined gradually till 1860, since which time almost none has been shipped abroad. The reason for this was the discovery in

1848 of great deposits of chromite near Brusa, 57 miles southwest of Constantinople, by Professor J. Lawrence Smith, who was employed by the Turkish Government to examine the mineral resources of that country. Other deposits were also discovered by him 15 miles farther south, and near Antioch."

Between 1880 and 1892 the annual production of chromite in the United States varied between 1,500 and 3,000 tons. During the succeeding decade the production was greatly diminished. Statistics for 1908 show an output, wholly from California, of but 280 long tons, valued at about $20.00 per ton. Some 7,876 tons were imported during this same year. The principal sources of supply are now Canada, Greece, New Caledonia, New South Wales, Russia and Turkey. The Canadian output during 1908 is placed at 7,225 tons.

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10. MANGANESE OXIDES.

The element manganese exists in nature under many different forms, of which those in combination as oxides, carbonates, and silicates alone need concern us in this work. The principal known oxides are Manganosite (MnO); Hausmannite (MnO,Mn_2O_3); Braunite ($3Mn_2O_3,MnSiO_3$); Polianite (MnO_2); Pyrolusite (MnO_2); Manganite (Mn_2O_3,H_2O); Psilomelane (H_4MnO_5); and Wad, the last being, perhaps, an earthy impure form of psilomelane. To this list should be added the mineral franklinite, a manganiferous oxide of iron and zinc. Of these, the first named, manganosite, is rare, having thus far been reported only in small quantities associated with other oxides in Wermland, Sweden. The other forms are described somewhat in detail as below. It should be stated, however, that with the exception of the well-crystallized forms it is often difficult to discriminate between them, as they occur admixed in all proportions, and, moreover, one variety, as pyrolusite, may result from the alteration of another (manganite). The better defined species may be separated from one another by their comparative hardness, streak, and hydrous or anhydrous properties, as shown in the accompanying table.

Variety.	Hardness.	Specific Gravity.	Color.	Streak.	Anhydrous or Hydrous.
Franklinite....	5.5 to 6.5	5 to 5.22	Iron-black.........	Reddish brown to black....	Anhydrous.
Hausmannite..	5 5.5	4.7 4.85	Brown-black.......	Chestnut-brown.....	Do.
Braunite......	6 6.5	4.7 4.85	Brown-black to steel-gray...........	Brown-black........	Do.
Polianite......	6 6.5	4.8 4.9	Light steel-gray....	Black............	Do.
Pyrolusite.....	2 2.5	4.8	Iron-black to steel-gray or bluish....	Black or blue-black..	*a* Do.
Manganite.....	4	4.2 4.4	Dark steel-gray to iron-black......	Red-brown to black..	Hydrous.
Psilomelane...	5.6 3.7	4.7	Iron-black to steel-gray...........	Brown-black........	Do.

a. Usually yields water in closed tube.

The chemical relationship of the ores as found in nature is thus set forth by Penrose:[1]

Chemical Composition.	Anhydrous Form.	Hydrous Form.
Protoxide (MnO)	Manganosite (MnO)	Pyrochroite ($MnO.H_2O$).
Proto-sesquioxide (Mn_3O_4)	Hausmannite (Mn_3O_4)	
Sesquioxide (Mn_2O_3)	Braunite (Mn_2O_3)	Manganite (Mn_2O_3,H_2O).
Peroxide (MnO_2)	Pyrolusite, Polianite (MnO_2)	Psilomelane. Wad.

Manganese oxides frequently occur admixed in indefinite proportions with the hydrous oxide of iron, limonite, giving rise to the manganiferous limonites.

Franklinite.—This may be termed rather a manganiferous ore of iron and zinc than a true ore of manganese. Nevertheless, as the residue after the extraction of the zinc is used in the manufacture of spiegeleisen, we may briefly refer to it here. The mineral occurs in rounded granules or octahedral crystals of a metallic luster and iron-black color, associated with zinc oxides and silicates in crystalline limestones, at Franklin Furnace, New Jersey. It bears a general resemblance to the mineral magnetite, but is less readily attracted by the magnet and gives a strong manganese reaction. Its average content of manganese oxides Mn_2O_3 and MnO is but from 15 to 20 per cent.

Hausmannite.—This form of the ore when crystallized usually takes the form of the octahedron, and may be readily mistaken for franklinite, from which, however, it differs in its inferior hardness, lower specific gravity, and in being unacted upon by the magnet. It occurs in porphyry, associated with other manganese ores, in Thuringia; is also found in the Harz Mountains; Wermland, Sweden, and various other European localities. In the United States it is reported as occurring only in Iron County, Missouri. The mineral in its ideal purity consists of sesquioxide and protoxide of manganese in the proportion of 69 parts of the former to 31 of the latter. Analyses of the commercial article as mined are not at hand.

Braunite.—This, like hausmannite, crystallizes in the form of the octahedron, but is a trifle harder. Chemically it differs, in that analyses show almost invariably from 7 to 10 per cent of silica,

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[1] Annual Report of the Geological Survey of Arkansas, I, 1890, p. 541.

though as to whether or no this is to be considered an essential constituent it is as yet difficult to say. Analyses I and II, on p. 124, show the composition of the mineral as found. The ore is reported as occurring both crystallized and massive in veins traversing porphyry at Oehrenstock in Ilmenau, in Thuringia, near Ilefeld in the Harz; Schneeberg, Saxony, and various other European localities. Also at Vizianagram in India; in New South Wales, Australia, and in the Batesville region, Arkansas.

Polianite.—Like pyrolusite, yet to be noted, this form of the ore is chemically a pure manganese binoxide, carrying some 63.1 per cent metallic manganese combined with 36.9 per cent oxygen. From pyrolusite it is readily distinguished by its increased hardness. So far as reported, it is a rather rare form of manganese, though possibly much that has been set down as pyrolusite may be in reality polianite.

Pyrolusite occurs in the form of iron-black to steel-gray, sometimes bluish opaque masses, granular, or commonly in divergent columnar aggregates sufficiently soft to soil the fingers, and in this respect easily separated from the other common forms excepting wad; not known in crystals except as pseudomorphs after manganite. In composition it is quite variable, usually containing traces of iron, silica, and lime, and sometimes barium and the alkalies. Analyses III and IV, on p. 124, as given by Penrose, will serve to show the general average. This is a common ore of manganese, and is extensively mined in Thuringia, Moravia, Bohemia, Westphalia, Transylvania, Australia, Japan, India, New Brunswick, Nova Scotia, and various parts of the United States.

Manganite differs and is readily distinguishable from the other ores thus far described, in carrying from 3 to 10 per cent of combined water, which can readily be detected when the powdered mineral is heated in a closed tube. From either psilomelane or pyrolusite it is distinguished by its hardness. When in crystals it takes prismatic forms with the prism faces deeply striated longitudinally. Its occurrence is essentially the same as that of braunite.

Psilomelane.—This is, with the possible exception of pyrolusite, the commonest of the manganese minerals. The usual form of occurrence is that of irregular nodular or botryoidal masses embedded in residual clays. It is readily distinguished from manganite or wad by its hardness, and from hausmannite, braunite, or polianite by yielding an abundance of water when heated in a closed tube. The sample from the Crimora Mines in Virginia, shown in Plate X, is characteristic. The composition of the commercial ore is given in analyses V, VI, and VII, below.

Wad or **Bog Manganese** is a soft and highly hydrated form of the ore, as a rule of little value, owing to impurities (analysis VIII). Asbolite is the name given to a variety of wad containing cobalt (see p. 28). See further Rhodonite and Rhodochrosite, pp. 159, 204.

ANALYSES OF MANGANESE ORES

Constituents.	Braunite.		Pyrolusite.		Psilomelane.			Wad.
	I.	II.	III.	IV	V	VI	VII	VIII
MnO	87.47	86.95	90.15	88.98	84.99	80.27	63.46	25.42
O	9.62	9.85	......	......	10.48	14.10	......	......
Fe_2O_3	......	......	2.55	0.21	......	......	1.75	......
CaO	0.34	......	......	......	......	0.51	......	......
BaO	0.48	2.25	1.12	......	......	4.35 K_2O	......	......
SiO_2	0.18	......	2.80	......	......	2.84	9.80	......
H_2O	......	0.95	2.05	......	......	......	6.00	33.52

I. Batesville region, Arkansas.
II. Elgersburg, Germany.
III. Cheverie, Nova Scotia.
IV. Cape Breton.
V. Batesville region, Arkansas.
VI. Schneeberg, Saxony.
VII. Crimora, Virginia.
VIII. Big Harbor, Cape Breton.

Origin.—The deposits of manganese oxides which are of sufficient extent to be of commercial importance are believed to be in all cases of secondary origin; that is, to have resulted from the decomposition of preexisting manganiferous silicate constituents of the older crystalline rocks and the subsequent deposition of the oxides in secondary strata. Indeed in many instances the ore has undergone a natural segregation, owing to the decomposition of the parent rock and the accumulate of the manganese oxides together with other difficult soluble constituents in the residual clay. Thus Penrose has shown[1] that the deposits of the Batesville (Arkansas) region result from the decay of the St. Clair limestone, the various stages of which are illustrated in the accompanying Plate XI. The fresh

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[1] Annual Report of the Geological Survey of Arkansas, I. 1890.

PLATE X.
Botryoidal Psilomelane, Crimora, Virginia.
[U. S. National Museum.]

[*Facing page* 124.]

limestone, as shown by analysis, contains but 4.30 per cent manganese oxide (MnO), while the residual clay left through its decomposition contains 14.98 per cent of the same constituent.

Occurrence.—As above noted, the ore is found in secondary rocks, and as a rule in greatest quantities in the clays and residual deposits resulting from their breaking down. The usual form of the ore is that of lenticular masses or irregular nodules distributed along the bedding planes, or heterogeneously throughout the clay. Penrose describes the Batesville ores as sometimes evenly distributed throughout a large body of clay, but in most places as being in pockets surrounded by clay itself barren of ore. These pockets vary greatly in character, being sometimes comparatively solid bodies separated by thin films of clay, and containing from 50 to 500 tons of ore; sometimes they consist of large and small masses of ore embedded together, and again at other times of small grains, disseminated throughout the clay. In the Crimora (Virginia) deposits the ore (psilomelane) is found in nodular masses in a clay resulting from the decomposition of a shale which has been preserved from erosion through sharp synclinal folds.

The position and association of these deposits may be best understood by reference to the accompanying figures,[1] Fig. 24 being that of the ground plan of the immediate vicinity of the mine, while Fig. 25 represents cross-sections along the lines marked in Fig. 24. The country rock is a massive Potsdam sandstone overlaid by shales, the latter having undergone extensive decomposition, giving rise to clay deposits in which the ore now occurs. At the east, along the line *AA* in Fig. 24, the sandstone dips to the westward. At *CC* is an anticline from which the beds dip both toward the west and east, forming thus a syncline the axis of which is indicated by the line *BB*. The sections across this syncline (Fig. 25) show the accumulated clay from the decomposition of the shales, in which the manganese occurs. The ore is found very irregularly distributed throughout the clay in lumps and masses from the size of a small pebble to those weighing a ton or more. The basin is described

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[1] From Geological Notes on the Manganese Ore Deposit of Crimora, Virginia. By Charles E. Hall, Trans. Am. Inst. of Min. Engs., Vol. XX, 1891, pp. 47, 48.

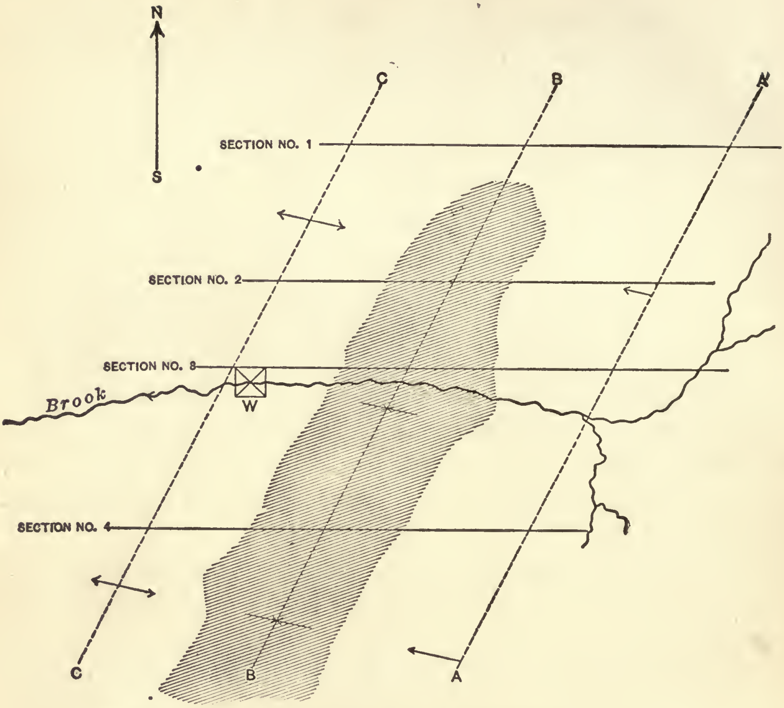

FIG. 24.—Ground plan manganese deposits, Crimora, Va.
[After C. E. Hall.]

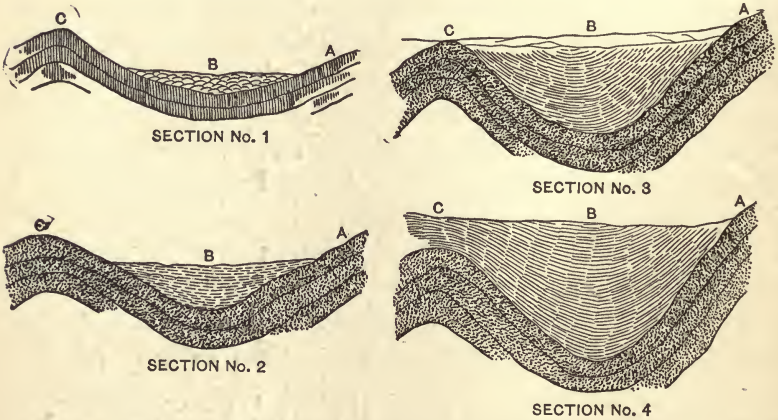

FIG. 25.—Sections through Crimora manganese deposits.
[After C. E. Hall.]

IDEAL SECTIONS SHOWING THE FORMATION OF MANGANESE-BEARING CLAY FROM THE DECAY OF THE ST. CLAIR LIMESTONE.

▨ BOONE CHERT ▨ MANGANESE-BEARING CLAY ▨ IZARD LIMESTONE
▨ ST. CLAIR LIMESTONE ▨ SACCHAROIDAL SANDSTONE

FIG. 1. ORIGINAL CONDITION OF THE ROCKS.

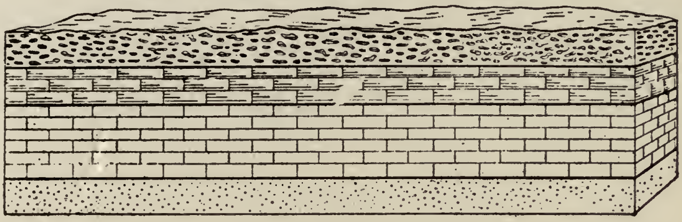

FIG. 2. FIRST STAGE OF DECOMPOSITION.

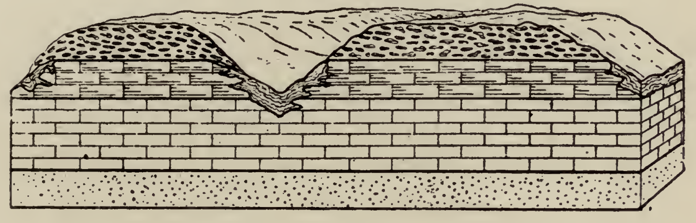

FIG. 3. SECOND STAGE OF DECOMPOSITION.

FIG. 4. THIRD STAGE OF DECOMPOSITION.

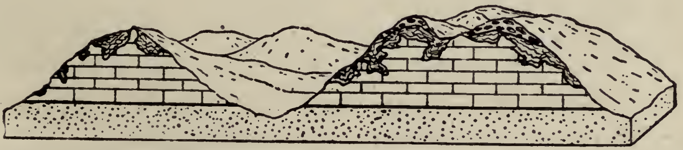

PLATE XI.

Ideal Sections to Show Origin of Manganese through Weathering of Limestone.
[After Penrose, Ann. Rep. Geol. Survey of Arkansas, Vol. I, 1892.]

[*Facing page* 126.]

as some 500 feet in width and 800 to 900 feet in length, the ore-bearing clay extending to a maximum depth, so far as determined, of 300 feet.

The manganese appears to have been here originally disseminated throughout the sandstone and shales and to have leached out, presumably as a carbonate, by percolating water, and redeposited in the basin, where the flow was retarded for a sufficient time for oxidation to take place.

In Cuba, maganese is found in the province of Santiago, the principal occurrence being in a belt lying back of the Sierra Maestra and extending from the vicinity of Guantanamo upon the east to Manzanillo upon the west. The ore, which may be either manganite, pyrolusite, or wad, singly or all together, occurs as a rule upon hills or knolls composed of sedimentary rocks—sandstones and limestones—in disconnected or pocket deposits and under such conditions as to point unmistakably to an origin through the influence of circulating waters. The ore is often associated with a hard jasper, or "bayate," occurring in large masses, or in the form of disseminated nodules or veinlets in the ore. The occurrence and association are such as to indicate that the two substances were deposited nearly contemporaneously, and from the water of hot springs.

Branner has described the maganese (psilomelane) deposit of Bahia, Brazil, as occurring in the form of a sheet or bed of from a few decimeters to ten meters thickness, standing at an angle of 60° in decomposed mica schist. (Fig. 26.)

Bog manganese is described as occurring in an extensive deposit near Dawson settlement, Albert County, New Brunswick, on a branch of Weldon Creek, covering an area of about 25 acres. In the center it was found to be 26 feet deep, thinning out toward the margin of the bed. The ore is a loose, amorphous mass, which could be readily shoveled without the aid of a pick, and contained more or less iron pyrites disseminated in streaks and layers, though large portions of the deposit have merely a trace. The bed lies in a valley at the northern base of a hill, and its accumulation at this particular locality appears to be due to springs. These springs are still trickling down the hillside, and doubtless the process of producing bog manganese is still going on.[1] A bed of manganese ore in the government of Kutais, in the Caucasus, is described as occurring in nearly horizontally lying Miocene sandstones. The ore is pyrolusite and the bed stated as being 6 to 7 feet in thickness.[2]

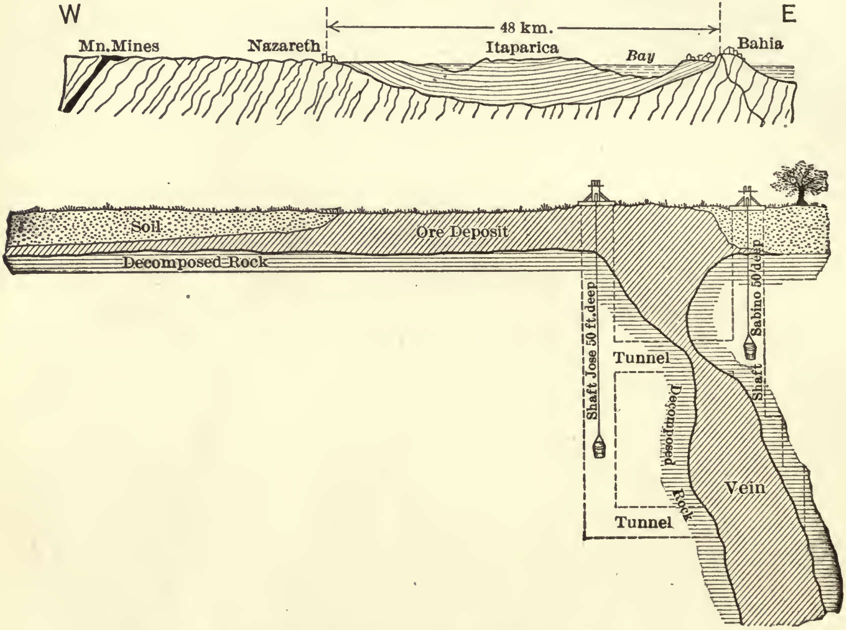

FIG. 26.—Sections of manganese deposit near Bahia, Brazil.
[After Branner, Transactions of the American Institute of Mining Engineers.]

Mining and preparation.—The mining and preparation of manganese ores is, as a rule, a comparatively simple process. At the Crimora (Virginia) mines the material is excavated by means of shafts and tunnels, and taken to the surface, where it is crushed, washed, screened, and dried for shipment. The machinery all works automatically, and the ore is not handled after having once passed into the crusher.[3]

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[1] Annual Report of the Geological Survey of Canada, VII, 1894, p. 146 M.

[2] F. Drake, Transactions of the American Institute of Mining Engineers, XXV, 1898, p. 131.

[3] The washing plant and a vertical section of the works of the Crimora Mines are given in the Engineering and Mining Journal for March 22, 1890, the same having drawn for its information on the American Manufacturer of Pittsburg. (Date not given.)

Uses.—The various uses to which manganese and its compounds are put may be divided into three classes: Alloys, oxidizers, and coloring materials. Each of these classes includes the application of manganese in sundry manufactured products, or as a reagent in carrying on different metallurgical and chemical processes. The most important of these sources of consumption may be summarized as follows:

Alloys	Spiegeleisen	Alloys of manganese and iron.
	Ferromanganese	
	Manganese bronze	Alloys of manganese and copper, with or without iron.
	Silver bronze	An alloy of manganese, aluminum, zinc, and copper, with a certain quantity of silicon.
	Alloys of manganese with aluminum, zinc, tin, lead, magnesium, etc.	
Oxidizers	Manufacture of chlorine.	
	Manufacture of bromine.	
	As a decolorizer of glass (also for coloring glass. see coloring materials).	
	As a dryer in varnishes and paints.	
	LeClanché's battery.	
	Preparation of oxygen on a small scale.	
	Manufacture of disinfectants (manganates and permanganates).	
Coloring materials	Calico printing and dyeing.	
	Coloring glass, pottery, and brick.	
	Paints	Green.
		Violet.

Besides these main uses a certain amount is utilized as a flux in smelting silver ores, and, in the form of its various salts, is employed in chemical manufacture and for medicinal purposes. Pyrolusite and some forms of psilomelane are utilized in the manufacture of chlorine, and for bleaching, deodorizing, and disinfecting purposes, also in the manufacture of bromine.

In glass manufacture the manganese is used to remove the green color caused by the presence of iron, and to impart violet, amber, and black colors.

The amount of manganese actually used for other than strictly metallurgical purposes in the United States is, however, small.[1] The value depends somewhat upon the uses to which it is to be applied.

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[1] Mineral Resources of the United States, 1892, p. 178.

Pyrolusite and psilomelane only are of value in the production of chlorine as above noted. These are rated according to their percentages of peroxide of manganese (MnO_2). The standard for the German ores is given at 57 per cent MnO_2, and 70 per cent for Spanish. For the manufacture of spiegeleisen the prices are based on ores containing not more than 8 per cent silica and 0.10 per cent phosphorus, and are subject to deductions as follows: For each 1 per cent silica in excess of 8 per cent, 15 cents a ton; for each 0.02 per cent phosphorus in excess of 0.10 per cent, 1 cent per unit of manganese. Settlements are based on analysis made on samples dried at 212°, the percentage of moisture in samples as taken being deducted from the weight. The prices paid at Bessemer, Pennsylvania, in 1894, based on these percentages, were as below:

Manganese.	Prices per Unit.	
	Iron.	Manganese
	Cents	Cents
Ore containing above 49 per cent	6	28
Ore containing 46 to 49 per cent	6	27
Ore containing 43 to 46 per cent	6	26
Ore containing 40 to 43 per cent	6	25

Otherwise expressed, the value ranges from $5 to $12 a ton, according to quality and condition of the market.

The total annual output of mines in the United States is but some 5,000 to 6,000 tons. This because with the exception of those at Crimora, Virginia, the deposits are of low grade or small in size.

It is probable that the total consumption in pottery and glass manufacture does not exceed 500 tons a year, of which about two-thirds are used in glass making. The amount used in bromine manufacture and the other purposes enumerated probably amounts to another 500 tons. The remainder is used in connection with iron and steel manufacture, chiefly in the production of steel and a pig iron containing considerable manganese for use in cast-iron car wheels. In the crucible process of steel manufacture manganese is charged into the pots, either as an ore at the time of charging the pots, or it is added as spiegeleisen or ferromanganese at the time of charging or during the melting, usually toward the close of the melting, so as to prevent too great a loss of manganese by oxidation. In the Bessemer and open-hearth process the manganese is added as spiegeleisen or ferromanganese at or near the close of the process, just before the casting of the metal into ingots.

It has been found in recent years that a chilled cast-iron car wheel containing a percentage of manganese is much tougher, stronger, and wears better than when manganese is absent. For this reason large amounts of manganiferous iron ores are used in the manufacture of Lake Superior pig iron intended for casting into chilled cast-iron car wheels. (See also The Mineral Industry, VIII. 1899.)

11 MINERAL WATERS.

From a strictly scientific standpoint any water is a mineral water, since water is itself a mineral—an oxide of hydrogen. Common usage has, however, tended toward the restriction of the name to such waters as carry in solution an appreciable quantity of other mineral matter although the actual amounts may be extremely variable.

Of the various salts held in solution, those of sodium, calcium, and iron are the more common, and more rarely, or at least in smaller amounts, occur those of potassium, lithium, magnesium, strontium, silicon, etc. The most common of the acids is carbonic, and the next probably sulphuric.

Classification.—The classification of mineral water is a matter attended with great difficulty from whatever standpoint it is approached. Such classification may be either geographic, geologic, therapeutic, or chemical, though the first two are naturally of little value, and the therapeutic, with our present knowledge, is a practical impossibility. The chemical classification is, on the whole, preferable, although even this, owing to the great variation of methods of stating results used by analytical chemists, is at present attended with some difficulty. Dr. A. C. Peale, the well-known authority on American mineral waters, has suggested the scheme given below,[1]

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[1] Annual Report of the United States Geological Survey, 1892–93, p. 64.

and from his writings has been gleaned a majority of the facts here given.

According to their temperatures as they flow from the springs the waters are divided primarily into (A) thermal and (B) non-thermal, a thermal water being one the mean annual temperature of which is 70° F. or above. Each of these groups is again subdivided according to the character of the acids and their salts held in solution as below:

- Class I. Alkaline.
- Class II. Alkaline-saline.
  - Sulphated.
  - Muriated.
- Class III. Saline ....
  - Sulphated.
  - Muriated.
- Class IV. Acid ....
  - Sulphated.
  - Muriated.
  - Siliceous
    - Sulphated.
    - Muriated.

Any spring of water may be characterized by the presence or absence of gas when it is designated by one of the following terms: (1) Non-gaseous (free from gas). (2) Carbonated (containing carbonic-acid gas). (3) Sulphureted (containing hydrogen sulphide). (4) Azotized (containing nitrogen gas). (5) Carbureted (having carbureted hydrogen).

In cases where there is a combination of gases such is indicated by a combination of terms, as sulphocarbonated, etc. The classes may be further subdivided according to the predominating salt in solution, as (1) sodic, (2) lithic, (3) potassic, (4) calcic, (5) magnesic, (6) chalybeate, (7) aluminous.

The alkaline waters, Class I above, include those which are characterized by the presence of alkaline carbonates. Generally such are characterized also by the presence of free carbonic acid. Nearly one-half the alkaline springs of the United States are calcic-alkaline, that is, carry calcium carbonate as the principal constituent. The saline waters include those in which sulphates or chlorides predominate. They are more numerous than are the alkaline waters. The alkali-saline class includes all waters in which there is a combination of alkaline carbonates with sulphates and chlorides; the acid class includes all those containing free acid, which is mainly carbonic, though it may be silicic, muriatic, or sulphuric.

The character of the salts held in solution is the same for both thermal and non-thermal springs, though as a general rule the amount of salt is greatest in those which are classed as thermal. Thus at the Hot Springs of Virginia one of the springs, with a temperature of 78° F., has 18.09 grains to the gallon of solid contents, while another, with a temperature of 110° F., has 33.36 grains to the gallon.

Source of mineral waters.—Pure water is an universal solvent and its natural solvent power is increased through the carbonic acid which it takes up in its passage through the atmosphere, and by this same acid and other organic and inorganic acids or alkalies which it acquires in passing through the soil and rocks. The water of all springs is meteoric, that is, it is water which has fallen upon the earth from clouds, and gradually percolating downward issues again in the form of springs at lower levels. In this passage through the superficial portion of the earth's crust it dissolves the various salts, the kind and quantity being dependent upon the kind of rocks, the temperatures and pressure of the water, as well as the amount of absorbed gases it contains.

Both the mineral contents and the temperature of spring waters are dependent upon the geological features of the country they occupy. As a rule springs in regions of sedimentary rocks carry a larger proportion of salts than those in regions of eruptive and metamorphic rocks. Thermal springs are limited to regions of comparative recent volcanic activity, or where the rocks have been disturbed, crushed, folded, and faulted, as in mountainous regions. Occasional thermal springs are met with in undisturbed areas, but such are regarded as of deep-seated origin, and to owe their temperatures to the great depths from which they are derived.

Distribution.—Mineral springs of some sort are to be found in each and all of the States of the American Union, though naturally the resources of the more sparsely settled States have not as yet been fully developed. For this reason the table given on page 134 is to a certain extent misleading.

Uses.—The mineral waters are utilized mainly for drinking and bathing purposes, the thermal springs being naturally best suited for bathing, and the non-thermal for drinking purposes.

PRODUCTION OF MINERAL WATERS IN 1899 BY STATES AND TERRITORIES.

State or Territory.	1908.		
	Springs Reporting.	Quantity Sold (gallons).	Value.
Alabama	8	99,192	$31,583
Arkansas	10	1,175,053	229,260
California	40	1,960,770	499,872
Colorado	11	761,150	127,720
Connecticut	15	424,826	36,404
Florida	12	123,552	20,569
Georgia	14	346,198	50,930
Illinois	17	685,763	58,904
Indiana	15	615,429	590,879
Iowa	6	493,500	55,350
Kansas	16	370,943	74,380
Kentucky	12	797,186	66,112
Louisiana	3	400,500	52,020
Maine	27	1,182,322	394,346
Maryland	8	806,673	75,858
Massachusetts	61	4,395,049	227,907
Michigan	24	2,004,433	88,910
Minnesota	11	10,985,536	551,986
Mississippi	8	257,200	52,780
Missouri	30	682,821	86,043
Nebraska	3	48,498	11,047
New Hampshire	9	835,349	259,520
New Jersey	13	1,199,023	126,603
New Mexico	6	152,200	16,060
New York	47	8,007,092	877,648
North Carolina	18	160,195	27,163
Ohio	27	2,409,598	124,938
Oklahoma	9	534,114	52,779
Oregon	6	25,350	8,830
Pennsylvania	32	1,430,489	197,497
Rhode Island	9	594,208	39,405
South Carolina	13	271,572	70,937
Tennessee	14	712,912	68,693
Texas	36	1,586,634	151,032
Vermont	5	107,800	16,380
Virginia	46	2,009,614	207,115
Washington	5	38,900	13,650
West Virginia	9	130,295	79,915
Wisconsin	28	6,084,571	1,413,107
States or Territories of one or two springs each	....	1,202,310	153,137
Total	695	56,108,820	$7,287,269

V. CARBONATES.

1. CALCIUM CARBONATE.

Calcite, Calc Spar, Iceland Spar.—These are the names given to the variety of calcium carbonate crystallizing in the rhombohedral division of the hexagonal system. The mineral occurs under a great variety of crystalline forms, which are often extremely perplexing to any but an expert mineralogist. The chief distinguishing characteristics of the mineral are (1) its pronounced cleavage, whereby it splits up into rhombohedral forms, with smooth, lustrous faces, and (2) its doubly refracting property, which is such that when looked through in the direction of either cleavage surfaces it gives a double image. It is to this property, accompanied with its transparency, that the mineral, as a crystallized compound, owes its chief value, though as a constituent of the rock limestone it is applied to a great variety of industrial purposes. When not sufficiently transparent for observing its doubly refracting properties the mineral is readily distinguished by its hardness (3 of Dana's scale) and its easy solubility, with brisk effervescence, in cold dilute acid. This last is likewise a characteristic of aragonite, from which it can be distinguished by its lower specific gravity (2.65 to 2.75) and its cleavage. Calcium carbonate, owing to its ready solubility in terrestrial waters, is one of the most common and widely disseminated of compounds. Only the form known as double spar, or Iceland spar, will here be considered.

Origin and mode of occurrence.—Calc spar is invariably a secondary mineral occurring as a deposit from solution in cracks, pockets, and crevices in rocks of all kinds and all ages. The variety used for optical purposes differs from the rhombohedral cleavage masses found in innumerable localities only in its transparency and freedom from flaws and impurities. The chief commercial source of the mineral has for many years been Iceland, whence has arisen the term Iceland spar, so often applied. For the account of the occurrences of the mineral at this locality, as given below, we are indebted mainly to Th. Thoroddsen.[1] The quarry is described as situated on an evenly sloping mountainside at Reydarfjord, about 100 meters above the level of the ocean and a little east of the Helgustadir farm. (See Plate XII.)

The veins of spar are in basalt, and at this spot have been laid bare through the erosive action of a small stream called the "Silfurlakur," the Icelandic name of the spar being "Silfurberg" The quarry opening is on the western side of this brook, and at date of writing was some 72 feet long by 36 feet wide (see Fig. 1 of plate). In the bottom and sides of this opening the calc spar is to be seen in the form of numerous interlocking veins, ramifying through the basalt in every direction and of very irregular length and width, the veins pinching out or opening up very abruptly. In Fig. 2 of plate is shown an area of some 40 square feet of the basaltic wall rock, illustrating this feature of the occurrence. Fig. 3 of the same plate shows the largest and most conspicuous vein, the smaller having been omitted in the sketch. The high cliffs on the north side of the quarry are poorer in calc-spar veins, the largest dipping underneath at an angle of about 40°.

A comparatively small proportion of the calc spar as found is fit for optical purposes. That on the immediate surface is, as a rule, lacking in transparency. Many of the masses, owing presumably to the development of incipient fractures along cleavage lines, show internal, iridescent, rainbow hues; such are known locally as "litsteinar" (lightstones). Others are penetrated by fine, tube-like cavities, either empty or filled with clay, and still others contain cavities, sometimes sufficiently large to be visible to the unaided eye, filled with water and a moving bubble. The most desirable material occurs in comparatively small masses embedded in a red-gray clay, filling the vein-like interspaces in the bottom of the pit. The non-transparent variety, always greatly in excess, occurs in cleavable masses and imperfectly developed rhombohedral, sometimes 1 to 2 feet in diameter, associated with stilbite.

Calc spar has been exported in small quantities from Iceland since the middle of the seventeenth century, though the business

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[1] Geologiska Foreningens I, Stockholm Forhandlingar, XII, 1890, pp. 247–254.

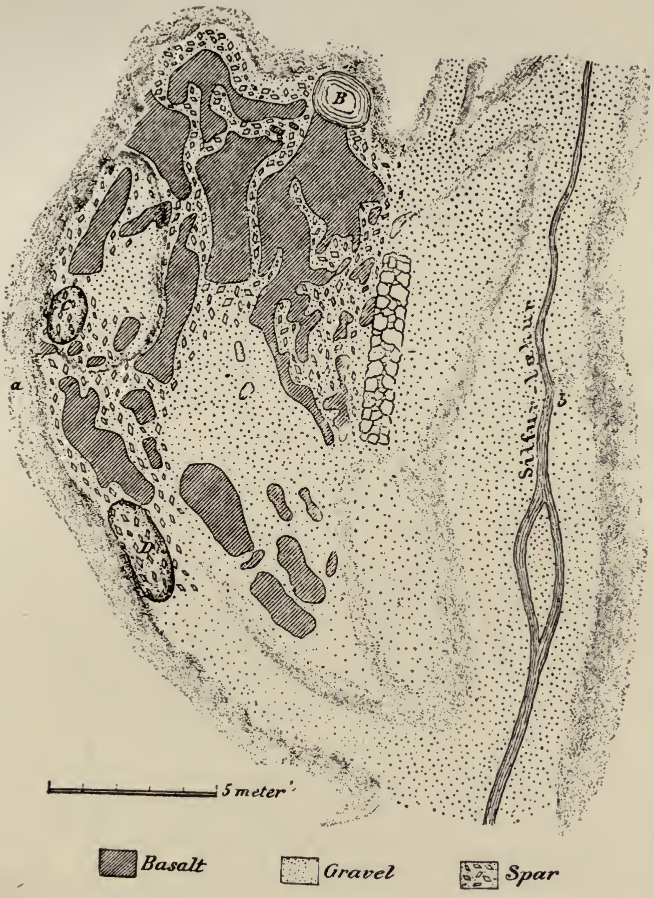

Fig. 2.

Fig. 3.

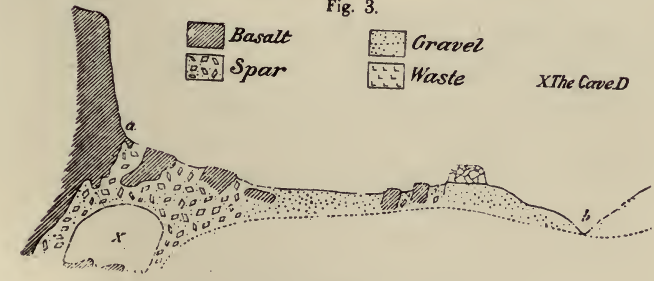

PLATE XII.
Views Showing Occurrence of Calcite in Iceland.
[After Thorroddsen.]

[*Facing page* 136.[

was not conducted with any degree of regularity before the middle of the nineteenth century, prior to that time every one taking what he liked or could obtain, asking no one's permission. About the time Bartholin discovered the valuable optical properties of the mineral (in 1669), the royal parliament under Frederick III granted the necessary permission for its extraction.[1] It was not, however, until 1850 that systematic work was begun, when a merchant by the name of T. F. Thomsen, at Seydisfjord, obtained permission of the owner of some three-fourths of the property (the pastor Th. Erlendsson) to work the same. The quarried material was then transported on horseback to the Northfjord, and thence to Seydisfjord by water. In 1854 the factor H. H. Svendsen, from Eskifjord, leased the pastor's three-fourths' right for 10 rigsdalers a year, and the remaining fourth, belonging to the Government, for 5 rigsdalers. Svendsen worked the mine successfully up to 1862, when one Tullinius, at Eskifjord, purchased the pastor's three-fourths and leased the Government's share for five years, paying therefor the sum of 100 rigsdalers (about $14 or $15). This lease was renewed for four years longer at the rate of 5 rigsdalers per year, and for the year 1872 at the rate of 100 rigsdalers, when the entire property passed into the hands of the Government in consideration of the payment of 16,000 kroner (about $3,800). From that time until 1882 the mine remained idle, when operations were once more renewed, though not on an extensive scale, owing, presumably in part, to the fact that Tullinius, the last year he rented the mine, had taken out a sufficient quantity to meet all the needs of the market. Over 300 tons of the ordinary type of the spar is stated to have been sent to England and sold to manufacturers at about 30 kroner a ton, though to what use it was put is not stated.

M. Lebonne describes[2] ramifications of the calcite veins into the neighboring rock, which have never been worked, and it is suggested that their exploitation might result in an increased output.

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[1] Laws of Iceland, I, 1668, pp. 321, 322.

[2] Comptes Rendus, Vol. V, 1887, p. 1144.

The workings have not been carried to a sufficient depth to fully indicate the extent of the deposit. For the most part the calcite is rendered semiopaque by minute cracks following the gliding and cleavage planes, and apparently produced by pressure.

Aside from the locality at Helgustadir, calc spar in quantity and quality for optical purposes is known to occur only at Djupifjörd, in West Iceland.

Limestones.—Any rock composed essentially of carbonate of lime is commonly designated a limestone. Pure limestone is a compound of calcium oxide and carbonic acid in the proportion of 56 parts of lime (CaO) to 44 parts of the acid (CO_2). In its crystalline form, as exemplified in some of our white marbles, the rock is therefore but an aggregate of imperfectly developed calcite crystals, or, otherwise expressed, is a crystalline granular aggregate of calcite. In this form the rock is white or colorless, sufficiently soft to be cut with a knife, and dissolves with brisk effervescence when treated with dilute hydrochloric or nitric acid.

As a constituent of the earth's crust, however, absolutely pure limestone is practically unknown, all being contaminated with more or less foreign material, either in the form of chemically combined or mechanically admixed impurities. Of the chemically combined impurities the most common is magnesia (MgO), which replaces the lime (CaO) in all proportions up to 21.7 per cent, when the rock becomes a dolomite. This in its pure state can readily be distinguished from limestone by its greater hardness and in its not effervescing when treated with cold dilute acid. It dissolves with effervescence in hot acids, as does limestone. As above noted, all stages of replacement exist, the name magnesian or dolomitic limestone being applied to those in which the magnesia exists in smaller proportions than that above given (21.7 per cent). Iron in the form of protoxide (FeO) may also replace a part of the lime. Of the mechanically admixed impurities silica in the form of quartz sand or various more or less decomposed silicate minerals, clayey and carbonaceous matter, together with iron oxides, are the more abundant. These exist in all proportions, giving rise to what are known as siliceous, aluminous, or clayey, carbonaceous, and ferruginous limestones. Phosphatic material may exist in varying proportions,

FIG. 1.—Limestone Quarry, Rockland, Maine.
[From photograph by E. S. Bastin, U. S. Geological Survey.]

FIG. 2.—Limestone Quarry, Oglesby, Illinois.
From a photograph by E. C. Eckel, U. S. Geological Survey.]

PLATE XIII.

[*Facing page* 138.]

forming gradations from phosphatic limestones to true phosphates.

Limestones are sedimentary rocks formed mainly through the deposition of calcareous sediments on sea bottoms; many beds, however, as the oölitic limestones, show unmistakable evidences of true chemical precipitation. They are in all cases eminently stratified rocks, though the evidences of stratification may not be evident in the small specimen exhibited in museum collections. Varietal names other than those mentioned above are given, and which are dependent upon structural features, adaptability to certain uses, or other peculiarities. A shaly limestone is one partaking of the nature of shale. Chalk is a fine pulverulent limestone composed of shells in a finely comminuted condition and very many minute foraminifera, as elsewhere noted. The name chalky limestone is frequently given to an earthy limestone resembling chalk. Marl is an impure earthy form, often containing many shells, hence called shell marl. An oölitic limestone is one made up of small rounded pellets like the roe of a fish; a hydraulic limestone one suited to the manufacture of hydraulic cement, and so on. The name marble is given to any calcareous or even serpentinous rock possessing sufficient beauty to be utilized for ornamental purposes.

Uses.—Aside from their uses as building materials as described elsewhere,[1] limestones are utilized for a considerable variety of purposes, the most important being that of fluxes and the manufacture of mortars and cements. Their adapatility to the last mentioned purposes is due to the fact that when heated to a temperature of 1,000° F. they lose their carbonic acid, becoming converted into anhydrous calcium oxide (CaO), or quicklime, as it is popularly called; and further, that this quicklime when brought in contact with water and atmospheric air greedily combines with, first, the water, forming hydrous calcium oxide ($CaOH_2O$), and on drying once more, with the carbonic acid of the air, forming a more or less hydrated calcium carbonate. In the process of combining with water the burnt lime (CaO) gives off a large amount of heat, swells to nearly twice its former bulk, and falls away to a loose, white

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[1] See Stones for Building and Decoration. Wiley & Sons, New York.

powder. This when mixed with siliceous sand forms the common mortar of the bricklayers, or, if with sand and hair, the plaster for the interior walls of houses. Quicklime formed from fairly pure calcium carbonate sets or hardens after but a few days' exposure, the induration, it is stated, being due in part to crystallization. The less pure forms of limestone, notably those which contain upwards of 10 per cent of aluminous silicates (clayey matter), furnish, when burned, a lime which slakes much more slowly—so slowly, in fact, that it is not infrequently necessary to crush it to powder after burning. The same limes when slaked are further differentiated from those already described by their property of setting (as the process of induration is called) under water. Hence they are known as hydraulic limes or cements, and the rocks from which they are made as hydraulic limestones. Their property of induration out of contact with the air is assumed to be due to the formation of calcium and aluminum silicates.[1] Inasmuch as these silicates are practically insoluble in water, it follows that quite aside from their greater strength and tenacity they are also more durable; indeed there seems no practical limit to the endurance of a good hydraulic cement, its hardness increasing almost constantly with its antiquity. Certain stones contain the desired admixtures of lime and clayey matter in just the right proportion for making hydraulic cement, and are known as natural cement rock. In the majority of cases, however, it has been found that a higher grade, stronger and more enduring material, can be made by mixing in definite proportions, determined by experiment, the necessary constituents obtained, it may be, from widely separated localities. As noted above magnesia is a common constituent of limestone and from the present standpoint it may be considered as an impurity. In the natural cements, however, the presence of an amount under 20 per cent is not considered as detrimental, provided the alumina and silica are present in sufficient

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[1] As assumption yet awaiting proof. Eckel, however, gives this assumed silicate in Portland cement, as having the approximate formula $3CaO,SiO_2$, which corresponds to the proportion of 73.6 per cent CaO and 26.4 per cent SiO_2. As a matter of fact, however, analyses of cements show invariably the presence of more or less alumina, and if such silicates are actually formed they must be of a more complex nature, and it is possible the mixture would be best represented by the formula $2(3CaOSiO_2).y(2CaOAl_2O_3)$.

proportions. A higher temperature is, however, necessary for burning than with the pure lime carbonate. In the making of the artificial admixture the presence of magnesia in amounts exceeding 5 per cent is considered undesirable.

The exact relationship existing between composition and adaptability to lime-making does not seem as yet to be fully worked out. As is well known, the pure while crystalline varieties yield a quicklime inferior to the softer blue-gray, less metamorphosed varieties. Nevertheless, there are certain distinctive qualities, due to the presence and character of impurities, which led Gen. Q. A. Gillmore to adopt the following classification:

(1) The common or fat limes, containing, as a rule, less than 10 per cent of impurities.
(2) The poor or meagre limes, containing free silica (sand) and other impurities in amounts varying between 10 per cent and 25 per cent.
(3) The hydraulic limes, which contain from 30 to 35 per cent of various impurities.
(4) The hydraulic cements, which may contain as much as 60 per cent of impurities of various kinds.

Most cements are manufactured from artificial admixtures of materials, and their considerations belong, therefore, more properly to technology. Nevertheless it has been thought worth the while here to give in brief the matter below relative to a few of the more important and well-known varieties now manufactured.

Portland Cement.—This takes its name from a resemblance of the hardened material to the well-known limestone of the island of Portland in the English Channel. As originally made on the banks of the Thames and Medway, it consists of admixtures of chalk and clay dredged from the river bottoms, in the proportions of three volumes of the former to one of the latter, though these proportions may vary according to the purity of the chalk. These materials are mixed with water, compressed into cakes, dried and calcined, after which it is ground to a fine powder and is ready for use. The following analyses from Heath's Manual of Lime and Cement will serve to show the varying composition of the chalk and clay from the English deposits:

Constituents.	Upper chalk.		Gray chalk.		Clay.	
Calcium carbonate	97.90 to	98.60	87.35 to	96.52	55 to 70	
Silica	.66	1.59	1.67	6.84		
Magnesium carbonate	.10	.21	.10	.50		
Iron oxide	.35	.74	.38	.46	3	15
Alumina			1.14	.93	11	24
Potash and soda			.42	4.29	3	4
Lime					4	8
Magnesia					1	2
Carbonic acid					4	5

It is stated that the presence of more than very small quantities of sand, iron oxides, or vegetable matter in the clay is detrimental. A good cement mud before burning may contain from 68 to 78 per cent of calcium carbonate, 21 to 15 per cent of silica, and from 10 to 7 per cent of alumina.

The following analyses from the same source as the above serve to show (I) the composition of the clay; (II) the mixed clay and chalk or "slurry," as it is called, and (III) the cement powder prepared from the same:

Constituents.	I. Clay.	II. Slurry.	III. Cement.
Lime			62.13
Calcium sulphate			2.13
Calcium carbonate	2.01	69.97	
Silica (soluble)	54.14	11.77	20.45
Alumina	14.68	4.45	8.05
Magnesium carbonate	4.48	2.87	
Magnesia			1.48
Iron oxide	7.76	2.13	4.37
Sand	.87	1.24	.98
Water	15.03	7.59	

Eckel defines [1] a Portland cement, as the term is now commercially used, as the product obtained by finely pulverizing a clinker formed by burning to semifusion an intimate artificial mixture of finely ground calcareous and argillaceous material, consisting approx-

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[1] Cements, Limes and Plasters. Wiley & Sons, New York.

imately of three parts of lime carbonate to one part of silica, alumina and iron oxide. The ratio of lime (CaO) in the finished product, to all other constituents named, should not be less than 1.6 to 1, or more than 2.3 to 1.

Several brands of Portland cement are now manufactured in America on the above basis, the proportions having been worked out by experiment. At the Coplay Cement Works, in Lehigh County, Pennsylvania, a blue-gray crystalline limestone and dark-gray more siliceous variety are ground and mixed into the desired proportions, molded into a brick, and burnt to the condition of a slag. The material is then ground to a powder and forms the cement.

The chemical composition of the samples as given are as follows:

Constituents.	Limestone.	Cement rock.	Compound of the two.	Clinker.
Silica (SiO_2)	2.10	15.22	13.22	22.74
Alumina (Al_2O_3) Iron Oxide (Fe_2O_3)	.84	4.24	5.20	10.50
Calcium carbonate ($CaCO_3$)	96.17	69.88	77.00	CaO 61.82
Magnesian Carbonate ($MgCO_3$)	Trace.	4.60	4.20	MgO 2.05

An impure limestone, forming a portion of the water-lime group of the Upper Silurian formations at Buffalo, New York, forms a "natural cement" rock which is utilized in the manufacture of the so-called Buffalo Portland Cement.[1]

The so-called Rosendale cement is made from the Tentaculite or Water Limestone of the lower Helderberg group as developed in the township of Rosendale, Ulster County, New York. According to Darton[2] there are two cement beds in the Rosendale-Whiteport region, at Rosendale the lower bed or dark cement averaging some 21 feet in thickness and the upper or light cement 11 feet, with 14 to 15 feet of water-lime intervening. In the region just south of Whiteport the upper white cement beds have a thickness of 12 feet and the lower or gray cement of 18 feet, with 19 to 20 feet of water-lime beds between them. The underlying formation is quartzite.

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[1] Cement Rock and Gypsum Deposits in Buffalo. J. Pohlman. Transactions of the American Institute of Mining Engineers, XVII, 1889, p. 250.

[2] Report of the State Geologist of New York, I, 1893.

The method of mining the material from the two beds, as well as their inclination to the horizon, is shown in Plate XIV.

Roman Cement.—The original Roman cement appears to have been made from an admixture of volcanic ash or sand (pozzuolana, peperino, trass, etc.) and lime, the proportions varying almost indefinitely according to the character of the ash. The English Roman cement is made by calcining septarian nodules dredged up from the bottoms of Chichester Harbor and off the coast of Hampshire, and from similar nodules obtained from the Whitby shale beds of the Lias formations in Yorkshire and elsewhere. The following analysis of the cement stone from Sheppey, near South End, will serve to show the character of the material:

Constituents.	
Carbonate of lime	64.00
Silica	17.75
Alumina	6.75
Magnesia	0.50
Oxide of iron	6.00
Oxide of manganese	1.00
Water	3.00
Loss	1.00
	100.00

The names concrete and beton are applied to admixtures of mortar, hydraulic or otherwise, and such coarse materials as sand, gravel, fragments of shells, tiles, bricks, or stone. According to Gillmore the matrix of the beton propor is a hydraulic cement, while that of the concrete is non-hydraulic. The terms are, however, now used almost synonymously.

Aside from their uses as above indicated limestones are used in the preparation of lime for fertilizing purposes. For this purpose, as before, the lime carbonate is reduced to the condition of oxide by burning and then allowed to become air-slaked, when it remains in the condition of a fine powder suitable for direct application to the land as is the plaster made from gypsum. A lime prepared by burning oyster shells is utilized in a similar manner.

PLATE XIV.
Cement Quarry near Whitehall, Ulster County, New York.
[From photograph by N. H. Darton, U. S. Geological Survey.]

[Facing page 144.]

Finely ground raw limestone is sometimes used with good effect. In regions favorably situated, as the salt regions of Michigan, large quantities of limestone are used in the manufacture of soda ash, or carbonate of soda, which in its turn is used in the manufacture of glass. Limestone of a high degree of purity is required for this purpose.

The name **chalk** is given to a white, somewhat loosely coherent variety of limestone composed of the finely comminuted shells of marine mollusks, among which microscopic forms known as foraminifera are abundant. The older text-books gave one to understand that foraminiferal remains constituted the main mass of the rock, but the researches of Sorby [1] showed that fully one-half the material was finely comminuted shallow-water forms, such as inoceramus, pecten, ostrea, sponge spicules, and echinoderms.

Chalk belongs to the Cretaceous era, occurring in beds of varying thickness, alternating with shales, sands, and clays, and often including numerous nodules of a dark chalcedonic silica to which the name flint is given. Though a common rock in many parts of Europe, it is known to American readers mainly by its occurrence in the form of high cliffs along the English coast, as near Dover. Until within a few years little true chalk was known to exist within the limits of the United States. According to Mr. R. T. Hill [2] there are, however, extensive beds, sometimes 500 feet in thickness, extending throughout the entire length of Texas, from the Red River to the Rio Grande, and northward into New Mexico, Kansas, and Arkansas. These chalks in many instances so closely simulate the English product, both in physical properties and chemical composition, as to be adaptable to the same economic purposes. The following analyses from the report above alluded to serve to show the comparative composition:

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[1] Address to Geological Society of London, February, 1879.

[2] Annual Report of the Arkansas Geological Survey, II, 1888.

Constituents.	Lower Cretaceous Chalk, Burnet County, Texas.	Upper Cretaceous Chalk, Rocky Comfort, Arkansas.	White Cliff Chalk, Little River, Arkansas.	White Chalk of Shoreham, Sussex, England.	Gray Chalk, Folkstone, England.
Carbonate of lime	92.42	88.48	94.18	98.40	94.09
Carbonate of magnesia	1.38	Trace.	1.37	.08	.31
Silica and insoluble silicates	1.59	9.77	3.49	1.10	3.61
Ferric oxide and alumina	.41	1.25	1.41		
Phosphoric acid, alumina, and loss				.42	Trace.
Chloride of sodium					1.29
Water	.18		.55		.70
	99.98	99.50	101	100	100

Chalk is used as a fertilizer, either in its crude form or burnt, in the manufacture of whiting, in the form of hard lumps by carpenters and other mechanics, and in the manufacture of crayons. Washed, chalk is used to give body to wall paper; as a whitewash for ceilings; as a thin coating on wood designed for gilding, being for this purpose mixed with glue; to vary the shades of gray in water-color paints, and as a polishing powder for metals.

The marl commonly used in cement work is described by Eckel as a fine-grained friable limestone which has been deposited in the beds of existing or recently extinct lakes. The deposition of the lime may have been due simply to the escape of the excess of carbonic acid necessary for holding it in solution, or to the abstraction of the carbonic acid by plants, particularly algae and mollusks, in the two last cases the remains of the organisms constituting an appreciable portion of the material. The beds are lenticular or basin-shaped, and of relatively small size—a natural consequence of their mode of origin, and limited largely to the lake countries of glaciated regions.

Playing Marbles.—At Oberstein on the Nahe, Saxony, playing marbles are made in great quantities from limestone. The stone is broken into square blocks, each of such size as to make a sphere the size of the desired marble. These cubes are then thrown into a mill consisting of a flat, horizontally revolving stone with numerous concentric grooves or furrows on its surface. A block of oak of the same diameter as the stone and resting on the cubes is then made to revolve over them in a current of water, the cubes being thus reduced to the spherical form. The process requires but about fifteen minutes.

Lithographic Limestone. — For the purpose of lithography there is used a fine-grained homogeneous limestone, breaking with an imperfect, shell-like or conchoidal fracture, and as a rule of a gray, drab, or yellowish color. A good stone must be sufficiently porous to absorb the greasy compound which holds the ink and soft enough to work readily under the engraver's tool, yet not too soft. It must be uniform in texture throughout and be free from all veins and inequalities of any kind, in order that the various reagents used may act upon all exposed parts alike. It is evident, therefore, that the suitability of this stone for practical purposes depends more upon its physical than chemical qualities. An actual test of the material by a practical lithographer is the only test of real value for stones of this nature. Nevertheless, the analyses given on the next page are not without interest as showing the variation in composition even in samples from the same locality.

Localities.—Stones possessing in a greater or less degree the proper qualities for lithographic purposes have from time to time been reported in various parts of the United States; from near Bath and Stony Stratford, England; Ireland; Department of Indre; France, and also Silesia, India, and the British American possessions. By far the best stone, and indeed the only stone which has as yet been found to satisfactorily fill all the requirements of the lithographer's art, and which is the one in general use to-day wherever the art is practiced, is found at Solenhofen, and Pappenheim, on the Danube, in Bavaria. These beds are of Upper Jurassic or Kimmeridgian Age and form a mass some 80 feet in thickness, though naturally not all portions are equally good or adapted for the same kind of work. The stone varies both in texture and color in different parts of the quarry, but the prevailing tints are yellowish or drab. In the United States materials partaking of the nature of lithographic stone have been reported from Yavapai County, Arizona; Talladega County, Alabama; Arkansas; Lawrence County, Indiana; near Thebes and Anna, Illinois; James and Van Buren counties, Iowa;

COMPOSITION OF LITHOGRAPHIC STONES.

Localities.	$CaCO_3$.	$MgCO_3$.	Al_2O_3.	Fe_2O_3.	Soluble Silica.	Insoluble Silica.	Organic Matter.	FeO.	H_2O.	Specific Gravity.	Authority.
Solenhofen, Bavaria	81.47	18.83	0.25		4.45		....	....	....	....	J. Lewis Howe.
Solenhofen, Bavaria (dark)..	90.934	3.571	0.584	0.236	0.520	2.00	0.720	0.13	0.40	2.95	C. W. Volney.
Solenhofen, Bavaria (yellow)..	89.589	4.380	0.101	0.321	0.02	1.893	0.132	0.003	1.379	2.84	Do.
Solenhofen, Bavaria	96.24	0.21	2.02				....	....	....	....	Gmelin.
Kentucky (light gray)	73.241	12.431	1.141		11.50		0.40	....	0.935	2.99	C. W. Volney.
Iowa (blue-gray)	82.20	4.327	1.076		6.795		3.30	....	0.24	2.82	Do.
Missouri (light gray)	77.03	14.27	2.143		4.30		1.83	....	0.341	2.75	Do.
Missouri, Ralls County	81.77	15.10	0.06		3.12		....	....	....	....	
Overton, Tennessee	77.62	17.32	0.66		4.10		....	....	....	....	
Canada (light-blue gray)	89.989	2.789	....	0.884	....	3.712	0.409	0.104	1.25	2.84	
Canada (dark-blue gray)	88.034	2.50	0.577	0.359	0.49	3.60	1.29	0.41	1.360	2.89	

Hardin, Estelle, Kenton, Clinton, Meade, Rowan, Wayne, and Simpson counties, Kentucky; near Saverton, Ralls County, Missouri; Clay and Overton counties, Tennessee; Burnet and San Saba counties, Texas; near Salt Lake City, Utah, and at Fincastle, Virginia. While, however, from nearly, if not quite every one of these localities, it was possible to get small pieces which served well for trial purposes, each and every one has failed as a constant source of supply of the commercial article, and this for reasons mainly inherent in the stone itself. It is very possible that ignorance as to proper methods of quarrying may have been a cause of failure in some cases.

The Arizona stone according to first reports seemed very promising. Samples submitted to the writer, as well as samples of work done upon it, seemed all that could be desired. It is stated by Mr. W. F. Blandy that the quarries are situated on the east slope of the Verdi range, about 2 miles south of Squaw Peak and at an elevation of about 1,200 feet above the Verdi Valley, 40 miles by wagon road east of Prescott. Two quarries have thus far been opened in the same strata, about 1,000 feet apart, the one showing two layers or beds 384 feet in thickness, and the other three beds 3,188 feet in thickness. As exposed the beds, which are of Carboniferous Age, are broken by nearly vertical fissures into blocks rarely 4 or 5 feet in length. Owing to the massive form of the beds and the conchoidal fracture the stone can not be split into thin slabs, but must be sawn. No satisfactory road yet exists for its transportation in blocks of any size, and such material as has thus far been produced is in small slabs such as can be packed out on the backs of animals.

The Alabama stone as examined by the writer is finely granular and too friable for satisfactory work. Qualitative tests showed it to be a siliceous magnesian limestone. It is, of course, possible that the single sample shown does not fairly represent the product. The Arkansas deposit is situated in Township 14° N., R. 15° W. of the 5th p.m., sections 14, 23, and 24, Searcy County. The color is darker than that of the Bavarian stone. The reports of those who have tested it are represented as being uniformly favorable.

The Illinois stone is darker, but to judge from the display made in the Illinois building at the World's Columbian Exposition, 1893, is capable of doing excellent work and can be had in slabs of good size.

The Indiana stone is harder than the Bavarian, and samples examined were found not infrequently traversed by fine, hard veins of calcite.

The stone from Saverton, Missouri, is compact and fine grained, with, however, fine streaks of calcite running through it. It leaves only a small brownish residue when dissolved in dilute acid. This stone has been worked quite successfully on a small scale. The State geologist, in writing on the subject, says:[1] "Some of the beds of the St. Louis limestone (Subcarboniferous) have been successfully used for lithographic work. No bed is, however, uniformly of the requisite quality, and the cost of selection of available material would seem to preclude the development of an industry for the production of lithographic stone."

From the deposit at Overton, Tennessee, it is stated slabs 40 by 60 inches by 3½ inches thick were obtained, though little, if anything, is now being done. An analysis of this stone is given in the table. Other promising finds are reported from McMinn County, in the same State. According to the State geological reports, the stone lies between two beds of variegated marble. The stratum is thought to run entirely through the county, but some of the stone is too hard for lithographic purposes. The best is found 8 miles east of Athens on the farm of Robert Cochrane, and a quarry has been opened by a Cincinnati company, which pays a royalty of $250 per annum. It is sold for nearly the same price as the Bavarian stone. It is a calcareous and argillaceous stone, formed of the finest sediment, of uniform texture, and possesses a pearl-gray tint. The best variety of this stone has a conchoidal fracture and is free from spots of all kinds.

In Meade County, Kentucky, the stone furnishing the best lithographic material occurs[2] in a nearly horizontal layer about 3 feet in thickness. The entire output is stated to be "of good quality for an engraving and printing base for certain classes of work." The

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[1] Bulletin No. 3, Geological Survey of Missouri, 1890, p. 38.

[2] S. J. Kubel, Engineering and Mining Journal, November 23, 1901, p. 668.

stone is of a blue-gray color, can be had in large sizes, and is being quite generally used in the south and southwest, where it is stated to compare very favorably with the imported Bavarian material. The quarries are operated by the American Lithographic Stone Company, located at Brandenburg. In Rowan County the stone, according to E. O. Ulrich,[1] occurs in nearly horizontal layers interstratified with yellow limestone, arenaceous oölite, and shales belonging to the St. Louis division of the Subcarboniferous formations. The quarries now developed lie east and across the river from the town of Yale. The bed yielding lithographic material is some 15 feet in thickness, and is overlaid by an equal thickness of stripping. The presence of flattened nodules of flint form the chief drawback as the quarry is at present developed. The stone has been tested in the lithographic department of the U. S. Geological Survey and found satisfactory.

A lithographic stone is described in the State survey reports of Texas as occurring at the base of the Carboniferous formations near Sulphur Springs, west of Lampasas, on the Colorado River, and to be traceable by its outcrops for a distance of several miles, the most favorable showing being near San Saba. The texture of the stone is good, but as it is filled with fine reticulating veins of calcite, and as moreover the lithographic layer itself is only some 6 or 8 inches in thickness, it is obvious that little can be expected from this source. A stone claiming many points of excellence has for some years been known to exist in the Wasatch range within a few miles of Salt Lake City, and several companies are or have been engaged in its exploitation.

Very encouraging reports of beds examined by men whose opinions should be conservative, come from Canadian sources, and it is possible a considerable industry may yet be here developed, though little is being done at present. The descriptions as given in the geological reports are as follows:[2]

"The lithographic stones of the townships of Madoc and Marmora and of the counties of Peterboro and Bruce have been examined

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[1] Engineering and Mining Journal, June 28, 1902, p. 895.

[2] Geology of Canada, 1863.

and practically tested by lithographers, and in several cases pronounced of good quality; they have also obtained medals at various exhibitions. They were obtained from the surface in small quarries, and possibly when the quarries are more developed better stones, free from 'specks' of quartz and calcite, will be available in large slabs."

It should be stated that in actual use the principal demand is for stones some 22 or 28 by 40 inches; the largest ones practically used are some 40 by 60 inches and 3 to 3½ inches thick. The better grades sell as high as 22 cents a pound.

2. DOLOMITE.

This is a carbonate of calcium and magnesium $(Ca,Mg), CO_3$,= calcium carbonate, 54.35 per cent; magnesium carbonate 45.65 per cent. Hardness 3.5 to 4; specific gravity 2.8 to 2 9; colors when pure, white, but often red, green, brown, gray or black from impurities. Dolomite, like calcite, occurs in massive beds or strata either compact or coarsely crystalline, and is to the eye alone often indistinguishable from that mineral. Like limestone, the dolomites occur in massive forms suitable for building purposes, or in some cases as marble. From the limestone they may be distinguished by their increased hardness and by being insoluble in cold dilute hydrochloric acids The dolomites, like the limestones, are sedimentary rocks, though it is doubtful if the original sediments contained sufficient magnesium carbonate to constitute a true dolomite. They are regarded rather as having resulted from the alteration of limestone strata by the replacement of a part of the calcium carbonate by carbonate of magnesium.

Uses.—Aside from its use as a building material, dolomite has of late come into use as a source of magnesia for the manufacture of highly refractory materials for the linings of converters in the basic processes of steel manufacture. According to a writer in the Industrial World[1] the magnesia is obtained by mixing the calcined dolomite with chloride of magnesia, whereby there is formed a soluble

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[1] June 1, 1893.

calcic chloride which is readily removed by solution, leaving the insoluble magnesia behind. According to another process the calcined dolomite is treated with dissolved sugar, leading to the formation of sugar of lime and deposition of the magnesia; the solution of sugar of lime is then exposed to carbonic acid gas, which separates the lime as carbonate, leaving the sugar as refuse. Recently it has been proposed to use magnesia as a substitute for plaster of Paris for casts, etc.

The snow-white coarsely crystalline Archean dolomite commercially known as snowflake marblė, and which occurs at Pleasantville, in Westchester County, New York, is finely ground and used as a source of carbonic acid in the manufacture of the so-called soda and other carbonated waters.

3. MAGNESITE.

This is a carbonate of magnesium, $MgCO_3$, = carbon dioxide, 52.4 per cent; magnesia, 47.6 per cent. Usually contaminated with carbonates of lime, iron and free silica.

The following analysis will serve to show the average run of the material, both in the crude state and after calcining:

Constituents.	Styria.	Greece.
Crude magnesite.		
Carbonate of magnesia..........	90.0 to 96.0	94.46
Carbonate of lime..............	0.5 to 2.0	4.40
Carbonate of iron..............	3.0 to 6.0	FeO 0.08
Silica.........................	1.0	0.52
Manganons oxide...............	0.5	Water 0.54
Burnt magnesite.		
Magnesia......................	77.6	82.46 to 95.36
Lime..........................	7.3	0.83 to 10.92
Alumina and ferric oxide........	13.0	0.56 to 3.54
Silica........................	1.2	0.73 to 7.98

The mineral occurs rarely in the form of crystals, but is commonly in a compact, finely granular condition of white or yellowish color somewhat resembling unglazed porcelain, and more rarely crystalline granular, like limestone or dolomite.

It is hard (3.5 to 4.5) and brittle, with a vitreous luster, and is unacted upon by cold, but dissolves with brisk effervescence in hot hydrochloric acid.

Origin and occurrence.—The mineral is nearly, if not quite, always secondary and, in many cases at least, a product of alteration of eruptive rocks rich in olivine or other iron magnesian silicates. A theoretical view of this origin, as given by various authorities, is shown in the following formulas:

$$\underset{\text{Olivine}}{3Mg_3FeSi_2O_8} + \underset{\substack{\text{Carbon}\\\text{dioxide}}}{3CO_2} + \underset{\text{Water}}{4H_2O} + \underset{\text{Oxygen}}{O} =$$

$$\underset{\text{Serpentine}}{2H_4Mg_3Si_2O_9} + \underset{\text{Magnetite}}{Fe_3O_4} + \underset{\text{Magnesite}}{3MgCO_3} + \underset{\text{Quartz}}{2SiO_2}.$$

The beds in the Swiss Tyrol are, however, regarded by M. Koch [1] as due to an alteration of limestone through the downward percolation of magnesian solutions, a process closely akin to the now commonly accepted idea of dolomization. The descriptions thus far given regarding the Canadian and Styrian deposits, while not conclusive, would seem to indicate that these might also result from the alteration of beds of sedimentary origin.

It naturally follows that magnesite deposits originating through the alteration of olivine rocks are commonly associated with serpentines. Such occur, as a rule, in the form of granular aggregates and irregular veins, some of which are apparently mere shrinkage cracks, as shown in Fig. 2, Plate XV. They may vary from mere threads to bed-like masses perhaps 20 feet in thickness. It is probable, from their mode of formation, that such deposits are all comparatively shallow, extending little, if any, below the permanent water level. This statement is, however, founded largely on theoretical considerations.

Localities.—Although a common mineral, magnesite in sufficient quantities to be commercially important is comparatively rare. The principal localities outside of the United States, so far as now known, are Austria, Greece, and India, although the material is reported

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[1] Zeit. deut. geol. Gesel. XLV, pt. 2 1893.

FIG. 1.—Quarry of Lithographic Limestone, Solenhofen, Bavaria.
[From a photograph.]

FIG. 2.—Stockwork of Magnesite Veins in Serpentine, near Winchester, Riverside County, California.
[After F. L. Hess, Bulletin No. 355, U. S. Geological Survey.]

PLATE XV.

as occurring in Italy, Norway, Russia, South Africa, Australia, and Mexico. In the United States the only commercially important localities are in California, though at one time material occurring in the form of small shrinkage cracks or gash veins in the serpentinous deposits of Lancaster County, Pennsylvania, and adjacent parts of Maryland was worked to a considerable extent, the material being utilized in the manufacture of Epsom salts.

Attention was first directed to the California deposits by W. P. Blake.[1] These were subsequently inspected by H. G. Hanks, the State mineralogist, and have since been the subject of a special monograph by Mr. Frank L. Hess[2] of the United States Geological Survey.

According to these various authorities the Californian deposits are scattered along the coast range from Mendocino County as far south as Kern and Santa Barbara counties. These are being or have been worked in Sonoma, Santa Clara, Tulare and Napa counties. In all cases the material occurs in connection with more or less decomposed serpentinous rocks which are themselves a product of decomposition of igneous rocks, of which olivine was the prevailing constituent.

Loose boulders of a peculiar granular, almost saccharoidal form of magnesite, looking much like a crystalline dolomite, have been found for many years in the glacial drift south of Quebec, and within a few years the material has been reported as having been found in place in the township of Grenville. The outcrops are described as being, in some cases, upwards of 100 feet in width and to have been traced for a distance of a quarter of a mile. The material is, however, by no means pure magnesite, but carries a varying amount, sometimes as high as 40 per cent of intermixed calcite and other impurities.

In Styria the magnesite lies among beds of Silurian age, consisting of argillaceous shales, quartzites, dolomites, and limestones resting upon gneiss. The beds in the Swiss Tyrol are said to be associated with subcarboniferous limestone. The Grecian deposits are on the island of Euboea on the eastern coasts. According to a writer in

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[1] Pacific Railroad Reports, V, p. 308.

[2] Bulletin No. 355, U. S. Geological Survey, 1908.

the Journal of the Society of Chemical Industry for May 31, 1909, the principal deposits of Indian magnesite lie in the "Chalk Hills," two miles from the town of Salem in the Madras Presidency, where they cover an area of some 2,000 acres, occurring in abundant irregular veins of unknown depth, but having a total aggregate of some 60 feet in thickness. These veins are in dunite which has undergone alteration into serpentine with the usual secondary magnesite, chalcedony, etc.

Uses.—In its raw state magnesite is used as a source of carbon dioxide the gas being obtained by calcining the material in retorts. The residue is sold to makers of efractory bricks, which are used for basic furnaces The calcined material is commercially classified, according to the temperature which has been employed, as (*a*) calcined or caustic magnesia and (*b*) dead burnt, sintered, or shrunk magnesia. The caustic magnesia is obtained by calcining at a temperature of 800° C. It is used for Sorel or oxychloride cements, fireproof partitions, plaster, artificial stone, steam packing, flooring, grindstones, millstones, emery wheels, etc. Large quantities are used in paper manufacture. Sorel cement is formed by mixing the caustic magnesia with a solution of magnesian chloride. This cement is very hard, white, and of great durability.

Th. Schlossing has proposed[1] to utilize magnesian hydrate obtained by precipitation from sea water by lime for the preparation of fire-brick, the hydrate being first dehydrated by calcination at a white heat, after which it is made up into brick form.

According to the Industrial World[2] magnesite as a substitute for barite in the manufacture of paint is likely to prove of importance. The color, weight, and opacity of the powder add to its value for this purpose. In Europe it is stated the material is used as an adulterant for the cheaper grades of soap.

