# ECONOMIC GEOLOGY

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*FOURTH EDITION, THOROUGHLY REVISED AND ENLARGED*

# PREFACE TO FOURTH EDITION

THE continued advance in our knowledge of Economic Geology has necessitated considerable revision for the new edition. In addition, the author has, at the request of a number of teachers, included a description of the more important Canadian mineral deposits, as well as brief references to some of the well-known ones of other countries.

While these additions to the text and illustrations have increased the size of the book somewhat, the number of pages is not to be taken as a gauge of the actual increase in size, for the reason that over one hundred full-page illustrations, formerly bound as inserts, are paged in with the text in the present edition.

The latest available statistics have been included, and unless otherwise stated are taken from the United States Geological Survey, and Canadian Department of Mines reports.

In a few cases, investigations to which reference might have been made in the text have appeared too late to include them, but it has still been possible to insert them in the reference list, and this has been done.

The author takes pleasure here in acknowledging his deep indebtedness to Professor T. L. Watson of the University of Virginia, for reading and criticising the manuscript. Thanks are also due to Dr. David White of the Geological Survey, for criticising the data contained in the chart on page 26, and to Mr. H. D. McCaskey of the same department, for aid in obtaining statistical data.

Acknowledgments for the loan of new illustrations are due to Dr. R. G. McConnell, Deputy Minister of Mines, Canada; Dr. E. Haanel, Director, Mines Branch, Canada; Professor E. C. Jeffrey, Harvard University, Mr. F. W. DeWolf, State Geologist, Illinois; The Southern Railway Company; Mr. F. C. Wallower, Webb City, Mo., and Mr. J. S. Hook, Cornell University. The latter also kindly took all of the photomicrographs made for this edition.

CORNELL UNIVERSITY, ITHACA, N. Y.
June, 1916

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# CHAPTER I

## COAL

**Kinds of Coal.** — There is such an intimate gradation between vegetable accumulation now in process of formation and mineral coal that it is generally admitted that coal is of vegetable origin. By a series of slow changes (p. 17) the vegetable remains lose water and gases, the carbon becomes concentrated, and the materials assume the appearance of coal. To the several stages of this process the following names are given: peat, lignite, subbituminous, bituminous, semibituminous, semianthracite, and anthracite.

*Peat* (119–130.) — This, which represents the first stage in coal formation, is formed by the growth and decay of grasses, sphagnum, and other plants in moist places. A section in a peat bog from the top downward may show: (1) A layer of living plants; (2) a layer of dead plant fibers, whose structure is clearly recognizable and which grades into (3) a layer of fully formed peat, a dense, brownish black mass, of more or less jellylike character, in which the vegetable structure is often indistinct.

The following analyses show the difference in composition of the different layers.[1] They also show that while during this change the hydrogen and oxygen diminish, the carbon increases in proportion.

ANALYSES OF DIFFERENT LAYERS OF A PEAT BOG

| MATERIAL | CARBON | HYDROGEN | OXYGEN | NITROGEN |
|---|---|---|---|---|
| Sphagnum . . . . . . . . . . . | 49.88 | 6.54 | 42.42 | 1.16 |
| Porous, light brown sphagnum peat | 50.86 | 5.8 | 42.57 | .77 |
| Porous, red-brown peat . . . . . | 53.51 | 5.9 | 40.59 | |
| Heavy brown peat . . . . . . . | 56.43 | 5.32 | 38.25 | |
| Heavy black peat . . . . . . . | 59.7 | 5.7 | 33.04 | 1.56 |

[1] The fact that sphagnum occurs on the surface is not necessarily an indication that it was the only peat-forming plant present.

*Lignite.* — This substance, also called *brown coal*, representing the second stage in coal formation, is usually brown or sometimes yellowish in color, woody in texture, and has a brown streak. It burns readily, but with a long smoky flame, and with lower heating power than the higher grades of coal. Because of the large amount of moisture it often dries out on exposure to the air, and rapidly disintegrates to a powdery mass.

Lignite is distantly jointed, and as mined is as a rule irregularly slabby.

The lignites are usually restricted to the younger formations. They are found in the various stages of the Cretaceous and Tertiary of the United States and Canada. Exceptionally they occur in beds as old as the Carboniferous, as in Russia (11*a*, p. 65).

*Jet* is a coal-black variety of lignite, with resinous luster and sufficient density to permit its being carved into small ornaments. It is obtained on the Yorkshire coast of England, where a single seam produced 5180 pounds, valued at $1250. According to Phillips, jet is simply a coniferous wood, still showing the characteristic structure under the microscope. ("Geology of England and Wales," p. 278.)

*Subbituminous Coal or Black Lignite.* — A grade intermediate between lignite and bituminous, and sometimes difficultly distinguishable from these. It is usually glossy black, and relatively free from joints. The moisture content is commonly over 10 per cent and the calorific value from 8000 to 10,000 British thermal units (12*a*). Campbell (13) has pointed out that it checks irregularly on drying and when weathered splits parallel with the bedding, while bituminous coal shows a columnar cleavage (Plate I).

*Bituminous Coal.* — This represents the fourth stage in coal formation. It is denser than the lignites, deep black, comparatively brittle, and breaks with cubical or sometimes conchoidal fracture. On superficial inspection it shows imperfect traces of vegetable remains (Plate III); but in thin sections examined under the microscope, traces of woody fiber, lycopod spores, etc., are commonly seen (Plate II). Bituminous coal burns readily, with a smoky flame of yellow color, but with greater heating power than lignite. It does not disintegrate on exposure to a r as readily as lignite does. Most bituminous coal is of earlier age than lignite; but where the two occur in the same formation, as in parts of the West, the lignite is commonly in horizontal strata, while the bituminous coal occurs in areas of at least slight disturbance.

PLATE I
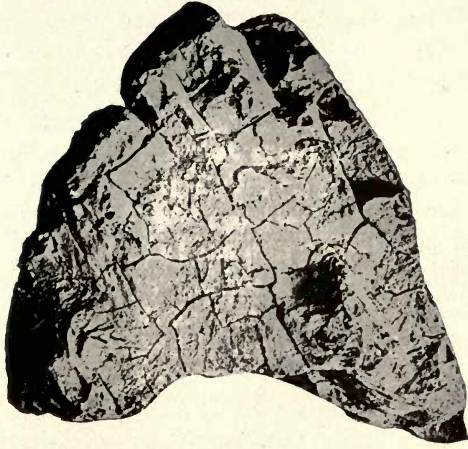


FIG. 1. — Subbituminous Coal, showing the irregular checking developed in drying. (*After Campbell, Econ. Geol., III.*)
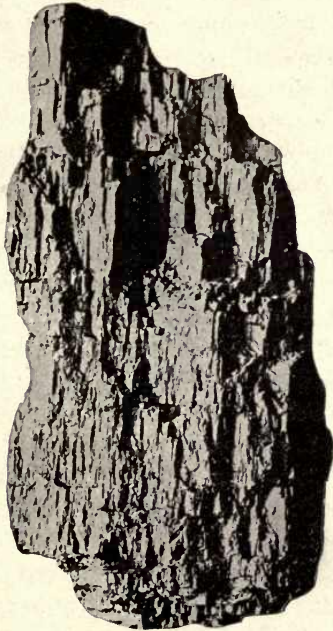


FIG. 2. — Bituminous Coal, showing prismatic structure. (*After Campbell.*)

(3)

When freed of their volatile hydrocarbons and other gaseous constituents by heating to redness in a coke oven, many bituminous coals cake to a hard mass called *coke*. Since all bituminous coals do not possess this characteristic, it is customary to divide these coals into *coking* and *non-coking* coals.

The cause of coking is not clearly understood, and the chemical analysis does not appear to throw much light on the matter. It has been suggested that the quality of coking may be influenced by the character of the plant remains making up the coal. A proper determination of the coking qualities of a coal usually involves a practical test, but it seems that the coking qualities of a coal may be inferred with fair accuracy by its behavior when ground in an agate mortar. Coals of good coking character stick to the mortar, while those of opposite quality are easily brushed loose (28).

The coking value of a coal (20) seems to be indicated with fair accuracy by the hydrogen-oxygen ratio, calculated on a moisture-free basis. Practically all coals with $\frac{H}{O} > 58$ per cent seem to possess coking qualities. Most coals with $\frac{H}{O}$ down to 55 make coke of some kind, and a few with ratios as low as 50 will coke, though the product is rarely good.

The hydrogen-oxygen ratio may fail as a guide in those coals undergoing anthracitization.

The formation of coke by natural processes is referred to on p. 5.

*Cannel Coal.* — This is a compact variety of non-coking bituminous coal, with a dull luster and conchoidal fracture. Owing to its unusually high percentage of volatile hydrocarbons, upon which its chief value depends, cannel coal ignites easily, burning with a yellow flame, and when heated tends to decrepitate. Microscopic examination of thin sections shows that it consists largely of spores (4a, 12a).

*Semibituminous Coal.* — This term was proposed by H. D. Rogers as early as 1858 [1] to apply to those grades above bituminous, whose volatile matters were between 12 and 18 per cent; while Frazer, in 1879,[2] used it to include those coals whose "fuel ratios" (p. 19) ranged from 8 to 5.

*Semianthracite Coal.* — This term was employed by Rogers at the same time, and included those coals between bituminous and anthracite having less than 10 per cent volatile matter. Frazer later included under it those coals whose fuel-ratios ranged from 12 to 8.

Both terms persist, perhaps unfortunately, to the present day, and are sometimes no doubt rather loosely used. Possibly

[1] Geology of Pennsylvania, II: 983.

[2] Second Pennsylvania Geological Survey, Rept. MM: 148, 1879.

the disagreement among different people as to what shall be included under these terms may be partly responsible for the confusion.

*Anthracite Coal.* — This coal is black, hard, and brittle, with high luster and conchoidal fracture. It represents the last stage in the formation of coal, and like bituminous coal, may show jet-like bands, representing flattened stems or trunks. Anthracite has a lower percentage of volatile hydrocarbons and higher percentage of fixed carbons than any of the other varieties. On this account, it ignites much less easily and burns with a short flame, but gives great heat.

The geological distribution of anthracite is more restricted than that of bituminous coal, and in fact its occurrence is often more or less intimately connected with dynamic disturbances.

*Carbonite or Natural Coke.* — This term is applied to natural coke, which is formed by igneous rocks cutting across bituminous coal seams. As illustrative may be mentioned an occurrence in central Utah,[1] where " dikes of igneous rocks ten feet in width have cut vertically across the coal bed, nine to sixteen feet thick, metamorphosing the coal into a coke-like substance to a distance of three feet on either side. The coal thus fused is distinctly columnar, the columns standing perpendicular to the face of the dike; it has a graphitic luster, but is not vesicular like artificial coke." Natural coke is also found in New Mexico, Colorado, and Virginia.

The higher quantity of volatile matter in carbonite than artificial coke may be due to its having formed at some depth below the surface, thus preventing the escape of the volatile matter, short heating, or enrichment by gases from the neighboring coal.

ANALYSES OF NATURAL COKE

|  | I | II | III |
|---|---|---|---|
| Moisture . . . . . . . . . | 1.116 | .32 | 4.55 |
| Volatile hydrocarbons . . . . . | 11.977 | 20.38 | 4.43 |
| Fixed carbon . . . . . . . | 75.081 | 65.90 | 84.67 |
| Ash . . . . . . . . . . . | 11.826 | 13.10 | 6.35 |

I. Richmond, Va., coal basin. — Watson, Min. Res. of Va., p. 343, 1907. II. Book Cliffs coal field, Utah. — Taff, Science, N.S. XXIII : 696, 1906. III. Cerrillos Hills district, N.M. — Johnson, Sch. of M. Quart., XXIV: 492, 1903.

[1] Taff, Science, N. S., XXIII: 696, 1906.

**Proximate Analysis of Coal.** — An elementary analysis of coal (see p. 18) is of comparatively little practical value. Therefore proximate analyses are commonly employed, in which the probable method of combination of the elements is given. By the proximate method the elements in the coal are grouped as moisture, volatile matter, fixed carbon, ash, and sulphur.[1]

The moisture can be driven off at 100° C. and is usually highest in peat and lignite. The volatile matter was formerly termed volatile hydrocarbons, but it is now clear that other substances also are driven off at a red heat, and that the volatile matter of coals differs greatly in its character.[2]

The coals of the younger geological formations of the West have a large proportion of carbon dioxide, carbon monoxide and water, and a correspondingly small proportion of hydrocarbons and tarry vapors. The Appalachian coals, on the other hand, contain much tarry vapor and hydrocarbon compounds.

The ash represents noncombustible mineral matter and bears no direct relation to the kind of coal; and the same is true of sulphur, which is present as an ingredient of pyrite or gypsum.

The value of coal for fuel or other purposes is determined mainly by the relative amounts of its fuel constituents, viz., the volatile hydrocarbons and the nonvolatile or fixed carbons. The fuel value, or *fuel ratio*, is determined by dividing the fixed carbon percentage by that of the volatile hydrocarbons.

The fixed carbon of the coal burns with difficulty and is highest in the anthracite variety. The value of a coal for fuel purposes is determined mainly by the relative amounts of its different constituents. Thus both the fixed carbon and volatile hydrocarbons represent heating elements in the coal, the former being the stronger. The maximum calorific value seems to be reached when the volatile combustible matter is about 18 per cent of the total combustible.

Coals with a high percentage of fixed carbon develop great heating power, while those lower in fixed carbon and high in volatile hydrocarbons lack in heating power, but are free burning.

Moisture is a nonessential constituent of coal. It not only displaces so much combustible matter, but requires heat for its evaporation. When present in large amounts it often causes the coal to disintegrate while drying out. It ranges from perhaps 2 or 3 per cent in anthracite to 20 or 30 per cent in lignites.

Ash also displaces combustible matter, but otherwise it is in most cases an inert impurity. The clinkering of coal is commonly due to a high percentage of fusible impurities in the ash, and for metallurgical work the composition of the ash often has to be considered.

[1] The proximate analysis, though apparently a simple operation, needs to be carefully carried out to prevent variable results. See in this connection U. S. Geol. Surv., Prof. Pap. 48, I, and Bur. Mines, Tech. Pap. 8, 1913.

[2] Bur. Mines, Bull. 1, 1910.

PLATE II
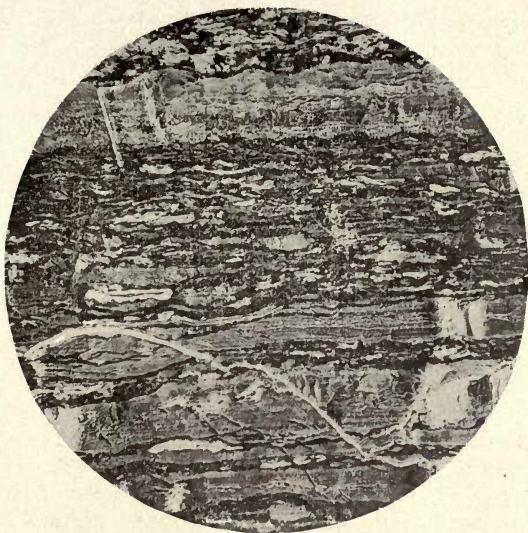


FIG. 1. — Enlarged section of bituminous coal from Ohio. Crenulated bands are modified lignitic material. Dark bands canneloid. White bodies, flattened spores. (*E. C. Jeffrey, photo.*)
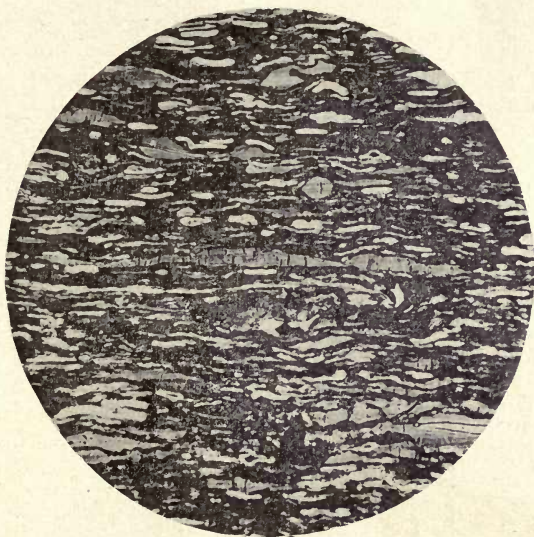


FIG. 2. — Enlarged section of cannel coal from Kentucky. Light undulating bands, wood. White bodies, flattened spores. (*E. C. Jeffrey, photo.*)

(7)

PROXIMATE AND ULTIMATE ANALYSES OF COAL

| LOCALITY | PROXIMATE | | | | ULTIMATE | | | | | CALORIES | B.T.U. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Moisture | Volatile Matter | Fixed Carbon | Ash | Sulphur | Hydrogen | Carbon | Nitrogen | Oxygen | | |
| *Peat* | | | | | | | | | | | |
| Halifax, Mass. | 49.80 | 27.27 | 10.88 | 12.05 | 0.34 | — | — | — | — | — | — |
| Orlando, Fla. | 13.19 | 56.83 | 24.30 | 5.68 | 0.49 | 6.06 | 51.18 | 2.56 | 34.03 | 4961 | — |
| *Lignite* | | | | | | | | | | | |
| Lehigh, Stark Co., N. Dak. | 32.64 | 29.19 | 26.75 | 11.42 | 3.54 | 6.15 | 39.53 | 0.49 | 38.87 | 3872 | 6,970 |
| Crockett, Tex. | 13.40 | 42.75 | 29.00 | 14.85 | 1.04 | 5.57 | 52.06 | 0.95 | 25.53 | 5199 | 9,358 |
| Lester, Ark. | 19.13 | 35.36 | 32.54 | 12.97 | 0.65 | 5.60 | 48.51 | 0.91 | 31.36 | 4714 | — |
| Coal Harbor (Unga Island), Alaska | 23.27 | 25.42 | 25.13 | 26.18 | 0.53 | 5.27 | 34.76 | 0.52 | 32.74 | — | — |
| Miles, Mont. | 35.51 | 26.75 | 28.87 | 8.87 | 0.40 | — | — | — | — | 3535 | 6,363 |
| Olsen, Tex. | 31.06 | 27.67 | 33.39 | 7.88 | 0.99 | 6.53 | 44.70 | 0.90 | 39.00 | 4372 | 7,870 |
| *Subbituminous* | | | | | | | | | | | |
| Tesla, Cal. | 18.51 | 35.33 | 30.67 | 15.49 | 3.05 | 5.93 | 47.34 | 0.66 | 27.53 | 4726 | — |
| Lafayette, Colo. | 13.49 | 37.11 | 43.03 | 6.37 | 0.58 | 5.75 | 61.13 | 1.22 | 24.95 | 5995 | 10,791 |
| Galleys, N. Mex. | 8.13 | 34.82 | 37.83 | 19.22 | 1.30 | 5.05 | 56.71 | 0.98 | 16.74 | 5668 | 10,202 |
| Glendive, Mont. | 34.89 | 43.48 | 13.56 | 8.07 | 1.33 | 6.41 | 41.66 | 0.56 | 41.97 | 3880 | 6,984 |
| Bear Creek, Mont. | 9.67 | 35.92 | 46.39 | 8.02 | 1.64 | 5.52 | 61.66 | 1.48 | 21.68 | 6018 | 10,832 |
| Beaver Hill, Oregon | 16.10 | 31.10 | 39.63 | 13.17 | 0.81 | 5.53 | 51.07 | 1.19 | 28.23 | 5017 | 9,031 |
| Coalville, Utah | 14.2 | 36.0 | 44.8 | 5.0 | 1.41 | 5.79 | 61.40 | 1.09 | 25.31 | 5905 | 10,630 |
| Tenino, Wash. | 16.02 | 31.86 | 28.93 | 23.19 | 1.50 | 5.04 | 43.44 | 0.73 | 26.10 | 4335 | 7,803 |
| *Bituminous* | | | | | | | | | | | |
| Huntington, Ark. | 1.17 | 17.83 | 68.12 | 12.88 | 1.27 | 4.00 | 75.68 | 1.47 | 4.70 | 7450 | 13,410 |
| Coffeen, Ill. | 5.13 | 32.68 | 47.46 | 14.73 | 4.45 | 4.88 | 60.51 | 1.23 | 14.20 | 6199 | 11,158 |
| Clarksburg, W. Va. | 1.46 | 40.14 | 50.50 | 7.90 | 3.50 | 5.09 | 74.44 | 1.37 | 7.70 | 7700 | 13,860 |
| Clarion Co., Pa. | 2.87 | 34.51 | 54.31 | 8.31 | 1.36 | — | — | — | — | — | — |
| Johnstown, Pa. | 2.35 | 14.30 | 71.40 | 11.95 | 3.30 | 4.22 | 75.16 | 1.13 | 4.24 | 7382 | 13,288 |
| Pocahontas steam coal, Va. | 0.54 | 19.86 | 74.61 | 4.99 | 0.344 | — | — | — | — | — | — |

PROXIMATE AND ULTIMATE ANALYSES OF COAL—*Continued*

| | PROXIMATE | | | | ULTIMATE | | | | | | |
| LOCALITY | MOIS-TURE | VOLA-TILE MATTER | FIXED CARBON | ASH | SUL-PHUR | HYDRO-GEN | CARBON | NITRO-GEN | OXYGEN | CAL-ORIES | B.T.U. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Bituminous* | | | | | | | | | | | |
| Coking coal, Wisc Co., Va.. | 0.924 | 35.97 | 58.44 | 4.09 | 0.579 | — | — | — | — | — | — |
| Blockton, Ala. | 3.21 | 32.05 | 60.79 | 3.95 | 0.60 | 5.52 | 77.91 | 1.20 | 10.82 | 7791 | 14,024 |
| Linton, Ill. | 13.53 | 33.54 | 45.38 | 7.55 | 0.95 | — | — | — | — | 6521 | 11,738 |
| Saginaw, Mich. | 11.91 | 31.50 | 49.75 | 6.84 | 1.24 | 5.84 | 66.56 | 1.19 | 18.33 | 6545 | 11,781 |
| Kirksville, Mo. | 14.59 | 32.05 | 39.45 | 13.91 | 3.69 | 5.56 | 56.12 | 0.93 | 19.79 | 5700 | 10,260 |
| Wellston, Ohio | 7.71 | 38.32 | 42.02 | 11.95 | 4.61 | 5.41 | 62.49 | 1.11 | 14.43 | 6397 | 11,515 |
| Lehigh, Okla. | 7.07 | 36.41 | 45.68 | 10.84 | 3.64 | 5.13 | 64.38 | 1.44 | 14.57 | 6371 | 11,468 |
| *Semibituminous* | | | | | | | | | | | |
| Coal Hill, Ark. | 1.28 | 12.82 | 73.69 | 12.21 | 2.01 | 3.74 | 77.29 | 1.39 | 3.36 | 7448 | 13,406 |
| Paris, Ark. | 2.77 | 14.69 | 73.47 | 9.07 | 2.79 | 4.02 | 78.71 | 1.46 | 3.95 | 7652 | 13,774 |
| Gary, W. Va. (bony layer) | 0.52 | 12.11 | 58.60 | 28.77 | 0.55 | 3.33 | 62.36 | 0.66 | 3.97 | 6002 | — |
| Sterling, Pa. | 3.2 | 18.5 | 72.4 | 5.87 | 1.27 | 4.84 | 80.43 | 1.27 | 6.32 | 7995 | 14,320 |
| Ashford, Wash. | 4.11 | 24.38 | 44.75 | 26.76 | 0.44 | 4.31 | 58.16 | 1.39 | 8.94 | 5719 | 10,294 |
| Coopers, W. Va. | 3.78 | 15.40 | 76.80 | 4.02 | 0.84 | 4.69 | 84.04 | 1.15 | 5.26 | 8118 | 14,612 |
| *Semianthracite* | | | | | | | | | | | |
| Russellville, Ark. | 2.07 | 9.81 | 78.82 | 9.30 | 1.74.. | 3.62 | 80.28 | 1.47 | 3.59 | 7612 | 13,703 |
| Blacksburg, Va. | 0.73 | 10.55 | 69.92 | 18.80 | 0.66 | 3.60 | 72.23 | 0.69 | 4.02 | 6929 | — |
| Carbon Mt., Behring River, Alaska | 2.95 | 6.81 | 75.74 | 14.50 | 1.08 | 3.69 | 74.09 | 1.18 | 5.46 | 7104 | 12,787 |
| Lopez, Pa. | 3.16 | 8.59 | 78.08 | 10.17 | 0.67 | 3.47 | 79.49 | 1.10 | 5.10 | 7431 | 13,376 |
| *Anthracite* | | | | | | | | | | | |
| Scranton, Pa. (culm) | 2.08 | 7.27 | 74.32 | 16.33 | 0.77 | 2.81 | 75.21 | 0.80 | 4.08 | 6929 | — |
| Mammothseam, St. Nicholas, Schuylkill Co., Pa. | 2.80 | 1.16 | 88.21 | 7.83 | 0.80 | 1.89 | 84.36 | 0.63 | 4.40 | 7388 | 13,298 |
| Crested Butte, Colo. | 3.25 | 3.65 | 87.72 | 5.38 | 0.94 | 3.50 | 84.53 | 1.53 | 4.12 | 7795 | 14,031 |
| Carbon Mountain, Alaska | 13.89 | 5.01 | 73.87 | 7.23 | 0.82 | — | — | — | — | 6743 | 12,137 |
| Tower City, Pa. | 3.33 | 3.27 | 84.28 | 9.12 | 0.60 | 3.08 | 81.35 | 0.79 | 5.06 | 7417 | 13,351 |
| Madrid, New Mexico | 5.70 | 2.18 | 86.13 | 5.99 | 0.69 | 2.38 | 82.87 | 1.26 | 6.81 | 7371 | 13,268 |

The following analyses will also serve to illustrate the composition of the ash:—

ASH ANALYSES

| | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $MnO_2$ | $SO_2$ | $Na_2O$ $K_2O$ | Cl | $P_2O_5$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Peat, average of several . . . | 25.50 | 5.78 | 18.70 | 24.00 | 3.20 | —— | 7.50 | 1.72 | .60 | 2.56 |
| Lignite . . . | 30.14 | 13.48 | 11.70 | 23.59 | .88 | 3.32 | 14.22 | —— | —— | —— |
| Bituminous coal | 34.32 | 14.62 | 22.94 | 14.85 | 1.42 | 1.16 | 10.97 | —— | —— | —— |

Sulphur is an objectionable impurity in steaming coals on account of its corrosive action on the boiler tubes. It is also undesirable in coals to be used for metallurgical purposes and gas manufacture.

The table on page 9 gives the proximate and ultimate analyses of a number of coals from different parts of the United States and Canada, the analyses being arranged according to grades.[1]

**Origin of Coal** (1–12$a$).— It has been shown that there are gradations between unquestioned plant beds and mineral coal, and that coal, besides containing the same elements as plant tissues, although in different proportions, often shows the presence of plant fibers, leaves, stems, seeds, etc., in addition to their occurrence in the associated rocks. Moreover, stumps of trunks of trees are sometimes found standing upright in the coal, with their roots penetrating the underlying bed of clay (6, 9), just as trunks of trees at present stand in bogs. While these facts point unmistakably to a vegetable origin of coal, it is less easy to understand the exact manner in which the great accumulations of vegetable matter have been made, and the changes from plant tissue to mineral coal. The several points requiring explanation therefore are: (*a*) conditions of accumulation, (*b*) character of organisms forming coal, (*c*) conditions of initial process of organic decomposition, and (*d*) nature of forces bringing about subsequent alteration of organic residues.

*Conditions of Vegetable Accumulation* (4$a$, 5, 9, 12, 12$a$). — While it is generally agreed that coal originated by the accumulation and slow decay of vegetable matter under water, a difference of opinion may exist as to whether the vegetable matter accumulated by growth in place (*autochthonous origin*) or by the

[1] The type names are in each case those given in the reports from which analyses were taken.

PLATE III
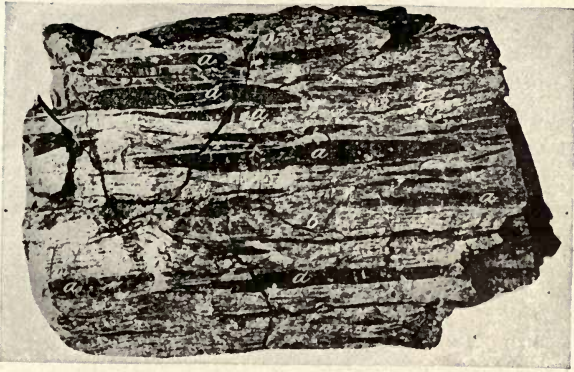


FIG. 1.—Subbituminous Coal from Marshall, Colo.

*a.* Jet-black Lenses represent Stems Flattened by Pressure.
*b.* Dull layers, composed of Decayed Wood, Cuticles, Leaf Laminæ, etc.



FIG. 2.—" Mineral Charcoal."   (*After White and Thiessen, Bur. Mines, Bull.* 38.)

accumulation of transported vegetable matter (*allochthonous origin*).

As favoring the former theory we have the perfect preservation of many plant remains, a condition unlikely to exist if the material had been transported by streams, and the upright trunks in coal, with roots extending into the under clay, the latter supposedly representing the old soils or bottom muds of the swamps in which the coal-forming plants grew.

It is true, however, that allochthonous coals may exist, because some formations have local coal deposits occurring as thin wedges or lenses, derived from drifting plant material, with no roots penetrating the under clay. Indeed, some recent writers, among them Jeffrey in the United States (4a, 24b), have argued most strongly in favor of this view, because of the high spore content of many coals, which could only be due to accumulation in open water. The process is a slow one, but its analogue is to be seen in modern lakes.

Possibly also some deposits represent vegetable accumulations in delta deposits, or in lacustrine beds, as in the case of the Commentry fresh-water basin of France [1] or the Tertiary coals of the Frazer delta in British Columbia.

A difficulty to be overcome is the fact that while peat bogs are known covering several square miles of area, they are not comparable in size to the extensive coal deposits found in many parts of the world.

Perhaps the most perfect resemblance to coal-forming conditions is that now found in the Dismal Swamp of Virginia and North Carolina, or the Great Sumatra Swamp.[2]

In the former the area is very level, though with slight depressions in which there is either standing water or swamp conditions. Indeed, there is such a general interference with free drainage that the swamp areas are extensive, and vegetable accumulations are taking place, a thickness of 8–12 feet of peat having formed. There is, moreover, a general absence of sediment.

In the latter swamp, which covers more than 80,000 hectares (308.8 square miles) there is being deposited a high-grade peat reaching a depth of 9 meters, and having only 6.39 per cent ash in the dry fuel.

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[1] Stevenson, Ann., N. Y. Acad. Sci., XIX: 161, 1910.
[2] Potonié, Entstehung der Steinkohle, 5th Ed.: 154, 1910.

If either of these areas were submerged beneath the sea, the vegetable remains would be buried and a further step made toward the formation of a coal bed. Re-elevation, making a coastal plain, would permit the accumulation of another coal bed above the first, and this process might be continued again and again.

The evidence now at hand indicates that the vast deposits of peat which represent the first stage in coal formations were probably accumulated near tide level for the following reasons: (1) Marine beds are often intercalated in the coal measures, and are sometimes found overlying the coal; (2) brackish-water molluscs are found in some of the rocks of the coal basins; (3) the coal strata show a marked parallelism and a frequency of salt-water invasion.

The coal-forming plants were of fresh-water character, and the ingress of the sea was probably prevented either by the presence of barrier ridges which kept out the salt water, or in other cases a thick plant growth around the borders of the swamps may have prevented any serious inflow of salt water.

The presumption is, then, that in many cases the coal-forming plants grew in coastal or lacustrine swamps developed in regions of slight submergence of a very mature and broadly extended peneplain.[1]

Some peat swamps were probably located in vast deltas, but it is doubtful if such large vegetable accumulations took place in salt water, for although peat is known to be in process of formation in salt marshes, White (12a) says, " it does not seem clear that coal with so large a percentage of mother of coal, jet-like wood, etc., and with such pure carbonaceous matter, that is, containing such a moderate percentage of ash, as the coal in the Carboniferous of Illinois or Indiana, or that interbedded with marine or brackish water beds in Wyoming, was laid down in estuaries flooded by sea water."