Prices.—During 1907 the material, 96 to 98 per cent pure, was quoted as worth $6 to $8 a ton in New York City. Material containing as high as 15 to 30 per cent silica and 8 to 10 per cent of iron is said to be practically worthless. Crude magnesite is

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[1] Comptes Rendus, 1885, p. 137.

[2] Industrial World, XXXVI, No. 20, 1891.

FIG. 1.—Magnesite Outcrop, Hixon Ranch, Mendocino County, California.
[After F. L. Hess, Bulletin No. 355, U. S. Geological Survey.]

FIG. 2.—Sonoma Magnesite Mine, near Cazadero, California.
[After F. L. Hess, Bulletin No. 355, U. S. Geological Survey.]

PLATE XVI.

[*Facing page* 156.]

quoted as worth from $3 to $4 a ton at the mines in California. The calcined material, the form in which it is sold to paper manufacturers, brings from $12 to $20 a ton. It requires about 2.4 tons of crude to make one ton of calcined.

4. WITHERITE.

This is a carbonate of barium of the formula $BaCo_3$, = baryta, 77.7 per cent, carbon dioxide, 22.3 per cent. Color, white to yellow or gray, streak white; translucent. Hardness, 3 to 3.75; specific gravity, 4.29 to 4.35. When crystallized, usually in form of hexagonal prisms, with faces rough and longitudinally striated. Common in globular and botryoidal forms, amorphous, columnar, or granular in structure. The powdered mineral dissolves readily in hydrochloric acid, like calcite, but is easily distinguished from this mineral by its great weight and increased hardness, as well as by its vitreous luster and lack of rhomboidal cleavage, which is so pronounced a feature in calcite. From barite, the sulphate of barium, with which it might become confused on account of its high specific gravity, it is readily distinguished by its solubility in acids as above noted. From strontianite it can be distinguished by the green color it imparts to the blow-pipe flame.

Localities and mode of occurrence.—The mineral occurs apparently altogether as a secondary product filling veins and clefts in older rocks and often forming a portion of the gangue material of metalliferous deposits. The principal localities as given by Dana are Alston Moor, Cumberland, where it is associated with galena; in large quantities at Fallowfield, near Hexam in Northumberland; at Anglezarke in Lancashire; at Arkendale in Yorkshire, and near St. Asaph in Flintshire, England; Tarnowitz, Silesia; Szlana, Hungary; Leogang in Salzburg; the mine of Arqueros near Coquimbo, Chile; L. Etang Island; near Lexington, Kentucky, and in a silver-bearing vein near Rabbit Mountain, Thunder Bay, Lake Superior.

Uses.—The mineral has been used to but a slight extent in the arts. As a substitute for lime it has met with a limited application in making plate glass, and is also said to have been used in the manufacture of beet-sugar, but is now being superseded by magnesite.

5. STRONTIANITE.

This is a carbonate of strontium, $SrCO_3$, = carbon dioxide, 29.9 per cent; strontia, 70.1 per cent. Often impure through the presence of carbonates and sulphates of barium and calcium. Colors, white to gray, pale green, and yellowish. Hardness, 3.5 to 4. Specific gravity 3.6 to 3.7. Transparent to translucent. When crystallized often in acute, spear-shaped forms. Also in graunlar, fibrous, and columnar globular forms. Soluble like calcite in hydrochloric acid, with effervescence, but readily distinguished by its cleavage and greater density. The powdered mineral when moistened with hydrochloric acid and held on a platinum wire in the flame of a lamp imparts to the flame a very characteristic red color.

Occurrence.—According to Dana the mineral occurs at Strontian in Argyllshire, in veins traversing gneiss, along with galena and barite; in Yorkshire, England; at the Giant's Causeway, Ireland; Clausthal in the Harz; Bräunsdorf, Saxony; Leogang in Salzburg; near Brixlegg, Tyrol; near Hamm and Münster, Westphalia. In the United States, at Schoharie, New York, in the form of granular and columnar masses and also in crystals, forming nests and geodes in the hydraulic limestone; at Clinton, Oneida County; Chaumont Bay and Theresa, Jefferson County; and Mifflin County, Pennsylvania.

Uses.—Strontianite, so far as the writer has information, has but a limited application in the arts. It is stated[1] that "basic bricks" are prepared from it by mixing the raw or burnt strontianite with clay or argillaceous ironstone in such proportions that the brick shall contain about 10 per cent of silica, and then working it into a plastic mass with tar or some heavy hydrocarbon. After molding, the bricks are dusted with fine clay or ironstone, dried, and burned. The effect of the dusting is to form a glaze on the surface, which protects the brick from the moisture of the air. Like celestite, it

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[1] Journal of the Society of Chemical Industry, III, 1884, p. 33.

is also used in the production of the red fire of fireworks. The demand for the material is small, and the price but from $2.50 to $4 a ton.

6. RHODOCHROSITE; DIALOGITE.

This is a pure manganese carbonate of the formula $MnCO_3$, = carbon dioxide, 38.3 per cent; manganese protoxide, 61.7 per cent. The color is much like that of rhodonite (see p. 204), from which, however, it is readily distinguishable by its rhombohedral form, inferior hardness (3.5 to 4.5), and property of dissolving with effervescence in hot hydrochloric acid, while rhodonite is scarcely at all attacked. The mineral is a common constituent of the gangue of gold and silver ores, as at Butte, Montana; Austin, Nevada, etc. So far as known the mineral has as yet no commercial value.

7. NATRON, THE NITRUM OF THE ANCIENTS.

This is a hydrous sodium carbonate, $Na_2CO_3 + 10H_2O$, = carbon dioxide, 15.4 per cent; soda, 21.7 per cent; water, 62.9 per cent. Occurs in nature, according to Dana, only in solution, as in the soda lakes of Egypt and elsewhere, or mixed with other sodium carbonates. The artificially crystallized material is of white color when pure, soft, and brittle, and with an alkaline taste. Crystals, thin, tabular, monoclinic. Thermonatrite, also a hydrous sodium carbonate of the formula $Na_2CO_3 + H_2O$, = carbon dioxide, 35.5 per cent; soda, 50 per cent, and water 14.5 per cent, occurs under similar conditions, and is considered as derived from natron as a product of efflorescence. (See further under Sodium sulphates, p. 333.)

8. TRONA; URAO.

This is a hydrous sodium carbonate, corresponding to the formula $Na_2CO_3.HNaCO_3 + 2H_2O$, = carbon dioxide, 38.9 per cent; soda, 41.2 per cent; water, 19.9 per cent.

Found in nature as an efflorescence or incrustation from the evaporation of lakes, particularly those of arid regions. W. P. Blake has recently described[1] crude carbonate of soda (Trona)

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[1] Engineering and Mining Journal, LXV, 1898, p. 188.

occurring in the central portion of a basin-shaped depression or dry lake in southern Arizona, near the head of the Gulf of California. The deposit covers an area of some 60 acres to a depth of from 1 to 3 feet, the lower portion being saturated with water from a solution so strong that when exposed to the air soda is deposited at the rate of an inch in thickness for every ten days. In its native condition the soda is naturally somewhat impure, from silt blown in from the surrounding land. The analysis given below shows the general average:

Constituents.	Per Cent.
Sand, silt, etc	13.00
Iron oxides and alumina	2.80
Lime	1.14
Salt (NaCl)	4.70
Sulphate of soda	4.70
Carbonate of soda	73.66
	100.00

See further under Thernardite, p. —.

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VI. SILICATES.

I. FELDSPARS.

The name feldspar is given to a group of minerals resembling each other in being, chemically, silicates of aluminum with varying amounts of lime and the alkalies potash and soda. All members of the group have in common two easy cleavages whereby they split with even, smooth, and shining surfaces along planes inclined to one another at angles of nearly if not quite 90°. They vary from transparent through translucent to opaque, the opaque form being the more frequent. In colors they range from clear and colorless through white and all shades of gray to yellowish, pink, and red, more rarely greenish.

On prolonged exposures to the weather they become whitish and opaque, gradually decomposing into soluble carbonates of lime and the alkalies, and soluble silica, any one of which may be wholly or in part removed by percolating waters, leaving behind a residual product, consisting essentially of hydrous silicates of alumina, to which the names kaolin and clay are given (see p. 217). The hardness of the feldspars varies from 5 to 7 of Dana's scale;

specific gravity 2.5 to 2.8 They are fusible only with difficulty, and with the exception of the mineral quartz are the hardest of the common light-colored minerals. From quartz they are readily distinguished by their cleavage characteristics noted above. Geologically the feldspars belong to the gneisses and eruptive rocks of all ages, certain varieties being characteristic of certain rocks and furnishing important data for schemes of rock classification. Nine principal varieties are recognized which on crystallographic grounds are divided into two groups. The first, crystallizing in the monoclinic system, including only the varieties orthoclase and hyalophane; the second, crystallizing in the triclinic system, including microclinic, anorthoclase, and the albite-anorthite series, albite, oligoclase, andesine, labradorite, and anorthite. The above-mentioned properties are set forth in the accompanying table.

Constituents.	Orthoclase.	Hyalophane.	Microcline.	Anorthoclase	Albite.	Oligoclase.	Andesine.	Labradorite.	Anorthite.
Silica, SiO_2. . . .	64.7	51.6	64.7	66.0	68.0	62.0	60.0	53.0	43.0
Alumina. Al_2O_3	18.4	21.9	18.4	20.0	20.0	24.0	26.0	30.0	37.0
Potash, K_2O . .	16.9	10.1	16.9	5.0	....	....	....	....	....
Soda, Na_2O. . . .	....	....	....	8.0	12.0	9.0	8.0	4.0	....
Barium, BaO. .	....	16.4	....	....	....	....	....	....	....
Lime, CaO. . . .	....	....	....	....	....	5.0	7.0	13.0	20.0
Specific grav. . .	2.4–2.6	2.8	2.4–2.6	2.0–5.8	2.5–2.6	2.56–2.7	2.6–2.7	2.6–2.7	2.6–2.8
Hardness..	6.0–6.5	6.0–6.5	6.0–6.5	....	6.0–7.0	6.0–7.0	5.0–6.0	6.0	6.0–7.0
Crystalline system.	Monoclinic.		Triclinic.						

Of the above those which most concern us here are the potash feldspars orthoclase and microcline, two varieties which for our purposes are essentially identical both as regards composition and general physical properties as well as mode of occurrence. Indeed, although crystallizing in different systems they are as a rule indistinguishable but by microscopic means or by careful crystallographic measurements.

Occurrence.—The potash feldspars are common and abundant constitutents of the acid rocks—such as the granites, gneisses, syenites—the orthoclase and quartzose porphyries, and the Tertiary and modern lavas—such as trachyte, phonolite, and the liparites.

Among the older rocks they frequently occur in large dikes or vein-like masses of coarse pegmatitic crystallization, the individual crystals being in some cases a foot or more in diameter. The

FIG. 1.—Feldspar Quarry, Topsham, Maine.
[From photograph by E. S. Bastin, U. S. Geological Survey.]

FIG. 2.—Feldspar Quarry, South Glastonbury, Connecticut.
[From photograph by E. S. Bastin, U. S. Geological Survey.

PLATE XVII.

[*Facing page* 162.]

associated minerals are quartz and white mica, with beryl, tourmaline, garnet, and a great variety of rarer minerals. The ordinary white mica of commerce comes from deposits of this nature and often the two minerals are mined contemporaneously. Such of our feldspars as have yet been worked for ecomomic purposes occur associated only with the older rocks—the granites and gneisses of the Archean and Lower Paleozoic formations.

Near Topsham, Maine, is one of these pegmatitic intrusions, running parallel with the strike of gneissoid schists in which it lies, i.e., northeast and southwest. The quarry is in the form of an open cut in the hillside, some 300 feet long by 100 feet wide, and of very irregular contours. The present floor and the sides of the cut are of feldspar, containing irregular bodies of quartz and mica, the first named occurring in large masses entirely free from other minerals, though a second grade is taken out which is in reality an intimate mixture of quartz and feldspar.

The quartz occurs, besides as mentioned above, in the form of irregular bodies, sometimes 6 or 8 feet across and 15 feet or more long. It also occurs in cavities, or geodes, in the form of flattened crystals. The mica is here of little economic importance, being embedded in the feldspar and occurring along the seams in the form of narrow, lanceolate masses, often arranged in small radiating conical forms with their apexes outward.

It should be noted that the rock pegmatite, a coarse aggregate of quartz and feldspar, is often mined and utilized for the same purpose, as is the pure feldspar itself. Albite, when occurring with the othoclase, is also mined and utilized in the same manner.

The principal feldspar quarries thus far worked are in the eastern United States, from Maine to New Jersey. The material is mined from open cuts, being blasted out with powder and separated from adhering quartz, mica, and other minerals by hand, after which it is shipped in the rough to the potteries, or in some cases ground and bolted in the near vicinity. In times past the material has been ground under huge granite disks mounted like the wheels of a cart on an axle through the center of which extended a vertical shaft. By the slow revolution of this shaft the wheels traveled around in a limited circle over a large horizontal granite slab. The pieces of spar being placed upon the horizontal slab were thus slowly ground to powder. A more modern method is by means of the so-called Cyclone crusher. The value of the uncrushed material delivered at the potteries is but a few dollars a ton. Hence, while there are unlimited quantities of the material in different parts of the Appalachian region, but few are so situated as to profitably worked.

Uses.—The feldspars are used mainly for pottery, being mixed in a finely pulverized condition with the kaolin or clay. When subjected to a high temperature the feldspar fuses, forming a glaze and at the same time a cementing constituent. There are other substances more readily fusible which are utilized for this purpose in the cheaper kinds of ware, but it is stated that in the highest grades of porcelain, as those of Sèvres, feldspar is the material used. The proportions used vary with different manufacturers, each having adopted a formula best adapted for his own workings.

For more than fifty years experiments have from time to time been made with a view of extracting the potash from feldspars on a commercial scale and also of using the ground feldspar in its crude or raw state as a fertilizer. The cheapness of the Stassfurth potash salts has thus far militated against the development of the first-named industry, and while experiment has shown that plants will assimilate a certain amount of potash from the raw, finely ground feldspar, the effect of such application has not proven sufficient to warrant its general adoption.

In the same way attempts have been made to utilize the potash of the nepheline in phonolites, but the results have been unsuccessful, owing to the insoluble character of the silicate.[1]

The labrador feldspar occurring as the chief constituent of a gabbro near Duluth, Minnesota, is crushed and made into sandpaper for use in woodworking.

2. MICAS.

Under this head are comprised a number of distinct mineral species, alike in crystallizing in the monoclinic system and having a highly perfect basal cleavage, whereby they split readily into thin, translucent to transparent, more or less elastic sheets. Chemically

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[1] Deut. Landes. Presse, XXXVI, 1909.

they are in most cases orthosilicates of aluminum with potassium and hydrogen, and in some varieties magnesium, ferrous and ferric iron, sodium, lithium, and more rarely barium, manganese, titanium, and chromium. Seven species of mica are commonly recognized, of which but three have any commercial value, though a fourth form, lepidolite, may perhaps be utilized as a source of lithia salts, and a fifth, roscoelite, as a source of salts of vanadium. Of these three forms the white mica, muscovite, and the pearl-gray phlogopite are of greatest importance, the black variety, biotite, being but little used. Muscovite, or potassium mica, is essentially a silicate of aluminum and potassium, with small amounts of iron, soda, magnesia, and water. Its color is white to colorless, often tinted with brown, green, and voilet shades. When crystallized it takes on hexagonal or diamond-shaped forms, as do also phlogopite and biotite. Its industrial value lies in its great power of resistance to heat and acids, its transparency, and its wonderful fissile property, in virtue of which it may be split into extremely thin, flexible sheets. Phlogopite, or magnesian mica, differs from muscovite in being of a darker, deep pearl-gray, sometimes smoky, often yellowish, brownish red, or greenish color and lacking in transparency. Biotite, or magnesia iron mica, differs in being often deep, almost coal black and opaque in thick masses, though translucent and of a dark-brown, yellow, green, or red color in thin folia. It further differs from the preceding in that its folia are less elastic, and the sheets of smaller size. Lepidolite, a lithia mica, is much more rare than either of the above, is of a pale rose or pink color, the folia usually of small size, commonly occurring in scaly granular forms without crystal outlines. The following table will serve to show the varying composition of the four varieties mentioned:

Variety.	SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	MgO.	CaO.	K_2O.	Na_2O.	F.	H_2O.
Muscovite.	45.71	36.57	1.19	1.07	0.71	0.46	9.22	0.79	0.12	4.83
	44.48	35.70	1.09	1.07	Trace.	0.10	9.77	2.41	0.72	5.50
	45.40	33.66	2.36	......	1.86	......	8.33	1.41	0.69	5.46
Phlogopite.	39.66	17.00	0.27	0.20	26.49	......	9.97	0.60	2.24	2.99
	43.00	13.27	1.71	......	27.70	......	10.32	0.30	5.67	0.78
	40.64	14.11	2.28	0.69	27.97	......	8.16	1.16	0.82	3.21
Biotite.	44.94	31.69	4.75	3.90	......	......	8.00	0.59	0.93	3.85
	34.67	30.09	2.42	16.99	1.98	......	7.55	1.57	0.28	4.64
	39.30	16.95	0.48	8.45	21.89	0.82	7.79	0.49	0.89	4.02
	40.16	15.79	2.53	4.12	26.15	......	7.64	0.37	......	3.58
Lepidolite.	50.39	28.19	......	......	5.08	Li_2O	12.34	......	5.15	2.36
	49.62	27.30	0.31	0.07	4.34	Li_2O	11.19	2.17	5.45	1.52

Although the basal cleavage which permits of the ready splitting of the mica into thin sheets is the only one sufficiently developed to be of economic importance, the mica as found is often traversed by sharp lines of separation, called gliding planes, which may, by their abundance, be disastrous to the interests of the miner. Such partings, or gliding planes, supposed to be induced by pressure, are developed at angles of about 66½° with the cleavage, and may cut entirely through a block or extend inward from the margin only a short distance and come to an abrupt stop. In many cases these planes divide the mica into long narrow strips, from the breadth of a line to several inches in thickness, with sides parallel, and as sharply cut as though done with shears.

The imperfections in mica are due to inclosures of foreign minerals, as flattened garnets, to the presence of free iron oxides, often with a most beautiful dendritic structure, to the partings or gliding planes noted above, and to crumplings and V-like striations which destroy its homogeneity.

Occurrence.—Mica in quantity and sizes to be of economic importance is found only among the older rocks of the earth's crust, particularly those of the granite and gneissoid groups. Muscovite and biotite are among the commonest constituents of siliceous rocks of all kinds and ages, while phlogopite is more characteristic of calcareous rocks. It is, however, only when developed in crystals of considerable size in pegmatitic and coarsely feldspathic veins, or, in the case of phlogopite, in gneissic and calcareous rocks associated with eruptive pyroxenites, that it becomes available for economic purposes. The associated minerals are almost too numerous to mention. The more common for muscovite are quartz and potash feldspar, which form the chief gangue materials in crystals and crystalline masses, sometimes a foot or more in diameter. With these are almost invariably associated garnets, beryls, and tourmalines, with more rarely cassiterite, columbite, apatite, fluorite, topaz, spodumene, uraninite, etc. Indeed, so abundant are, at times, the accessory minerals in the granitic veins, and so perfect their crystalline development, that they furnish by far the richest collecting grounds for the mineralogists. Of these minerals the quartz and feldspars are not infrequently mined contemporaneously with the mica and utilized in the manufacture of pottery and abrasives.

Origin.—It is now commonly assumed that these pegmatitic "veins" are undoubted intrusives, though to some authorities it seems scarcely possible that the extremely coarse aggregates of quartz, feldspar, and mica, with large garnets, beryls, and tourmalines, can be a direct result of cooling from an igneous magma. To such it appears more probable that they are portions of an original rock mass altered by exhalations of fluorhydric acids, like the Saxon "greisen." Others regard them as resulting from the very slow cooling of granitic material injected in a pasty condition, brought about by aqueo-igneous agencies, into rifts of the pre-existing rocks. It must be remembered that the high degree of dynamic metamorphism which these older rocks have undergone renders the problems relating to their origin extremely difficult. As to the origin of the Canadian phlogopite there seems no reason for not adopting the conclusion of Cirkel, who regards it as a product of crystallization from an aqueo-igneous solution, which permeated upward along lines of fracture either in pyroxenic rocks or along the line of contact between these rocks and the prevailing gneisses and limestones.

The common association of apatite with the phlogopite indicates a common and practically contemporaneous origin for both.

Localities.—From what has been said regarding occurrences, it is evident that mica deposits are to be found mainly in regions occupied by the older crystalline rocks. In the United States, therefore, one need look for them only in the States bordering immediately along the Appalachian range and in the granitic areas west of the front range of the Rocky Mountains.[1] In the Appalachian region south of Canada mica mines, worked either for mica alone or for quartz and feldspar in addition, have from time to time been opened in various parts of Maine, New Hampshire, Connecticut, Maryland, Virginia, North Carolina, and perhaps other States, but in none of them, with the exception of New Hampshire and North Carolina, has the business proven sufficiently lucrative to warrant continuous and systematic working. Indeed,

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[1] The region of the Black Hills of South Dakota is an important exception.

were it not for the increased demand lately arising for the use of mica in electrical machines it is doubtful if any but the most favorably situated mines would remain longer in operation in the United States. This for the reason not so much that foreign mica is better as that it is cheaper.

Muscovite.—In Maine muscovite has been mined in an intermittent manner along with quartz and feldspar at the well-known mineral localities at Paris Hill and Rumford, Oxford County; Auburn, Androscoggin County; Topsham, Sagadahoc County; Edgecomb, Lincoln County, and other counties in the southeastern part of the State. In New Hampshire the industry has assumed greater importance. The mica-bearing belt is described by Professor C. H. Hitchcock as usually about 2 miles in width, and extending from Easton, in Grafton County, to Surry, in Cheshire County; being best developed about the towns of Rumney and Hebron. The mica occurs in immense coarse granite veins in a fibrolitic mica schist, and is found in sheets sometimes a yard in length, but the more common sizes are but 10 or 12 inches in length. Immense beryls, sometimes a yard in diameter, and beautiful large tourmalines occur among the accessory minerals. Mines for mica were opened at Grafton as early as 1840, and as many as six or eight mines have been worked at one time, though by no means continually. Other mines have been worked in Groton, Alexandria, Grafton, and Alstead, in Grafton County; Acworth and Springfield, Sullivan County; Marlboro, Cheshire County; New Hampton, Belknap County, and Wilmot, Merrimack County.

As seen by the present writer, in 1894 the veins in Grafton County cut sharply across the fibrolitic schist, and though the vein materials adhere closely to the wall rock on either side, without either selvage or slickensides, still the line of demarcation is perfectly sharp. There seems no room for doubt but that the vein material was derived by injection from below, though from their extremely irregular and universally coarsely crystalline condition we must infer that the condition of the injected magma was more in the nature of solution than fusion, as the word is ordinarily used, and also that the rate of cooling and consequent crystallization was very slow. The feldspars frequently occur in huge crystalline masses several feet in diameter, though sometimes more finely intercrystallized with quartz in the form known as pegmatite. The mica is by no means disseminated uniformly throughout the vein, but on the contrary is very sporadic, and the process of mining consists merely in following up the mineral wherever indications as shown in the face of the quarry are sufficiently promising. Most of the mines are in the form of open cuts and trenches, though in a few instances underground cuts have been made for a distance of a hundred feet or more. The mica blocks as removed are of a beautiful smoky-brown color, and often show a distinct zonal structure, indicating several periods of growth. The associated feldspar is not in all cases orthoclase, but, as at the Alexandria mines, sometimes a faint greenish triclinic variety.

In Connecticut some mica (muscovite) has been obtained in connection with the work of mining feldspar and quartz in and about the towns of Haddam, Glastonbury, and Middletown, but the business has never assumed any importance.

South of the glacial limit mica mining has proven more successful from the reason that the gangue minerals (feldspar and quartz) are in a state of less compact aggregation, due to weathering, the feldspar being often reduced to the state of kaolin, and hence readily removed by pick and shovel.

North Carolina.—It is for the above reason, in part, that the mica industry has prospered in North Carolina more than elsewhere in the eastern United States. The deposits here were first described in a systematic manner by W. C. Kerr [1] in 1880, and have since been the subject of numerous investigations on the part of the State and United States Geological Surveys.[2] As in New Hampshire and elsewhere the mica occurs in intrusive masses of pegmatite which have most frequently followed the lines of least resistance in the inclosing Archaean gneisses and schists, forming thus what Kerr described as *bedded veins*, although he recognized their intrusive character.

The area of the mica-bearing pegmatites extends entirely across the western part of the State in a northeasterly and southwesterly direction, from Virginia to Georgia, but the chief centers of produc-

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[1] Transactions of the American Institute of Mining Engineers, VIII, p. 457.

[2] See D. B. Sterrett, Bulletin No. 315, U. S. Geological Survey, p. 400.

tion have been in Mitchell, Yancey, Macon, Jackson, Haywood, Ashe and Cleveland counties. (See map, Fig. 27.) Sterrett recognizes three zones, or belts, (1) the Cowee-Black mountain, (2) the Blue Ridge and (3) the Piedmont. The first runs nearly through the State parallel with its western border; the second follows the Blue Ridge and extends several miles to the southeast along the foothills. It is the least important of the three. The Piedmont belt lies southeast of the ridge, mainly in Cleveland, Lincoln, Burke and Stokes counties.

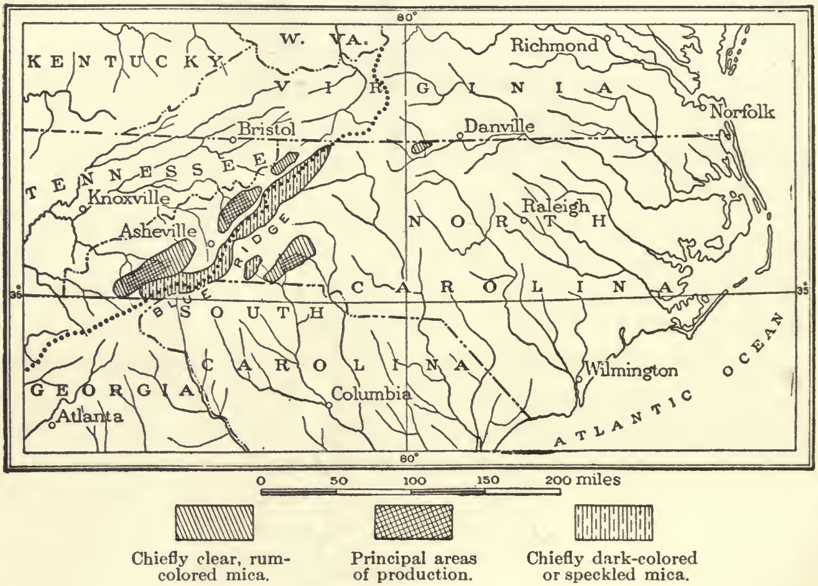

FIG. 27.—Map showing mica-producing areas of North Carolina. [After Douglas Sterrett, Bulletin No. 315, U. S. Geological Survey, 1907.

The pegmatites form, for the most part, lens-shaped masses conformable with the schistosity of the country rock in one or several parallel planes. In cross-section some are short and bulky, with a length but two or three times their thickness, while others are long and tapering, often much branched, and follow the windings and contortions of the inclosing rock. (See Fig. 28.)

The size of the dikes is variable, but as a rule none are worked of a thickness less than one of two feet and then only when excep-

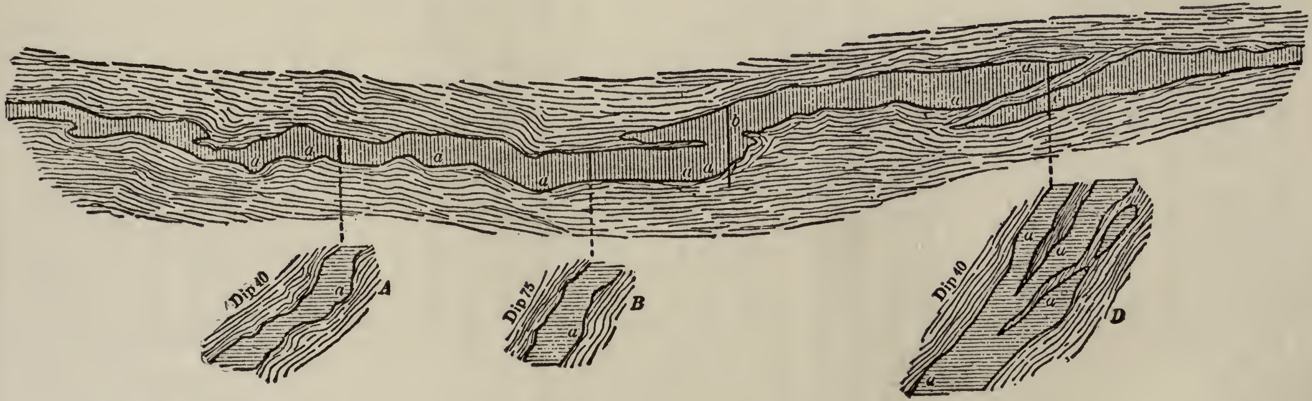

FIG. 28.—A horizontal section, with transverse vertical sections of a typical mica "vein" at the Presnel mine, Yancey County, North Carolina.

[After W. C. Kerr.]

The length of the section is 125 feet; the thickness from 3 to 10 feet. The mica was here found most abundant near the foot wall, in the recesses, or pouches, but at *c* in Section *D* it was found next the hanging wall. The inclosing rock is a gray schistose gneiss.

tionally rich. As elsewhere, the mica is rarely uniformly disseminated throughout the rock, nor does it keep the same relative position in any one dike for long distances. In some of the larger dikes the rock is so coarsely crystalline as to yield cleavage masses of feldspar several tons in weight, and mention is made of a feldspar crystal weighing nearly a thousand pounds, and of sheets of mica three and four feet in diameter.

In Alabama, along a line stretching from Chilton County, northeast, through Coosa, Clay, and Cleburne counties, there are numerous evidences of prehistoric mica mining. Many pits are met with around which pieces of mica are still to be seen. In some places, as in Mitchell County, North Carolina, large pine trees have grown up on the débris, so that a considerable time must have elapsed since the mines were worked.

In Colorado mica has long been known to be widely disseminated and to occur in many places in bodies of workable size. Many mines have been located, but the product has always proved worthless, until in the summer of 1884 the Denver Mica Company opened a mine near Turkey Creek, about 35 miles from Denver. This mica is of fair quality, and quite a considerable quantity of it has been mined. It is slightly brown, and the largest plates which have yet been cut are not more than 2¾ by 6 inches in size. Only an extremely small percentage of the gross weight is available for cutting into sheets. Mica of good quality and large plates has also been recently reported from the neighborhood of Fort Collins.

In Wyoming mica has been found in workable quantities near Diamond Park and in the Wind River country, as well as at many points along the mountain ranges in Laramie County. It has recently been mined to some extent at Whalen Cañon, 20 miles north of Fort Laramie, and some of the product has been shipped to the Eastern market.

In New Mexico mica has been mined near Las Vegas and Petaca. In California many deposits of mica have been noted, especially at Gold Lake, Plumas County; in Eldorado County; Ivanpah district, San Bernardino County; near Susanville, Lassen County, and at Tehachapi pass, Kern County. In 1883 a large deposit was discovered in the Salmon Mountains, in the northwestern part of the State, and some prospecting was done.[1]

The mica-bearing deposits of the Black Hills of South Dakota have been variously regarded by observers as intrusive granites or true segregation veins lying parallel to the apparent bedding. Newton and Jenny,[2] Blake,[3] and Vincent regarded them as intrusive, while Carpenter [4] and Crosby [5] held the opposite view.

According to Blake the mica occurs in granitic masses, remarkable for the coarseness of their crystallization, the constituent minerals being usually large and separately segregated. "Large masses of pure quartz are found in one place and masses of feldspar in another, and the mica is often accumulated together instead of being regularly disseminated through the mass. It also occurs in large masses or crystals, affording sheets broad enough for cutting into commercial sizes." Associated with the mica at this point are the minerals quartz and feldspar, mainly a lamellar albite (Clevelandite), which form the gangue, and irregularly disseminated cassiterite (tinstone), gigantic spodumenes, black tourmalines, and, in small quantities, black mica, beryls, garnets, columbite, and a variety of phosphatic minerals, such as apatite, triphylite, etc.

Sterrett describes [6] a mica deposit near Custer as occurring in a pegmatite intruded into gneiss and biotite schist, dipping with the country rock about 50° to the southwest. (See Fig. 29.) The intrusive is about 30 feet in thickness at the surface and 28 feet at the 200-foot level. The mica occurs in two streaks or "veins" from 1 to 8 feet wide, along each wall, the middle portion being practically barren, or at best too poor to work. The mica occurs mostly in flattened or tabular blocks lying perpendicular to the walls and varying up to 5 inches in thickness and from 2 to 8 inches in diameter. Crystals a foot in diameter are, however, not rare, while some have been found of three times that dimension. In certain portions of the pegmatite

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[1] Mineral Resources of the United States, 1883–84, p. 911.

[3] Geology of the Black Hills of Dakota, Monograph, U. S. Geolgoical Survey, 1880.

[3] Engineering and Mining Journal, XXXVI, 1883, p. 145.

[4] Transactions of the American Institute of Mining Engineers, XVII, 1889, p. 570.

[5] Proceedings of the Boston Society of Natural History, XXIII, 1884–88, p. 488.

[6] Bulletin No. 380, U. S. Geological Survey, 1909.

there occurs abundant black tourmaline in size up to 10 inches in diameter, and it is noteworthy that in these portions the mica content is poor.

In Nevada mines have been worked in the St. Thomas mining district, Lincoln County, the mica occurring in hard, glassy quartz rock forming an outcrop some 200 feet wide by 600 feet long in gneiss and schists. At the Czarina Mine, located in May, 1891, near Rioville, the mica occurs under similar conditions. The mineral seems to follow the division plane of the stratification, along the line or axis of a fold. This line runs north and south, slightly east of north of the main trend of the range, thus running into Arizona a few miles north of Rioville. In fact the mica belt forms the boundary line between Nevada and Arizona for 50 miles. The mica, mostly small, is abundant, but marketable sizes are rare, and not to be had without a great deal of hard work.[2]

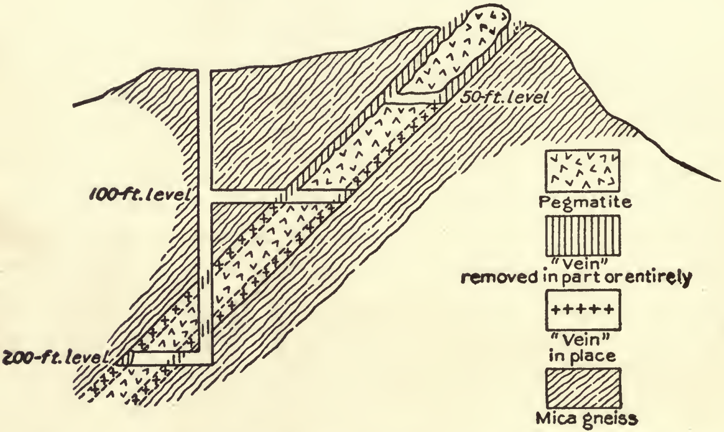

FIG. 29.—Generalized section of mica mine, near Custer, South Dakota. [After D. Sterrett, Bulletin No. 380, U. S. Geological Survey.]

Merchantable mica has been reported on the Payette River and Bear Creek, in the Cœur d'Alene region of Idaho, and in Oregon and Alaska. Also in the Saguenay district of Canada; in the vicinity of Mattawa, north of Ottawa; in Ontario and in British Columbia.

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[2] Mineral Resources of the United States, 1893, p. 754.

The India mica mines occur in coarse intrusive pegmatitic-granite dikes, cutting what is known as the newer gneiss of Singrauli. At Inikurti the crystals are at times as much as 10 feet in diameter. Sheets 4 or 5 feet across have been obtained, it is stated, free from such adventitious inclusions as would spoil their commercial value.[1]

Phlogopite.—The occurrence of the pearl-gray mica phlogopite in commercial quantities is much more restricted and so far as is at present known, is limited to an area of some 520 square miles north of Ottawa, in the province of Quebec, Canada, and in the townships of Burgess, Lanark, and Loughborough, province of Ontario. The deposits are closely associated with intrusive pyroxenic rocks which penetrate the Laurentian gneisses and overlying crystalline limestone, sometimes running parallel with the gneisses and again cutting across them. R. W. Ells has given[2] the conditions of occurrence as follows:

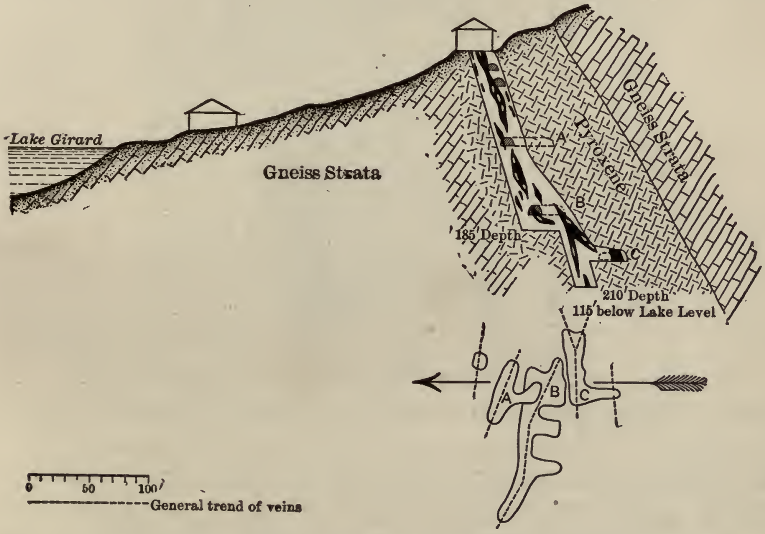

FIG. 30.—Section through Lake Girard Mica Mine, Quebec, Canada. [After Cirkel: Mica, Occurrence, Exploitation, and Uses.]

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[1] Geology of India, 2d ed., 1895, p. 34.

Bulletin of the Geological Society of America, V, 1894, p. 484.

1. In pyroxene intrusive rocks which either cut directly across the strike of grayish or other colored gneisses or are intruded along the line of stratification. Some of these deposits have been worked downward along the contact with the gneiss, where the mica is most generally found, for 250 feet, as at the Lake Girard Mine (Fig. 30), and irregular masses of pink calcite are abundant. In certain places apatite crystals occur associated with the mica, but at other times these are apparently wanting. As in the case of apatite deposits, mica occurring in this condition would apparently be found at almost any workable depth.

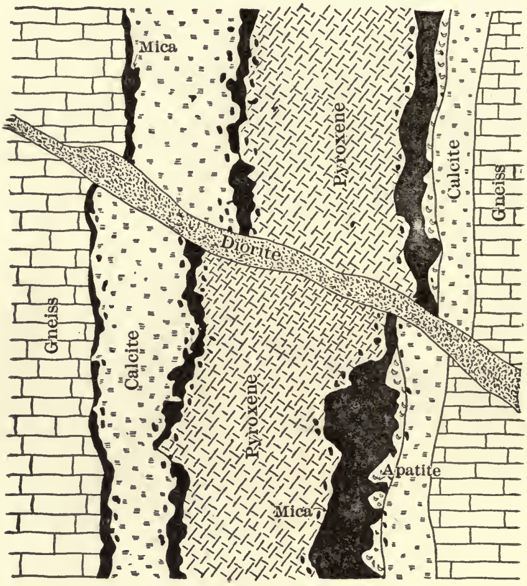

FIG. 31.—Section of vein in Baby Mine, North Burgess, Ontario. [After Cirkel: Mica, Occurrence, Exploitation, and Uses.]

In pyroxene rocks near the contact of cross-dikes of diorite or feldspar, the action of which on the pyroxene has led to the formation of both mica and apatite. Numerous instances of this mode of occurrence are found, both in the mines of apatite and mica, the deposits of the latter in certain areas being quite extensive and the crystals of large size. (Fig. 31.)

3. In pyroxene rock itself distinct from the contact with the gneiss. In these cases the mica crystals, often of large size but frequently crushed or broken, apparently follow certain lines of faults or fracture. Some of these deposits can be traced for several yards, but for the most part are pockety. Some of these pyroxene masses are very extensive, as in the case of the Cascade Mine on the Gatineau River and elsewhere in the vicinity. In these cases calcite is rarely seen and apatite is almost entirely absent. When cut by cross-dikes conditions for the occurrence of mica or apatite should be very favorable.

[Fig. 32.—Mica-bearing pyroxene dike in gneiss. An illustration of pocket deposits. [After Cirkel: Mica, Occurrence, Exploitation, and Uses.]

4. Dikes of pyroxene, often large, cutting limestone through which subsequent dikes of diorite or feldspar have intruded, as in Hincks township. The crystals occurring in the pyroxene near to the feldspar dikes are often of large size and dark color, resembling in this respect a biotite mica. (Fig. 33.)

It is stated by Dr. Ells that when the pyroxene is of a light shade of greenish gray and comparatively soft, the mica is correspondingly light colored and clear, and in some places almost approaches the muscovite in general appearance. As the pyroxene becomes darker in color and harder in texture, the mica assumes a correspondingly darker tint and a brittle or harder character, and in certain cases where dikes of blackish hornblendic diorite are present the mica also assumes a black color as well.

The principal areas at present worked are in the belt which extends from North Burgess, in the province of Ontario, approximately along the strike of the gneiss into the territory adjacent to the Gatineau and Lievre.

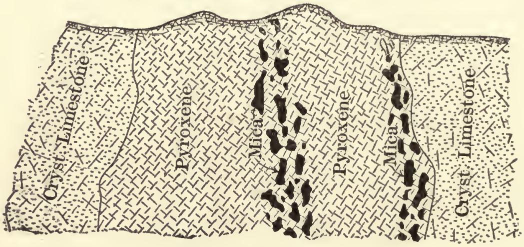

FIG. 33.—Mica-bearing pyroxene dike in limestone. An illustration of pocket deposits. [After Cirkel: Mica, Occurrence, Exploitation, and Uses.]

Biotite.—Black mica (biotite, lepidomelane, etc.) is a much more common and widely distributed variety than the white, but unlike the latter is found not so much in veins as an original constituent disseminated in small flakes throughout the mass of eruptive and metamorphosed sedimentary rocks. The small sizes of the sheets, their color, and lack of transparency render the material, as a rule, of little value. In Renfrew County, Canada, the mineral occurs in large cleavable masses, which yield beautiful smoky-black and greenish sheets sufficiently elastic for industrial purposes.

Lepidolite.—This variety of mica is much more rare than any of the others described. While in a few instances it has been reported as accompanying muscovite in certain granites, as those of Elba and Schaistausk, its common form of occurrence is in the coarse pegmatitic veins already described, where if is associated with muscovite, tourmalines, and other minerals of similar habit. As a rule it is readily distinguished from other micas by its beautiful peach-blossom pink color, though sometimes colorless and to be distinguished only by the lithia reaction.[1] The folia are thicker than those of muscovite and of small size, the usual form being that of a scaly granular aggregate. At Auburn, Maine, it is found both in this form and forming a border a half inch, more or less, in width about the muscovite folia. The more noted localities in the United States are Auburn, Androscoggin County; Hebron, Paris, Rumford, and Norway, Oxford County, Maine, where it is associated with beautiful red and green tourmalines and other interesting minerals; Chesterfield, Massachusetts; Haddam, Connecticut; the Black Hills, South Dakota; and near San Diego, California. The most noted foreign locality is Zinnwald, Saxony, where the mineral occurs in large foliated masses together with quartz forming the gangue minerals of the tin veins. Also found in Moravia. (See further under Spodumene, p. 200.)

Roscoelite, *Vanadium mica.*—The name roscoelite has been given to a clove-brown to greenish, micacous mineral occurring in minute scales, stellate or fan-shaped forms, and of a somewhat doubtful chemical formula. It may be mentioned here as a possible future source of vanadium salts. On the next page are given the results of two analyses from a recent paper by W. F. Hillebrand, (1) being of material from Placerville, Colorado, and (2) from Eldorado County, California.

Occurrence.—The material has been reported as filling cavities in quartz at the Granite Creek gold mines near Coloma, El Dorado County, California, and in the Magnolia district of Colorado. More recently deposits of some considerable economic importance have been found near Placerville in San Miguel County, in the last-named State. The roscoelite is described[2] as occurring as an impregnation in the lower bed of what is known as the La Plata sandstone (Jurassic). The beds at this point are nearly horizontal, the portion carrying the roscoelite occurring in a nearly continuous band

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[1] The mineral when moistened with hydrochloric acid and held on a wire in the flame of a lamp imparts to the flame a brilliant lithia-red color.

[2] F. L. Ransome, American Journal of Science, X, August, 1900.

approximately parallel to the bedding planes and varying in thickness from a few inches up to 5 or 6 feet, the vanadiferous portion being readily distinguished from the prevailing light-buff sandstone by the greenish tint imparted by the roscoelite. The vanadiferous zone is, however, quite irregular, the roscoelite sometimes constituting 20 per cent of the mass of the sandstone and from this fading out to nothing. It is often associated with Carnotite (see p. 332).

ANALYSES OF ROSCOELITE, A VANADIUM MICA.

Constituent.	Vanadium Mica frrom Placerville, Colo.	Roscoelite from Eldorado County, California.
SiO_2	46.06	45.17
TiO_2	....	.78
V_2O_3	12.84	24.01
Al_2O_3	22.55	11.54
Fe_2O_3	.73	(FeO) 1.60
CaO	.44	....
BaO	1.35	....
MgO	.92	1.64
K_2O	8.84	10.37
Na_2O	.22	Trace.
H_2O at 105°	1.98	*a*.40
H_2O at 105°–300°	.51	*b*.17
H_2O above 300°	3.56	*c*4.12
	100.00	99.80

a. At 100°. *b*. At 180°. *c*. Above 180°.

Uses.—Until within a few years almost the only commercial use of mica was in the doors or windows of stoves and furnaces, the peepholes of furnaces and similar situations where transparency and resistance to heat were essential qualities. To a less extent it was used in lanterns, and, it is said, in the portholes of naval vessels, where the vibrations would demolish the less elastic glass. In early days it was used for window panes, and is, in isolated cases, still so used to some extent. For all these purposes the white variety muscovite is most suited. For use in stoves and furnaces the mica is generally split into plates varying from about one-eighth to one sixty-fourth of an inch in thickness. In preparing these plates for market the first step is to cut them into suitable sizes. Women are frequently employed in this work. The cutter sits on a special bench which is provided with a huge pair of shears, one leg of which is firmly fixed to the bench itself, while the movable leg is within convenient grasp.

There is an enormous waste in the processes of preparation. One hundred pounds of block mica will scarcely yield more than about fifteen pounds of the cut material, and sometimes even less. The proportion varies, of course, with different localities.[1]

According to J. H. Pratt[2] the North Carolina mines yield from 1 to 10 per cent of mica, and of this amount not over 10 to 15 per cent will yield commercial sheet mica. Selected blocks will sometimes yield 30 to 40 per cent, and very rarely 75 per cent. Many of the Western mines do not yield more than 2 or 3 per cent of cut mica. Sterrett states that the New York mine at Custer, South Dakota, averages about 6.6 per cent of rough mica. Cirkel states[3] that under ordinary circumstances the Canadian phlogopite mines must yield at least 1,250 pounds of trimmed mica for every 100 tons of rock moved from depths not exceeding 300 feet, in order to be profitable. The percentage amounts of sizes of the trimmed mica is extremely variable. A fairly good average is given as: 50 per cent of 1″ x 3″; 30 per cent of 2″ x 3″; 10 per cent of 2″ x 4″; 6 per cent of 3″ x 5″, and 4 per cent of 4″ x 6″ and over.

Mica being a non-conductor is of value for insulating purposes, and since the introduction of the present system of generating electricity there has arisen a considerable demand for it in the construction of dynamos and electric motors. For these purposes the mica must be smooth and flexible, as well as free from spots or inequalities of any kind. It is stated that it should be sufficiently fissile to split into sheets not above three one-hundredths inch in thickness, and which may be bent without cracking into a circle of 3 inches diameter. Strips of various dimensions are used in building up the armatures, the more common sizes being about 1 inch wide by 6 or 8 inches long. Muscovite serves the purposes

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[1] Engineering and Mining Journal, LV, 1893, p. 4.

[2] Mineral Resources of the United States, 1904.

[3] Mica, Its Occurrence, Exploitation and Uses, p. 46.

well, but is less used than phlogopite, the latter serving equally well, and being less desirable for stoves and furnaces. Black mica would doubtless serve for many purposes, could it be procured in sheets of sufficient size.

Mica scraps such as until within a few years have been thrown away as worthless are now utilized by grinding, the product being used for a variety of purposes, noted below. The material is, as a rule, ground to five sizes, such as will pass through sieves of 80, 100, 140, 160, and 200 meshes to the inch, respectively. The prices of the ground material vary from 5 to 10 cents a pound according to sizes. Large quantities of ground mica are used in the manufacture of wall paper, in producing the frost effects on Christmas cards, in stage scenery, and as a powder for the hair, being sold for the latter purposes under the name of diamond powder. The so-called French "silver molding" is said to be made from ground mica. It is also used as a lubricant, and as a non-conductor for steam and water heating; in the manufacture of door-knobs and buttons. It is stated further that owing to its elasticity it can be used as an absorbent for nitroglycerine, rendering explosion by percussion much less likely to occur. Small amounts of inferior qualities are also mixed with fertilizers where it is claimed to be efficacious in retaining moisture. A brilliant and unalterable mica paint is said to be prepared by first lightly igniting the ground mica and then boiling in hydrochloric acid, after which it is dried and mixed with collodion, and applied with a brush. Owing to the unalterable nature of the material under all ordinary conditions, and the fact that it can be readily colored and still retain its brilliancy and transparency, the ground mica is peculiarly fitted for many forms of decoration. Much of the ground material now produced is stated to be sent to France.

The chief and indeed only use for lepidolite thus far developed is in the manufacture of the metal lithium and lithia salts. For possible uses of roscoelite see under Vanadates.

Prices.—The total value of the cut mica produced annually in the United States during the past fifteen years has varied from $50,000 to over $360,000, while the value of the imports has varied between $5,000 and $100,000. During 1901 but 360,000 pounds of cut mica were produced, valued at $98,859. During the same period there were produced 2,171 tons of scrap mica, valued at $19,719. Statistics for 1907 show 1,060,182 pounds sheet mica valued at $349,311, and 3,025 short tons of scrap, valued at $42,800. The price of the cut mica, it should be stated, varies with the size of the sheets, the larger naturally bringing the higher price. The average price of the cut mica, all sizes, is not far from $1 a pound, while the scrap mica is worth perhaps half a cent a pound. The dealers' lists, as published, include 193 sizes, varying from 1½ by 2 inches up to 8 by 10 inches, the prices ranging from 40 cents to $13 a pound. For electrical work upward of 400 patterns are called for, the prices varying from 10 cents to $2.50 a pound.

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3. ASBESTOS.

The name asbestos in its original sense includes only a fibrous variety of the mineral amphibole; hence it is a normal metasilicate of calcium and magnesium with usually varying amounts of iron and manganese, and not infrequently smaller quantities of the alkalies. As is well known, the amphiboles crystallize in the monoclinic system in forms varying from short, stout crystals, like common hornblende, to long columnar or even fibrous forms, to which the names actinolite, tremolite, and asbestos are applied. The word asbestos is derived from the Greek *ασβεστος*, signifying incombustible, in allusion to its fire-proof qualities. The name amianthus was given it by the Greeks and Romans, the word signifying undefiled, and was applied in allusion to the fact that cloth made from it could be readily cleansed by throwing it into the fire. As now used, this term is properly limited to fibrous varieties of serpentine. Owing to careless usage, and in part to ignorance, the name asbestos[1] is now applied to at least four distinct minerals, having in common only a fibrous structure and more or less fire- and acid-proof properties. These four minerals are: First, true asbestos; second, anthophyllite; third, fibrous serpentine (chrysotile), and, fourth, crocidolite. The true asbestos is of a white or gray color, sometimes greenish or stained yellowish by iron oxide. Its fibrous structure is, however, its most marked characteristic, the entire mass of material as taken from the parent rock being susceptible of being shredded up into fine fibers sometimes several feet in length. In the better varieties the fibers are sufficiently elastic to permit of their being woven into cloth. Often, however, through the effect of weathering or other agencies, the fibers are brittle and suitable only for felts and other non-conducting materials. The shape of an asbestos fiber is, as a rule, polygonal in outline and of a quite uniform diameter. Often however, the fibers are splinter-like, running into fine, needle-like points at the extremity. The diameters of these fibers are quite variable, and, indeed, in many instances there seems no practical limit to the shredding. Down to a diameter of 0.002 mm. and sometimes to even 0.001 mm. the fibers retain their uniform diameter and polygonal outlines. Beyond this, however, they become splinter-like and irregular as above noted.

The mineral anthophyllite, like amphibole, occurs in both massive, platy, and fibrous forms, the latter being to the unaided eye indistinguishable from the true asbestos.

Chemically this mineral is a normal metasilicate of magnesia of the formula $(Mg,Fe)SiO_3$, differing, it will be observed, from asbestos

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[1] Also spelled asbestus. The termination *os* seems most desirable when the derivation of the word is considered.

proper in containing no appreciable amount of lime. It further differs in crystallizing in the orthorhombic rather than the monoclinic system, a feature which is determinable only with the aid of a microscope. The shape and size of the fibers are essentially the same as true asbestos. The fibrous variety of serpentine to which the name asbestos is commercially given is a hydrated metasilicate of magnesia of the formula $H_4Mg_3Si_2O_9$ with usually a part of the magnesia replaced by ferrous iron. It differs, it will be observed, from asbestos and anthophyllite in carrying nearly 14 per cent of combined water and from the first named in containing no lime. This mineral is in most cases readily distinguished from either of the others by its soft, silk-like fibers and further by the fact that it is more or less decomposed by acids. As found in nature the material is of a lively oil-yellow or greenish color, compact and quite hard, but may be readily reduced to the white, fluffy, fibrous state by beating, hand-picking, or running between rollers The length of the fiber is quite variable, rarely exceeding 6 inches, but of very smooth, uniform diameter and great flexibility.

The mineral crocidolite, although somewhat resembling fibrous serpentine, belongs properly to the amphibole group. Chemically it is anhydrous silicate of iron and soda, the iron existing in both the sesquioxide and protoxide states. More or less lime and magnesia may be present as combined impurities. The color varies from lavender-blue to greenish, the fibers being silky like serpentine, but with a slightly harsh feeling. The composition of representative specimens of these minerals from various sources is given in the accompanying table.[1] (See pp. 186, 187.)

Mode of occurrence and origin.—Concerning the associations, occurrence, and origin of the fibrous structure of these minerals existing literature is strangely silent. It is known that all occur in regions occupied by the older eruptive and metamorphic rocks. It is probable that in the fibrous forms the mineral is always secondary, and in the true (amphibole) asbestos due in part, at least, to shearing

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[1] From Notes on Asbestos and Asbestiform Minerals, by George P. Merrill. Proceedings of the U. S. National Museum, XVIII, 1895, pp. 281–292.

ANALYSES OF ASBESTIFORM MINERALS.

No.	Locality.	Mineralogical Nature.	Extinction Angle	SiO_2	Al_2O_3.	Fe_2O_3.	FeO.	CaO.	MgO.	MnO.	K_2O.	Na_2O.	Ign.	Totals.	Authority.
1	Salls Mountain, Georgia..	Anthophyllite......	0	57.12	0.75	......	6.36	......	29.44	......	(a)	(a)	5.47	99.14	R. L. Packard.
2	Nacoochee, Ga.	do.	0	57.73	0.72	......	8.61	0.08	28.77	......	0.14	0.57	2.52	....	do.
3	Rabun Co. Ga.	do.	0	56.52	3.57	......	10.08	Trace	27.13	......	(a)	(a)	2.96	100.26	Geo. P. Merrill.
4	Tallapoosa Co., Ala.	do.	0	55.92	3.69	11.00		0.60	26.33	......	(a)	(a)	2.40	99.94	do.
5	Lenoir. Caldwell Co., N.C.	do.	0	56.21	2.78	......	8.58	0.82	28.95	Trace	(a)	(a)	2.23	99.31	do.
6	Warrenton, Warren Co., N.C.	do.	0	57.00	.....	10.32	......	Trace	29.98	......	(a)	(a)	2.29	99.59	do.
7	Franklin, N.C.	do.	0	54.79	.....	13.65	......	......	28.52	......	(a)	(a)	2.55	99.51	do.
8	Mitchell Co., N.C.	do.	0	59.00	0.91	......	6.09	0.45	29.90	......	0.43	0.68	2.35	99.81	R. L. Packard.
9	Alberton, Md.	do.	0	56.75	1.54	......	10.76	0.10	27.46	Trace	(a)	(a)	2.88	99.49	do.
10	Carbon Co., Wyo.	do.	0	54.56	1.47	......	12.39	1.86	25.28	......	(a)	(a)	2.95	99.51	Geo. P. Merrill.
11	San Diego, Cal.	do.	0	57.31	1.57	......	7.06	......	30.24	......	(a)	(a)	2.73	98.91	R. L. Packard.
12	Albemarle Co., Va.	Amphibole, v. asbestos.	0–16	56.26	1.81	......	6.40	11.98	20.85	Traces	(a)	(a)	2.65	99.95	do.
13	Parkton, Md.	do.	0–15	56.96	0.52	......	1.12	13.84	23.90	......	(a)	(a)	2.37	98.71	Geo. P. Merrill.
14	Roanoke, Va.	do.	0–15	55.81	1.66	......	6.81	12.74	21.09	......	......	.....	1.81	99.92	R. L. Packard.
15	Chester, S.C.	do.	0–15	54.66	3.72	......	6.83	12.81	19.87	Traces	(a)	(a)	2.28	100.17	Geo. P. Merrill.
16	Pylesville, Harford Co., Md.	do.	0–15	56.76	.....	......	3.10	12.75	23.85	......	(a)	(a)	2.68	98.94	do.
17	Aston, Delaware Co , Pa..	do.	.....	53.42	.....	......	......	13.42	22.85	......	(a)	(a)	4.36	98.05	do.
18	Staten Island, New York.	do.	.....	52.50	.....	......	11.82	......	30.73	......	......	.....	2.25	100.0	Hintze, p. 1241.
19	Zillerthal, Tyrol.	do.	0–15	55.08	1.64	......	4.57	14.65	22.56	0.81	......	.....	2.39	100.4	Hintze, p. 1235 (av. of 4 dets.).
20	Cow Flats, Bathurst, New South Wales.	do.	0–15	54.75	1.21	......	2.79	13.99	22.93	Traces	(a)	(a)	2.58	98.25	Geo. P. Merrill.
21	Corsica.	do.	0–17	56.72	0.545	......	1.73	14.72	23.63	Traces	(a)	(a)	2.33	99.67	do.
22	Zillerthal.	Amphibole, v. mountain cork.	.....	57.20	.....	......	4.37	13.39	22.85	......	......	.....	2.43	100.24	Dana, p. 395.
23	Frankenstein, Silesia.	Amphibole, v. asbestos.	.....	57.69	.....	......	2.46	13.39	23.68	0.13	......	3.14	0.17	100.66	do.
24	Cunsdorf, Saxony.	do.	.....	57.98	0.58	......	6.32	12.95	22.38	......	......	.....	....	100.21	Hintze, p. 1234.
25	Taberg, Sweden.	do.	.....	59.75	.....	......	3.95	14.25	21.10	0.31	Fl.1.16	.....	....	100.52	Hintze, p. 1238.
26	Cow Flats, New South Wales.	do.	.....	49.45	9.69	16.33	5.15	11.97	Trace	4.39	......	.....	3.03	100.01	Hintze, p. 1240.
27	Bolton. Mass	do.	.....	58.80	.....	......	3.05	16.47	22.23	......	......	.....	....	100.55	Hintze, p. 1242.

28	Malden, Mass.	....	0–17	48.60	6.64	......	18.23	12.55	9.52	......	......	.....	2.85	98.39	Geo. P. Merrill.
29	Nahant, Mass.	....	0–17	51.58	1.88	......	14.99	9.72	16.65	......	......	.....	4.98	99.8	R. L. Packard.
30	Mexico.	....	0–20	55.48	2.01	12.32	......	10.35	17.23	......	......	1.54	1.47	100.40	Bauer, Neues Jahrbuch, I, 1882, p. 159.
31	South Africa.	Crocidolite.	0	52.11	1.01	20.62	16.75	......	1.77	......	......	6.16	1.58	99.00	Dana, p. 400.
32	Idaho.	....	.....	53.28	.....	......	......	None.	22.87	......	......	.....	19.53	98.97	Geo. P. Merrill.
33	Glen Urquhart, Scotland.	Amphibole, v. asbestos.	.....	47.721	3.837	0.176	5.741	5.64	28.745	0.159	0.186	0.264	7.648	100.117	M. F. Heddle.
34	The Balta, Scotland.	do.	.....	56.153	1.539	0.388	3.111	11.716	22.461	0.769	0.188	0.692	2.5	99.517	do.
35	Shinness, Sutherland, Scotland.	do.	.....	56.864	0.232	0.484	2.124	12.535	23.923	0.23	0.437	0.538	2.325	99.866	do.
36	Portsoy, Scotland.	do.	.....	56.307	0.77	0.527	2.323	12.578	23.307	0.153	0.439	0.633	2.941	99.978	do.
37	Italy.	Fibrous serpentine, amianthus	0	40.30	.....	2.27	0.87	......	43.37	......	......	.....	12.72	100.53	J. T. Donald.
38	Canada.	do.	0	40.57	.....	0.90	2.81	......	41.50	......	......	.....	13.55	99.33	do.
39	Victoria, British Columbia	do.	0	41.95	.....	......	2.81	......	41.62	......	......	.....	14.85	100.23	Geo. P. Merrill.
40	Alberton, Md.	Hydrous anthophyllite (?).	0	51.84	.....	1.51	......	......	24.54	(*a*)	0.25	0.45	*b*20.18	98.77	do.

a Not determined.

b H_2O at 110°, 10.55 per cent; at bright, red heat, an additional loss of 9.63 per cent.

agencies; that is, to movements in the mass of a rock whereby a mineral undergoing crystallization would be compressed laterally and drawn out along the line of least resistance. It is even probable that the structure is but an extreme development of the prismatic cleavage, due to the shearing forces.

The asbestos of Alberene, in Albemarle County, Virginia, occurs in thin platy masses along slickensided zones in the so-called soapstone (altered pyroxenite) of the region, the fibers always running parallel with the direction of the movement which has taken place. The same is true of the asbestos found in the magnetite mines near Blacksburg, in Cherokee County, South Carolina, where the fibrous structure is developed only along shear zones. At Alberton, Maryland, the fibrous anthophyllite occurs along a slickensided zone between a schistose actinolite rock and a more massive serpentinous or talcose rock, which is also presumably an eruptive peridotite or pyroxenite. The fibration here runs also parallel with the direction of movement as indicated by the slickensided surfaces.

The Sall Mountain (Georgia) asbestos is anthophyllite, of a grayish-white color, though often stained by iron oxides. The entire mass of the material as mined is made up of groups of bundles of more or less radial fibrous structure, the fibers tending to form spherical bunches, though, owing to imperfect development caused by interference in crystallization, the radial structure is obscured and the mass consists of fibrous sheaves or bundles running in all directions. As mined, it is said to consist of over 90 per cent of material which can be utilized as fiber. Within an area a little more than one-half mile square, in the vicinity of Sall Mountain, there are stated to be six separate masses of this material, each one roughly elliptical in shape, with their longer axes approximately parallel and running north 80° east. The country rock is gneiss, and the asbestos itself is regarded by Diller[1] as an altered igneous rock. The largest mass reported had a length of about 75 feet and a maximum width of 50 feet. It has been mined to a depth upwards of 50 feet.

The asbestiform serpentine, as noted elsewhere, occurs in short, disconnected gash veins which traverse the massive rock of the

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[1] Mineral Resources of the U. S., 1907.

same general nature in every direction. These veins are short, rarely more than a few feet in length, and it is impossible that there should have been any appreciable differential movement between their walls. The present writer has attempted to account for these on the assumption that the vein cavities were formed by shrinkage, and the vein filling by a process of growth of the fibers from the walls of the cavities inward.[1]

Localities.—As already stated true amphibole asbestos occurs only in regions of eruptive and metamorphic rocks belonging to the Archæan and Paleozoic formations. The same is true of anthophyllite. Fibrous serpentine occurs sporadically with the massive forms of the same rock which is, so far as known, almost invariably an altered eruptive.[2] The three forms are therefore likely to occur in greater or less abundance in any of the States bordering along the Appalachian system, but are necessarily lacking in the great Interior Plains regions, recurring once more among the crystalline rocks of the Western Cordilleras and the Pacific coast. The principal States from which either the true asbestos or anthophyllite has been obtained in anything like commercial quantities are Massachusetts, Connecticut, New York, Maryland, Virginia, North Carolina, South Carolina, Georgia, and Alabama, though it has been reported from other Eastern as well as several of the Western States. Fibrous serpentine (chrysotile, or amianthus) occurs in small amounts at Deer Isle, Maine; in northern Vermont; at Easton, Pennsylvania; Montville, New Jersey; the Grand Cañon region of Arizona; in the Casper Mountains of Wyoming, and in the State of Washington. It is known also to occur in Newfoundland.

Asbestiform serpentine occurs in Canada, in an interrupted belt of serpentinous rocks extending from the Chaudière River, in Quebec

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[1] On the Formation of Veins of Asbestiform Serpentine. Bulletin of the Geological Society of America, XVI, 1905, p. 133.

[2] The Montville, N. J., occurrence is evidently an exception, as is also perhaps that of the Grand Cañon region. In the first-mentioned instance the serpentine results from the alteration of nodular masses of gray and white pyroxene. The veins of fibrous material are here, as a rule, roughly parallel to the outer surfaces of these nodules. They are small, and of no commercial value. (See On the Serpentine of Montville, N. J. By Geo. P. Merrill, Proc. U. S. National Museum, XI, 1885, pp. 105–111.)

province, southwesterly to the Vermont line, and beyond. The principal producing points thus far developed are in the Thetford and Black Lake area, which begins at a point between the towns of St. Joseph and St. Francis, and extends southwesterly into Broughton, Thetford, Coleraine, Wolfestown and Ham. A second area begins at Danville and extends through Brompton, Oxford, Bolton, and

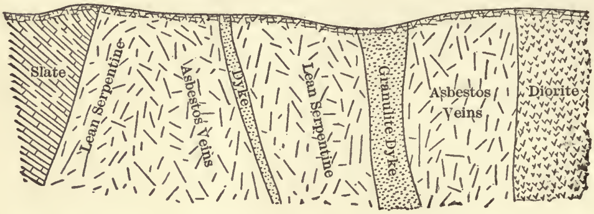

Fig. 34.—Section of asbestos-bearing rocks, Thetford, Canada. [After Cirkel: Asbestos, Its Occurrence, Exploitation, and Uses.]

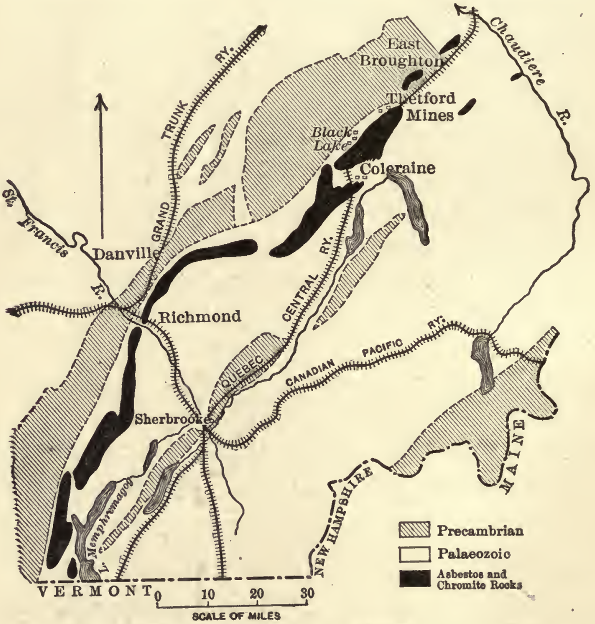

Fig. 35.—Map showing serpentine areas in Eastern Townships of Quebec. [After Cirkel: Asbestos, Its Occurrence, Exploitation, and Uses.]

Potton to the Vermont line. This area has as yet been productive only at Danville. A third area occurs on the Gaspé Peninsula. At Thetford the serpentine occurs in a series of apparently disconnected masses of comparatively small extent which are presumably altered gabbros or peridotites that were intruded into the prevailing schists. These serpentinous masses have been in their turn intruded by dikes of diabase and granite. The fibrous material occurs in the form of short gash veins, evidently shrinkage cracks, which traverse the massive rock in all directions. These are at best but a few inches in width, pinching out to mere knife-like edges, and of but a few feet in length. The edges of two adjacent veins often overlap, but are apparently wholly disconnected (see Fig. 36). They also cut one another at every conceivable angle. Veins which do not pinch out to knife edges are often split up, or "frayed out" at the ends, like a ragged piece of cloth. They occur at intervals of a few inches to many feet, the wider the vein the greater the intervening distance, as a rule. The vein material is itself of almost silk-like fiber, though the individual fibers rarely extend from wall to wall, but are interrupted by splinters and granules of the massive material. Veins of more than 3 or 4 inches in width are rare, though 6 inches in width has been reported.

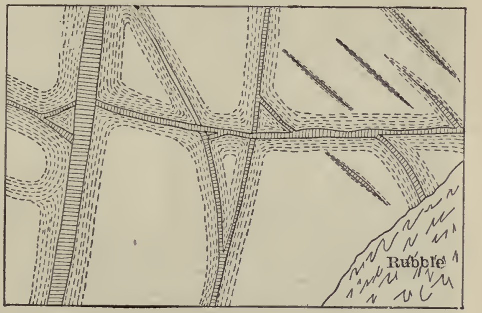

FIG. 36.—Vertical section wall of asbestos pit, Black Lake, Canada.

The Vermont asbestos is of the same type as the Canadian. It is found near Eden, in Lamoille County, and the adjacent town of Lowell, in Orleans County, in the northern part of the State. At Eden the mines occur in the south face of Belvidere Mountain, where there is a great mass of serpentine intruded between a micaceous schist below and a hornblendic schist above. The serpentine occurs in the form of bold escarpments, and the mining is carried on wholly from open cuts. The veins are rarely more than three-fourths of an inch in width. At Lowell two types of material are met with, the one with fibers standing practically at right angles with the walls, as in the localities described, and the other with fibers parallel to the slickensided faces of joints. This last variety is much the more brittle, and as it occurs in layers seldom more than an inch in thickness, is less desirable.

According to Pratt, the serpentine asbestos of the Grand Cañon region is exposed only in the cañon wall in Coconino County, Arizona. The material is found in a serpentinized limestone belonging to the Algonkian series, where, in contact with intrusive sheets of basalt, the serpentinized areas are almost constant over an area of some 9,000 feet in length, but only from 18 to 24 inches in thickness. The asbestiform seams are quite regular, varying in width up to 3 inches, the fibers being at times of a most beautiful golden color, and remarkably soft and silky. The smaller seams yield the highest

FIG. 37.—Serpentine asbestos in massive serpentine.
[U. S. National Museum.]

grade of material, but the quality as a whole is very high, as good as that of Canada, or elsewhere.

The veins lie nearly 5,000 feet below the rim of the Cañon, and within the area of the National reservation.

The Italian asbestos which finds its way to the American markets is both of the amphibolic and serpentinous varieties, both being remarkable for the beautiful long fibers they yield. The amphibolic variety, the true asbestos, comes from Mont Cenis, and the serpentinous variety from Aosta.

Methods of mining and preparation.—The mining of asbestos is carried on almost wholly from open cuts and shallow tunnels. Rarely does it pay to follow the material to any great depth.

In the mining of the Canadian material the rock is blasted out and the asbestos separated from the inclosing rock by a process known as "cobbing," which consists in breaking away the fibrous material from the walls of the vein or from other foreign ingredients by means of hammers.

The cobbed material is separated into grades, according to quality, which depends upon the length, fineness, and flexibility of the fiber. During 1888 the finest grades brought prices varying from $80 to $110 a ton. The prices at times have gone even higher. The amphibole asbestos, on the other hand, rarely brings over $20 a ton.

Uses.—The uses of asbestos are manifold, and ever on the increase. Among the ancient Greeks it was customary to wrap the bodies of those to be burned in asbestos cloth, that their ashes might be kept intact. In the eighth century Charlemagne is said to have used an asbestos tablecloth, which, when the feast was over, he would throw into the fire, after a time withdrawing it cleaned but unharmed, greatly to the entertainment of his guests. The most striking use to which the material is put is the manufacture of fireproof cloths for theater curtains, for suits of firemen and others liable to exposure to great heat. It is also used for packing pistons, closing joints in cylinder heads, and other fittings where heat, either dry or from steam and hot water, would shortly destroy a less durable substance. For this purpose it is used in the form of a yarn, or as millboard. The lower grades, in which the fibers are short or brittle, are made into a felt which, on account of its non-conducting powers, is utilized in covering steam boilers. It is also ground and made into cements and paints, the cement being used as a non-conductor on boilers, and the paint to render wooden structures less susceptible to fire. In the chemical laboratory the finely fibered, thoroughly purified asbestos forms an indispensable filtering medium. For this purpose the true asbestos is preferable to the fibrous serpentine.[1] In the manufacture of cloth, rope, and other materials where strength and flexibility of fiber are essential the serpentine asbestos (chrysotile) is preferable to the amphibolic form, though, owing to its hydrous condition, it is, in reality less fire-proof.