A distinction is, however, sometimes made between: (1) *limnetic* coals, or those derived from plant remains accumulated in fresh water; and (2) *paralic* coals, or those derived from plant remains which collected in marshes near the sea border.

*Character of Organisms Forming Coal* (4a, 12, 12a, 24b). —

[1] Schuchert points to the persistent high sulphur content of the Mississippi Valley coals as significant, for he states that this element is always present in marine marshes and almost wanting in fresh-water ones.

Microscopic study of different coals shows that the material is composed of plant residues, consisting of the most resistant components of plants.

The three important recognizable constituents are *spores* or *canneloid*, modified wood or *lignitoid*, and to a less extent of relatively unmodified carbonized wood or *mineral charcoal* (*mother of coal*) (Plate III, Fig. 2). There may also be resins, and resin waxes.

Examination of lignites by White (12a) showed them to consist chiefly of woody material, the interstices being filled with debris of macerated plant refuse, comparable to many of the corresponding varieties of black amorphous peat, and composed of the more resistant residue of plant parts, such as woody fragments, resinous substances, spore and pollen eximes, cuticles and a cellulosic residue forming the binding substance.

Subbituminous coal shows greater density and higher concentration of resinous and cutinous substances, while stems, trunks or branches appear as layers or lenses of dark black, or jetty, glassy character, and characteristic luster (Plate III, Fig. 1).

These same jetty layers show in bituminous coal (Plate III, Fig. 1), while the dull laminæ between represent plant debris.

Cannel coal is formed almost entirely of spore eximes, the resins and cuticles forming only a small proportion of the mass. These spores were formerly mistaken by some for algæ, and it is now recognized that neither the latter nor any homogeneous fundamental jelly-like substance of this nature is present in bog-head, cannel, or any other coal.

*Conditions of Decomposition.* — Two stages may be recognized in the coalification process, viz., (a) the putrefaction stage, which is a biochemical process, and (b) the alteration or metamorphic stage, involving dynamo-chemical action.

When dead vegetable matter accumulates under water, it does not remain unchanged, but undergoes a deoxygenation and dehydrogenation process, which is accomplished by fermentation or maceration in which minute plants (bacteria) and also animals take part. As a result of this the plant tissues break down to a greater or less degree, depending on the stage of decay. The change may advance no further than to convert the mass into woody or fibrous peat, or it may go far enough to obliterate most of the plant structures, giving a somewhat jelly-like black

peat, which changes into the so-called amorphous coal. It is highly probable that the process of decay had not advanced to the same stage in all peats prior to their burial under sediment.

The decomposition of the original cellulose ($C_6H_{10}O_5$) of the plant tissue liberates substances such as $CH_4$, as well as $CO_2$, $CO$, $H_2O$, etc. It seems probable that the jellification process leads no further than peat, and that for the development of the later stages dynamo-chemical changes are necessary.

While in peat beds the lower layers are under gentle pressure, so that a bed 1 foot thick, when buried under 15 or 20 feet of other peat layers, may be reduced to about 1 inch in thickness, the real consolidation does not begin until it is buried under a greater weight of sediment.

Indeed, heat and pressure seem necessary for the change from lignite to bituminous coal, and long periods of time are apparently required for the slow changes that take place.

The process of change from lignite on is to be regarded as a dynamo-chemical one, which may in fact overlap the bio-chemical changes.

The first stage in the densification of peat under load is of this nature. Occluded gases are expelled, liquid putrefaction products forming the cementing paste or binder of the coal are partly hardened, and a reduction of the mass takes place.

As the change continues, there is a progressive devolatilization due to geodynamic processes, and while the exact changes and compounds evolved are not known, we do know that there is a reduction of the volatile combustible matter.

It has been commonly assumed that to produce the higher grades such as anthracite, strong folding was necessary, in order to develop sufficient heat and pressure for this degree of metamorphism. M. R. Campbell (2, 10) has, however, argued with apparent reason that while the chemical changes involved are induced by heat (of ordinary temperature), still these changes are retarded or prevented unless the structural conditions (presence of joints, etc.) are favorable for the escape of the gaseous products of this change.

Thus, for example, the Pennsylvania anthracites are formed not so much because of heat and pressure, but because of the cracking of the rocks which allowed thorough oxidation. The same amount of folding in the Pocono rocks of Maryland has not produced any anthracite, as the structural conditions were not favorable for the free escape of the gases.

Cases are known, where the heat causing the changes is intense and local, as in the Cerrillos coal field of New Mexico (80), or the Crested Butte district of Colorado (55), where bituminous coal has been locally changed to anthracite by a near-by igneous intrusion.

Some geologists, notably J. J. Stevenson, have argued that the anthracite coal has not been developed from bituminous coal by metamorphism, but that the volatile constituents were partly removed by longer exposure of the vegetable matter to oxidation before burial (11). Among paleobotanists there is also a difference of opinion as to whether the succession, peat, lignite, etc., is a strictly lineal one.

David White (12a) has recently again called attention to the thrust-pressure hypothesis, which postulates that the devolatilization of coal is the result of thrust pressure.

He points out that as a result of regional thrust pressure, essentially horizontal in direction, the coal has become dense, lithified, jointed, further reduced in volume, schistose and even crushed, or possibly cemented, while gradually becoming progressively dehydrated, devolatilized, and concentrated both as to volume and as to its combustible matter.

This pressure, acting on and transmitted with diminishing (progressively compensated) force through the buried and loaded coal-bearing strata, has converted lignite successively into subbituminous, semibituminous, semianthracite, anthracite, and even into graphitic coal.

The degree of devolatilization depends, other things being equal, on the intensity and the duration of the pressure movement, a long moderate pressure being as effective as a short intense one.

In considering the evidence bearing on this hypothesis White points out that we must remember that: (1) The devolatilization of coal is still going on in many parts of the world, the rate being almost insensible in some districts, but clearly perceptible in others, where active gas production is observed in certain mines. (2) There is no sharp line of separation between the different kinds of coal, the intergradation being complete between peat, lignite and semigraphitic coal. (3) The physical evidences of thrust pressure, such as jointing, cleavage, folding, faulting, crushing, etc., become in general more highly developed and conspicuous, not only in the coal, but also the enclosing rocks, as the alteration of the coal proceeds, and hence regions

of greater change in the coal show the physical effects of greater pressure.

In regions of initially equal stress the metamorphism will, other things being equal, be greater in districts where no buckling or overthrusting of beds has permitted escape from the intensity of the thrust.

The following theory of coal formation has recently been advanced by Dowling (4). The death of a plant is marked by the loss of power to form oxidized hydrocarbon compounds, consequently chemical reactions are set up in the material of the dead plant. The formation of compounds of oxygen and carbon is the first evidence of decay. With the escape of these gases the hydrocarbons left behind become unstable, and loss of marsh gas follows. If fermentation accompanies decay, new hydrocarbon compounds are formed by this parasitic form of life and the reduction of oxygen is accomplished without great loss of hydrogen, which is the element that gives character to the material, especially when in the coal stage. When solidified by superposed load, the fermentation is arrested and pressure and heat cause the subsequent alteration. Static pressure favors the combination of oxygen with carbon or hydrogen. Heat causes the combination of carbon with oxygen or hydrogen. Pressure effects the alteration without loss of carbon, while heat wastes it.

*Chemical Changes.* — The chemical changes referred to above may be illustrated by the following chemical equations (19, p. 26):

| VEGETABLE TISSUE= | | LOSS BY DECOMPOSITION | | | COALS |
|---|---|---|---|---|---|

(1) $5 C_6H_{10}O_5 = 6 CO_2 + CO + 3 CH_4 + 8 H_2O + C_{20}H_{22}O_4$
     Cellulose          Carbon oxides      Marsh gas   Water        Lignite

(2) $6 C_6H_{10}O_5 = 8 CO_2 + CO + 5 CH_4 + 10 H_2O + C_{22}H_{20}O$
     Cellulose          Carbon dioxide     Marsh gas    Water       Bituminous

(3) $7 C_6H_{10}O_5 = 8 CO_2 + 4 CH_4 + 19 H_2O + C_{30}H_{16}O$
     Cellulose          Carbon dioxide   Marsh gas   Water   Semibituminous
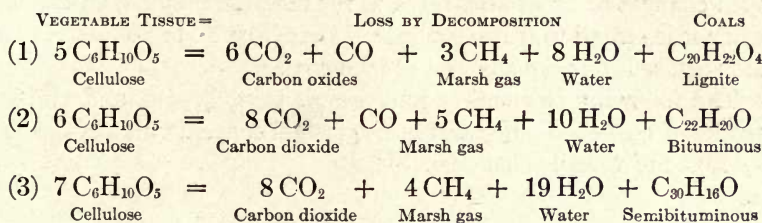
These equations are not intended to indicate that there is necessarily a direct passage from cellulose to semi-bituminous coal, without the development of intermediate stages; and to bring out this lineal succession as well as to show the changes by a graphical method we may use the following diagram (Fig. 1) prepared by the late Professor Newberry.

In this diagram the rectangle *ABCD* represents a given volume of fresh vegetable matter, which contains a small percentage of mineral matter, the rest being organic substances consisting roughly of 50 per cent carbon (*EFCD*) and 50 per cent hydrogen, oxygen, and nitrogen (*ABEF*). In the change from fresh vegetable tissue to peat, part of these four elements pass off as gaseous compounds,

so that the remaining volume of peat is less ($BGDH$) than the original volume of vegetable matter ($ABCD$). Since, however, H, O, and N have passed off in larger amounts than the carbon, the percentage of the latter in the peat will be higher than it was in the fresh plant tissue. (Compare $BFGI$ and $FIDH$ with $ABEF$ and $EFCD$.) The actual weight of mineral matter will be the same,
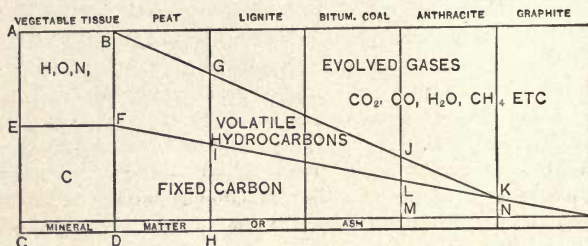


FIG. 1. — Diagram showing changes occurring in passage of vegetable tissue to graphite. (*After Newberry.*)

but its percentage will be larger. This change, continued, will result finally in anthracite, the last of the coal series, in which the per cent of carbon ($LKMN$) is high and that of the other organic elements low ($JKL$). The amount of compression that occurs in such changes as those illustrated in the diagram may be understood when it is stated that it is estimated that from 16 to 30 feet of peat are required to make one foot of true coal.

The following elementary analyses of peat, lignite, and various grades of coal clearly illustrate this gradual concentration of carbon by losses of volatile elements.

### ELEMENTARY ANALYSES OF COALS

| KIND | C | H | O | N | S | ASH | MOISTURE |
|------|------|------|-------|------|------|-------|----------|
| Peat . . . . . . . . | 59.47 | 6.52 | 31.51 | 2.51 | — | — | 22 |
| Lignite . . . . . . | 52.66 | 5.22 | 27.15 | .71 | 2.02 | 12.24 | — |
| Subbituminous . . . . | 58.41 | 5.06 | 28.99 | 1.09 | .63 | 4.79 | — |
| Bituminous . . . . . | 82.70 | 4.77 | 9.39 | 1.62 | .45 | 1.07 | — |
| Semibituminous . . . | 83.14 | 4.58 | 4.65 | 1.02 | .75 | 5.86 | — |
| Anthracite . . . . . | 90.45 | 2.43 | 2.45 | — | — | 4.67 | — |

**Classification of Coals.** — At the present time a number of kinds of coal are recognized in the United States and Canada, whose differentiation depends on their physical and chemical properties. But even these few type names are often used in a rather loose way.

Perhaps the first important attempt at classification was that of P. Frazer, Jr., based on the fuel ratio (17). This was as follows: —

|                 |                    | FUEL RATIO |
|-----------------|--------------------|------------|
| Anthracite      | . . . . . . . . .  | 100–12     |
| Semianthracite  | . . . . . . . . .  | 12– 8      |
| Semibituminous  | . . . . . . . . .  | 8– 5       |
| Bituminous      | . . . . . . . . .  | 5– 0       |

Objections which have been urged against this are that all coals with a fuel ratio of less than 5 are grouped into one class and no provision made for lignite. It also groups good and poor bituminous coals together.

Collier (15) proposed that all coals having a moisture content of over 10 per cent should be classed as lignite and those with less as bituminous, but this differentiation has been shown to be unreliable.

M. R. Campbell, while agreeing to the usefulness of the fuel ratio classification for coals above the bituminous grade, criticised its application to coals of this type or lower ones, and suggested a provisional classification based on the carbon-hydrogen ratio (14).[1]

| GROUP | $\dfrac{C}{H}$ |
|-------|----------------|
| A (Graphite) . . . . . . . . . . | $\infty$ |
| B⎫ Anthracite . . . . . . . . | ?–30 (?) |
| C⎭ | |
| D Semianthracite . . . . . . . | 26 (?)–23 (?) |
| E Semibituminous . . . . . . . | 23 (?)–20 |
| F⎫ | 20–17 |
| G⎪ Bituminous . . . . . . . . | 17–14.4 |
| H⎬ | 14.4–12.5 |
| I⎭ | 12.5–11.2 |
| J Lignite . . . . . . . . . . | 11.2–9.3 |
| K Peat . . . . . . . . . . . | 9.3–? |
| L Wood . . . . . . . . . . . | 7.2 |

This table is likewise faulty, as it does not completely separate the peats, lignites, subbituminous, and even some of the bituminous coals.

Parr (19), in attempting to make a satisfactory classification, points out that the term *volatile combustible* is incorrect as it consists of combustible hydrocarbons and noncombustible H, O, and N. Thus in a Pocahontas coal with 18.70 per cent volatile combustible, 14.5 per cent is hydrocarbons and 4.2 per cent hydrogen, oxygen, and nitrogen. Again, a North Dakota lignite had 41.91 per cent volatile combustibles, made up of 20.28 per cent hydrocarbons and 21.63 per cent hydrogen, oxygen, and nitrogen. In a logical classification, therefore, allowance should be made for this inert volatile matter.

In Parr's classification the terms used are: $vc$, or volatile carbon unassociated with hydrogen, obtained from $C - fc$ (total carbon minus fixed carbon);

[1] Campbell found that subdivisions based on total carbon, total hydrogen, and calorific value were all unsatisfactory.

$C$, or total carbon as determined by analysis; and *inert volatile matter*, obtained by subtracting from 100 per cent the sum of total carbon, available hydrogen,[1] sulphur, ash, and water.

It will be seen that Parr's classification, which follows, requires data from both the elementary and the proximate analysis of the coal.

## PARR'S CLASSIFICATION.

| | | | | |
|---|---|---|---|---|
| Coals | Anthracitic | Anthracites Proper | | Ratio $\frac{vc}{C}$ below 4 %. |
| | | Semianthracite | | Ratio $\frac{vc}{C}$ between 4 % and 8 %. |
| | | Semibituminous | | Ratio $\frac{vc}{C}$ from 10 % to 15 %. |
| | Bituminous | Bituminous Proper | A | Ratio $\frac{vc}{C}$ from 20 % to 32 %. Inert volatile from 5 % to 10 %. |
| | | | B | Ratio $\frac{vc}{C}$ from 20 % to 27 %. Inert volatile from 10 % to 16 %. |
| | | | C | Ratio $\frac{vc}{C}$ from 32 % to 44 %. Inert volatile from 5 % to 10 %. |
| | | | D | Ratio $\frac{vc}{C}$ from 27 % to 44 %. Inert volatile from 10 % to 16 %. |
| | | Black Lignites | | Ratio $\frac{vc}{C}$ from 27 % up. Inert volatile from 16 % to 20 %. |
| | | Brown Lignites | | Ratio $\frac{vc}{C}$ from 27 % up. Inert volatile from 20 % to 30 %. |

Grout expresses the fuel ratio as follows (18):

$$\frac{\text{Fixed carbon}}{100 - \text{Fixed carbon}}.$$

He makes the following classification based on pure coal:—

| | |
|---|---|
| Graphite . . . . . . . | Fixed carbon, over 99 per cent. |
| Anthracite . . . . . . | Fixed carbon, over 93 per cent. |

[1] That part of hydrogen content, excluding the hydrogen united with oxygen to form water, which is free to enter into combustion with oxygen for the production of heat.

| | |
|---|---|
| Semianthracite . . . . . | Fixed carbon, 83 per cent to 93 per cent. |
| Semibituminous . . . . . | Fixed carbon, 73 per cent to 83 per cent. |

Bituminous

| | |
|---|---|
| High grade . . . . . . | Fixed carbon, 48 per cent to 73 per cent.<br>Total carbon, 82 per cent to 88 per cent. |
| Low grade . . . . . . | Fixed carbon, 48 per cent to 73 per cent.<br>Total carbon, 76.2 per cent to 82 per cent. |
| Cannel . . . . . . . | Fixed carbon, 35 per cent to 48 per cent.<br>Total carbon, 76.2 per cent to 88 per cent. |
| Black lignite . . . . . | Fixed carbon, 35 per cent to 60 per cent.<br>Total carbon, 73.6 per cent to 76.2 per cent. |
| Brown lignite . . . . . | Fixed carbon, 30 per cent to 55 per cent.<br>Total carbon, 65 per cent to 73.6 per cent. |
| Peat and turf . . . . . | Fixed carbon, below 55 per cent.<br>Total carbon, below 65 per cent. |

Wood

D. B. Dowling (16) notes that one objection to Campbell's $\frac{C}{H}$ classification is the necessity for having an elementary analysis, which is rarely made, costly, and time requiring. As a substitute for Campbell's classification, he substitutes what he has provisionally termed the " split volatile ratio " viz. $\dfrac{\text{Fixed carbon} + \frac{1}{2} \text{ volatile combustible}}{\text{Moisture} + \frac{1}{2} \text{ volatile combustible}}$.