Within a few years it has been found that the massive material previously considered as waste at the mines could, by proper treatment, be reduced to a fibrous pulp admirably adapted for a wall plaster, and similar uses. This material is known under the commercial name of *asbestic.*

The chief use of asbestos is based upon its highly refractory or non-combustible nature. The popular impression that it is a non-conductor of heat is, according to Professor Donald, erroneous, the non-conducting character of the prepared material being due rather to its porous nature than to the physical properties of the mineral itself.[2] Owing to the comparatively high price of asbestos, it is, in the manufacture of the so-called non-conducting materials, largely admixed with plaster of Paris, powdered limestone, dolomite, magnesite, diatomaceous earth, or carbonaceous matter, as hair, paper, sawdust, etc. With the possible exception of the magnesite (carbonate of magnesia) these are all less effective than the asbestos, and deteriorate as well as cheapen the manufactured article. The following table will serve to convey some idea of the relative portions of the various materials used as non-conducting pipe coverings, etc.:

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[1] Prof. A. H. Chester: Some Misconceptions Concerning Asbestos. Engineering and Mining Journal, LV, 1893, p. 531.

[2] The Mineral Industry, II, 1893, p. 4.

	Parts.
Asbestos sponge, molded:	
Plaster of Paris	95.80
Fibrous asbestos	4.20
	100.00
Fire-felt sectional covering:	
Asbestos	82.00
Carbonaceous matter (hair, paper, sawdust, etc.)	18.00
	100.00
Magnesia sectional covering:	
Carbonate of magnesia	92.20
Fibrous asbestos	7.80
	100.00
Magnesia plastic:	
Carbonate of magnesia	92.20
Fibrous asbestos	7.80
	100.00
Asbestos cement felting:	
Powdered limestone	64.50
Plaster of Paris	3.50
Asbestos	32.00
	100.00
Asbestos-sponge cement felting:	
Powdered limestone	59.00
Plaster of Paris	10.00
Asbestos	31.00
	100.00
Fossil meal:	
Insoluble silicate	75.00
Carbonaceous matter (hair, paper, sawdust, etc.)	11.00
Soluble mineral matter	8.00
Moisture	6.00
	100.00

At Phillipsburg, New Jersey, and the adjoining town of Easton, Pennsylvania, a mineral pulp is prepared from a metamorphic rock of somewhat mixed composition, occurring in the immediate vicinity. As quarried, the material is hard, compact and massive, though with a somewhat fibrous structure, and of a gray white or greenish color, the variation in color being due to the different stages of alteration which the rock has undergone. The least altered material, of a white or gray color, consists essentially of the mineral tremolite, which, as the writer has elsewhere[1] noted, undergoes alteration into serpentine, giving rise to the green color above noted. According to Professor F. P. Peck,[2] the tremolite at times also undergoes an alteration into talc. The unaltered tremolite has the following composition:

Constituents.	Per cent.
Silica, SiO_2	58.27
Alumina Al_2O_3	0.33
Manganese, MnO	0.08
Lime, CaO	11.90
Magnesia, MgO	25.93
Potash, K_2O	0.42
Soda, Na_2O	1.25
Water, H_2O	1.22
	99.40

The massive serpentinous rock resulting from its alteration, and which is used in the manufacture of the better grades of pulp, has the following composition:

Constituents.	Per cent.
Silica SiO_2	45.23
Aluminum, Al_2O_3	2.68
Iron, Fe_2O_3	
Lime, CaO	1.41
Magnesia, MgO	38.34
Loss on ignition	12.30
	99.96

The material is ground between French buhrstones and is used in the manufacture of rubber goods and as a filler in paper manufacture. The ground pulp, at the mills, was quoted in 1904 as worth $6.50 per ton.

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[1] Proceedings U. S. National Museum, XII, 1890, p. 599.

[2] Annual Report State Geologist of New Jersey, 1904, p. 163.

The annual amount of asbestos of all kinds produced in the United States varies from 600 to 1,000 tons, valued at about $15 per ton. Some 30,000 tons of asbestos and asbestic are produced by the Canadian mines, a considerable proportion of which finds its way into American markets.

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London, 1897, pp. 368.
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4. GARNET.

The chemical composition of the various minerals of the garnet group is somewhat variable, though all are essentially silicates of alumina, lime, iron, or magnesia. The more common types are the lime-alumina garnet *grossularite*, and the iron-alumina garnet *alamandite*. Other varieties of value as minerals or as gems are *pyrope*, *spessartite*, *andradite*, *bredbergite*, and *uvarovite*.

The ordinary form of the garnet is the regular 12- or 24-sided solid, the dodecahedron and trapezodedron, as shown in Fig. 38. The color is dull red or brown, though in the rarer forms yellow, green, and white. Hardness from 6.5 to 7.5 of the scale.

Occurrence.—Garnets occur mainly in metamorphic siliceous rocks, such as the mica schists and gneisses, and though sometimes found in limestones and in eruptive rocks, are rarely sufficiently abundant to be of economic importance. In the gneisses and schists, however, they at times preponderate over every other constituent, varying from sizes smaller than a pin's head to masses of 100 pounds' weight, or more.

The most important garnet-producing regions of the United States are Roxbury, Connecticut, Warren County, New York, and Delaware County, Pennsylvania. At the first-named locality, the garnets occur in a mica schist; in New York they are found in laminated pockets scattered through beds of a very compact hornblende feldspar rock, the size of the pockets ranging from 5 or 6 inches in diameter to such as will yield 1,000 pounds or more. In the Delaware County localities the garnets occur in aggregates of small crystals in a quartzose gneiss.[1]

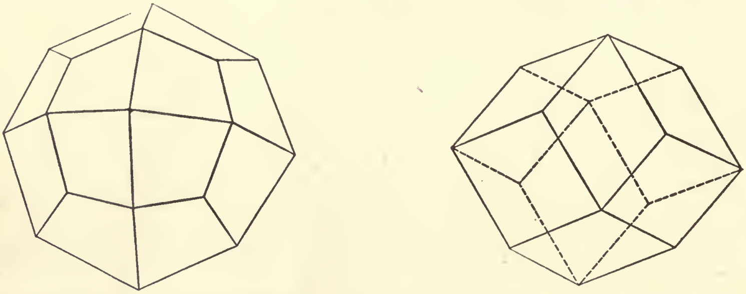

FIG. 38.—Outlines of garnet crystals.

One of the most noted garnet regions of the world is that near Prague, Bohemia. According to G. F. Kunz,[2] the garnets of the pyrope variety are indigenous to an eruptive rock now changed to serpentine, and the mineral is found "loose in the soil or in the lower part of the diluvium, or embedded in a serpentine rock. . . . In mining the earth is cut down in banks and only the lower layer removed, and the garnets are separated by washing. The earth

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[1] The Mineral Industry, V, 1896.

[2] Transactions of the American Institute of Mining Engineers, XXI, 1892, p. 241.

is first dry-sifted and then washed in a small jig consisting of a sieve moved back and forth in a tank of water."

According to Mr. D. B. Sterrett, the garnets at Roxbury, noted above, occur in the form of dodecahedrons of all sizes up to an inch and a half in diameter, embedded in a mica schist.

The present quarry is situated upon a hilltop some three miles outside of the town of Roxbury. Mining is done wholly by open cuts. The rock is blasted out by dynamite and broken into masses suitable for handling, which are then raised from the quarry, dumped into a gravity car, and run to a crushing mill. The schist is soft, crushing easily, the garnets coming out, in large part, free from the matrix and unbroken.

From the crusher pieces of all sizes up to a hen's egg fall through a chute and are scattered evenly over a broad belt, some 2 feet in width and 12 or more in length, over which small streams of water are kept playing in order to settle the dust and cleanse the garnets. On either side of this belt men are employed to pick out the garnets, which are placed upon a small belt above moving in the same direction. This carries them to the storing bins, where they are run into sacks of 100 pounds' weight each and shipped.

The waste at the quarry is very great, amounting, it is estimated, to from one-half to three-fourths of the entire amount mined.

Uses.—Aside from their uses in the cheaper forms of jewelry, garnets are used for abrading purposes and mainly as a sand for sawing and grinding stone or for making sandpaper. The material is of less value than corundum or emery, owing to its inferior hardness. The commercial value is variable, but as prepared for market it is about 2 cents a pound.

5. ZIRCON.

This is a silicate of zirconium, $ZrSiO_4$, = silica, 32.8 per cent; zirconia, 67.2 per cent; specific gravity, 4.68 to 4.7; hardness, 7.5; colorless, grayish, pale yellow to brown or reddish brown. Ordinarily in the form of square prisms (Fig. 39).

Zircon is a common constituent of the older eruptives like granite and syenite, and also occurs in granular limestone, gneiss, and the schists. It is so abundant in the elæolite syenites of Southern Norway as to have given rise to the varietal name Zircon syenite. Although widespread as a rock constituent it has been reported in but few instances in sufficient abundance to make it of commercial value. Being hard and very durable it resists to the last ordinary atmospheric agencies, and hence is to be found in beds of sand, gravel, and other débris resulting from the decomposition of rocks in which it primarily occurs. It has thus been reported as found in the alluvial sands in Ceylon, in the gold sands of the Ural Mountains, Australia, and other places. In the United States it occurs in considerable abundance in the elæolite syenite of Litchfield, Maine, and is also found in other States bordering along the Appalachian Mountains. The most noted localities are in Henderson and Buncombe counties in North Carolina, whence several tons have been mined during the past few years from granite débris.

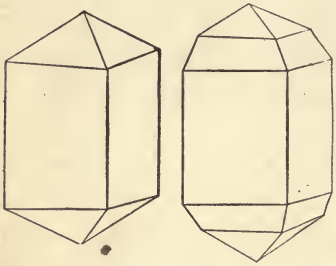

FIG. 39.—Outlines of zircon crystals.

Uses.—See under Monazite, p. 298.

6. SPODUMENE AND PETALITE.

Spodumene.—This is an aluminum-lithium silicate of the formula $LiAl(SiO_3)_2$, = silica, 64.5 per cent; alumina, 27.4 per cent; lithia, 8.4 per cent; in nature more or less impure through the presence of small amounts of ferrous oxide, lime, magnesia, potash, and soda. Luster, vitreous to pearly; colors, white, gray, greenish, yellow, and amethystine purple, transparent to translucent. Usual form that of flattened prismatic crystals, with easy cleavages parallel with the faces of the prism. Also in massive forms. Crystals sometimes of enormous size, as noted below.

Mode of occurrence.—Spodumene occurs commonly in the coarse granitic veins associated with other lithia minerals, together with tourmaline, beryls, quartz, feldspar, and mica. The chief localities as given by Dana are as below:

FIG. 1.—Large Spodumene Crystals in Granitic Rock, Etta Mine, Black Hills, South Dakota.
[From photograph by E. O. Hovey.]

FIG. 2.—Soapstone Quarry, Nelson County, Virginia.
[After Thos. Watson, Mineral Resources of Virginia.]

PLATE XVIII.

[*Facing page* 200.]

"In the United States, in granite at Goshen, Massachusetts, associated at one locality with blue tourmaline and beryl; also at Chesterfield, Chester, Huntington (formerly Norwich), and Sterling, Massachusetts; at Windham, Maine, with garnet and staurolite; at Peru with beryl, triphylite, petalite; at Paris, in Oxford County; at Winchester, New Hampshire; at Brookfield, Connecticut, in small grayish or greenish-white individuals looking like feldspar; at Branchville, Connecticut, in a vein of pegmatite, with lithiophilite, uraninite, several manganesian phosphates; near Stony Point, Alexander County, North Carolina, the variety hiddenite in cavities in a gneissoid rock with beryl (emerald), monazite, rutile, allanite, quartz, mica; near Ballground, Cherokee County, Georgia; in South Dakota at the Etta tin mine in Pennington County, in immense crystals. At Huntington, Massachusetts, it is associated with triphylite, mica, beryl, and albite."

At the Etta tin mine, in the Black Hills of South Dakota, the mineral occurs, according to W. P. Blake, in sizes the magnitude of which exceeds all records. Crystalline masses extend across the face of the open cut from 2 to 6 feet in length and from a few inches to 12 and 18 inches in diameter. The gigantic crystals preserve the cleavage characteristics and show the common prismatic planes. The color is lighter and is without the delicate creamy-pink hue of the specimens from Massachusetts. It is very hard, compact, and tough and is difficult to break across the grain. Some of the fragments are translucent. See (Plate XVIII.)

The chief foreign localities of spodumene are Utö in Södermanland, Sweden, where it is associated with magnetic-iron ore, tourmalines, quartz, and feldspar, near Sterzing and Lisens, in Tyrol; embedded in granite at Killiney Bay near Dublin, and at Peterhead, Scotland.

Uses. — Spodumene and the lithia-mica lepidolite are used in the manufacture of lithia salts, although the industry is not yet one of great importance. The price of the crude material varies with the percentage of lithium, which as noted is greatest in the first-named mineral. During the year 1901 the prices ranged from $11.00 to $40.00 per ton. the total production for the year being but 1,750 tons, derived mainly from California and in the form of lepidolite.

Petalite, another lithium-aluminum silicate containing 2.5 to

5 per cent lithia occurs associated with lepidolite, tourmaline, and spodumene in an iron mine at Utö, Sweden, with spodumene and albite at Peru, Maine, and with scapolite at Bolton, Massachusetts.

7. LAZURITE; LAPIS LAZULI; OR NATIVE ULTRAMARINE.

Composition essentially $Na_4(NaS_3.Al)Al_2Si_3O_{12}$, = silica, 31.7 per cent; alumina, 26.9 per cent; soda, 27.3 per cent; sulphur, 16.9 per cent; hardness, 5.5; specific gravity, 2.38 to 2.45. Color, rich azure-violet or greenish blue, translucent to opaque. The ordinary lapis lazuli is not a simple mineral as given above, but a mixture of lazurite, hauynite, and various other minerals.

The following analyses quoted from Dana serve to show the heterogeneous character of the material as found:

Localities.	Silica, SiO_2.	Alumina, Al_2O_3.	Ferric Iron. Fe_2O_3.	Lime, CaO.	Soda Na_2O.	Water, H_2O.	Sulphur, SO_3.
Orient	45.33	12.33	2.12	23.56	11.45	0.35	3.22
Ditrô	40.54	43.00	0.86	1.14	12.54	1.92	....
Andes	45.70	25.34	1.30	7.48	10.55	....	4.32

Occurrence.—The localities are mostly foreign. The ultramarine reported not long since as occurring near Silver City, New Mexico, has been shown by R. L. Packard to be a magnesian silicate.

Mexico, Chile, Siberia, India, and Persia are the chief sources. The following regarding the Indian localities is taken from Ball's Geology of India, Part III.

The lapis lazuli sold in Kandahar is brought from Sadmoneir and Bijour, where it is said to occur in masses and nodules embedded in other rocks. It is also said to have been found at Hazara, and in Khelat. Several writers speak of its occurrence in Beluchistan, but possibly this may be due to some confusion in names. Beyond a question it does exist in Badaksham, the mines south of Firgamu, in the Kokcha valley, having been described by Wood in the narrative of his journey to the Oxus.

The entrance to the mines is on the face of the mountain at an elevation of about 1,500 feet above the level of the stream. The country rocks are veined, black and white limestones. The principal mine as represented in elevation pursues a somewhat serpentine direction. The shaft by which one descends to the gallery is about 10 feet square, and 30 paces long, with a gentle descent, and is unsupported by pillars. Fires are used to soften the rock and cause it to crack; on being hammered it comes off in flakes, and when the precious stone is disclosed a groove is picked round it, and together with the portion of the matrix it is pried out by means of crowbars. Three varieties are distinguished by the miners, the *nili*, or indigo colored, the *asmani*, or sky-blue, and the *sabzi*, or green. The labor is compulsory, and mining was only practiced in the winter. According to Wood, these mines and also those for rubies had not been worked for years, as they had ceased to be profitable. Formerly the produce from these mines, which must have been considerable, was exported principally to Bokhara and China, whence a portion found its way to Europe.

Marco Polo states that the *azure* found here was the finest in the world, and that it occurred in a vein. The Yamgan tract, in which the mines were situated, contained many other mines, and doubtless Tavernier referred to it when he spoke of the territory of a Raja beyond Kashmir and toward Thibet, where there were three mountains close to one another, one of which produced gold, another *granats* (garnets, or rather balas rubies), and the third lapis lazuli.

A small quantity of the mineral is said to be imported into the Punjab from Kashgar, and a mine is reported to exist near the source of the Koultouk, a river which falls into Lake Baikal.

Uses.—Ultramarine for coloring purposes has in modern times lost much of its value, owing to the discovery by M. Guimet in 1828 of an artificial substitute. Formerly it was much used as a pigment, being preferred by artists in consequence of its possessing greater purity and clearness of tint. According to Ball,[1] the artificial substitute is now commonly sold in the bazars of India under the same name, lajward, for about 4 rupees a seer, while at Kandahar in the year 1841, according to Captain Hutton, the true lajward, which was used for house painting and book illuminating, was sold, when purified, at from 80 to 100 rupees a seer. Mr. Emanuel states that the value of the stone itself, when of good color, varies, according to size, from 10 to 50 shillings an ounce. In Europe the

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[1] Geology of India, III, p. 528.

refuse in the manufacture is calcined, and affords delicate gray pigments, which are known as ultramarine ash.

Lajward is prescribed internally as a medicine by native physicians; it has been applied externally to ulcers. That it possesses any real therapeutic powers is, of course, doubtful.

Although no longer a source of any considerable amount of the ultramarine of commerce, the compact varieties of the mineral, such as that from Persia, are highly esteemed for the manufacture of mosaics, vases, and other small ornaments.

8. ALLANITE; ORTHITE.

This is a cerium epidote of the formula $HR^{II}R^{III}_3Si_3O_{13}$, in which R^{II} may be either calcium or iron (or both) and R^{III} aluminum, iron cerium, didymium, or lanthanum. The analyses given below are selected from Dana's Mineralogy as showing variation in the composition sufficient for present purposes:

Constituents.	I.	II.	III.
Silica (SiO_2)	31.63	33.03	30.04
Thoria (ThO_2)	0.87	1.12	None.
Alumina (Al_2O_3)	13.21	17.63	16.10
Iron sesquioxide (Fe_2O_3)	8.39	5.26	5.06
Cerium sesquioxide (Ce_2O_3)	8.67	2.84	11.61
Didymium sesquioxide (Di_2O_3)	5.60	7.68	5.39
Lanthanum sesquioxide (La_2O_3)	5.46	None.	4.11
Yttrium sesquioxide (Y_2O_3)	0.87	2.92	None.
Erbinum sesquioxide (Er_2O_3)	0.52	None.	None.
Iron protoxide (FeO)	7.86	7.01	9.89
Manganese (MnO)	1.66	0.64	Trace.
Lime (CaO)	10.48	12.78	13.02
Magnesia (MgO)	0.08	0.11	1.11
Potash (K_2O)	0.28	0.40	0.02
Soda (Na_2O)	None.	None.	0.28
Water (H_2O)	3.49	9.37	2.56
	99.07	100.79	99.19

(I) Hitterö, Norway; (II) Ytterby, Sweden; (III) Nelson County, Virginia.

When in crystals often in long slender nail-like forms (orthite); also massive and in embedded granules. Color, pitch-black, brownish, and yellow. Brittle. Hardness, 5.5 to 6. Specific gravity, 3.5 to 4.2. Before the blowpipe it fuses and swells up to a dark, slaggy, magnetic glass.

Localities and mode of occurrence.—The more common occurrence is in the form of small, acicular crystals as an original constituent in granitic rocks. It also occurs in white limestone, associated with magnetic-iron ore, and in igneous rocks as andesite, diorite, and rhyolite. At the Cook Iron Mines, near Port Henry, New York, it is reported as occurring in great abundance and in crystals of extraordinary size, in a gangue of quartz and orthoclase.

The variety orthite occurs in forms closely simulating rusty nails in the granitic rock about Brunswick, Maine. In Arendal, Norway, it is found in massive forms. At Finbo, near Falun, Sweden, in acicular crystals a foot or more in length. In Amherst and Fauquier counties, Virginia, it occurs in large masses, as it also does near Bethany Church, Iredell County, North Carolina, and Llano County, Texas. At Balsam Gap, Buncombe County, North Carolina, it occurs in slender crystals 6 to 12 inches long and in crystalline masses, in a granitic vein and under similar conditions at the Buchanan and Wiseman mines in Mitchell County.

Uses.—See under Monazite, p. 307.

9. GADOLINITE.

This is a basic orthosilicate of yttrium, iron, and glucinum, though with frequently varying amounts of didymium, lanthanum, etc. The formula as given by Dana is $Gl_2FeY_2Si_2O_{10}$, = silica, 23.9 per cent; yttrium oxides, 51.8 per cent; iron protoxide, 14.3 per cent, and glucina, 10 per cent. Actual analyses yielded results as below:

Constituents.	I.	II.
Silica (SiO_2)	24.35	23.79
Thoria (ThO_2)	0.30	0.58
Yttrium sesquioxide (Y_2O_3)	45.96	41.55
Cerium sesquioxide (Ce_2O_3)	1.65	2.62
Didymium sesquioxide (Di_2O_3)	3.06	5.22
Lanthanum sesquioxide (La_2O_3)		
Iron sesquioxide (Fe_2O_3)	2.03	0.96
Iron protoxide (FeO)	11.39	12.42
Berylium (Glucina) protoxide (BeO)	10.17	11.33
Lime (CaO)	0.30	0.74
Soda (Na_2O)	0.17	Trace.
Water (H_2O)	0.52	1.03
	99.90	100.24

(I) Ytterby, near Stockholm, Sweden; (II) Llano County, Texas.

The mineral is sometimes found in form of rough and coarse crystals, but more commonly in amorphous, glassy forms. Hardness, 6.5 to 7; specific gravity, 4 to 4.47. Color, brown, black, and greenish black, usually translucent in thin splinters and of a grass-green to olive-green color by transmitted light. No true cleavage; fracture conchoidal or splintery like glass, and with a vitreous or somewhat greasy luster. Through oxidation and hydration the mineral becomes opaque, brown, and earthy. Hence masses are not infrequently found consisting of the normal glassy gadolinite enveloped in a brown-red crust of oxidation products. On casual inspection the mineral closely resembles samarskite and the dark, opaque varieties of orthite, but is easily distinguished from the fact that before the blowpipe it glows brightly for a moment and then swells up, cracks open, and becomes greenish without fusing. Some varieties (the normal anisotropic forms) swell up into cauliflower-like forms and fuse to a whitish mass. Like orthite, it gives a jelly when the powdered mineral is boiled in hydrochloric acid.

Localities and mode of occurrence.—The mineral occurs mainly in coarse pegmatitic veins associated with allanite and other allied minerals. The principal locality in the United States thus far described is some five miles south of Bluffton on the west bank of the Colorado River, in Llano County, Texas. The region is described[1] as occupied by Archæan rocks with granite, and occasional cappings of limestone.

A coarse deep-red granite is the most abundant, and is cut by numerous extensive veins of quartz and feldspar which carry the gadolinite, in pockety masses, and the other minerals mentioned. Most of the mineral thus far found is altered into the brown-red waxy material noted above and occurs in the form of masses weighing half a pound and upward. One "huge pointed mass, in reality a crystal, weighed fully 60 pounds"; another, 42 pounds. One of the earliest opened pockets yielded some 500 kilos (1100 pounds) of the mineral.

Of the foreign localities those of Kårarfvet, Broddbo, and Finbo,

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[1] American Journal of Science, XXXVIII, 1889, p. 474. See also Bulletin No. 340, U. S. Geological Survey, 1908, pp. 286–294.

near Falun, Sweden, and at Ytterby, near Stockholm, are important, the mineral here occurring in the form of rounded masses embedded in a coarse granite. On the island of Hitterö, in the Flecke fiord, Southern Norway, crystals sometimes four inches across have been obtained.

Uses.—See under Monazite, p. 307.

10. CERITE.

This is a silicate of the metals of the cerium group and of a complex and doubtful formula. The analyses below, taken from Dana's System of Mineralogy, will serve to show the varying character of the mineral.

Constituents.	I.	II.	III.
Silica (SiO_2)	19.18	22.79	18.18
Cerium oxide (Ce_2O_3)	64.55	24.06	33.25
Didymium oxide (Di_2O_3)	7.28	35.37	34.60
Lanthanum (La_2O_3)			
Iron oxide (FeO)	1.54	3.92	3.18
Alumina (Al_2O_3)	....	1.26	....
Lime (CaO)	1.35	4.35	1.69
Water (H_2O)	5.71	3.44	5.18

The mineral occurs in gneiss and mica schist, and is of a prevailing pink to gray color.

Uses.—See under Monazite, p. 307.

11. RHODONITE.

This is a metasilicate of manganese of the formula $MnSiO_3$, = silica, 45.9 per cent; manganese protoxide, 54.1. As a rule, iron, calcium, or zinc replaces a part of the manganese. The prevailing form of the mineral when in crystals is that of rough, tabular, or elongated prisms with rounded edges. It is also common in massive highly cleavable forms, and in disseminated granules. Rarely, as in the Ekaterinburg district of Russia, it occurs in massive forms suitable for ornamental work. Color, brownish red, flesh-red, and pink; sometimes rose-red. Hardness, 5.5 to 6.5. Specific gravity, 3.4 to 3.68.

On exposure the mineral undergoes oxidation, becoming coated with a black film and giving rise thus to indefinite admixtures of silicate, oxides, and carbonates of manganese.

The mineral occurs in abundance associated with the iron ores of Wermland, Sweden, and at other localities in Europe; in Ekaterinburg, Russia, as above noted. A vein of the massive material was discovered some years ago, near Waits River, Vermont, and it has been reported as occurring near Sitka, Alaska. The zinciferous variety associated with the zinc ores in granular limestones of Sussex County, New Jersey, is known as fowlerite.

So far as the writer has information, rhodonite has as yet little commercial value, excepting as an ornamental stone. To some extent it has been utilized in glazing pottery and as a flux in smelting furnaces.

12. STEATITE; TALC; AND SOAPSTONE.

Steatite, or talc, is a soft micaceous mineral of the formula $H_2Mg_3Si_4O_{12}$, and consisting when pure of 63.5 per cent of silica, 31.7 per cent of magnesia, and 4.8 per cent of water. Its most striking characteristics are its softness, which is such that it can be readily cut with a knife or even with the thumb nail, and soapy feeling, there being an entire absence of anything like grit. The prevailing colors are white or gray and apple-green. Several varietal forms are recognized; the name *talc* a as rule being applied to the distinctly foliaceous or micaceous variety, while that of *steatite* is reserved for the compact cryptocrystalline to coarsely granular forms.

Pyrallolite and rensselaerite are names given to varietal forms of talc resulting from the alteration of hornblende or pyroxene. Such forms are found in various portions of northern New York, Canada, and Finland. According to Dana, a part of the so-called agalmatolite used by the Chinese is steatite.

The name soapstone is given to dark-gray and greenish talcose rocks, which are soft enough to be readily cut with a knife, and which have a pronounced soapy or greasy feeling; hence the name. Such rocks are commonly stated in text-books to be compact forms of steatite, or talc, but as the writer has elsewhere pointed out,[1] and as shown by the analyses here given, few of them are even approximately pure forms of this mineral, but all contain varying proportions of chlorite, mica, and tremolite, together with perhaps unaltered residuals of pyroxene, granules of iron ore, iron pyrites, quartz, and, in seams and veins, calcite and magnesian carbonates.

Composition.—The varying composition of talc is shown in the series of analyses given below:

ANALYSES OF TALC AND STEATITE.

<table>
<tr><th>Locality.</th><th>SiO_2.</th><th>Al_2O_3.</th><th>FeO.</th><th>MgO.</th><th>CaO.</th><th>MnO.</th><th>Na_2O.</th><th>K_2O.</th><th>H_2O.</th><th>Totals.</th></tr>
<tr><td>St. Lawrence Co., New York.</td><td>60.59</td><td>0.13</td><td>0.21</td><td>34.72</td><td>.....</td><td>1.16</td><td>.....</td><td>.....</td><td>3.77</td><td>100.58</td></tr>
<tr><td>Do</td><td>62.10</td><td>.....</td><td>1.30</td><td>32.40</td><td>.....</td><td>2.15</td><td>.....</td><td>.....</td><td>2.05</td><td>100.00</td></tr>
<tr><td>Hewitt Mine, N. Carolina</td><td>61.35</td><td>4.42</td><td>1.68</td><td>26.03</td><td>0.82</td><td>.....</td><td>0.62</td><td>.....</td><td>.....</td><td>100.07</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">0.17</td><td></td><td></td></tr>
<tr><td>Luzenach, France</td><td>61.85</td><td>2.61</td><td>0.25</td><td>34.52</td><td>Trace</td><td>.....</td><td>.....</td><td>.....</td><td>0.60</td><td>100.00</td></tr>
<tr><td>Valley of Pignerolles, Italy</td><td>60.60</td><td>0.30</td><td>0.60</td><td>35.30</td><td>0.40</td><td>.....</td><td>2.80</td><td>.....</td><td>Not determined.</td><td>100.00</td></tr>
</table>

The following analyses of soapstone have been made in the laboratory of the U. S. National Museum:

ANALYSES OF SOAPSTONE.

Locality.	SiO_2.	Al_2O_3.	FeO.	MgO.	CaO.	MnO.	Na_2O.	K_2O.	H_2O.	Totals.
Francestown, New Hampshire	42.43	6.08	13.07	25.71	3.27	Trace	0.16	0.32	8.45	99.49
Grafton, Vermont	51.20	5.22	8.45	26.79	1.17	0.32	.....	.....	6.90	100.05
Dana, Massachusetts	38.37	5.64	8.86	28.62	3.90	Trace	.....	.....	14.49	99.88
Baltimore County, Maryland	52.70	5.57	7.63	26.88	1.77	.....	.....	.....	5.48	100.03
Guilford Co., North Carolina	40.03	10.86	9.59	26.97	1.70	.....	.....	.....	10.78	99.93
Lafayette, Pennsylvania	33.47	0.45	7.38	33.72	1.34	0.21	.....	.....	23.00	99.57

Occurrence and origin.—Talc in all its forms is presumably always a secondary mineral, a product of alteration of other magnesian silicates. If resulting from the alteration of a pure enstatite, the process might be illustrated as follows: $4(MgSi)O_{12}+H_2O+CO_2=H_2Mg_3Si_4O_{12}+MgCO_3$, or, if from tremolite, as follows: $CaMg_3Si_4O_{12}+H_2O+CO_2=H_2Mg_3Si_4O_{12}+CaCO_3$. In the large majority of cases it is safe to assume that the alteration is from minerals carrying more or less alumina and iron, in which case the latter may separate out as an oxide or may remain, replacing a portion of

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[1] Rocks, Rockweathering, and Soils, 2d ed., p. 95.

the lime or magnesia, in any case a less pure variety of talc resulting.

New York.—Talc in quantities sufficient to be of commercial importance occurs in beds intercalated in schistose Azoic limestones in the towns of Edwards and Fowler, near Gouverneur in St. Lawrence County. The beds dip with the inclosing rock at a high angle, the individual "veins" varying from a few inches to 20 feet in width. The mineral, which is regarded by Smyth[1] as an alteration product of schistose aggregates of enstatite, or perhaps tremolite, is mainly in the form known as agalite and rensselaerite, the one a smooth, fibrous variety and the other foliated and lamellar, either being of a beautiful white color. Masses of unaltered tremolite still occur imbedded in the talc, which also at times carries a small amount of quartz. These are the largest and most extensively worked deposits at present known within the limits of the United States.

Virginia.—Numerous deposits of talc occur in Fairfax County, Virginia, the material being invariably associated with lenses of dioritic or gabbroic rock in such a manner as to indicate that they originated through the alteration of the more basic, non-feldspathic portions of these intrusives. The mineral is mainly in schistose and somewhat fibrous form and is found in very indefinitely outlined lenses extending with their longer axes in a northeast-southwest direction conforming closely with the general strike and dip of the inclosing rock. The lenses or pockets of commercial material are of comparatively limited extent, but a few feet in width, though they may be reaching to a depth beyond practical mining. The bodies of good, gritless material wedge out, often quite abruptly, and become interleaved with harder, amphibolic and chloritic minerals, wholly without discernable law or system. Small cross veins sometimes occur, which are filled with light-green, foliated talc. Such are, however, too small to be taken into account in working.

The mining is carried on by a system of comparatively shallow open trenches which are abandoned when through the presence of water or deterioration of product they became unprofitable. The material found near Wiehle and Hunter's Station is used largely in foundry work.

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[1] Fifteenth Annual Report of the State Geologist of New York, 1895.

The Carolinas.—In western North Carolina and northern Georgia, particularly in Cherokee and Swain counties in the first-named State, and in the Cohutta Mountains of Murray County in the last, are numerous beds of very clean white or greenish fibrous talc occurring in part, at least, in connection with the marble beds. Some of the material is soft, white, and almost translucent, while other is tough and semi-translucent, horn-like. The beds are mostly very irregular in extent as well as in quality of material.

According to Dr. Pratt the talc formation begins in Swain County about six miles east of the Valley River Mountains, following up the valley of the Nantehala to near the Macon County line, whence it ascends Nelson Creek ravine, crossing the mountain at Red Marble Gap. Entering Cherokee County it then follows Valley River, crossing it and the Hiawassee near Murphy and following thence the Nottely River Valley into Georgia. The country rock of the talc region is mainly marble and quartzite, bordered by gneiss and crystalline schists, the talc itself occurring in connection with the marble and lying for the most part directly between the marble and quartzite, but sometimes inclosed wholly in the marble. The material is found in lenticular masses and is of good quality only where the beds have been protected by the capping of quartzite; elsewhere it is more or less stained by iron oxides, and otherwise injured. There is a considerable variation in the character of the talc throughout the region. To the east of Red Marble Gap it is of a bluish-white color and much of it sufficiently compact to allow of its being cut and used for slate pencils; that to the west is of a pale greenish-white to bluish-white color, and more fibrous and foliated. All the varieties are regarded by Pratt as alteration products of tremolite.

Soapstone occurs mainly associated with the older crystalline rocks and in some cases is undoubtedly an altered eruptive; in others there is a possibility of its being a product of metamorphism of magnesian sedimentaries. The principal beds now known lie in the Appalachian regions of the eastern United States, though others have recently been found in California, and there is no reason for supposing that many more may not exist in the Rocky Mountain regions. The beds, if such they can be called, are not extensive, as a rule, but occur in lenticular masses of uncertain age intercalated with other magnesian and hornblendic or micaceous rocks frequently more or less admixed with serpentine. The rock, like serpentine, is traversed by bad seams and joints, and the opening of any new deposit is always attended with more or less risk, as there is no guarantee that sound blocks of sufficient size to be of value will ever be obtainable.

Localities.—An extensive bed of fine quality soapstone was discovered as early as 1794 at Francestown, New Hampshire. This was worked as early as 1802, and up to 1867 some 5,500 tons had been quarried and sold. Other beds, constituting a part of the same formation, occur in Weare, Warner, Canterbury, and Richmond, in the same State. All of these have been operated to a greater or less extent.

Fine beds of the stone also occur in the town of Orford, and an important quarry was opened as early as 1855 in Haverhill, but it has not been worked continuously.

At least sixty beds of soapstone are stated[1] to occur in Vermont, mostly located along the east side of the Green Mountain range, and extending nearly the entire length of the State. The rock occurs associated with serpentine and hornblende, and the beds, as a rule, are not continuous for any distance, but have a great thickness in comparison with their length. Several isolated outcrops may occur on the same line of strata, perhaps miles apart, in many cases alternating with beds of dolomitic limestone.

Beds occur in the towns of Readsboro, Marlboro, New Fane, Windham, Townsend, Athens, Grafton, Andover, Chester, Cavendish, Baltimore, Ludlow, Plymouth, Bridgewater, Thetford, Bethel, Rochester, Warren, Braintree, Waitsfield, Moretown, Duxbury, Waterbury, Bolton, Stow, Cambridge, Waterville, Berkshire, Eden, Lowell, Belvidere, Johnson, Enosburg, Westfield, Richford, Troy, and Jay. Of these those of Grafton and Athens are stated to have been longest worked and to have produced the most stone. The beds lie in gneiss. Another important bed occurs in the town of Weatherfield. This, like that of Grafton, is situated in gneiss, and the material can be had in inexhaustible quantities. It was first worked

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[1] Geology of Vermont, 1861, Vols. I and II.

about 1847. The Rochester beds were at one time of great importance, the stone being peculiarly fine grained and compact. It was once much used in the manufacture of refrigerators. The bed at New Fane occurs in connection with serpentine, and is some half mile in length by not less than 12 rods in width at its northern extremity.

In Massachusetts quarries of soapstone have been worked from time to time in Lynnfield and North Dana. The Lynnfield stone occurs associated with serpentine. It has not been quarried of late, but was formerly used for stove backs, sills, and steps. In New York State soapstone and talc occur in abundance near Fowler and Edwards in St. Lawrence County. Some of this is very pure, nearly snow-white talc, and is quarried and pulverized for commercial purposes, as already noted.

In Pennsylvania, in the southern edge of Montgomery County, extending from the northern brow of Chestnut Hill between the two turnpikes acrosss the Wissahickon Creek and the Schuylkill to a point about a mile west of Marion Square, there occurs a long, straight outcrop of steatite and serpentine. The eastern and central part of this belt on the southern side consists chiefly of steatite, while the northern side contains much serpentine, interspersed through it in lumps. Only in a few neighborhoods, as at LaFayette, does either the steatitie or serpentine occur in a state of sufficient purity to be profitably quaried. (Plate XIX.) On the east bank of the Schuylkill, about 2 miles below Spring Mill, a good quality of material occurs that has long been successfully worked. The material is now used principally for stoves, fireplaces, and furnaces, though toward the end of the eighteenth century and during the early part of the nineteenth, before the introduction of the Montgomery County marble, it was in considerable demand for doorsteps and sills. It proved poorly adapted for this purpose, owing to the unequal hardness of the different constituents, the soapstone wearing away rapidly, while the serpentine was left projecting like knots, or "hobnails in a plank."

Several small deposits of soapstone occur in Maryland, and some of them have been worked on a small scale. The material is of good quality, but apparently to be had only in small pieces.

In Virginia soapstone occurs in Fairfax, Fluvanna, and Buckingham counties. There is also a bed at Alberene, Albemarle County, a little west of Green Mountain. This is the bed so extensively worked by the Alberene Soapstone Company. From these points the beds extend in a southwesterly direction through Nelson County, where they are associated with serpentine; thence across the James River above Lynchburg, and present an outcrop about 2 miles west of the town on the road leading to Liberty; also one some 2½ miles west of New London. Continuing in the same direction the bed is seen at the meadows of Goose Creek, where it has been quarried to some extent. Parallel ranges or soapstone appear near the Pigg River in Franklin County. About 30 miles southwest from Richmond, at Chula, in Amelia County, there are outcrops of soapstone said to be of fine quality, and in former times quite extensively operated by the Indians. They have been reopened within a few years and the material is now on the market.

North Carolina contains, in addition to an abundance of the finest grades of talc and steatite as already noted, beds of the compact common soapstone. Deposits in Cherokee and Moore counties furnish especially desirable material for lubricating and other purposes. Murphy, Guilford, Ashe, and Alamance counties are also capable of affording good materials, but much of it is inaccessible at present on account of poor railroad facilities.

Beds of soapstone are stated to occur in Saline County, Arkansas, and in Chester, Spartanburg, Union, Pickens, Oconee, Anderson, Abbeville, Kershaw, Fairfield, and Richmond counties in South Carolina. Llano County, Texas, and Santa Catalina Island, California, also contain good material of this nature.

Uses.—The uses to which talc and soapstone are put vary greatly according to purity and physical characteristics. The white, fibrous talc, from St. Lawrence County, New York, is used as a filler in paper manufacture, something like 30 per cent of the weight of printing paper being made up of this material. Pulverized talc is also used as a lubricator, for which purpose it is remarkably well adapted. Rubbed between the thumb and finger the powder is smooth and oily, without a particle of grit. It is also used in soap making, for which purpose it can, however, be considered only as an adulterant, increasing the weight but not the cleaning

PLATE XIX.
Soapstone Quarry, Lafayette, Pennsylvania.
[U. S. National Museum.]

[Facing page 214.]

properties of the article. It is further used as a dressing for fine leathers, and in considerable quantities in foundry work. Small quantities are used by shoe and glove dealers, and large quantities in the form of "talcum powder" for toilet purposes. The pure creamy-white talc, such as is obtained from North Carolina, is used for crayons and slate pencils, while the still finer, crypto-crystalline varieties are used by tailors under the name of French chalk and for making the tips for gas burners. Fine compact grades of a somewhat similar rock (agalmatolite) are used extensively in China and Japan for small ornaments. The stone is readily carved in fine sharp lines, and is a general favorite for making the grotesque images for which these countries are noted, and which are often sold throughout the country under the name of jadestone.

The following account of the soapstone industry of China is taken from the Engineering and Mining Journal of September 30, 1893. The material referred to as soapstone is, however, very probably agalmatolite.

"The mines are distant 42 miles from Wenchow, and are reached by a boat journey of 35 miles up the river, followed by a land journey of 7 miles over rough ground. The hills containing steatite are owned by 20 to 30 families, who in some cases work the mines themselves, in others engage miners to do it on their account. The galleries are driven into the sides of the hills, and are often nearly a mile in length. The stone when first extracted is soft, hardening on exposure to the air. It is brought out of the mine in shovels, and is sold at the pit mouth to the carvers at a uniform price of about one-half a penny per pound. This when the purchaser buys it in gross. When picked over the mineral varies very considerably in value—according to the color, size of the lump, or its shape. The colors are given as purple, red, mottled red, black, dark blue, light blue, gray, white, eggshell-white, 'jade,' beeswax, and 'frozen.' Of these 'jade' (the white variety, not the green) and 'frozen' are the most valuable. The industry finds employment for some 2,000 miners and carvers. A great impetus was given to it by the opening of Wenchow to foreign trade. Previous to that event the chief purchasers were officials and literary men, and the article most often carved was a stamp or seal. When it was discovered that foreigners admired the stone, articles were produced to meet what was supposed to be their taste. Such were landscapes in low or high relief, flower vases, plates, card trays, fruit dishes, cups, teapots, and pagodas. If left to his own devices the native carver proceeds first to examine his stone, much as a cameo cutter would do, to discover how best he can take advantage of its shape and shades of color." (See further under Agalmatolite.)

The soapstones are suited for a considerable range of application. Although so soft, they are among the most indestructible and lasting of rocks, but are too slippery and perhaps of too somber a color for general structural purposes. At present the chief use of the material in the United States is in the form of thin slabs for sinks, stationary washtubs, laboratory fittings, and electric switchboards. At one time it was quite extensively used throughout New England in the manufacture of stoves for heating purposes and to some extent for fire-brick, the well-seasoned stone being thoroughly fireproof. The putting upon the market of unseasoned materials or of material with bad veins, which caused the stone to crack or perhaps fly to fragments when subjected to high temperature, aroused a prejudice against the employment of this material, and the manufacture is stated to have been to a considerable extent discontinued as a consequence. In the manufacture of either stoves or washtubs, slabs of considerable size, free from segregation nodules of quartz, pyrite, or other minerals, or from dry seams, are essential. As but few of the now known outcrops can furnish material of this nature, the main part of the business of the country is in the hands of but two or three companies. The waste material from the quarries, or the entire output in certain cases, is pulverized and used as a lubricant or white earth, as is the micaceous variety.

13. PYROPHYLLITE; AGALMATOLITE; AND PINITE (IN PART).

This is a hydrous silicate of aluminum corresponding to the formula H_2O, Al_2O_3, $4SiO_2$. The analyses given below show the average composition of the material as it occurs in nature:

Locality.	Silica.	Alumina.	Water.	Remarks.
Westanå, Sweden	65.61	26.09	7.08	With small amounts of iron, magnesia, and lime.
China	66.38	27.95	5.20	
Deep River, North Carolina	65.93	29.54	5.40	

The mineral is not known in distinct crystals, but occurs rather in foliated lamellar, massive and compact forms, closely resembling some forms of talc, for which its soapy or greasy feeling renders it very likely to be mistaken, though its hardness (2 to 2.5) is somewhat greater. The prevailing colors are white or greenish gray and dull red, variously mottled.

Occurrence.—The principal localities furnishing pyrophyllite in any considerable quantities in the United States are in the extreme north-central portion of Moore County and the south-central portion of Chatham County, North Carolina. The deposits are associated with slates, but usually separated from them by bands of siliceous and iron breccia from 100 to 150 feet in thickness. The formation has a strike of approximately 55°–60° E. and dips 60°–70°+NW., and has been traced for a distance of upward of 6 miles. Some of the bands are highly siliceous and of poor quality. Others are entirely free from grit. Small seams of quartz often penetrate the bed, and occasional particles of chlorite and hematite occur, giving the material a speckled appearance. Of the 500 feet maximum thickness of the bed not over 100 feet are workable, and of this not more than 25 per cent can be expected to prove merchantable.[1]

Uses.—The more compact varieties, like that of Deep River, are used for making slate pencils and tailors' chalk, or French chalk, so-called. The still more compact forms, known as agalmatolite and pagodite, are used extensively by the Chinese and Japanese for making small images and art objects of various kinds. Dana states, however, that a part of the so-called Chinese agalmatolite is in reality pinite and a part steatite. The objects sold by Chinese dealers at the various expositions of late years under the name of jadestone are, however, of agalmatolite.

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[1] J. H. Pratt, Economic Paper No. 3, North Carolina Geological Survey, 1900.

Pinite: Agalmatolite in part. Composition, a hydrous silicate of aluminum and the alkalies. According to Dana,[1] the name is made to include a large number of alteration products of white spodumene, nepheline, feldspar, etc. Professor Heddle has described [2] a pinite (agalmatolite) occurring in large lumps of a sea-green color, surrounding crystalline masses of feldspar in the granites of Scotland, and which he regards as alteration products of oligoclase. The composition as given is: Silica, 48.72 per cent; alumina, 31.56 per cent; ferric oxide, 2.43 per cent; magnesia, 1.81 per cent; potash, 9.48 per cent; soda, 0.31 per cent; water, 5.75 per cent.

14. SEPIOLITE; MEERSCHAUM.

This mineral is a hydrous silicate of magnesia, having the composition indicated by the formula $H_4Mg_2Si_3O_{10}$, = silica, 60.8 per cent; magnesia, 27.1 per cent; water, 12.1 per cent. The prevailing colors are white or grayish, sometimes with a faint yellowish, reddish, or bluish-green tinge. It is sufficiently soft to be impressed by the nail, opaque, with a compact structure, smooth feel, and somewhat clay-like aspect; rarely it shows a fibrous structure. In nature it rarely occurs in a state of absolute purity. The first three of the following analyses are quoted from Dana's Mineralogy:

Locality.	SiO_2.	MgO.	FeO.	H_2O.	CO_2.
Turkey	61.17	28.43	0.06	9.83	0.67
Greece	61.30	28.39	0.08	9.74	0.56
Utah (fibrous)	52.97	22.50	CuO 0.87	9.90	Hygroscopic H_2O 8.80
New Mexico	57.10	27.16	Trace	14.78	

The name is from the German words *Meer*, sea, and *Schaum*, foam, in allusion to its appearance. The chief commercial localities are in Asia Minor, Bosnia, and New Mexico.

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[1] System of Mineralogy, 6th ed., p. 621.

[2] Mineralogical Magazine, IV, p. 215.

Mode of occurrence and origin.—According to J. Lawrence Smith,[1] the Asiatic material occurs in the form of nodular masses in alluvial deposits on the plain of Eski-Shehr. It was thought by him to owe its origin to the carbonate of magnesia derived from the adjacent mountains, decomposed after its separation by waters containing silica. This supposition he based in part upon the presence of the carbonate in variable amounts in the sepiolite nodules, and in part upon their association, even in the same mass, with serpentine. In the light of to-day it would seem more probable that the serpentine was itself a product of alteration of an igneous magnesian rock (peridotite) and the sepiolite and magnesite ($MgCO_3$) incidental products, or perhaps products of a further alteration of the serpentine in its turn. F. Katzer describes[2] the Bosnian material as likewise occurring in form of lumps and masses irregularly distributed throughout a Tertiary conglomerate, and also in lumps, veins and aggregates in serpentine, the last named rock being derived from a bronzite peridotite. He conceives the alteration (serpentinization) to have been brought about through the agency of water-carrying carbonic acid, a part of the magnesia separating out as a carbonate, while a smaller portion combined with silica and water to form the sepiolite.

In an article in the Cyclopedia of Arts and Sciences it is stated that the meerschaum of the Crimea forms a stratum some 2 feet thick beneath a much thicker stratum of marl. Cleveland in his elementary treatise on minerals (1822) states that at Anatolia, in Asia Minor, meerschaum occurs in the form of a vein more than 6 feet wide (?), in compact limestone. At Vallecas, Spain, a very impure form is stated to occur in the form of beds and in such abundance as to be utilized for building material. Aside from the localities above mentioned, sepiolite is known to occur in Greece, at Hrubschitz in Moravia, and in Morocco, in all cases being associated with serpentine, with which it is apparently genetically related.

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[1] American Journal of Science, 1849, VIII, p. 285.

[2] Berg- u. Hüttenmänn. Jahrb., LVII, p. 65, Abstr. in Chem. Abstr., III, October 10, 1909, p. 2287.

According to Kunz,[1] meerschaum has occasionally been met with in compact masses of smooth, earthy texture in the serpentine quarries of West Nottingham Township, Chester County, Pennsylvania. Only a few pieces were found, but they were of good quality. It also occurs in grayish and yellowish masses in the serpentine in Concord, Delaware County, Pennsylvania. Masses of pure white material, weighing a pound each, have been found in Middletown, in the same county, and of equally good quality at the Cheever Iron Mine, Richmond, Massachusetts, in pieces over an inch across, also in serpentine at New Rochelle, Westchester County, New York. Two localities for meerschaum have of late years been exploited in the upper Gila valley of New Mexico, one some 23 miles northeast of Silver City, on Alunogen Creek and the other about 12 miles northwest of the same city, in the cañon of Bear Creek. The rock forming the walls of this cañon, and in which the meerschaum occurs, is a gray cherty limestone of supposed Ordovician Age, with intercalated strata of sandstone. The meerschaum is reported [2] as occurring in veins, lenses, seams, and balls, all but the last named filling fractures and joints in the limestone. Chert is a common gangue mineral, and with it occur quartz, calcite and clay. Two types or varieties of material are found: One in the form of irregular nodules of all sizes up to several inches in diameter, having an uneven fracture, and somewhat fibrous, leathery, porous structure, and the other in a more massive form and compact nature. The origin of the material seems to not have been worked out, nor has the commercial value of the deposit yet been fully demonstrated. The analysis given on p. 218 is of a sample from the Dorsey claim on Bear Creek.

Uses.—The mineral owes its chief value to its adaptability for smokers' use, being utilized in the manufacture of what are known as meerschaum pipes. In Algeria a soft variety is used in place of soap at the Moorish baths and for washing linen.

According to a writer in the Engineering and Mining Journal,[3] the Eski-Shehr mineral is mined from pits and horizontal galleries in

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[1] Gems and Precious Stones, p. 189.

[2] D. B. Sterrett, Bulletin No. 340, U. S. Geological Survey.

[3] Volume LIX, 1895, p. 464.

PLATE XX.
Kaolin Pit, Delaware County, Pennsylvania.
[From a photograph.]

[Facing page 220.]

much the same manner as coal. As first brought to the surface it is white, with a yellowish tint, and is covered with red clayey soil. In this condition it is sold to dealers on the spot. Before exporting the material is cleaned, dried, and assorted, the drying taking place in the open air, without artificial heat in summer, and requiring from five to six days. The bulk of the material is sent direct to Vienna and Paris.

15. CLAYS.

The term clay as commonly used is made to comprise materials of widely diverse origin and mineral and chemical composition, but which have in common the property of plasticity when wet, and that of becoming indurated when dried either by natural or artificial means. Of so variable a nature is the material thus classed that no brief definition can be given that is at all satisfactory. One may perhaps describe the clays, as a whole, as heterogeneous aggregates of hydrous and anhydrous aluminous silicates, free silica, and ever-varying quantities of free iron oxides and calcium and magnesian carbonates, all in a finely comminuted condition.

Origin and mode of occurrence.—The clays are invariably of secondary origin—that is, they result from the decomposition of pre-existing rocks and minerals and the accumulation of their less soluble residues, either in place (residual clays) or through the transporting power of ice and water (drift clays). That silicate of aluminum is so characteristic a constituent of nearly all clays is due to the fact that this substance is one of the most insoluble of natural compounds, and hence when, under the action of atmospheric or subterranean agencies, rocks decompose and their more soluble constituents—as lime, magnesia, potash, soda, or even silica—are removed, the aluminous silicate remains.

The kaolins, which may be regarded as the simplest of clays, are the product, mainly at least, of the decomposition of feldspars, a form of decomposition which consists essentially of hydration and a more or less complete removal of the lime and alkalies and a part of the silica. The following tables show the composition of the common feldspars and the approximate loss and gain of material they undergo in passing into the condition of kaolin. The formula $Si_2O_9Al_2H_4$ given is, it should be noted, that of the mineral kaolinite, of which the material kaolin is commonly regarded as an impure form.

		SiO_2	Al_2O_3	K_2O	H_2O	%
1.	Orthoclase	64.86	18.29	16.85	.....	100.00
	Lost	43.24	.....	16.85	.....	60.09
	Taken up	.....	.....	.....	6.45	6.45
	Kaolinite	21.62	18.29	.....	6.45	46.36

		SiO_2	Al_2O_3	Na_2O	H_2O	%
2.	Albite	68.81	19.40	11.79	.....	100.00
	Lost	45.87	.....	11.79	.....	57.66
	Taken up	.....	.....	.....	6.85	6.85
	Kaolinite	22.94	19.40	.....	6.85	49.19

		SiO_2	Al_2O_3	CaO	H_2O	%
3.	Anorthite	43.30	36.63	20.07	.....	100.00
	Lost	.....	.....	20.07	.....	20.07
	Taken up	.....	.....	.....	12.92	12.92
	Kaolinite	43.30	36.63	.....	12.92	92.85

From this it appears that, in the case of orthoclase and albite, two-thirds of the silica and all the alkalies are removed. In all, over half of the feldspathic constituents are lost during the transition, while, in the anorthite, only the lime is carried away. The proportional loss and gain is shown as follows:

Orthoclase.. $2Si_3O_8AlK - 4SiO_2 - K_2O + 2H_2O = Si_2O_9Al_2H_4$.
Albite ...... $2Si_3O_8AlNa - 4SiO_2 - Na_2O + 2H_2O = Si_2O_9Al_2H_4$.
Anorthite... $Si_2O_8Al_2Ca - CaO + 2H_2O = Si_2O_9Al_2H_4$.

In other words, two molecules of albite or orthoclase are necessary for the formation of one molecule of kaolin, while, in the case of anorthite, one molecule is sufficient to produce one molecule of kaolin.

As to the method by which this decomposition is brought about authorities differ. It has been commonly assumed that the same was a purely superficial phenomenon, a form of weathering. The observed frequent asociation of kaolin with fluorine minerals led von Buch and Daubrée to suggest that in certain instances the *kaolinization*, as this form of decomposition is called, might be due to exhalations of fluorhydric acid. J. H. Collins showed by experiment the possibility of such an origin, and was led to think, in the case of veins and bands sometimes extending far below the drainage level, no other conclusion was tenable.[1] Dr. Heinrich Ries, in a paper read before the American Ceramic Society in 1900, gave it as his opinion that the kaolins of Cornwall (England) and possibly those of Zettlitz in Bohemia were of deep-seated origin and due to fluoric exhalations, as noted above. Recently H. Rösler has come forward with an apparently exhaustive paper in which he advocates this origin for all kaolins.[2] Inasmuch, however, as many American kaolins do not occur in veins, but so far as observed are merely superficial phases of granitic decomposition, so far-reaching a conclusion cannot at present be accepted unqualifiedly. The fact that a large portion of American kaolin deposits occur, so far as known, in regions south of the glacial limit seems to substantiate the prevailing opinion that such are due to long-continued—secular—decay of rock masses through the action of heat and cold, moisture and the carbonic acid of rainfalls, in short are due to weathering processes, as are many of the common clays. It has been repeatedly shown that rocks of any type containing aluminous silicates will on prolonged decomposition through atmospheric influences break down into clayey soils and clays, the nature of which is dependent to a considerable extent upon the character of the parent rock. Such are the residual clays of non-glaciated regions, and of limestone caves, and perhaps also the so-called Indianaite of Lawrence County, Indiana.[3]

The assorting and transporting power of running waters rarely allows beds of kaolin or other residual clays to remain in a condition of virgin purity or even in the place of their origin. The minute size and the shape of the constituent particles are such as to render them easy of transportation by rains and running streams to be redeposited in regularly stratified and laminated beds when the streams lose their carrying power by flowing into lakes and seas. It is through such agencies that have been formed the bedded Leda and Champlain clays of the glacial period, the Cretaceous

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[1] Mineralogical Magazine, VII, 1886–87, p. 217.

[2] Neues Jahrb. für Min. Geol. u. Pal. XV Beilage-Band, 2. Heft, 1902.

[3] See Rocks, Rockweathering, and Soils, 2d ed., pp. 150–273.

clays of New Jersey and the fire clays of the Coal Measures, though their original constituents may have been of purely chemical or of mechanical origin.

The glacial clays of Wisconsin have been described by Chamberlain as owing their origin mainly to the mechanical grinding of glacial ice upon strata of limestone, sandstone, and shale, resulting in a comminuted product that now contains from 25 to 50 per cent of carbonates of lime and magnesia. This product of glacial grinding was separated from the mixed stony clays produced by the same action by water either immediately upon its formation or in the lacustrine epoch closely following. The process of separation must have been rapid and comparatively free from the agency of carbonated waters, otherwise the lime and magnesia would have been leached out.

The formation of beds of clay has been confined to no particular period of the earth's history, but has evidently gone on ever since the first rocks were formed and when rock decomposition began. The older beds are as a rule greatly indurated and otherwise altered, and in many instances no longer recognizable as clays at all. Throughout the Appalachian region clay beds of Cambrian and Silurian ages have, by the squeezing and shearing incident to the elevation of this mountain system, become converted into argillites and roofing slates.

Mineral and chemical composition.—Formed thus in a variety of ways, and consisting frequently of materials brought from diverse sources, it is easy to comprehend that the substances ordinarily grouped under the name of clay may vary widely in both mineral and chemical composition. It may be said at the outset that the statement so frequently made to the effect that kaolinite or even kaolin is the basis of all clays is not well substantiated.

Kaolinite is in itself not properly a clay, nor is it plastic. Further, in many cases it is present only in non-essential quantities. More open to criticism yet, because more concise, is the statement sometimes made that clay is a hydrated silicate of alumina having the formula $Al_2O_3,2SiO_2+2H_2O$. It is doubtful if, with the exception of kaolin and halloysite, a clay exists which could be reduced to such a formula excepting by a liberal exercise of the imagination.

There is scarcely one of the silicate minerals that will not when sufficiently finely comminuted yield a substance possessing those peculiar physical properties of unctuous feel, plasticity, color, and odor which are the only constant characteristics of the multitudinous and heterogeneous compounds known as clays.[1] Daubrée, as long ago as 1878,[2] pointed out the fact that by the mechanical trituration of feldspars in a revolving cylinder with water, an impalpable mud was obtained, which remained many days in suspension, and on drying formed masses so hard as to be broken only with a hammer, resembling the argillites of the Coal Measures.

The kaolins, when examined under the microscope, are found to consist largely of extremely minute colorless shreds of material which may be kaolinite; intermixed with this are fragments of undecomposed feldspars and particles of quartz and other refractory minerals as tourmaline, iron ores, mica, etc., that were constituents of the parent rock and have escaped decomposition. The ordinary residual clays have a yet more indefinite composition, as a rule are more or less ferruginous and contain sand particles, grains of magnetite, titanic iron, garnet, rutile or any of the less destructible minerals. The drift or transported clays are like heterogeneous aggregates. Prof. W. O. Crosby has shown that the ordinary glacial Champlain or Leda clays of Cambridge, Massachusetts, contain but from one-fourth to one-third their bulk of what he designates "true clay," the remainder being finely comminuted material of various kinds which he calls rock flour. The brick clays at Lewiston and vicinity contain, as shown by the microscope, a comparatively small amount of material that can be designated kaolin, but carry particles of free quartz, scales of mica, bits of still undecomposed feldspar and other silicate minerals, and more rarely tourmaline, etc. Many of these clays are highly calcareous, also—indeed

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[1] Referring to the odor of clay when a shower of rain first begins to wet a dry, clayey soil, Mr. C. Tomlinson has remarked that it is commonly attributed to alumina, and yet pure alumina gives off no odor when breathed upon or wetted. The fact is, the peculiar odor referred to belongs only to impure clays, and chiefly to those that contain oxide of iron. (Proceedings of the Geological Association, I, p. 242; quoted in Woodward's Geology of England and Wales, p. 439.)

[2] Geologie Expérimentale, 1879, p. 251.

both lime and magnesia, in the form of carbonate, are common constituents of any but the residual clays. The alkalies potash and soda are also common constituents, though occurring as silicates in the undecomposed residual material. Iron in some of its forms, as hydrated oxide, carbonate or sulphide, is an almost universal constituent of clays of all kinds.

The above remarks will explain why a purely chemical analysis of a clay may be of little value for the purpose of ascertaining its suitability for any particular purpose. It is essential that we know not merely the presence or absence of certain elements, but also how these elements are combined. Further than this, except in brick and tile making, few clays are used in their natural condition, being first purified by washing or mixed with other constituents to give them body or fire-resisting properties.

Kinds and classification.—From a geological standpoint the clays may be divided into two general classes, as above noted, (1) residual, and (2) transported, the first class including a majority of the kaolin, halloysite, etc., and the second the ordinary brick and potters' clays, the loess, adobe, Leda, and the bedded alluvial deposits of the Cretaceous, Carboniferous, and other geological periods. Special names, based upon such properties as render them peculiarly adapted to economic purposes, are common. We thus have (1) the kaolin and China clay, (2) potters' clay, (3) pipe clay, (4) fire clay, (5) brick tile, and terra cotta clays, etc., (6) slip clays, (7) adobe, and (8) fullers' earth. These will be discussed in the order given, though they must necessarily be discussed but briefly, since the subject of clays alone could be made to far exceed the entire limits of the present volume. The names fat and lean clays are workmen's terms for clays relatively pure and plastic or carrying a large amount of mechanical admixtures, such as quartz sand. The term ganister is sometimes applied to a siliceous fire-clay or a mixture of fire-clay and sand used for refractory purposes in steel and iron works.[1]

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[1] The name is somewhat loosely applied, and incapable of exact definition. Page, in his dictionary of terms, defines it as "The local name for a fine hard-grained grit which occurs under certain coal beds in Derbyshire, Yorkshire, and the north of England."

(1) China clays.—Under the name of kaolin, or China clay, it is customary to include a white pulverulent highly plastic material, resulting from feldspathic decomposition, and used in the manufacture of the finer grades of porcelain and china ware. The name kaolin, as applied, is due to a misconception, the material being supposed to be similar to that obtained by the Chinese at Kaoling (Highridge), and from which was made the high grades of Chinese porcelain.

According to Richthofen,[1] however, the material from which the porcelain of King-te-chin is made is not kaolin at all, as the word is now used, but a hard greenish rock which occurs intercalated between beds of clay slate. He says:

"This rock is reduced, by stamping, to a white powder, of which the finest portion is ingeniously and repeatedly separated. This is then molded into small bricks. The Chinese distinguish chiefly two kinds of this mineral. Either of them is sold in King-te-chin in the shape of bricks, and as either is a white earth, they offer no visible differences. They are made at different places, in the manner described, by pounding hard rock, but the aspect of the rock is nearly alike in both cases. For one of these two kinds of material, the place Kaoling ('high ridge') was in ancient times in high repute; and though it has lost its prestige since centuries, the Chinese still designate by the name 'Kao-ling' the kind of earth which was formerly derived from there, but is now prepared in other places. The application of the name by Berzelius to porcelain earth was made on the erroneous supposition that the white earth which he received from a member of one of the embassies occurred naturally in this state. The second kind of material bears the name Pe-tun-tse ('white clay')."

The following analysis will serve to show the average composition of (1) the natural material from King-te-Chin, such as is used in the manufacture of the finest porcelain; (II) that from the same locality used in the so-called blue Canton ware; (III) that of the English Cornish or Cornwall stone; (IV) washed kaolin from

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[1] American Journal of Science, 1871, p. 180.

St. Yrieux, France, and (V) washed kaolin from Hockessin, Delaware.[1]

Constituents.	I.	II.	III.	IV.	V.
Silica	73.55	73.55	73.57	48.68	48.73
Alumina	21.09	18.98	16.47	36.92	37.02
Ferric oxide	....	....	.27	....	.79
Lime	2.55	1.58	1.17	....	.16
Magnesia	.15	1.08	.21	.52	.11
Potash	....	.46	5.84	.58	.41
Soda	....	2.09			.04
Combined water	2.62	1.96	2.45	13.13	12.83
Total	99.62	99.70	99.98	99.83	100.09

Plate XXI, Figs. 1 and 2, will serve to show the shape and kind of the particles in the mineral kaolinite and in a prepared sample of the Hockessin kaolin, as seen under the microscope.

The name halloysite is given to a white or yellowish material closely simulating kaolin in composition, but occurring in indurated masses, with a greasy feel and luster, and which adheres strongly to the tongue, a property due to its capacity for absorbing moisture.[2] As it is utilized for much the same purpose as is kaolin, it is included here.

Halloysite is described by Gibson[3] as occurring in a bed some 3 feet in thickness, lying near the base of the Lower Siliceous (L. Carboniferous) formation, a little above or close to the Black Shale (Devonian), in Murphrees Valley, Alabama. This bed has been worked with satisfactory results near Valley Head, in Dekalb County. The present writer has found the material in comparatively small quantities, associated with kaolin, in narrow veins in the decomposing gneissic rock near Stone Mountain, Georgia. A

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[1] Analyses I and II by J. E. Whitfield, Bulletin 27, U. S. Geological Survey; III from Langenbeck's Chemistry of Pottery; IV from Zirkel's Lehrbuch der Petrographie, III, p. 758, and V by George Steiger, U. S. Geological Survey.

[2] This property is characteristic of nearly all clay compounds when they are dry. It is to this same property that many of the so-called "madstones" owe their imaginary virtues. Nearly all the stones of this type examined by the writer have proved to be of indurated clay, halloysite, or a closely related compound. When applied to a fresh wound, such adhere until they become saturated with moisture, when they fall away. Their curative powers are of course wholly imaginary.

[3] Geological Survey of Alabama. Report on Murphrees Valley, 1893, p. 121.

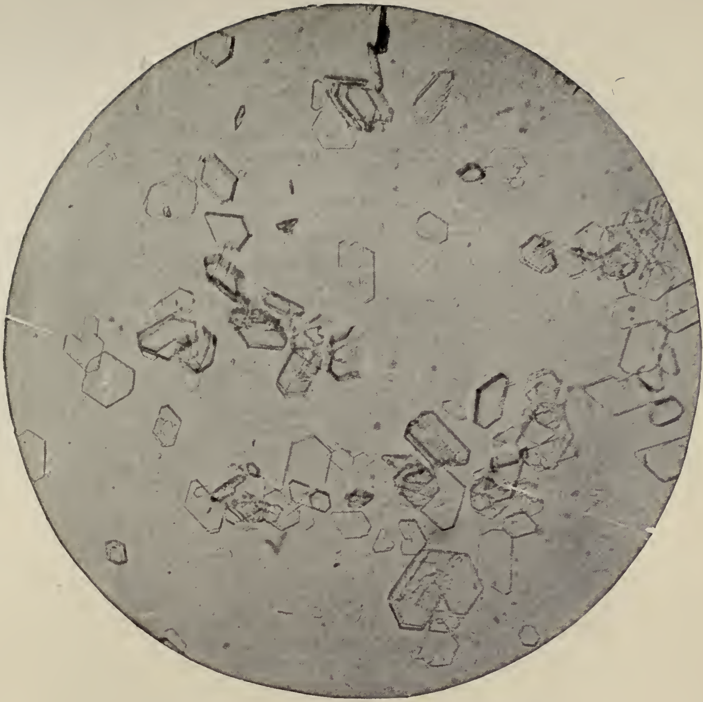

FIG. 1.

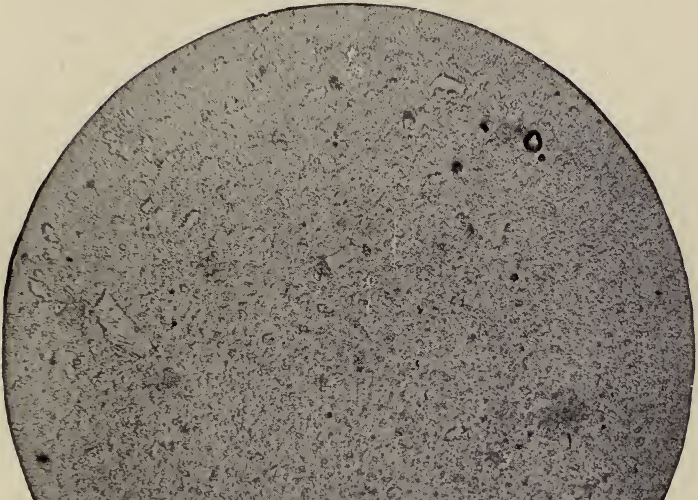

FIG. 2.

PLATE XXI.

FIG. 1, Kaolinite, and FIG. 2, Washed Kaolin as Seen under the Microscope.
[U. S. National Museum.]

[*Facing page* 228.]

similar occurrence is described near Elgin, Scotland. Near Tüffer, Styria, halloysite is described[1] as occurring in extensive thick and veinlike agglomerations in porphyry. It is quite pure, and in the form of irregular nodules of various sizes, frequently with a pellucid, steatite-like central nucleus, passing outwardly into a pure white substance, greasy to the touch, in which are occasionally included minute pellucid granules. Outside it passes into an earthy, friable substance. The following analyses show the varying composition of halloysite from (I) Elgin, Scotland, (II) Steinbruck, Styria, and (III) Detroit Mine, Mono Lake, California:

Constituents.	I.	II.	III.
Silica	39.30	40.7	42.91
Alumina	38.52	38.40	38.4
Lime	0.75	0.60	0.6
Magnesia	0.83	1.50	1.5
Ferric oxide	1.42	....	Trace.
Manganese	0.25	....	....
Water	19.34	18.00	18.00
		99.20	

A white chalky halloysite from the pits of the Frio Kaolin Mining Company in Edwards County, Texas, has the composition given below as shown by analyses made in the laboratory of the department of Geology in the National Museum:

Constituents.	Per Cent.
Silica	45.82
Alumina	39.77
Potash	0.30
Ignition	13.38
	99.27

The material is somewhat variable, corresponding in composition to the halloysite described by Dana, and being, in part, non-plastic, and in part plastic to an extraordinary degree. The plastic portions are almost as gritless as starch paste. Its appearance under the microscope is shown in Plate XXII, Fig. 1, the interspaces of the

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[1] Mineralogical Magazine, II, 1878, p. 264.

visible angular particles being occupied by the pasty, almost amorphous material. The particles themselves act very faintly on polarized light, and it is not possible to determine their mineralogical nature by optical means alone. Much of the material is evidently of a colloidal nature.

The name Indianaite was given by Cox to a variety of halloysite found in Lawrence County, Indiana, and regarded by him as resulting from the decomposition of Archimedes (Lower Carboniferous) limestone. It is represented as forming a stratum from 6 to 10 feet thick, underlying a massive bed of Coal Measure conglomerate 100 feet thick and overlying a bed of limonite 2 to 5 feet thick. The material like kaolin is used in the manufacture of porcelain ware. The composition as given by Dana is as follows: Silica 39 per cent, alumina 36 per cent, water 23.50 per cent, lime and magnesia 0.63 per cent, alkalies 0.54 per cent, total 99.67 per cent.

(2) The potters' and (3) pipe clays belong mainly to what are known geologically as bedded clays, and are as a rule very siliceous compounds, carrying in some instances as much as 50 per cent of free quartz and 6 to 10 per cent of iron oxides and other impurities. They are highly plastic and of a white to blue, gray, or brown color and burn gray, brown, or red. The tables on page 248 will show the varying composition of materials thus classed.

(4) The fire clays, so called on account of their refractory nature, differ mainly in the small percentages of lime and the alkalies they carry, and to the absence of which they owe their refractory properties.

The bedded clays include also most of the brick, tile, and terra cotta clays. In the United States they reach their maximum development in strata of Cretaceous and Carboniferous ages. To the Cretaceous age belong the celebrated plastic clays of New Jersey and South Carolina and a very large proportion of the brick, tile, and terra-cotta clays of Delaware,[1] Maryland, and Virginia. The New Jersey beds are very extensively utilized in Middlesex County

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[1] This of course does not include the kaolin deposits of Hockessin, Newcastle County, and similar deposits.

FIG. 1.