An arrangement of a series of coals by this method and also Campbell's $\frac{C}{H}$ ratio does not indicate great disagreement; moreover, Dowling's classification has the advantage of being based on the proximate composition. He makes the following subdivisions: —

| GROUP | SPLIT VOL. RATIO |
|---|---|
| Anthracite . . . . . . . . . . . . . | 15 up |
| Semianthracite . . . . . . . . . . . . | 13–15 |
| Anthracite coal . . . . . . . . . . . | 10–13 |
| High carbon bituminous . . . . . . . | 6–10 |
| Bituminous . . . . . . . . . . . . | 3.5–6 |
| Low carbon bituminous . . . . . . . | 3–3.5 |
| Lignitic coal . . . . . . . . . . . | 2.50–3 |
| Lignite . . . . . . . . . . . . . | 1.00–2.50 |

More recently, Campbell has suggested the recognition of two classes of coal below bituminous, calling the upper grade "subbituminous" and the lower grade "lignite." He suggests that the manner of weathering be used as a criterion for separating the bituminous from the subbituminous, the former cleaving into prisms, while the latter checks irregularly on drying, and when weathered on the outcrop cleaves into plates parallel to the bedding. The subbituminous coals with their black color he claims can be distinguished from lignites, because the latter are brown.

*White's Classification.* — White (20) has shown that if a series of coals of different ages, kinds, and regions are plotted according to the C : (O + ash) ratios and calorific values as components, they describe a curve, which shows a close relation between the increase of the above mentioned ratio and the calorific power. Weathered coals, those having over 78 per cent fixed carbon in pure coal, and the boghead-cannel group (high in hydrogen) are the greatest variants. Oxygen is ranked with ash in this ratio because the two are approximately equal in anti-calorific potency. This ratio cannot be used as a basis for separation into kinds, such as peat, lignite, etc.

**Structural Features of Coal Beds.** — *Outcrops* (24, 25). — The outcrop of a coal bed is usually easily recognizable on account of its color and coaly character; but unless the exposure is a rather fresh one, the material is disintegrated and mellowed, the wash from it mingling with the soil, and if the outcropping bed is on a hillside, often extending some feet down the slope. This weathered outcrop has been termed the "smut" or "blossom" by coal miners. In

areas where the beds have been tilted and the slopes are steep, the outcrops of coal can usually be easily traced; but in regions where the dip is low and the surface level, the search for coal is often attended with difficulty, which is increased if the country is covered with glacial drift. In such cases boring or pitting is commonly resorted to.

The number of coal beds found in any given region varies, and may at times be large. Thus in the Pennsylvania section, as many as 20 beds are known; in Alabama, at least, 55 have been counted, but not all are workable; while in Indiana there are 25, of which 9 are minable over large areas. The beds are rarely parallel, and, moreover, thin out if followed any distance.

*Associated Rocks.* — Most coal beds are interbedded with shales, clays, or sandstones, though conglomerates or limestones are at times also found in close proximity, the latter sometimes even when of marine character, resting directly on them. Coal beds are often underlain by a bed of clay, which in some regions is of refractory character (Fig. 2); but the widespread belief that all these under clays are fire-clays is unwarranted.

*Variations in Thickness.* — Coal beds or "seams" are rarely of uniform thickness over

FIG. 2. — Section in coal measures of western Pennsylvania, showing fire clay under coal beds. (*After Hopkins.*)

large areas; indeed, a bed which is of sufficient thickness to work in one mine may be so thin in a neighboring one as to be scarcely noticeable. This irregularity is in some cases due to variations in thickness of vegetable accumulations, in other cases to local squeezing of the coal bed subsequent to its formation.
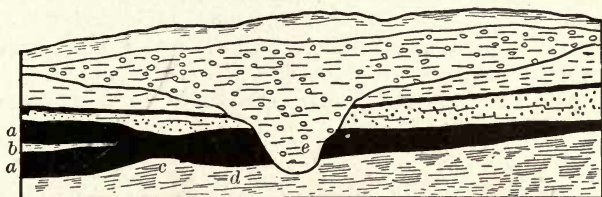


FIG. 3. — Section showing irregularities in coal seam. *a*, split; *b*, parting of shale; *c*, pinch; *d*, swell; *e*, cut out.

These thinnings and thickenings are commonly called "pinchings" and "swellings" (Fig. 3). In regions of pronounced folding, the beds are usually found in separate synclinal basins, the intervening anticlinal folds having been worn away.

While coal beds may vary in thickness from a mere film, to even more than 100 feet in extreme cases, they are rarely over 8 or 10 feet thick.

The Mammoth seam of the Pennsylvania anthracite region is 50 to 60 feet thick. The Commentry basin of central France contains a single bed of Permian coal that locally exceeds 80 feet in thickness. But on one side of the basin the coal splits up into six beds separated by sand and shales.
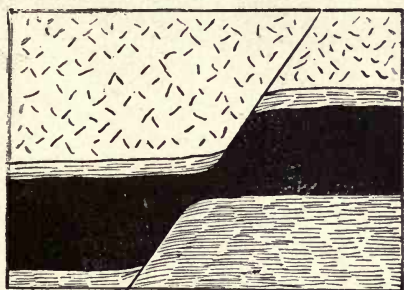


FIG. 4.—Section of faulted coal seam. (*After Keyes, Ia. Geol. Surv., II.*)

This indicates that coal accumulation went on continuously on one side of the basin, but was interrupted six times by sand deposits on the other side.

*Other Irregularities.* — Splitting (Fig. 3) is a common feature of many coal seams. The Mammoth bed, so prominent in most of the anthracite basins of Pennsylvania, splits into three separate beds in the Wilkesbarre basin. This splitting is caused by the appearance of beds of shale (called "slate" by coal miners), which often become so thick as to split up the coal seam into

two or more beds. When narrow, such a bed of slate is called
a parting. The Pittsburg seam of western Pennsylvania shows
a fire-clay parting or " horseback " from 6 to 10 inches over
many square miles.

An interesting case of parting is found in the 13-foot seam at Inverness,
Nova Scotia. At the outcrop this showed three shale partings, of 1 foot,
9 inches and 11 inches respectively. At 2500 feet down the dip, these
partings had increased to 19, 3, and 22 feet respectively. A 7-foot seam,
lying 284 feet below the 13-foot one, maintained its thickness, however,
for this same distance on the dip.

A split may occasionally be caused by overthrust folds as
shown in Fig. 5.
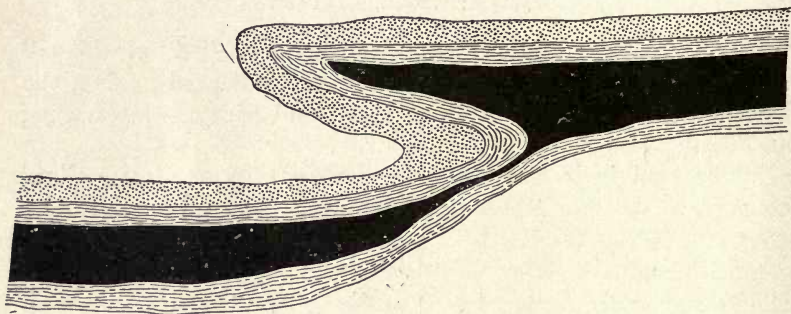


Fig. 5.—Section of coal bed, showing the development of a " split," due to an
overthrust roll. (*Pa. Top. and Geol. Surv., Rep.* 10.)

In addition to these " slate " partings, which run parallel with
the bedding, others are often encountered which cut across the beds
from top to bottom. These in some cases represent erosion channels
formed in the coal during or subsequent to its formation, and later
filled by the deposition of sand or clay. In other cases they are due
to the filling of fissures formed during the folding of the strata.

Coal beds may pass into shale, the latter representing possibly
islands of mud or ridges which arose above the level of the marsh in
which the coal plants accumulated.

Faulting (Fig. 4) is not an uncommon feature of coal beds,
and the coal is sometimes badly crushed on either side of the line of
fracture. The amount of throw and the number and kinds of faults
may vary, so that one might expect normal, reverse, overthrust,
and even step faults.

PLATE IV. — Map of coal f

BITUMINOUS COAL | LIGNITE

Areas that may contain workable coal beds | Areas probably containing workable coal beds under such heavy cover as not to be available at present | Areas containing workable lignite beds | Areas that may contain workable lignite beds

States. (U. S. Geol. Survey.)

**Weathering of Coals.** — Parr and Hamilton (27), as a result of their investigations of the weathering of coal, concluded that submerged coal does not lose appreciably in heat value, but that outdoor exposure results in a loss of heating value varying from 2 to 10 per cent. Dry storage is only of advantage for high sulphur coals, where the disintegrating effect of sulphur in process of oxidation facilitates escape of hydrocarbons by oxidation of the same. Storage losses usually appear to be complete at end of five months.

**Coal Fields of the United States.**[1] (Pl. IV.) — Coal in commercial quantities occurs in thirty-three states and territories, as well as in Alaska. These occurrences can be grouped into the following fields:

|  | AREA, SQ. MI. |
|---|---|
| (1) *Appalachian*, including parts of Pennsylvania, Ohio, Maryland, Virginia, West Virginia, Eastern Kentucky, Tennessee, Georgia, and Alabama | 69,755 |
| (2) *Atlantic Coast Triassic*, including parts of Virginia and North Carolina | 210 |
| (3) *Eastern Interior*, including parts of Indiana, Illinois, and Western Kentucky | 47,000 |
| (4) *Northern Interior*, including a part of Michigan | 11,000 |
| (5) *Western Interior*, including parts of Iowa, Missouri, Nebraska, Kansas, Oklahoma, Arkansas, and Texas | 74,900 |
| (6) *Gulf Coast Lignite Field*, including portions of Arkansas and Texas | 2,100 |
| (7) *Rocky Mountain field*, including parts of Colorado, Arizona, New Mexico, Utah, Wyoming, Idaho, Montana, North Dakota, South Dakota | 126,022 |
| (8) *Pacific Coast Field*, including parts of Washington, Oregon, and California | 1,900 |
|  | 332,887 |
| (9) *Alaska* | 1,210 |

The estimates of areas given above are from calculations made by the United States Geological Survey, and are to be regarded as fairly accurate, but some of these fields may be extended in the future by the development of areas now classed as unproductive. This applies especially to those in which the coal lies too deep to be profitably mined at present. It is a noteworthy fact that the production of the fields is by no means proportional to their areas (compare above list with table, p. 54). Proximity to markets, value of the coal for fuel, and relative quantity of coal per square mile of productive area are factors of importance in determining the output of a field.

[1] The Rhode Island area of graphitic anthracite, formerly included in this list, is referred to under Graphite.

**GEOLOGIC AND GEOGRAPHIC DISTRIBUTION OF COAL IN UNITED STATES AND ALASKA\***

Column groups: *Carboniferous* = Mississippian + Pennsylvanian (Pottsville, Alleghany, Conemaugh, Monongahela) + Permian; *Cretaceous* = Colorado, Montana, Lance; *Tertiary* = Eocene, Miocene, Pliocene.

| Field | State | Mississippian | Pottsville | Alleghany | Conemaugh | Monongahela | Permian | Triassic | Jurassic | Colorado | Montana | Lance | Eocene | Miocene | Pliocene |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Appalachian | Pennsylvania | ⋯ | +×× | +×× | +×× | +×× | +×× | | | | | | | | |
| | Ohio, Md. | ⊙ ⋯ × | +×× +○ | +× | +× | +× | +× | | | | | | | | |
| | Virginia | ⋯ | ×× | × | × | × | × | | | | | | | | |
| | West Virginia | ⋯ | ××× | ×× | ×× | ×× | | | | | | | | | |
| | Kentucky | ⋯ | ××× | ××× | | | | | | | | | | | |
| | Ga., Ala., Tenn. | ⋯ | ××× | | | | | | | | | | | | |
| Triassic | Virginia | | | | | | | ×× ⊙ | | | | | | | |
| | North Carolina | | | | | | | ×× | | | | | | | |
| N. Int. | Michigan | | × | × | | | | | | | | | | | |
| E. Int. | Ill., Ind., Ky. | | × | × | ×? | ×? | | | | | | | | | |
| W. Int. | Iowa | ⋯ | ××× | ××× | ×× | ×× | | | | | | | | | |
| | Kansas | ⋯ | ××× | ××× | ×× | ×× | | | | | | | | | |
| | Mo., Ark., Okla., Tex. | ⋯ | ⋮ ×× | ⋮ × | ⋮ | ⋮ | | | | | | | ⋯ | | |
| S. W. | Texas | ⋯ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋯ | × | ⋯ | ⊕ | | |
| Gulf Prov. | Ala., Miss., La., Arkansas | ⋯ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋯ | ⋯ | ⋯ | ⊕⊕ | | |
| Rocky Mt. | Colorado | ⋯ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ×⊕ ○□ | ×○ □□ + | ×× ⊕⊕⊕ ○⊕□□ +□×○□ | □ ⊕ □ | | |
| | Wyoming | ⋯ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋯ | ⋯ | ⊕⊕ □□ | ⊕ ⊕ | | |
| | Montana | ⋯ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋯ | ×× | ⊕□ ⊕ | × □ | | |
| | North Dakota | ⋯ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋯ | ⋯ | ⋯ | ⋯ | | |
| | Idaho | ⋯ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ ⋯ | ⋯ | ⋯ | ⋯ | ⋯ | | |
| | Nevada | ⋯ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋯ | ⋯ | ⋯ | ⋯ | | |
| | Arizona | ⋯ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋯ | ⋯ | ⋮ × | ⋯ | | |
| | New Mexico | ⋯ | ⋮ | ⋮ ⋮ × | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ □ × | □ × ○ ⊙ + | □ × × + | ⋮ × × × | □ × | ×? | |
| | Utah | ⋯ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | × ○ | + | ⋮ | □ × | | |
| Pac. Coast | California | | | | | | | | | | | | ⊕ ⊕ □ × ⊕ + ⊙ | ⊕ □ | ⊙ |
| | Oregon | | | | | | | | | | | | | | |
| | Washington | | | | | | | | | ⋯ | ⋯ | ⋯ | ⊕⊕ □× ×○ ⊙ | | |
| Alaska | | × | □ | ⋯ | ⋯ | ⋯ | | | ⊕ □ × | × | □ | | □ ⊕ × + ⊙ ○ | ⋯ | ⊙ |

\* Prepared by J. D. Thompson, Jr. +, anthracite; ⊙, semianthracite; ○, semibituminous; ×, bituminous; □, subbituminous; ⊕, lignite.
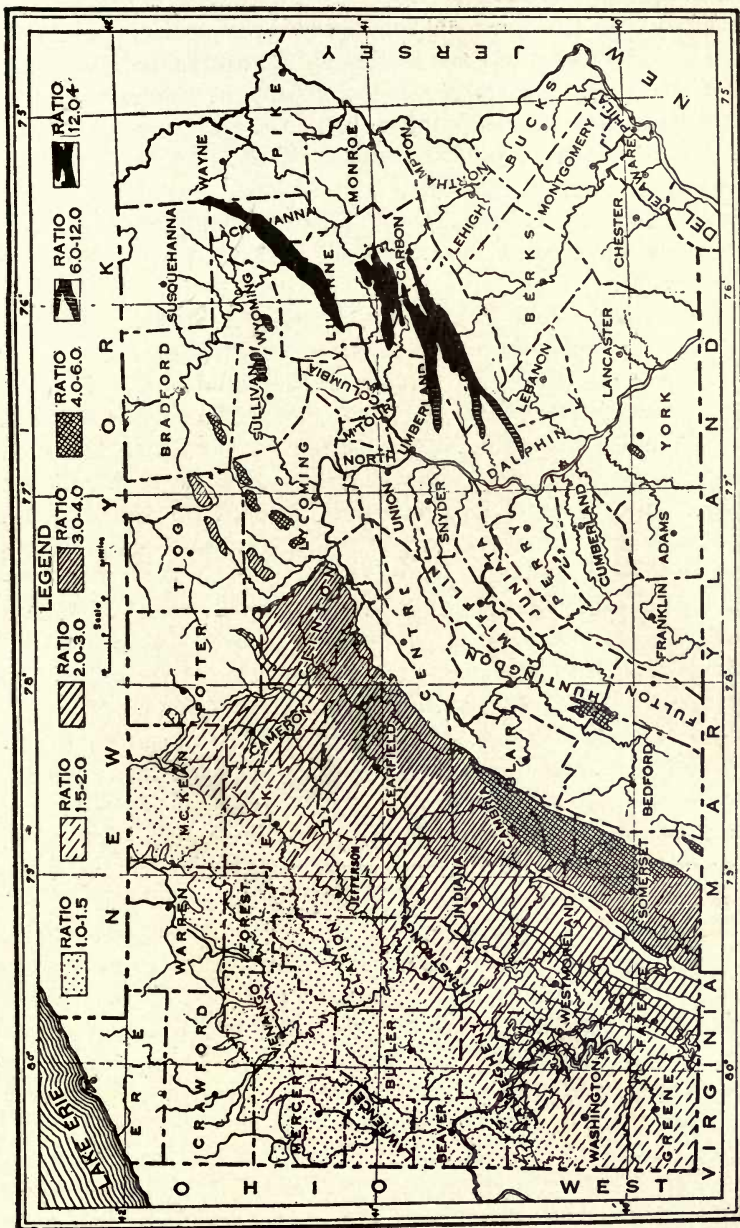
Plate V. — Map of Pennsylvania, showing distribution of coals by fuel ratios. (Pa. Geol. and Top. Com. Rept., 1906–1908.)

(27)

**Geologic Distribution of Coals in the United States.** — The accompanying table, which shows both the geologic and geographic distribution of coals in the United States, indicates that the Carboniferous coals are found chiefly in the eastern half of the country, and the younger coals in the western half. The separation of the Carboniferous coals into well-defined areas is probably the result of folding and erosion,[1] and to a certain extent, the same is true of the Rocky Mountain Coal fields. The latter have often been seriously disturbed by post-Cretaceous uplifts.

**Appalachian Field** (33, 36, 39, 91, 99, 101, 109, etc.). — This, the most important coal field in the United States, extends 850 miles, from northeastern Pennsylvania to Alabama. It shows a maximum of 180 miles at the northern end, narrows to less than 30 miles in Tennessee, and expands again to 85 miles in Alabama. About 75 per cent of its area contains workable coal. At the southern end the coal measures pass beneath the coastal plain deposits, and they may connect with the Arkansas Coal Measures beneath the Mississippi embayment.

Being closely associated with the Appalachian Mountain uplift, the coal measures of this region partake of the structural features of the Appalachian belt. The eastern margin of the field borders on a belt of steeply folded strata, forming the Appalachian Valley, and hence the coal-bearing formations are much folded here (Fig. 6, 10), while at the southern end of the field they are faulted in addition (Fig. 6). Extensive erosion following the folding of the Coal Measures has resulted in the development of a number of basins.

The Coal Measures of the Appalachian field consist of a great thickness of overlapping lenses of conglomerate, sandstone, limestone, shale, fire clay, and coal. The formations in general show a thinning from the eastern margin of the field, westward, as well as showing a decrease in the number and thickness of the beds. Owing to the lenticular character of the deposits, and the local thickenings, it is difficult to trace individual beds of coal over wide areas, or correlate sections at widely separated points.

The middle Carboniferous or Pennsylvanian includes most of the coal beds of the Appalachian field, but there are some also in the upper Carboniferous and in the Pocono of the lower Carboniferous or Mississippian.

[1] Ashley, Econ. Geol., II: 650, 1907.

The classic section of the Coal Measures, first worked out in Pennsylvania, was as follows:—

(1) Dunkard or Upper Barren Measures.

(2) Monongahela or Upper Productive Measures.

(3) Conemaugh] or Lower Barren Measures.

(4) Alleghany or Lower Productive Measures.

(5) Pottsville conglomerate.

At the time it was made the second and fourth members were thought to be the only ones carrying coal, and hence the name "Productive"; but since then the Pottsville has been found to be locally productive, and a few seams have been found even in the Barren Measures. By some the Dunkard series is now placed in the Permian.

The divisions named above are recognizable also in Ohio, West Virginia, and Maryland, but farther south the identification of all becomes difficult.

The Appalachian field is divisible into two parts of very unequal size, viz. (1) the anthracite field of northeastern Pennsylvania; and (2) the bituminous area, which occupies the balance of the field.[1]

*Pennsylvania Anthracite Field* (100). — This field (Fig. 7) lies in the northeastern part of the state, covering an area of about 3300 square miles, about one-seventh of which is underlain by workable coal measures. The field has four main subdivisions, known respectively as the northern, eastern middle, southern, and western middle. Intense folding (Fig. 8) has placed some of the coal in synclinal troughs, where it has been preserved from erosion which [has removed the coal from the intervening anticlines. Therefore the anthracite is found in a number of more or less separated narrow basins. It has been



Fig. 6. — Section across Coosa coal field, Alabama, showing folding and faulting characteristics of southern end of Appalachian coal fie'd. (*After Gibson, Ala. Geol. Surv., 1895.*)

*a.* BALD ROCK  *b.* CANE CREEK  *c.* VERTICAL MEASURES  *d.* WOLF CREEK MT.  *e.* BOUNDARY FAULT  *f.* CARACKER BEAM 4'-0"  *1.* COAL SEAM 4'-0"  *2.* COAL SEAM 4'-0"

1ST AND 4TH CONGLOMERATE    2ND CONGLOMERATE    BLACK SLATE    SANDSTONES SHALES, ETC.    COAL SEAMS

SEA LEVEL

[1] This includes some small areas of semianthracite.
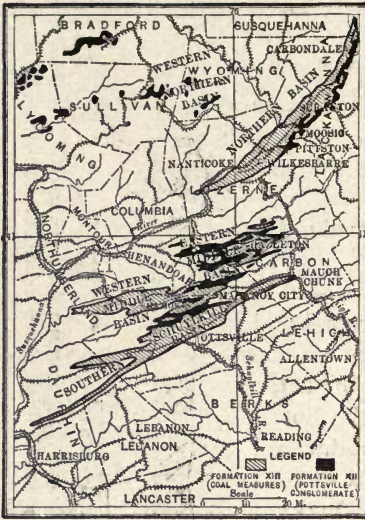
Fig. 7. — Map of Pennsylvania anthracite field. (*After Stoek, U. S. Geol. Surv., 22d Ann. Rept., III.*)

estimated that from 94 to 98 per cent of the coal originally deposited has been removed from this field by denudation.

The Coal Measures of the anthracite district consist of beds of sandstone, shale, and clay, with coal beds at intervals varying from a few feet to several hundred feet, though rarely exceeding 200 feet. The coal beds, which vary in thickness from a few inches to 50 or 60 feet, occur throughout the entire section of the Coal Measures, but are most important in the lower 300 to 500 feet. Among these the Mammoth is of importance, but splits in some areas.

The anthracite section, though not yet accurately correlated with the bituminous field of Western Pennsylvania, is nevertheless known to con-
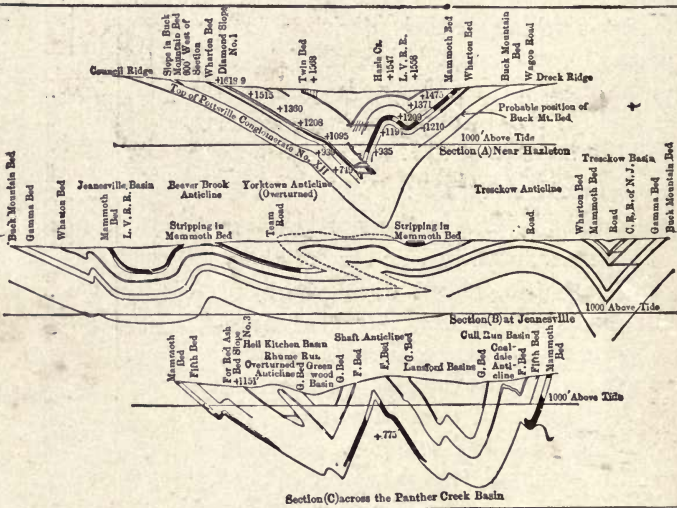


Fig. 8. — Sections in Pennsylvania anthracite field. (*After Stoek, U. S. Geol. Surv., 22d Ann. Rept., III.*)

tain the Pocono, Mauch Chunk, Pottsville, and Alleghany series, as well as some of the higher ones of the Coal Measures (39). The Pottsville conglom-

erate forms an important stratigraphic horizon, recognizable by its litho-
logical characters and bold outcrops.

The position of the coal beds and physical characteristics of the coal have
necessitated the use of special methods of mining and of treatment after
mining (100). Sharpness of folding and steep dips prevail, these intro-
ducing many mining problems not found in bituminous regions. When
brought to the surface, the anthracite consists of lumps varying in size and
mixed with more or less shaly coal called *bone*, so that before shipment
to market it is necessary to break, size, and sort it. This is done in a *coal
breaker* (Fig. 9), in which the coal is crushed in rolls and sized by screens,
while the slate is separated either by hand, automatic pickers, or jigs.
These breakers are a prominent feature of the anthracite region, and much
money has been spent in increasing their efficiency. As the result of years
of mining, the refuse from the breakers, consisting of a fine coal-dust and
bone, termed "*culm*," has accumulated in enormous piles. Much of it is
now being washed to save the finer particles of clean coal; and much is also
washed into the mines to support the roof, so that the pillars of coal, origi-
nally left for that purpose, can be extracted.

On account of its cleanliness and high fuel ratio, anthracite coal is
much prized for domestic purposes. Most of that mined is marketed in the
eastern and middle states, although small quantities are shipped to the
western states, especially those that can be reached by way of the Great
Lakes.
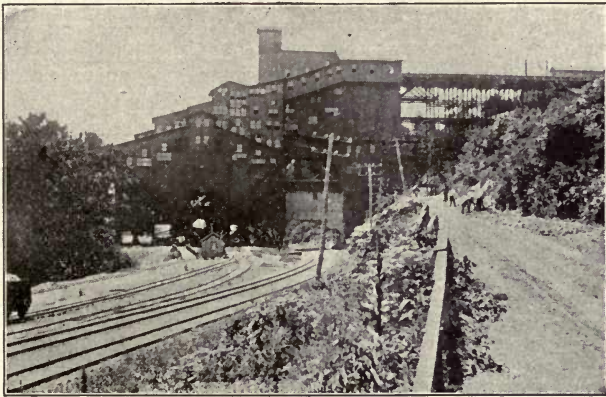


FIG. 9.— Coal breaker in Pennsylvania anthracite region.

**Appalachian Bituminous Area** (36, 41). *Pennsylvania.* — The
Pennsylvania bituminous field includes an area of about 12,000
square miles lying mostly in the western part of the state (Pl. V),
and having an exceedingly irregular boundary. In the north-
western part, where folding is slight, the coal measures form outliers,
capping the high hills and ridges; but to the eastward, the more
marked synclinal structure has resulted in the formation of a

strung out series of basins. The most northeastern areas are quite isolated, and include the Bernice (semi-anthracite), Barclay, and Blossburg basins, as well as an easterly one, the Broadtop (Pl. V).

The coals range in age from Pottsville to Dunkard, and in about four-fifths of the territory the thickness of the Upper Carboniferous rocks, including Dunkard, is less than 1000 feet, while in one-third it is under 500 feet (41). Faults are rarely found. On account of the variation in thickness of the sandstones and other rocks, splitting of coal seams, and other irregularities, correlation is difficult. But in a general way the beds above the Pittsburg seam appear to be more regular in their appearance and more constant in their distance from one another, than the beds in the lower part of the section. The number of coal seams recognized in the several series is as follows (99): —

Dunkard series, 1100–1200 feet thick, 12 coals
Monongahela, 200– 300 feet thick, 6 coals
Conemaugh, 500– 700 feet thick, 6 coals, mostly unimportant
Alleghany, 300 feet thick, 4 coals
Pottsville, several

The Alleghany yields about forty per cent of the bituminous coals mined in Pennsylvania. While most of the coal beds are of limited extent, the celebrated Pittsburg seam at the base of the Monongahela has an average thickness of 7 feet over about 2100 square miles of its area and an estimated tonnage of 9,641,792,907 short tons, thus making it one of the most important bituminous coal beds in the world. This same seam is also recognizable and important in Ohio, West Virginia, and Maryland.

*Ohio.* — In Ohio (40, 90–92) the five subdivisions of the middle and Upper Carboniferous are also recognized, and there are at least 16 coal beds, of which 6 are important. These include the Pomeroy,[1] Pittsburg, Meigs (Sewickley of Pennsylvania), Clarion, Lower Kittanning, Middle Kittanning, Upper Freeport, Wellston, and Block (Sharon). The Pittsburg coal is of high importance and the Middle Kittanning includes the well-known Hocking Valley coal.

*Maryland.* — In Maryland the coals lie in three broad northeast-southwest synclinal folds, the coal measures of these being separated by Mississippian or Devonian Rocks, exposed by erosion of the intervening anticlines. The eastern or Potomac basin is the most important of the three. The geologic position and number of coals is as follows: Monongahela, with Pittsburg (Elk Garden), Tyson, and Koontz coals; Conemaugh, 2 coals; Alleghany with Upper Freeport (Thomas or three foot), Middle Kittanning (Davis or six foot), Brookville (Parker), and Clarion (Bluebaugh); Pottsville, with two seams. The coals are good steaming fuels and will coke (71).

[1] Formerly regarded as Pittsburg, but shown by Bownocker to be equivalent of Redstone of Pennsylvania and West Virginia. (Ohio Geol. Surv., 4th ser., Bull. 9, p. 96, 1908.)