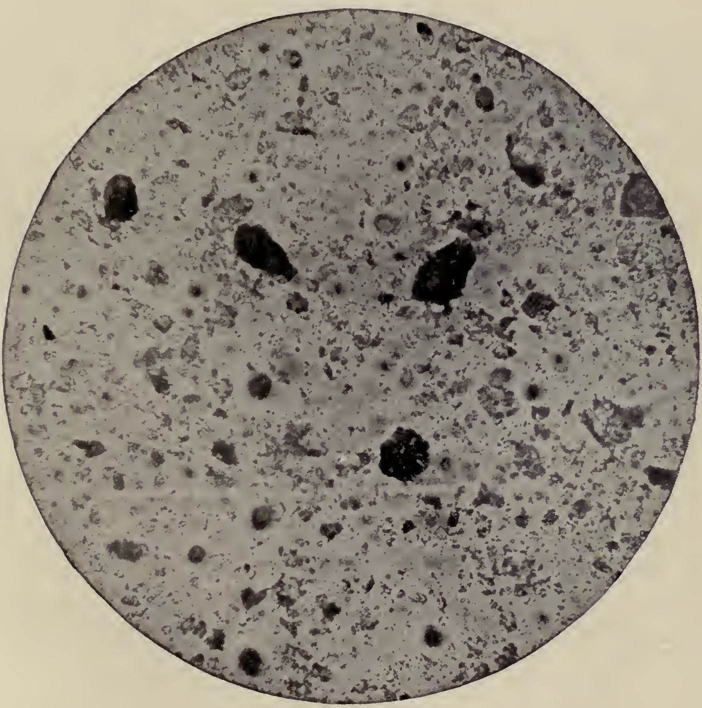

FIG. 2.

PLATE XXII.

FIG. 1, Halloysite, and FIG. 2, Glacial (Leda) Clay, as Seen under the Microscope.
[U. S. National Museum.]

[*Facing page* 230.]

and fully described in the State Geological Reports,[1] from which the following section is taken:

	Feet.
(1) Dark-colored clay (with beds and laminæ of lignite)	50
(2) Sandy clay, with sand in alternate layers	40
(3) Stoneware clay bed	30
(4) Sand and sandy clay (with lignite near the bottom)	50
(5) South Amboy fire-clay bed	20
(6) Sandy clay (generally red or yellow)	3
(7) Sand and kaolin	10
(8) Feldspar bed	5
(9) Micaceous sand bed	20
(10) Laminated clay and sand	30
(11) Pipe clay (top white)	10
(12) Sandy clay (including leaf bed)	5
(13) Woodbridge fire-clay bed	20
(14) Fire-sand bed	15
Raritan clay beds:	
(15) Fire clay	15
(16) Sandy clay	4
(17) Potters' clay	20
Total	347

The Aiken, or Savannah River region of South Carolina furnishes a remarkable illustration of transported or bedded clays free from admixture with foreign materials. These clays are nearly pure kaolin, the materials of which were derived from decomposing granites and brought by easterly flowing rivers of Cretaceous times to be deposited in the quiet marginal waters of the then existing seas. The beds as now uplifted are overlaid by sand and gravels of the Lafayette and other subdivisions of the Pliocene period, and are themselves interbedded with sands and gravels bearing witness to the varying strength of the currents instrumental in their transportation. The material is reported as yielding on analysis: SiO_2 45.02 per cent; Al_2O_3 38.98 per cent; Fe_2O_3 0.77 per cent; FiO_2 0.85 per cent; CaO 0.03 per cent; MgO 0.07 per cent; Na_2O 0.55 per cent; K_2O 0.26 per cent; Ignition 13.58 per cent.[2]

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[1] Report on Clay Deposits of Woodbridge, South Amboy, and other places in New Jersey, 1878.

[2] A Preliminary Report on Clays of South Carolina, by Earle Sloan, 1904.

The following section from Bulletin No. 3 of the Geological Survey of Missouri will serve to show the alternating character of the Coal Measure clays at St. Louis and their varying qualities as indicated by the uses to which they are put:[1]

"(1) Loess, 20 feet.

"(2) Limestone (Coal Measure), 5 feet.

"(3) Clay, white and yellow, used for sewer-pipe manufacture, called 'bastard fire clay,' 3 to 4 feet.

"(4) Clay, yellow and red, sold for paint manufacture and for coloring plaster and mortar, called 'ochre,' 3 feet.

"(5) Clay, gray to white, used for paint manufacture and filling, 1 foot 6 inches.

"(6) Pipe clay, variegated, reddish brown and greenish, called 'keel,' 12 feet.

"(7) Sandstone.

"(8) Slaty shale.

"(9) Coal.

"(10) Fire clay, becoming sandy toward the base."

When first mined these Coal Measure clays are usually very hard, but on exposure to the weather slake and fall into powder. They are as a rule much less fusible than are the glacial clays, and are used mainly in the manufacture of fire brick, sewer pipe, terra-cotta stoneware, as crocks, fruit jars, jugs, etc., glass and gas retorts, smelting pots, etc. Some of these articles are made direct from the natural clays, while others are from a mixture of several clays or of a clay mixed with powdered quartz and feldspar.

(5) For ordinary brick-making purposes a great variety of materials are employed; in some cases residuary deposits, and in others alluvial and sedimentary. Throughout the glacial regions of the United States a fine unctuous blue-gray material, laid down in estuaries during the Champlain epoch, the so-called Leda clays, are the main materials used for this purpose. The bowlder clays of the glacial regions are also sometimes used when sufficiently homogeneous.

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[1] Bulletin No. 3, Geological Survey of Missouri, 1890.

PLATE XXIII.
Bed of Glacial (Leda) Clay, Lewiston, Maine.
[From a photograph by L. H. Merrill.]

[*Facing page 232.*]

The prevailing colors of the Leda clays are blue-gray below the zone of oxidation and yellowish or brownish above. They all carry varying amounts of iron, lime, magnesia, and the alkalies, and when burned turn to red of varying tints. They fuse with comparative ease and are used, aside from brick and tile making, for the coarser forms of earthenware, as flower pots, being as a rule mixed with siliceous sand to counteract shrinkage. The mining of such material is of the simplest kind, and consists merely of scraping away the overlying soil and sand, if such there be, and removing the clay in the form of sidehill cuts or open pits.

Plate XXIII, facing page 232, shows a cut in one of the beds at Lewiston, Maine. The material here is fine and homogeneous, of a blue-gray color, and contains no appreciable grit. It is mixed with siliceous sand and used for making bricks, baking red. An analysis of the material in its air-dry state yielded results as below:

Constituents.	Percentages.
Silica (SiO_2)	56.17
Alumina (Al_2O_3)	24.25
Ferrous oxide (FeO)	3.54
Lime (CaO)	2.09
Magnesia (MgO)	2.57
Potash (K_2O)	4.06
Soda (Na_2O)	2.25
Ignition (H_2O)	4.69
	99.62

The appearance of the Lewiston clay under the microscope is shown in Plate XXIII, Fig. 2.

Leda clays from Beaver County, Pennsylvania, used in the manufacture of terra cotta at New Brighton, are reported[1] as having the following composition:

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[1] Second Geological Survey of Pennsylvania, Report of Chemical Analyses, p. 257.

Constituents.	Percentages.	
Silica	46.160	67.780
Alumina.	26.976	16.290
Sesquioxide of iron	7.214	4.570
Titanic acid	.740	.780
Lime.	2.210	.600
Magnesia.	1.520	.727
Alkalies.	3.246	2.001
Water.	11.220	6.340
Total.	99.286	99.088

Vitrified brick for street pavements are made from fusible clays, sometimes in their natural condition and sometimes mixtures of ground shale and clay.

The following analyses are given of the materials used by the Onondaga Vitrified Pressed Brick Company, of New York:[1]

Constituents.	Calcareous layer in shale bank.	A green brick; being a mixture of the different shales.	Red shale.	Blue shale.	Clay.
Silica.	25.40	54.25	52.30	57.79	45.35
Alumina	9.46	16.89	18.85	16.15	12.19
Peroxide of iron	2.24	5.81	6.55	5.20	4.41
Lime	22.81	4.34	3.36	2.73	10.99
Magnesia	10.39	5.21	4.49	4.67	6.38
Carbonic acid	20.96	4.30	3.04	3.42	7.24
Potash.	.95	2.95	4.65	4.11	3.26
Soda.	....	.83	1.35	1.22	1.14
Water and organic matter	7.60	5.01	5.30	4.50	8.90
Oxide of manganese	....	....	Trace.	Trace.	....
Total.	99.81	99.59	99.89	99.79	99.86

(6) The name slip clay is given to a readily fusible, impalpably fine clay used for imparting a glaze to earthenware vessels. These clays carry iron oxides, potash, and soda, together with lime and magnesia, in such proportions that they vitrify readily, forming thus an impervious glass over those portions of the ware to which they are applied.

The following analyses show (I) the composition of a slip clay used in pottery works in Akron, Ohio, and (II) one from Albany, New York:

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[1] Bulletin of the New York State Museum, III, No. 12, March, 1895. Clay Industries of New York, p. 200.

Constituents.	I.	II.
Silica	60.40	58.54
Alumina	10.42	15.41
Iron sesquioxide	5.36	3.19
Lime	9.88	6.30
Magnesia	4.28	3.40
Alkalies	0.87	4.45
Sulphuric acid	0.65	1.10
Phosphoric acid	0.09	....
Carbonic acid and water	8.05	8.08
Total	100.00	100.47

The Albany clay is stated by Nason[1] to glaze at comparatively low temperatures and to rarely crack or check. It occurs in a stratum 4 to 5 feet thick. It is used very extensively in the United States, and has even been shipped to Germany and France.

(7) The name *adobe* is given to a calcareous clay of a gray-brown or yellowish color, very fine grained and porous, which is sufficiently friable to crumble readily in the fingers, and yet has sufficient coherency to stand for many years in the form of vertical escarpments, without forming appreciable talus slopes. It is in common use throughout Arizona, New Mexico, and Mexico proper for building material, the dry adobe being first mixed with water, pressed in rough rectangular wooden molds some 10 by 18 or more inches and 3 or 4 inches deep, and then dried in the sun. In some cases chopped straw is mixed with it to increase its tenacity. Buildings formed of this material endure for generations and even centuries in arid climates. The material of the adobe is derived from the waste of the surrounding mountain slopes, the disintegration being mainly mechanical. According to Prof. I. C. Russell it is assorted and spread out over the valley bottoms by ephemeral streams. It consists of a great variety of minerals, among which quartz is conspicuous. The chemical nature of the adobes varies widely, as would naturally be expected, and as is shown in the following analyses from Professor Russell's paper:[2]

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[1] Forty-seventh Annual Report of the State Geologist of New York, 1893, p. 468.

[2] Subaërial Deposits of North America, Geological Magazine, VI, 1889, pp. 289 and 342.

ANALYSES OF ADOBE.

Constituents.	I. Santa Fé, New Mexico.	II. Fort Wingate, New Mexico.	III. Humboldt, Nevada.	IV. Salt Lake City, Utah.
SiO_2	66.69	26.67	44.64	19.24
Al_2O_3	14.16	0.91	13.19	3.26
Fe_2O_3	4.38	0.64	5.12	1.09
MnO	0.09	Trace.	0.13	Trace.
CaO	2.49	36.40	13.91	38.94
MgO	1.28	0.51	2.96	2.75
K_2O	1.21	Trace.	1.71	Trace.
Na_2O	0.67	Trace.	0.59	Trace.
CO_2	0.77	25.84	8.55	29.57
P_2O_5	0.29	0.75	0.94	0.23
SO_3	0.41	0.82	0.64	0.53
Cl.	0.34	0.07	0.14	0.11
H_2O	4.94	2.26	3.84	1.67
Organic matter	2.00	5.10	3.43	2.96
Total.	99.72	99.97	99.79	100.35

(8) The name *loess* is given to certain Quaternary surface deposits closely simulating adobe, but concerning the origin of which there has been considerable dispute. Deposits in the United States are, according to the best authorities, or subaqueous origin. Clays of this nature are, as a rule, higher in silica than the adobes and correspondingly poorer in alumina. Loess is a common surface deposit throughout the Mississippi Valley, and is in many instances of such consistency as to be utilized for brickmaking.

The analyses given on p. 237 are from Professor Russell's paper.

Properties of Clays.—The cause of the peculiar properties of clays, particularly those of plasticity and induration, cannot as yet be said to have been fully explained. Various explanations have been made with reference to plasticity, but none which have proven to be conclusive. It has been ascribed to the alumina, to the combined water and the shape and size of the constituent particles and to the presence of colloidal matter, but no one quality seems to cover all cases, and in the end it will probably be shown that there are many phases of plasticity due perhaps to as many causes. Cook thought to show[1] that some of the non-plastic clays which become plastic on kneading were

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[1] Report on Clay Deposits, Geological Survey of New Jersey.

ANALYSES OF THE LOESS OF THE MISSISSIPPI VALLEY.

Constituents.	No. 1.	No. 2.	No. 3.	No. 4.
SiO_2	72.68	64.61	74.46	60.69
Al_2O_3	12.03	10.64	12.26	7.95
Fe_2O_3	3.53	2.61	3.25	2.61
FeO	0.96	0.51	0.12	0.67
TiO_2	0.72	0.40	0.14	0.52
P_2O_5	0.23	0.06	0.09	0.13
MnO	0.06	0.05	0.02	0.12
CaO	1.59	5.41	1.69	8.96
MgO	1.11	3.69	1.12	4.56
Na_2O	1.68	1.35	1.43	1.17
K_2O	2.13	2.06	1.83	1.08
H_2O	[a]2.50	[a]2.05	[a]2.70	[a]1.14
CO_2	0.39	6.31	0.49	9.63
SO_3	0.51	0.11	0.06	0.12
C.	0.09	0.13	0.12	0.19
Total.	100.21	99.99	99.78	99.54

[a] Contains H of organic matter, dried at 100° C.

composed of masses of hexagonal plates or scales piled up in long bundles, and that the kneading necessary to produce plasticity broke up the bundles leaving a homogeneous matrix of crushed material derived therefrom. Subsequent investigation has, however, failed to confirm this view. The presence of combined water has undoubtedly some effect, since clays so highly heated as to drive off this water are no longer plastic. The alumina alone cannot be the cause, otherwise kaolin would be one of the most plastic of clays, which is far from being the case. Moreover there are other hydrous aluminum compounds which are not plastic in the least. According to certain Russian authorities plasticity is due not only to the interlocking of clay particles but varies with the texture, the extremely coarse and fine varieties being less plastic than the intermediate forms. This view has, in the past, been held by Dr. H. Ries and H. A. Wheeler.[1] H. Rösler [2] regards plasticity as due to the flattened form of the constituents, their softness and their fineness, and there is much to support this view.

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[1] Clay Deposits and Clay Industry in North Carolina, Bulletin No. 13, North Carolina Geological Survey, 1897. See also Clays, Occurrences, Properties, and Uses, 1906.

[2] Neues Jahrb. für Min. u. Paleon., Beilage-Band, 2. Heft, Vol. XV, 1902.

So far as the compiler's own observations go, plasticity is not dependent wholly upon hydration nor size nor shape of the constituent particles. The glacial (Leda) clays are made up of fresh, sharply angular particles of various minerals and contain less than 5 per cent combined water; yet in their natural condition they are extremely plastic, and scarcely less so when mixed with two-fifths their bulk of ordinary siliceous sand, as is done in the process of brickmaking. The Albany County, Wyoming, clay, on the other hand, equally or even more plastic and exceedingly pasty, is made up of extremely minute particles of fairly uniform size, scarcely angular, and apparently all of the same mineral (colloidal) nature throughout. This yields some 16 per cent of water, on ignition, as shown in analysis, p. 247. On the whole, the evidence seems to show that the plasticity is due to the manner in which the particles conduct themselves toward moisture, and this is apparently dependent upon the size and shape and the proportional admixture of varying sizes of the constituents rather than upon their chemical composition. The colloidal nature of the constituents of certain clays is undoubtedly an important factor.[1]

The expulsion of the absorbed and combined water in a clay is nearly always accompanied by a diminution in volume, which varies directly as the water, or the purity of the clay. Pure kaolin shrinks as much as one-fourth of its bulk, it is stated, sometimes even more. The sandy clays used in making sewer-pipe and stoneware shrink in the tempered state from one-ninth to one-sixteenth, usually about one-twelfth.

A clay, when all the water of crystallization is expelled, will not shrink any more at red heat, but with increased heat will continue to shrink up to the moment of fusion. A pure kaolin apparently shrinks when heated a second time, even if the water is all expelled by the first heat, yet it is practically impossible to fuse it. But a good flint clay containing some sand will lose all shrinkage on being once calcined at white heat. Such clay is then used to counteract shrinkage in a body of green clay, as is also siliceous sand. Many

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[1] See The Colloidal Matter of Clay and Its Measurement, Bulletin No. 388, U. S. Geological Survey, 1909.

clays contain sand enough naturally and some are so sandy as to actually expand on heating, though usually at the expense of soundness of structure; for the particles of clay will shrink away from the grains of sand, rendering the product very friable.

The refractory or fire-proof property of clay depends largely upon the alumina and silica, and their freedom from all constituents which are fusible in themselves or which would combine with others to form a flux. Pure alumina, or pure quartz alone, is practically infusible. The constituents tending to make a clay fusible are iron, soda, potash, lime, and magnesia. Which of these is the more detrimental it would be difficult to say. Iron is not so powerful a flux as either potash or soda; but on the other hand it is much more abundant, and may moreover impart an unsatisfactory color.

The extent to which iron may be present without detriment is a point on which authorities do not agree. The Stourbridge clay of England has 2.25 per cent of iron, with extremes of 1.43 and 3.63 per cent. Gros Almerode clay has 2.12; Coblentz, 2.03; New Castle, 2.32, and yet all these are famous fire clays. Test mixtures of iron and pure kaolin have been run higher than this and have stood well, but as a general rule it is unsafe to rely for fire qualities on a clay with over 2 per cent of iron, particularly if the other impurities are developed in any amount. It is a well-known principle in chemistry that mixtures of bases are much more active fluxes than an equal amount of any one base; so with iron, its effect shows worse when in presence of other fluxing agents.

The condition of the iron, whether as a sesquioxide or protoxide is also an important matter, the latter form only, it is stated, being likely to combine with the silica, to form silicates.

Sulphide of iron has a bad effect, since its decomposition gives rise to the lower oxide; the effect which the sulphur may have must also receive consideration. Iron in the uncombined state imparts to a piece of ware a buff or red color; when combination begins and progresses the ware becomes of a bluish-gray cast, deepening as the fusion of the iron proceeds, and finally becoming glassy black if much iron is present.

In any but the glacial clays the comparatively small amounts of lime and magnesia present causes them to be but little thought of as detrimental. They occur both as silicates and carbonates. When present as carbonates they combine at a higher temperature than is required for iron or potash. The Milwaukee brick clays, as already noted, carry considerable amounts of carbonates of lime and magnesia, and require a very hot burn, but when once the lime and silica combine they destroy the effect of 5 per cent of iron, and impart a cream color. A brick of this kind presents an even, fine-grained, vitrified appearance on its fracture.[1]

The amount of potash which a clay may contain and keep its fire properties is variously put by different authorities. As with iron, kaolin will stand a good deal when no other base is present, but a multiplicity of bases makes fusion easy. Titanic acid in the form of ilmenite or rutile, is regarded as neutral to fire qualities, being itself practically infusible.

Testing clays.—Knowing the effect of the various constituents in promoting fusion or imparting color changes it might at first thought seem that chemical analyses would serve to indicate the uses to which any clay was best adapted. In practice, however, it is not customary to rely wholly on analyses, but rather to couple them with special tests made to ascertain their strength and fire-resisting properties. Fire tests are of two kinds—one consists in subjecting the clay

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[1] They (lime and magnesia) have also the remarkable property of uniting with the iron ingredient to form a light-colored alumina-lime-magnesia-iron silicate, and thus the product is cream-colored instead of red. Mr. Sweet has shown by analysis that the Milwaukee light-colored brick contain even more iron than the Madison red brick. At numerous points in the Lake region and in the Fox River valley cream-colored brick are made from red clays. In nearly or quite all cases, whatever the original color of the clay, the brick are reddish when partially burned. The explanation seems to be that at a comparatively moderate temperature the iron constituent is deprived of its water and fully oxidized, and is therefore red, while it is only at a relatively high heat that the union with the lime and magnesia takes place, giving rise to the light color. The calcareous and magnesian clays are, therefore, a valuable substitute for true aluminous clays, for they not only bind the mass together more firmly, but give a color which is very generally admired. They have also this practical advantage, that the effects of inadequate burning are made evident in the imperfect development of the cream color, and hence a more carefully burned product is usually secured. It is possible to make a light-colored brick from a clay which usually burns red by adding lime. The amount of lime and magnesia in the Milwaukee brick is about 25 per cent. In the original clays in the form of carbonates they make up about 40 per cent. (Geology of Wisconsin, I, 1873–79, p. 669.)

to absolute heat without the action of any accompaniments, and the other in putting the clay through the course of treatment for which it is designed to be used. The former develops the absolute quality of the clay as good or bad, the latter proves or disproves the fitness of the clay for any particular work. The latter is better of course as a business test wherever it is practicable to use it. The former can be made only in a specially adapted furnace. The clay in this test is cut into one-inch cubes with square edges, and is set in a covered crucible resting on a lump of clay of its own kind, so that it touches no foreign object. The heat is then applied, and its effect will vary from fusing the mass to a button to leaving it with edges sharp and not even glazed on the surface. Experience soon renders one proficient in judging of clays by this test.[1]

A method of testing the fusibility of clays by comparing them with samples of known composition and fusibility has of late years come into extensive use. These prepared samples, known from their inventor and their shape as Seger's pyramids, or cones, consist of mixtures in varying proportions of kaolin and certain fluxes, so prepared that there is a constant difference between their fusing points. When such cones, together with the samples to be tested, are placed in a furnace or kiln, they begin to soften as the temperature is raised, and as it approaches their fusion points the cones bend over until the tip is as low as the base. When this occurs the temperature at which they fuse is considered to have been reached.[2]

Uses.—Clay when moistened with water is plastic and sufficiently firm to be fashioned into any form desired. It can be shaped by the hands alone; by the hands applied to the clay as it turns with the potter's wheel, or it can be shaped by molds, presses, or tools. When shaped and dried, and then burned in an oven or kiln, it becomes firm and solid, like stone; water will not soften it, it has entirely lost its plastic property, and is permanently fixed in its new forms, and for its designed uses. These

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[1] Geological Survey of Ohio, Economic Geology, V, pp. 652–655.

[2] See Dr. Ries's paper on North Carolina clays, already quoted, and also his numerous contributions on their subject in the volumes of the United States Geological Survey relating to mineral statistics.

singular and interesting properties are possessed by clay alone, and it is to these it owes its chief utility. It is used (1) for making pottery; (2) for making refractory materials; (3) for making building materials; (4) for miscellaneous purposes.

Pottery.—Clay worked into shapes and burned constitutes earthenware. The ware of itself is porous, and will allow water and soluble substances to soak through it. To make it hold liquids, the shaped clay before burning is covered with some substance that in the burning of the ware will melt and form a glass coating or glazing which will protect the ware, and give it a clean, smooth surface. The color of the ware depends on the nature of the clay. Clays containing oxide of iron burn red, the depth of color depending on the amount of the oxide, even a small fraction of 1 per cent being sufficient to give a buff color.

Clay containing oxide of iron in sufficient quantity to make it partially fusible in the heat required to burn it is called stoneware clay. The heat is carried far enough to fuse the particles together so that the ware is solid and will not allow water to soak through it; but not so far as to alter the shapes of the articles burned. The oxide of iron by the fusion combines with the clay, and instead of its characteristic red, gives to the ware a bluish or grayish color.

Clay which is white in color and entirely free from oxide of iron may be intimately mixed with ground feldspar or other minerals which contain potash enough to make them fusible, and the mixture still be plastic so as to be worked into forms for ware. When burned, such a composition retains its white color, while it undergoes fusion sufficient to make a body that will not absorb water. Ware of this kind is called *porcelain* or *china*.

Refractory materials.—Modern improvements in metallurgy, and furnaces for many other industrial purposes, are dependent to a great degree on having materials for construction which will withstand intense heat without fusing, cracking, or yielding in any way. The two materials to which resort is had in almost all cases are pure aluminous clay, and quartz in the form of sand or rock. They are both infusible in any but the very highest furnace heats. A clay, however, is liable to have in it small quantities of fusible constituents and to shrink when heated to a high temperature. Quartz rocks are liable to crack to pieces if heated too rapidly, and both the rocks and sand are rapidly melted when in contact with alkaline earths, or metallic oxides, at a high temperature. They do not, however, shrink in heating. Bricks to resist intense heat are made of clay, of sand, or of a mixture of clay and sand. The different kinds are specially adapted to different uses.

To make fire bricks a clay which stands an intense heat is selected. This is tempered so that it may not shrink too much or unevenly in burning, by adding to the raw clay a portion of clay which has been burned till it has ceased to shrink and then ground, or a portion of coarse sand, or a quantity of feldspar. These materials are added in the proportions which the experience of the manufacture has found best. The formula for the mixture is the special property of each manufacturer, and is not made public. The materials, being mixed together and properly wet, are molded in the same way as common bricks, and after they have dried a little they are put into a metallic mold and subjected to powerful pressure. They are then taken out, dried, and burned in a kiln at an intense heat.

It does not appear which is the best for tempering, burned and ground clay, or coarse sand, or feldspar. Reputable manufacturers are found who use each of these materials, and make brick that stand fire well.

Fire bricks intended, in addition to their refractory qualities, to retain their size and form under intense heat without shrinkage, have been made to some extent. The English Dinas bricks are of this kind, and the German and French "silica bricks." The Dinas bricks are of quartz sand or crushed rock, and contain very little alumina and about 1 per cent of lime. They stand fire remarkably well, the lime causing the grains of sand to stick together when the bricks are intensely heated. In the other "silica bricks," fire clay to the amount of 5 or 10 per cent is mixed with the sand, the plastic material causing the particles of sand to cohere sufficiently to allow handling before burning.

Paper clay.—Clay which is pure white and that also which is discolored and has been washed to bring it to a uniform shade of color, is used by the manufacturers of paper hangings, to give the smooth satin surface to the finished paper. It is used by mixing it up with a thin size, applying it to the surface of the paper, and then polishing by means of brushes driven by machinery. The finest and most uniformly colored clays only are applicable to this use, and they are selected with great care. Clay is also used to give body and weight to paper. Heavy wrapping paper, such as is used by the United States Post-office Department, must, according to specifications, contain 95 per cent of jute butts and 5 per cent of clay. The cheaper forms of confectionery are very heavily adulterated with this material.

Alum clay.—A large quantity of clay is used for making alum. A rich clay is needed for this purpose.

The white clay of Gay Head and Chilmark, Martha's Vineyard, Massachusetts, was at one time used extensively for alum-making, according to Edward Hitchcock.[1]

As a substitute for sand in making mortar and concrete, clay is perhaps the best material to be found. For this purpose the clay is burnt so that it is produced in small irregular pieces that are very hard and durable. These pieces are then ground to a fairly fine powder, which is mixed with the lime or cement as sand would be. The result is a very strong mortar, in some cases stronger than when sand is employed.[2]

The so-called gumbo clays, sticky, tough, and dark-colored clays of the Chariton River region, Missouri, are hard burned and used for railroad ballast and macadam.

Under the names of *Rock Soap* and *Mineral Soap* there have from time to time been described varieties of clay which, owing to their feeling, are suggestive of soap, and which in a few instances have been actually used in the prparation of this material.

A rock soap from Ventura County, California, has been described by Prof. G. H. Koenig as a mixture of sandy and clayey or soapy material in the proportion of 45 per cent of the first and 55 per cent of the second. The chemical composition of the material and of the two portions is given below:

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[1] American Journal of Science, XXII, 1832, p. 37.

[2] The World's Progress, February, 1893.

Constituents.	Crude material.	Sandy portion.	Soapy portion
Silica	67.55	69.40	73 10
Alumina and iron	12.97	13.50	14 10
Lime	0.77	0.30	Not determined.
Magnesia	0.85	Trace.	
Potash	1.43	4.55	
Soda	3.63		
Water	13.67	12.25	6.70

Nearly all the silica is in a soluble or opalescent state and the alumina either a hydrate or very basic silicate. It is said[1] that at one time the material was made into a variety of useful articles, as "salt water soap," scrubbing and toilet soap, tooth powder, etc.

A somewhat similar material from Elk County, Nevada, has been used for like purposes, and put upon the market under the name of San-too-gah-choi mineral soap. This clay is of a drab color, with a slight pinkish tint, a pronounced soapy feeling and slight alkaline reaction when moistened and placed upon test paper. An analysis by R. L. Packard in the laboratory of the U. S. National Museum yielded:

Constituents.	Per Cent.
Silica	48.80
Alumina	18.57
Iron oxides	3.88
Lime	1.07
Magnesia	2.52
Soda	2.32
Potash	1.12
Ignition	21.13
Total	99.41

Mention may be made here also of the material sold in the shops under the name of Bon Ami, and used for cleansing glass and other like substances. This under the microscope shows abundant mi-

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[1] Sixth Annual Report of the State Mineralogist of California, 1886, Pt. 1, p. 132.

nute sharply angular particles, consisting of partially decomposed feldspar mixed with a completely amorphous mineral which may be opalescent silica or possibly a very finely comminuted pumice. An analysis by R. L. Packard yielded:

Constituents.	Per Cent.
Silica	59.86
Alumina	18.74
Magnesia	0.34
Potash	10.70
Soda	3.51
Ignition	7.67
Total	100.82

Alcohol extracts 7.43 per cent, and water 0.244 per cent in addition, the extract having a soapy appearance and the odor of some essential oil.

A peculiar soapy clay found in Albany, Crook, Weston, and Natrona Counties, Wyoming, has been shipped in considerable quantities during the past few years to Philadelphia, New York, and Chicago, where it was sold under the name of Bentonite at prices varying from $5.00 to $25.00 per ton. It is stated [1] to have been used in paper manufacture, as a packing for horses' feet; for a time as a soap in one of the local railway hotels, and in the making of "antiphlogistine," a substance widely used in the West in the form of a plaster applied to the chest in cases of pneumonia or croup. It has been suggested as admirably suited for use as a "retarder" for the hard-finish plasters now coming into use for walls.

This clay is regarded by T. B. Read as originating through the decomposition of the feldspar labradorite occurring in the anorthosite of the Laramie Mountains. The chief physical characteristic, aside from its soapy feeling, is its enormous absorptive power, the absorption being attended naturally with an increase

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[1] Engineering and Mining Journal, LXIII, 1897, p. 600, LXVI, 1898, p. 491, and LXXVI, 1903, p. 48.

in bulk amounting to several times that of the original mass.[2] Plate XXV, Fig. 1, shows the extreme fineness and homogeneity of this clay as seen under the microscope.

The reported analyses are as follows:

Constituents.	I. Rock Creek.	II. Crook County.	III. Weston County.	IV. Natrona County.
SiO_2	59.78	61.08	63.25	65.24
Al_2O_3	15.10	17.12	12.62	15.88
Fe_2O_3	2.40	3.17	3.70	3.12
MgO	4.14	1.82	3.70	5.34
CaO	0.73	2.69	4.12	5.34
Na_2O, K_2O	(*a*)	*b*0.20	....	(*a*)
SO	(*a*)	0.88	1.53	(*a*)
H_2O	16.26	....	....	9.17
Specific gravity	....	....	2.132	....

a. No estimate. *b*. NaO.

The analyses given on the following pages, compiled from works believed to be authoritative, show the varying character of clays, so far as their chemical composition is concerned. In many of these analyses, it will be observed, the silica existing in the form of quartz is given a separate column from that combined, while in column 4 is given the calculated percentage of kaolin which the analyses seem to indicate each sample contains.

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[1] A small plug of this clay fitted to accurately occupy a space of 20 cubic centimeters in the bottom of a conical measuring-flask, and kept saturated with water for two days, swelled to a bulk of 160 cubic centimeters. The absorption was so complete that none of the water ran off when the flask was inverted, and the condition of the clay resembled that of flour or starch paste.

COMPOSITION OF CLAYS.

Name of Company and Location.	Combined Silica (SiO_2).	Alumina (Al_2O_3).	Combined Water (H_2O).	Per Cent of the Kaolin Base.	Quartz (free SiO_2).	Titanic Acid (TiO_2).	Total Sandy Material.	Sesquioxide of Iron (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Potash (K_2O).	Soda (Na_2O). Lithia (Li_2O).	Total Deleterious Impurity.	Moisture.	Sum Total.
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.
China Clays.															
Kaolin (washed), Hockessin, Newcastle County, Delaware.	40.72	34.10	12.35	87.17	6.50	......	......	2.49	......	0.39	1.64	0.27	4.79	1.35	99.81
China clay, Redruth, Cornwall, England.*	28.40	24.11	7.20	59.71	37.80	0.20	38.00	0.79	......	......	0.96	......	1.75	0.70	100.16
China clay, from Huron, Lawrence County, Indiana.*	40.10	36.35	22.60	99.05	0.40	0.00	0.40	0.15	......	0.13	0.14	......	0.42	.....	99.87
China clay, St. Yrieux, France.	48.37	34.95	12.62	......	....	......	......	1.26	......	......	2.40		......	......	... ...
Potters' Clays.															
Brummage's stoneware clay, Roseville, Ohio.†	25.60	19.08	5.57	50.25	43.73	0.29	44.02	1.26	0.60	0.63	2.14	0.02	4.65	0.94	99.86
Walker's stoneware clay, Roseville, Ohio.†	69.79	19.31	5.08	94.18	With clay.	......	......	......	......	......	.....	......	By diff 4.80	0.94	100.00
Uniontown stoneware clay, Perry County, Ohio.†	29.35	23.05	7.39	59.79	35.85	0.55	36.40	0.99	0.58	0.58	1.45	{Tr. Li_2O}	3.60	1.11	100.90
Myers, Atchison & Co., North Springfield, Ohio, stoneware.†	68.24	22.61	5.56	96.41	....	......	......	......	0.99	0.11	.....	......	1.10	1.00	98.51
East Liverpool, Ohio (yellow-ware clay).†	42.28	24.12	7.77	74.17	18.02	1.20	19.22	1.46	0.59	0.68	2.42	Tr.	5.15	0.86	99.40
H. Cutter & Sons, Woodbridge, New Jersey.*	43.90	38.24	14.10	96.24	1.10	1.30	2.40	0.96	0.00	0.11	0.15	0.00	1.22	0.70	100.56
Blue Ball clay, Pennsylvania.†	44.55	39.00	13.66	97.21	....	1.70	......	1.44	0.02	0.07	0.53	......	2.06	.....	100.98

Pipe Clay.															
N. U. Walker, Walker's Station, Ohio (sewer pipe).†	39.03	27.88	8.87	75.08	15.50	1.26	16.76	2.41	0.42	0.68	3.31	0.12	6.94	0.76	99.54
W. H. Evans, Waynesburg, Ohio (drain pipe).†	16.20	15.89	7.07	39.16	52.69	0.16	52.85	2.86	0.59	0.66	2.23	0.29	6.61	1.03	99.65
A. O. Jones, Columbus, Ohio (drain tile).†	14.50	12.63	7.30	34.43	56.80	......	56.80	5.07	1.05	......	......	......	6.12	.....	99.35
Whitmore, Robinson & Co., Akron, Ohio (kaolite slip clay).†	60.40	10.42	H_2SO_4 0.65	H_3PO_4 0.09	CO_2+H_2O 8.05		......	5.36	9.88	4.28	0.87		20.39	.....	100.00
Fire Clay.															
C. E. Holden, Mineral Point, Ohio.†	35.39	31.84	11.68	78.91	17.13	1.68	18.81	0.67	0.50	0.19	0.59	0.00	1.95	0.69	100.36
Scioto Fire Brick Co., Sciotoville, Ohio.†	43.78	40.82	13.77	97.97	....	......	......	With Al_2O_3					......	0.82	98.79
Do.†	52.56	34.80	10.50	97.80	With clay.	......	......	1.00	1.20				2.20	.....	100.00
Wassall Fire Clay Co., Columbus, Ohio.†	60.77	25.74	9.46	95.97	With clay.	......	......	1.61	0.89	0.63	1.20	......	4.33	.....	100.30
Island Fire Clay Co., near Steubenville, Ohio.†	29.22	24.97	8.90	63.09	31.34	1.30	32.64	1.66	0.63	0.40	0.28	Tr.	2.97	1.69	100.39
Etna Fire Brick Co., Oakhill, Ohio.†	63.12	26.20	10.72	100.05	With clay.	......	......	......	......	......	.....	......	......	.....	100.05
Brick Clay.															
Milwaukee brick clay, Wisconsin.†	38.22	9.75	1.85	49.82	....	CaO 3.24	FeO 1.16	2.84	$CaCO_3$ 23.20	$MgCO_3$ 15.83	2.16	0.65	49.07	0.95	99.84
Mount Savage, Maryland.*	39.90	30.08	7.00	77.58	16.90	1.15	18.05	1.67	......	......	2.30	......	3.97	0.90	100.50
Newcastle, England.†	55.50	27.75	10.57	93.78	....	......	......	2.01	0.67	0.75	2.19	0.44	6.06	.....	99.84
Sayre & Fisher, front brick clay, Sayreville New Jersey.*	28.30	27.42	6.60	62.32	27.80	1.00	28.80	2.68	......	0.18	2.71	......	5.57	2.90	99.59

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* Report on Clay Deposits, Geological Survey of New Jersey.

† Geological Survey of Ohio, Vol. V.

The bibliography of clays is very extensive, and but a few references are given here. The reader is referred particularly to Branner's Bibliography of Clays and the Ceramic Arts,[1] and to the papers of Dr. H. Ries in the reports on the Mineral Resources of the United States, published annually by the U. S. Geological Survey.

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[1] Bulletin No. 143, U. S. Geological Survey, 1896.

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16. FULLERS' EARTH.

The name fullers' earth is made to include a variety of clay-like materials of a prevailing greenish-white or gray, olive or olive-green or brownish color, soft, and with a greasy feel. When placed in water such fall into powder, imparting a slight murkiness to the liquid, but do not become plastic to the same extent as the ordinary clays.

For a long time the principal source of fullers' earth was England, but an increased demand has resulted in the discovery of large quantities on American soil, the more important localities thus far developed being Bakersville, California; Gadsden County, Florida, and Custer County, South Dakota. The more important foreign sources are Bala, in North Wales, and Buckingham and Surrey, in England.

The celebrated beds at Nutfield, near Redhill, Surrey, England, occur in Cretaceous formations, a section of which is here given.[1]

Folkstone beds, gray and iron shot sand		15	ft.
Sandgate beds	Buff sandy clay with greensand	15	"
	Soft sandstone	4	"
	Greenish sandy clay	½	"
	Sandstone	12	"
	Fullers' earth	8	"

The fullers' earth bed sometimes reaches a thickness of 12 feet. The upper portion is, as a rule, oxidized to a brownish color by the action of percolating water, the lower portion being blue. In addition to the analyses given on p. 254 the following are of interest as showing the relative amounts of soluble and insoluble matters.[2]

BLUE EARTH. (Dried at 100° C.)

			Insoluble Residue.	
Insoluble residue	69.96%	=	SiO_2	62.81%
Fe_2O_3	2.48%		Al_2O_3	3.46%
Al_2O_3	3.46%		Fe_2O_3	1.30%
CaO	5.87%		CaO	1.53%
MgO	1.41%		MgO	0.86%
P_2O_5	0.27%			69.96%
SO_3	0.05%			
NaCl	0.05%			
K_2O	0.74%			
H_2O (combined)	15.57%			
	99.86%			

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[1] H. B. Woodward, Geology of England and Wales, p. 371.

[2] P. G. Sanford, Geological Magazine, Vol. VI, 1889, pp. 456 and 526.

FIG. 1.—Fuller's Earth Pit, Quincy, Florida.
[After H. Ries: Clays, Their Properties and Uses.]

FIG. 2.—Phosphate Pit, Florida.
[From a Photograph.]
PLATE XXIV.

[*Facing page* 252.]

YELLOW EARTH. (Dried at 100° C.)

		Insoluble Residue.	
Insoluble residue	76.13% =	SiO_2	59.37%
Fe_2O_3	2.41%	Al_2O_3	10.05%
Al_2O_3	1.77%	Fe_2O_3	3.86%
CaO	4.31%	CaO	1.86%
MgO	1.05%	MgO	1.04%
P_2O_5	0.14%		
SO_3	0.07%		76.18%
NaCl	0.14%		
K_2O	0.84%		
Combined waters	13.19%		
	100.05%		

When examined with a microscope this material is found to consist of extremely irregular corroded particles of a siliceous mineral which in its least altered state is colorless, but which in nearly every case has undergone a chloritic or talcose alteration whereby the particles are converted into a faintly yellowish-green product almost wholly without action, on polarized light. These are of all sizes up to 0.07 mm. The larger portion of the material is made up of particles fairly uniform in size and about the dimensions mentioned. In addition to these are minute colorless fragments down to 0.01 mm. in diameter, and even smaller.

The minute size of these colorless particles renders a determination of their mineral nature practically impossible, but the outline of the cleavage flakes is suggestive of a soda lime feldspar. The high percentage of silica in the insoluble residue would indicate the presence of a considerable amount of free quartz. This, however, the microscope only partially substantiates, very few of the particles showing the brilliant polarization colors characteristic of this mineral. (See Plate XXV, Fig. 2.)

The Gadsden County, Florida, earth is a light-gray material, often blackened by organic matter, and shows under the microscope the same greenish, faintly doubly refracting particles, as does the English, intermixed with numerous angular particles of quartz. This earth is quite plastic and sticky when wet. A section of the beds at the pits of the Cheesebrough Manufacturing Company, as given in The Mineral Resources for 1895–96, is as follows:

Soil	18 ins.
Red clay	3 ft.
Blue clay	3 "
Fullers' earth	5½ "
Sandy blue earth	3 "
Fullers' earth (second bed)	Thickness not stated.

The following table[1] as compiled by Dr. Ries shows the variable character of the earth from different sources:

Constituents.	Smectite from Cilly.(*a*)	Fullers' Earth from Reigate.(*b*)	Malthite from Steindörfel.(*c*)	Fullers' Earth from England.(*d*)	Fullers' Earth from England.(*e*)	Fullers' Earth from Gadsden County, Florida.(*f*)	Fullers' Earth from Decatur County, Georgia.(*f*)	Fullers' Earth from Fairborn South Dakato.(*g*)	Fullers' Earth from Southeast of River Junction, Florida.(*h*)	Fullers' Earth from between Mount Pleasant and Norway, Florida.(*i*)	Fullers' Earth from near Norway, Florida.(*j*)
SiO_2	51.21	53.00	50.17	44.00	44.00	62.83	67.46	58.72	50.70	58.30	54.60
Al_2O_3	12.25	10.00	10.66	11.00	23.06	10.35	10.08	16.90	21.07	10.63	10.99
Fe_2O_3	2.07	9.75	3.15	10.00	2.00	2.45	2.49	4.00	6.88	6.72	6.61
CaO	2.13	.50	.25	5.00	4.08	2.43	3.14	4.06	4.40	1.71	6.00
MgO	4.89	1.25	......	2.00	2.00	3.12	4.09	2.56	.30	3.15	3.00
H_2O	27.89	24.00	35.83	.....	24.95	7.72	5.61	8.10	9.60	9.05	10.30
Na_2O	......	.....	......	5.00	......	0.20	...	2.11			
K_2O	......	.....	......	.....	......	0.74	...		......	.....	.....
Moisture	......	.....	......	.....	......	6.41	6.28	2.30	7.90	9.55	7.45
Total	100.44	98.50	100.06	77.00	100.09	96.25	99.15	98.75	100.85	99.11	98.95

(*a*) Pogg. Ann., LXXVII, 1849, p. 591.
(*b*) Klaproth. Beitr., Vol. IV. 1807, p. 338.
(*c*) Dana, System of Min., 1893, p. 695.
(*d*) Geikie, 1893, p. 133.
(*e*) Penny Encyclopedia, XI, Dr. Thompson, analyst.
(*f*) P. Fireman, analyst.
(*g*) E. J. Riederer, analyst.
(*h*) Standard Oil Company's property, E. J. Riederer, analyst.
(*i*) Howell property, E. J. Riederer, analyst.
(*j*) Morgan property, E. J. Riederer, analyst.

Uses.—The material was formerly used almost wholly by fullers for removing the grease from cloths. It is now largely used in deodorizing and clarifying fats, oils, and greases. The manufacturers of lard and cottolene are large consumers. Some 2,000 to 3,000 tons are annually imported and 25,000 to 30,000 tons produced in the United States. The value is about $9.00 per ton.

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[1] Seventeenth Annual Report, U. S. Geological Survey, Part III, 1895–96, p. 880

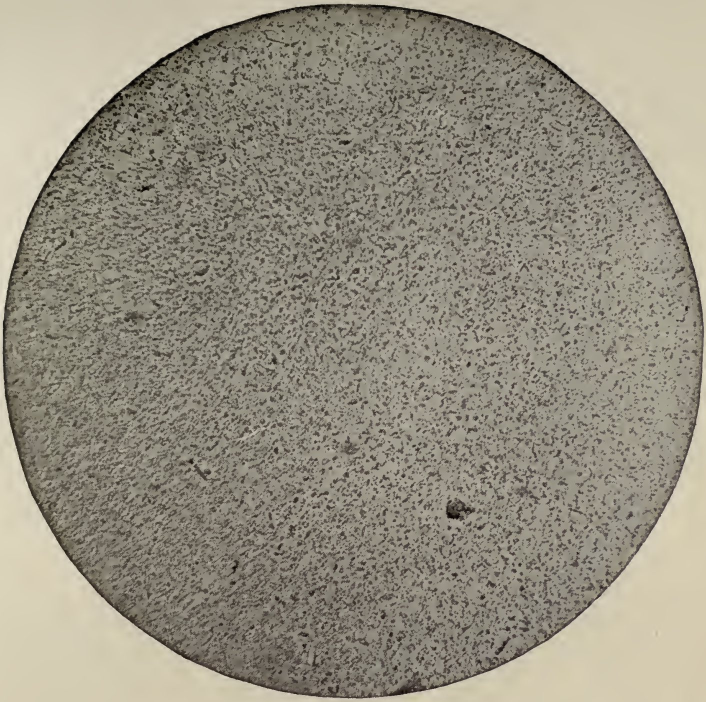

FIG. 1.

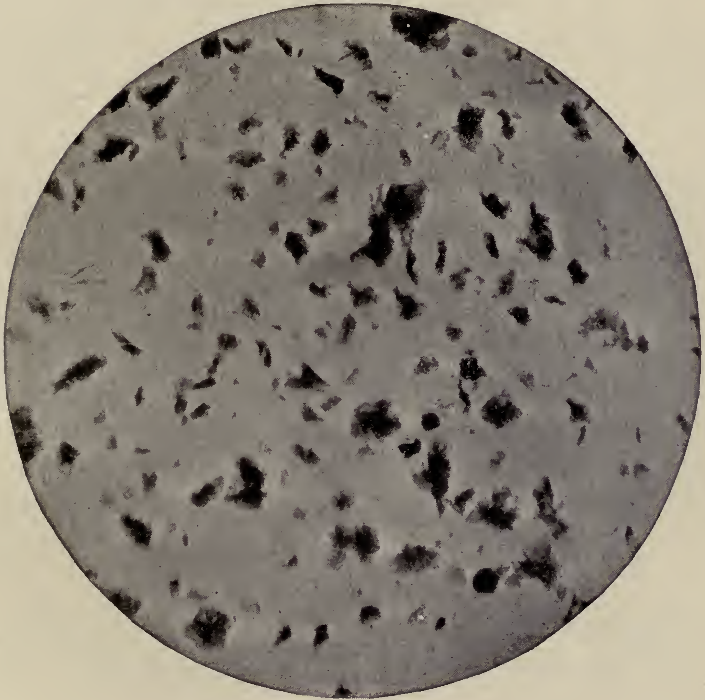

FIG. 2.

PLATE XXV.

FIG. 1, Clay, Albany, Wyoming, and FIG. 2, Fuller's Earth, as Seen under the Microscope.

[U. S. National Museum.]

[*Facing page* 254.]

VII. NIOBATES, TANTALATES, AND TUNGSTATES.

1. COLUMBITE AND TANTALITE.

These minerals are columbates and tantalates of iron and manganese, columbite representing the nearly pure columbate and tantalite the nearly pure tantalate. Both are likely to carry varying quantities of iron and manganese. The analyses given below will serve to show the varying composition, No. I being columbite from Greenland, No. II from Haddam, Connecticut, and Nos. III and IV from the Black Hills of South Dakota:

Constituents.	I.	II.	III.	IV.
Columbium pentoxide....	77.97	51.53	54.09	29.78
Tantalium pentoxide.....	....	28.55	18.20	53.28
Iron protoxide.	17.33	13.54	11.21	6.11
Manganese protoxide. ...	3.28	4.55	7.07	10.40

With traces of tin, wolfram, lime, magnesia, etc.

The minerals are of an iron-black, grayish, or brownish color, opaque, often with a bluish iridescence, dark-red to black streak, specific gravity varying from 5.3 to 7.3 and hardness of 6. Insoluble in acids.

Occurrence.—Columbite occurs in granitic and feldspathic dikes in the form of crystals, crystalline granules, and cleavable masses. In the United States it has been found in greater or less abundance in nearly all the States bordering along the Appalachian Mountain system, in the Black Hills of South Dakota, and also in California and Colorado. It has also been found in Italy, Bavaria, Finland, Greenland, and western South America. Tantalite occurs under similar conditions.

Uses.—The material is used only in the preparation of salts of columbium and tantalium, and is in but little demand, except for mineralogical specimens.

2. YTTROTANTALITE.

This name is given to a mineral closely related to samarskite (see next page), but carrying smaller percentages of uranium and lacking in didymium and lanthanum. It is essentially a tantalate of yttrium with small amounts of other of the rarer earths. In appearance it is distinguished from samarskite only with difficulty. Pyrochlore, fergusonite, æschynite, euxenite, etc., are closely related compounds, the commercial uses of which have not yet been demonstrated.

3. SAMARSKITE.

Composition as given below. When crystallized, in the form of rectangular prisms, but occurring more commonly massive and in flattened granules. Cleavage, imperfect; fracture, conchoidal; brittle. Hardness, 5 to 6; specific gravity, 5.6 to 5.8. Luster, vitreous to resinous. Color, velvet-black. Analyses of North Carolina materials yielded:

Constituents.	I.	II.	III.	IV.
Columbic oxide	54.81	54.96	55.13	37.20
Tantalic oxide				18.60
Tungstic and stannic oxides	....	0.16	0.31	0.08
Uranic oxide	17.03	9.91	10.96	12.46
Ferrous oxide	14.07	14.02	11.74	10.90
Manganous oxide	....	0.91	1.53	0.75
Cerous oxide, etc	3.95	5.17	4.24	4.25
Yttria	11.11	12.84	14.49	14.45
Magnesia	....	....	Trace.	....
Lime	....	0.52	....	0.55
Loss by ignition	0.24	0.66	0.72	1.12
Insoluble	....	1.25	....	....
	101.21	100.40	99.12	100.36

Localities and mode of occurrence.—The only localities of importance in the United States are the Wiseman Mica Mine and Grassy Creek Mine, in Mitchell County, North Carolina. At the Wiseman Mine large masses, one weighing upwards of 20 pounds, were found some years ago. The analyses quoted above were made from material from this mine.[1] The mineral has also been found in Rutherford and McDowell counties.

Uses.—See under Monazite, p. 298.

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[1] See Minerals of North Carolina, Bulletin No. 74, U. S. Geological Survey, 1891.

4. WOLFRAMITE, HÜBNERITE, AND FERBERITE.

Composition.—Wolframite is a tungstate of manganese, and iron. The proportions of the iron and manganese are quite variable, the tungsten remaining nearly constant. The name hübnerite is given to the variety containing very little iron, but consisting essentially of tungsten and manganese. Ferberite is the theoretically pure ferrous tungstate. The following table shows the range in composition:

Locality.	WO_3	FeO.	MnO.	CaO.	MgO.
Wolframite:					
Adun-Chalon	75.55	21.31	2.37	0.26	0.51
Monroe, Connecticut	75.47	9.53	14.26	....	....
Hübnerite:					
Bonita, New Mexico	76.33	3.82	19.72	0.13	Trace.
Nye County, Nevada	74.88	0.56	23.87	0.14	0.08
Ferberite:					
Colorado	74.13	23.15	0.56	1.28	....

These are all dark reddish brown to black in color, with a resinous luster; a hardness of about 5, a specific gravity of 7.55, and a pronounced tendency to cleave with flat, even surfaces. The great weight, color, and cleavage tendencies are strongly marked characteristics, and the minerals once identified are easily recognized.

Occurrence.—The tungstates are found, as a rule, in veins, often associated with tin ores, and also with quartz, pyrite, galena, and sphalerite. The principal known localities in the United States are Boulder and Gilpin counties, Colorado; Monroe and Trumbull counties, Connecticut; Blue Hill Bay, Maine; Rockbridge County, Virginia; Mecklenburg County, North Carolina; The Black Hills, South Dakota; Stevens County, Washington; Russellville, Arizona; Nye, Lanier, and Osceola counties, Nevada; Lincoln County, New Mexico; Falls County, Texas. Wolframite has been also reported from Oregon, Montana, and Idaho. The principal foreign localities are the tin regions of Cornwall, England; Bohemia, Saxony, and Autsralia. It is also found in Peru, Bolivia, and the Argentine Republic.

In the Black Hills region of South Dakota wolframite, according to J. D. Irving,[1] occurs in connection with a crystalline

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[1] Transactions of the American Institute of Mining Engineers, XXXI, 1901, p. 682.

dolomite lying between shales above and quartzite and auriferous gravels below. The dolomite is often highly siliceous, and passes at times through the intermediate stage of a dolomitic sand rock into quartzite, the silicification in such cases seeming to have been contemporaneous with the formation of the ore body. The wolframite itself occurs in flat, horizontal but rather irregular masses of all thicknesses up to 2 feet. Such frequently cover considerable areas, but are so extremely irregular that it is difficult to form exact estimates of their extent.

The ore bodies are intimately associated with the flat masses or chutes of refractory siliceous gold ore, which has been so extensively developed of late years in this region, and which consists of an extremely hard, brittle rock, composed chiefly of secondary silica, carrying pyrite, fluorite, barite, and occasionally gypsum. In the areas where the wolframite is found the siliceous ore is always oxidized and is usually coarse in texture. The ore is generally banded, the banding being continuous with the bedding planes of the adjoining strata, and the chutes occur along lines of fracture termed *verticals*, on either side of which the dolomite has been replaced for a distance varying from a fraction of an inch up to 12 feet.

Investigation of the ore bodies of this type shows that they are replacements of the dolomitic beds by silica, pyrite, and other minerals, the mineralizing waters having gained access to the soluble beds through the fractures above mentioned. At times the wolframite forms a rim around the outer edge of the siliceous ore chutes, often extending inward and upward so as to form a thin capping for the ore. It thus appears as a sort of envelope to the siliceous ore mass which it incloses on all except the lower sides. Margins of this kind are often 2 to 2½ feet thick, though the capping portion is usually thinner. At other times the wolframite occurs in irregular masses scattered through the siliceous ore or in stringers and thin contorted layers in the partially silicified dolomite. In general the ore is separated from the non-mineralized rock by a fairly sharp line of demarkation, but in many instances it grades off so that the ore becomes leaner and passes, by almost imperceptible gradations, into the country rock.

As taken from the mines the wolframite is a dense black massive rock, of fine granular texture and, of course, great weight, closely resembling a fine-grained magnetite, but having a greater specific gravity and slightly brownish streak. An analysis of this ore, as made by W. F. Hillebrand of the U. S. Geological Survey, is given below and also a calculation made from these analyses to show the proportions of the principal minerals contained therein.

As to the source of the ore in these deposits there is some question, but it is thought most probable by Irving that circulating waters permeating the Algonkian rocks below brought the material to its present position, where it was deposited through a process of metasomatic interchange; this being true, this particular deposit would belong to the category of what are known as secondary. Wolframite, it should be stated, is also found at the Etta Tin Mines and at Nigger Hill in the southern portion of the Black Hills, but under totally different conditions, being here a constituent of the pegmatite, and hence a primary mineral.

ANALYSES OF BLACK HILLS WOLFRAMITE ORE.

Constituents.	I.	II.
	Per Cent.	Per Cent.
SiO_2	12.87	9.60
WO_3	61.50	61.70
Fe_2O_3	3.85	12.67*
FeO	9.18	
Al_2O_3	0.52	
MnO	8.21	7.21
CaO	0.93	5.39
SrO	0.02	
BaO	0.04	
$K_2O+Na_2OLi_2O$	0.08	
H_2O	0.20†	
H_2O	0.87‡	
As_2O_5	1.25	
P_2O_5	0.12	
V_2O_5	Trace.	0.10§
S or SO_3	Trace.	
	99.64	

Assays of I.—Gold, 0.05 oz. per ton; silver, 0.25 oz. per ton.
Extremely minute traces of Mg, Zn, Cu, Sb, and Sn were also found.
* Determined as Fe_2O_3, includes FeO.
† Up to 105° C.
‡ Above 105° C.
§ Approximate.

PROPORTIONS OF PRINCIPAL MINERALS.

Constituents	I.	II
Wolframite (FeMn)O.WO_3....	75.60	51.58
Quartz, SiO_2................	12.54	9.60
Scheelite, CaO.WO_3..........	4.77	27.68
Barite, BaO.SO_3.............	0.06	....
Ferric oxide, FeO............	3.85	....
Water, H_2O	0.20	....
Arsenic oxide................	1.25	....
Residual clay (kaolin).........	1.34	....

According to State Commissioner of Mines Harry A. Lee, wolfram occurs in several counties in Colorado. In Boulder and Gilpin counties it has been found in a complex of granite, gneiss, and schist, where it occurs in small pockets or streaks disseminated through fissure veins.

R. D. George states[1] that the ore is largely in the form of ferberite, and the majority of the veins are in granite, though a number of good producing mines are close to the contact between the granite and gneiss, and in some instances in the gneiss itself. The veins, however, seemingly, decrease in productiveness or become quite barren in the more schistose varieties of the rock. Throughout the various areas the veins have no constant trend, the angle of dip is generally steep, often vertical, and rarely falling below 45°. The conditions of vein formation and filling, as outlined, are as follows:

(1) A period of earth movements in which fissures were formed, some of which follow the pegmatite and granite dikes, while others cut the country rock. At the close of the movements these fissures were left partially filled by loose masses of angular rock fragments.

(2) Silica-bearing waters, probably at high temperatures, then circulated through the rock fragments in the fissures, and by a process of replacement feldspars and biotite in the rock fragments were slowly dissolved out and silica in the form of chalcedony-like quartz or hornstone deposited in their place. Locally a small deposition of ferberite accompanied this replacement.

(3) This was followed by a second period of earth movements

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[1] First Report Colorado Geological Survey, 1908, p. 60.

in which the vein breccia, and in places the country rock itself was crushed and mingled into a new mass of fragments. This movement was accompanied by a considerable vertical displacement and dragging along the walls of the veins.

(4) This period was followed by the most important deposition of tungsten. The heated waters, loaded with tungsten salt, rose toward the surface and deposited the ferberite in the interstices of the rock fragments. In places more or less silica was deposited with the ferberite.

(5) Then followed a third movement which crushed the vein filling and added more of the dike rock or country rock to the fragmental mass. This was followed by (6) a second considerable deposition of hornstone silica, and this in turn by (7) a second period of tungsten deposition. Following this there were (8) contemporaneous depositions of silica and tungsten ore and (9) local solutions of the tungsten and deposition of silica, possibly producing a secondary enrichment.

Formed at these various periods there is naturally considerable diversity in the ores. Professor George has grouped them in three rather well-defined forms which frequently grade into one another. These are (1) well-crystallized crusts and layers covering the surface of the rock fragments and cementing them into a breccia; (2) massive, granular ore showing few or no crystal faces and occurring as more dense seams and masses in the wider and less brecciated portions of the veins, and (3) a highly siliceous ore in which the berberite is in fine grains, sometimes showing crystal forms, and scattered throughout hornstone or cryptocrystalline quartz.

The following analyses of material from the Nederland-Beaver Creek area of Colorado, as given by George, are selected as showing the average composition. The CaO is regarded as belonging to admixed scheelite, while the silica, alumina, and magnesia are present as impurities and non-essential:

Localities.	WO_3.	FeO.	MnO.	CaO.	SiO_2.	Al_2O_3.	MgO.
Clyde Mine.....	61.15	19.33	0.51	0.38	16.10	2.42	0.39
Lost Chance Mine.........	62.20	19.90	0.69	0.79	14.68	1.34	....
Manchester Lake	74.13	23.15	0.56	1.28	0.76	0.46	....

In Osceola County, Nevada, tungsten in the form of hübnerite occurs in veins varying from 6 to 36 inches in width, and having a strike north 70° east and a dip of 65° northwest. The veins are in granite with a well-defined selvage and carry quartz as the principal gangue.

The hübnerite is found in crystals and masses with very pronounced cleavage planes from 2 to 4 inches in length and 1 to 3 inches in width. It also occurs in fine grains and irregular bodies, the quartz and hübnerite having apparently been deposited contemporaneously. In a few instances scheelite has been found associated with the hübnerite. A little pyrite and fluorite are also occasionally met with. The ore is stated to have averaged from 65 to 70 per cent of WO_3.[1]

In Arizona, tungsten ore, also in the form of hübnerite, occurs, according to W. P. Blake, in the granite hills of the Dragoon Mountains, about 6 miles north of Dragoon Summit Station on the Southern Pacific Railway in Cochise County.

The veins here are nearly vertical and generally traverse the granite gneiss in the direction of the rude structural bedding planes. They are from a few inches to 2 or 3 feet in width. The gangue material is quartz, throughout which the hübnerite occurs, somewhat irregularly disseminated, sometimes in patches or bunches centrally disposed with quartz on either side, and sometimes disseminated from side to side or in layers or bunches in close contact with the continuous walls. The hübnerite itself is in the form of large tubular blocks or thick plates, often with a somewhat radial arrangement, penetrating the solid gangue of white quartz. Masses of all sizes up to 500 pounds in weight have been reported. The color of the mineral is light brownish red, thin films or plates seen by transmitted light being of a ruby-red color. Aside from quartz, which forms the prevailing gangue mineral, the presence of a little fluorspar and mica has been noted.

A. M. Finlayson describes [2] tungsten ores, both wolframite and

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[1] Fred. D. Smith, Engineering and Mining Journal, March 1, 1902, p. 304; F. B. Weeks, 21st Annual Report of the U. S. Geological Survey, 1899–1900, Part VI, p. 319.

[2] Geological Magazine, January, 1910, p. 20.

scheelite, occurring in small veins in a post Silurian "greisen" in Carrock Fell. This greisen is regarded as an acid modification of the Skiddaw granite, the feldspar of the normal rock having almost wholly disappeared, and a white mica (gilbertite) replacing the biotite, leaving a quartz muscovite aggregate comparable with the greisen of the Saxon mines and having some points in common with the beresite of the Russian Urals and the alaskite of J. E. Spurr. The veins consist essentially of the quartz and white mica mentioned with a pale bluish-green apatite. There is a complete absence of tourmaline, fluorite or other minerals indicative of pneumotolitic action. The wolframite, with a less amount of scheelite, is disseminated irregularly in bunches through the vein. Some arsenopyrite is present and also molybdenite.

Uses.—See under Scheelite, below.

5. SCHEELITE.

This is a calcium tungstate, consisting when pure of some 80.6 per cent tungsten trioxide (WO_3) and 19.4 per cent lime; usually, however, carrying from 1 to 8 per cent of molybdic oxide (MoO_3). The mineral is white and translucent, sometimes yellow and brownish in color, with a hardness of 4.5–5, gravity 6, and a tendency to cleave into octahedral forms.

Scheelite is much less common in its occurrence than wolfram and few localities of any apparent commercial importance have thus far been reported.

A deposit that at one time seemed promising was discovered some years ago near Long Hill Station on the Housatonic Railroad in Trumbull Parish, Fairfield County, about 8 miles from the city of Bridgeport. The country rock is a metamorphic amphibolic gneiss of a dark, blackish color, overlying a crystalline limestone, and this in turn overlying a second hornblendic gneiss, the main mass of the ore being segregated along the line of contact between the limestone and the hornblendic gneiss, the latter being considered as an altered igneous rock and the deposit as a whole, therefore, a contact deposit.

In the main opening the fresh contact rock between the gneiss and the limestone is a massive quartz-zoisite-epidote-hornblende rock, throughout which the scheelite is irregularly disseminated and often scattered in crystalline masses which are sometimes as large as one's fist. Associated with the scheelite is more or less pyrite, and numerous crystals of wolframite which are, however, in all cases pseudomorphous.

A considerable amount of capital has been expended in prospecting and in the erection of works for concentrating, but, so far as the present writer has information, a comparatively small amount of pure scheelite has thus far been produced.

Scheelite has been found in some quantity in gold-bearing veins of the Minnehaha mine in Kern County, California. Two "shoots" of the ore are stated to occur in the veins, the full width of which is from 18 to 20 inches. The hanging wall is of mica schist and the footwall of limestone.[1] Scheelite is also known to occur in quartz veins cutting diorite at Atolia in San Bernardino County, this same State.

Recent reports from the Canadian Department of Mines[2] indicate that the mineral is by no means of rare occurrence in Nova Scotia, British Columbia, and other parts of the dominion. It is found in small, disconnected, lenticular masses, sometimes forming a third or fourth of the filling matter in gold-bearing quartz veins in Halifax County, Nova Scotia. The veins are in slate, of all widths up to 22 inches, approximately parallel, and all in a belt not more than 100 yards in width following the strike of the slate, which is here east and west, with a dip of 80° toward the north. Arsenopyrite is a common associate. In the Barkerville district of British Columbia scheelite occurs associated with iron pyrites and galena in small quartz veins and vugs in mica schist.

Uses.—Tungsten is used mainly in the manufacture of the so-called self-hardening steel, the material being introduced either as a ferro-tungsten or as the powdered mineral. This tungsten steel is said to be particularly adaptable to the manufacture of

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[1] The Mining World, Mar. 31, 1906, p. 414.

[2] Report on Tungsten Ores of Canada, by T. L. Walker, 1909.

cutting tools, which can be used even when heated to temperatures that would destroy the temper of the ordinary carbon steel. Its consideration in this connection belongs properly to works on merallurgy. It is also used in the preparation of tungstic acid and sodium tungstates, and attempts have been made to utilize it in porcelain glazes, though thus far without much success.

The production of tungsten ore of all kinds in the United States during 1908 amounted to some 497 short tons of concentrates, valued at $126,238. The price of the tungsten metal in 1901 varied from 58 to 64 cents per pound, of the ferro-tungsten from 27 to 31 cents per pound. The price of the ore during 1906–08 ranged from $254 to $487 per ton, the ores, as a rule, carrying from 60 to 75 per cent of WO.[1] Prices are based upon the per cent of tungstic oxide, the concentrates being sold by the "unit" of 1 per cent, or 20 pounds per short ton.

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[1] These figures are taken from the Mineral Industry for 1901.

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VIII. PHOSPHATES AND VANADATES.

1. APATITE; ROCK PHOSPHATE; GUANO; ETC.

Phosphorus is one of the most widespread of the elements, and is apparently indispensable to both animal and vegetable life. In nature it occurs in various compounds, by far the more common being the phosphates of calcium and aluminum, such as are commercially used as fertilizers. These in various conditions of impurity occur under several forms, some distinct and well defined, others illy defined and passing by insensible gradations into one another, but all classed under the general term of phosphates. Their origin and general physical properties are quite variable, and any attempt at classifying must be more or less arbitrary. For our present purposes it is sufficient that we treat them under the heads of mineral phosphates and rock phosphates, as has been done by Dr. Penrose.[1] These two classes are then subdivided as below:

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[1] Bulletin No. 46 of the U. S. Geological Survey.

- (I) Mineral phosphates[1]...
  - Apatites.....
    - Fluor-apatites
    - Chlor-apatites.
  - Phosphorite.
- (II) Rock phosphates......
  - Amorphous nodular phosphates loose or cemented into conglomerates.
  - Phosphatic limestones.
  - Guanos......
    - Soluble guanos.
    - Leached guanos.
  - Bone beds.

Apatite.—Under the name of apatite is included a mineral composed essentially of phosphate of lime, though nearly always carrying small amounts of fluorine or chlorine, thereby giving rise to the varieties *fluor-apatite* and *chlor-apatite*. The mineral crystallizes in the hexagonal system, forming well-defined six-sided elongated prisms of a green, blue, yellow, rose, or reddish color, or sometimes quite colorless. It also occurs as a crystalline granular rock mass. The hardness is 4.5 to 5; specific gravity, 3.23; luster, vitreous. Apatite in the form of minute crystals is an almost universal constituent of eruptive rocks of all kinds and all ages. It is also found in sedimentary and metamorphic rocks as a constituent of veins of various kinds, and is a common accompaniment of beds of magnetic iron ores. It is only when occurring segregated in veins and pockets, either in distinct crystals or as massive crystalline aggregates, as in Canada and Norway, that the material has any great economic value. The average composition of the apatites, as given in the latest edition of Dana's Mineralogy, is as follows:

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[1] Fuchs (Notes Sur la Constitution des Gîtes Phosphate de Chaux) divides the natural phosphates into three classes. In the first the phosphatic material is concentrated in sedimentary beds; in the second it is disseminated throughout eruptive rocks, and in the third it constitutes entirely or partially the material filling veins and pockets. That found in sedimentary beds occurs in rounded and concretionary masses called nodules. In eruptive and metamorphic rocks the phosphate occurs in the crystalline form of apatite, sometimes isolated or grouped in aggregates. In veins the phosphate occurs massive and in pockets, crystalline, but not in distinct crystals; rather as globular and radiating masses. To such the name phosphorite is given. The three varieties show a like variation in solubility, the amorphous phosphates being soluble in citrate or oxalate of ammonia to the extent of 30 to 50 per cent; the phosphorites to the extent of only 15 to 30 per cent, and the apatite scarcely at all. The amorphous phosphates alone have proven of value for direct application to soils, the other varieties needing previous treatment to render them soluble.

Variety.	P_2O_5.	CaO.	F.	Cl.	
Chlor-apatite.....	41.0	53.8	....	6.8	or $Ca_3P_2O_8$, 89.4 + CaCl, 10.6.
Fluor-apatite	42.3	55.5	3.8	....	or $Ca_3P_2O_8$, 92.25 + CaF_2, 7.75.

The name *phosphorite* covers a material of the same composition as apatite, but occurring in massive concretionary and mammillary forms. The name was first used by Kirwan in describing the phosphates of Estremadura, Spain, which occur in veins and pockety masses in Silurian schists, as noted later.

Rock Phosphate.—The general name of rock phosphate is given to deposits having no definite composition but consisting of amorphous mixtures of phosphatic and other mineral matter in indefinite proportions. Here would be included the amorphous nodular phosphates like those of our Southern Atlantic States, phosphatic limestones and marls, guano, and bone-bed deposits These are so variable in character that no satisfactory description of them as a whole can be given. The name *coprolite* is given to a nodular phosphate such as occurs among the Carboniferous beds of the Firth of Forth in Scotland, and is regarded as the fossilized excrement of vertebrate animals. Phosphatic limestones and marl, as the names denote, are simply limestones and marls containing an appreciable amount of lime in the form of phosphate. Such are rarely sufficiently rich to be of value except in the immediate vicinity of their occurrence, owing to cost of transportation. Guano is the name given to the accumulations of sea-fowl excretions, such as occur in quantities only in rainless regions, as the western coast of South America. The material is of a white-gray and yellowish color, friable, and contains some 20 or more per cent of phosphate of lime, 10 to 12 per cent of organic matter, 30 per cent of ammonia salts, and 20 per cent of water. Through prolonged exposure to the leaching action of meteoric waters, similar deposits in the West India Islands have lost their ammonia salts and other soluble constituents and become converted into insoluble phosphates, or leached guanos like those of the Navassa Islands.

Origin and Occurrence.—The origin of the various forms of phosphatic deposits has been a subject of much speculation. Their occurrence under diverse conditions renders it certain that not all can be traced to a common source, but are the result of different agencies acting under the same or different conditions. By many, all forms are regarded as being phosphatic materials from animal life, and owing their present diversity of form to the varying conditions to which they were at the time of formation or have since been subjected. This, however, as long since pointed out, is an uncalled-for hypothesis, since phosphatic matter must have existed prior to the introduction of animal life, and there is no reason to suppose it may not, under proper conditions, have been brought into combination as phosphate of lime without the intervention of life in any of its forms. The almost universal presence of apatite in small and widely disseminated forms in eruptive rocks of all kinds and all ages would seem to declare its independence of animal origin as completely as the pyroxenic, feldspathic, or quartzose constituents with which it is there associated. The occurrence of certain of the Canadian apatites as noted later, in veins and pockets, sometimes with a banded or concretionary structure and blending gradually into the country rock, is regarded by some as strongly suggestive of an origin by deposition from solution, that is, by a process of segregation of phosphates from the surrounding rock contemporaneously with their metamorphism and crystallization.

Dr. Ells, of the Canadian survey, would regard those occurring in close juxtaposition with eruptive pyroxenites as due to combination of the phosphoric acid brought up in vapors along the line of contact with the calcareous materials in the already softened gneisses. This explanation as well as others will perhaps be better understood in the part of this work relating to localities. On the other hand, the presence of apatite in crystalline form associated with beds of iron ore, as in northern New York, has been regarded by Prof. W. P. Blake and others as indicative of an organic and sedimentary origin for both minerals. Later work has, however, shown that these ores are probably of igneous origin. The Norwegian apatite from its association with an eruptive rock (gabbro) has been regarded as itself of eruptive origin.

The phosphorites, like the apatites, occur in commercial quantities mainly among the older rocks, and in pockets and veins so situated as to lead to the conclusion that they are secondary products derived by a process of segregation from the inclosing material. Davies regards the Bordeaux phosphorites, in the Jurassic limestones of southern France as the result of phosphatic matter deposited on the rocky floor of an Eocene ocean, from water largely impregnated with it. Others have considered them as geyserine ejections, or due to infiltration of water charged with phosphatic matter derived from the bones in the overlying clays. Stanier, on the other hand, regards the phosphorites of Portugal as due to segregation of phosphatic matter from the surrounding granite, the solvent being meteoric waters. Such deposits are superficial and limited to those portions of the rock affected by surface waters.

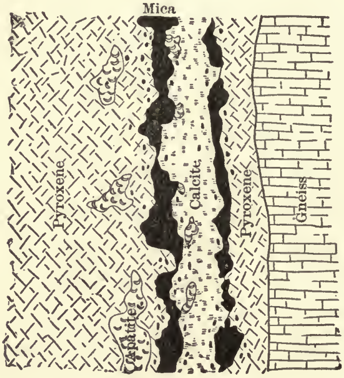

FIG. 40.—Section showing apatite deposits in Wallingford Mica Mine. (After Cirkel)

The origin of the amorphous, nodular, and massive rock phosphates can be traced more directly to organic agencies. All things considered, it seems most probable that the phosphatic matter itself was contained in the numerous animal remains,[1] which, in the shape of phosphatic limestones, marls, and guanos, have accumulated under favorable conditions to form deposits of very considerable thickness. Throughout these beds the phosphatic matter would, in most cases, be disseminated in amounts too sparing to be of economic value, but it has since their deposition been concentrated by a leaching out by percolating waters of the more soluble carbonate of lime. Thus H. Lösne, in writing of the nodular phosphates occurring in pockety masses in clay near Doullens (France),

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[1] T. S. Hunt showed, in 1854, that shells of fossil lingulæ were largely phosphatic, calcined shells of *L. ovalis* yielding 85.79 per cent phosphate of lime. American Journal of Science, XVII, 1854, p. 235.

argues that the nodules as well as the clay itself are due to the decalcification of preexisting chalk by percolating meteoric waters.

In this connection it is instructive to note that phosphatic nodules, in size rarely exceeding 4 to 6 cm., were dredged up during the *Challenger* expedition, from depths of from 98 to 1,600 fathoms on the Agulhas Banks, south of the Cape of Good Hope. These are rounded and very irregular capricious forms, sometimes angular, and have exteriorly a glazed appearance, due to a thin coating of oxides of iron and manganese. The nodules yield from 19.96 to 23.54 per cent P_2O_5. In those from deep water there are found an abundance of calcareous organic remains, especially of rhizopods. The phosphate penetrates the shell in every part, and replaces the original carbonate of lime.

The nodules are most abundant apparently where there are great and rapid changes of temperature due to alternating warm and cold oceanic currents, as off the Cape of Good Hope and the eastern coast of North America. Under such conditions marine organisms would be killed in great numbers, and by the accumulation of their remains furnish the necessary phosphatic matter for the nodules. It seems probable that the Cretaceous and Tertiary deposits in various parts of the world may have formed under similar conditions.

Hughes has described[1] phosphatic coralline limestones on the islands of Barbuda and Aruba (West Indies), as having undoubtedly originated through a replacement of the original carbonic by phosphoric acid, the latter acid being derived from the overlying guano. The phosphatic guano has, however, now completely disappeared through the leaching and erosive action of water, leaving the coral rock itself containing 70 to 80 per cent phosphate of lime.

Hayes[2] regards the Tennessee black phosphates as due to the

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[1] Quarterly Journal of the Geological Society of London, XLI, 1885, p. 80.

[2] Sixteenth Annual Report of the U. S. Geological Survey, 1894–95, Pt. 4, p. 620; Seventeenth Annual Report U. S. Geological Survey, 1895–96, Pt. 2, p. 22.

slow accumulation on sea bottoms of phosphatic organisms (Lingulæ), from which the carbonate of lime was gradually removed by the leaching action of carbonated waters, leaving the less soluble phosphate behind. The white bedded phosphates of Perry County, in the same State, are regarded as a product of secondary replacement—that is, as due to phosphate of lime in solution, replacing the carbonate of lime of preexisting limestones, as in the case noted above. The source of the phosphoric acid, whether from the overlying Carboniferous limestones or from the older Devonian and Silurian rocks, is not, however, in this case apparent.

Teall has shown[1] that some phosphatic rocks from Clipperton Atoll, in the northern Pacific, are trachytes in which phosphoric acid has replaced the original silica. The replacement he regards as having been effected through the agency of alkaline (principally ammonium) phosphate which has leached down from overlying guano. A microscopic examination of the rock in thin sections showed that the replacing process began with the interstitial matter, then extended to the feldspar microlites, and lastly the porphyritic sanidin crystals. The gradual change in the relative proportion of silica and phosphoric acid, as shown by analyses of more or less altered samples, is shown below, No. I being that of the unaltered rock and II and III of the altered forms:

Constituents.	I	II.	III.
SiO_2	54.0	43.7	2.8
P_2O_5.................	8.4	17.0	38.5
Loss on ignition.......	3.8	12.3	23.0

From a comparison of these rocks with those of Redonda, in the Spanish West Indies, it is concluded that the latter phosphates have likewise resulted from a similar replacement in andesitic rocks. In this connection reference is made to the work of M. A. Gautier,[2]

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[1] Quarterly Journal of the Geological Society of London, LIV, 1898, p. 230.

[2] Formation des Phosphates Naturels d'Alumina et de Fer, Comptes Rendus de Académie des Sciences, Paris, CXVI, 1893, p. 1491.

in which he describes the formation of aluminous phosphates through the action of the ammonium phosphate arising from decomposing organic matter on the clay of the floor of caverns. (See under Occurrences.)

The guanos, as noted elsewhere, owe their origin mainly to the accumulations of sea-fowl excretions. Such deposits when unleached, are relatively poor in phosphatic matter and rich in salts of ammonia. Where, however, subjected to the leaching action of rains the more soluble constituents are carried away, leaving the less soluble phosphates, together with impurities, in the shape of alumina, silica, and iron oxides to form the so-called leached guanos of the West India Islands. As stated in the descriptions of localities, guano deposits are not infrequently of a thickness such as to cause their origin as above stated to seem well-nigh incredible were there not sufficient data acquired within historic times to demonstrate its accuracy beyond dispute. Thus it is said[1] that in the year 1840 a vessel loaded with guano on the island of Ichabo, on the east coast of Africa. During the excavations which were necessary the crew exhumed the dead body of a Portuguese sailor, who, according to the headboard on which his name and date of burial had been carved with a knife, had been interred fifty-two years previously. The top of this headboard projected 2 feet above the original surface, but had been covered by exactly 7 feet of subsequent deposit of guano. That is to say, the deposition was going on at the rate of a little over an inch and a half yearly.

LOCALITIES OF PHOSPHATES.

(1) *Mineral Phosphates.*

Canada.—According to Dr. Ells, of the Canadian Survey,[3] the discovery of apatite in the Laurentian rocks of Eastern Canada was first made in the vicinity of the Lievre by Lieutenant Ingall in 1829, though it was not until early in 1860 that actual mining was begun.

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[1] R. Ridgway, Science, XXI, 1893, p. 360.

[2] The Canadian Mining and Mechanical Review, March, 1893.

The mineral occurs in the form of well-defined crystals in a matrix of coarsely crystalline calcite and in vein-like and pockety granular masses along the line of contact between eruptive pyroxenites and Laurentian gneisses. The first form is the predominant one for Ontario only, the second for Quebec. From a series of openings made at the North Star Mine, in the region north of Ottawa, it appears that the massive coarsely crystalline granular apatite follows a somewhat regular course in the pyroxenite near the gneiss, but occurs principally in a series of large bunches or chimneys connected with each other by smaller strings or leaders. Sometimes these pockety bunches of ore are of irregular shape and yield hundreds of tons, but present none of the characteristics of veins, either in the presence of hanging or foot walls, while many of the masses of apatite appear to be completely isolated in the mass of pyroxenite, though possibly there may have been a connection through small fissures with other deposits. The lack of any connection between these massive apatites and the regularly stratified gneiss is evident, and their occurrence in the pyroxenite is further evidence in support of the view that the workable deposits are not of organic origin, but confined entirely to igneous rocks. In certain cases where a supposed true-vein structure has been found, such can be explained by noticing that the deposits of phosphates occur, for the most part at least, near the line of contact between the pyroxenite and the gneiss. (Fig. 41.)

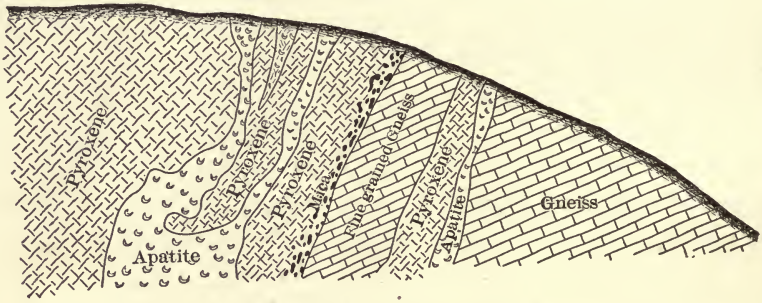

Fig. 41.—Section through apatite and mica deposits. Templeton, Canada. [After Cirkel.]

The principal producing fields lie in Ottawa County, Province of Quebec, and Leeds, Lanark, Frontenac, Addington, and Renfrew counties, Province of Ontario. The first, which is by far the more important field, extends from the Ottawa River on the south, in a northerly direction through Buckingham, Templeton, Wakefield, Denholm, Bowman, Hincks, and other townships with an average width of 15 to 25 miles. It is therefore practically coincident with the mica (phlogopite) belt. The second lies to the southwest and extends from the Ottawa for a distance of about 100 miles southerly, or to within 15 miles of the St. Lawrence. It has a width of from 50 to 75 miles.

Davies gives the following table as showing the average composition of the Canadian phosphates:

Constituents.	I.	II.	III.	IV.	V.	VI.
Moisture, water of combination, and loss on ignition	0.62	0.10	0.11	1.09	0.89	1.83
Phosphoric acid	33.51	41.54	37.68	30.84	32.53	31.87
Lime	46.14	54.74	51.04	42.72	44.26	43.62
Oxide of iron, alumina, fluorine, etc.	7.83	3.03	6.88	13.32	12.15	9.28
Insoluble siliceous matter	11.90	0.59	4.29	12.03	10.17	13.50
	100.00	100.00	100.00	100.00	100.00	100.10
Equal to tricalcic phosphate of lime	73.15	90.68	82.25	67.32	71.01	69.35

Norway.—The principal apatite fields lie along the coast in the southern portion of the peninsula between Langesund and Arendal. The material occurs in crystals and crystalline granular aggregates of a white, yellow, greenish, or red color in veins and pockets embedded in the mass of an eruptive gabbro, near the line of contact of the gabbro and adjacent rocks, in the country rock itself in the immediate vicinity of the gabbro, and in coarse pegmatitic veins which are cut by the gabbro. The largest veins are in the mass of the gabbro itself or near the line of contact. Where the apatite occurs in the gabbro the latter is, as a rule, altered into a hornblende scapolite rock. The principal associated minerals are quartz, mica, tourmaline, scapolite, feldspars, rutile, and magnetic and titanic iron and sulphides of iron and copper. The country rock is gneiss, schist, and granite. The mineral belongs to the variety called fluor-apatite, as shown by the following analysis from Dr. Penrose's Bulletin:

APATITE FROM ARENDAL.

Constituents.	Per Cent.
Phosphoric acid (P_2O_5) [1]	42.229
Fluorine [2]	3.415
Chlorine [3]	0.512
Lime (CaO)	49.96
Calcium	3.884
	100.000

The Norway apatites have been mined according to Penrose since 1854, the earliest workings being at Kragerö. According to Davies, however, the discovery of deposits that could be profitably worked dates only from 1871. The distribution of the material is very uncertain and irregular, and the value of the deposits can not be foretold with any great approximation to accuracy. A large mass of this material, weighing nearly 2 tons, is on exhibition in the National Museum at Washington.

Spain.—Important deposits of phosphorites occur between Logrosan and Cáceres, in Estremadura Province. The deposits are in the form of pockets and veins in slates and schists supposed to be of Silurian age; at times a vein is found at the line of contact between the slate and granite. The veins vary in thickness from 1 to several feet, the largest being some 20 feet and extending for over 2 miles. This is by far the largest of its kind known. As described, the Logrosan phosphate has a subcrystalline structure; sometimes fibrous and radiating. It is soft and chalky to the touch, easily broken, but difficult to grind into a fine powder. An examination under the microscope exhibits conchoidal figures, interrupted with spherical grains, devoid of color and opaque.

The highest-grade material is rosy white or yellowish white in color, soft, concentric, often brilliantly radiated, with a mam-

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[1] Equal 92.189 per cent tricalcic phosphate.

[2] Equal 7.01 per cent fluoride of calcium.

[3] Equal 0.801 per cent chloride of calcium.

millary or conchoidal surface. Red spots from iron and beautiful dendrites of manganese are not infrequent. The poorer qualities are milky white, vitreous, hard, and, though free from limestone, contain considerable silica.

In the Cáceres district the phosphorites occur not in veins, but rather in pockety masses in veins of quartz and dark-colored limestone, which are found cutting both the granite and slate.

The following analyses from Dr. Penrose's paper show about the average composition of these phosphorites:

LOGROSAN.

Constituents.	Per Cent.
Silica	1.70
Protoxide of iron	3.15
Fluoride of lime	14.00
Phosphate ol lime	81.15

CÁCERES.

Constituents.	Per Cent.
Insoluble siliceous matter	21.05
Water expelled at a red heat	3.00
Phosphate of lime	72.10
Loss, iron oxides, etc	3.85

Portugal.—Phosphorites occur in Silurian and Devonian rocks under similar conditions to those of Spain in Estremadura, Alemetjo, and Beira provinces, and which need, therefore, no further notice here. Stanier,[1] however, describes a variety found in pockety and short veinlike masses which are worthy of a passing notice. These occur not in schists and sedimentary rocks but in massive granites. They are found mainly in the superficial portions, where the granite has weathered away to a coarse sand, and in short gash-like veins and pockets of slight width and extent. The phosphatic material is described as of a milk-white color, opaque, and showing when

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[1] Les Phosphorites du Portugal, Annales de la Société Géologique de Belgique, XVII, 1890, p. 223.

broken open a palmately radiating structure, like hoarfrost upon a window pane. As a rule the masses when found are enveloped in a thin coating of kaolin-like material supposed to be derived by decomposition from the feldspar of the granites. They are mined only from open cuts and in the superficial more or less decomposed portions of the rock, to which they are believed to be mainly limited, having originated, as elsewhere indicated, through a segregation of the phosphatic material dissolved by meteoric waters from the surrounding granite and subsequently depositing it in pre-existing fissures. The percentage of tricalcic phosphate is given as varying between 60 and 80 per cent.

(2) *Rock Phosphates.*

United States.—Nodular phosphatic deposits are found at intervals all along the Atlantic coast of the United States, from North Carolina down to the southern extremity of Florida. The North Carolina deposits occur principally in the counties of Sampson, Duplin, Pender, Onslow, Columbus, and New Hanover, all in the southeastern part of the State. The deposits are of two kinds: (1) a nodular form overlying the Eocene marls and consisting of phosphate nodules, sharks' teeth, and bones embedded in a sandy or marly matrix, and (2) as a conglomerate of phosphate pebbles, sharks' teeth, bones, and quartz pebbles, all well rounded and cemented together along with grains of greensand in a calcareous matrix.

The beds of the first variety usually overlie strata of shell marl, though this is sometimes replaced by a pale green indurated sand. The two following sections will serve to illustrate their mode of occurrence:

SAMPSON COUNTY.

(1) Soil, sand, or clay, 5 to 10 feet.
(2) Shell marl, 5 to 10 feet.
(3) Bed with phosphate nodules, 1 to 3 feet.
(4) Sea-green sandy marl, 2 to 4 feet.
(5) Ferruginous hardpan, 6 to 12 inches.
(6) Interstratified lignites and sands as in (4).

DUPLIN COUNTY.

(1) Sandy soil, 1 to 10 feet.
(2) Nodule bed, 1 to 2 feet.
(3) Shell marl.

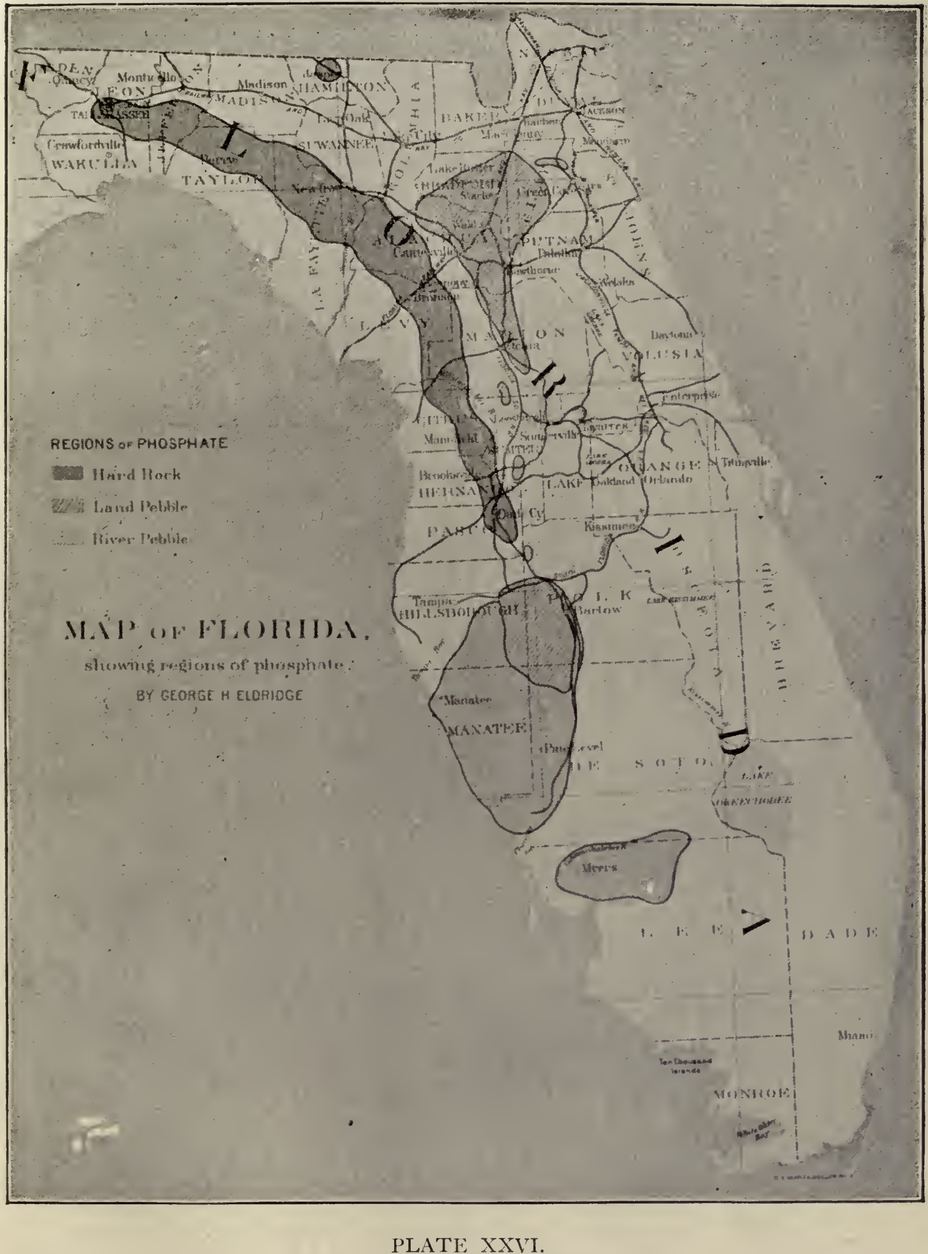

PLATE XXVI.
Map of the Florida Phosphate Regions.
[After G. H. Eldridge, U. S. Geological Survey.]
[*Facing page 278.*]

The nodules are of a lead-gray color, varying in size from that of a man's fist to masses weighing several hundred pounds. In texture they vary from close, compact and homogeneous masses to coarse-grained and highly siliceous rocks distinguished by considerable quantities of sand and quartz pebbles sometimes the size of a chestnut. Occasionally the nodules, which as a rule are of an oval flattened form, contain Tertiary shells. The second or conglomerate variety occurs mainly in New Hanover and Pender counties, the beds in some instances being 6 feet in thickness, though usually much less. The following section, taken from Dr. Penrose's Bulletin, shows their position and association as displayed at Castle Hayne, New Hanover County.

"(1) White sand, 0 to 3 feet.

"(2) Brown and red ferruginous sandy clay, or clayey sand, 1 to 3 feet.

"(3) Green clay, 6 to 12 inches.

"(4) Dark-brown indurated peat, 3 to 12 inches.

"(5) White calcareous marl, 0 to 2 feet.

"(6) White shell rock, 0 to 14 inches.

"(7) Phosphatic conglomerate, 1 to 3 feet.

"(8) Gray marl containing smaller nodules than the overlying beds, 2½ to 4½ feet.

"(9) Light-colored, calcareous marl, containing nodules which are smaller than those in the overlying beds, which grow fewer and smaller at a depth. Many shells."

The phosphatic nodules in this conglomerate are kidney and egg shaped and sometimes make up as much as three-fourths the contents of a bed; usually, however, the proportion is smaller, and sometimes there are none at all. The mass as a whole does not contain more than 10 to 20 per cent phosphate of lime, but it is said to have been successfully used as a fertilizer. The individual nodules may be richer in phosphatic matter on the outer surface than toward the center.

Aside from the phosphatic layer as described above, phosphatic nodules are found in large quantities in the beds of rivers of these districts, where they have accumulated through the washing action of flowing water, the finer sand, clay, and gravel having been carried away. Such phosphates naturally do not differ materially from those on land except that they are darker in color and sometimes more siliceous.

The deposits of South Carolina are of the same nature as those described above but of low grade. For many years they were more generally used than any other American phosphate. This was due not only to the cheapness of the material but to the many good qualities of the low-grade acid phosphate made from it. Of late years the Florida phosphates have gradually replaced them.

Phosphates in the form of nodules and phosphatic marls and green sands occur in Alabama in both the Tertiary and Cretaceous formations. Their geographical distribution is therefore limited to areas south of the outcrops of the lowest Cretaceous beds which stretch in a curve from the northwest corner of the State across near Fayette Courthouse, Tuscaloosa, Centerville, and Wetumpka, to Columbus, Georgia. As all the Cretaceous and Tertiary beds have a dip toward the Gulf of from 25 to 40 feet to the mile, the phosphate-bearing strata appear at the surface in a comparatively narrow belt along the line above indicated and are to be found only at gradually increasing depths below at points to the southward.

Although selected nodules may run as high as 27 per cent of phosphoric acid, and marls as high as 6.7 per cent, the Tertiary is not regarded by Professor Smith as a promising source of commercial phosphates in the State.

The principal phosphate region of Florida, as known to-day, comprises an area extending from west of the Apalachicola River eastward and southward to nearly 50 miles south of Caloosahatchee River, as shown on the accompanying map.[1] According to Mr. Eldridge, the deposits comprise four distinct and widely different classes of commercial phosphates, each having a peculiar genesis, a peculiar form of deposit, and chemical and physical properties such as readily distinguish it from any of the others.

According to their predominant characteristics or modes of occurrence, these classes have come to be known as hard-rock phosphates, soft phosphate, land pebble or matrix rock, and river pebble. With the exception of the soft phosphates, they underlie distinct regions,

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[1] Preliminary sketch of Phosphates of Florida, by George H. Eldridge.

each class being separate or but slightly commingling with one another. The hard-rock phosphate is a hard, massive, close-textured, homogeneous, light-gray rock, showing large and small irregular cavities, which are usually lined with secondary mammillary incrustations of nearly pure phosphorite.

The deposits, which average some 36.65 per cent P_2O_5, lie in Eocene and Miocene strata, occurring in the first named as a bowlder deposit in a soft matrix of phosphatic sands, clays, and other material, resulting from the disintegration of the hard rock and constituting the soft phosphates. They underlie sands of from 10 to 20 feet in thickness, and have been penetrated to a depth of 60 feet. The phosphate deposit proper is white, the bowlders of rounded and irregular outline, varying in diameter from 2 or 3 inches to 10 feet. None of the hard-rock deposits of the Eocene originated in the positions they now occupy. The Miocene hard-rock phosphates, on the other hand, lie in regular bedded deposits *in situ*, as well as in bowlders. The beds lie horizontal but a few feet below the surface, being covered only by superficial sand. They are, as a rule, but from 4 feet to 5 feet thick. The name soft rock, or soft phosphate, as above indicated, is given to the softer material associated with the hard rock, which in part results from the disintegration of the last named. It is also applied somewhat loosely to any variety not distinctly hard. It varies greatly in color, chemical and physical characteristics, and rarely carries more than 20 to 25 per cent of P_2O_5.

The name land-pebble phosphate includes pebbles from deposits consisting of either earthy material carrying fossil remains, grains of quartz, and pisolitic grains of lime phosphate, or of a material resembling in texture and other characteristics the hard-rock phosphate. The individual pebbles vary in size up to that of the English walnut, are normally white, but when subjected to percolating water become dark gray or nearly black. The exteriors are quite smooth and glossy; such yield on an average some 30 to 35 per cent P_2O_5.

The river-pebble varieties differ from the last mainly in mode of occurrence, being found, as the name would indicate, in the beds of streams, where presumably they have accumulated through the washing away of finer and lighter materials. They are most abundant in the Peace, Caloosahatchee, Alafia, and other rivers entering the Gulf south of Tampa and Hillsborough bays, though the Withlacoochee, Aucilla, and rivers of the western part of the State, carry also a mixture of pebbles, hard-rock fragments, and bones derived from the various strata through which they have cut their channels. The pebbles of the Western rivers show a very uniform composition, and range from 25 to 30 per cent phosphoric anhydride (P_2O_5), or about 65 per cent of phosphate of lime, the impurities being mainly siliceous matter, carbonate of lime, alumina, and iron oxides.

Phosphatic deposits of high grade and covering considerable areas in western middle Tennessee were discovered during the latter part of 1893. Since then development has been rapid, and the State now stands second in rank, as a producer, being exceeded only by Florida. The general distribution of the beds is shown in the accompanying sketch map (Fig. 42), while their varying thickness is shown in the columnar sections on Pl. XXVII. The essential facts regarding these deposits have been summarized by C. W. Hayes[1] from whose reports a large part of the material here given is compiled. The deposits are classified as—

I. Black phosphate (an original deposit).
    1. Nodular.
    2. Bedded, including oölitic, compact conglomeratic, and shaly varieties.
II. White phosphate (a secondary deposit).
    1. Stony.
    2. Breccia.
    3. Lamellar.

The first of these, the black phosphate, is of Devonian age. The second, the white phosphates, which are altogether secondary deposits, are very recent. The surface rocks of the region include Silurian, Devonian, and Carboniferous beds arranged as follows:

Carboniferous		Cherty, shaly limestone.	
Devonian.	*D*	Greensand with phosphatic nodules	8–14 inches
	C	Carbonaceous black shale	0–6 feet
	B	Bedded phosphate.	0–40 inches
	A	Gray sandstone.	0–6 feet
Silurian.		Blue limestone	

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[1] See 16th, 17th, and 21st Annual Reports, U. S. Geological Survey.

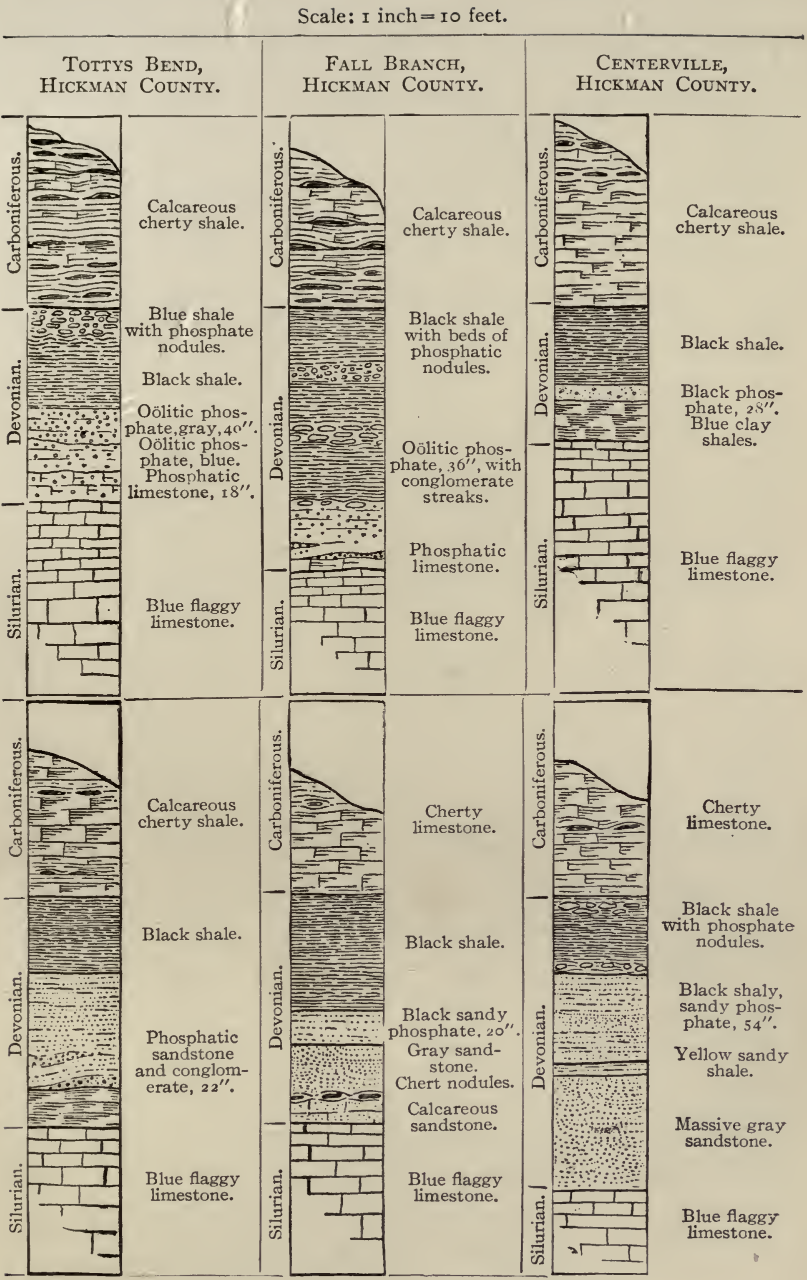

PLATE XXVII.

Sections through the Tennessee Phosphate Beds.

[After C. W. Hayes, U. S. Geological Survey.]

[*Facing page* 282.]

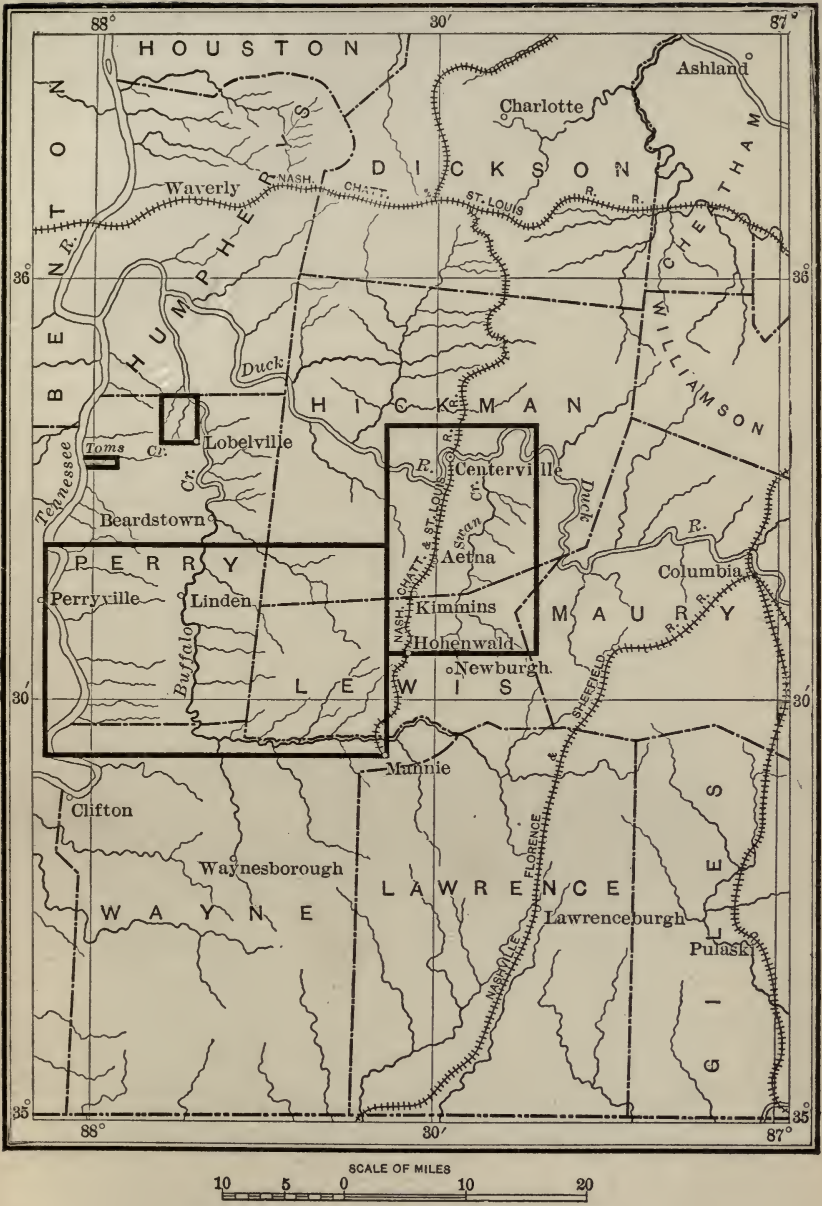

FIG. 42.—Map of Tennessee phosphate region.
[After C. W. Hayes, 17th Ann. Rep. U. S. Geological Survey.]

The black nodular phosphate occurs in a black shale, in spherical to broadly oval and flattened ellipsoidal forms, with smooth surfaces and black color. They are easily detached from the matrix and weather down rapidly to a gray, at times almost white, sand. Their distribution is extremely irregular and they have not yet been found in sufficient abundance to be profitably mined, although individual nodules may contain from 60 to 70 per cent phosphate of lime.

The black bedded phosphate lies immediately beneath the black shale containing the phosphate nodules just noted and overlying a compact Silurian limestone. It is evident that it represents a residual accumulation of the less soluble portions of preexisting limestones which has been rearranged and stratified during a subsequent period of depression of the land, and finally covered by the sediments now forming the black shale. The beds lie nearly horizontally and are now exposed only where creeks have cut through in the ordinary processes of erosion. As noted above, it occurs in several varieties. The oölitic form has in the weathered outcrop the appearance of a rusty porous sandstone. A close inspection of the unweathered rock shows it to be made up of rounded or flattened ovules of a blue-black color and small fossil shells or casts of shells embedded in a fine-grained or structureless matrix which, like the ovules, is composed mainly of phosphatic material made dark by carbonaceous matter.

The compact phosphate variety resembles a fine-grained carbonaceous sandstone. When fresh it is of a dark gray to bluish-black color, but weathers to a buff or dull yellow color, natural joint blocks when broken across often showing a nearly black nucleal portion surrounded by concentric shells of oxidized material of varying shades of brown or yellow. Under the microscope this variety is seen to be made up of small ovules and fossil casts closely packed together without the amorphous matrix noted in the oölitic variety.

Closely associated with the above forms is the conglomeratic variety consisting of beds of coarse sandstone and conglomerate containing varying amounts of phosphate. These are black in color and weather brownish, also. The truly phosphatic portion of this

PLATE XXVIII.

Phosphate Mine, Mt. Pleasant, Tennessee. Showing Area Stripped of Overburden, and Method of Mining.

[Photograph by C. W. Hayes, U. S. Geological Survey.]

[*Facing page* 284.]

variety resembles that of the compact and oölitic forms, but it differs in the presence of varying amounts of quartz sand and pebbles.

These three varieties of the black bedded phosphate are stated to yield on the average some 70 per cent of phosphate of lime.[1] The shaly variety is poorer in phosphoric acid and has the appearance of a dark gray to black shaly sandstone. The distribution of the black and blue-black phosphate is limited mainly to Hickman, Lewis, and Perry counties, the beds varying in thickness from 0 to 48 inches.

The white phosphates are associated with Carboniferous rocks, though the formation of the phosphate itself is much more recent. The stony variety, as it is called above, is a finely granular gray rock sometimes resembling a quartzitic sandstone, which occurs in more or less regular bands alternating with thinner bands of chert in a dark shaly siliceous limestone. Thin sections, under the microscope, show a ground mass of chalcedonic silica inclosing numerous very minute isotropic forms with the rhombic outlines of calcite but which chemical tests show to be phosphate. This variety yields from 27 to 33 per cent phosphate of lime, $Ca_3(PO_4)_2$. The breccia phosphate occurs in irregular masses composed of small, angular fragments of the chert embedded in a matrix of the lime phosphate, the chert fragments varying in diameter from a fraction of an inch to 3 or 4 inches. The lamellar variety consists, as the name suggests, of thin parallel plates or layers, sometimes several inches in width of phosphatic material.

The white phosphate is limited in its distribution to an area of about 12 square miles in the northern part of Perry County.

In addition to the above Hayes has described[2] a brown residual phosphate occurring in the form of a "blanket" deposit (see Fig. 43), immediately underlying the surface soil and overlying Silurian and Devonian limestones, in Hickman, Williamson, Maury, and Lewis

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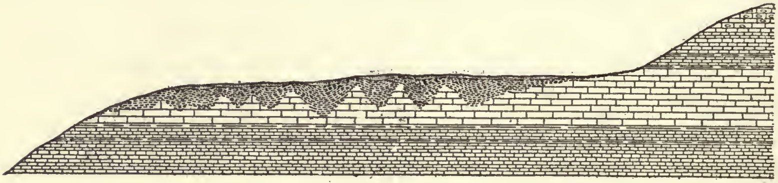
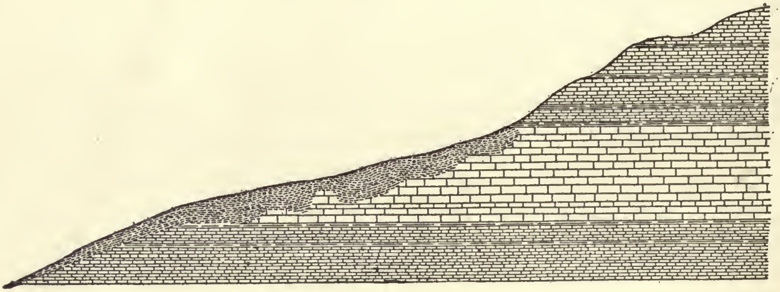
[1] The author's investigations led him to place the average considerably lower, selected samples yielding but from 50 to 66 per cent $Ca_3(PO_4)_2$.

[2] Columbia Folio, No. 95, U. S. Geological Survey, 1903.

counties of the same State. The material plainly results from the weathering of the surface rocks, the prevailing lime carbonate being carried away in solution while the phosphatic and other less soluble constituents remain. The amount of phosphate naturally varies with the amount of leaching the beds have undergone and their content of insoluble constituents. Thicknesses of 30 feet, carrying from 70 per cent to 80 per cent of phosphate of lime, are reported.



(*a*) Blanket deposit formed on broad level outcrop. Shows sagging of leached phosphatic limestone between unleached portions (" horses ") of the limestone.



(*b*) Collar deposit formed on steep slope by surface leaching of the limestone. Shows also overplaced deposit covering the edges of underlying nonphosphatic limestone.

FIG. 43.—Sections showing mode of occurrence and formation of residual phosphates in Tennessee.

[After C. W. Hayes, U. S. Geological Survey.]

Phosphatic limestones of Ordovician age have a wide geographic distribution throughout northern Arkansas, and have been developed on a commercial scale on Lafferty Creek, in the western part of Independence County. The following section of the bed is given by Purdue:[1]

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[1] Bulletin No. 315; U. S. Geological Survey, 1906, p. 469.

ST. CLAIR LIMESTONE.

	Ft.	In.
Brown and black shale	2	0
Low-grade manganiferous iron	0	15
Green to dark clay shale	0	14
High-grade phosphate	4½ to 6	0
Manganiferous iron ore	0	2
Low-grade phosphate	4	0
Polk Bayou limestone	0	0

The upper bed phosphate only is worked, the lower being of too poor grade. The better class of rock is described as light gray in color, compact and homogeneous, though sometimes conglomeratic, the larger particles being at times a fourth of an inch in diameter. It carries from 25 per cent to 32 per cent P_2O_5. The phosphatic nature is ascribed to organic matter—shells, bones, and the droppings of marine animals.

Within a few years certain portions of strata of Carboniferous rocks—mainly limestones—in northern Utah, southeastern Idaho, and adjoining portions of Wyoming, and in northern Nevada, have been found surprisingly rich in phosphate. The entire phosphatic series, which in places is 90 feet in thickness, consists of alternating layers of black or brown phosphatic materials, shale, and hard blue or gray compact limestone. The beds themselves vary from a few inches to 10 feet in thickness, but in the latter cases, are usually broken by lean, shaley layers. At the base, the series begins with limestone, which is succeeded by 6 to 8 inches of soft brown shales. Overlying this is the main phosphate bed, 5 to 6 feet in thickness. This is oölitic in structure, and runs high in P_2O_5. Several other beds, from a few inches to 10 feet in thickness, separated by thin beds of limestone or shale, occur. The series is overlaid by a coarse-grained, locally brecciated limestone, and above this again, white limestone, red sandstone, and shales, and still again, other limestones of blue-gray and greenish colors. Beneath are found red, white, and greenish quartzites and sandstones. The strata have all been uplifted, and sharply folded and faulted. A typical section is shown in Fig. 44. The material as thus far shipped runs a little over 3 per cent of P_2O_5, which is equivalent to 70 per cent of bone phosphate.[1]

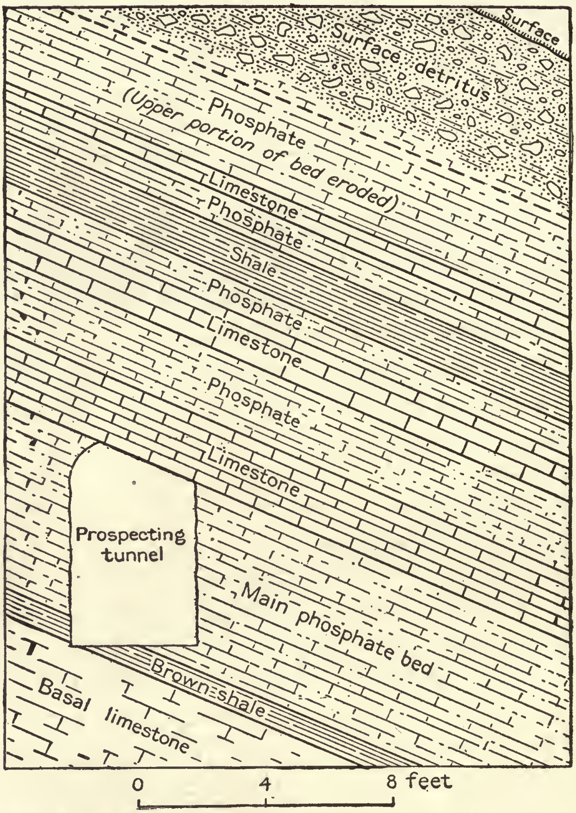

FIG. 44.—Typical Section of Lower Portion of Phosphate Series, Montpelier, Idaho. [U. S. Geological Survey.]

England.—Deposits of phosphates sufficiently concentrated for commercial purposes lie near the upper limit of Cambro-Silurian strata in North Wales. According to Davies, the material occurs in the form of nodular concretions of a size varying from that of an egg to a cocoanut, closely packed together and cemented by a black slaty matrix. The concretions have often a black, highly polished appearance, due to the presence of graphite, but owing to

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[1] F. B. Weeks, Bulletin No. 315, U. S. Geological Survey, 1906, p. 449.

the presence of oxidizing pyrite they sometimes become rusty brown. The concretions carry from 60 to 69 per cent of phosphate of lime; the matrix is also phosphatic. The beds are highly tilted and are overlaid by gray shales with fossilized echinoderms and underlaid by dark crystalline limestone, which also contains from 15 to 20 per cent of phosphatic material. Davies regards the deposit as representing an old sea bottom on which the phosphatic matter of crustacean and molluscan life was precipitated and stored during a long period; certain marine plants may also have contributed their share of phosphatic matter. He thinks it also possible that, as in the Laurentian deposits, the water of the sea may have contained phosphatic matter in solution to be deposited independently of organic agencies.

These phosphated beds have been mined at Berwin, where an average production over a space of 360 fathoms was 2 tons 10 hundredweight of phosphate per fathom, of an average strength of 46 per cent. The nodules averaged from 45 to 55 per cent of phosphate of lime.

Amorphous nodular phosphates also occur in both the Upper and Lower Greensands of the Cretaceous and in Tertiary deposits. Those of the upper beds have been mined in Cambridgeshire and Bedfordshire. The phosphatic material occurs in the form of shell casts, fossils, and nodules, of a black or dark-brown color, of varying hardness, embedded in a sand consisting of siliceous and calcareous matter as well as phosphatic and glauconitic grains. The average composition shows from 40 to 50 per cent of phosphate of lime. The thickness of the nodule-bearing bed is rarely over a foot. The nodules of the Lower Greensands differ from those of the Upper in many details, the more important being their lower percentages of phosphate of lime (from 40 to 50 per cent). They occur in a bed of siliceous sand which itself is not phosphatic. The Tertiary phosphates reach their best development in the county of Suffolk, where they are found at the base of the Coralline and Red Crag groups and immediately overlying the London clays. The beds consist of a "mass of phosphatic nodules and shell casts, siliceous pebbles, teeth of cetaceans and sharks, and many mammal bones, besides occasional fragments of Lower Greensand chert, granite, and chalk flints." The nodules vary in both quality and quantity. They are at times of a compact and brittle nature, while at others they are tough and siliceous. They average about 53 per cent phosphate of lime and 13 per cent phosphate of iron.

France.—Phosphates of the nodular type occur in beds of Cretaceous age in the provinces of Ardennes and Meuse, and to a less extent in others in Northern France; in the department of Côte-d'Or, and along the Rhone at Bellegarde, Seyssel, and Grenoble. As in England, the phosphatic nodules of the northern area, such as are of commercial importance, occur in both the Upper and Lower Greensands. They resemble in a general way the English phosphates, but are described as soft and porous and easily disintegrating when exposed to the air. Those of the Upper Greensand average some 55 per cent of phosphate of lime.

More recently deposits have been described by M. J. Gosselet,[1] near Fresnoy-le-Grand, in the north of France. The phosphatic material occurs in a zone of gray chalk some 6 feet in thickness (1½ to 2 meters), and is in the form of concretionary nodules forming a sort of conglomerate in the lower part of the bed. A portion of the chalk is also phosphatic. Phosphatic material (of the type of phosphorites) is found in fissures and pockets in the upper portion of limestones of Middle Jurassic (Oxfordian) age, in the departments of Tarn-et-Garonne, Aveyron, and Zoti.

The deposits are of two kinds. The first occurring in irregular cavities or pockets never over a few yards long, and the second in the form of elongated leads with the sides nearly vertical. These are generally shallow, and thin out very rapidly at a short distance below the surface.

The nodules or concretions are of a white or gray color, waxy luster, and opal-like appearance, and occur in the form of tubercular or kidney-shaped masses embedded in ferruginous clay in the clefts of the limestone, or in geodic, fibrous, and radiating forms.

The material of this region is known commercially as Bordeaux phosphate, being shipped mainly from Bordeaux. It averages from 70 to 75 per cent phosphate of lime, the impurities being mainly iron oxides and siliceous matter.

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[1] Annales de la Société Géologique du Nord, XXI, 1895, p. 149.

Gautier[1] describes deposits of phosphates estimated to the amount of 120,000 to 300,000 tons on the floors of the Grotte de Minerve, near the village of Minerve on the northeast flank of the Pyrenees, in Aude, France. The cave proper is in nummulitic limestone of Eocene age, the floors being formed by Devonian rocks. The filling material consists of cave earth and bone breccia below which are the aggregates of concretionary phosphorites and other phosphatic compounds of lime and alumina, the more interesting being *Brushite*, a hydrous tribasic calcium phosphate hitherto known only as a secondary incrustation on guano from the West India Islands, and *Minervite*, a new species having the formula $Al_2O_3.P_2O_5,7H_2O$, a hydrous aluminum phosphate, existing in the form of a white plastic clay-like mass filling a vein from a few inches to 2 or more feet in thickness.

Germany.—According to Davies, the principal phosphate regions of North Germany occupy an irregular area bounded on the northeast by the town of Weilburg, on the northwest by the Westerwald, on the east by the Taunus Mountains, and on the south by the town of Dietz. The material occurs in the form of irregular nodular masses of all sizes up to those of several tons weight, embedded in clay which rests upon Devonian limestone and is overlaid by another stratum of clay. The phosphate-bearing clay varies in thickness from 6 inches to 10 feet. With the phosphate nodules are not infrequently associated deposits of manganese and hematite. Davies regards the deposits as of early Tertiary age. The color of the freshly mined material varies from pale buff to dark brown, varying in specific gravity from 1.9 to 2.8, the quality deteriorating with the increase in gravity. Selected samples of the staple nodules yielded as high as 92 per cent phosphate of lime; but the average is much lower, being but about 50 to 60 per cent phosphate of lime.

Belgium.—Nodular phosphates belonging to the Upper Cretaceous formations occur in the province of Hainaut, where they form the basis of an extensive industry. The nodules which are

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[1] Annales des Mines, V, p. 5.

generally of a brown color and vary in size from the fraction of 1 to 4 or 5 inches in diameter, lie in a coarse-grained, friable rock called the brown or gray chalk, which itself immediately underlies what is known as the Ciply conglomerate. The phosphate-bearing bed is sometimes nearly 100 feet in thickness, but is richest in the upper 10 feet, where it is estimated the phosphatic pebbles constitute some 75 per cent of its bulk. Below this the bed grows gradually poorer, passing by gradations into the white chalk below.

The overlying conglomerate also carries phosphate nodules, which carry from 25 to 50 per cent phosphate of lime. Owing to the hardness of the inclosing rock they are less mined than those in the beds beneath. The mining of phosphates is carried on extensively near the town of Mons, on the lands of the communes of Cuesmes, Ciply, Mesvin, Nouvelles, Spiennes, St. Symphorien, and Hyon. The annual output has gradually increased from between 3,000 and 4,000 tons in 1887 to 85,000 tons in 1894. Other phosphatic deposits are described [1] as occurring in the provinces of Antwerp and Liège.

Italy.—Phosphatic deposits consisting of coprolites, bones, etc., embedded in a porous Tertiary limestone, occur between Gallipoli and Otranto, Cape Leuca, west of the Gulf of Taranto, on the Italian coast. There are two beds having a thickness of 19½ and 31½ inches, respectively, and which have been traced for a distance of some 160 yards. Analyses show them to be of low grade, rarely carrying as high as 10 per cent P_2O_5.

Tunis.—Phosphatic nodules in the form of cylindrical coprolites and clustered aggregates have been found in Tertiary strata covering considerable areas in the region south of Tunis. The coprolite nodules are stated to carry as high as 70 per cent of calcium phosphate, and the clustered aggregate some 52 per cent.

Russia.—Rich phosphate deposits of Cretaceous age occur in the governments of Smolensk, Orlow, Koursk, and Vorouez, between the rivers Dnieper and the Don in European Russia. The deposits lie mostly in a sandy marl, underlying white chalk and overlying green-

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[1] Annales de la Société Géologique de Belgique, XVIII, 1890, p. 185.

sands, which also carry beds of from 6 to 12 inches thickness of phosphatic nodules. The nodules are dark, often nearly black in color, and are intermixed with gray, brown, and yellow sands. The depth of the beds below the surface is variable. Yermolow [1] divides the deposits into two groups, the first presenting the form of separate nodules, rounded or kidney-shaped, of variable size, and black, brown, gray, or green in color. The second is in form of an agglomeration of large nodules cemented together into a sort of flag, which used to be quarried for road purposes. The nodules in this agglomerate are richer in phosphoric acid when most dense and of a deep-black color, the sandy varieties being comparatively poor. The cement carrying the nodules contains numerous fossil bones, shells, corals, etc., which are also phosphatic. The samples yield about 30 to 60 per cent phosphate of lime. Other deposits occur south of Saratov, on the Volga; at Tambov and Spask, where the overlying rock is a greensand in place of the chalk; north of Moscow; east of Nijni Novgorod; at Kiev, on the Dnieper; Kamenetz, Podolsk, on the Dniester, and at Grodno, on the Niemen.

Maltese Islands.[2]—Nodular phosphates occur in Miocene beds on the islands of Malta, Gozo, and Comino, of the Maltese group in the Mediterranean Sea. The bed containing the nodules is in what is known as the Globigerina limestone, which underlies an upper coralline limestone, greensands, and blue clays, and overlies the lower coralline limestone. Upper and lower beds all carry phosphoric acid in small amounts. There are four seams of nodules, the first varying in different localities from 9 to 15 inches in thickness. The second is more constant in character, averaging some 2 feet in thickness and consisting of an aggregate of irregularly shaped nodules, intermixed with which are considerable quantities of the phosphatized remains of mollusks, corallines, echinoderms, crustaceans, sharks, whales, etc., the whole being firmly bound together by an interstitial cement, composed of foraminiferal and other calcareous matter similar to that of which the overlying beds are made up. The third seam is the poorest of the lot and consists

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[1] Recherches sur les Gisements de Phosphate de Chaux Fossil en Russie.

[2] J. H. Cooke, The Phosphate Beds of the Maltese Islands. Engineering and Mining Journal, LIV, 1892, p. 200.

of two or more thin layers of nodules, none of which exceeds 3 inches in thickness. Between this and the fourth and lowest seam, which is the most important of all, is a bed of rock some 50 to 80 feet in thickness. The seam averages some 3½ feet in thickness. The nodules are of a dark-chocolate color embedded in a calcareous matrix, from which they are freed by calcination. The composition of I, the nodules, and II, the average composition of nodules and interstitial cement, is given below, from analyses by Drs. Murray and Blake:

Constituents.	I.	II.
Sulphate of lime	2.26	1.97
Carbonate of lime	47.14	51.12
Phosphate of lime	38.34	31.66
Alumina (Al_2O_3)	5.98	10.59
Oxide of iron (Fe_2O_3)	Trace.	*a*3.83
Residue.	6.08	*b*0.87
Total.	99.80	100.00

a. Silica. *b*. Moisture.

Guano, soluble and leached.—The largest and best-known deposits of unleached guanos are found on the mainland and small islands off the coasts of Peru and Bolivia, where abundant animal life and lack of rainfall have contributed to their formation and preservation. These deposits consist mainly of the evacuations of sea fowl and marine animals, such as flamingoes, divers, penguins, and sea lions. Mixed with them is naturally more or less bone and animal matter furnished by the dead bodies of both birds and mammals. The deposits vary indefinitely in extent and thickness, but have attained in places a depth of upward of 100 feet. As a rule they are more compact beneath than at the surface, but may be readily removed by pick and shovel. The first deposits to be worked are stated to have been those of the Chincha Islands, off the Peruvian coast. These were practically exhausted as early as 1872. Other islands which have been worked and completely if not entirely stripped are those of Macabi, Guañape, Ballestas, Lobos, Foca, Pabellon de Pica, Tortuga, and Huanillos.

A mean of 21 analyses of Macabi Island guano, by Barral, as quoted by Penrose,[1] showed:

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[1] Bulletin No. 46 of the United States Geological Survey.

Nitrogen	10.90
Phosphates	27.60
Potash	2 to 3

Other analyses are given in the following table:

Constituents.	Angamos, Coast of Bolivia, White Guano.	Bolivian.	Los Patos.	Island of Elide, Coast of California.
Organic matter	70.21 to 52.92	23.00	32.45	27.37 to 34.50
Containing nitrogen	20.09 " 14.38	3.38	5.92	1.34 " 6.98
Equivalent in ammonia	24.36 " 17.44	4.10	7.18	1.62 " 8.46
Total phosphates	13.30 " 20.95	48.60	34.81	[a]28.00 " 31.00

Constituents.	Îlot de Pedro-Bey, Coast of Cuba.	Mexican Coast.	Galapagos, Ecuador.	Falkland Islands.
Organic matter	6.16	13.05 to 18.00	....	17.35 to 28.68
Containing nitrogen	0.28	0.21 " 3.45	0.7	0.56 " 2.26
Equivalent in ammonia	0.34	0.26 " 4.19	0.85	0.68 " 2.74
Total phosphates	48.52	8.00 " 25.00	60.30	[a]21.46 " 25.62

[a] Containing sometimes very considerable quantities of phosphates of alumina and the oxide of iron.

Aside from on the islands, guano is found all along the coast of the Chilean province of Tarapaca, from Carmarones Bay to the mouth of the river Loa, there being scarcely a prominence or rock on the shore that is entirely free from it. According to the Journal of the Society of Chemical Industry,[1] the deposits have been known from a very early date. The aborigines of the valleys and gullies of Tarapaca, Mamina, Huatacondo, Camina, and Quisma were acquainted with the fertilizing qualities of guano, and conveyed it from the coast to their farms on the backs of llamas.

The southern beds vary so much in aspect and color that it frequently requires an experienced eye to make them out. Many of the deposits are covered with immense layers of sand, while others are buried beneath a solid layer of conglomerate. Guano is also frequently found in the fissures and gullies which descend to the seashore. The richest and largest beds are at Pabellon de Pica, Punta de Lobos, Huanillos, and Chipana.

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[1] Volume VI, 1887, p. 228.

Aside from the localities above mentioned, guano is found on the islands Itschabo, Possession, Pamora, and Halifax, off the Namagua coast of South Africa. The material is described as forming a grayish-brown powder, free from large lumps, and possessing a faint ammoniacal odor. It carries from 8 to 14 per cent of nitrogen and 8 to 12 per cent of phosphoric acid.[1]

The West India Islands.—Phosphates belonging to the class of leached guanos occur in considerable abundance on several of the islands of the West Indies group, the principal localities being Sombrero, Navassa, Turk, St. Martin, Aruba, Curaçao, Orchillas, Arenas, Roncador, Swan, Cat or Guanahani, Redonda, the Pedro and Morant Keys, and the reefs of Los Monges and Aves in Maracaibo Gulf. These, as would naturally be expected from their mode of origin, vary greatly, not merely in appearances, but in chemical composition as well. That of Sombrero is described[2] as occurring in two forms—one a granular, porous, and friable mass of a white, pink, green, blue, or yellow color; the other as a dense, massive, and homogeneous deposit of a white or yellow color. Many bones occur. The phosphate carries from 70 to 75 per cent phosphate of lime. An analysis as given by Davies[3] is as follows:

ANALYSIS OF SOMBRERO PHOSPHATE.

Constituents.	Per Cent.
Moisture and water of combination......	8.92
Phosphoric acid[4]......................	31.73
Lime................................	45.69
Carbonic acid[5]........................	5.99
Oxide of iron and alumina.............	7.07
Insoluble siliceous matter..............	0.60
	100.00

The Navassa phosphate is described by D'Invilliers[6] as occurring (1) in the form of a gray phosphate confined to the lower levels of

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[1] Journal of the Society of Chemical Industry, I, 1882, p. 29.

[2] R. F. Penrose, Bulletin No. 46 of the U. S. Geological Society.

[3] D. C. Davies, Earthy and Other Minerals, p. 178.

[4] Equal to tricalcic phosphate, 69.27 per cent.

[5] Equal to carbonate of lime, 13.61 per cent.

[6] Bulletin of the Geological Society of America, II, 1891, p. 75–89.

the island, and (2) a red variety occupying the oval flat of the interior. The gray is the better variety, as shown by the analyses below, though both are aluminous, and difficult of manipulation on that account. Both varieties occur in cavities and fissures in the surface of the hard gray, white, or blue limestone, of which the island is mainly composed. These cavities or pockets are rarely more than 4 or 5 yards wide on the surface, and frequently much smaller, and of depths varying from 5 to 25 feet. The deposits, so far as explored, are wholly superficial. Experimental shafts sunk to a depth of 250 feet have failed to bring to light any deeper lying beds.

ANALYSIS OF GRAY NAVASSA PHOSPHATE.

Constituents.	Per Cent.
Water at 100° C.	2.33
Organic matter and water of combination	7.63
Lime	34.22
Magnesia	0.51
Sesquioxide of iron and alumina	15.77
Potash and soda	0.86
Phosphoric acid	31.34
Sulphuric acid	0.28
Chlorine	0.15
Carbonic acid	1.84
Silica	4.53
Total	99.46

ANALYSIS OF RED NAVASSA PHOSPHATE.

Constituents.	Per Cent.
Loss on ignition	14.223
Lime	23.090
Magnesia	Trace.
Sesquioxide of iron	9.796
Alumina	18.425
Phosphoric acid	29.779
Sulphuric acid	1.160
Carbonic acid (by difference)	3.527
Total	100.020

The Aruba phosphate is described as a hard, massive variety of a white to dark-brown color. The underlying corals of this island are sometimes found phosphatized. An analysis given by Davies is as follows:

ANALYSIS OF ARUBA PHOSPHATE.

Constituents.	Per Cent.
Moisture	8.50
Water of combination	4.15
Phosphoric acid [2]	28.47
Lime	34.07
Magnesia	0.45
Carbonic acid [3]	2.30
Oxide of iron	4.49
Alumina	9.48
Sulphuric acid	1.81
Insoluble siliceous matter	6.28
Total	100.00

The Pedro Keys, Redonda, and Alta Vela phosphates carry larger percentages of alumina and iron oxides, necessitating special methods of preparation.

Deposits of leached guano of considerable extent have existed on several islands of the Polynesian Archipelago, in the Pacific Ocean, the better known being those of Baker, Howland, Jarvis, Malden, Birmie, Phœnix, and Enderbury islands. The deposits are described [4] as varying from 6 inches to several feet in thickness, of a whitish-brown or red color, pulverulent when dry, sometimes in the form of fine powder and again in coarse grains. Though closely compacted, the material can, as a rule, be readily removed by pick and shovel. The purest varieties are those lying on the unaltered coral limestones, of which the islands are mainly composed. Those lying upon gypsum have become contaminated with sulphate of lime. In places the deposits are covered with a thin crust due

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[2] Equal to tricalcic phosphate, 62.15 per cent.

[3] Equal to carbonate of lime, 5.22 per cent.

[4] J. D. Hague, American Journal of Science, XXXIV, 1862, p. 224.

to the action of atmospheric agencies. On Jarvis Island a considerable share of the deposit is covered by material of this crust-like character. Such on analysis are found to contain less water and a corresponding higher percentage of lime and phosphoric acid than the loosely compacted material, being, indeed, a nearly pure phosphate of lime. The following analyses show the general character of the guanos from Baker Island, No. I being freshly deposited and consisting of the dung of the frigate bird (*Pelicanus aquilus*). No. II is a light-colored variety from a deep part of the deposit, and No. III dark guano from a shallow part.

ANALYSES OF GUANO.

Constituents.	I.	II.	III.
Moisture expelled at 212° F.	10.40	2.92	1.82
Loss by ignition	36.88	8.32	8.50
Insoluble in HCl (unconsumed by ignition)	0.78	....	....
Lime	22.41	42.74	42.34
Magnesia	1.46	2.54	2.75
Sulphuric acid	2.36	1.30	1.24
Phosphoric acid	21.27	39.70	40.14
Carbonic acid, chlorine, and alkalies, undetermined	4.44	2.48	3.21
Total	100.00	100.00	100.00

Bat Guano.—The dry atmosphere of caves preserves indefinitely the fecal matter of bats and such other animals as may frequent them. Such under favorable conditions may accumulate in sufficient quantities to become of economic importance, being gathered and used as a fertilizer under the name of bat guano. The usual form of the entrances to caves is, however, such as to make the process of removal tedious and expensive.

Bat guano is, as a rule, dark in color, of a glossy, almost mucilaginous appearance, and quite hard. Its composition is shown in the following analysis of a sample from the Wyandotte caves[1] in southern Indiana:

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[1] Geology of Indiana, 1878, p. 163.

ANALYSIS OF BAT GUANO.

Constituents.	Per Cent.
Loss at red heat	44.10
Organic matter	4.90
Ammonia	4.25
Silica	6.13
Alumina	14.30
Ferric oxide	1.20
Lime	7.95
Magnesia	1.11
Sulphuric acid	5.21
Carbonic acid	3.77
Phosphoric acid	1.21
Chloride of alkalies and loss	5.82
	100.00

According to the reports of the State geologist, the caves in the Silurian strata in Burnet County, Texas, are in many instances enormously rich in bat guano.

Muntz and Marcano[1] have called attention to the extensive deposits of guano, sometimes amounting to millions of tons, in caves in Venezuela and other parts of South America.

According to them the deposits consist not merely of the excreta of the birds and bats which frequent the caves, but also of the dead bodies of these and other animals. The excreta were found to consist almost wholly of the remains of insects. Through the agency of bacteria, nitrification takes place, whereby the organic nitrogen is converted into nitric acid, which combines with the lime from the bones or the carbonate of lime in the soils to form nitrates, as described on page 319.

Uses.—The phosphates of the classes thus far described are used wholly for fertilizer purposes. In their natural condition they exist in the form known to chemists as tribasic phosphates—that is, a compound in which three atoms of a base mineral, usually calcium, are combined with one of phosphoric anhydride (P_2O_5). Thus the common tribasic phosphate of lime, or tricalcic phosphate

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[1] Comptes Rendus de l'Académie des Sciences, Paris, 1885, p. 65.

as it is more commonly termed, has, the formula $Ca_3(PO_4)_2=45.81$ parts by weight P_2O_5 and 54.19, CaO. Other bases, as alumina, iron, or magnesia, may partially replace the lime, but the phosphate is always deteriorated thereby. This is particularly the case when aluminum and iron are the replacing constituents. Although when finely ground the tricalcic phosphates are of possible value for fertilizers, it is customary to first submit them to chemical treatment in order to render them more readily soluble.

This treatment consists, as a rule, in converting them into a superphosphate by sulphuric acid, whereby a portion of the bases become converted into sulphates and the anhydrous and insoluble tribasic phosphate into a hydrous and soluble monobasic form of the formula $CaO.(H_2O)_2.P_2O_5$. There are other reactions than that above given, the discussion of which would be out of place here, and the reader is referred to especial treatises on the subject.

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2. Monazite.

Composition, a phosphate of the cerium metals of the general formula (Ce, La, Di) PO_4. Actual analyses as given by Dana yielded results as shown in table on page 304.

Hardness, 5 to 5.5; specific gravity, 4.9 to 5.3. Color, hyacinth-red to brown and yellowish, subtransparent to translucent.

Localities and mode of occurrence.—The common mode of occurrence of the mineral is that of minute crystals or crystalline granules disseminated throughout the mass of gneissoid rocks. Owing to their small size they have been very generally overlooked,

Constituents.	I.	II.
Phosphoric anhydride (P_2O_5)	29.28	27.55
Cerium sesquioxide (Ce_2O_3)	31.38	29.20
Lanthanum sesquioxide (La_2O_3)	30.88	26.26
Didymium sesquioxide (Di_2O_3)		
Yttrium sesquioxide (Y_2O_3)	....	3.82
Iron sesquioxide (Fe_2O_3)	....	1.13
Silica (SiO_2)	1.40	1.86
Thoria (ThO_2)	6.49	9.57
Lime (CaO)	....	0.69
Ignition	0.20	0.52
Total	99.63	100.60

I. Burke County, North Carolina. II. Arendal, Norway.

and it is only where, through the decomposition of the inclosing rock and the concentration of the monazite and the accompanying heavy minerals—as magnetite, garnet, etc.—in the form of sand, that it becomes sufficiently conspicuous to be evident. Prof. O. A. Derby was the first to point out the widespread occurrence of the mineral as a rock constituent, having obtained it in numerous and hitherto unsuspected localities by washing the débris from decomposed gneisses of Brazil. Although widespread as a rock constituent and of interest from a mineralogical and petrographical standpoint only the localities mentioned below have thus far yielded the mineral in commercial quantities.

The Carolinas.—The mineral is found in commercial quantities in the form of small brownish or yellow-brown water-worn granules in stream beds and placer deposits of the Carolinas throughout the area shown in the accompanying map (Fig. 45). The principal producing areas include between 1,600 and 2,000 square miles in Burke, McDowell, Rutherford, Cleveland, and Polk counties, North Carolina, and the northern part of Spartanburg County, South Carolina. The better deposits are found along the waters of Silver, South Muddy, and North Muddy creeks, and Henry's and Jacob's Forks of the Catawba River in DcMowell and Burke counties; the Second Broad River in McDowell and Rutherford counties; and the First Broad River in Rutherford and Cleveland counties, North Carolina, and Spartanburg County, South Carolina. These streams have their sources in the South Mountains, an eastern outlier of

PLATE XXIX.
Monazite Mining, Gaffney, South Carolina.
[From photograph by Douglas Sterrett, U. S. Geological Survey.]

[*Facing page* 304.]

the Blue Ridge. The country rock is granitic biotite gneiss and dioritic hornblende gneiss, intersected nearly at right angles to the schistosity by a parallel system of small auriferous quartz veins, striking about N. 70° E. and dipping steeply to the N. W. The thickness of the gravel deposits is from 1 to 2 feet, and the width of the mountain streams in which they occur is seldom over 12 feet. The percentage of monazite in the original sand varies from an infinitesimal quantity up to 1 or 2 per cent. The deposits are naturally richer near the headwaters of the streams.

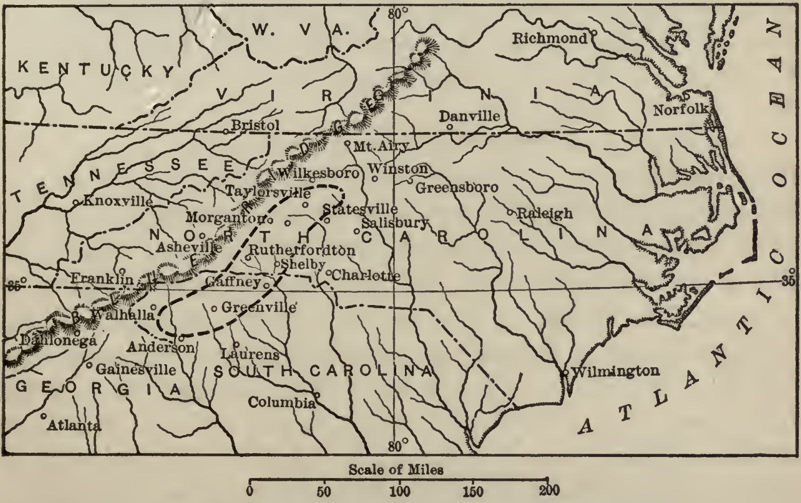

FIG. 45.—Map of monazite areas in the Carolinas.
[After J. H. Pratt, Transactions of the American Institute of Mining Engineers.]

From these deposits amounts varying from 30,000 pounds to 1,573,000 pounds have been washed annually since systematic mining began in 1893. In 1901 the amount was 748,736 pounds, valued at $59,262. The miner usually receives from 3½ to 5 cents per pound. The existence of monazite in commercial quantities in this region was first demonstrated by W. E. Hidden in 1879.

According to Lindgren[1] monazite sand occurs in considerable quantities in the region known as the Idaho Basin, an area of some

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[1] Eighteenth Annual Report U. S. Geological Survey, III, 1896–97, p. 677.

150 square miles about the headwaters of Moore Creek, in Boise County, Idaho. The mineral is here associated with ilmenite, garnet, and zircon.

Brazil.—As above noted, the original source of the Brazilian monazite were gneisses from which the mineral has been liberated by decomposition. The particular localities examined by Professor Derby are in the provinces of Minas Geraes, Rio de Janeiro, and São Paulo. The most extensive accumulation thus far reported is in the form of considerable patches on the sea beach near the little town of Alcobaca in the southern part of the province of Bahia, though it has been also found on other sea beaches and in river sands. Nitze states:[1]

"Sacks filled with this sand were shipped to New York in 1885, the deposit having been taken for tin ore. Its true character was, however, soon recognized, and since then a number of tons have been shipped in the natural state, without any further concentration or treatment, as ballast, mainly to the European markets. It is reported to contain 3 to 4 per cent thoria. . . . Monazite has also been found in the gold and diamond placers of the provinces of Bahia (Salabro and Caravellas), Minas Geraes (Diamantia), Rio de Janeiro, and São Paulo. It has been found in the river sands of Buenos Ayres, Argentine Republic, and also in the gold placers of Rio Chico, at Antioquia, in the United States of Colombia."

Russia.—"In the Ural Mountains of Russia monazite is found in the Bakakui placers of the Sanarka River. The placer gold mines of Siberia are reported to be rich in monazite, which is rafted down the Lena and the Yenesei rivers to the Arctic Ocean, and thence to European ports.

Norway.—"Economic deposits of monazite are also reported to exist in the pegmatic dikes of Southern Norway. It is picked by the miners while sorting feldspar at the mines. It is not known to exist in placer deposits. The annual output is stated to be not more than 1 ton, which is shipped mainly to Germany.

Methods of extraction.—In the Carolinas the monazite is won by

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[1] Sixteenth Annual Report U. S. Geological Survey, 1894–95, pt. 4, p. 685.

washing the sand and gravel in sluice boxes after the manner of placer gold. Magnetite, and other ferriferous minerals, if present, are eliminated from the dried sand by the electro-magnet. Many of the heavy minerals, such as zircon, menaccanite, rutile, brookite, corundum, garnet, etc., can not be thus completely eliminated, and the commercially prepared sand, therefore, is not *pure* monazite. A cleaned sand containing from 65 to 70 per cent monazite has in the past been considered of good quality, but of late years concentrating machines have been introduced by means of which sands running as high as 80 per cent monazite are obtained.