PLATE VI.
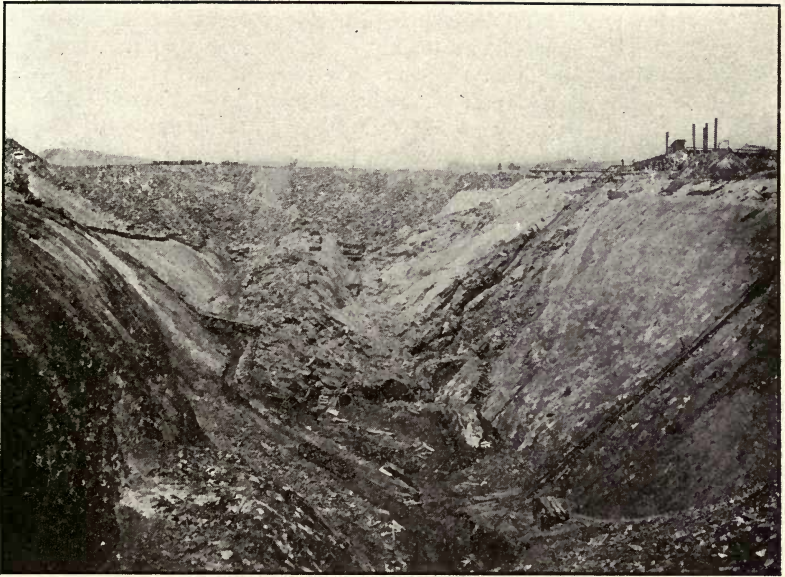


FIG. 1. — Pit working (strippings) near Milnesville, Pa. The Mammoth seam is uncovered in bottom of pit.
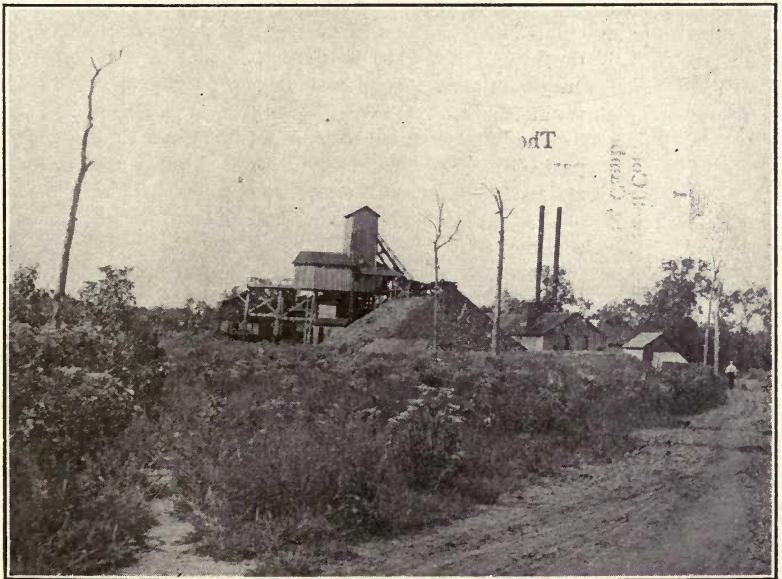


FIG. 2. — View in Arkansas coal field. (*H. Ries, photo.*)

(33)

*West Virginia.* — In this state the Coal Measures occupy an irregular rectangle extending from the Alleghany Mountain region northwestward to the Ohio River. The deepest part of the Appalachian basin takes a southwest course across the state, the axis rising to the southward. From this the strata rise to the northwest, while to the southeast the basin shows a series of folds of increasing steepness and height towards the eastern boundary of the fields.

The coal beds range from the Pocono to the Dunkard in age. The Pocono contains some unimportant beds of anthracite along the eastern border of the field, but westward the formation is noted for its petroleum and absence of coal.

The Pottsville carries the coals of the New River and Pocahontas series, these underlying an area of about 2600 square miles in the southeastern and eastern part of the field. These coals are of high quality, being low in sulphur and ash. In northern West Virginia the Alleghany series carries several coal beds, but with one exception these disappear to the southwestward. The Conemaugh carries two coal beds of importance, while the Monongahela carries six distinct beds, including the famous Pittsburg seam. No coals of much importance are found in the Dunkard.

*Virginia* (111). — The coals of the Mountain Province are of either Mississippian or Pennsylvanian age. The first or least important forms a belt of small areas of either semibituminous or semianthracite character extending from Wythe to Frederick counties, but the only one of much importance is the Montgomery-Pulaski counties area.

The Pennsylvanian coals lie in the extreme southwestern part of the state in the Cumberland Plateau region, and are the most important producers. The two chief fields are the Pocahontas or Flat Top and the Big Stone Gap coal fields.

The coal measures, which are probably mostly of Pottsville age, show comparatively little disturbance, although they lie immediately west of the highly folded rocks of the Great Valley (Fig. 10), but the Pocahontas field is abruptly terminated on the east by a fault. In the Pocahontas field there are at least six workable beds; the coal is of excellent quality for steaming purposes, shows often a remarkably low ash content, and makes a good coke. The Big Stone Gap field, which extends into Kentucky, contains eight workable seams and is even a more important producer of coal and coke.

*Southern Appalachian Field.* — In the southern Appalachian field the coal-bearing rocks are mainly

Fig. 10. — Structure section in Tazewell County, east of Richlands, southwest Virginia coal field. (*From Min. Res. Va.,* 1907.) 1–8, Carboniferous; 9, Devonian; 10, Cambro-Silurian; 11, Cambrian.

of Pottsville age, and in the Birmingham, Ala., district, have a thickness of probably 5000 to 6000 feet. The Coal Measures, which show much disturbance on their eastern margin, with but little toward the west, are divisible into a lower (Lee, Lookout, or Millstone Grit) group, carrying about three thin seams in the lower part, and an upper group, with many beds of coal.

Although the coals and associated rocks were originally deposited in a broad trough, this has been subsequently folded, and faulted, while the basins are separated partly by faulting and partly by erosion of intervening anticlinal crests.

There are three main districts, known as the Jellico, Chattanooga, and Birmingham, the latter containing four fields, viz., the Warrior, Coosa, Cahaba, and Blount Mountain.

**The Triassic Field** (111, 112). — This coal field, which is more important historically than economically, having been worked as early as 1700, includes several small steep-sided basins (Fig. 11), lying in the Piedmont
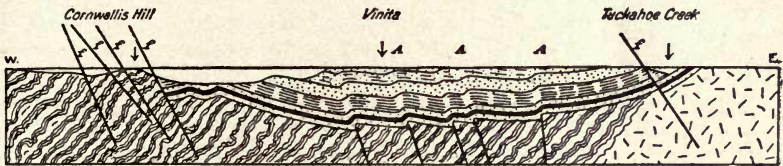


Fig. 11. — General structure section of the Richmond Basin in the vicinity of James River. $A, A, A$, minor flexures, with beds downthrown to the west; $f, f, f$, faults. The heavy black band represents the supposed position of the coal beds. North and south of this section the beds appear to be deeply faulted down against the western margin, and the apparent synclinal structure disappears. The superficial portion of this section is based on observation and reliable information; the deeper portion is hypothetical. (*After Shaler and Woodworth, U. S. Geol. Surv., 19th Ann. Rept., Pt. II.*)

region of Virginia and North Carolina. It is probable that the coal-bearing beds of the several areas, originally horizontal, were formerly continuous, having been separated by folding, faulting, and denudation. In addition to this, the coal is cut by dikes and sheets of igneous rock, which have locally altered it to natural coke or *carbonite*.

**Eastern Interior Field** (34, 57–59, 65–69). — This field is an oval, elongated basin (Fig. 12), extending northeast and southwest, with the marginal beds dipping gently toward the lowest portion, which lies in Illinois, where the beds are nearly horizontal. It covers most of Illinois, southwestern Indiana, and a small part of Western Kentucky, with some small outliers in Missouri, near St. Louis and St. Charles, and two in Illinois.

The coal-bearing rocks rest unconformably on lower Carboniferous, Devonian, and Silurian strata, the basal member being a sandstone, probably the equivalent of the Pottsville. The coal-bearing rocks, which have a maximum thickness of fully 2200 feet in Illinois, belong to the Coal Measures, although the upper part may be of Permian age, and the highest workable coals beds are classed as Freeport or Conemaugh. The coal seams occur in the lower portion of the section, and hence outcrop around the margin, the mining operations being therefore confined to a narrow belt, because near the center of the basin the coal beds underlie too great a thickness of unproductive strata to permit of profitable working under present conditions.

Great difficulty has been encountered in attempts at correlation of the coal beds of different parts of the field, because of the varying section shown from place to place, and lack of continuity of the beds. In consequence, the custom has arisen of giving the coal beds numbers instead of names.

The coals of the Eastern Interior field, although varying widely in quality, are all bituminous. On account of their higher percentage of ash and sulphur, they are little used for coking. Most of the coal used in and near this field is supplied from it; but even within the field the Appalachian coals enter into competition. The cannel coal found near Cannelsburg, Kentucky, which is the only good gas producer found in this field, finds a ready market.



Fig. 12. — Section across Eastern Interior coal field. (After Ashley, U. S. Geol. Surv., 22d Ann. Rept., III.)

In Illinois the section involves (57): —

a. Upper or Barren Coal Measures.
b. Lower or Productive Coal Measures; coal bearing.
c. Millstone Grit or Mansfield Sandstone.

The old survey recognized 16 beds, of which 1–7 are commonly worked, but later work throws doubt on this classification; the areas of important development of the different

beds are not coincident, but as a general rule the coals above No. 2 in the western part of the state are persistent in extent and thickness over large areas, while in the eastern portion all the seams are irregular in both extent and thickness. As a rule, the lower seams are better than the upper ones, and the quality also increases from north to south. The Illinois seams vary from 3 to 8 feet in thickness, and all are bituminous.

Ashley subdivides the Indiana section as follows:—

Permian-Merom group; Upper or Barren Measures, 0'–400'.

Coal Measures { Wabash group; main coal-bearing measures, 100'–600'.
Mansfield group; basal sandstone member, 0'–200'.

The coal field is roughly divisible into two areas, viz. an eastern or "block-coal" area, and a western or bituminous area. The former is also bituminous, but shows a peculiar block-like jointing.

The Indiana section shows at least 25 distinct coal beds (59), nearly all of them 2 feet or more thick in some places, and nine of them continuing of minable thickness over large areas. The upper five of the nine numbered ones are coking and occur in broad sheets, while the lower four occur in basins and are
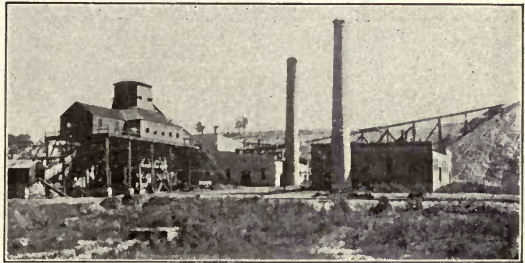


Fig. 13.—Shaft house and tipple, bituminous coal mine, Spring Valley, Ill.

not extensively workable. No. 5 is the most important bed in the state and can be correlated the entire length of the field.

In Kentucky the coals have been numbered from 1–12, beginning at the bottom and lettered beginning at the top. Nos. 9, 11, and 12 are the chief ones worked. One of these is exceedingly persistent, being found under a part of the whole of two counties, with an average thickness of 5 feet, and at a depth commonly of less than 200 feet.

**Northern Interior Field** (72). — This field forms a large basin in which the coal dips irregularly from the margin toward the center (Fig. 14), but on account of the heavy mantle of glacial drift it has been difficult to determine its exact boundaries, and prospecting is necessarily done by means of drilling. The Coal Measures, which are probably of Pottsville age, attain a total thickness of 600 to 700 feet in the center of the basin, and include 7 horizons of workable coal with an average thickness of 2 feet and rarely exceeding 4 feet. The Verne coals near the top may correspond with the Mercer coals of Ohio (Lane). Coal is found near the center of the basin at depths of 400 feet or more, though the beds that are mined are mostly at depths of 100 to 250 feet. All the coals are bituminous

and used chiefly for fuel, but some are coking, and others will prob-
ably prove of value for gas manufacture. Saginaw and Bay City
are important mining towns.

**Western Interior Field and Southwestern Fields** (35). — These
two fields form a practically continuous belt of coal-bearing forma-
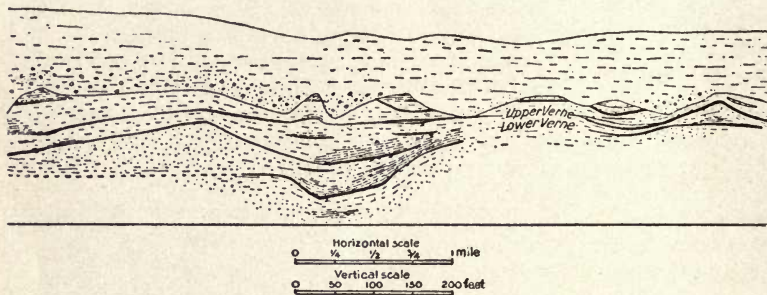


Fig. 14. — Generalized section of Northern Interior coal field. (*After Lane,
U. S. Geol. Surv., 22d Ann. Rept., III.*)

tions, extending from northern Iowa southwestward for a distance
of 880 miles into central Texas. Throughout most of this area the
beds lie horizontal, or have a gentle westward dip averaging 10 to
20 feet per mile, but a notable exception is found in the beds of east-
ern Oklahoma and Arkansas, which are rather strongly folded,
reminding one of the Pennsylvania anthracite area.
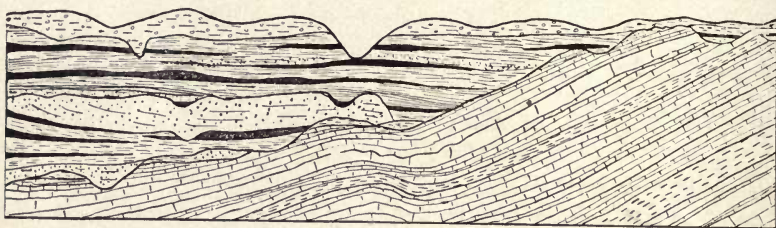


Fig. 15. — Composite section showing structure of lower coal measures of Iowa.
(*After Keyes, Ia. Geol. Surv., I.*)

*Western Interior Field.*— The Coal Measures, composed of lime-
stones, shales, fire clays, and coal beds, rest unconformably on the
Mississippian and dip westwardly under beds of Permian, Creta-
ceous, and Pleistocene. Toward the south and west the beds increase
in thickness, the maximum being 1000 feet in Iowa (62), 3000 in
Kansas (63), and 200 in Missouri (74). In a general way there is
a prevailing dip westward of 10–20 feet per mile; in detail the dip

Lawrence
823

Iola Limestone

30

PLATE VII.—Geologic Section from Kansas City to Topeka, Kan. (*Kas. Geol. Surv., III.*)

*Wakarusa River*
←Eudora
813

20

De Soto
792

Garnett Limestone

Scale of Miles

Cedar Junction
780

Wilder
772

Bethany Falls Limestone

Holiday
760

10

8

Turner
754

6

4

Argentine
750

2

Kansas City Well
758

0

Kansas City

400
600
800
1000
1200
1400

Willard
912

70

Osage Shales

Valencia
904

Osage Coal
Topeka Limestone
Calhoun Shales

Sugar Works

Deer Creek L.

60

←Topeka
886

Lecompton Limestone

Tecumseh Shales

←Tecumseh
868

Oread Limestone

Spencer
861

50

Lecompton Shales

Lecompton
846

Lawrence Shales

40

Coal

is south-southwest in Iowa, west-northwest in Missouri, and usually northwest in Kansas.

The Coal Measures are divisible into two parts. The lower is known as the Des Moines in Iowa, and the Cherokee and Marmaton in Kansas. The upper is termed the Missourian in Iowa, but in Kansas is made up of the Pottawatomie, Douglas, and Shawnee. In both states most of the coal mined comes from the Cherokee shales horizon. Those found in the upper measures are thin, even though persistent.

Most of the coal mined in this field comes from the lower part of the coal measures, where the beds are irregular in thickness and distribution, in conse- quence of deposition on a very uneven surface.

All the coals of this field are essentially bitu- minous and used chiefly for steaming and heating purposes, being of no value for either coking or gas making. Some of the seams will coke, but there is no demand for the product, and the sulphur and ash are too high for gas making.

The Oklahoma and Ar- kansas portions of the Western Interior field are directly connected, but the coals differ somewhat.

The rocks of the Okla- homa field (60), belong to the Coal Measures (Fig. 16), the lowest coal beds being probably in the



Fig. 16. — Columnar section of coal-bearing rocks in Oklahoma coal field. (*After Taff, U. S. Geol. Surv., 22nd Ann. Rept., Pt. III.*)

upper part of the Lower Coal Measures, and the highest coal in the Upper Coal Measures.

The coal field is characterized by both folds and faults. The anticlines are generally narrower and deeper than the synclines, with a tendency to overturn to the north, but the folds die out to the

westward and northwestward. There are seven important beds of workable character, as well as some that are workable locally. The coals are bituminous and coking.