3. TORBERNITE.

Composition: a hydrous phosphate of uranium and copper of the general formula CuO, $2UO_3$, P_2O_5, $8H_2O$, which is equivalent to uranium trioxide (UO_3) 61.2 per cent, copper 8.4 per cent, phosphorous pentoxide (P_2O_5) 15.1 per cent, water (H_2O) 15.3 per cent. Arsenic sometimes replaces, in part, the phosphorus. Color, green; when crystallized in the form of small square tablets, sometimes very thin and foliated, in which form it has been called uranium mica. The laminæ are, however, brittle. The mineral has been found in Cornwall, England, and in Saxony, Bohemia, and Belgium, but in quantities of only mineralogical interest. What is reported as a deposit of possible economic value has recently been discovered in the Province of Guarda, in Portugal. Wm. Nivens also reports[1] the finding of the material in a vein from 2 to 6 feet in width near the Cerro Metafe, State of Guerrero, Mexico. Average samples are reported to yield one-half of one per cent of uranium.

Uses.—The rare elements cerium, zirconium, thorium, yttrium, lanthanum, etc., which are as a rule associated with each other in the minerals cerite, zircon, monazite, samarskite, etc., as described, find their commercial use not in the form of metals, but as oxides only; and it is only since the introduction of the Welsbach incandescent system of lighting that their use in this form has assumed any commercial importance.

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[1] The Mining World, Jan. 15, 1910

This Welsbach light consists of a cap or hood to gas or other burners, to increase their illuminating powers. The cap is made of cotton or other suitable material, impregnated with the oxides in proportions 60 per cent zirconia, 20 per cent yttria, and 20 per cent lanthanum. The fabric is strengthened and supported with fine platinum wire and suspended in the flame. On igniting in the flame the fabric is quickly reduced to ash, the cotton being burnt away and the earthy matter still retaining the form of a cap or hood.[1]

The drawback to the use of these oxides has been, it is said,[2] the great difficulty in obtaining them in a pure condition. Several methods have been used, but usually with poor results, especially when the mineral contains iron. The cerium oxalate is used in pharmacy.

The demand for the minerals of this group being so limited, there is no regular market price. The Mineral Industry for 1893 quotes zircon at 10 cents a pound, monazite, 25 cents, and samarskite, 50 cents. In 1901 monazite from North Carolina was quoted at 8 cents per pound, of which the original miners received from 3½ cents to 5 cents per pound, according to the purity of the material. The total output of the United States for 1908 was 422,646 pounds, valued at $50,718, or 12 cents per pound. It is stated that 1 ton of zircon will yield sufficient zirconia for half a million Welsbach burners. For uses of torbenite see under Uranates, p. 330.

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4. WAVELLITE.

Wavellite.—This mineral is a hydrous phosphate of alumina corresponding to the formula $3Al_2O_32P_2O_5, 12H_2O$. The theoretically pure mineral would therefore carry some 15.37 per cent of

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[1] Journal of the Society of Chemical Industry, V, 1886, p. 522.

[2] Mineral Resources of the United States, 1885, p. 393.

phosphorus. Commonly in globular, botryoidal, and stalatitic forms showing internally a finely fibrous, radiate structure; rarely in distinct crystals; colors, white, yellowish, brown, or rarely greenish or black. Hardness, 3.25 to 4; streak white; specific gravity, 2.33.

Occurrence and origin.—The common form of occurrence is as a secondary mineral in residual clays and soils though also found in rifts and pockets of still firm rocks associated with amblygonite and other phosphates. It is fairly common as a mineral, but rarely occurs in sufficient abundance to be of commercial value. At the foot of the northern slope of South Mountain, in the vicinity of Holly Springs, Pennsylvania, the mineral is found in quantity, together with manganese ores and limonite in the surface sands, gravels, and clays, which cover the rock outcrops, and which were themselves derived from the neighboring sandstones, limestones, and hydro-mica slates. It seems reasonable to conclude, according to G. W. Stose[1] that the original deposition of the iron (limonite) together with the wavellite, was in some way a feature of the change of sedimentation from shore detritus to calcareous silt, probably not as a massive bed of ore but as ferruginous sediments. The phosphorus was probably associated with the iron in its original occurrence and in the process of redeposition it combined with the alumina, but it is possible that a part of the phosphorus may have been derived from the remains of invertebrate animals, trilobites and other fossils being found in the limestones.

The wavellite, in form of nodular, disconnected masses is found scattered through a white clay and is mined by open cuts. The output is used in the manufacture of phosphorus which, in its turn is consumed mainly in the manufacture of matches.

5. AMBLYGONITE.

This is a fluo-phosphate of aluminum and lithium of the formula $Li(AlF)PO_4$. Analysis of a sample from Paris, Maine, as given by Dana, shows: Phosphoric acid, 48.31 per cent; alumina, 33.63 per cent; lithia, 9.82 per cent; soda, 0.34 per cent; potash, 0.08

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[1] Bulletin No. 315, U. S. Geological Survey, 1907, p. 477.

per cent; water, 4.89 per cent; fluorine, 4.82 per cent. Hardness, 6; specific gravity, 3.01 to 3.09. Luster vitreous to greasy, color white to pale greenish, bluish, yellowish, to brownish; streak white. On casual inspection the mineral somewhat resembles potash feldspar (orthoclase), but when finely pulverized is soluble in sulphuric acid, and less readily so in hydrochloric acid. Before the blowpipe the mineral gives the characteristic lithia red color to the flame.

Mode of occurrence.—Amblygonite occurs in the form of coarse crystals, or compact and columnar forms in pegmatic dikes associated with lepidolite, tourmaline, and other minerals so characteristic of this class of rocks. In the United States it occurs at Hebron; Mount Mica, in Paris; Auburn and Peru, Maine, at the last-named place associated with spodumene, petalite, and lepidolite. In Saxony the mineral is found at Chursdorf and Arnsdorf, near Penig, and near Geier. Also found at Arendal, Norway, and at Montebras and Creuze, France.

Uses.—Since 1886 the mineral has been utilized as a source of lithia salts, in place of the lithia mica. The chief commercial source is at present Montebras, France, where it occurs in a coarse granitic vein yielding also cassiterite and kaolin in commercial quantities. (See also Spodumene, p. 200.)

6. TRIPHYLITE AND LITHIOPHILITE.

These are names given to phosphates of iron, manganese, and lithium, and which pass into one another by insensible gradations through variations in the proportional amounts of manganese protoxide, the triphylite containing from 10 to 20 per cent of this oxide, while the lithiophilite contains twice that amount. The comparative composition of extreme types is shown below:

Name.	P_2O_5,	FeO.	MnO.	Li_2O.	Na_2O.	H_2O
Triphylite.	43.18	36.21	8.96	8.15	0.26	0.87
Lithiophilite.	44.67	4.02	40.86	8.63	0.14	0.82

Triphylite is a gray to blue-gray mineral in crystals and coarsely-cleavable masses of a hardness of 4.5 to 5 of Dana's scale, and specific gravity of 3.42 to 3.56.

Lithiophilite differs mainly in color—aside from composition as above noted—being of a pink to clove-brown hue. Both minerals may undergo a darkening in color, becoming almost black through a higher oxidation and hydration of the manganese protoxide. This feature is best shown in the lithiophilite from Branchville, Connecticut.

Occurrence.—These minerals occur chiefly in granitic veins, associated with spodumene and other lithia-bearing minerals, as at the localities above mentioned. Peru, Hebron, and Norway, Maine, Keityö, Finland, etc. They have as yet been put to no practical use.

7. VANADINITE.

This is a vanadinate and chloride of lead of the formula (PbCl) $Pb_4V_3O_{12}$=vanadium pentoxide, 19.4 per cent; lead protoxide, 78.7 per cent; chlorine, 2.5. In nature often more or less impure through the presence of arsenic and traces of iron, manganese, zinc, and lime. Color deep red to brown and straw-yellow, resinous luster; translucent to opaque. Hardness, 2.75 to 3. Gravity, 6.66 to 7.23. When a drop of nitric acid is applied to a particle of a crystal there is soon formed a yellow coating of vanadic oxide. This reaction is quite characteristic and furnishes an easy and convenient means of determination.

Localities and mode of occurrence.—The mineral occurs in prismatic crystals with smooth faces and sharp edges; crystals sometimes cavernous at the top. Also common in parallel grouped and rounded forms and globular incrustations. Dana gives the following relative to the known localities:

" This mineral was first discovered at Zimapan in Mexico, by Del Rio. Later obtained among some of the old workings at Wanlockhead in Dumfriesshire, where it occurs in small globular masses on calamine, and also in small hexagonal crystals; also at Berezov in the Ural, with pyromorphite; and near Kappel in Carinthia, in crystals; at Undenäs, Bölet, Sweden; in the Sierra de Córdoba, Argentine Republic; South Africa.

"In the United States it occurss paringly with wulfenite and pyromorphite as a coating on limestone, near Sing Sing, New York. In Arizona it is found at the Hamburg, Melissa, and other mines in Yuma County, in brilliant deep-red crystals; Vulture, Phœnix, and other mines in Maricopa County; at the Black Prince mine; also the Mammoth gold mine, near Oracle, Pinal County, and in brown barrel-shaped crystals in the Humbug district, Yavapai County. In New Mexico it is found at Lake Valley, Sierra County (endlichite); and the Mimbres mines near Georgetown."

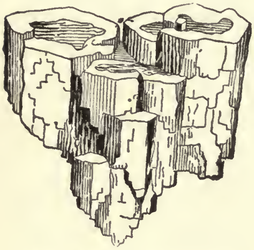
FIG. 46.—Vanadinite crystals.

The characteristic mode of occurrence at the Mimbres mines, above noted, is associated with descloizite in the form of small hopper-shaped crystals and drusy or botryoidal and globular masses coating the siliceous residues of the limestone in the irregular cavities with which the stone abounds. The color of these coatings varies from beautiful ruby red to light ocherous yellow. The mineral is here nearly always associated with descloizites as noted below.

Uses.—See under Descloizite.

8. DESCLOIZITE.

This is a vanadinate of lead and zinc of the formula $4(PbZn)O.V_2O_5,H_2O$, = vanadium pentoxide, 22.7 per cent; lead protoxide, 55.4 per cent; zinc oxide, 19.7 per cent; water, 2.2 per cent. The published analyses show also small amounts of arsenic, copper, iron, manganese, and phosphorus. Color, red to brown; luster, greasy; no cleavage; fracture small conchoidal to uneven. Occurs in small prismatic or pyramidal crystals and in fibrous, mammillated or massive forms. Often associated with and pseudomorphous after vanadinite.

Localities and mode of occurrence.—Dana gives the following relative to occurrence:

"Occurs in small crystals, 1 to 2 millimeters thick, clustered on a siliceous and ferruginous gangue from South America, at the Venus Mine and other points in the Sierra de Córdoba, Argentine

Republic, associated with acicular green pyromorphite, vanadinite, etc. At Kappel, in Carinthia, in small clove-brown rhombic octahedrons.

* * * * * * *

"Sparingly at the Wheatley Mine, Phœnixville, Pennsylvania, as a thin crystalline crust on wulfenite, quartz, and a ferruginous clay. Abundant at the Sierra Grande Mine, Lake Valley, Sierra County, New Mexico, in red to nearly black crystals, pyramidal and prismatic in habit, associated with vanadinite, iodryite, etc.; at the Mimbres and other mines, near Georgetown, New Mexico, in stalactitic crystalline aggregates. In Arizona near Tombstone, in Yavapai County, in brownish olive-green crystals; at the Mammoth Gold Mine, near Oracle, Pinal County, in orange-red to brownish red crystals with vanadinite and wulfenite."

A vanadinite, probably identical with descloizite, occurs at the Mayflower Mine, Bald Mountain district, in Beaverhead County, Montana; it is in an impure earthy form of a dull yellow to pale orange color. (See further under Carnotite, p. 332.)

Vanadium is also found in small quantities in certain Swedish iron ores; in the cupriferous schists of Mansfeld, Saxony; in cupriferous sands of Cheshire, England, and Perm, Russia; in coals from various localities; in beauxite and in clay near Paris. As stated by Fuchs and De Launay,[1] vanadium has been shown to exist in extremely small proportions in primordial rocks, from which it became concentrated in the clays on their breaking up. Certain oölitic iron ores (limonites) at Mafenay, Saône et Loire, France, contain the substance in such proportions that the slags from their smelting have become commercial sources of supply.

The following referring to the occurrence and value of vanadinates in the United States is of sufficient interest to bear reproduction here:

The lead vanadates are frequently found in association with lead ores, as, for instance, in the deposits at Leadville, whence some very handsome specimens were formerly obtained. The most important occurrence of lead vanadates in the United States, however, is probably in Arizona, where it has been reported in the

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[1] Traité des Gîtes Minéraux, II, p. 95.

ores of several mines, among others those of the Castle Dome district, the Crowned King mine in the Bradshaw Mountains, and the Mammoth gold mines at Mammoth, in Pinal County. The last-mentioned mines are probably the only ones in the United States from which vanadium minerals have been won on an industrial scale. The vanadium minerals, of which nearly all the known varieties occurred, the dechenite and descloizite predominating, were found in the upper levels of the mine, forming about 1 per cent of the ore on the average, though within limited areas they formed from 3 to 4 per cent. In the lower levels they occurred less abundantly, only an occasional pocket and a small quantity of disseminated crystals being found. The red crystals, according to an analysis by the late Dr. F. A. Genth, contained chlorine, 2.43 per cent; lead, 7.08 per cent; lead oxide, 69.98 per cent; ferric oxide, 0.48 per cent; vanadic acid, 17.15 per cent; arsenic acid, 3.06 per cent, and phosphoric acid, 0.29 per cent. In milling the ore (gold) the vanadium minerals collected in riffles. The total quantity of concentrates obtained in this manner did not exceed 6 tons. An average sample of the lot, analyzed by Dr. Genth, gave the following results: Vanadic acid, 15.40 per cent; molybdic acid, 3.35 per cent; arsenic acid, 1.50 per cent; carbonic acid, 0.90 per cent; chlorine, 0.48 per cent; oxide of lead, 56.80 per cent; oxide of zinc, 10.70 per cent; oxide of copper, 0.95 per cent; oxide of iron, 0.35 per cent; soluble silica, 0.60 per cent; insoluble matter, 5.29 per cent. The price realized on this first lot was 12.5 cents per pound, or $250 per ton, on board the cars at Tucson.

The vanadic salts manufactured from this lot of concentrates were said to have been the first produced on a commercial scale in the United States, and owing to the limited market for the same the price dropped over 50 per cent. (See also under Patronite, p. 41, and Roscoelite, p. 179.)

Uses.—The uses thus far developed for these minerals are as a source for vanadium salts used as a pigment for porcelain and in the manufacture of ferrovanadium alloys to be used in steel-making. Vanadate of ammonium and vanadic oxide are used in the manufacture of ink and in textile dyeing and printing, imparting intense black colors with a slight greenish cast. Vanadium oxide obtained from the slags of the Creusot steel works in France is utilized as a mordant in dyeing. When used in steel the vanadium is stated to very greatly increase the tensile strength and elastic limit. A larger supply, it is thought, would result in its use in armor plate, projectiles, and bronzes.

IX. NITRATES.

There are three compounds of nitric acid and a base occurring in nature in such quantities and of sufficient economic importance to merit attention here. These are (1) the true niter or potassium nitrate (KNO_3), (2) soda niter or sodium nitrate ($NaNO_3$), and (3) nitrocalcite, a calcium nitrate (CaN_2O_6). All are readily soluble in water, and hence found in any quantity only in arid regions or where protected, as in the dry parts of caves.

1. NITER, POTASSIUM NITRATE.

Composition.—KNO_3, = nitric anhydride (NO_2), 53.5 per cent; potash (K_2O), 46.5 per cent. Hardness, 2; specific gravity, 2.1; color, white, subtransparent. Readily soluble in water. Taste, saline and cooling. Deflagrates vividly when thrown on burning coals and colors the flame violet.

The mineral occurs in nature mainly in the form of acicular crystals and efflorescences on the surface or walls of rocks and scattered in the loose soil of limestone caves and similar dry and protected places.

It is also found in certain soils of tropical countries, as noted later under origin (p. 319). In the United States it has been found in caves of the Southern States, as those of Madison County, Kentucky, but never as yet in commercial qualities. The chief commercial source of the salts has been the artificial nitraries of France, Germany, Sweden, and other European countries. It is also prepared artificially from soda niter.

2. SODA NITER.

Nitrate of sodium, $NaNo_3$, = nitric anhydride (NO_2), 63.5 per cent; soda (Na_2O), 36.5 per cent. This in its pure state is a white or colorless salt, but in nature often brown or bright lemon-yellow, of a slight saline taste, but with a peculiar cooling sensation when placed upon the tongue. It is by far the most common of the nitrates, and indeed the only one of the natural salts of any great commercial value, owing to the comparative rarity of the others. Though found to a slight extent in caves and protected places, the commercial supply is drawn almost wholly from the arid or pampas regions of the Pacific coast of South America and particularly from Chile, the chief deposits being found in the provinces of Tarapaca and Antofagasta.

According to Penrose[1] the pampas region has a general slope from east to west. As a result the western border, where is abuts against the foothills of the coast range, is the lowest, and it is along this zone that the nitrate deposits occur, occupying in Tarapaca province a narrow north and south belt for a distance of over 100 miles. The beds are all superficial deposits, from several to many feet in thickness, and often capped by several feet of earthy material. Most of the deposits, it should be noted, consist largely of sodium chloride (common salt), or a mixture of this salt and the niter. Rarely does the crude salt carry over 70 per cent of niter and 25 per cent is considered a fair average. Sometimes the nitrate deposits are found in the bottom of shallow basins, but more commonly this position is occupied by the chloride salts, while the nitrate forms terraces or benches around them. The two salts may, however, occur mixed indiscriminately. The deposits, which where exposed present a rough and leached appearance, are quite variable in thickness even over small areas, a depth of several feet fading out within a few yards to but a few inches. Thicknesses of 1 to 1½ to 3 feet are common; less so are thicknesses of 4 to 6 feet. The overlying material, rarely absent, varies from 2 to 20 feet in thickness, sometimes to even 30 or 40 feet. The following section is given for the Province of Tarapaca.

Loose windblown material, sand and gravel, known as *Chaca*	0 to several feet
Capping of clay, gravel, and sand, known as *Costra*	0 to 20–40 feet
Crude nitrate, known as *Caliche*	0– 6 "
Earthy floor of nitrate beds, known as *Coba*	Indefinite
Stratified clays, sands, and gravels	"

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[1] Journal of Geology, Vol. XVIII, No. 1, Jan.-Feb., 1910.

As above noted the natural nitrate is never chemically pure. The following analyses are selected to show averages:

ANALYSES OF CRUDE CHILEAN NITRATE.

Constituents.	Per Cent.				
Sodium nitrate	28.54	53.50	41.12	61.97	22.73
Potassium nitrate	Trace.	17.25	3.43	5.15	1.65
Sodium chloride	17.20	21.28	3.58	27.55	41.90
Potassium perchlorate	Trace.	0.78	0.75	0.21	Trace.
Sodium sulphate	5.40	1.93	Trace.	2.13	0.94
Magnesium sulphate	3.43	1.35	10.05	0.15	3.13
Calcium sulphate	2.67	0.48	3.86	0.41	4.80
Sodium biborate	0.49	0.56	0.20	0.43	0.53
" iodide	0.047	....	....	....	....
" iodate	0.043	0.01	0.05	0.94	0.07
Insoluble matter	40.30	2.07	31.86	0.39	22.50
Combined water, etc	1.88	0.79	5.00	0.67	1.75
	100.00	100.00	100.00	100.00	100.00
Total nitrates ($NaNO_3$)	28.54	68.00	44.00	66.29	24.11
" chlorides ($NaCl$)	17.20	21.28	3.58	27.55	41.90
" iodine	0.067	0.0064	0.36	0.604	0.045

Several of the analyses showed also traces of calcium and magnesium chlorides, ammonia salts, and sodium chromate. Iodine, although present in but small proportion, is an important constituent, the commercial supply of it being obtained almost wholly from the nitrate, in process of refining.

The nitrate deposit is quarried by blasting with a coarse-grained powder, of which as much as 150 pounds are sometimes used at a single blast. Neither dynamite nor nitroglycerin is used, as it would shatter and pulverize the salt so as to occasion a serious loss.

After being brought to the surface the caliche is carefully assorted by experts, broken into pieces double the size of an orange, and carted to the refinery establishment, situated on the pampas or on the seacoast, or carried to Iquique, Pisagua, Patillos, and Antofagasta by rail, all of these places having connection, by narrow-gauge railways, with the nitrate deposits, and which, consequently, are rapidly becoming the chief centers of nitrate production and export.

The following map, Fig. 47, from Fuchs and De Launay's Traité des Gîtes Minéraux, will serve to show the geographic position of the deposits.

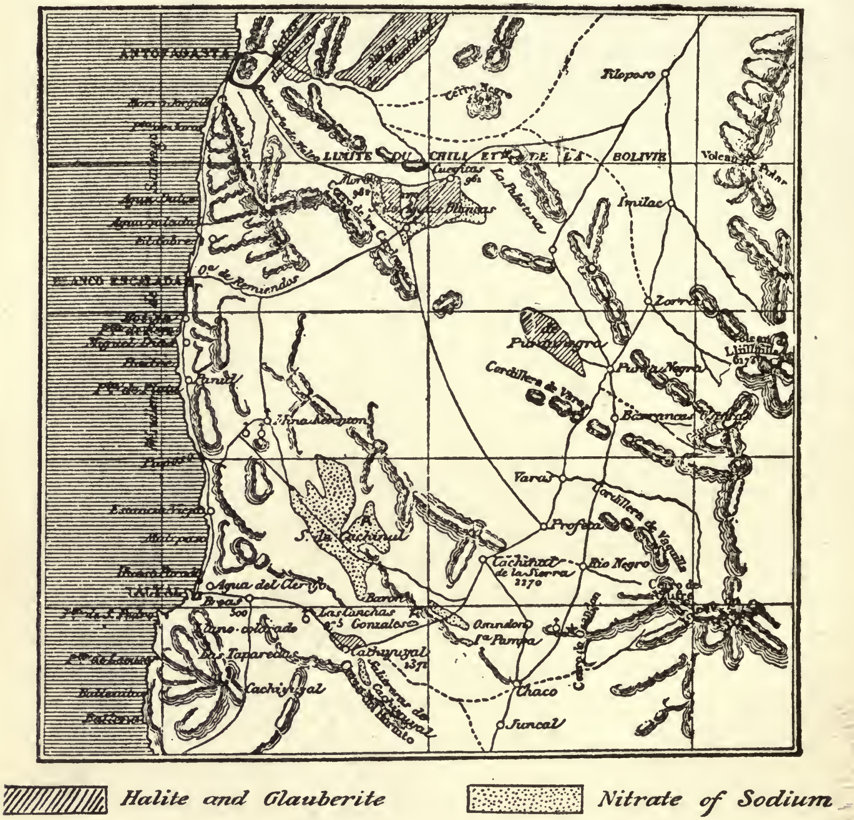

FIG. 47.—Map of Chilean nitrate region. [After Fuchs and De Launay.]

3. NITRO-CALCITE.

Nitro-calcite, or calcium nitrate, $CaN_2O_6+nH_2O$, is not uncommon as a silky efflorescence on the floors and walls of dry limestone caverns, and may be extracted in considerable quantities from their residual clays by a process of leaching. During the war of 1812 the clays upon the floors of Mammoth Cave, Kentucky, were systematically leached and the dissolved nitrate converted into potassium nitrate by filtration through wood ashes. The wooden tanks and log pipes for conducting the water are still in a remarkable state of preservation, owing to the dry air of the cavern.

The nitrous earths of Wyandotte Cave in southern Indiana, and doubtless of other localities, were similarly treated during these times of temporary stringency.

According to the reports of the State geologist[1] this earth, in its air-dry condition, has the following composition:

ANALYSIS OF NITROUS EARTH.

Constituents.	Per Cent.
Loss at red heat	16.50
Silica	20.60
Ferric oxide	6.03
Manganic oxide	0.75
Alumina	20.40
Lime	8.06
Magnesia	4.58
Carbonic acid	10.38
Sulphuric acid	6.55
Phosphoric acid	2.43
Nitric acid	3.50
Chlorides of alkalies and loss	0.32
Total	100.10

The researches of Muntz and Marcano[2] have shown that the soils as well as the earth from the floor of caves, in Venezuela and other portions of South America, may be rich in calcium nitrate to an extent quite unknown in other countries.

Origin.—The original source of the nitrates, both of caves and of the Chilean pampas, has been a subject of considerable discussion. There appears little doubt but the deposits in caves and those disseminated in soils are due to the nitrifying agencies of bacteria acting upon organic matter whereby the organic nitrogen is converted into nitric acid, which immediately combines with the most available bases, be they of lime, soda, or potash. The accumulation

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[1] Geological Report of Indiana, 1878, p. 163.

[2] Comptes Rendus de l'Académie des Sciences, CI, Paris, 1885, p. 1265.

of the niter in caves is probably due, as suggested by W. H. Hess,[1] to the retention by the clay of the nitrates brought in from the surface by percolating waters. In other words, the caves serve merely as receptacles, or storehouses, for nitrates which had their origin in the surface soil. The Chilean nitrate beds are considered by Muntz and Marcano as having a very similar origin. The material being soluble is gradually leached out from the soils in which it originated and drained into inclosed salt marshes or inland seas where a double decomposition takes place between the sodium chloride and calcium nitrate, whereby sodium nitrate and calcium chloride are produced. That such a double decomposition may take place has been shown by actual experiment.

This is not widely different from the view taken also by W. Newton.[2] After discussing briefly theories previously advanced, including Darwin's theory of derivation from decomposing seaweeds accumulated on old sea beaches, and the even less plausible one of its derivation from guano, his writer shows that the Tamarugal plain within which the deposits lie, is covered by an alluvial soil rich in organic matter. This organic matter, under the now well-known action of bacteria, aided by the prevailing high temperatures of the region, gives rise to nitrates, which, owing to the absence of rains for long periods, accumulate to an extent impossible under less favorable circumstances. Mountain floods, which occur at periods of seven or eight years, swamp the plain, bringing in solution the nitrate drained from the soils of the surrounding slope, to accumulate in the lower levels. On the evaporation of the water this is again deposited. The occurrence of the nitrate so far up the slope of the hills is regarded by Newton as due to the tendency of the nitrate salt, in saturated solutions, to creep up, as in experiment it may be seen to creep up and over the sides of a saucer or other shallow dish in which the evaporation is progressing.

Penrose, on the other hand, in the most recent paper bearing on the subject, argues that the nitrogenous matter was derived from ancient guano deposits which once lined the waters of these inclosed basins.

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[1] Journal of Geology, VIII, No. 2, 1900, p. 129.

[2] Geological Magazine, III, 1896, p. 339.

Uses.—Munroe[1] gives the consumption of nitrate of soda in the United States for 1905 as 254,772 short tons, which was divided among the various industries as follows:

In the manufacture of fertilizers	42,213 tons
" " dyestuffs	261 "
" " chemicals	38,048 "
" " glass	11,915 "
" " explosives	133,034 "
" " sulphuric, nitric, and other acids	29,301 "
	254,772 "

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Journal of Geology, XVIII, 1910, pp. 1–32.

X. BORATES.

Of the ten or more species of natural borates but three, or possibly four, are commercial sources of borax, and need consideration here. These are, (1) borax or tincal; (2) ulexite, or boronatrocalcite; (3) priceite, colemanite, or pandermite, and (4) boracite, or stassfurtite. Sassolite, or native boric acid, occurs chiefly in solution. The intimate association of these minerals renders it advisable to treat of their origin and mode of extraction in common, after giving the composition and general physical characters of each by itself.

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[1] The Nitrogen Question, etc. Proceedings U. S. Naval Institute, XXXV, No. 3, 1910, p. 715.

1. BORAX OR TINCAL; BORATE OF SODA.

Composition.—$Na_2B_4O_7.10H_2O$, = boron trioxide, 36.6 per cent; soda, 16.2 per cent; water, 47.2 per cent. Color, white to grayish, and sometimes greenish; translucent to opaque. It crystallizes in short, stout prisms, belonging to the monoclinic system. Hardness, 2 to 2.5; specific gravity, 1.7. Readily soluble in water; taste, sweetish alkaline.

2. ULEXITE; BORONATROCALCITE.

Composition.—$NaCaB_5O_9.8H_2O$, = boron trioxide, 43 per cent; lime, 13.8 per cent; soda, 7.7 per cent; water, 35.5 per cent. Color, white, with silky luster. Occurs usually in rounded masses of loose texture, which consist mainly of fine acicular crystals or fibers. Insoluble in cold water, and only slightly so in hot, the solution being alkaline. Hardness, 1; specific gravity, 1.65.

3. COLEMANITE.

Composition.—$Ca_2B_6O_{11}.5H_2O$, = boron trioxide, 50.9 per cent; lime, 27.2 per cent; water, 21.9 per cent. Color, milky to yellowish white, or colorless; transparent to translucent. Hardness, 4 to 4.5; specific gravity, 2.41. Insoluble in water, but readily so in hot hydrochloric acid. Priceite and pandermite are closely allied varieties occurring in loosely coherent and chalky or massive forms.

4. BORACITE OR STASSFURTITE; BORATE OF MAGNESIA.

Composition.—$Mg_7Cl_2B_{16}O_{30}$, = boron trioxide, 62.5 per cent; magnesia, 31.4 per cent; chlorine, 7.9 per cent. Color, white to yellow or greenish. In crystals transparent to translucent. Crystals cubic and tetrahedral. Insoluble in water; readily soluble in hydrochloric acid. Hardness, 7; specific gravity, 2.9 to 3.

Localities and manner of occurrence of the borates.—Throughout what is known as the Great Basin region of the western United States, and in particular that portion including Inyo, Kern, and San Bernardino counties in California, and that portion of southwest Nevada adjoining Inyo County, are numerous inclosed lakes or marshes, the waters of which are sufficiently rich in borates and other sodium salts to allow of their extraction on a commercial scale. At least ten of these marshes have been noted along the California-Nevada line, the most widely known being Teels, Columbus, and Rhodes marshes, and Fish Lake Valley in Nevada, and Searles Marsh in San Bernardino County, California. A detailed description of the last named will serve all purposes of illustration here.[1]

Locally considered, the marsh lies near the center of an extensive mountain-girdled plain, to which the names "Alkali Flat," "Dry Lake," "Salt Bed," and "Borax Marsh" have variously been applied. It is, in fact, a dry lake, the bed of which has been filled up in part with the several substances named. Its contents consist of mud, alkali, salt, and borax, largely supplemented with volcanic sand. This depression, which has an elevation of 1,700 feet above sea-level, and an irregular oval shape, is about 10 miles long in a north and south direction, and 5 miles wide. It is surrounded on every side but the south by high mountains, the Slate Range bounding it on the east and north, and the Argus Range on the west.

What may have been the depth of the lake has not yet been ascertained, borings put down 300 feet having failed to reach bed rock. These borings, commenced in 1878, disclosed the following underlying formations:

First, 2 feet of salt and thenardite (Na_2SO_4); second, 4 feet of clay and volcanic sand, containing a few crystals and bunches of hanksite ($4Na_2SO_4,Na_2CO_3$); third, 8 feet of volcanic sand and black, tenacious clay, with bunches of trona, of black, shining luster from inclosed mud; fourth, 8-foot stratum, consisting of volcanic sand containing glauberite, thenardite, and a few flat, hexagonal crystals of hanksite; fifth, 28 feet of solid trona of uniform thickness; sixth, 20-foot stratum of black, soft mud, smelling strongly of sulphureted hydrogen, in which there are layers of glauberite, soda, and hanksite; seventh, 230 feet (as far as explored) of brown clay, mixed with volcanic sand and permeated with sulphureted hydrogen.

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[1] From the Tenth Annual Report of the State Mineralogist of California, 1890, p.534.

While most of the water contained in this basin is subterranean, a little from atmospheric sources accumulates during very wet winters and stands for a short time on portions of the surface. In no place, however, does it reach a depth of more than a foot or two, hardly anywhere more than 3 or 4 inches.

The water of the lake is of a dark-brown color, strongly impregnated with alkali, and has a density of 28° Baumé. The salts obtained from it by crystallization contain carbonate and chloride and borate of sodium, with a large percentage of organic matter.

Summarized, the following minerals have been found associated with the borax occurring in the Searles Marsh: Anhydrite, calcite, celestite, cerargyrite, colemanite, dolomite, embolite, gay-lussite, glauberite, gypsum, halite, hanksite, natron, soda, niter, sulphur, thenardite, tincal, and trona, the most of them occurring in only small quantities.

The submerged tract above described is called the "Crystal Bed," the mud below the water being full of large crystals, which occur in nests at irregular intervals to a depth of 3 or 4 feet. Many of these crystals, which consist of carbonate of soda and common salt with a considerable percentage of borate, are of large size, some of them measuring 7 inches in length. The water 15 feet below this stratum of mud contains carbonate of soda, borax, and salts of ammonia. The ground in the immediate vicinity, a dry, hard crust about 1 foot thick, contains:

Constituents.	Per Cent.
Sand	50
Sulphate of soda	16
Common salt	12
Carbonate of soda	10
Borax	12

The borax here occurs in the form of the borate of soda only, no ulexite (borate of lime) having yet been found.

About 1890 it was discovered that these marsh deposits were all secondary, the borax contents being derived from bedded deposits of colemanite in the Tertiary lake sediments of the surrounding hills. The marshes were, therefore, very generally abandoned in favor of the beds. What was, until recently, the most important of these deposits is at a locality appropriately named Borate, some 12 miles north of Daggett in the old Calico Mining District. The mineral colemanite—the borate of lime—occurs here in beds of from 3 to 5 feet thickness interstratified with lake sediments which are composed of semi-indurated clays, sandstones, and coarse conglomerates with sheets of volcanic tuffs and lava. At the mine, according to Messrs. W. H. Storms[1] and M. R. Campbell,[2] there are two outcrops some 50 feet apart, representing two distinct beds or perhaps a repetition by folding of what was originally one and the same bed. These throughout their extent vary from 5 to 30 feet in thickness, and have a strike approximately east and west,

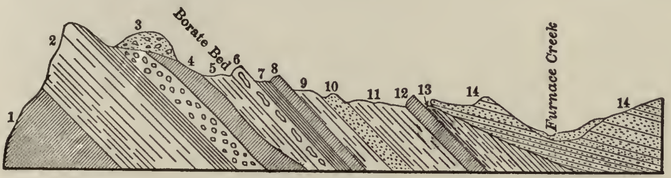

FIG. 48.—Section of tilted borate beds, Furnace Valley, California.

1.	Andesite (exposed)	500 ft.
2.	Clay-shale, blue above, yellowish below	1000 "
3.	Gravels, coarse, little or no clay	300 "
4.	Basalt	200 "
5.	Shale, argillaceous and sandy, buff	300 "
	Unconformity.	
6.	Clay, shaly, colemanite in large nodules and nodular layers	50 "
7.	Clay, shaly, olive-green to yellow	60 "
8.	Basalt, surface-flow	100 "
9.	Clay, shaly, yellow to green	150 "
10.	Sandstone, friable, red in color	25 "
11.	Clay, shaly, pale yellow	500 "
12.	Basalt, black, surface-flow	50 "
13	Clay, shaly, argillaceous, yellowish	200 "
14.	Clays and gravels, pale reddish-brown and purple	500 "
	Unconformity, very marked.	

[After C. R. Keyes, Bulletin of the American Institute of Mining Engineers, 1909.]

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[1] Eleventh Annual Report of the State Mineralogist of California, 1892, p. 345.

[2] Bulletin No. 200, U. S. Geological Survey, Series A, Economic Geology, p. 7.

dipping to the south from 10° to 45°. The lake beds extend across the mountains for a distance of 8 miles, but the borax deposit, so far as yet discovered, has a practical limit of not above a mile and a half. The illustration (Plate XXX), conveys better than words an idea of the character of the desolate country in which the borax occurs, and also the method of mining.

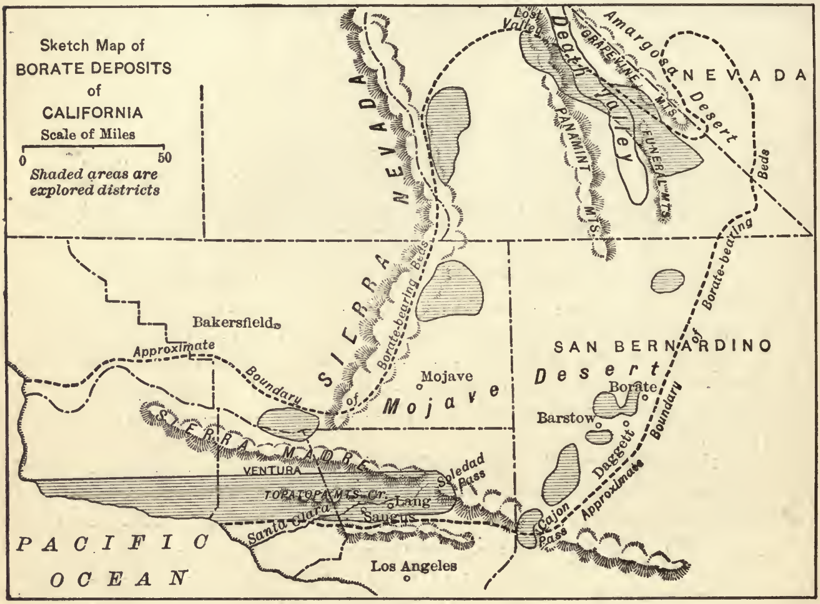

Fig. 49.—Sketch map of California borax localities.
[After C. R. Keyes, Bulletin of the American Institute of Mining Engineers, 1909.]

For a decade or more, according to C. R. Keyes,[1] the mines at Daggett were the chief source of borax in the United States. Recently extensive developments have taken place in Furnace Cañon in Death Valley and in the Santa Clara Valley, south of the Sierra Madre and west of Daggett. (See map, Fig. 49.) At the first-named locality the borax deposits lie in a deep valley and canyon between high mountain ranges, and in beds consisting mainly of

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[1] Borax Deposits of the United States, Bulletin American Institute of Mining Engineers, October, 1909, pp. 1–37.

PLATE XXX.
Borax Mine, near Daggett, California. Interior and Exterior Views.
[From photographs.]

[Facing page 326.]

soft clays, and sands or friable sandstone, the mountains on either hand being composed of eruptive and metamorphic rocks.

The rich borate beds are from a few inches to 50 feet in thickness, often highly tilted and folded as shown in the accompanying typical section (Fig. 48). They are described as consisting of bluish clays, thickly interspersed with milk-white layers, nodular bands and nodules of crystallized colemanite, the clays yielding by leaching from 10 to 25 per cent of boric acid. Mingled with the colemanite there is often much selenite in large plates.

In the Santa Clara Valley the entire borax-bearing formation is described as from 5,000 to 8,000 feet in thickness, consisting mainly of fine, more or less indurated gravel, yellow sandstone and clays. The beds have been much faulted and flexed and intruded by dikes of igneous rocks.

Borax in the form of colemanite (priceite) has also been found about 5 miles north of Chetco, in Curry County, Oregon.

A borax deposit in form somewhat resembling the marsh deposits of Nevada and California already referred to occurs in Harney County, southeastern Oregon. The region is extremely flat and bare of all vegetation, the immediate surface of the ground being covered for a depth of several inches with a white incrustation consisting of the borate contaminated with carbonate, sulphate, and chloride of sodium.[1]

The chief foreign sources of borax salts are Northern Chile, Stassfurt in Germany, Italy, Asia Minor, and Thibet.

The Chilean mineral is ulexite and is reported as occurring throughout the province of Atacama and the newly acquired portions of Chile. Ascotan, which is now on the borders of the Republic, but formerly belonged to Bolivia, and Maricunga, to the north of Copeapo, are the places which have proved most successful commercially. The crude material occurs in both places in lagoons or troughs. Those of Maricunga lie about 64 kilometers from the nearest railway station, and are estimated to cover 3,000,000 square meters. The boronatrocalcite occurs in beds alternating with layers of salt and salty earth. The crude material contains, in the form of gypsum and glauberite, a large amount of calcium sulphate.

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[1] W. B. Dennis, Engineering and Mining Journal, April 26, 1902, p. 581.

Recently deposits have been described in the dry bed of Lake Salinas, about 12 miles east of Arequipa City. The borate is in the form of ulexite and in a massive impure form known as *corriente.* A section of the deposit shows (1) chloride and sulphate of soda and fine sand 10 to 14 cm.; (2) gravel 6 cm.; (3) sand with layers of the borate 20 to 50 cm.; (4) fine sand and borate in variable thicknesses 40 cm. to 1 meter. The lake lies at an altitude of 14,200 feet and is surrounded by high mountains, many of which are volcanic.[1]

Dana also mentions ulexite as occurring in the form of rounded masses from the size of a hazelnut to that of a potato in the dry plains of Iquique, where it is associated with pickeringite, glauberite, halite, and gypsum.

The German mineral is boracite (stassfurtite) and is found in small granular masses associated with the salt deposits of Stassfurt. In Italy sassolite, or crystallized boric acid, has long been obtained by the evaporation of the water of hot springs in Siena, in Tuscany. Concerning the deposits of Asia Minor little is accurately known. The mineral is pandermite (colemanite), which is found in thick white lumps at Suzurlu, south of the sea of Marmora. Borax or tincal, from Thibet, in Northern India, was probably the first of the boron salts to be utilized. It is stated to have been brought on the backs of sheep from the lakes in which it is formed across the Himalayas to the shipping points in India.

Methods of mining and manufacture.—At the East Calico Colemanite Mine, in San Bernardino County, the borax mineral is taken out in the same manner as ores of the precious metals. Inclined shafts are sunk, drifts and levels run, and slopes carried up as in any other mine. The material, when hoisted to the surface, is loaded into wagons and hauled to Daggett, whence it is shipped to the works at Alameda, where it is purified.

At Searle's marsh the overlying crust mentioned constitutes the raw material from which the refined borax is made. The method of collecting it in the past has been as follows: When the crust, through the process of efflorescence, has gained a thickness of about

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[1] Engineering and Mining Journal, LXXXIV, 1907, p. 780.

1 inch, it is broken loose and scraped into windrows far enough apart to admit the passage of carts between them, and into which it is shoveled and carried to the factory located on the northwest margin of the flat, 1 to 2 miles away.

As soon as removed, this incrustation begins again to form, the water charged with the saline matter brought to the surface by the capillary attraction evaporating and leaving the salt behind. This process having been suffered to go on for three or four years, a crust thick enough for removal is again formed, the supposition being that this incrustation, if removed, will in like manner go on reproducing itself indefinitely.[1]

At the Harney County, Oregon, works the crude material is carefully shoveled up during the summer into small conical heaps, the crust continually renewing itself, so that the same ground is worked over repeatedly. This crude material, which contains from 5 to 20 per cent boric acid, is refined by throwing into tanks of hot water into which small amounts of chlorine or sulphuric acid are introduced. The various salts are all dissolved and subsequently separated one from another by fractional crystallization.

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[1] In order to determine the proportionate growths of the various salts contained in this crust while undergoing this recuperative process, analyses were made on samples representing respectively six months', two, three, and four years' growth. From the ground from which these were taken the crust had been removed several times during the preceding twelve years.

The analysis of samples gave the following results:

Constituents.	Six Months' Growth.	Two Years' Growth.	Three Years' Growth.	Four Years' Growth.
Sand.	58.0	55.4	52.4	53.3
Carbonate of soda	5.2	5.0	8.1	8.0
Sulphate of soda	11.7	6.7	16.6	16.0
Chloride of soda	10.9	20.0	11.1	11.8
Borax	14.2	12.9	11.8	10.9
Total.	100.0	100.0	100.0	100.0

From this list it will be seen that the first six months' growth is richest in borax, and that the proportion of carbonate of soda to borax increases with time. The presence of so much sand as is here indicated is caused by the high winds that blow at intervals, bringing in great quantities of that material from the mountains to the west. This sand, it is supposed, facilitates the formation of the surface crust by keeping the ground in a porous condition.

XI. URANATES.

1. URANINITE; PITCHBLENDE.

Composition very complex, essentially a uranate of uranyl, lead, thorium, and other metals of the lanthanum and yttrium groups. The mineral is unique in containing nitrogen, argon, helium and radium. The analyses given below are for the most part by Hillebrand, to whom is due the credit of a large share of the present knowledge on the subject.

Locality.	UO_3.	UO_2.	ThO_2.	CeO_2.	La_2O_3.	Y_2O_3.
Glastonbury, Connecticut..	23.03	59.93	11.10			
North Carolina...........	50.83	39.31	2.78	0.26	0.50	0.20
Änneröd, Norway........	30.63	46.13	6.00	0.18	0.27	1.11
Johanngeorgenstadt......	59.30	22.33	....	....	....	....

Locality.	PbO.	CaO.	N.	H_2O.	Fe_2O_3.	Misc.
Glastonbury, Connecticut..	3.08	0.11	2.41	0.43	0.29	1.11
North Carolina...........	4.20	0.85	0.37	1.21	....	0.48
Änneröd, Norway........	9.04	0.37	1.17	0.74	0.25	4.66
Johanngeorgenstadt......	6.39	1.00	0.02	3.17	0.21	5.53

Several varieties of uraninite are recognized, the distinctions being based upon the relative proportions of the two oxides UO_2 and UO_3 (see analyses above). Inasmuch, however, as these variations may be due merely to oxidation they need not be taken into consideration here. When crystallized the mineral assumes octahedral and dodecahedral forms, more rarely cubes. Hardness, 5.5; specific gravity, 9 to 9.7. Color, grayish, greenish to velvet-black, streak brown; fracture conchoidal, uneven. The massive and probably amorphous variety is known under the name of pitchblende. This last is the chief commercial source of uranium salts, and is the common "ore" of radium. Through oxidation and hydration the mineral passes into gummite, a gum-like yellow to brown or red mineral of a hardness of but 2.5 to 3 and specific gravity of 3.9 to 4.2.

Localities and mode of occurrence.—Uraninite occurs as a primary constituent of granitic rocks and as a secondary mineral, with sulphide ores of silver, lead, gold, copper, etc. In this last form, according to Dana, it is found at Johanngeorgenstadt, Marienberg, and Schneeberg, Saxony; at Joachimsthal and Pribram, in Bohemia, and Rezbánya, in Hungary. Considerable quantities have been mined from the tin-bearing lodes of Cornwall, England. The crystallized variety *bröggerite* is found in a pegmatite vein near Ånneröd, Norway, and the variety *cleveite* in a feldspar quarry at Arendal. In the United States the mineral has been found in small quantities in several localities, but only those of Mitchell and Yancey counties, North Carolina, where the mineral occurs partially altered to gummite and uranaphane, in mica mines; Llano County, Texas; Black Hawk, near Central City, Gilpin County, Colorado, and the Bald Mountain district of the Black Hills of South Dakota need here be mentioned. Of the above the Cornwall localities are at present of greatest consequence, having during 1890 yielded some 22 tons of ore, valued at some £2,200 ($11,000). During 1891, it is stated, the output was 31 long tons, valued at £620, and in 1892, 37 tons, valued at £740. The next most important locality is that of Joachimsthal, in Bohemia, where 22.52 metric tons of ore were produced in 1891 and 17.71 tons in 1892, the value being some 1,000 florins a ton.

In the Cornwall mines the pitchblende is stated[1] to occur in small veins crossing the tin-bearing lodes. At the St. Austell Consols Mines it was associated with nickel and cobalt ores; at Dolcoath with native bismuth and arsenical cobalt in a matrix of red quartz and purple fluorspar; at South Tresavean with kupfer-nickel, native silver, and argentiferous galena. At the Wood Lode, Russell district, in Gilpin County, Colorado, pitchblende was found in the form of a lenticular mass in one of the ordinary gold-bearing lodes traversing the gneiss and mica schists of the district. The body occurred some 60 feet below the surface and was some 30 feet long by 10 feet deep and 10 inches thick. The mass yielded some 4 tons of ore carrying 70 per cent oxide of uranium.

Other natural uranium compounds, but which at present have no use in the arts, are as below: Torbenite, a hydrous phosphate of uranium and copper (see p. 307); autunite, a hydrous phosphate

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[1] The Mineral Industry, II, p. 572.

of uranium and calcium; zeunerite, an arsenate of uranium and copper; uranospinite, an arsenate of uranium and calcium; uranocircite, a phosphate of barium and uranium; phosphuranylite, a hydrous uranium phosphate; trögerite, a hydrous uranium arsenate; walpurgite, probably an arsenate of bismuth and uranium; and uranosphærite, a uranate of bismuth.

Uses.—Uranium is never used in the metallic state, but in the form of oxides, or as uranate of soda, potash, and ammonia, finds a limited application in the arts. The sesquioxide salt imparts to glass a gold-yellow color with a beautiful greenish tint, and which exhibits remarkable fluorescent properties. The protoxide gives a beautiful black to high-grade porcelains. The material has also a limited application in photography. Recently the material has been used to some extent in making steel in France and Germany, but the industry has not yet passed the experimental stage. It has been stated that the demand, all told, is for about 500 tons annually. Should larger and more constant sources of supply be found, it is probable its use could be considerably extended. According to Nordenskiold, £50,000 worth of uranium minerals are consumed every year, the various salts produced being used in porcelain and glass manufacture, in photography, and as chemical reagents. The material has of late—in the public mind at least—possessed an almost sensational interest in connection with the discovery of its radio-active properties, and the new elements radium and polonium, of which it forms the chief commercial source.

2. CARNOTITE

The name carnotite was given in 1899 by MM. E. Cumenge and C. Friedel to a beautiful canary-yellow ocherous pigment which was found impregnating a siliceous sandstone in Montrose County, Colorado. Material from the same and other sources has since been examined by Dr. W. F. Hillebrand,[1] whose results show the material to be not a simple mineral, but a mixture made up in large part of an impure uranyl-vanadate of potash and the alkaline earths. The

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[1] American Journal of Science, X, August, 1900.

composition of material from (1) the Copper Prince claim, Roe Creek, and (2) the Yellow Boy claim, La Sal Creek, and in Montrose County, as shown by Hillebrand's analyses, is given below:

ANALYSES OF CARNOTITE FROM COLORADO.

Constituent.	I.			II.	
	A.	B.	C.	A.	B.
Insoluble	7.10	8.34	19.00	10.33	....
UO_3	54.89	52.25	47.42	54.00	52.28
V_2O_5	18.49	18.35	15.76	18.05	17.50
P_2O_5	.80	.35	.40	.05	Trace.
As_2O_3	Trace.	.25	None.	None.	None.
AlO	.09	?	.08	.29	?
Fe_2O_3	.21	1.77	.72	.42	3.36
CaO	3.34	2.85	2.57	1.86	1.85
SrO	.02	?	?	Trace.	Trace.
BaO	.90	.72	.65	2.83	3.21
MgO	.22	.20	.24	.14	.17
K_2O	6.52	6.73	6.57	5.46	5.11
Na_2O	.14	.09	.07	.13	.02?
Li_2O	Trace.	?	?	Trace.	?
H_2O, 105°	2.43	2.59	1.85	3.16	[a] 4.52
H_2O, 350°	2.11	3.06	2.79	2.21	3.49
PbO	.13	.25	.18	.07	....
CuO	.15	.20	.22	Trace.	....
SO_3	None.	.12	.18	None.	....
MoO_3	.18	.23	.18	.05	....
SiO_2	.15	.06	.13	.20	....
TiO_2	.03	.10	?	?	....
CO_2	.56	.33	None.	None.	....
Total	98.46	98.84	99.01	99.25	....

[a] Total H_2O in ore.

Occurrence.—As above stated, the material is found in sandstone. F. L. Ransome[1] describes the La Sal Creek deposit as occurring in irregular bunchy pockets, the ore bodies being usually flat-lying streaks but a few inches thick grading both above and below into the common light-buff sandstone, the carnotite gradually dying out until the rock shows no trace of the mineral. At Roe Creek the carnotite occurs in a nearly horizontal sandstone which has been cut by a fault-plane dipping about 75° N. The material is here found in the hanging-wall of the fissure in the form of small, irregular branches in a loose mass of crushed sandstone and also as an im-

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[1] American Journal of Science, X, August, 1900.

pregnation of some of the finer portions of the bed, the impregnation, as at La Sal Creek, taking place mainly along the bedding planes. In all cases thus far reported the deposits are superficial and apparently result " from a local concentration of material already existing in the sandstone . . . under conditions determined by proximity to the surface."

Carnotite is also found impregnating the Dakota (Cretaceous) sandstone of Rio Blanco County in the same State.

Uses.—The material has been used to some extent as a source of uranium and vanadium salts.

XII. SULPHATES.

1. BARITE; HEAVY SPAR.

Composition.—$BaSO_4$, = sulphur trioxide, 34.3 per cent; baryta, 65.7 per cent; specific gravity, 4.3 to 4.6; hardness, 2.5 to 3.5.

The sulphate of barium to which the mineralogical name of barite is given occurs, as a rule, in the form of a white, translucent to transparent, coarsely crystalline mineral, about as hard as common calcite, but from which it may be readily distinguished by its great weight and its not effervescing when treated with acid. A common form of the mineral is that of an aggregate of straight or somewhat curved plates, separating readily from one another when struck with a hammer, and cleaving readily into rhomboidal forms much like calcite. It is also found in globular and nodular concretions, stalactitic and stalagmitic, granular, compact, and earthy masses, and in single and clustered broad and stout crystals. In nature the material is rarely pure, but nearly always contaminated with other elements, as noted in the following analyses of samples from Fulton, Blair, and Franklin counties, Pennsylvania.[1]

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[1] Pennsylvania Second Geological Survey, Chemical Analyses, pp. 568, 569.

Constituents.	Fulton County.		Blair County.	Franklin County.	
Sulphate of barium	95.22	96.91	97.08	95.91	98.65
Oxides of iron and aluminum.	0.38	0.31	0.76	0.24	0.14
Oxide of manganese	0.05	None.	None.	None.	None.
Lime	0.59	Trace.	None.	0.17	Trace.
Magnesia	0.18	Trace.	Trace.	0.11	Trace.
Carbonic acid	0.65	None.	None.	None.	None.
Water	0.23	0.08	0.32	0.09	0.20
Silica	2.45	2.35	1.74	2.80	1.11
Total	99.75	99.65	99.90	99.32	100.10

Occurrence.—The mineral is a common accompaniment of metallic ores, but as such has not proven of any value commercially. Such deposits as have been worked for the mineral itself are, as a rule, pockety or lenticular masses mainly in limestone and following the dip and strike of the rocks with which they are associated. In Washington County, southwest Virginia, the mineral occurs in coarsely cleavable masses in certain beds of the Cambrian limestone, filling irregular fractures or at times replacing the limestone itself. In Tazewell County, this same State, it is described as occurring in a series of lenticular pockets having a general northeast-southwest strike, and dipping from 20° to 30° toward the east. The general width of this series of pockets is given[1] as from 100 to 200 or more feet and occurring over an area some 4 miles in length. The pockets are at times quite distinct from one another, or again may be connected by a thin seam of barite. In Madison and Gaston counties, North Carolina, the material is found in a seam or vein from 3 to 6 feet in width in a decomposed schist.

In Missouri barite occurs in cavities in a dolomite of Ordovician age, the cavities, according to A. A. Steel,[2] being due in part to a shattering which he regards as incidental to dolomitization, and in part to fissuring and faulting, in either case being subsequently

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[1] J. H. Pratt, Mineral Resources of the United States, 1901, p. 915.

[2] Bulletin American Institute of Mining Engineers, No. 38, February, 1910.

enlarged by solution. The barite filling was probably a result of a process of concentration by leaching from the country rock, though its primary source was undoubtedly the pre-existing igneous rocks forming the neighboring ancient land areas. The chief barite-producing ground is at present eastern Washington County, the mineral being mined in nodular masses from the residual clay. The average yield, mainly from open cuts and trenches, is about 600 tons per acre. Where mined to a depth of 8 feet, yields as high as 2,500 to 4,000 tons per acre have been reported.

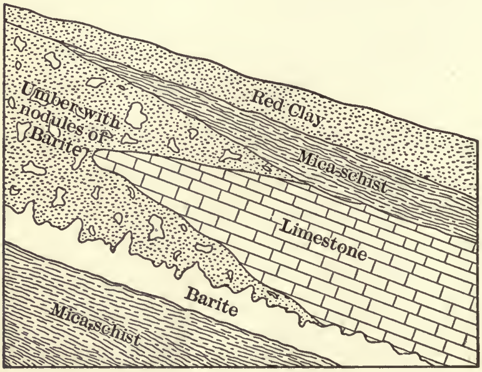

Fig. 50.—Ideal section of Bennett Barite Mine, Pittsylvania County, Virginia. [After Watson, Mineral Resources of Virginia.]

The principal localities in the United States where barite has been mined on a commercial scale are in Connecticut, Virginia, North Carolina, Tennessee, and Missouri, though the first-named State has ceased to be a producer. The mining is almost wholly from open cuts, the cheapness of the material militating against the expense of deep mining. When occurring in limestone the material is found superficially in loose nodules and fragments embedded in the residual clay resulting from its decomposition. In Missouri and Tennessee it is often associated with a small amount of galena.

Preparation and uses.—The mineral is washed and ground like grain between millstones and used as an adulterant for white lead or to give weight and body to certain kinds of cloth and paper. Considerable quantities are utilized in the preparation of barium salts for various chemical purposes.

According to a writer in the Mineral Resources of the United States for 1885, the " floated " or " cream-floated " barite used as paint is prepared as follows: The crude mineral as mined is first sorted by hand and cleaned, after which it is crushed into pieces about the size of the tip of one's finger. Next it is refined by boiling in dilute sulphuric acid until all the impurities are removed, when it is washed by boiling in distilled water and dried by steam. It is then ground to flour, mixed with water, and run through troughs or sluiceways into receiving vats, whence it is taken, again dried by steam, and barreled. The crude material is worth only about $3.50 per ton.

2. GYPSUM.

Composition.—$CaSO_4 + 2H_2O$, = sulphur trioxide, 46.6 per cent; lime, 32.5 per cent; water, 20.9 per cent. The natural mineral is often quite impure through the presence of organic, ferruginous, and aluminous matter, together with small quantities of the carbonates of lime and magnesia (see analysis, below). Specific gravity, 2.3; hardness, 1.5, to 2. Color, usually white or gray, but brown, black, and red through impurities. The softness of the mineral, which is such that it can be easily cut with a knife, or even by the thumb nail, is one of its most marked characteristics. Three principal varieties are recognized, (1) the crystallized, foliated, transparent variety, selenite, (2) the fine fibrous, often opalescent variety, satin spar, and (3) the common massive, finely granular variety, gypsum. When of a white color and sufficiently compact for small statues and other ornamental works, it is known as alabaster, though this name has unfortunately become confounded with the calcareous rock travertine and stalagmite.[1]

The following is an analysis of a commercial gypsum from Ottawa County, Ohio, as given by Professor Orton:[2]

Constituents.	Per Cent.
Lime	32.52
Sulphuric acid	45.56
Water	20.14
Magnesia	0.56
Alumina	0.16
Insoluble residue	0.68
Total	99.62

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[1] See The Onyx Marbles, their Origin, Uses, etc., Report of the U. S. National Museum, 1893, pp. 539–585.

[2] Geology of Ohio, VI, 1888, p. 700.

Origin.—Gypsum in considerable quantities occurs associated only with stratified rocks, and is regarded mainly as a chemical deposit resulting from the evaporation of waters of inland seas and lakes; it may also originate through the decomposition of sulphides and the action of the resultant sulphuric acid upon limestone; through the mutual decomposition of the carbonate of lime (limestone) and the sulphates of iron, copper, and other metals; through the hydration of anhydrite and through the action of sulphurous vapors and solutions from volcanoes upon the rocks with which they come in contact. According to Dana,[1] the gypsum deposits in western New York do not form continuous layers in the strata, but lie in embedded, sometimes nodular masses. In all such cases, this authority says, the gypsum was formed after the beds were deposited, and in this particular instance are the product of the action of sulphuric acid from springs upon the limestone. "This sulphuric acid, acting on limestone (*carbonate* of lime), drives off its carbonic acid and makes *sulphate* of lime, or gypsum; and this is the true theory of its formation in New York." Dr. F. J. H. Merrill, however, regards a portion at least of the New York beds as a product of direct chemical precipitation from sea water.[2]

The gypsum of northern Ohio is regarded by Professors Newberry and Orton as a deposit from the evaporation of landlocked seas, as was also the rock salt which overlies it. By this same process must have originated a large share of the more recent gypsum deposits of the Western States.

Geological age and mode of occurrence.—As may be readily inferred from the above, beds of gypsum have formed at many periods of the earth's history, and are still forming wherever proper conditions exist. The deposits of New York State occur in a belt extending eastward from Cayuga Lake and in beds belonging to the Salina period of the Upper Silurian Age. The rock is often earthy and impure, and is used nearly altogether for land plaster. It is associated with dark, nearly black, limestones and shales and beds of rock salt. In southwest Virginia, along the Holston River, are also

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[1] Manual of Geology, p. 234.

[2] Bulletin No. 11 of the New York State Museum, April, 1893.

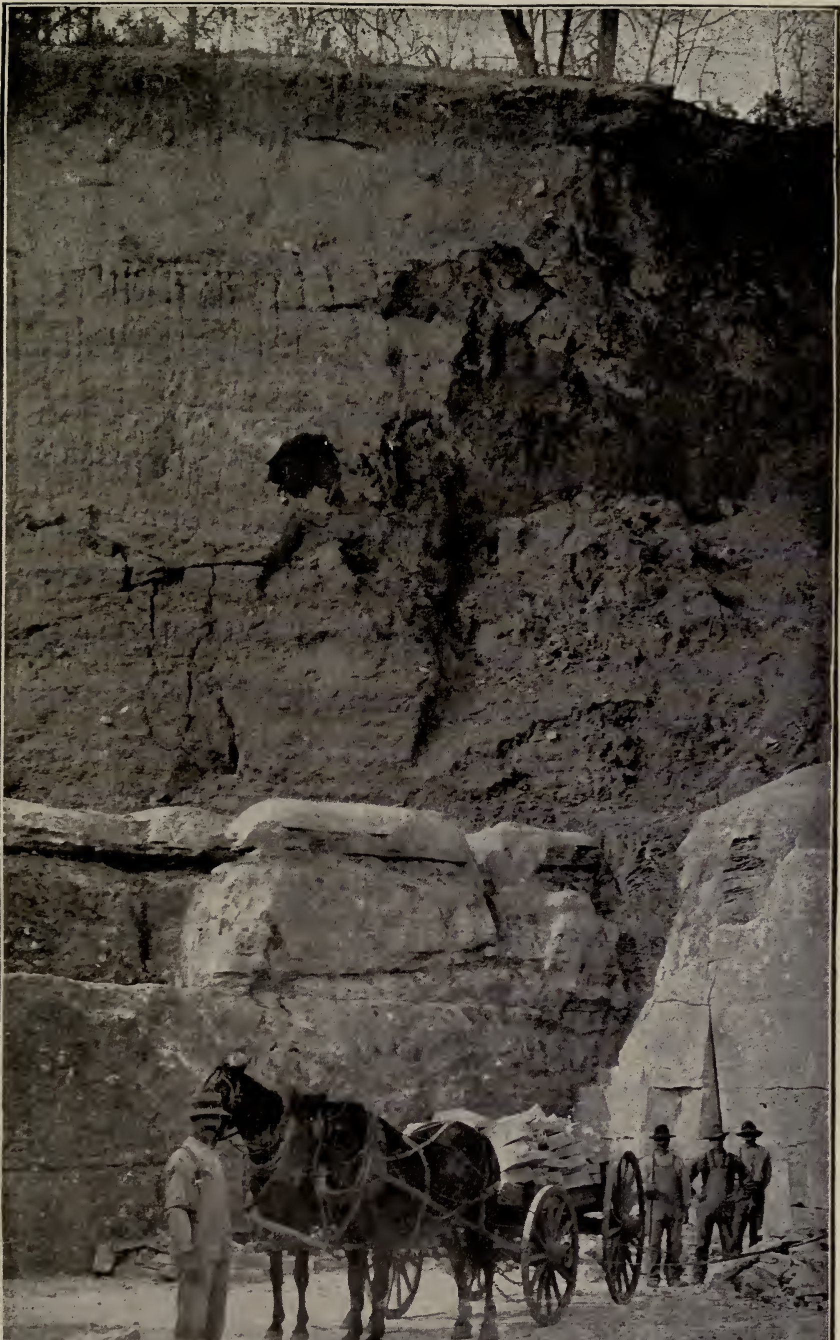

PLATE XXXI.
Gypsum Quarry, Fort Dodge, Iowa.
[From photograph by Iowa Geological Survey.]

[*Facing page* 338.]

beds of gypsum associated with salt and referred by Dana to this same horizon. The rock is mined at Saltville in Washington County from underground pits, and is used mainly for fertilizing.

Gypsum deposits of varying thickness and occurring at various depths below the surface are found continuous over thousands of square miles in northern Ohio, but are at present worked only in Ottawa County at a station on the Lake Shore and Michigan Southern Railway which bears the appropriate name of Gypsum. The associated rocks are Lower Helderberg limestones and shales, and the beds, which vary from 3 to 7 feet in thickness, are found at all depths up to 200 or 300 feet.

The following is a section of the Ottawa County beds as given by Orton:[1]

		Feet.
Drift clays		12 to 14
No. 1.	Gray rock, carrying land plaster	5
	Blue shale	½
No. 2.	Bowlder bed carrying gypsum in separate masses embedded in shaly limestone	5
	Blue limestone, in thin and even courses	1
No. 3.	Main plaster bed	7
	Gray limestone in courses	1
No. 4.	Lowest plaster bed, variable	3 to 5

Mixed limestone and plaster, bottom of quarry.

Sections like the above are stated to be capable of yielding 50,000 tons of plaster an acre.

The purest gypsum of the region occurs in No. 2, the bowlder bed, as given above. It consists of calcareous shales through which are scattered concretionary balls of gypsum varying in diameter from 6 to 24 inches. This pure variety is used mainly for *terra alba;* about 40 per cent of the total product has in years past been calcined for use as stucco or plaster of Paris and 60 per cent for land plaster.

At Fort Dodge, in Iowa, is a deposit of quite pure, light-gray, regularly bedded gypsum, resting unconformably upon St. Louis limestone and lower coal strata and overlain by drift. It is supposed

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[1] Geological Survey of Ohio. Economic Geology, VI, 1888, p. 698.

to cover an area of some 25 square miles. The material was at one time used for building purposes, but proved too soft[1] and is now used mainly for land plaster. (See Plate XXXI.)

There are large deposits of gypsum in Michigan, the most extensive, so far as explored, being near Grand Rapids, Kent County, in the western part of the State, and at Alabaster Point, in Iosco County, on the eastern margin of the State. At both localities there is a succession of beds beginning at or near the surface and aggregating many feet in depth. The beds are regarded as of Carboniferous age. The following section shows the number and thickness of the beds thus far discovered:

	Feet.
Earth stripping	20
Gypsum	8
Soft shale, slate	1
Gypsum	12
Shale or clay slate	7
Gypsum	6½
do.	8½
Slate, shale	3½
Gypsum	12½
Shale or clay slate	1½
Gypsum	9½
Shale, clay slate	8
Total	98

In Kansas are notable deposits of gypsum associated with rocks regarded by Haworth[2] as of Permian age. The most important beds so far as now known are in Marshall and Barber counties. Southwest of Medicine Lodge in the last-named county the material occurs in beds from 20 to 30 feet in thickness and covering many square miles of territory.

West of the front range of the Rocky Mountains are many important beds of gypsum, but which have as yet been but little exploited

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[1] Stones for Building and Decoration, 2d ed., 1897, p. 76.

[2] Mineral Resources of Kansas, 1897.

owing to cost of transportation, there being but little local demand. These beds so far as yet worked are mostly of more recent origin than those in the eastern United States, many being of Tertiary or even Quarternary Age.

Near Fillmore, Utah, are deposits of gypseous sand formed by the winds blowing up from the dry beds of playa lakes the minute crystals deposited by evaporation. The material thus blown together forms veritable dunes from which the material may be obtained by merely shoveling. Prof. I. C. Russell has estimated these dunes to contain not less than 450,000 tons of gypsum.

Important deposits of gypsum also occur in Colorado, South Dakota, Wyoming, California, New Mexico, Oklahoma, and Texas.

Gypsum is a very abundant mineral in New Brunswick, the deposits being numerous, large, and in general of great purity. They occur in all parts of the Lower Carboniferous district in Kings, Albert, Westmoreland, and Victoria, especially in the vicinity of Sussex, in Upham, on the North River in Westmoreland, at Martin Head on the bay shore, on the Tobique River in cliffs over 100 feet high, and about the Albert Mines. At the last-named locality the mineral has been extensively quarried from beds about 60 feet in thickness.[1] The mineral is usually met with in very irregular masses, associated with red marls, sandstones, and limestones, and varies much in character. At Hillsborough considerable masses of very beautiful snow-white gypsum or alabaster are also met with, and a little selenite. At Petitcodiac the deposit has a breadth of about 40 rods and total length of about 1 mile. The whole bed is fibrous and highly crystalline and traversed through its entire extent by a vein of nearly pure selenite, 8 feet wide. The rock on the Tobique River, which rises in bluffs along the stream some 30 miles above

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[1] Dawson's Acadian Geology, p. 249.

its mouth, is mostly soft, granular or fibrous, and of a more decidedly reddish color than in the other localities.

Important beds of gypsum belonging to the same geological horizon likewise occur in Nova Scotia, particularly at Wentworth and Montague in Hants County, at Oxford, River Philip, Plaster Cove, Wallace Harbor, and Bras d'Or Lake, Cape Breton. At Wentworth there are stated to be "cliffs of solid snowy gypsum from 100 to 200 feet in height."

Gypsum deposits occur in the Onondaga formations of Ontario, Canada, and are exploited along the Grand River between Cayuga and Paris. The mineral here occurs in lenticular masses varying from a few yards to a quarter of a mile in horizontal diameter and from 3 to 7 feet in thickness.

The foreign sources of gypsum are almost too numerous to mention. Important beds occur in Lincolnshire and Derbyshire, England; near Paris, France; in Spain, Italy, Germany, Austria, and Switzerland. The Paris beds are of Tertiary Age, and the mineral carries some 10 to 20 per cent of carbonate of lime, together with silica in a soluble form. The presence of these constituents is stated to cause the plaster to set much harder, permitting it, therefore, to be used for external work. The Italian gypsum is often of great purity. The finest alabaster is stated to come from the Val di Marmolago, near Castellina.

Uses.—These have been already, in part, noted. The principal use of the ordinary massive varieties is for fertilizers (land plaster), and in the manufacture of plaster of Paris, or stucco. The New York material is also used in the preparation of the so-called adamant cement for wall plaster.

As above noted, gypsum is but little used for building purposes, being too soft. Several residences, a railway station, and other minor structures are, however, stated to have been built of this stone at Fort Dodge, in Iowa. The variety satin spar is sometimes used for small ornamentations, but it is only the snow-white variety (alabaster) that is of any economic importance as an ornamental stone. The main use of alabaster is for small statues, vases, fonts, and small columns; it is too soft for exposed positions where subjected to much wear. At present there are not known any deposits of alabaster within the limits of the United States which are of sufficient purity and extent to be of commercial value. A large share of the alabaster statuettes now on our markets are of Italian make as well as of Italian materials.

In preparing the gypsum for market the stone is first broken in a crusher into pieces of the size of a hickory nut, after which it is ground between millstones (French buhrstones) to a proper degree of fineness and then put up in bags or barrels, if designed for land plaster; if for stucco it is calcined after being ground. This process is in Michigan carried on in large kettles some 8 feet in diameter, and capable of holding about 14 barrels at a charge. The powder is heated until all the included water is driven off, being subjected to constant stirring in the mean time, and is then drawn off through the bottom of the kettles and conveyed by carrying belts and spouts to the packing room.[1]

Under the name of "terra alba" (white earth) ground gypsum is used as an adulterant in cheap paints.

The commercial value of gypsum depends mainly on accessibility to market. In 1899 the ground material was quoted at $2.00 a ton in New York. In Michigan the average price of crude material has been some $1.25 a ton, and for calcined plaster (plaster of Paris) $3.00 to $5.00 a ton. During 1908 the domestic production of crude gypsum amounted to 1,721,289, tons, valued at $4,138,560.

3. CELESTITE.

Composition.—Sulphate of strontium, $SrSO_4$, = sulphur trioxide, 43.6 per cent; strontia, 56.4 per cent. Hardness, 3 to 3.5; specific gravity, 3.99; color, white, often bluish, transparent to translucent. Differs from the carbonate (strontianite) by being insoluble in acids, but gives the characteristic red color to the blowpipe flame.

According to Dana the mineral occurs usually associated with limestones or sandstones of Silurian or Devonian, Jurassic, and other geological formations, occasionally with metalliferous ores. It also occurs in beds of rock salt, gypsum, and clay, and is abundantly

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[1] See Mineral Statistics of Michigan, 1881, for details of plaster work of that State.

associated with the sulphur deposits of Sicily. The principal localities in the United States are in the limestones of Drummond Island, Lake Huron; Put-in-Bay, Lake Erie; Kingston, Ontario, in crystalline masses, and in radiating fibrous masses in the Laurentian formations about Renfrew. Large crystals of a red color are also found in Brown County, Kansas, and at Lampasas and near Austin, Texas. Near Bells Mills, Blair County, Pennsylvania, the mineral occurs in lens-shaped masses between the bottommost beds of the Lower Helderberg limestone. On South Bass Island, in Put-in-Bay, Lake Erie, the mineral occurs frequently in the form of beautiful crystals of all sizes up to 100 pounds in weight, transparent to translucent, and sometimes of a fine blue color, lining the walls and floor of limestone caverns.

The Texas celestite is described[1] as occurring in rounded cavities varying in size up to 18 inches in diameter in certain zones of Cretaceous limestone. The cavities are sometimes fairly well filled by the mineral, but in most instances a portion has been removed in solution by percolating waters. It is estimated that the average amount of the celestite in the limestone does not exceed 5 per cent.

Uses.—Celestite is used in the preparation of nitrate of strontia employed in fireworks, its value for this purpose being due to the fine crimson color it imparts to the flame. Other strontium salts, prepared either from celestite or strontianite, are used in refining beet sugar. Small quantities are utilized in medicine. The demand for the material is very small, and the annual product in the United States limited to 40 tons in 1901.

4. MIRABILITE ; GLAUBER SALT.

This is a hydrous sodium sulphate, $Na_2SO_4+10H_2O$, = sulphur trioxide, 24.8 per cent; soda, 19.3 per cent; water, 55.9 per cent. In its pure state white, transparent to opaque; hardness, 1.5 to 2; specific gravity, 1.48. Readily soluble in water, taste cool, then saline and bitter.

Occurrence.—Aside from its occurrence in soda lakes associated with other salts as described later this sulphate is of common occur-

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[1] F. L. Hess, Engineering and Mining Journal, June 17, 1909.

rence as an efflorescence on limestones, and in protected places, as in Mammoth Cave, Kentucky, may accumulate in considerable quantities, though not sufficient to be of economic value. Salt Lake, Utah, contains a proportionately large amount of this sulphate, which during the winter months is precipitated to the bottom, whence it is not infrequently thrown upon the shore by waves.

According to Prof. J. E. Talmage,[1] when the temperature falls to a certain point, the lake water assumes an opalescent appearance from the separation of the sulphate. This sinks as a crystalline precipitate and much is carried by the waves upon the beach and there deposited. Under favorable circumstances the shores become covered to a depth of several feet with crystallized mirabilite. The substance must be gathered, if at all, soon after the deposit first appears; as, if the water once rises above the critical temperature, the whole deposit is taken again into solution. This change is very rapid, a single day being oftentimes sufficient to effect the entire disappearance of all the deposit within reach of the waves. Warned by these circumstances, the collectors heap the substance on the shores above the lap of the waters, in which situation it is comparatively secure until needed. To a slight depth the mirabilite effloresces, but within the piles the hydrous crystalline condition is maintained. The sulphate thus lavishly supplied is of a fair degree of purity, as will be seen from the following analyses of two samples taken from opposite shores of the lake:

Constituents.	Per Cent.	Per Cent.
Water.	55.070	55.760
Sodium sulphate (Na_2SO_4)	43.060	42.325
Sodium chloride (NaCl)	0.699	0.631
Calcium sulphate ($CaSO_4$)	0.407	0.267
Magnesium sulphate ($MgSO_4$)	0.025	0.018
Insoluble.	0.700	0.756
Total.	99.961	99.757

Some 14 miles southwest of Laramie, in Albany County, Wyoming, there exist deposits of sulphate of soda, such as are locally

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[1] Science, XIV, 1889, p. 446.

known as "lakes." The deposits in question comprise three of these lakes lying within a stone's throw of one another. They have a total area of about 65 acres, the local names of the three being the Big Lake, the Track Lake, and the Red Lake. Being the property of the Union Pacific Railroad Company, they are generally known as the Union Pacific Lakes.

In these lakes the sulphate occurs in two bodies or layers. The lower part, constituting the great bulk of the deposit, is a mass of crystals of a faint greenish color mixed with a considerable amount of black, slimy mud. It is known as the "solid soda," of which an analysis is given below.[1]

Constituents.	Anhydrous.	Crystallized.
Na_2SO_4	36.00	81.63
$CaSO_4$	1.45	1.82
$MgCl_2$	0.77	1.64
NaCl	0.21	0.21
	38.43	85.30
Insoluble residue (at 100° C.)	....	13.86
		99.16

Total chloride calculated as NaCl equals 1.16 per cent. This, calculated on 100 parts anhydrous Na_2SO_4, equals 3.22 per cent NaCl.

This solid soda is stated to have a depth of some 20 or 30 feet.

Above this occurs a superficial layer of pure white crystallized material. This is formed by solution in water of the upper part of the lower bed, the crystals being deposited by evaporation or cooling. A little rain in the spring and autumn furnishes this water, as do also innumerable small, sluggishly flowing springs present in all the lakes. On account or the aridity of the region the surface is generally dry, or nearly so, and in midsummer the white clouds of efflorescent sulphate that are whirled up by the ever-blowing winds can be seen for miles. Even when there is a little water present there is no difficulty in gathering the crystals by the train load. The layer of this white sulphate is from 3 to 12 inches in thickness. When the crystals are removed the part laid bare is soon replenished by a new crop.

The following is an analysis of the purest of the white sulphate of soda, calculated upon an anhydrous basis:

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[1] Jour. Franklin Inst., 1893, p. 52.

Constituents.	Per Cent.
Na_2SO_4	99.73
$MgCl_2$	0.26
Insoluble	Trace.
	99.99

Below is given an analysis of the water of the Track lake:

Density = 14½ Tw. (= 1.0725 specific gravity). Ten cubic centimeters contain:

Constituents.	Grams.	Per Cent.
Na_2SO_4	0.7563 =	92.23
$CaSO_4$	0.0146 =	1.79
$MgSO_4$	0.0070 =	0.85
$MgCl_2$	0.0300 =	3.66
$Na_2B_4O_7$	0.0121 =	1.47
Total solids	0.8200	100.00
Total solids by evaporation	0.8240	

Other soda deposits occur in Carbon and Natrona counties, and still others are reported in Fremont, Johnson, and Sweetwater counties.

It has been stated[1] that glauber salts has been found on the bottom of Bay of Kara Bougas, an inlet of the Caspian Sea, in deposits sometimes a foot in thickness.

5. GLAUBERITE.

Composition.—Sodium and calcium sulphate. $Na_2SO_4.CaSO_4$, = sulphur trioxide, 57.6 per cent; lime, 20.1 per cent; soda, 22.3 per cent. This is a pale yellow to gray salt, partially soluble in water —leaving a white residue of sulphate of lime—and with a slightly saline taste. On long exposure to moisture it fails to pieces, and hence is to be found only in protected places or arid areas. It occurs associated with other sulphates and carbonates, as with thenardite

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[1] Engineering and Mining Journal, LXV, 1898, p. 310.

and mirabilite at Borax Lake, in San Bernardino County, California, and with rock salt at Stassfurt and other European localities.

6. THENARDITE.

Composition.—Anhydrous sodium sulphate. Na_2SO_4, = sulphur trioxide, 43.7 per cent; soda, 56.3 per cent. Color when pure, white, translucent to transparent; hardness, 2 to 3; specific gravity, 2.68; brittle. In cruciform twins or short prismatic forms roughly striated. Readily soluble in water. Is found in various arid countries, as on the Rio Verde in Arizona, at Borax Lake, California, and Rhodes Marsh in Nevada, associated with other salts of sodium and boron.

7. EPSOMITE; EPSOM SALTS.

Composition.—Sulphate of magnesia $MgSO_4 + 7H_2O$, = sulphur trioxide, 32.5 per cent; magnesia, 16.3 per cent; water, 51.2 per cent.

This is a soft white or colorless mineral readily soluble in water and with a bitter saline taste. It is a constant ingredient of sea water and of most mineral waters as well. Being readily soluble it is rarely met with in nature except as an efflorescence in mines and caves. In the dry parts of the limestone caverns of Kentucky, Tennessee, and Indiana it occurs in the form of straight acicular needles in the dirt of the floor, and in peculiar recurved fibrous and columnar forms or in loose snow-white masses on the roofs and walls. In all these cases it is doubtless a product of sulphuric acid set free from decomposing pyrites combining with the magnesia of the limestone. It is stated that at the so-called "alum cave" in Sevier County, Tennessee, masses of epsomite, very pure and nearly a cubic foot in volume have been obtained. The material in all these cases is of little value, the chief source of the commercial supply being that obtained as a by-product during the manufacture by evaporation of common salt (sodium chloride).

In Albany County, Wyoming, are several lakes, the largest of which has an area of but some 90 acres, in which deposits of epsom salts in compact, almost snow-white aggregates of small acicular crystals of a high degree of purity are formed on a very large scale.

According to W. C. Knight,[1] the deposits are situated upon a high plateau about three miles north of Rock Creek, and lie in a huge, undrained depression that is deepest at its southern end, where it is about two miles wide and lies a hundred feet or more below the level of the surrounding country. From this deepest portion a rather broad, shallow valley extends to the northwest for several miles and contains numerous small and a few larger deposits of sodium and magnesium salts which have for a long time been tributary to the large epsomite deposit of about 90 acres in extent occupying the lowest basin. The deposits are often covered with water in early spring or after a hard storm, but this soon evaporates and leaves them solid epsomite or an accumulation of mud, sand, and epsomite, the depth of which has been found by digging to exceed ten feet.

Knight regards the salts as having been derived by leaching from the decomposing Triassic or Permian red sandstones which prevail in the vicinity. Both epsomite and mirabilite occur in the rocks and in the process are separated from one another by a natural method of differential crystallization, the epsomite being more soluble, remaining longest in solution and being laid down at a greater distance from the original source.

The composition of the deposits is shown in the accompanying analyses, No. 1 being taken from near the head of the gulch, and No. 6 from the large deposit at the greatest distance from the source, the others from intermediate points:

Constituents.	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.
Na_2SO_4	95.46	95.54	50.90	47.74	39.18	25.61
NaCl	0.28	0.28	0.50	1.86	1.00	5.28
$MgSO_4$	4.26	5.29	48.60	50.16	59.82	70.11
$CaSO_4$	....	1.89	....	....	....	....

8. For description of POLYHALITE, KAINITE, and KIESERITE, see under Halite, p. 43.

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[1] Engineering and Mining Journal, February 14, 1903.

9. ALUMS.

Under this head are included a variety of minerals consisting essentially of hydrous sulphates of aluminum or iron, with or without the alkalies, and which are not always readily distinguished from one another but by quantitative analyses. The principal varieties are kalinite, tschermigite, mendozite, pickeringite, apjohnite, halotrichite, and alunogen. Aluminite and alunite are closely related chemical compounds, but differ in hardness and general physical qualities and in being insoluble except in acids.

Although possible sources of alum, none of these minerals have been to any extent utilized in the United States, owing to a lack of quantity or inaccessibility, the main source of the alum of commerce being cryolite, bauxite, and clay, as elsewhere noted.

Kalinite is a native potash alum; composition $K_2SO_4.Al_2(SO_4)_3+24H_2O$, = sulphur trioxide, 33.7 per cent; alumina, 10.8 per cent; potash, 9.9 per cent; water, 45.6 per cent, or, otherwise expressed, potassium sulphate, 18.1 per cent; aluminum sulphate, 36.3 per cent; water, 45.6 per cent. Hardness, 2 to 2.5; specific gravity, 1.75. This in its pure state is a colorless or white transparent mineral, crystallizing in the isometric system, readily soluble in water, and characterized by a strong astringent taste. In nature it occurs as a volcanic sublimation product, or as a secondary mineral due to the reaction of sulphuric acid set free by decomposing iron pyrites upon aluminous shales. Its common mode of occurrence is, therefore, in volcanic vents or as an efflorescence upon pyritiferous and aluminous rocks. Being so readily soluble, it is to be found in appreciable amounts in humid regions only where protected from the rains, as in caves and other sheltered places. So far as known to the author, the mineral is nowhere found native in such quantities as to have any great commercial value.

Tschermigite is an ammonia alum of the composition $(NH_4)_2SO_4.Al_2(SO_4)_3+24H_2O$, = aluminum sulphate, 37.7 per cent; ammonium sulphate, 14.6 per cent; water, 47.7 per cent. So far as reported this salt has been found only at Tschermig and in a mine near Dux, Bohemia. It is obtained artificially from the waste of gas works. **Mendozite** is a soda alum of the composition $Na_2SO_4.Al_2(SO_4)_3+24H_2O$, = sodium sulphate, 15.5 per cent; aluminum sulphate, 37.3 per cent; water, 47.2 per cent. The mineral closely resembles ordinary alum, and has been reported from Mendoza, in the Argentine Republic, hence the name. **Pickeringite** is a magnesium alum of the composition $MgSO_4.Al_2(SO_4)_3+22H_2O$, = aluminum sulphate, 39.9 per cent; magnesium sulphate, 14 per cent; water, 46.1 per cent. The mineral is of a white, yellowish, or sometimes faintly reddish color, of a bitter, astringent taste, and occurs in acicular crystals or fibrous masses. **Halotrichite** has the composition $FeSO_4.Al_2(SO_4)_3+24H_2O$, = aluminum sulphate, 36.9 per cent; ferrous sulphate, 16.4 per cent; water, 46.7 per cent. The mineral is of a white or yellowish color, and of a silky, fibrous structure, hence the name from the Greek word ἅλς, salt, and θρίξ, a hair. **Apjohnite** has the formula $MnSO_4.Al_2(SO_4)_3+24H_2O$, = manganese sulphate, 16.3 per cent; aluminum sulphate, 37 per cent; water, 46.7 per cent. It occurs in silky or asbestiform masses of a white or yellowish color, and tastes like ordinary alum. It has been found in considerable quantities in the so-called "Alum cave" of Sevier County, Tennessee. According to Safford:[1]

"This is an open place under a shelving rock. . . . The slates around and above this contain much pyrites, in fine particles and even in rough layers. . . . The salts are formed above and are brought down by trickling streams of water. . . . Fine cabinet specimens could be obtained, white and pure, a cubic foot in volume."

Dana states that the cave is situated at the headwaters of the Little Pigeon, a tributary of the Tennessee River, and that it is properly an overhanging cliff 80 or 100 feet high and 300 feet long, under which the alum has collected. It occurs, according to this authority, in masses, showing in the cavities fine transparent needles with a silky luster, of a white or faint rose tinge, pale green or yellow.

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[1] Geology of Tennessee, 1869, p. 197.

Epsomite and melanterite occur with it. **Alunogen** has the composition $Al_2(SO_4)_3+18H_2O$, = sulphur trioxide, 36 per cent; alumina, 15.3 per cent; water, 48.7 per cent; hardness, 1.5 to 2; specific gravity, 1.6 to 1.8. This is a soft white mineral of a vitreous or silky luster, soluble in water, and with a taste like that of the common alum of the drug stores. It occurs in nature both as a product of sublimation in volcanic regions, and as a decomposition product from iron pyrites (iron disulphide) in the presence of aluminous shales. So far as the present writer is aware, the native product has no commercial value, being found (on account of its ready solubility) in too sparing quantities in the humid East, while the known deposits in the arid regions are remote and practically inac-

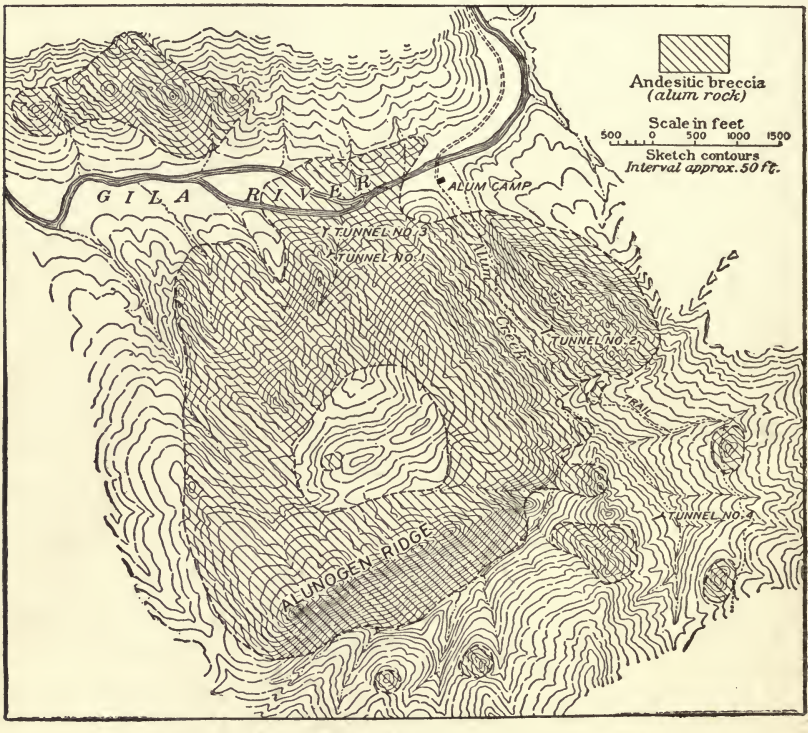

FIG. 51.—Sketch Map of Gila River Alum Deposits.
[U. S. Geological Survey.]

cessible. A white, fibrous variety is stated by Dana to occur in large quantities at Smoky Mountain, in North Carolina, and large quantities of an impure variety, often of a yellowish cast, are found in Grant County, cn the Gila River, about 40 miles north of Silver City, New Mexico. The mineral is also found in Crooke and Fremont counties, Wyoming; in Schemnitz, Hungary, and in Japan.

The Gila deposits occupy a somewhat circular area—what is in fact the cracter of an extinct volcano. The country rock is basalt, while the rock which carries and also gave rise to the deposits is an andesitic breccia, now highly altered by solfataric action. The alum salts—which have undoubtedly originated through the action of acid solfataric waters on the porous breccia, are found in the form of incrustations wherever the conditions have been favorable to their formation and preservation. The original salt would appear to have been mainly halotrichite, but in many instances this has been dissolved by surface waters, when the iron separates out as an insoluble oxide and on evaporation the salt is deposited in the iron-free condition, alunogen. The following analyses[1] show the composition of selected samples of these salts from this locality:

HALOTRICHITE, GILA RIVER, NEW MEXICO.

Constituents.	*A*	*B*	*C*
FeO	7.94	13.59	7.8
Al_2O_3	11.77	7.27	11.00
SO_3	35.25	37.19	34.5
H_2O	45.09	40.62	46.7
Insoluble	....	0.50	....
	100.05	99.17	100.00

A. Carefully selected fibrous material.
B. Fibrous material of silky luster.
C. Theoretical composition of halotrichite.

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[1] Bulletin No. 315, U. S. Geological Survey, p. 220.

ALUNOGEN, GILA RIVER, NEW MEXICO.

Constituents.	*A*	*B*	*C*
Al_2O_3	16.29	15.52	15.3
SO_3	36.93	34.43	36.0
H_2O	46.45	42.56	48.7
Insoluble residue	....	7.62	....
Total	99.67	100.13	100.0

A. Carefully selected crystals.
B. Pinkish crusts.
C. Theoretical composition of alunogen.

The upper portion of the deposit has naturally been leached of all or a considerable proportion of its soluble salts by surface waters. Though no borings have been made it is thought that the deeper-lying portions contain an almost unlimited supply. It was at first reported[1] that the residual rock from which the sulphates had been leached consisted essentially of bauxite, and it was so stated in the first edition of this work (p. 341). Subsequent investigation has, however, shown this to be an error.

In New South Wales alunogen is commonly met with as an efflorescence in caves and under sheltered ledges of the Coal Measure sandstone, usually with epsomite, as at Dabee, County Phillip; Wallerawang and Mudgee road, County Cook; the mouth of the Shoalhaven River, and other places. It is also found in the crevices of a blue slate at Alum Creek, and at the Gibraltar Rock, County Argyle, and occurs as a deposit, with various other salts, from volcanic vents at Mount Wingen, County Brisbane, together with native sulphur in small quantities; and at Appin, Bulli, and Pitt Water, County Cumberland; Cullen Bullen, in the Turon district, County Roxburgh; Tarcutta, County Wynyard; Manero; Wingello Siding, and Capertee.

A specimen in the form of fibrous masses, made up of long, acicular crystals of a white, silky luster, like satin spar, found as an efflorescence in a sandstone cave near Wallerawang, was found to have the following composition:

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[1] Transactions American Institute of Mining Engineers, XXIV, 1894, p. 572.

Constituents.	Per Cent.
Water	47.585
Matter insoluble in water	1.079
Alumina	15.198
Sulphuric acid	34.635
Soda	0.931
Potash	0.337
Loss	0.235
Total	100.000

Aluminite.—Aluminite is a dull, lusterless, earthy aluminum sulphate of the composition indicated by the formula $Al_2O_3.SO_3,9H_2O$, = sulphur trioxide, 23.3 per cent; alumina, 29.6 per cent; water, 47.1 per cent. It is soluble only in acids, white in color, opaque, and occurs mainly in beds of Tertiary and more recent clays.

Alunite.—Composition $K_2O.3Al_2O_3.4SO_3,6H_2O$, = sulphur trioxide, 38.6 per cent; alumina, 37.0 per cent; potash, 11.4 per cent; water, 13.0 per cent. Hardness, 3.5 to 4; specific gravity, 2.58 to 2.75. This mineral occurs native in the form of a fibrous, or compact, finely granular rock of a dull luster somewhat resembling certain varieties of aluminous limestones. It is infusible, and soluble only in sulphuric acid. The more compact varieties are so hard and tough as to be used for millstones in Hungary. No deposits of such extent as to be of economic importance are known within the limits of the United States. Alunite as an alteration product of rhyolite has been described by Whitman Cross[1] as occurring at the Rosita Hills in Colorado, the alteration being brought about through the influence of sulphurous vapors incident to the volcanic outbursts. The altered rhyolite as shown by analyses had the following composition: Silica, 65.94 per cent; alumina, 12.95 per cent; potash, 2.32 per cent; soda, 1.19 per cent; sulphur trioxide, 12.47 per cent; water, 4.47 per cent; Fe_2O_3, etc., 0.55 per cent. This indicates that the rock is made up of alunite and quartz, in the proportion of about one-third of the former to two-thirds of the latter. Ransome mentions the alteration of the feldspar labradorite into alunite and

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[1] American Journal of Science, XLI, 1891, p. 468.

quartz in the dacites of Goldfield, Nevada, the alteration being brought about through the action of sulphuric acid. The most noted occurrences of alunite are at Tolfa, near Rome, and Montioni, in Tuscany, Italy; Musaz, in Hungary; on the islands of Milo, Argentiera, and Nevis, in the Grecian Archipelago; Mount Doré, in France, and at Bullah-Delah, in New South Wales. The Bullah-Delah deposit is regarded by Pittman [1] as probably one of the most remarkable in the world. It occurs in the form of a narrow, anticlinal mountain range, some three miles in length and with a maximum height of 900 feet, which for nearly one-third its total length is made up almost wholly of alunite of varying degrees of purity. The core of the range (see Fig. 52) is of rhyolite, and is flanked on either side by sandstone. "A large, almost perpendicular crown of alunite, 400 feet high, occupies the center, while at intervals along the backbone of the ridge, to the north and south, are other projecting crags of the same material but of lesser height. . . . Between the projecting crags are saddles which are occupied by dykes of dolerite trending across the range. Naturally a comparatively small part of this enormous mass of material is sufficiently pure to bear mining and transportation. Four varieties are recognized, (1) a light pink, containing 1.7 per cent silica; (2) a chalk-white containing 16.4 per cent silica; (3) a purple containing 19.5 per cent silica, and (4) a granular variety containing 39.5 per cent silica.

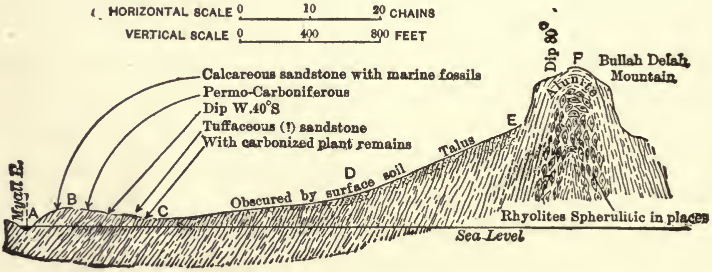

FIG. 52.—Section across Bullah-Delah Mountain, showing alunite beds. [After Pittman, Mineral Resources of New South Wales.]

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[1] Mineral Resources of New South Wales, 1901, p. 415.

At present only that carrying less than 10 per cent of silica is worked.

Here, as in the cases above mentioned, the alunite is regarded as an alteration product of rhyolite, the agents of alteration being sulphurous fumes following the intrusion of dolerite.

DeLauney regards the Tolfa, Italy, alunite as a product of superficial alteration of the pyritized portions of a trachyte, the products of decomposition being kaolin or alunite, according to the presence or absence of a sufficient amount of pyrite to yield the necessary sulphuric acid. That alunite is a less common product of feldspathic decomposition than kalinite is due to the special condition of pressure and temperature requisite for the formation of the first-named mineral.[1]

Alunite from the mines at Tolfa varies considerably in composition. The crystallized variety contains about 32 per cent alumina, whereas the cruder specimens which contain a large quantity of silica have only about 17.5 per cent. The following is an analysis of an average sample:[2]

Constituents.	Per Cent.
Alumina	27.60
Sulphuric acid	29.74
Potash	7.55
Water	11.20
Iron	1.20
Silica	22.71
Total	100.00

Alum Slate or Shale is a name given to fine-grained arenaceous rocks of variable composition, but consisting essentially of siliceous and feldspathic sands and clays with disseminated iron pyrites. The following analyses from Bischof's Chemical Geology will serve to show their varying nature:

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[1] La Metallogenie de l'Italie, p. 127.

[2] Journal of the Society of Chemical Industry, I, 1882, p. 501.

Constituents.	I.	II.	III.
Silica	65.44	72.40	50.13
Alumina	14.87	16.45	10.73
Iron oxides	1.05	....	2.27
Lime	.15	.17	.40
Magnesia	1.34	1.48	1.00
Potash	4.59	5.08	....
Soda	.48	.53	....
Iron pyrites	1.25	2.26	7.53
Carbon and water	Undet.	Undet.	25.04

(I) An alum slate from Opsloe, near Christiania, Norway, (II) from Bornholm, and (III) from Garnsdorf, near Saalfeld, Prussia.

Concerning No. III it is stated that on the roof of the adit, driven into the slate, there are almost everywhere yellow or white opaque stalactites, and more rarely a green transparent deposit is produced. Both consist of hydrated basic sulphate of alumina and peroxide of iron. In the former, iron predominates; in the latter, alumina. Both substances are quite insoluble in water.

From shales and slates of this type the alum is obtained by allowing the crushed material to undergo prolonged weathering or a roasting process. The essential part of the reaction consists in oxidizing the bisulphide to the condition of a sulphate and finally into iron sesquioxide, with separation of free sulphuric acid, which attacks the alumina, forming an equivalent quantity of sulphate of aluminum. So far as is known this process is not now carried on in the United States.

The alum shale of the English Upper Liassic formation consists of hard blue shale with cement stones. On exposure to the air it gradually becomes incrusted with sulphur, and occasionally with alum.

In composition the alum shale is as shown in table on page 359.

From this shale potash-alum was formerly made near Whitby and Redcar, the aluminum sulphate being extracted from the shale, and the potash-salt being added. The trade, which since the days of Queen Elizabeth has been largely carried on, has now almost passed away, as alum is now manufactured in other places from coal shale.

Constituents.	Per Cent.
Iron sulphide	8.50
Silica	51.16
Iron protoxide	6.11
Alumina	18.30
Lime	2.15
Magnesia	0.90
Sulphuric acid	2.50
Potash	Trace.
Soda	Trace.
Carbon	8.29
Water	2.00
Total	99.91

XIII. HYDROCARBON COMPOUNDS.

Under the name hydrocarbon compounds are included a variety of substances differing at times widely in physical properties and in the proportional amounts of their main constituents, but alike in being composed essentially of carbon and hydrogen. None of the series crystallize in nature, and as a rule the chemical composition is so variable as to render futile all attempts at classification on a mineralogical basis. In practice it is customary to divide them into two main groups, (1) The Coal Series, (2) The Bitumen Series.

1. THE COAL SERIES.

Here are included a variety of more or less oxidized hydrocarbons, differing considerably in their physical properties and in chemical composition, but alike in that they have originated through the accumulation and decomposition of plant débris largely out of reach of the oxidizing influence of the air. As to the method of this accumulation there has from time to time been more or less discussion.

By many the coal beds are regarded as having resulted from the gradual accumulation, in place, of organic matter growing on gradually subsiding marshes, or marshes and swamps subject to periodic overflow, the material itself being largely in the nature of sphagnous mosses. By others it is thought that the plant material was first transported by running streams and laid down on the bottoms of deltas and lagoons; that the coal beds are, in short, as true sedimentary deposits as the shales and sandstones with which they are associated. This last view, though not generally accepted, would seemingly best account for the constant interlamination of the coaly and sandy or clayey material and the marked stratification of the coal itself. Moreover, it would explain the almost completely structureless nature of many coals, since calcium sulphate, one of the constituents of sea water, tends to decompose organic matter, reducing it to a pulp-like and at times almost mucilaginous condition.

According to the amount of change that has taken place in the original plant material, the amount of volatile matter still retained by it, its hardness and burning qualities, several varieties of coal are recognized, which are described somewhat in detail below. The general subject, it may be said, is far too large to be satisfactorily disposed of here, and the reader is referred to the special works noted in the bibliography.

Peat.—This name is given to a material resulting from the accumulation of plant remains, largely of the nature of sphagnous mosses, in bogs, and which has, as a rule, undergone so slight modification that the plant fibers are still readily recognizable, though where the beds have reached a considerable thickness the lower portion may be reduced to a dense brownish-black mass somewhat resembling true coal. These deposits as existing to-day are all of recent origin, and to be found only in humid and temperate or north temperate climates. They are developed to an enormous extent in Ireland, where they average, in some cases, twenty-five feet in thickness. They are also abundant on the continent of Europe and throughout the northern and eastern United States. In Ireland and on the Continent the material has been extensively used as fuel, in the first-named country largely in its native state, but in Germany

PLATE XXXII.
Map Showing Developed Coal Fields in the United States.
[From Report of Eleventh Census.]

[*Facing page* 360.]

after being made up into briquettes.[1] The material, it should be noted, rarely occurs in such form as to be immediately available for fuel, the chief drawbacks being the large amount of water it contains and its loosely compacted nature. Recourse must therefore be had to artificial drying and compression. Ordinarily fresh peat, as taken from the bog, will contain from 75 per cent to even 90 per cent of moisture. By compression, as in briquette manufacture, it is reduced to about one-fourth its original bulk, i.e., 4 cubic feet of fresh will yield 1 cubic foot of the compressed material.

The analyses given below are calculated on a *water-free* basis. Ordinary air-dried peat will contain about 20 per cent of moisture. The analyses are selected out of a large number simply to show averages. No. 1 is of material from Penobscot County, Maine; No. 2 from near Ottawa, Canada:

Constituents.	I.	II.
Vegetable, combustible matter....	63.06	67.57
Fixed carbon....................	31.21	25.35
Ash............................	5.73	7.18
Sulphur........................	0.36	0.314
Nitrogen.......................	2.09	1.40

Cheapness of wood and coal has caused peat to be largely disregarded in America, but recent events have turned attention toward it once more, and it seems probable that within a few years numerous plants will be established for converting the crude material into a satisfactory form for burning.

The rate of growth of peat, or otherwise expressed, the rate of accumulation of coal-bed material, has been a matter of frequent observation. Naturally it is widely variable for different localities.

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[1] A new method of making charcoal from peat has been patented in England, and is to be tried in Italy, where there are large deposits of peat which can, it is claimed, be handled very cheaply. In this process the peat is first reduced to a fine paste and leaves the machine in a continuous thick tube 3 to 5 inches in diameter, and is then cut off in sticks and dried for three days on wooden supports and for a longer period in the air on wire netting. After twenty-five days the sticks become dry and hard and may be burned as fuel; but it is more profitable to convert these sticks into charcoal. This is accomplished in six hours in a retort, and 3 tons of peat make 1 ton of charcoal.—Engineering and Mining Journal, LXV, February 26, 1898, p. 248.

G. H. Ashley has calculated [1] that a fair average maximum of peat growth is at the rate of one foot in ten years. But one foot of the spongy material at the surface will, owing to pressure and loss through decomposition, shrink to a little over an inch, and it is probable that one foot a century would more nearly represent the rate of accumulation of the dense, compact material found in the deeper part of bogs. This material, even were there no further loss through decomposition, would suffer a reduction in mass of fully two-thirds in passing into the condition of ordinary bituminous coal. On this basis it would require 300 years for the accumulation of material to form one foot of coal, or 2,100 years to form the seven-foot Pittsburg bed, and probably 100,000 years, in round numbers, for the total approximate 300 feet of the entire Appalachian coal fields.

Lignite or Brown Coal.—This name is given to a brownish-black variety of coal characterized by a brilliant luster, conchoidal fracture, and brown streak. Such contain from 55 to 65 per cent of carbon, and burn easily, with a smoky flame, but are inferior to the true coals for heating purposes. They are also objectionable on account of the soot they create, and their rapid disintegration and general deterioration when exposed to the air. They occur in beds under conditions similar to the true coals, but are of more recent origin. The lignitic coals of the regions of the United States west of the Mississippi River are mainly of Laramie age, and often show easily recognizable traces of their organic origin, such as compressed and flattened stems and trunks of trees with traces of woody fiber.

Jet is a resinous, coal-black variety of lignite sufficiently dense to be carved into small ornaments. According to Professor Phillips, it is simply a coniferous wood, and still shows the characteristic structure under the microscope. It has been known since early British times, having at first been found on the seashore at Whitby and other places. The largest piece on record was obtained from the North Bats, near Whitby. It weighed some 5,180 pounds and was valued at about $1,250. The material is now regularly mined both in the cliffs and inland, and is one of the most valuable products of the Yorkshire coast.[2]

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[1] Economic Geology, II, 1907, p. 46.

[2] Geology of England and Wales, p. 278.

Fig. 1.—Typical Moss or Peat Bog near Augusta, Maine.
[After E. S. Bastin, Bulletin No. 376, U. S. Geological Survey.]

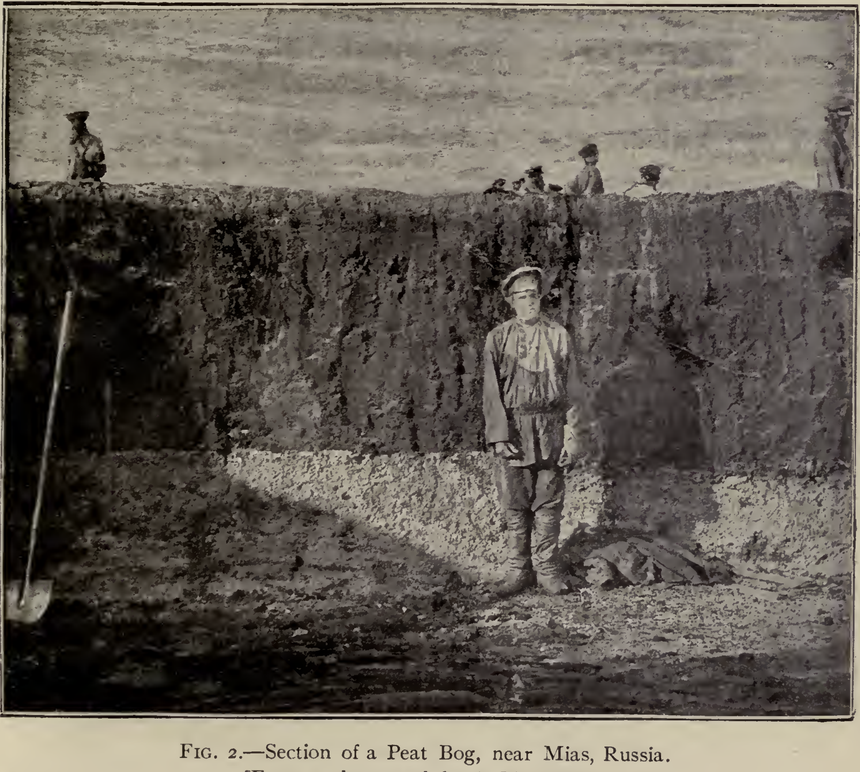

Fig. 2.—Section of a Peat Bog, near Mias, Russia.
[From a photograph by A. M. Miller.]
PLATE XXXIII.

Bituminous Coals.—Under this name are included a series of compact and brittle products in which no traces of organic remains are to be seen on casual inspection, but which under the microscope often show traces of woody fiber, spores of lycopods, etc. These coals are usually of a brown to black color, with a brown or gray-brown streak, breaking with a cubical or conchoidal fracture, and burning readily with a yellow, smoky flame. They contain from 35 to 75 per cent of fixed carbon, 18 to 60 per cent of volatile matter, from 2 to 20 per cent of water, and only too frequently show traces of sulphur, due to included iron pyrites. Several varieties of bituminous coals are recognized, the distinctions being based upon their manner of burning. *Coking* coals are so called from the facility with which they may be made to yield coke. Such give a yellow flame in burning and make a hot fire. Other varieties of apparently the same composition and general physical properties can not be made to yield coke, and are known as *non-coking coals*. *Cannel* coal has a very compact structure, breaks with a conchoidal fracture, has a dull luster, ignites easily, and burns with a yellow flame. It does not coke. Its chief characteristic is the large amount of volatile matter given off when heated, whereby it is rendered of particular value for making gas. Before the discovery of petroleum it was used for the distillation of oils. Below is given the composition of (I) a coking coal from the Connellsville Basin of Pennsylvania, and (II) a cannel coal from Kanawha County, West Virginia.

Constituents.	I.	II.
Water.	1.105	....
Volatile matter.	29.885	58.00
Fixed carbon	57.754	23.50
Ash.	9.895	18.50
Sulphur.	1.339	....
Total.	99.978	100.00

Torbanite.—The name torbanite, boghead mineral and kerosene shale have been variously given to a tough brownish-black to coal-black, lusterless substance, breaking with a conchoidal fracture and somewhat resembling cannel coal, which is found in both the upper and Lower Coal measures of New South Wales, Australia, and near the base of the Carboniferous near Bathgate, in Linlithgowshire, in Scotland. It occurs, according to E. F. Pittman,[1] in lenticular areas or patches passing at the edges into bituminous or splint coal or grading into carbonaceous shale. The beds are but a few feet in thickness and the largest deposit known not over a mile in length. It is regarded by different authorities as due to the accumulation in lakes of vegetable material, either sporangia or algae, and is therefore classed with the coals.

The New South Wales torbanite contains from 70 to 80 per cent of volatile hydrocarbons; 6 to 8 per cent of fixed carbon, and 7 to 20 per cent of ash. It has in times past been used mainly for gas and oil making, by a process of distillation. The best qualities, yielding from 150 to 160 gallons of oil to the ton or about 20,000 feet of gas of 48 candle intensity.[2]

Anthracite Coal.—This is a deep-black, lustrous, hard and brittle variety, and represents the most highly metamorphosed variety of the coal series. Traces of organic nature are almost entirely lacking in the matter of the anthracite itself, though impressions of ferns, lycopods, sigillaria, and other coal-forming plants are frequently associated with the beds in such a manner as to leave little doubt as to their origin. Anthracite is ignited with difficulty and burns with little flame, but makes a hot fire. Below is given the average composition of a coal from the Kohinoor Colliery, Shenandoah, Pennsylvania.[3]

Constituents.	Per Cent.
Water	3.163
Volatile matter	3.717
Fixed carbon	81.143
Sulphur	0.899
Ash	11.078
Total	100.000

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[1] Mineral Resources of New South Wales, p. 358.

[2] A. Liversidge, Minerals of New South Wales, p. 145.

[3] F. P. Dewey, Bulletin No. 42, United States National Museum, 1891, p. 231.

FIG. 1.—Quarry of Bituminous Sandstone, Oklahoma.

FIG. 2.—Quarry of Bituminous Sandstone, Santa Cruz District, California.

PLATE XXXIV.

[After G. H. Eldridge, U. S. Geological Survey.]

[*Facing page* 364.]

Until recently it has been quite generally assumed that anthracite is but a bituminous coal from which a large portion of the volatile matter has been driven off by the heat and pressure incidental to mountain making or the intrusion of igneous rocks. Undoubtedly anthracite may be thus produced and in some cases has been thus produced, as in the Cerrillos coal field of New Mexico, where a bituminous coal containing some 30 per cent of volatile matter has been locally converted into anthracite through the intrusion of a mass of an andesitic trachyte.

Prof. J. J. Stevenson has, however, argued [1] that the difference between anthracite and the bituminous coals is due, not to metamorphism through heat and pressure after being buried, but rather to the former having been longer exposed to the percolating action of water, whereby the volatile constituents were removed, prior to its final burial, and the consolidation of the inclosing rocks.

Like the other coals, anthracite occurs in true beds, but is confined mostly to rocks of the Carboniferous Age. Thin seams of anthracite sometimes occur in Devonian and Silurian rocks, but which are too small to be of economic value. Rarely coals of more recent geological horizon have been formed locally, altered into anthracite by the heat of igneous rocks. Through a still further metamorphism, whereby it loses all its volatile constituents, coal may pass over into graphite. (See p. 71.)

The principal anthracite coal regions of the United States are in eastern Pennsylvania. From here westward throughout the interior States to the front range of the Rocky Mountains the coals are all soft, bituminous coals. Those of the Rocky Mountain region proper are largely lignitic, passing into the bituminous varieties. A small field of anthracite exists, however, in Colorado, and recent discoveries point to a larger one in Alaska. (See Plate XXXII.)

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[1] Bulletin Geological Society of America, VII, 1895, p. 525.

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2. THE BITUMEN SERIES.

Under this head are included a series of hydrocarbon compounds varying in physical properties from solid to gaseous and in color from coal-black through brown, greenish, red, and yellow to colorless. Unlike the members of the series already described, they are not the residual products of plant decomposition *in situ*, but are rather, in part at least, distillation products from deeply buried organic matter of both animal and vegetable origin. The members of the series differ so widely in their properties and uses that each must be discussed independently. The grouping of the various compounds as given below is open to many objections from a strictly scientific standpoint, but, all things considered, it seems best suited for the present purposes.[1]

TABULAR CLASSIFICATION OF HYDROCARBONS.[2]

Hydrocarbons.	Bituminous.	Gaseous.	Marsh gas (Natural gas).
		Fluidal.	Petroleum (Naphtha).
		Viscous and semisolid.	Pittasphalt (Maltha). Mineral tar. Asphalt.
		Elastic	Elaterite. Wurtzillite.
		Solid.	Albertite. Grahamite. Uintaite.
	Resinous.		Succinite. Copalite. Torbanite. Ambrite.
	Cerous (waxy).		Ozokerite. Hatchettite.

TABULAR CLASSIFICATION OR GROUPING OF NATURAL AND ARTIFICIAL BITUMINOUS COMPOUNDS.

Bituminous Compounds.	Natural.	Mixed with limestone, "asphaltic limestone."	Seyssel, Val de Travers, Lobsan, Illinois, and other localities.
		Mixed with silica and sand, "asphaltic sand."	California, Kentucky, Utah, and other localities. "Bituminous silica."
		Mixed with earthy matter, "asphaltic earth."	Trinidad, Cuba, California, Utah.
		Bituminous schists.	Canada, California, Kentucky, Virginia, and other localities.
	Artificial.	Fluid.	Thick oils from the distillation of petroleum. "Residuum."
		Viscous.	Gas-tar. Pitch.
		Solid.	Refined Trinidad asphaltic earth. Mastic of asphaltite. Gritted asphaltic mastic. Paving compounds.

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[1] See article What is Bitumen, by S. F. Peckham, Journal of the Franklin Institute, CXL, 1895, pp. 370 to 383.

[2] W. P. Blake, Transactions of the American Institute of Mining Engineers, XVIII, 1890, p. 582.

Still another arrangement is that given below:

TABLE OF OCCURRENCE OF IMPORTANT NATURAL BITUMEN.[1]

Important natural bitumens.	Natural gas			Ohio, Pennsylvania, California, etc., in the United States, Russia, France, etc.
	Natural naphtha			Found in petroleum districts.
	Petroleum			Pennsylvania, Ohio, Wyoming, California, etc., in United States; Russia, etc.
	Maltha			California, Wyoming, Alabama, Utah, Colorado, Kentucky, New Mexico, Ohio, Texas, Indian Territory, etc.; Russia, France, Germany, etc.
	Asphaltum.	Asphaltum almost pure.	North America	Utah, California, Texas, etc.
			Central America	Cuba, Mexico, etc.
			South America	Trinidad, Venezuela, Peru, Colombia, etc.
			Europe	Caucasia, Syran-on-the-Volga, Germany, France, Italy, Austria, etc.
			Asia	Hit on the Euphrates, Asia Minor, Palestine, etc.
			Africa	Oran in Egypt; probably other places.
		Asphaltic compounds.	North America	West Virginia, Kentucky, Texas, Wyoming, Utah, Colorado, California, Oklahoma, Montana, New Mexico.
			Central America	Mexico, Cuba, etc.
			South America	Trinidad, Venezuela, Peru, Colombia, etc.
			Europe	Germany, Switzerland, France, Italy, Sicily, Russia, Austria, Spain, etc.
			Asia	Asia Minor, Palestine, Bagdad, and probably in China.
			Africa	Egypt, and probably elsewhere in Africa.

Origin.—Of the many views, mainly theoretical, that have been put forward to account for the origin of bituminous compounds, but two need be noted in detail here. Interested readers are referred to the bibliography given on page 398, and particularly to the works of

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[1] J. W. Howard, as quoted by S. P. Sadtler, Journal of the Franklin Institute, CXL, 1895, p. 200.

Peckham, Orton, and Redwood. F. W. Clarke's excellent summary[1] is also to be read with profit. Prof. Edward Orton, after an exhaustive consideration of the occurrence of petroleum, natural gas, and asphalt in Kentucky,[2] gives the following precise summary:

"1. Petroleum is derived from organic matter.

"2. Petroleum of the Pennsylvania type is derived from the organic matter of bituminous shales, and is probably of vegetable origin.

"3. Petroleum of the Canadian type is derived from limestones, and is probably of animal origin.

"4. Petroleum has been produced at normal rock temperatures (in American fields), and is not a production of destructive distillation of bituminous shales.

"5. The stock of petroleum in the rocks is already practically complete."

Hofer[3] regards petroleum as of animal origin only, and advances the arguments given below in support of his theory:

"1. Oil is found in strata containing animal, but little or no plant remains. This is the case in the Carpathians, and in the limestone examined in Canada and the United States by Sterry Hunt.

"2. The shales from which oil and paraffin were obtained in the Liassic oil shales of Swabia and of Steirdorf, in Styria, contained animal, but no vegetable remains. Other shales, as, for instance, the copper shales of Mansfield, where the bitumen amounts to 22 per cent, are rich in animal remains and practically free from vegetable remains.

"3. Rocks which are rich in vegetable remains are generally not bituminous.

"4. Substances resembling petroleum are produced by the decomposition of animal remains.[4]

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[1] Data for Geochemistry Bulletin No. 330, U. S. Geological Survey, p. 111.

[2] Report on the Occurrence of Petroleum, etc., in Western Kentucky. Geological Survey of Kentucky, John R. Proctor, director, 1891.

[3] As quoted by Redwood, I, p. 238.

[4] Dr. Engler, as quoted by Redwood, obtained by distillation of menhaden oil, among other products, a substance remarkably like petroleum, and a lighting oil indistinguishable from commercial kerosene.

"5. Fraas observed exudations of petroleum from a coral reef on the shores of the Red Sea, where it could be only of animal origin."

In both cases, it will be noted, the original source of the material was organic matter.

The second theory, which advocates an inorganic origin, is based largely upon theoretical grounds. It has been shown that hydrocarbons may be formed under conditions that prevailed deep in the earth, below any possible deposits of organic matter, and intimately associated with igneous intrusions. In brief, hydrocarbons may be formed from the reduction of metallic carbides.

The presence of the material in quantity only in unaltered sedimentary rocks remote from all signs of igneous disturbance must, however, be regarded as direct evidence in favor of an organic genesis, whatever may be said with reference to the small quantities sometimes found in igneous rocks or derived from volcanic sources.[1]

The relationship which exists between the solid or viscous bitumen and the fluidal petroleum has not in all cases been satisfactorily worked out, though Peckham has shown [2] that in California at least there are almost infinite gradations from one extreme to the other. In Ventura County, for instance, the petroleum is held, primarily, in strata of shale, from which it issues as petroleum or maltha, accordingly as the shales have been brought into contact with the atmosphere, the asphaltum being produced by a still further exposure to the atmosphere after the bitumen has reached the surface.

The relationship between petroleum and natural gas is scarcely better defined. That the gas can be derived from petroleum is undoubted, and indeed the latter apparently never occurs free from gas. But on the other hand, as Professor Orton states, the gas often originates under many conditions in which petroleum does not occur. The formation of marsh gas from decomposing plant remains on the bottom of stagnant pools, and its presence in coal mines show with seeming conclusiveness that a part, at least,

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[1] Messrs. Arnold and Anderson have recently shown (Bulletin No. 322, U. S. Geological Survey) that the petroleums of the Santa Maria, Cal., district, are derived from the Monterey shales, which are made up largely of diatom, foraminiferal and radiolarian remains.

[2] See report of the Tenth Census, p. 68.

of the gas is formed quite independently of petroleum. It would seem on the whole most probable that no one theory was universally applicable to all cases.

Marsh Gas; Natural Gas.—This is a colorless and odorless gas arising from the decomposition of organic matter protected from the oxidizing influence of atmospheric air. By itself it burns quietly, with a slightly luminous flame, but when mixed with air it forms a dangerous explosive. It is this gas which forms the dreaded fire-damp of the miners. In small quantities this gas may be found and collected, if desired, from the bottom of shallow pools and stagnant bodies of water by merely disturbing the decomposing plant matter at the bottom, when the bubbles of the gas will rise to the top. Under this head may properly be considered the so-called *natural gas*, which has of late years become of so much importance from an economic standpoint. This gas is, however, by no means a simple compound, but a variable admixture of several gases, samples from different wells showing considerable variation in composition, as well as those from the same well collected at different periods. This last is shown by the seven analyses following, which may serve well to illustrate the average composition, though in some instances the percentage of marsh gas has been found greater.[1]

Constituents.	I.	II.	III.	IV.	V.	VI.	VII.
Hydrogen	1.89	1.64	1.74	2.35	1.86	1.42	1.20
Marsh gas	92.84	93.35	93.85	92.67	93.07	94.16	93.58
Olefiant gas	0.20	0.35	0.20	0.25	0.49	0.30	0.15
Carbonic oxide	0.55	0.41	0.44	0.45	0.73	0.55	0.60
Carbonic acid	0.20	0.25	0.23	0.25	0.26	0.29	0.30
Oxygen	0.35	0.39	0.35	0.35	0.42	0.30	0.55
Nitrogen	3.82	3.41	2.98	3.53	3.02	2.80	3.42
Sulphuretted hydrogen	0.15	0.20	0.21	0.15	0.15	0.18	0.20
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

I, Fostoria, Ohio; II, Findlay, Ohio; III, St. Marys, Ohio; IV, Muncie, Indiana; V, Anderson, Indiana; VI, Kokomo, Indiana; VII, Marion, Indiana.

Natural gas in quantities to be of economic importance is necessarily limited to rocks of no particular horizon. It is not, however,

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[1] From Orton's Report on Petroleum, Natural Gas, and Asphalt in Kentucky, pp. 108–110.

indigenous to the rocks in which it is now found, but occurs in an overlying more or less porous sand or lime rock into which it has been forced by hydrostatic pressure. The first necessary condition for the presence of gas in any locality may indeed be said to depend upon the existence of such a porous rock as may serve as a reservoir to hold it, and also the presence of an impervious overlying strata to prevent its escape. In Pennsylvania the reservoir rock is a sandstone of Carboniferous or Devonian age; in Ohio and Indiana a cavernous dolomitic limestone of Silurian (Trenton) age.

Petroleum.—This is a name given to a mixture of complex hydrocarbon compounds, together with small amounts of their sulphur nitrogen and oxygen derivatives, which is liquid at ordinary temperatures, though varying greatly in viscosity, of a black, brown, greenish, or more rarely red or yellow color, and of extremely disagreeable odor. Its specific gravity varies from 0.6 to 0.9. Through becoming more and more viscous, the material passes into the solid and semisolid forms asphalt and maltha. Chemically it is considered as a mixture of the various hydrocarbons included in the marsh gas, ethyline, and paraffin series.

An ultimate analysis of several samples, as given by the reports of the Tenth Census of the United States (1880), showed the following percentages of the three essential constituents:

Locality.	Hydrogen.	Carbon.	Nitrogen.
West Virginia........	13.359	85.200	0.54
Mecca, Ohio..........	13.071	86.316	0.23
California...........	11.819	86.934	1.109

Petroleum is limited to no particular geological horizon, but is found in rocks of all ages, from the lower Silurian to the most recent, its existence in quantities sufficient for economic purposes being dependent upon local conditions for its generation and subsequent preservation. Inasmuch as its accumulation in large quantities necessitates a rock of porous nature to act as a reservoir, the petroleum-bearing rocks are mostly sandstones, though not uniformly so. Petroleums are found in California and Texas in Tertiary sands; in Colorado in the Cretaceous; in West Virginia both above and below the Crinoidal (Carboniferous) limestones; in Pennsylvania in the Mountain sands (Lower Carboniferous) and the Venango sands (Devonian); in Canada in the Corniferous (Lower Devonian) limestones; in Kentucky in the Hudson River shales (Lower Silurian), and in Ohio in the Trenton limestone.

In some instances petroleum oozes naturally from the ground, forming at times a thin layer on the surface of pools of water, whence in times past it has been gathered and used for chemical and medicinal purposes. The so-called "Seneca oil" thus used some fifty or sixty years ago was obtained from a spring in Cuba, Allegany County, in New York. The immense supply now demanded for commercial purposes is, however, obtained altogether from artificial wells of varying depths, which are in some cases self-flowing, while in others the oil is raised by means of pumps. Wells of from 500 to 1,500 feet in depth are of common occurrence, while those upwards of 2,000 feet are not rare. The principal sources of petroleum are in the United States—New York, Pennsylvania, Ohio, and Oklahoma, with smaller fields in West Virginia, Kentucky, Tennessee, Illinois, Indiana, Kansas, Louisiana, Texas, Colorado, and California. The chief foreign source is the Baku region on the Caspian Sea, and Galicia, in Austria.

Uses of petroleum.—The early uses of petroleum in America seem to have been for medicinal purposes only. The oil as pumped from the wells has but a limited application in its crude condition excepting as a fuel, and owes its great value to the large and varied series of derivatives which it yields. A discussion of the methods employed in obtaining these derivatives belongs properly to the department of chemical technology, and can not be dwelt upon here. It must suffice for present purposes to say that the treatment as ordinarily carried out at present involves a process of destructive distillation whereby the crude material, heated under pressure, is resolved into a variety of products of different densities, and varying from gaseous through liquid to solid forms. Prominent among these derivative may be mentioned, aside from the gaseous compounds, rhigolene, gasoline, naphtha, benzine, kerosene, various lubricating oils, paraffin, and the soild residues (coke, etc.). Various pharmaceutical compounds are prepared from petroleum products, many of which are well known to the public, as vaseline, cosmoline, etc. It is also used as a basis for ointments and in soaps.

For full and detailed information relative to the petroleum industry and general distribution of allied bituminous compounds throughout the world, the reader is referred to the works mentioned in the bibliography, that of Boverton Redwood being the most systematic and complete.

Asphaltum; Mineral Pitch.—These are names given to what are rather indefinite admixtures of various hydrocarbons, in part oxygenated and which, for the most part solid or at least highly viscous at ordinary temperatures, pass by insensible gradations into pittasphalt or mineral tar, and these in turn into the petroleums. They are characterized by a black or brownish-black color, pitchy luster, and bituminous odor. The solid forms melt ordinarily at a temperature of from 90° to 100° F., and burn readily with a bright flame, giving off dense fumes of a tarry odor. The fluidal varieties become solid on exposure to the atmosphere, owing to evaporation of the more volatile portions.

The nature of the material, its mode of occurrence, and indeed the uses to which it can be put, vary to such an extent with each individual occurrence that a few only of what are the most noted or best known can here be mentioned.

Island of Trinidad.—The occurrence on this island of an immense body of asphaltic material has been known for upwards of a hundred years, and numerous, often widely differing, accounts of it are to be found in literature. The latest and perhaps most satisfactory, when everything is taken into consideration, is that of S. F. Peckham.[1] The deposit, which covers an area of nearly 100 acres, is situated at an elevation of 138 feet above the level of the sea (see map, Fig. 53), and on superficial examination has an appearance such as has caused it to be known by the not wholly inappropriate name of the Pitch Lake of Trinidad. The depth of the deposit, in various parts, has been estimated at from 18 to 78 feet. According to Richardson the maximum depth is 35 feet. Early accounts de-

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[1] American Journal of Science, L, 1895, pp. 33–51.

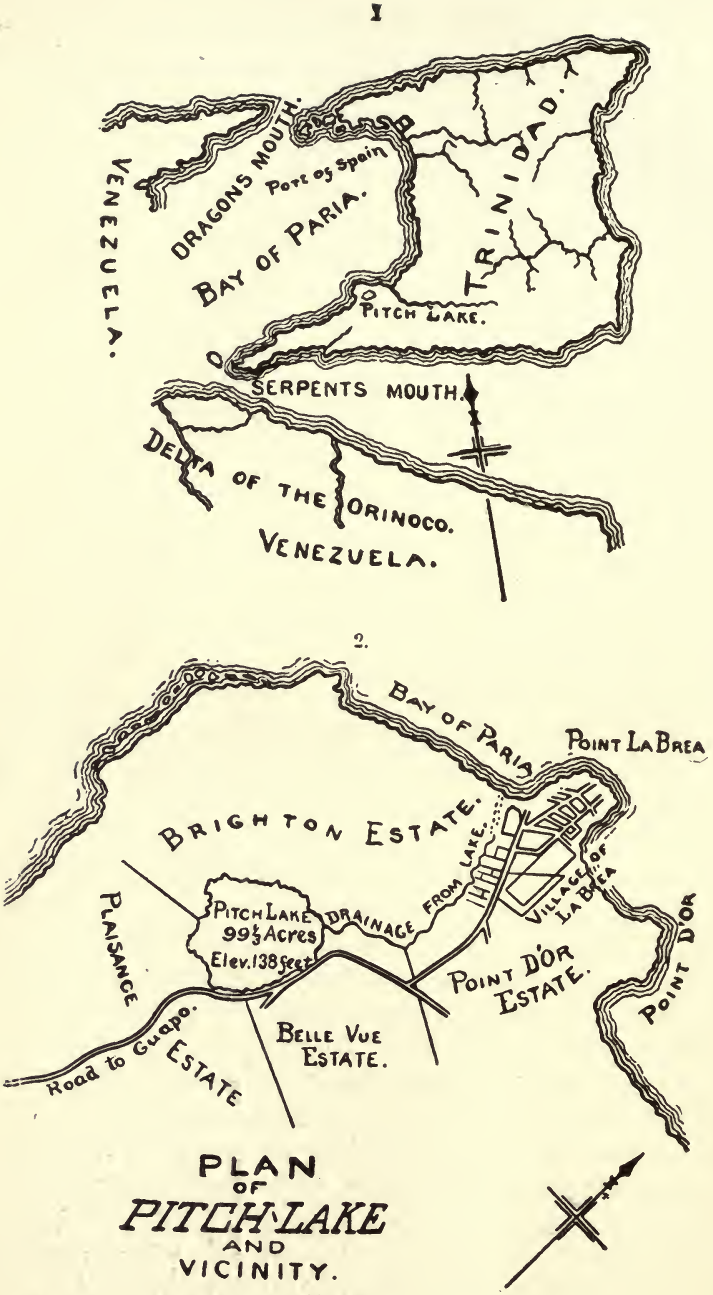
1
VENEZUELA.
DRAGONS MOUTH.
Port of Spain
BAY OF PARIA.
TRINIDAD.
PITCH LAKE.
SERPENTS MOUTH.
DELTA OF THE ORINOCO.
VENEZUELA.
2.
BAY OF PARIA
POINT LA BREA
BRIGHTON ESTATE.
DRAINAGE FROM LAKE.
VILLAGE OF LA BREA
PITCH LAKE
99½ Acres
Elev. 138 feet
PLAISANCE
Road to Guapo.
ESTATE
BELLE VUE ESTATE.
POINT D'OR ESTATE.
POINT D'OR
PLAN OF PITCH LAKE AND VICINITY.

FIG. 53.

scribed the pitch at the margin of the lake as cold and hard, becoming gradually warmer and more viscous toward the center, until a point is reached where it is too soft to support the weight of a man and actually "boiling." However, this may have been years ago; the material is now sufficiently firm over the entire surface to support men and teams. The deposit is commonly regarded as a mud volcano, the bitumen being still brought up intermixed with water and mud, the numerous small islands which occupy the surface of the lake being but masses of earthy matter buoyed up by the pitch. Though the deposit has been worked for many years and thousands of tons of asphalt removed, no appreciable impression has as yet been produced upon the amount of material available.

The crude material has the following composition and physical characteristics:[1]

Specific gravity, 1.28; hardness at 70° F., 2.5 to 3 of Dana's scale; color, chocolate-brown; composition:

Bitumen	39.83
Earthy matter	33.99
Vegetable matter	9.31
Water	16.87
Total	100.00

Cuba.—Asphalt in some of its varieties occurs in nearly every one of the Cuban provinces and in several instances in sufficient abundance to be of economic importance. In all instances thus far described,[2] the material occurs in veins or pockets, or exudes in the form of springs, usually in serpentinous rocks or limestones. As long ago as 1837 R. C. Taylor described[3] a deposit of asphalt—at that time regarded as bituminous coal—occurring some 10 miles east of Havana as occupying an irregularly branching fissure from 1 to 9 feet in width in a soft clay rock, which is now known to be a decomposed eruptive. The appearance of the

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[1] F. V. Greene. Asphalt and Its Uses. Transactions of the American Institute of Mining Engineers., 17, 1888–89, p. 355.

[2] See Report on Geological Reconnoissance of Cuba, 1901.

[3] London and Edinburgh Philosophical Magazine and Journal of Science, X, 1837, p. 161.

vein, in vertical section, is shown in Fig. 54, the bottom of the cut representing a distance from the surface of 30 feet. The asphalt itself was described as of a jet-black color, resplendent luster, conchoidal fracture, and with a specific gravity varying from 1.42 to 1.97. An analysis by T. G. Clemson showed 63 per cent volatile matter, 34.97 per cent carbon, and 2.03 per cent ash.

FIG. 54.—Asphalt vein, Cuba. [After R. C. Taylor.]

Several interesting submarine deposits exist in Cardinos Bay, which may be mentioned on account of the unique methods of mining. These have been described by J. L. Hance. The country rock is a limestone and the asphalt of a brilliant black color and about as friable as cannel coal. In mining a lighter is anchored directly over the body of asphalt and a long, pointed iron bar raised by a winch, on board, dropped upon it, the weight of the bar being sufficient to break away pieces of the asphalt, which are then collected by divers and sent to the surface in nets. The material has been utilized in making varnish, and formerly brought a high price.

A large deposit of an inferior grade, and used mainly for roofing is situated near Diana Key, 15 miles from the city of Cardenas, and a massive bed, some 12 feet in thickness, near Villa Clara. Material from this last source has, during years past, been used for making the illuminating gas used in the city.

Sandstones and limestones are sometimes so impregnated with bituminous matter that they may be used as sources of the material by refining processes or for the direct manufacture of pavements by simply crushing. Such are the so-called bituminous or asphaltic sand rocks and limestones of Kentucky, Texas, Oklahoma, Utah, Colorado, California, Wyoming, and other States, and of Canada and Spain.

According to G. H. Stone,[1] the asphaltic sandrock of western Colorado and eastern Utah consists of grains of sand which are in contact with one another, the spaces between the grains being filled with asphalt, the proportioned amount of which varies up to 15 per cent by weight, or 27 per cent by volume. One stratum of fully charged rock in the region described was nearly 40 feet in thickness, though usually the strata of high-grade material are not more than 4 to 10 feet thick and alternate with others which are quite poor or barren, so that the amount of "pay rock" is often grossly exaggerated.

Asphaltic sands and sandrocks are of common occurrence in the immediate vicinity of the Coast Range in California from Point Arena, north of San Francisco, to the southernmost part of the State.[2] The deposits occur almost invariably as sands and shales, belonging to the Neocene formations, impregnated with varying amounts of bitumen, though rarely exceeding 15 to 20 per cent by weight. The material is mined from open cuts, rarely from shafts, and is utilized in large part for street-paving purposes.

In the region south of the Canadian River, in Oklahoma, asphalt and asphaltic lime and sandstones occur over extensive areas, the more important being in what are known as the Buckhorn and Brunswick districts. The rocks of the regions are wholly sedimentary, and the bituminous members belong mainly to the Lower Silurian (Ordovician), Coal Measure, and Cretaceous formations. In the eastern part of the territory, the Ten Mile district, is found a very pure, brittle material somewhat resembling albertite (p. 383), and for which the name impsonite has been suggested.[3] It contains some 86 per cent of carbon and 8 per cent of hydrogen. The material is found in a vein in greenish gray shales, having a trend of 15° N. to 20° E., and pitching 45° to 65° to the eastward.

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[1] American Journal of Science, XLII, 1891, p. 148.

[2] See Thirteenth Annual Report State Mineralogist of California, 1896, also Twenty-second Annual Report, U. S. G. S., 1900–1901, Pt. I, pp. 209–464.

[3] After the Impson Valley, where it occurs. See Eldridge's paper, Twenty-second Annual Report, U. S. G. S. Richardson regards this material as grahamite.

At the Ralston quarry in the Buckhorn district the rock is a massive Ordovician sandstone some 15 feet in thickness overlaid by some 75 to 100 feet of conglomerate. The bitumen contents amounts to between 10 and 12 per cent. At the quarry of the Gilsonite Paving and Roofing Company in this same district, the bitumen is in strata referred to the Lower Coal Measures. (See section, Fig. 55.) The bitumen-bearing member here (No. 9 in section) is a hard massive limestone, the upper portion of which is highly fossiliferous, and the lower sometimes conglomeratic. It yields on an average some 14 per cent of bitumen.

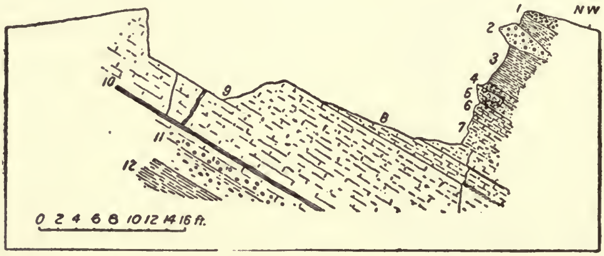

FIG. 55.—Section across quarry of Gilsonite Paving and Roofing Company, showing bituminous limestone and associated strata.
[U. S. Geological Survey.]

1 and 2, conglomerate; 3, shales; 4, conglomerate; 5, quartzite, 6, limestone, bituminous; 7, limestone, somewhat bituminous; 8, calcareous with wood fiber and coal; 9, limestone averaging 14 per cent bitumen; 10, shale; 11, conglomerate; 12, bituminous shale.

Uses.—The uses of the common type of material such as is known simply as asphalt are quite varied. The walls of Babylon are stated to have been cemented with it, and doubtless it was so used in other ancient cities. It was also, as at present, used for making vessels water-tight. At the present day the refined asphalts are used as a varnish or paint, as an insulating material, for waterproofing, as a cement in ordinary construction, and as a cement in roofing and paving compounds. For these purposes it is first tempered with some form of oil, the kind and amount used depending on the purposes to which it is to be applied. A mixture of asphalt and sand forms the ordinary concrete for sidewalks and basement floors. The most extensive use of asphaltic compounds is at present for street pavements, the material for this purpose being mixed with fine sand and sometimes powdered limestone.[1] The asphaltic sands, sandstones, and limestones are sometimes so evenly impregnated with bituminous matter that they may be crushed and applied directly to the roadbed. The uses to which are put the higher grades of asphaltic compounds, such as are designated by special names, are given further on.

Manjak.—The local name of manjak is applied to a variety of bitumen somewhat resembling uintaite, occurring on the island of Barbados, in the West Indies. The material is a very pure hydrocarbon of a black color, but yielding a brown powder, high luster, and with a bright conchoidal fracture. It is brittle, and so friable that it can be ground to powder between the thumb and fingers. It occurs in seams or veins, varying from one-fourth of an inch to 30 feet in thickness, cutting the country rock, which is an argillite or shale, at all angles with the horizon and with a general NNE. strike. In places the bituminous matter has saturated the entire rock in the neighborhood of the veins, producing a shale from which as much as 37 gallons a ton of petroleum have been obtained by destructive distillation. Thus far the greatest development is along a vein 200 feet in length, 100 feet in depth, and from 8 to 9 feet in width. One vein, which has been explored to a depth of 200 feet, is stated to have dwindled down to a width of 6 feet, though 30 feet wide at the surface.[2]

Manjak is stated [3] also to occur on the island of Trinidad some 12 miles from Pitch Lake, with which, however, it apparently has no connection. The material occurs in form of a steeply pitching seam which as perforated by shafts shows a width of 10 feet at a depth of 55 feet below the surface and of 33 feet at a depth of 200 feet. The material yielded on analysis as below: [4]

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[1] Asphalt and its Uses, Transactions of the American Institute of Mining Engineers, XVII, 1889, p. 335. See also The Modern Asphalt Pavement, by Clifford Richardson, Wiley & Sons: New York, 1905.

[2] W. Merivale, Engineering and Mining Journal, LXVI, 1898, p. 790; also the Mineral Industry, VI, 1897, p. 54.

[3] Engineering and Mining Journal, April 14, 1906, p. 710.

[4] Analyses I and II by B. Redwood, III by P. Camody.

	I.	II.	III.
Water	4.2	4.4	4.00
Petrolene	17.5	20.3	16.80
Asphaltene	71.2	66.9	72.00
Total bitumens	88.7	87.2	88.80
Non-bituminous organic matter	5.0	6.5	0.4
Mineral matter	6.3	6.0	4.2
Sulphur	2.97	3.06	2.6
Specific gravity	1.14	1.15	1.13
Melting-point	360° F.	....	464° F.

Uses.—Like gilsonite, the material is used for making varnishes, insulating electric wires, etc., bringing the price of this mineral, from $5 to $10 a ton, according to quality and freedom from impurities.

Elaterite; Mineral Caoutchouc.—This is the name given to a soft and elastic variety of bitumen much resembling pure india-rubber. It is easily compressible in the fingers, to which it adheres slightly, of a brownish color, and of a specific gravity varying from 0.905 to 1.00. It has been described from mines in Derbyshire and elsewhere in England, but so far as the writer is aware is of no commercial value. Its composition, so far as determined, is carbon, 85.47 per cent; hydrogen, 13.28 per cent.

Wurtzillite.—The name wurtzillite has been given by Prof. W. P. Blake to a hydrocarbon very similar in appearance to the uintaite (described on page 386), but differing in physical and chemical properties. It is a fine black solid, amorphous in structure, brittle when cold, breaking with a conchoidal fracture, but when warm tough and elastic, its elasticity being best compared with that of mica. If bent too quickly it snaps like glass. It cuts like horn, has a hardness between 2 and 3, a specific gravity of 1.03, gives a brown streak, and in very thin flakes, shows a garnet-red color. It does not fuse or melt in boiling water, but becomes softer and more elastic; in the flame of a candle it melts and takes fire, burning with a bright luminous flame, giving off gas and a strong bituminous odor. It is not soluble in alcohol, and but sparingly so in ether, in both of which respects it differs from elaterite. In the United States it occurs near

Scofield, Carbon County, and in the Uinta Mountains of Wasatch County, Utah.

Albertite.—This is a brilliant jet-black bitumen compound breaking with a lustrous, conchoidal fracture, having a hardness of between 1 and 2 of Dana's scale, a specific gravity of 1.097, black streak, and showing a brown color or very thin edge. In the flame of a lamp it shows signs of incipient fusion, intumesces somewhat, and emits jets of gas, giving off a bituminous odor; when rubbed it becomes electric. According to Dana it softens slightly in boiling water, is very slightly soluble in alcohol, 4 per cent in ether, and some 3 per cent soluble in turpentine. The following is the composition as given by Wetherill: Carbon, 86.04 per cent; hydrogen, 8.96 per cent; oxygen, 1.977 per cent; nitrogen, 2.93 per cent; ash, 0.10 per cent.

Dr. Antisell made the following comparative tests to show the relative richness of the material in volatile matter:

Constituents.	Cannel Coal.	South American Asphalt.	Lake Asphalt.	Albertite.
Volatile matter......	50.52	70.15	71.67	59.88
Coke...............	47.69	29.85	28.04	39.59
Ash...............	1.79	....	0.29	0.53
Total	100.00	100.00	100.00	100.00

The mineral is described[1] as occurring in "true cutting veins" in shale of Lower Carboniferous Age in Hillsborough County, New Brunswick. The shales themselves contain a large amount of carbonaceous matter and by distillation have been made to yield 30 gallons to the ton of refined illuminating oil. They contain immense numbers of fossil fish and are mostly inflammable. The veins vary from a fraction of an inch to 12 feet in width with a general N. 65° east course, sometimes vertical and sometimes inclined northwestward from 75° to 80°. They enlarge and contract very irregularly, but in general increase in thickness as followed downward. Hitch-

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[1] American Journal of Science, XXXIX, 1865, p. 267; see also Dawson's Acadian Geology, 3d ed., pp. 231–241.

cock regarded the veins as having been filled by the injection of the material in a liquid state and being subsequently indurated.

Uses.—This vein seems to have been discovered about 1840 by Dr. Abraham Gesner, who, in 1850, took out a patent in the United States for the manufacture of illuminating gas from this and other asphalts.[1] A company was organized and for some years active mining operations were carried on, but which have been discontinued since the discovery of petroleum.