In the Arkansas field (49) the rocks (sandstones and shales) are all of Pennsylvanian age, and involve a section several thousand feet thick, which can be correlated fairly well with the Oklahoma area.

| Names of coal beds | Section | Formation and thickness in feet | General character of formations |
|---|---|---|---|
| | | Savanna 100-1,000 | In Indian Territory this formation comprises three sandstone members with interbedded shales; only the lower part is present in Arkansas. |
| Paris | | Paris 600-700 | Sandy shale with thin beds of shaly sandstone. Paris coal bed about 400 feet from top. |
| Charleston | | Fort Smith 375-425 | Sandstone interbedded with shales. Formation yields building stones, flagstones, and brick shale. Coal beds are usually too thin for mining. |
| Upper Hartshorne | | Spadra 400-500 | Shale with lenses of sandstone. Hartshorne coal at base is most important bed in Arkansas. |
| Hartshorne | | Hartshorne 100-300 | Typically massive sandstone, but varying to sandy shale in some places |
| | | Atoka 1,500-5,000 + | Mainly shale, but sandstone lenses comprise from one-tenth to one-third of the section. Coal beds in the eastern part of the field may be thick enough in some places for mining. |

Fig. 17. — Generalized columnar section of the coal-bearing rocks of Arkansas.
(*After Collier, U. S. Geol. Surv. Bull.* 326.)

They are bent into a trough in which there are a number of subordinate folds and some normal and thrust faults. The coals of the Hartshorne horizon (Fig. 17) are economically the most important, while those below it are probably thin and not continuous. The coals range from bituminous to semianthracite, and, although not of coking character, excel in quality any found west of West Virginia.

*Southwestern Field* (40). — This area, lying in northern Texas, is separable into a northern and southern portion by an arm of Cretaceous strata, extending across it. The coals, which are all Pennsylvanian, rest uncomformably on the Mississippian and are overlain by the Permian on the north. There are five divisions, which carry three workable coal beds, and while all are of bituminous character, none of them are coking.

**Rocky Mountain Fields** (38). — These cover a broad area extending from the Canadian boundary southward into New Mexico, a distance of about 1000 miles, and including a large number of fields of varying size and irregular shape. Most of these beds lie within the mountainous region, but at the northern end of the area, in Wyoming and the Dakotas, the coal fields extend eastward under the Great Plains for some distance. The age of the coal ranges from Lower Cretaceous to Eocene (Tertiary), though most of it belongs to the former.

While portions of this enormous area of coal-bearing strata are only slightly disturbed, mountain-building forces and igneous intrusions have affected a large proportion of the region, often materially changing the character of the coal. Thus, while in undisturbed portions of the field the beds may be lignitic (Pl. VIII, Fig. 2), in the disturbed parts they have been altered to bituminous. Igneous intrusions may have changed the latter locally to anthracite, as in the Crested Butte (55) area of Colorado or the Cerrillos field of New Mexico (80). Some of the bituminous coals produce an excellent quality of coke.

*Colorado* (54, 55) is the most important coal-producing state of the Rocky Mountain region, the distribution of its coal fields being shown in Fig. 18. The Raton field in the southeastern part of the state, extending into New Mexico (82), is the most important producer and yields coking coal. Like many of the fields of this region the coals which are of Cretaceous age are both folded and faulted. They are, moreover, crossed by igneous intrusions, which have in some places produced natural coke, but in others destroyed the value of the coal. The subbituminous coals of the South Platte field, and the bituminous ones of the Canon City area are also important. Anthracite is obtained in the Yampa and Crested Butte fields. The latter lies at the eastern end of the great Uinta Basin field, which extends into Utah.

*Wyoming* (116–118) has a larger percentage of its area underlain by coal-bearing rocks than any other Rocky Mountain state, but most of this lies in the Great Plains region, and the coals, which are chiefly Cretaceous, are on the whole of subbituminous character (Fig. 19). The Green River basin in southwestern Wyoming is the most productive area and yields

PLATE VIII
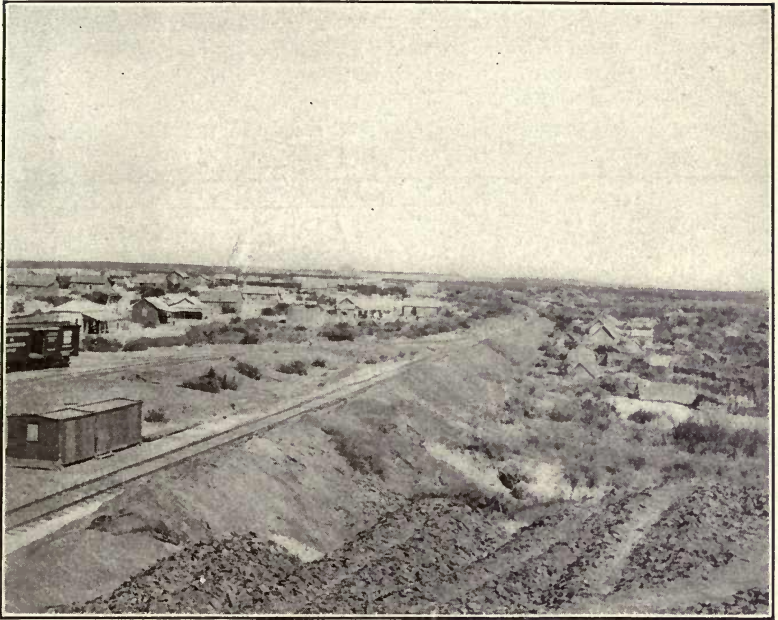


FIG. 1. — View in sub-bituminous coal area, between Minera and Cannel, Texas.
(*H. Ries, photo.*)
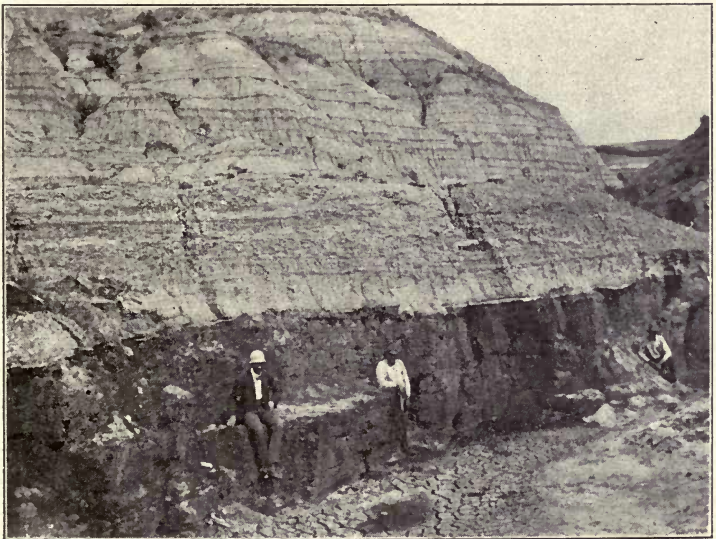


FIG. 2. — Lignite seam, Williston, N. Dak.　(*After F. Wilder, photo.*)

(43)

bituminous coal, and the same is also obtained from small areas in the Powder River basin of northeastern Wyoming.

*Utah* (109) has two large coal areas (Fig. 18). The largest of these is that of the Uinta Basin, which carries Upper Cretaceous bituminous coals of coking character, and which are worked chiefly in the Book Cliffs fields
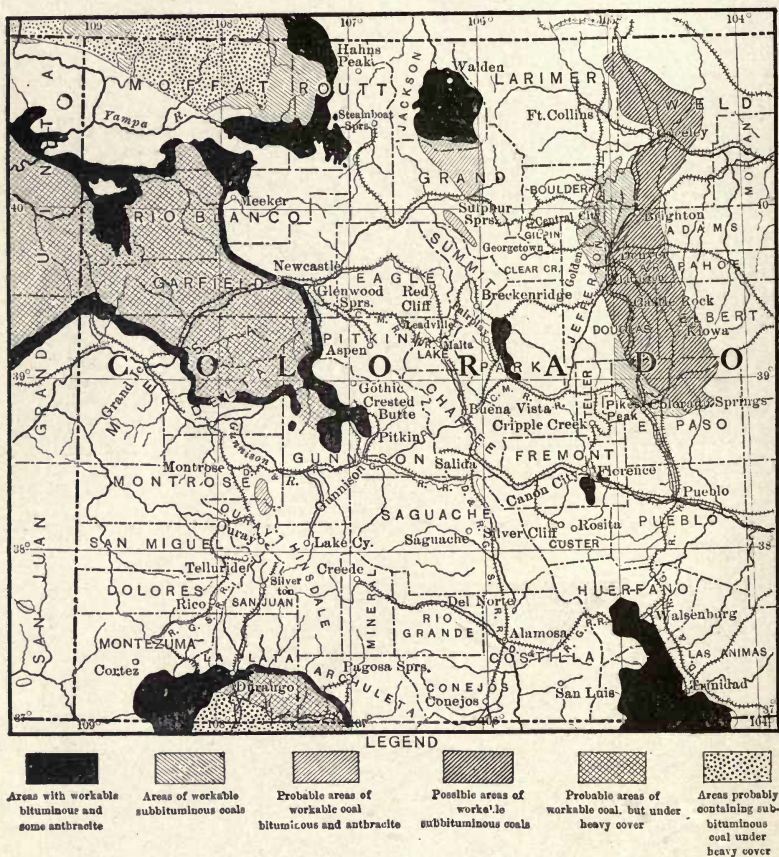


FIG. 18. — Map showing distribution of different kinds of coal in Colorado.
(*After Parker, U. S. Geol. Surv.*)

on the southern rim of the basin. The other large field lies in southern Utah, but is not commercially developed.

*Other Rocky Mountain States.* — A great area of Eocene lignitic coal is found in the Fort Union region of North Dakota, South Dakota, and Montana (75-77). Passing towards the mountainous district of Montana, the coals pass into high-grade subbituminous and bituminous ones. Red Lodge, Carbon County, yielding a coal between bituminous and subbitumi-

nous, is the most important producer, and the Bull Mountain area is now second. Coking bituminous coal is also obtained.
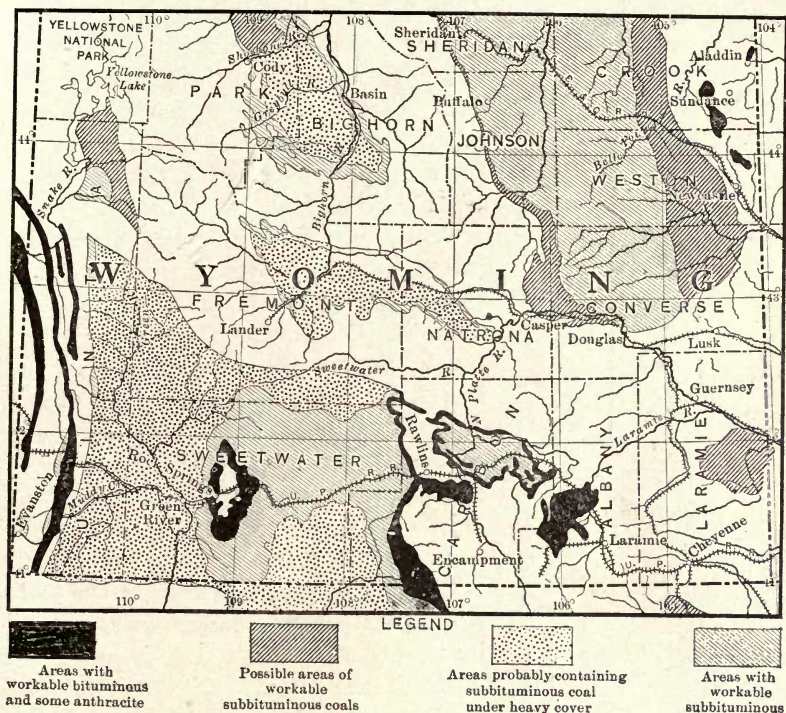


FIG. 19. — Map showing distribution of different kinds of coal in Wyoming. (*After Parker, U. S. Geol. Surv., Min. Res.*, 1910.)

**Gulf Province Lignites** (70, 73, 105–107). — These are of Eocene (Tertiary) age and are all low grade, with the exception of those along the Rio Grande, northwest of Laredo, which may be regarded as subbituminous. Those found near Eagle Pass are of still better quality, but occur in the Cretaceous.

**Pacific Coast Fields** (37). — Tertiary coals, partly bituminous, though mainly lignitic, occur scattered over a wide area in the states of California (50–53), Washington (114), and Oregon (93, 94). The separate fields are limited in extent, and widely separated. Their output is small as compared with some other states, but still it is becoming of growing importance.

Of the scattered fields in Washington, the most important lie directly east of Seattle and Tacoma. The total thickness of
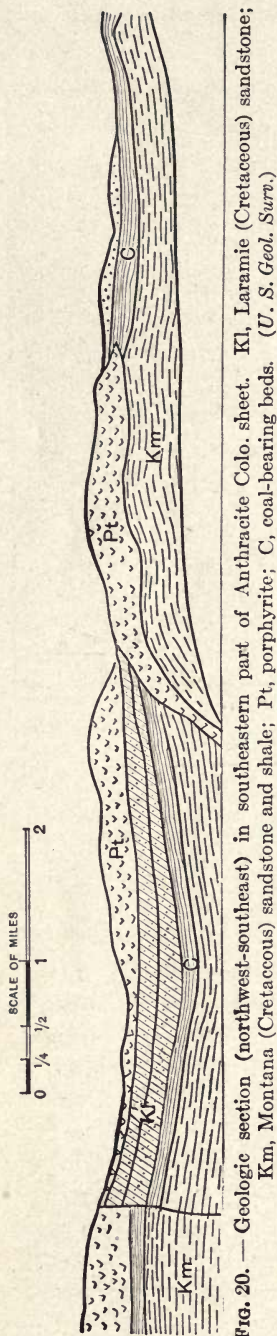
FIG. 20. — Geologic section (northwest-southeast) in southeastern part of Anthracite Colo. sheet. Kl, Laramie (Cretaceous) sandstone; Km, Montana (Cretaceous) sandstone and shale; Pt, porphyrite; C, coal-bearing beds. (U. S. Geol. Surv.)

coal-bearing strata is about 10,000 feet, but important coal beds are found only in the lower 2000 feet. The quality of the coal varies with the extent of the dynamic disturbance, and hence there may be variation even in a single field. Some of the coal is coking. The industry suffers, however, from competition with oil fuel.

Both California and Oregon are small producers. In the former coals of subbituminous character have been mined near Tesla, Alameda County, and recently coal of good bituminous grade has been worked in Stone Canyon, Monterey County. Indeed this is of sufficiently high quality to compete with foreign coals brought into San Francisco.

In Oregon, the Coos Bay field has been a small but fairly steady producer.

Oil may be said to dominate the fuel situation along the Pacific coast, and as long as this continues, the demand for coal will be limited.

**Alaska** (45, 46). — Although Alaskan coal was first mined in 1852 at Port Graham, and coal deposits have been discovered at a number of localities, the quantity produced is small. This is due to location (Fig. 21), character of deposits, which are often badly folded and crushed, cheaper oil fuel, and also conditions obtaining as relating to patent claims regulated by the U. S. Government. These last named obstacles have no been largely removed and developments are expected to follow the building of railroads which will render the fields accessible.[1] Indeed, in 1913, the domestic

[1] Bur. Mines, Bull. 36, 1912.

product formed only 1.7 per cent of all the coal used in Alaska.

The table on p. 48 gives the character and location of the Alaskan coals.



Fig. 21.—Map of Alaska, showing distribution of coal and coal-bearing rocks, so far as known. (*After Martin, U. S. Geol. Surv., Bull. 314.*)

**Canada.** — The coal regions of Canada include: (1) The Maritime Provinces; (2) Western Provinces; (3) Vancouver and other Pacific Coast islands.