Grahamite.—Grahamite has a less brilliant luster and more coke-like aspect than albertite. It has been described by Dr. Henry Wurtz as occurring in shrinkage fissures running N. 76° to 80° E. in Carboniferous shales and sandstones, on a branch of Hughes River, Ritchie County, West Virginia. It is completely soluble in chloroform and carbon disulphide, nearly so in turpentine, and partially so in naphtha and benzine, but not at all in alcohol. Melts somewhat imperfectly, beginning to smoke and soften like coking coal at a temperature of about 400° F. Specific gravity, 1.145.

As occurring in the vein the material shows four distinct, though somewhat irregular, divisional planes, having a general parallelism with the walls. Next to the walls the structure of the mineral is coarsely granular, with an irregularly cuboidal jointed cleavage, very lustrous on the cleavage surfaces. The material in immediate contact with the walls usually adheres thereto very tenaciously, as if fused fast to the granular sandstone.

The general aspect of the mass has led to the conclusion that the vein is a fissure which has been filled by exudation, in a pasty condition, of a resinoid substance derived from or formed by some organic matter contained in deep-seated strata intersected by the fissure or dike.

J. P. Kimball has described [2] a deposit of similar material on the west bank of the Capadero River in the Huasteca, Vera Cruz, Mexico. The country rock is a fossiliferous Tertiary shale overlaid

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[1] Review of reports on the Geological Relations, etc., of the coal of the Albert Coal Mining Company, situated in Hillsborough, Albert County, New Brunswick, as written and compiled by Charles T. Jackson, M.D., a Fellow of the Geological Society of London, etc., New York, 1852.

[2] American Journal of Science, XII, 1876, p. 277.

by conglomerate. The grahamite occurs in a fissure some 34 inches in thickness terminating in an "overflow" some 6½ feet in maximum thickness, thinning away at the edges, but the full extent of which was not determined. The evidence showed that the fissure had been filled by material oozing up from below and spreading out upon the surface prior to the deposition of the overlying gravel. The strike of the fissure was nearly north and south. The material is more uniformly lustrous than that from Ritchie County, and of a greater coherence, though none the less distinctly cleaved and jointed. An analysis of a sample from the Cristo mine, as given, yielded results as follows:

Constituents.	Per Cent.	
Volatile matter: Illuminating gas	61.32	
Sulphur	0.46	
Water	0.36	
		62.14
Coke: Fixed carbon	31.63	
Sulphur	0.37	
Ash	5.86	
		37.86
		100.00
Specific gravity	1.156	

Carbonite or Natural Coke is the name given to a peculiar hydrocarbon compound occurring in the form of beds like bituminous coal, in Chesterfield County, Virginia, and having a dull black and, for the most part, lusterless aspect, somewhat resembling coke.

An analysis by Wurtz [1] yielded the following:

	Per cent.
Coke	84.57
Volatile combustible matter	15.43

Other analyses by Dr. T. M. Drown [2] on two portions, the one dull and lusterless and the other lustrous, yielded:

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[1] Transactions of the American Institute of Mining Engineers, III, 1875, p. 456.

[2] Idem, XI, 1883, p. 448.

Constituents.	Dull Portion.	Lustrous Portion.
Specific gravity	1.375	1.350
Loss at 100° C.	2.00	0.69
Volatile matter.	15.47	11.10
Ash	3.20	6.68
Fixed carbon	79.33	81.53
	100.00	100.00
Sulphur	4.08	1.60

The material occurs interbedded with shales much like ordinary bituminous coal, there being, according to Raymond, three distinct beds varying from 1 foot 9 inches to 9 feet in thickness, interstratified with the shales, the lowermost bed of 9 feet thickness being underlaid by fire clay. The origin of the material is in doubt, the earlier writers regarding it as a bituminous coal coked by the heat of intrusive rocks. Later writers throw doubt upon this by stating that there are in the vicinity no intrusives of such size as to warrant any such assumption.

Uses.—The material is said to burn without smoke or soot, like anthracite, and to have been used for domestic purposes.

Uintaite; Gilsonite.—This is a black, brilliant, and lustrous variety of bitumen, giving a dark-brown streak, breaking with a beautiful conchoidal fracture, and having a hardness of 2 to 2.5 and a specific gravity of 1.065 to 1.07. If fuses readily in the flame of a candle, is plastic but not sticky while warm, and unless highly heated will not adhere to cold paper. Its deportment is stated to be much like that of sealing wax or shellac. Like albertite and grahamite it dissolves in turpentine and is not soluble in alcohol. It is a nonconductor of electricity, but like albertite becomes electric by friction. Its composition as given is: Carbon, 80.88 per cent; hydrogen, 9.76 per cent; nitrogen, 3.30 per cent; oxygen, 6.05 per cent, and has, 0.01 per cent. The name uintaite was given this substance by W. P. Blake in 1885, after the Uinta Mountains, where it was first found. It is also known under the trade name of gilsonite, after S. H. Gilson.

Occurrence.—According to George H. Eldridge[1] the gilsonite deposits of Utah occur filling a series of essentially vertical fissures in Tertiary sandstones lying within the Uncompahgre Indian Reservation, or in its immediate vicinity. The fissures have smooth, regular walls, and vary in width from the sixteenth of an inch to 18 feet, and in length from a few hundreds yards to 8 or 10 miles.

The larger veins are somewhat scattered, one lying about 3½ miles east of Fort Duchesne, a second in the region of the Upper Evacuation Creek, and the three others of most importance in the vicinity of the White River and the Colorado-Utah line. Besides these there is a 14-inch vein crossing the western boundary of the reservation near the fortieth parallel; another about equal size about 6 miles southeast of the junction of the Green and White rivers; a third in the gulch 4 or 5 miles north of Ouray Agency, west of the Duchesne River, and a number from one-sixteenth of an inch to a foot in thickness in an area about 10 miles wide, extending from Willow Creek eastward for 25 miles along both sides of the Green and White rivers. The veins are sometimes slightly faulted, and often pinch out to mere feather edges. The filling material is quite structureless excepting where, as near the surface, it has been exposed to the atmospheric influences, where it shows a fine pencillate or columnar structure at right angles to the walls. The walls of the veins are impregnated with the gilsonite for a distance of several inches, but all indications point to the veins themselves having been filled, not by lateral impregnation, but by injection from below.

The mining of uintaite is conducted in the ordinary manner by means of shafts and tunnels. The work is, however, attended with considerable difficulty and some danger, owing to the fine dust arising from it. This penetrates the skin and lungs, and is a source of great annoyance, and moreover becomes highly explosive when mixed with atmospheric air.

Uses.—The principal use of uintaite thus far has been in the manufacture of varnishes for ironwork and baking japans. It is not well adapted for coach varnishes. It has been also used for mixing with asphaltic limestone for paving material. Other pos-

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[1] Seventeenth Annual Report U. S. Geological Survey, 1895–96, Pt. I, p. 915.

sible uses suggested are as below: For preventing electrolytic action on iron plates of ship bottoms; for coating barbed-wire fencing, etc.; for coating sea walls of brick or masonry; for covering paving brick; for acid proof lining for chemical tanks; for roofing pitch; for insulating electric wires; for smokestack paint; for lubricants for heavy machinery; for preserving iron pipes from corrosion and acids; for coating poles, posts, and ties; for torredo-proof pile coating; for covering wood-block paving; as a substitute for rubber in the manufacture of cotton garden hose; as a binder pitch for culm in making brickette and eggette coal.

3. OZOKERITE; MINERAL WAX; NATIVE PARAFFIN.

This is a wax-like hydrocarbon, usually with a foliated structure, soft and easily indented with the thumb nail; of a yellow-brown or sometimes greenish color, translucent when pure, with a greasy feeling, and fusing at 56° to 63° F.; specific gravity, 0.955. It is essentially a natural paraffin. The name is derived from two Greek words, signifying to smell, and wax. Below is given the composition of (I) samples from Utah, and (II) from Boryslaw, in Galicia.

Constituents.	I.	II.
Carbon	85.47	85.78
Hydrogen	14.57	14.29
Total	100.04	100.07

The substance is completely soluble in boiling ether, carbon disulphides, or benzine, and partially so in alcohol.

The following, from a paper by Boverton Redwood,[1] will serve to show the character of the material from the various reported sources:

Baku.—Specific gravity, 0.903; melting point, 76° C.:

Constituents.	Per Cent.
Paraffin mass	81.80
Gas	13.80
Coke	4.40
Total	100.00

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[1] Journal of the Society of Chemical Industry, XI, 1892, p. 114.

Persia.—Dark green, rather hard; specific gravity, 0.925:

Constituents.	Per Cent.
Light oil, 0.740 to 0.780	2.35
Light oil, 0.800 to 0.820	3.50
Oil, 0.880	16.63
Paraffin	53.55
Coke	16.73
Loss	7.24
Total	100.00

Boryslaw.—Specific gravity, 0.930. I, dark yellow; II, dark brownish black:

Constituents.	I.	II.
Benzine, 0.710 to 0.750	4.32	3.50
Kerosene, 0.780 to 0.820	25.65	27.83
Lubricating oil, 0.895	7.64	6.95
Paraffin, etc.	56.54	52.27
Coke	2.85	4.63
Loss	3.00	4.82
Total	100.00	100.00

Occurrences.—Ozokerite occurs in the United States in Emery and Uinta counties, Utah, where, in the form of small veins in Tertiary rocks, it extends over a wide area. It is also found in Galicia, Austria, in Miocene deposits; in Roumania, Hungary, Russia, and other Asiatic and European localities. As a rule, the deposits are in beds of Tertiary or Cretaceous age, the Boryslaw, Dwiniacz, and Starunia (Galicia) deposits being in Miocene while the Kouban deposits are on the borders of the Lower Tertiary and Upper Cretaceous. In Teheleken ozokerite is found accompanying petroleum in pockets in beds of sand above the clay shales and Muschelkalk of the Aralo-Carpathian formation. In southern Utah and Arizona it occurs in Tertiary rock, probably Miocene.

The Galician deposits are by far the most important of those above mentioned, Boryslaw, a town of some 14,500 inhabitants, forming the principal seat of the mining and manufacturing industry.

The soil of the valley in which Boryslaw lies is a bed of diluvial deposit some meters in thickness. In sinking a shaft, first yellow clay, then rounded flints and gravel, and then plastic clay are met with. Below this sandstone and blue shale, much disturbed, alternate, and it is in these beds, which have a thickness of some 200 meters, that the ozokerite is found. The ozokerite-bearing formation lies on a basis of petroliferous menilite shale, the strata of which, as they approach the surface, are disposed almost vertically, but incline toward the south. The strata are composed of layers of coarse-grained sandstone, green marl, fine-grained sandstone with veins of calcite, dark shale alternating with gray sandy shale, imperceptibly merging into the main beds of the non-petroliferous sandstone and shale. Below these are Carpathian sandstones of the Lower Eocene (Nummulitic sandstone) and Upper Cretaceous formations.

The geological conditions prevailing at Dwiniacz and Starunia are similar to those at Boryslaw, but the ozokerite is more largely mixed with petroleum. The soil is gray and red diluvial clay, below which is a bed of gravel, lying on the Miocene formation, in which the ozokerite and petroleum occur in association with native sulphur, iron pyrites, and zinc blende. Still lower a highly porous calcareous rock is met with, containing cavities filled with petroleum and sulphureted water, and below this again is marl with gypsum and the salt-clay formation destitute of petroleum. The ozokerite occurs in the form of veins of a thickness ranging from a few millimeters to some feet, and is accompanied with more or less petroleum and gaseous hydrocarbons. It fills the many fissures with which the disturbed shales and Miocene sandstone abound, and frequently forms thus a kind of network.

The Boryslaw deposit extends over a pear-shaped area, the axis of which lies E. 30° S. The upper layers of the richest portion of the deposit occupy an area of about 21 hectares, with a length of

1,000 meters and a maximum breadth of 350 meters, but outside this there is an outer zone of less productive territory which increases the total superficies to about 60 hectares, with dimensions of 1,500 meters by 560 meters. The deposit narrows considerably as the depth increases, and at a distance of 100 meters from the surface of the ground has a breadth of only 200 meters.

Uses.—The crude ozokerite, after being freed so far as possible from impurities, is melted and cast into loaves or blocks of the form of a truncated cone, and weighing about 50 to 60 kilos. There are two or three recognized commercial qualities of the melted and cast ozokerite. The first quality is transparent in thin sheets, and it color ranges from yellow to greenish brown. Adulteration by means of crude petroleum, heavy oils, the residues from refineries, asphaltum, and even earthy matter, are not unknown, and occasionally by a process of double casting the exterior of the block is made to differ in quality from the interior.

The refined material is known as ceresin. It is used for candles, as an adulterant or a complete substitute for beeswax, and in the manufacture of ointments and pomades. A residual product from the purifying process, of a hard, waxy nature, is combined with india-rubber and used as an insulating material for electrical cables. In this form it is known as *okanite.* A ball blacking, used on the heels of shoes, is also manufactured from it.

The names Scheererite, Hatchettite, Fichtelite, and Könlite are applied to simple hydrocarbons allied to ozokerite found in beds of peat and coal, but, so far as the writer is aware, never in such abundance as to be of commercial value.

4. RESINS.

Succinite; Amber.—The mineral commonly known as amber is a fossil resin consisting of some 78.94 parts of carbon, 10.53 parts of oxygen, and 10.53 parts of hydrogen, together with usually from two to four-tenths of a per cent of sulphur. It is not a simple resin, but a compound of four or more hydrocarbons. According to

Berzelius, as quoted by Dana, it consists mainly (85 to 90 per cent) of a resin which resists all solvents, along with two other resins soluble in alcohol and ether, an oil, and 2½ to 6 per cent of succinic acid.

The mineral as found is of a yellow, brownish, or reddish color, frequently clouded, translucent or even transparent, tasteless, becomes negatively electrified by friction, has a hardness of 2 to 2.5, a specific gravity when free from inclosures of 1.096, a conchoidal fracture, and melts at 250° to 500° F. without previous swelling but boils quietly, giving off dense white fumes with an aromatic odor and very irritating effect on the respiratory organs.

As above noted, amber is a fossil resin or pitch, an exudation product principally of the *Pinus succinifer*, a now extinct variety of pine of the Tertiary period.

Occurrence.—Amber or closely related compounds has been found in varying amounts at numerous widely separated localities, but always under conditions closely resembling one another. The better-known localities are the Prussian coast of the Baltic; on the coast of Norfolk, Essex, and Suffolk, England; the coasts of Sweden, Denmark, and the Russian Baltic provinces; in Galicia, Westphalia, Poland, Moravia, Norway, Switzerland, France, Upper Burmah, Sicily, Mexico, the United States at Martha's Vineyard, and near Trenton and Camden, New Jersey.

The substance occurs in irregular masses, usually of small size. One of the largest masses on record weighed 18 pounds. This is now in the Berlin Museum. A mass found in the marl pits near Harrisonburg, New Jersey, weighed 64 ounces. This last is presumably not true amber, since it contained no succinic acid, which is now regarded as the essential constituent.

The amber of commerce comes now, as for the past two thousand years, mainly from the Baltic, where it occurs in a strata of lignite-bearing sands of Lower Oligocene age. According to Berendt,[1] there are two amber-bearing strata, the one carrying the amber in nests and both underlaid and overlaid by clayey seams, and the

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[1] Schriften der Physikalisch-ökonomischen Gesellschaft, VII, 1866.

second and lower a glauconitic sand commonly known as the blue earth. The material is mined by open cuts where the strata come to the surface, by means of shafts and tunnels, as in coal mining, and by dredging or diving, in the latter case the material having been derived originally from the amber-bearing strata and redeposited on the present sea-bottom.[1]

The pieces obtained vary from the size of a pea to that of the hand. The annual product at present amounts to some 300,000 pounds, valued at about $1,000,000. The price of the material varies greatly with the size and purity of the pieces. Pieces of one-fourth pound weight bring about $15 a pound, while the small granules will not bring one-twentieth that amount. The value of the material is often lessened by the presence of flaws and impurities or inclosures, such as insects and twigs of plants.

Uses.—Amber is used mainly in jewelry, in small ornamentations, and smokers' goods, the smaller pieces being used in making varnish. The clear pieces and chippings have of late been compressed by a newly discovered process into tablets some 6 by 3 by 1 inches in size, which can be utilized in the manufacture of articles for smokers' use.

Retinite.—The name retinite is used by Dana to include a considerable series of fossil resins allied to amber, differing mainly in containing no succinic acid. They occur in beds of brown coal of Tertiary and Cretaceous Age, much as does the amber proper. The principal varieties that have thus far proven of any economic importance are noted below:

Chemawinite.—This is the name given by Professor Harrington,[2] to an amber-like resin found associated with woody débris on the southeast shore of Cedar Lake in Canada. The material occurs in granular form and in small sizes only, such as are quite unsuited for manufacturing purposes. The true gum-bearing stratum, if such exists, has not yet been discovered, the material thus far found being washed up by waves on the beach. Accord-

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[1] According to the Engineering and Mining Journal of May 20, 1893, the dredging process on the Baltic coast has been discontinued as no longer profitable.

[2] American Journal of Science, XLII, 1891, p. 332.

ing to O. J. Klotz,[1] the beach matter resembles the refuse of a sawmill, no stones and very little sand being associated with the débris, which is everywhere underlaid by clay. The principal beach was estimated to contain some 700 tons of granular material.

A somewhat similar resin is found in the lignite and soft greenish sandstone near Kuji, Japan.[2] It is reported as being of inferior quality, opaque, cloudy, and much fissured. It is, however, mined and shipped to Tokio, where it is presumably worked up into small ornaments.

The so-called Burmese amber, or *Burmite* from the Hukong Valley, is reported as occurring in a soft blue clay, probably of Lower Miocene Age, and in lumps not exceeding the size of a man's hand.

Gum copal.—The name copal or gum copal is made to cover, commercially, a somewhat variable series of resins found for the most part buried in the sands in tropical and subtropical regions. They are in general amber-like or resin-like in appearance, of a hardness inferior to that of true amber, of a light yellow to brown color, brilliant glass-like luster, transparent to translucent, and have a conchoidal fracture. When cold they are brittle and can be readily crushed to powder, but possess a slight amount of elasticity. When rubbed on cloth they become electric and emit a peculiar resinous odor. The specific gravity varies from 1 to 1.10. When heated the material softens, swells up, and bubbles, finally melting, remaining liquid until carbonized. It burns with a yellow smoky flame; is partially soluble in alcohol, wholly so in ether, and also in turpentine on prolonged digestion. The so-called Kauri gum is a light amber-colored variety from the *Dammara Australis*, a living coniferous tree of New Zealand. The principal source is the northern portion of the Auckland provincial district which has exported since 1863 (and up to 1897) some 134,630 tons of gum valued at £5,394,687, the product for 1890 being 7,438 tons valued at £378,563.

The gum-digging industry is one that gives employment to both

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[1] American Jeweler, No. 2, XII, 1892.

[2] Transactions of the American Institute of Mining Engineers, V, 1876, p. 265.

Europeans and natives.[1] The gum is found but a short distance below the surface, and is dug with the aid of a few implements, the entire outfit often consisting of a steel prod, a spade, and knife and haversack. With the copal is often found the more amber-like resin *ambrite*, which has a slightly greater hardness, a specific gravity of 1.034, a yellowish gray to reddish color and which yields on analysis carbon, 76.88; hydrogen, 10.54 per cent, and oxygen, 12.77 per cent. It becomes strongly electric by friction and is insoluble in alcohol, ether, chloroform, benzine, or turpentine, and burns with yellow, smoking flame. Quite similar to the kauri gum is the copal of the African coasts. According to Dr. F. Welwitsch[2] gum of the west coast and probably all the gum resin exported under this name from tropical Africa is to be regarded as a fossil resin produced by trees which, in periods long since past, adorned the forests of that continent, but which are at present either totally extinct or exist only in a dwarfed posterity. The gum, which is called by the Bunda negroes *Ocate Cocoto*, or *Mucocoto*, is found in the hilly or mountainous districts all along the coast of Angola, including the districts of Congo and Benguella, and is brought by the natives to the different market places on the coast of Angola, including the districts of Congo and Benguella. The larger quantities of the resin are mostly found in the sandy soil, and it is apparently limited in its geographical distribution with that of the tree *Adansonia digitata*, the lands in the Government of Benguella extending along the mountain terrace of Amboin, Selles, and Mucobale, south of the Cuanza River being most productive, having yielded between 1850 and 1860 some 1,600,000 pounds of gum a year.

"It is a general and widely spread opinion," writes Welwitsch, "that the gum copal in Angola is gathered from trees; but this, according to my own observation, is obviously erroneous, for the gum copal is either dug out of the loose strata of sand, marl, or clay, or else it is found in isolated pieces washed out and brought to the surface of the soil by heavy rainfalls, earthfalls, or gales; and such

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[1] Report of the Mining Industry of New Zealand for 1888. In the report for 1887 it is stated that "according to the last census" the number of persons employed in the occupation of gum digging was 1,283.

[2] Journal of the Linnaean Society of London, Botany, IX, 1866, p. 287.

pieces, where found, induce the negroes to dig for larger quantities in the adjacent spots. This digging after larger quantities is, as may be supposed, often very successful; but sometimes it is less satisfactory, or totally without result, just in the same manner as with people digging for gold. At times numerous larger and smaller pieces of copal are found close to the surface of the sand, or within the depth of a few feet; while in other places, after digging to the depth of 5 to 8 or even 10 or more feet, only single pieces, or sometimes none at all, are brought to light.

" The secured resin is cleaned by washing and packed in sacks, to be ready for sale in the markets on the coast. Different varieties of unequal value being often obtained on the same spot, the resin, when brought to market, has to be sorted before being sold. It is classified mostly according to its color, and the price is determined by weight. The deep-colored quality is generally worth double the price of the lighter sort. The shape in which the gum is found is quite variable; it often has the form of an egg, a ball, or a drop, at other times it looks like a flat, pressed cake, and it is also met with in sharp-canted pieces. The pieces vary as much in size as in shape; they are rarely larger than a hen's egg, and there are many much smaller, others (which, however, seldom occur) are as big as a man's fist, or even a child's head, weighing three to four pounds and more. All the pieces of different shape and size have one common characteristic, namely, that on their surface they are covered with a thinner or thicker close-sticking, whitish, nearly chalky crust, which exhibits on many pieces veins or network, while in most instances it covers the surface like an earthy, powdery coat. The surface of fresh-broken pieces appears conchoidal, with finely radiating lines in each conchoidal impression. The luster is glossy, the mass is hard and transparent to a certain depth, and where scratched with a knife or needle it leaves a white powdered stroke. It can easily be scraped with a knife into powder which, if sprinkled over red-hot coals, changes instantaneously into thick vapors, at first with a slight yellow color, with a strong aromatic smell, somewhat similar to that of incense. Large pieces brought into contact with a light soon burn up, developing at the same time the above-mentioned vapors. When chewed it crackles between the teeth without leaving a noticeable taste."

"The interior of the Angola copal pieces, when not mixed with earthy substances, or with remains of bark, is even glossy and transparent; but I have never observed insects in any of the numerous samples which, partly in Angola and partly at Lisbon, came under my notice, while in the copal sent to Lisbon from the province of Mozambique, on the east coast of Tropical Africa, various hymenopterous insects are to be met with. The different colors of the copal of Angola just described are connected more or less with its availability for varnishes, etc. Thus the copal dealers distinguish three sorts, namely, (1) red copal gum (gomma copal vermellia); (2) yellow (G.C. amarella); (3) whitish (G.C. bianca). The red and whitish sorts furnish the best and finest varnish, and therefore are most in request and the dearest, while the whitish quality is sold at the lowest price." [1]

According to Burton [2] the present limit of distribution of the gum-yielding trees on the east coast is less extensive than that of the extinct forests which have yielded the true or "ripe" copal, or "sandarusi," as it is locally called. Every part of the coast from Ras Gomani, in south latitude 3, to Ras Delgado, in 10° 41′, with a mean depth of 30 miles inland, may be called the copal coast. The material is found in red, sandy soil, but is not evenly distributed, occurring rather in patches, as though produced by isolated trees. Dr. Kirk considers this gum as a product of trees of the same species as those at present producing the raw gum called by the natives and Arabs *sandarusiza miti* or *chakazi;* that is, the *Trachylobium mozambicense* Peters. The gum when dug from the soil has superficially a peculiar pebbled appearance, best described as "goose skin," and which Burton considered as due to the impress of the sandy grains in which it had been buried, but which Dr. Kirk regards as due to the structure of the cellular tissues of the tree. The copal when freshly dug has, according to this authority, exteriorly no trace of the goose-skin structure.

As is the case with the New Zealand and West African gums, the methods of digging are very crude, careless, and desultory. The

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[1] Journal of the Linnaean Society of London, Botany, IX, 1866, pp. 291–293.

[2] Lake Region of Central Africa, II, p. 403. See also report by Dr. M. C. Cooke, on the gums, resins, etc., in the India Museum, or produced in India. London, India Museum, 1874.

diggings are mostly beyond the jurisdiction of Zanzibar, but as this is the principal port, most of the material is known commercially as Zanzibar copal.

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XIV. MISCELLANEOUS.

1. GRINDSTONES; WHETSTONES; AND HONES.

The custom of sharpening edge tools on pieces of stone has been practiced by barbarous and civilized nations ever since the adoption of cutting implements of any kind, however crude and of whatever materials.

With the first crude implements, it is safe to say almost any stone possessing the requisite grit would serve to produce the rough edge desired. With the improvement in the cutting implement there has, however, been necessitated a corresponding improvement in the character of the sharpening implement as well. Formerly, it may be safely assumed, every man used that which was most accessible and could be made to best answer its purpose. Now the grindstone and whetstone industry is as well organized as any other branch of manufacture, and forms no inconsiderable feature of the nation's trade. Localities are ransacked and material is brought from far and near, carried long distances, overland or across the ocean, to the workshops of the manufacturer to be cut into the desired shapes and sizes, classified and assorted according to quality, and sent abroad once more to meet the demands of the ever-increasing trade. The use of the grindstone, it should be noted, is not confined merely to sharpening edge tools, but, as will be noted later, they are made from a variety of materials, and of an equal variety of sizes, from the 2-inch wheel of novaculite, used by jewelers, to a coarse grit monster of over 2 tons weight for the grinding of rough castings in machine shops, or wood pulp in paper manufacture.

A stone to be suitable for grinding purposes must possess a fine and even grain, free from all hard spots and inequalities of any kind. It is essential, too, that the various particles of which it is composed be cemented together with just sufficient tenacity to impart the necessary strength to the stone, and yet allow them to crumble away when exposed to friction, thus continually presenting fresh sharp grains and surfaces to act upon the material being ground. Simple as these essential qualities may seem they are in reality but rarely met with in perfection, and the majority of grindstones now on the market are quarried from a comparatively limited number of sources. If the stone be too friable it wears away too rapidly, and the grinding done is coarse and uneven; a sharp edge or polish is unobtainable If too hard it glazes and loses its cutting qualities, or cuts so slowly as to be no longer desirable. If, moreover, the particles composing the stone adhere with too little tenacity, the stone, particularly if it be a large one, such as is used for grinding castings, is liable to burst, perhaps to the serious injury of workmen and machinery.

The requisite qualities as above enumerated are found mainly in those stones that have originated as sandy deposits on sea bottoms and have undergone little if any metamorphism—in other words, in sandstones. For some particular reason, or rather owing to certain peculiar conditions, although sandstones were formed throughout a great number of periods in the earth's history, those formed during the Carboniferous age seem best adapted for the purpose, and from stone found somewhere in this formation are manufactured a large share of the grindstones now in use.

A majority of the grindstones now found in the markets of the United States are made from sandstones quarried from the Upper, Middle, and Lower Carboniferous formations of Ohio, Michigan, Nova Scotia, New Brunswick, England or Scotland. A few are, or have been, made from stone from Missouri and Kentucky. The Ohio stones are obtained nearly altogether from quarries in the sub-Carboniferous sandstones at or near Berea, Amherst, Bedford, Constitution, Massillon, Marietta, Independence, and Euclid. Few if any of the quarries are worked wholly for grindstones, but in the majority of cases the stone is sought for building purposes as well, and the grindstone output may be merely incidental, certain layers only being adapted for the latter purpose. This is well illustrated by the following section, as shown at one of the Amherst quarries and as described[1] by Professor Orton, the State geologist. The reader will understand that by section is meant the various layers exposed in the quarry wall, or that would be passed through in digging or boring from the surface downward.

At Amherst, then, the stone lies as follows, beginning at the surface:

	Feet.
Drift material (soil, sand, etc.)	1 to 3
Worthless shell rock	6 to 10
Soft rock used only for grindstones	12
Building stone	3
Bridge stone	2
Grindstone	2
Building and grindstone	10
Building stone	4 to 7
Building stone or grindstone	12

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[1] Geological Survey of Ohio, V, p. 586.

Commenting on the condition of affairs as here displayed, Professor Orton says:

"As will be noticed in this section, the different strata are not applicable alike to the same purpose, and the uses for which the different grades of material can be employed depend principally upon the texture and the hardness of the stone. The softest and most uniform in texture is especially applicable for certain kinds of grinding, and is used for grindstones only, and the production of these forms an important part of the quarry industry. In its different varieties the material is applicable to all kinds of grinding, and stones made from it are not only sold throughout this country, but are exported to nearly all parts of the civilized world. Some of the finest-grained material is also used in the manufacture of whetstones. There are various points in the system of the Berea grit where the stone is adapted to this use, but such a manufacture is best carried on when joined with a large interest in quarrying, so that the small amount of suitable material can be selected; and thus it happens that only at Amherst and at Berea are whetstones manufactured in large quantities."

Below are given in brief outline the sources and main characteristics of the principal grindstones now in the market, beginning with those of the United States. In speaking of the texture of any stone, that of Berea has been taken as the standard. This is the stone most used for grinding cutting tools, such as axes and scythes. It must be remarked here that the term Berea grit is applied not merely to the stone from the immediate vicinity of the town of Berea, but is rather a general name applied to this particular subdivision of the sub-Carboniferous formation of Ohio and extending over a wide field.

Berea.—Medium fine; blue gray, light yellowish, or nearly white. For edge tools in general; the finer varieties also used for whetstones.

Amherst.—Medium fine, like the Berea, being a part of the same formation. Light gray, with small rust-colored spots due to iron oxides. For grindstones and whetstones for edge tools in general; the softer varieties for saws.

Independence.—Similar to the Amherst, and especially adapted for the manufacture of large grindstones for dry grinding; stones said not to glaze when used for this purpose.

Bedford.—Rather coarser, though of even texture and filled with brown spots of iron oxide. Especially adapted for grinding springs.

Euclid.—Fine, light bluish gray; for wet grinding edge tools.

Massillon.—Medium to rather coarse; the microscope shows it to be an aggregate of rounded, colorless grains of quartz, with little, if any, cementing material. Not so finely compacted as the last, and small fragments can be readily broken from the sharp edges by means of the thumb and fingers. Color, light yellowish or pinkish; for edge tools, springs, files, and nail-cutters' face stones, but mainly for the dry grinding of castings.

Constitution.—Medium; light gray and rather more friable than the last. A variety of textures, however, and all kinds of grits for wet grinding are furnished.

Huron, Michigan.—Fine; uniform blue-gray color, with numerous flecks of silvery mica. Smells strongly of clay when breathed upon. For wet grinding of edge tools; produces a fine edge.

The Joggins, Nova Scotia.—Fine gray; of uniform texture; used for wet grinding all kinds of edge tools; the large stones for grinding springs, sad irons, and hinges; extensively exported to the United States.

Bay of Chaleur, New Brunswick.—Fine dark bluish gray; of firm texture; smells strongly of clay when breathed upon. Resembles the stone of Huron, Michigan, but contains less mica. Used in the manufacture of table cutlery; also machinists' tools and edge tools in general.

Newcastle, England.—Light gray and yellowish; with a sharp grit; rather friable, and texture somewhat coarser than that of the Berea stone, which it otherwise somewhat resembles. The finer grades used for grinding saws and the coarser and harder ones for sad irons, springs, pulleys, shafting, for bead and face stones in nail work, and for dry grinding of castings; also used by glass cutters.

Wickersly, England.—A dull, brownish or yellowish, somewhat micaceous stone of medium texture and rather soft. For grinding saws, squares, bevels, and cutlers' work in general.

Liverpool, or Melling, England.—Dull reddish; a somewhat loosely compacted aggregate of siliceous sand, so friable that the sharp angles are easily crumbled away by the thumb and fingers. A very sharp grit, used for saws and edge tools, particularly axes in ship-yards.

FIG. 1.

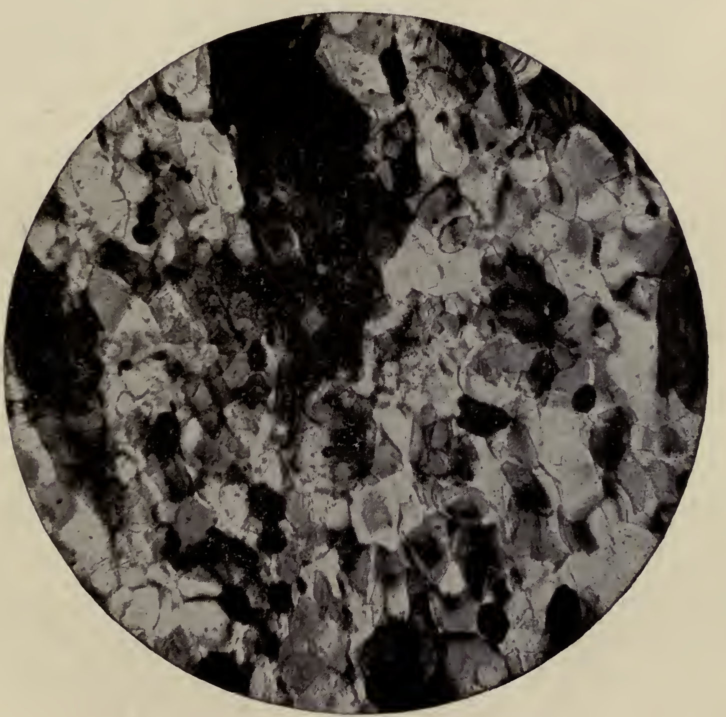

FIG. 2.

PLATE XXXV.

Microstructure of Mica Schist used in making Hones. Fig. 1, Cut across the Grain. Fig. 2, Cut parallel with Grain. The enlargement is the same in both cases. [U. S. National Museum.]

[*Facing page* 404.]

Craigleith, Scotland.—Fine-grained and nearly white. A very pure siliceous sandstone with a sharp grit. Said to be the best stone known for glass cutting, though the Newcastle, Warrington, and Yorkshire grits are also used for a similar purpose.

For whetstones the same qualities are essential as for grindstones, though as a rule the whetstones are designed for a finer class of work, and hence a finer grade of material is utilized. For sharpening scythes and other coarse cutting tools, however, the same stone is used as for grindstones, the same quarry producing stone for building, grindstones, and whetstones, as above noted. The so-called Hindostan, or Orange stone, from Orange County, Indiana, is a very fine-grained siliceous sandstone of remarkably sharp and uniform grit, and which for carvers and kitchen implements is unexcelled. The so-called Labrador stone is also a sandstone of a dark blue-gray color and of less sharp grit than that just mentioned. Many scythe-stones like "Indian Pond" "Chocolate," "Farmers' Choice," "Black Diamond," "Vermont Quinebaug," and the "Lamoille," are fine-grained mica schists from New Hampshire and Vermont quarries. These as a rule are very fine-grained schistose dark-gray rocks, sometimes of a light chocolate color on a freshly fractured surface. The microscope shows them to consist of a compact and slightly schistose aggregate of quartz and mica in which are frequently included very abundant small octahedral crystals of magnetic iron and sometimes garnets. (See Plate XXXV.) So abundant are these magnetic granules in some of these rocks, especially those of Grafton County, New Hampshire, as to constitute an important feature, and it is doubtless in part to them that the stone owes its excellent abrasive qualities. Magnetite, it will be remembered, has a hardness of about 6.5 of the scale, and constitutes a very considerable proportion of the ordinary emery of commerce. We have here, then, what is almost a natural equivalent of the artificial emery stone, the compact groundmass of quartz and mica serving as a binding material for the magnetite grains while they perform their work in wearing away the implement being ground. A part of the abrading quality of these stones is, however, due to the abundant quartz and mica scales and their peculiar arrangement in relation to one another.

The well-known Water of Ayr, Scotch hone, or snake stone, as it is variously called, is also a very compact schist. It is said to come from Dalmour, in Ayrshire, Scotland.

The name novaculite is applied to a very fine-grained and compact rock consisting almost wholly of chalcedonic silica, and which, owing to the fineness of its grit, is used only in the finer kinds of work, as in sharpening razors, knives, and the tools of engravers, carpenters, and other artisans. The true novaculites are at present quarried in America only in Montgomery, Saline, Hot Springs, and Garland counties, in Arkansas, and are known commercially as the Washita (or Ouachita, as the name is properly spelled) and Arkansas stones. Both varieties are nearly pure silica, the Ouachita being often of a yellowish or rusty red tint, and the Arkansas of a pure snow whiteness, the latter variety being also the hardest, most compact, and highest priced. The analyses given below show the average composition of the two varieties:

Constituents.	Arkansas.	Ouachita.
SiO_2	99.50	99.49
Al_2O_3	0.20	0.13
Fe_2O_3	0.10	0.06
CaO	0.10	0.04
MgO	0.05	0.08
K_2O	0.10	0.16
Na_2O	0.15	0.10
H_2O	0.10	0.14

According to Griswold stone suitable for the manufacture of whetstones occurs in quantity in two distinct horizons in the Arkansas novaculite series of rocks, both of which are now being worked. The principal quarries are in the massive white beds of the Hot Springs region, the material being mainly of the fine, compact white Arkansas type. Within a limited region, northeast of Hot Springs, the stone becomes more porous, owing in part to the existence of a larger number of the rhomboidal cavities, and passes over to the Ouschita type.

The microscopic structure of the Arkansas novaculite is shown in Plate XXXVII, Fig. 1, the large white areas being angular granules of quartz.

Owen regarded the Arkansas novaculites as belonging to the age of the millstone grit formation; that is, to the lower part of the

Fig. 1.—Quarry in Mica Schist used in making Whetstones, Pike Manufacturing Co.

Fig. 2.—Quarry in Novaculite, Arkansas, Pike Manufacturing Co.

PLATE XXXVI.

[*Facing page* 406.]

Carboniferous, and considered them as a sandstone metamorphosed and freed from impurities by the action of hot alkaline waters. State Geologist Branner, however, regards the finer grade of novaculite as a metamorphosed chert, a conclusion more in accordance with the microscopic structure of the rock, which is more that of chalcedony than of an altered sandstone. Griswold, on the other hand, regards the novaculite as a product of sedimentation of a fine siliceous silt, and of Lower Silurian age,[1] while Rutley [2] considers it as a product of chemical replacement by silica of the calcareous material of dolomite or dolomitic limestone beds.

The view in quarry of the Pike Manufacturing Co., Plate XXXVI, shows the novaculite beds dipping 60° to the southeast, the bed of good stone being some 12 or 15 feet in thickness. The rock is everywhere badly jointed, in one case mentioned by Griswold as many as six different systems being developed in a single quarry. The natural result is that pieces of only very moderate dimensions are obtainable even under the most favorable of circumstances. Fine veins of quartz intersecting the rock in various directions increase the difficulty of getting homogeneous material and thereby increase the cost of the output.

The Arkansas stone is now used for many purposes by artisans of all classes, by wood-carvers, jewelers, manufacturers of fine machinery and metal work, and by dentists in various forms of files and points. Dentists use particularly the "knife-blade," a very thin, broad slip of stone, triangular in section, with one short side, the other two forming a thin edge as they come together. They are used for filing between the teeth. Carvers use wedge-shaped, flat, square, triangular, diamond-shaped, rounded, and bevel-edged files for finishing their work. Jewelers, especially manufacturing jewelers and watchmakers, use all these forms of files and also points. These last are sometimes made the size of a leadpencil, having a cone-shaped end, and are about 3 inches long and ¼ inch square, tapering to a point. They are used chiefly in manufacturing watches to enlarge jewel-holes.

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[1] See Whetstones and Novaculites, by L. S. Griswold, Annual Report of the Geological Survey of Arkansas, III, 1892. This report contains a very full discussion of the Arkansas novaculite in all its bearings.

[2] Quarterly Journal of the Geological Society of London, I., 1894, p. 377.

Wheels of various thicknesses and diameter are also made from Arkansas stone. Such are used chiefly by jewelers and dentists. The difficulty of obtaining pieces of clear stone large enough for wheels several inches in diameter makes the price very high, and the difficulty of cutting out a circular form increases the cost. Wheels are quoted at from $1.10 to $2.20 an inch of diameter.

Fragments of the Arkansas stone are saved at the factories, and now and then sent away to be ground for polishing powder. In the manufacture of this powder millstones are worn out so rapidly that the process is rather expensive, but as waste stone is utilized, the powder can be sold by the barrel at 10 cents a pound. It makes a very fine, pure white powder of sharp grit, suitable for all kinds of polishing work; it is known as "Arkansas powder."

The so-called Turkish oilstone from Smyrna, in Asia Minor, is both in structure and abrasive qualities quite similar to the Arkansas novaculites. It, however, is of a drab color and carries an appreciable amount of free calcium carbonate and other impurities, as shown by the analysis given below, as quoted by Griswold:

TURKEY-STONE.

Constituents.	Per Cent.
Silica (SiO_2)	72.00
Alumina (Al_2O_3)	3.33
Lime (CaO)	13.33
Carbonic acid (CO_2)	10.33

According to Renard,[1] the celebrated Belgian razor hone quarried at Lierreux, Sart, Salm-Chateau, Bihau, and Recht is a damourite slate containing innumerable garnets, more than 100,000 in a cubic millimeter. Like the Ratisbon hone, this occurs in the form of thin, yellowish bands, some 6 centimeters wide (2⅜ inches) in a blue-gray slate (phyllade). The bands are essentially parallel with one another and with the grain of the slate, into which they at times gradually merge. The chemical composition of a sample from Recht is given on the next page. The microscopic structure of the stone as described and figured by Renard is essentially the same as that of the Ratisbon stone in the collections of the U. S. National

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[1] Mémoires Couronnés et Mémoires des Savants Etrangers de L'Academie Royal des Sciences, etc., Belgique, 1878, pp. 1–44.

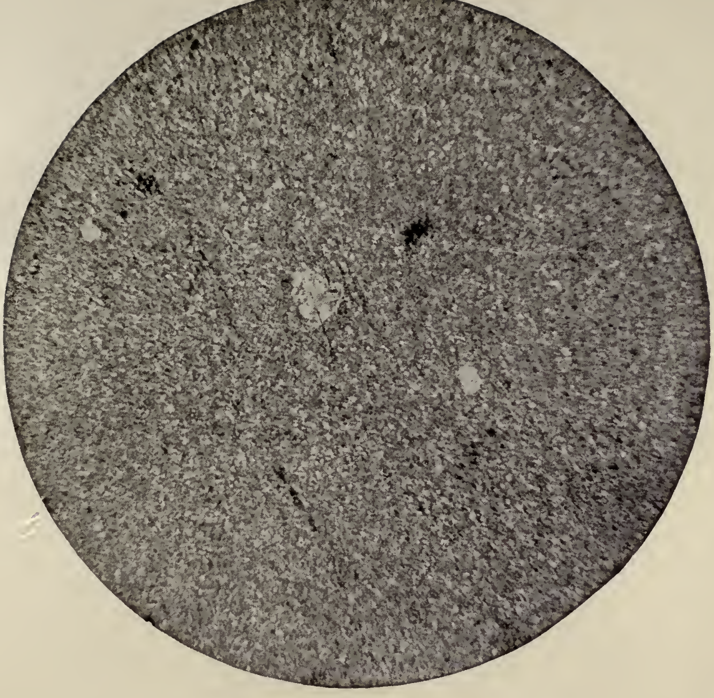

FIG. 1.

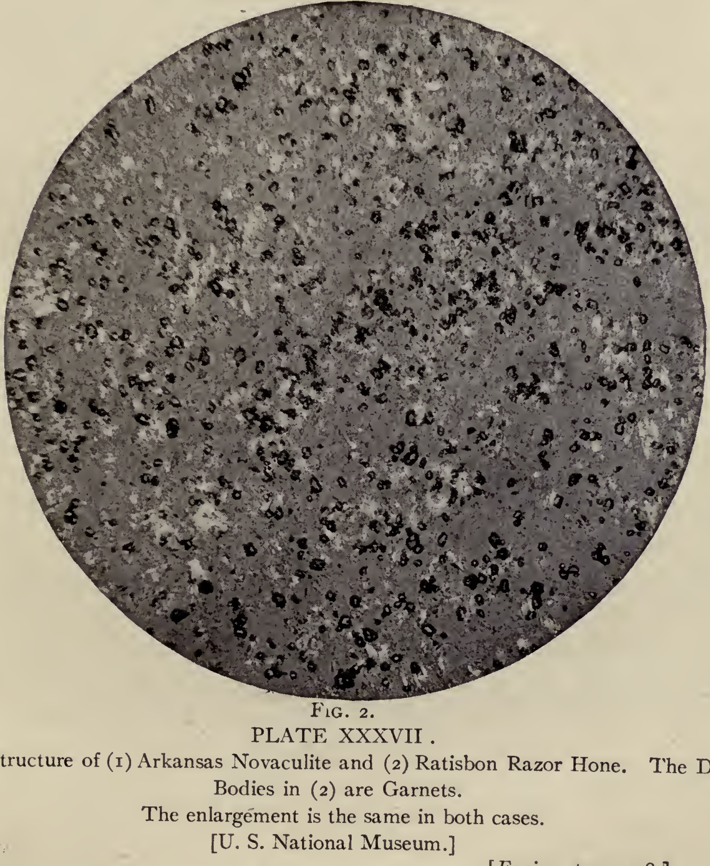

FIG. 2.

PLATE XXXVII.

Microstructure of (1) Arkansas Novaculite and (2) Ratisbon Razor Hone. The Dark Bodies in (2) are Garnets.

The enlargement is the same in both cases.

[U. S. National Museum.]

[*Facing page* 408.]

COMPOSITION OF BELGIAN RAZOR HONE.

Composition.	Per Cent.
Silica (SiO_2)	46.5
Titanic oxide (TiO_2)	1.17
Alumina (Al_2O_3)	23.54
Ferric iron (Fe_2O_3)	1.05
Ferrous iron (FeO)	0.71
Manganese oxide (MnO)	17.54
Magnesia (MgO)	1.13
Lime (CaO)	0.80
Soda (Na_2O)	0.30
Potash (K_2O)	2.69
Water (H_2O)	3.28
Carbon dioxide (CO_2)	0.04
Phosphoric acid (P_2O_5)	0.16
Sulphur (S)	0.18
Organic matter	0.02
Total	99.11

Museum (See Plate XXXVIII, Fig. 2), and the stones are practically identical in color and texture as well.

The cutting property of the stone would appear to be due to the presence of the small garnets above noted.

The so-called holystone is but a fine, close-grained sandstone of the same nature of that used in grind and whet stones. The greater part of those made in this country are from the Berea sandstone of Ohio, though some are said to be imported from Germany. They are used mainly on shipboard.

2. MILLSTONES.

The use of stone in the form of flat circular disks for grinding grain has fallen away greatly since the introduction of the steel-roller process. Nevertheless, the smaller mills, and particularly the "grist mills" of country districts, are still utilizing the old-time material. Two types of stone are in common use for this purpose, the one a siliceous conglomerate of quite variable structure, and the other a vesicular chalcedonic rock commonly known as buhrstone.

Material of the first mentioned type is found in the United States near Esopus Creek in Oneida county, New York, the beds belonging to the Oneida conglomerate division of the Niagara (Upper Silurian) period. The rock consists of rounded and subangular pebbles of quartz sometimes 2 c.m. in diameter, compactly embedded in a fine siliceous matrix forming an exceedingly tough and hard mass with at the same time a sufficiently sharp grit to make it available for grinding purposes. The celebrated German millstone from Zittau is of a somewhat similar nature, though the large quartz pebbles are in this case embedded in a more sandy matrix. Buhrstone, as is noted above, is a chalcedonic cellular rock commonly regarded as a silicious replacement of limestone, and containing numerous casts of shells, and other cavities. The rock is very tough, breaking with a sharp splintery fracture. It is admirably adapted for grinding grain, and has been so used from a very early period. That best known comes from Tertiary beds near Paris, in France. A good grade of material of similar nature is stated to exist in large quantities along the Savannah River, in Georgia. Though occurring abundantly it is not found in a continuous stratum, but rather in sporadic masses in the marl beds.

3. PUMICE.

The material to which the name pumice is commonly given is a form of glassy volcanic rock, which, by the expansion of its included moisture while in a molten condition, has become, like a well-raised loaf, filled with air cavities or vesicles. The cutting or abrasive quality of the material is due to the thin partitions of glass composing the walls between these vesicles. Any variety of volcanic rock, flowing out upon the surface is likely to assume the vesicular condition known as pumiceous, but only certain acid varieties known as liparites seem to possess just the right degree of viscosity and amount of moisture to produce a desirable pumice, and in this rock only in exceptional circumstances. Almost the entire commercial supply of pumice is now brought from the Lipari Islands, a group of volcanoes north of Sicily, in the Mediterranean Sea, where it is dug from the loose tuff forming the cone of the volcano. The material is usually brought over in bulk and sold in small pieces in the drug and paint shops, or ground and bolted to various degress of fineness and sold like emery and other abrasive materials. At times an inferior grade

FIG. 1.—Bed of Pumice Dust, Kansas.
[From a photograph.]

FIG. 2.—Quarry of Quartz Sand, Ottawa, Illinois.
[From a photograph.]

PLATE XXXVIII.

[*Facing page* 410.]

of pumice has been produced from volcanic flows near Lake Merced, in California. In Harlan County, Nebraska, and adjacent portions of Kansas, as well as in many other of the States and Territories farther west, have been found extensive beds of a fine, white powder, which was first shown by the present writer[1] to be pumiceous dust, drifted an unknown distance by wind currents and finally deposited in the still waters of a lake. Through a mistaken notion regarding its origin this material was first described in Nebraska as *geyserite*. So far as the writer is aware, these natural pumice powders have thus far been exploited only for polishing purposes and as a cleansing or scouring agent in soap. As the material exists in almost inexhaustible quantities, it would seem that a wider scope of usefulness might yet be discovered.

The analyses given below show (I) the composition of the pumice dust of Harlan, Orleans County, Nebraska,[2] and (II) a pumice from Capo di Costagna, Lipari Islands:

Constituents.	I.	II.
Silica	69.12	73.70
Alumina	17.64	12.27
Iron oxides		2.31
Lime	0.86	0.65
Magnesia	0.24	0.29
Potash	6.64	4.73
Soda	1.69	4.25
Ignition	4.05	1.22
Total	100.24	99.42

The Lipari pumice, in commerce is classified as follows—*grosse* (large size), *correnti* (medium), and *pezzani* (small); the large and middle sizes are subdivided into *lisconi* (flat and *rotondi* (round). The *lisconi* are filamentous, that is, the vesicles are elongated all in one direction, and break less easily than the *rotondi*. The

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[1] See On Deposits of Volcanic Dust in Southwestern Nebraska (Proceedings U. S. National Museum, VIII, 1885, p. 99), and Notes on the Composition of Certain Pliocene Sandstones from Montana and Idaho (American Journal of Science, XXXII, 1886, p. 199).

[2] Rocks, Rock weathering, and Soils, p. 350.

lisconi and *rotondi* are again subdivided into white, black, and uncertain, according to their color.

The price, it is stated, varies according to the quality from 50 to 2,000 lire the ton. The common price for the assorted is 350 to 500 lire the ton. As much as 5,000 tons a year are exported. The best pumice is that of Campo Bianco. It is also obtained at Perera, but it is in small quantity and was produced at the eruption of the Forgia Vecchia. It is a first class gray pumice and fetches from 600 to 750 lire the ton, and does not so easily break as the Campo Bianco. Also at Vulcano a gray pumice is found, but the presence of included crystals renders it useless for commercial purposes. At Castagna a commoner pumice is obtained called *Alessandrina*, of which brick-shaped pieces are made and used for smoothing oil-cloth.[1]

According to the Engineering and Mining Journal [2] a merchantable pumice has recently been found in Miller County, Idaho, but the demands for material of this nature is likely to be lessened by the putting upon the market of a German artificial product. In 1897 some 1700 tons of pumice were mined near Black Rock, Millard County, Utah.

Ground and bolted pumice is quoted as worth from $25 to $35 a ton according to quality.

4. ROTTENSTONE.

The name rottenstone has been given to the residual product from the decay of silico-aluminous limestones. Percolating carbonated waters remove the lime carbonate from these stones, leaving the insoluble residue behind in the form of a soft, friable, earthy mass of a light gray or brownish color, which forms a cheap and fairly satisfactory polisher for many metals.

The chemical compositon of rottenstone, as may well be imagined from what has been said regarding its method of origin, is quite variable, though alumina is always the predominating constituent. Analyses as given, are of doubtful value; they show: Alumina, 80 to 85 per cent; silica, 4 to 15 per cent; 5 to 10 per cent of carbon,

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[1] The South Italian Volcanoes, by H. J. Johnston-Lavis, Naples, F. Furchheim, 1891, pp. 67–71.

[2] Volume LXIV, July 24, 1897, p. 91.

and equal amounts of iron oxides and varying small quantities of lime. The material has little commercial value.

5. MADSTONES.

The fallacy of the madstone dates well back into the dark ages, and, strange as it may seem, continues down to the present day. Not longer ago than December, 1898, the Washington newspapers chronicled the sale for $450 of a madstone in Loudoun County, Virginia, and from year to year very many letters are received by the Smithsonian authorities making inquiries regarding such, or possibly offering one for sale at fabulous prices.

So far as the writer is able to learn, either from literature or from personal examination, stones of this class are almost invariably of an aluminous or clayey nature, and their supposed virtue is due wholly to their avidity for moisture—their capacity for absorption, which causes them to adhere to any wet surface, as the tongue or to a wound, until saturated, when they will drop away. It should not be necessary to state, at this late day, that their curative powers are purely imaginary. The ancient bezoar stone, used in extracting or expelling poisons, consisted of a calculus or concretion found in the intestines of the wild goat of northern India.[1]

6. MOLDING SAND.

For the purpose of making molds for metallic casts, a fine, homogeneous argillaceous sand is commonly employed.

The physical qualities which go to make up a molding sand consist, according to Nason,[2] of elasticity, strength, and a certain degree of fineness. It must be plastic in order to be molded around the pattern; it must have sufficient strength to stand when unsupported by the pattern, and to resist the impact of the molten metal when poured into the mold. Too much clay and iron present in the sand will

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[1] W J Hoffman, Folk Medicine of the Pennsylvania Germans, Proceedings of the American Philosophical Society, XXVI, 1889, p. 337.

[2] Forty-seventh Annual Report of the Regents State Museum of New York, 1893, p. 469.

cause the mold to shrink and crack under the intense heat; too little will cause it to dry and crumple, if not to entirely collapse.

The peculiar virtues of molding sand, as outlined above, are ascribed to the fact that each of the sand grains is coated with a thin film of clay.

The accompanying table will serve to show the varying chemical character of sands thus employed, though, according to authorities quoted by Crookes and Röhrig,[1] the quality of the sand for molding depends less on its chemical composition than on its physical properties, namely, whether the grains are round, angular, scaly, etc., and whether they are of uniform size. The adhesiveness is dependent not alone on the quantity of clay, but upon the angularity of the grains, and by a mixture of smaller and larger grains. Reinhardt states that to the naked eye, a good sand should consist of particles seemingly uniform in size, with a sharp feel to the touch. When strewn upon dark paper it should show no dust, and when moistened with from 10 to 20 per cent of water it must be capable of being formed into balls without becoming pulpy or being too easily crushed.

Constituents.	I.	II.	III.	IV.	V.	VI.	VII.	VII.
SiO_2	92.083	91.907	92.913	90.625	79.02	86.68	87.6	90.25
Al_2O_3	5.415	5.683	5.850	6.667	13.72	9.23	7.7	4.10
Fe_2O_3 and FeO..	2.498	2.177	1.249	2.708	2.40	3.42	3.6	5.51
CaO	Traces	0.415	Traces	Traces	....	0.96	0.96	0.23
MgO..........	....	....	....	....	0.71			
K_2O	....	....	....	....	4.58			
	99.996	100.182	100.012	100.000	100.43	100.29	99.86	100.09

Of the above No. 1 is from Charlottenburg, Germany, No. II, a sand employed for bronze castings in Paris foundries; No. III, sand from Manchester, England; No. IV, from near Stromberg; No. V, from Ilsenburg, in the Hartz Mountains; No. VI, from Sheffield, England; No. VII, from Birmingham, England, and No. VIII, from Lüneburg.

The sand from Ilsenburg, the composition of which is given in

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[1] A Practical Treatise on Metallurgy, II, p. 626.

column 5, is stated [1] to be prepared by mixing "common argillaceous sand, sand found in alluvial deposits, and sand from solid sandstone." In preparation the first two are carefully heated to dehydrate the clay and then mixed, equal proportions of each with the same amount of sandstone. The mixture is then ground and bolted, the product being as fine as flour and capable or receiving the most delicate impressions.

According to D. H. Truesdale,[2] the four essential qualities in molding sand are, in the order of their importance, (1) refractoriness, (2) porosity, (3) fineness, and (4) bond. These qualities are dependent mainly upon the varying properties of siliceous sand and clay, the refractory nature being governed by the absence of such fluxing constituents as calcium cabonate, the alkalies, or of iron oxides. Since in nature it is not always possible to obtain the admixture of just the right proportion, artificial mixtures are often resorted to, as mentioned above. Ferguson gives [3] the following analyses of molding sand in actual use in his foundries:

Constituents.	No. 1, Fine Sand for Snap Work.	No. 2, Medium Grade for Medium Class of Work.	No. 3, Coarse Sand for Heavy Machine Castings.	No. 4, for Heavy Machinery in Dry-sand Molds.
Silica	81.50	84.86	82.92	79.81
Alumina	9.88	7.03	8.21	10.00
Ferric oxide	3.14	2.18	2.90	4.44
Combined water	3.00	2.20	2.85	2.89
Calcium carbonate	1.85	1.10	1.10	1.25
Magnesia	0.65	0.98	None.	0.88
Potassium	No estimate.	No estimate.	No estimate.	No estimate.
Manganese	Trace.	Trace.	Trace.	Trace.
Organic matter	Trace.	Trace.	Trace.	Trace.
Total	100.02	98.35	97.98	99.27

Sands containing lime or alkalies, that is those containing free calcite or feldspathic granules, are sometimes liable to fusion in the case of heavy castings. It is customary in such cases to coat the surface of the mold with graphite.

The following table, from a recent report of the State Geologist

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[1] Percy's Metallurgy, 1861, p. 239.

[2] The Iron Trade Review, October, 1897, p. 24.

[3] Iron Age, LX, December, 1897, p. 16.

MECHANICAL ANALYSES OF MOLDING SANDS.

Name and Grade.	Percentage Remaining on Sieve.									Clay Adhering.	Per Cent of Fineness.	Specific Gravity.	Per Cent of Pore Space.	Tensile Strength in Pounds per Square Inch.
	4	8	10	20	40	60	80	100	Pan.					
Albany sand No. 0, finest castings	0	0	0	0	0.23	0.15	0.14	0.12	98.94	......	99.5	2.62	40.8	6.9
" " No. 2, machinery castings	0.3	1.02	0.85	1.82	5.34	6.19	13.59	19.53	50.06	2.3	84.8	2.65	38.5	4.39
" stove-plate sand	0	0	0	0	trace	1.0	7.0	14.0	77.0	1+	95.0	2.635	41.55	undet.
Greenville No. 1 for brass molding.....	0	0	0	0	0	0	trace	0.155	99.28	undet.	99.84	......	43.0	"
" No. 3 for general founding..	0	0.5	0.5	4.0	29.0	25.0	19.5	9.0	11.5	3.0	65.8	......	36.0	"
" No. 8 for core sand.........	49.01	28.88	5.77	7.03	6.39	2.37	1.38	0.55	1.33	undet.	14.7	......	27.0	"
Florence for steel molding............	0	0	trace	1.0	6.5	12.0	27.5	33.0	18.5	3.5	79.5	2.63	41.8	1.59
Lumberton loam....................	0	0	"	3.5	32.0	23.0	16.0	9.5	15.0	7.5	67.2	2.613	45.1	15.37
" "	0	0	0	3.5	15.0	11.0	19.0	20.0	30.5	16.5	78.2	2.637	41.0	undet.
" molding loam..............	0	0	trace	3.0	12.0	16.5	18.5	12.0	36.5	8.5	78.6	......	37.9	32.04
Coarse sand for heavy castings......	1 pebble	2.8	2.5	11.5	24.0	17.5	12.0	13.5	16.0	7.5	65.0	2.582	39.5	12.57
Fine mild sand for iron and brass......	0	trace	trace	3.5	21.0	11.0	12.5	12.5	37.0	11.5	76.6	2.631	41.8	10.35
Centreton, for heavy foundry work....	0	0	"	6.0	28.5	18.5	14.5	9.0	22.5	11.5	69.6	2.613	38.7	44.57
South Amboy molding sand..........	0	0	"	trace	20.36	21.41	22.43	14.55	21.25	3.6	74.6	......	39.25	undet.
Jersey molding sand No. 3	0	0	0	5.25	44 20	13.37	10.62	5.8	20.35	3.15	66.0	......	42.26	"
Silica molding sand for steel molding ..	0	0	0	0.92	21.34	28.75	29.57	14.63	4.63	0.3	68.6	......	38.65	"
Core sand..........................	12.0	5.5	3.5	12.0	31.5	13.0	7.0	5.0	9.5	20.0	49.0	2.642	43.2	1.59
" "	5.0	9.0	7.0	24.0	37.0	8.5	5.0	2.0	2.5	18.0	43.7	2.609	37.8	undet.
" "	8.5	7.5	5.0	13.0	39.0	14.0	7.0	3.5	2.5	8.5	46.1	2.639	38.6	4.62
" " (Millville)................	0	3.5	3.32	19.35	56.55	6.38	2.92	1.94	4.53	13.5	49.2	......	41.06	undet.

of New Jersey,[1] will show the physical condition of some well-known molding sands:

Sands suitable for ordinary castings are widespread, though the finer grades are often brought considerable distances, some of those used in bronze casting in America being imported from Europe. In the United States the beds are alluvial deposits of slight thickness. Large areas occur in New York State, in counties extending from the Adirondacks to New Jersey. At date of writing a very considerable proportion of the material used in the eastern United States is dug in Selkirk, Albany County, New York, and central and southern New Jersey.

The Selkirk molding sand is of a yellow-brown color, showing under the microscope angular and irregular rounded particles rarely more than 0.25 mm. in diameter, interspersed with finely pulverulent matter which can only be designated as clay. The yellow-brown color of the sand is due to the thin film of iron oxide which coats the larger granules. When this film is removed by treatment with dilute hydrochloric acid, the constituent minerals are readily recognized as consisting mainly of quartz and feldspar fragments (both orthoclase and a plagioclase variety), occasional granules of magnetic iron oxide, and irregularly outlined scales of kaolin, together with dust-like material too finely comminuted for accurate determination. Many of the larger granules are white and opaque, being presumably feldspar in transition stages toward kaolin. An occasional flake of hornblende is present.

The sands occur in beds varying from 6 inches to 3 feet or even 5 feet in thickness. They immediately underlie the surface soil and overlie coarser, well-stratified sand beds more nearly allied to quicksands.

In gathering the sands for market, a section of land 1 or 2 rods in width is stripped of its overlying soil down to the sand, which is then dug up and carried away. When the area thus exposed is exhausted, a like area immediately adjoining is stripped, the soil from the second being dumped into the first excavation. By this method

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[1] Ann. Rept. of State Geologist of New Jersey, 1904, pp. 187–244. See also Ries and Rösen, On Foundry Sands, Rept. Geological Survey of Michigan, 1907.

the field, when finally stripped of its molding sand, is ready again for cultivation.

It is estimated that a bed of sand 6 inches in thickness will yield 1,000 tons an acre. The royalty paid the farmers from whose land it is taken varies from 5 to 25 cents a ton. Some 60,000 to 80,000 tons are shipped annually from Albany County alone.

The term *green-sand*[1] is applied to the argillaceous molding sands in an undried state, and which is employed in its native state, new and damp. The term *dry sand* is used in contradistinction, to indicate a sand that must be dried by heat before being fit for use. The dry sand is stated to be firmer and better adapted than the green for molding pipes, columns, shafts, and other long bodies of cylindrical form.

In England good molding sands are obtained from the Lower Mottled Sands of the Bunter (Trias) beds and from those of the Thanet (Lower Eocene).

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7. SAND FOR MORTARS AND CEMENTS.

Enormous quantities of siliceous sand are annually used in the preparation of mortar for plastering and bricklaying, or in cements. As a rule no great amount of discrimination is shown in the selection of the material, the matters of locality and cheapness being perhaps the controlling items. It by no means follows, however, that care

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[1] This must not be confounded with the Greensand Marl, or Glauconitic Sand used for fertilizing purposes (see p. 420).

is not necessary or desirable. It is stated that the best grades are those in which the granules present a considerable diversity of size and are sharply angular. A standard adopted for use in construction on one of the leading railroads demanded that 54 per cent should pass a 24-mesh sieve, and 11 per cent a 50-mesh. Clay in amounts as high as 12 per cent is not in all cases objectionable.

The sources of such sand are almost infinite. River beds, sea beaches, and sand banks wherever found are the common resorts.

8. SAND FOR GLASS MAKING.

Quartz sand is extensively used in glass making. For this purpose a fairly pure quartz sand is needed, though naturally the common grades of bottle glass demand a much less pure material than do the higher grades of flint, or plate glass. It is stated [1] that, aside from purity, the matter of size and shape of the individual sand grains are matters of primary importance. By some it is contended that in the best grades the grains are sharply angular, rather than rounded. Uniformity, and in sizes varying from 0.15 mm. to 0.60 mm., seem most desirable. Sands containing a majority of the grains less than 0.136 mm. in diameter (i.e., passing a 120-mesh sieve) " burn out," and produce less glass per unit than those which are coarser. The finer grains have a tendency to settle to the bottom of the batch, thus preventing a homogeneous mixture. Sand in which the grains are more than 0.64 mm. in diameter (30-mesh) fuse slowly, thus diminishing the daily output of the furnace and incidentally increasing the cost.

The chemical composition of some glass sands from Southern New Jersey and Pennsylvania, and others in use by manufacturers is shown in the table on page 420.

The impurities in these sands are due as a rule to mechanically entangled bits of mica, magnetite, ilmenite, or rulite, feldspar, etc., which can often be largely eliminated by washing.

Large quantities of sand suitable for glass making are attained either from beds of loose sand or by crushing a loosely consolidated

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[1] Annual Report State Geologist of New Jersey, 1906.

	1	2	3	4	5	6	7	8
SiO_2 ...	99.40	99.62	99.11	99.72	98.94	99.21	99.99	99.58
Fe_2O_3..	0.0058	0.0047	0.0108	0.0017	0.0036	0.003	Trace.	0.21
Al_2O_3 ..	0.2752	0.142	0.355	0.1203	0.30	0.30	0.008	0.350
FiO_2...	0.0737	0.0543	0.2213	0.0147	....	....	....	....
CaO...	0.008	0.01	0.009	0.007	0.40	0.20	0.002	0.50
MgO ..	0.012	0.005	0.023	0.008	Trace.	Trace.		
Ignit...	0.231	0.162	0.19	0.134	0.23	0.21	....	....

Nos. 1 and 2 used chiefly for window, green, and amber glass.
No. 3 used only in cheaper grades of glass, as for beer bottles.
No. 4 used for best grades of flint glass.
Nos. 5 and 6 sands used by the Pittsburg Plate Glass Co.
Nos. 7 and 8 sands used by the American Window Glass Co.

sandstone in Illinois, Indiana, Maryland, Massachusetts, Missouri, New Jersey, New York, Ohio, Pennsylvania, and West Virginia. Doubtless equally good sands may be found in other localities, but the cost of fuel is the controlling item and a large share of the furnaces are in regions of cheap fuel or with peculiarly favorable facilities for transportation or for market. The price varies from \$0.90 to \$1.50 a ton.

9. GLAUCONITIC SAND.

The names greensand, greensand marl, and glauconitic marl are given to a dull greenish, loosely coherent arenaceous deposit, consisting essentially of the hydrous silicate of iron and potassium, but variously contaminated with particles of quartz and siliceous minerals, oxides of iron, clay, rock fragments, and particles of shells. The table on page 421 from the Annual Report of the State Geologist of New Jersey will serve to show the varying composition of the material.

The most extensive and best-known deposits in the United States are included in what are known as the Upper, Middle, and Lower marl beds of the Cretaceous formations in southeastern New Jersey, though it is also known to occur in beds of Eocene age in Maryland, Virginia, North and South Carolina, and Alabama. Though apparently limited to beds of no particular age, it seems, nevertheless, most abundant, both in America and in Europe, in the Mesozoic formations.

CHEMICAL COMPOSITION OF GLAUCONITIC MARLS.

Constituents.	I.	II.	III.	IV.	V.	VI.
Phosphoric acid	1.15	0.58	0.19	0.50	6.87	3.73
Sulphuric acid	1.28	....	0.41	0.34	3.12	2.44
Silica and sand	34.50	45.50	51.15	47.50	44.68	49.68
Potash	1.54	3.79	7.08	5.29	3.97	4.98
Lime	2.52	1.51	0.49	0.56	4.97	4.14
Magnesia	2.15	2.20	2.02	2.70	2.90	0.47
Alumina	6.00	5.80	8.23	8.60	6.04	?
Oxide of iron	31.50	24.50	23.13	20.52	18.97	28.71
Water	18.80	15.40	6.67	13.57	8.63	5.54
Totals	99.43	99.18	99.37	99.58	99.32	99.69

Origin.—The glauconitic beds are believed to have been formed in comparatively shallow waters during periods of slow sedimentation along coasts receiving debris from continental slopes and of a nature such as would result from the breaking down of feldspathic rocks. In New Jersey the beds vary from 30 to 60 feet in thickness, but the glauconitic layers are not homogeneously distributed throughout.

Uses.—The material is mined from open pits and used locally as a fertilizer. The percentages of phosphoric acid, potash, and lime are too low to warrant transportation for any distance.

10. ROAD-MAKING MATERIALS.

Roadways subject to any considerable amount of traffic demand almost invariably some sort of stone bedding to prevent their becoming soft or badly cut up and rutted by wheels and hoofs of horses. Until within a comparatively few years, it has been the general custom to pave the streets of cities and towns with rectangular blocks of granite, trap, or other hard rock, forming thus the well-known Belgian block and Telford pavements. Such are set in regular rows and the interspaces filled with sand and sometimes with tar or asphalt. For suburban and country roads a pavement of broken stone, the invention of a Mr. L. Macadam about 1820, and known by his name, is at present the most extensively used. The invention is based upon the property possessed by freshly broken stone of becoming compacted and to a certain degree even cemented when subject to heavy rolling and the impact of wheels. The finer particles, broken away by the action of the wheels and hoofs of animals, fill the interstices of the larger pieces and gradually bring about an induration, forming a roadbed hard, smooth, and durable.

Not all materials are equally good for macadamizing purposes. If the rock is too hard ordinary travel is not sufficient to produce the desired amount of fine material, and satisfactory cementation does not ensue. If too soft it grinds away too rapidly. If the material is decomposed, it does not become sufficiently indurated —refuses to set, as it were.

It is impossible to lay down other than the most general rules for the selection of road material, since rocks of the same kind, or at least known under the same name, vary almost as much in different localities in their physical properties as do the different kinds. The following very general rules have been formulated:[1]

The granites are generally brittle, and many of them do not bind well, but there are a great many which, when used under proper conditions, make excellent roads. The felsites are usually very hard and brittle, and many have excellent binding power, some varieties being suitable for the heaviest macadam traffic. Limestones generally bind well, are soft, and frequently hydroscopic. Quartzites are almost always very hard, brittle, and have very low binding power. The slates are usually soft, brittle, and lack binding power.

Obviously the bulk matter of any roadbed must be built up of materials from nearby sources, owing to cost of transportation. For surfacing, however, materials are often carried long distances. For this purpose a hard, dense rock, such as the finer grades of trappean rocks, are now most generally used.

Macadam is laid with or without a foundation of larger stones.[2]

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[1] L. W. Page. The Selection of Materials for Macadam Roads, Yearbook Dept of Agriculture, 1900.

[2] With the foundation of larger stones the pavement becomes known as the Macadam-Telford pavement

When such is used, a thickness of from 6 to 12 inches is recommended and over this is laid from 4 to 6 inches of the broken stone or "metal."

"Taking all points into consideration, it is probable that the best size for macadam, for hard and tough stones, such as basalt, close-grained granite, syenite, gneiss, and the hardest of primary crystallized rocks, is from 1½ to 1⅓ inches cube, according to their respective toughness and hardness, while stones of medium quality ought to be broken to gage of from 1½ to 2¼ inches, and the softer kinds of stone might vary between the limits of 2 and 2½ or 2¾ inches, but the latter is a size which should seldom be specified."

On roads for light driving it is customary to place a final surfacing of smaller stone, such as will pass a 1-inch mesh.

"Considerable importance is attached to the manner in which the macadam is prepared for use. Machine-broken stone is not considered of the same value as that broken by hand. The stones are not so regular a size and shape, and there is a greater proportion of inferior stuff. A mechanical crusher is apt to stun the material, and does not leave the edges so sharp for binding as they are when the stone is broken with a small hammer."[1]

The cost of macadamized roads from necessity varies almost indefinitely. The primary factors are (1) cost of labor, (2) accessibility of materials, and (3) character of country. From $2,000 to $2,500 a mile is perhaps an average figure for localities where materials are available close at hand.

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