**Maritime Provinces.** — Leaving out the coals of New Brunswick, which are of little importance, we have several areas of active production in Nova Scotia. There the coal-bearing rocks range from Lower Carboniferous to possibly Permian, but the only important beds are those occurring in the Coal-Measures proper, lying above the Millstone Grit. The four areas are (1) the Cumberland (including Joggins and Spring Hill), (2) Pictou, (3) Inverness, and (4) Sydney. In all of these the coal is bituminous, and in (2) and (4) of coking character. The beds show more or less folding, and in one area at least (Pictou) some strong faulting. It is interesting to note that in

KIND AND DISTRIBUTION OF ALASKA COALS

| SYSTEM | SERIES | CHARACTER OF COAL | PRINCIPAL DISTRIBUTION |
|---|---|---|---|
| Quaternary | Pleistocene | Lignitic | Yukon basin and other parts of Alaska. |
| Tertiary | Pliocene | Lignitic | Yakutat Bay and other localities. |
| | Miocene or Eocene | Anthracitic and bituminous | Bering River |
| | Eocene | Chiefly lignitic; also some bituminous and subbituminous. | Throughout A l a s k a, notably on Cook Inlet and in Matanuska Valley, and Yukon basin. |
| Cretaceous | Upper Cretaceous | Subbituminous and bituminous | Alaska peninsula, Yukon and Colville basins. |
| Jurassic | | Lignitic, subbituminous, and bituminous | Near Cape Lisburne and in Matanuska Valley. |
| Carboniferous | Pennsylvanian | Subbituminous | Yukon River. |
| | Mississippian | Bituminous | Twenty miles south of Cape Lisburne. |

the Pictou area, the upper and lower series of seams are separated by oil shales.
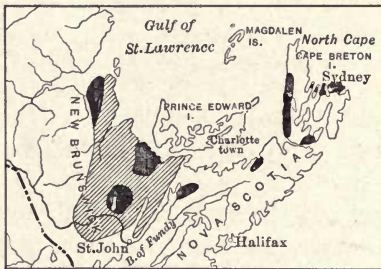


FIG. 22. — Map showing coal areas of Nova Scotia. (After Dowling, Can. Geol. Surv., Mem. 59.)

**Western Provinces.** — Coal-bearing rocks of Cretaceous, and to a lesser extent Tertiary age are widely distributed throughout the western provinces.

Within the Great Plains regions the beds lie fairly flat, and the coals are either lignite or subbituminous but along the foothills and in the mountains themselves the coal-measures are folded and faulted, the sediments usually more consolidated, and the coals of a higher grade ranging from bituminous to anthracite.

Some of the areas are actively worked at several points, but there still remain undeveloped districts, awaiting a market and transportation facilities.

*Saskatchewan.* — Lignite-bearing Tertiary rocks cover a wide extent of territory in the southern part of the province, and a number of beds are  known, which are worked chiefly in the



Anthracite and Bituminous
Known Areas

Anthracite and Bituminous
Probable Coal Areas

Sub-butuminous
Coal Areas

Lignite
Areas

Probable Lignite
Areas

SCALE OF MILES

0    100    200    300    400    500
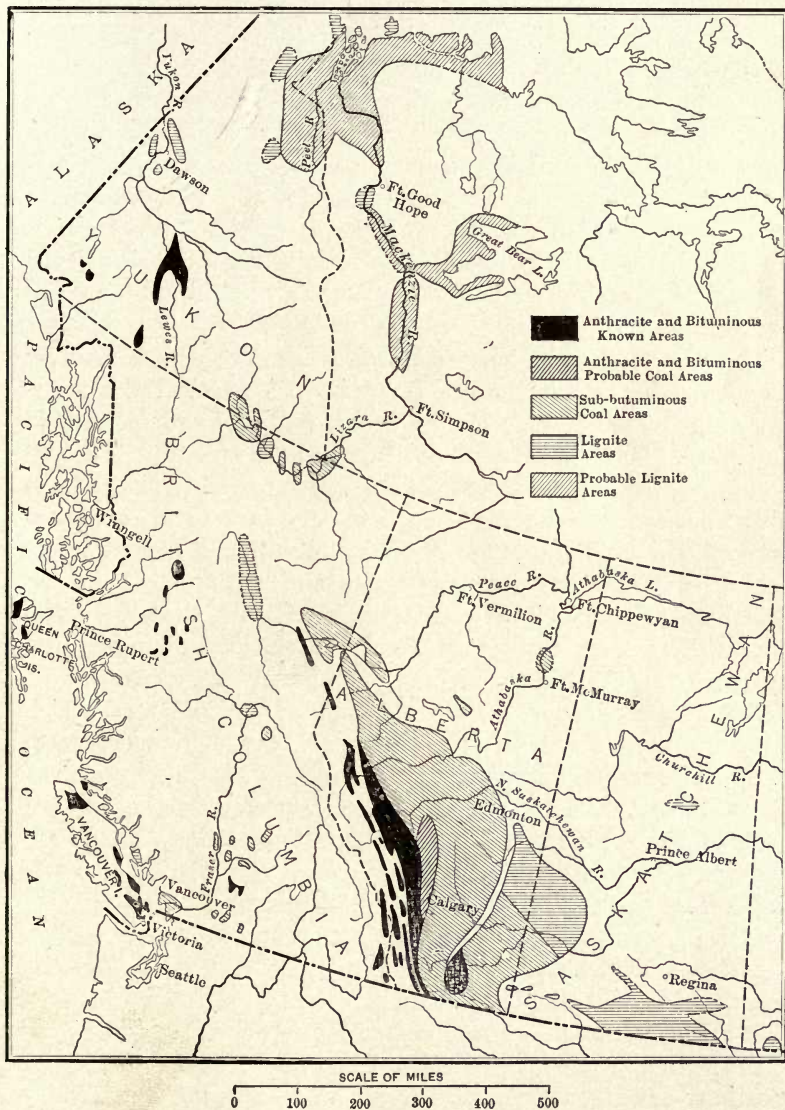
FIG. 23. — Map showing coal areas of Western Canada. (*After Dowling, Can-Geol. Surv., Mem. 59.*)

Souris field.   (Fig. 23.)   The Cretaceous coals of the Belly
River series are as yet unimportant.

*Alberta.* — Coal is found at three horizons of the Cretaceous,
viz., Edmonton and part of Paskapoo, Belly River and Kootenay.
The Edmonton coals lie in a great syncline, with the Paskapoo
sandstone forming the upper beds in the center.   The beds
of the eastern limb have a lower dip than those of the western
cne towards the mountains, so that the coals change from lignites
in the northeastern part to coking coals in the foothills.   Ed-
monton is the chief mining center.

The Belly River coal series, which covers about 16,000 square
miles in central and southern Alberta, carries coals ranging
from lignites near Medicine Hat to subbituminous coals around
Lethbridge, but the series traced to the foothills also carries
coking coals.

The coal of the Kootenay formation lies deeply buried under
the Plains, but in the Rocky Mountains it is exposed at a num-
ber of points in uplifted fault blocks, and along the crests of
anticlines.   Some is also found in synclinal troughs.   The Al-
berta areas are known both in the outer ranges and in the foot-
hills from near the international boundary to beyond the Atha-
basca River.   The coals are generally bituminous, sometimes of
coking character, but semianthracite and anthracite beds are
also known.   The bituminous type is actively worked in the
Crows Nest Pass district at Coleman and Frank, while the
anthracite is mined in the vicinity of Canmore and Banff.

*British Columbia.* — On the mainland, the coal areas, which
are more or less isolated, are chiefly of Lower Cretaceous age,
and of bituminous character, although sometimes locally altered
to anthracite.   An important basin is situated in the western
part of the Crows Nest Pass, where the section, sometimes
showing 3700 feet of measures, may carry over 20 beds, exceed-
ing 1 foot in thickness.   Scattered deposits of Tertiary coal
are also known, and worked specially around Princeton and in
the Nicola Valley.   These have been partly covered by igneous
flows, and locally altered to bituminous coal.

*Vancouver Island.* — The coals, so far as known, are of Upper
Cretaceous age, associated with the thick Nanaimo series of
clastic sediments.   A variable degree of folding and some fault-
ing occurs, and the seams lack persistence.   Some of the bitu-
minous coals are coking.

PLATE IX
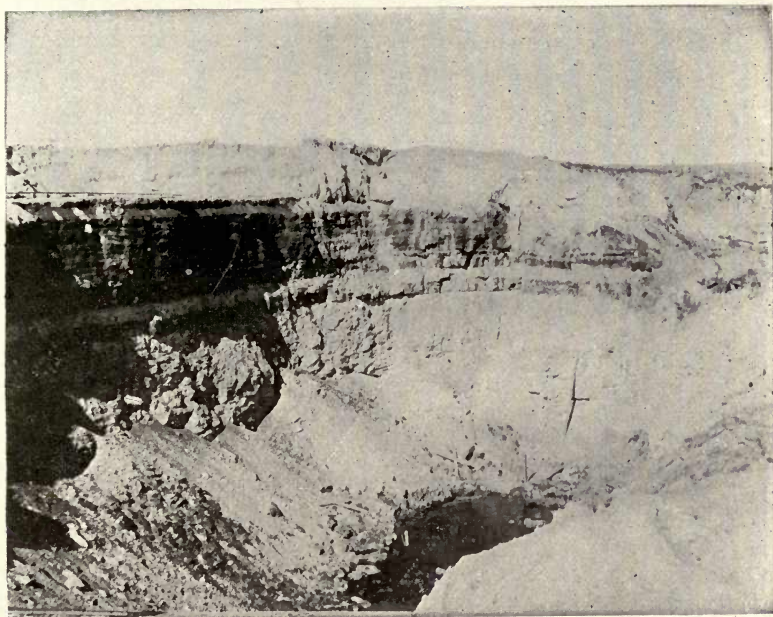


FIG. 1. — Beds of subbituminous coal near Estevan, Sask. (*H. Ries, photo.*)
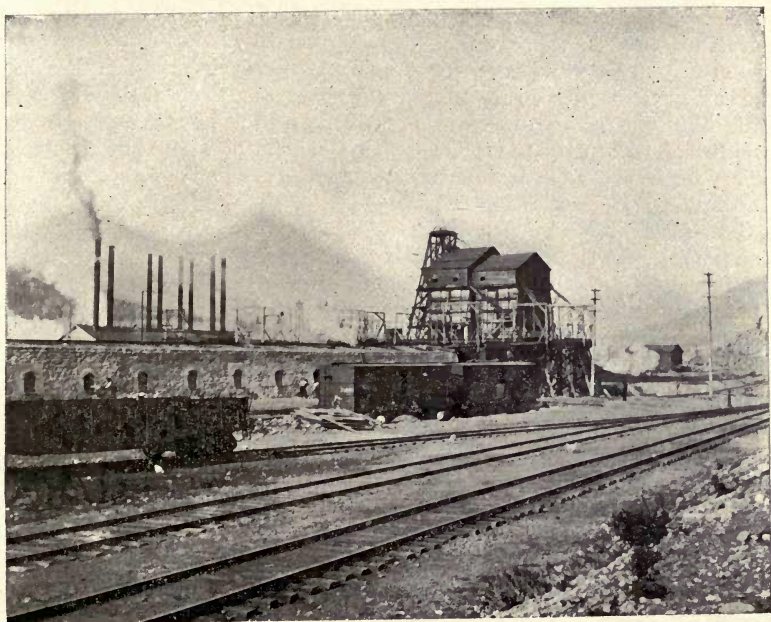


FIG. 2. — Coke ovens and tipple at Coleman, Alberta; Crows Nest Pass field.
(*H. Ries, photo.*)

(51)

*Yukon.* — Lignites of Tertiary, and lignites to anthracites of Jura-Cretaceous age are known.

**Other Foreign Fields.** — Europe contains extensive deposits of coal, the bituminous and anthracite varieties being chiefly of Upper Carboniferous age, although important Lower Carboniferous deposits are known in Central Russia and Scotland. Of the Upper Carboniferous or Coal Measures proper, there are important deposits in western Germany, Belgium, Northern France, and Great Britain. They are mostly bituminous, and may show strong folding and faulting. Anthracite is mined in Wales and Russia.

The lower grades of coal chiefly of Tertiary age, are an important source of supply in southern Russia, as well as in Austria, Germany, and to a lesser extent France.

Asia contains extensive areas of Permo-Carboniferous coals in China (anthracite to lignite), as well as India, while Tertiary coals are an important source of supply in Japan (bituminous) and northeast Siberia.

Australia contains both Carboniferous and Tertiary coals, the former being especially important in New South Wales. In South America the best grades of coal appear to be those along the Pacific and Gulf of Mexico in formations of Tertiary age, while in Africa, the important deposits—of Carboniferous to Jurassic age—are confined to the southern part of the continent.

In Mexico the most important fields are Cretaceous ones of bituminous character, near the Texas border, on the Rio Grande and its tributaries.

The Philippine coals are of Tertiary age, and range from lignite to bituminous, but the area known to be underlain by mineable coal does not cover more than 7 square miles.

**Estimated Coal Reserves of the World.** — Much attention has been given in recent years to the necessity of conserving the coal supply, and in this connection the figures given on p. 53 and collected by the executive committee of the International Geological Congress of 1913,[1] are of interest. They include both the actual and probable reserves, and have been classified according to kinds of coal as follows:—

A. Coals with large percentages of fixed carbon, including, besides the anthracites, the dry, non-coking coals that burn with a short flame.

B and C. Bituminous coals, including some of the non-coking, but free-burning coals, and the coking coals burning with a long flame. The cannel coals and coals with very high volatile are under C.

D. Subbituminous coals, and the lignites.

**Production of Coal.** — The first mention of coal in the United States is probably in the journal of Father Hennepin, who in 1679 recorded the site of a " cole mine " on the Illinois River near the present city of Ottawa, Illinois, but the first actual mining appears to have occurred in the Richmond basin, Virginia, about seventy years later. The first records of production are

[1] The Coal Resources of the World. Vols. I, II, III and Atlas. Morang & Co., Ltd., Toronto, 1913.

## Coal Reserves of the World (in Million Tons)

| | Class of Coal | | | Totals | |
| --- | --- | --- | --- | --- | --- |
| | A | B and C | D | | |
| | Anthracitic Coals | Bituminous Coals | Subbituminous and Lignites | | |
| *United States* | | | | | |
| Eastern fields . . | 16,906 | 494,454 | . . . . . . . . | 511,360 | |
| Interior fields . . | 363 | 478,232 | . . . . . . . . | 478,595 | |
| Gulf fields . . . | . . . . . . | . . . . . . . . | 20,952 | 20,952 | |
| Northern plains . | . . . . . . | 41,106 | 1,134,000 | 1,175,106 | |
| Mountains and coast . . . . | 484 | 335,460 | 692,207 | 1,028,151 | |
| Coal deeply covered . . . . | . . . . . . | 604,900 | . . . . . . . . | 604,900 | |
| Alaska . . . . | 1,931 | 1,369 | 16,293 | 19,593 | |
| | 19,684 | 1,955,521 | 1,863,452 | . . . . . . . . | 3,838,657 |
| *Canada* | | | | | 500 |
| Newfoundland. . | . . . . . . | 500 | . . . . . . . . | . . . . . . . . | |
| Nova Scotia . . | . . . . . . | 9,719 | . . . . . . . . | 9,719 | |
| New Brunswick . | . . . . . . | 151 | . . . . . . . . | 151 | |
| Ontario . . . . | . . . . . . | . . . . . . . . | 25 | 25 | |
| Manitoba . . . | . . . . . . | . . . . . . . . | 160 | 160 | |
| Saskatchewan . . | . . . . . . | . . . . . . . . | 57,400 | 57,400 | |
| Alberta . . . . | 768 | 198,092 | 876,179 | 1,075,039 | |
| British Columbia. | 1,350 | 69,489 | 5,196 | 76,035 | |
| Yukon . . . . | 40 | 210 | 4,690 | 4,940 | |
| N. W. Territories. | . . . . . . | . . . . . . . . | 4,800 | 4,800 | |
| Arctic Islands . . | . . . . . . | 6,000 | | | |
| | 2,158 | 283,661 | 948,450 | . . . . . . . . | 1,234,269 |
| U. S. and Can. . | 21,842 | 2,239,182 | 2,811,902 | . . . . . . . . | 5,073,426 |
| South America. . | 700 | 31,397 | . . . . . . . . | . . . . . . . . | 32,097 |
| Europe . . . . | 54,346 | 693,162 | 36,682 | . . . . . . . . | 784,190 |
| Asia . . . . . | 407,637 | 760,098 | 111,851 | . . . . . . . . | 1,279,586 |
| Oceania . . . . | 659 | 133,481 | 36,270 | . . . . . . . . | 170,410 |
| Africa . . . . | 11,662 | 45,123 | 1,054 | . . . . . . . . | 57,839 |
| World total. . . | . . . . . . | . . . . . . . . | . . . . . . . . | . . . . . . . . | 7,397,548 |

in 1822. Ohio probably ranks second in priority of production, as coal was discovered there in 1755, but the records of mining date only to 1838. The mining of Pennsylvania anthracite began

in 1790, and in 1807, 55 tons were shipped to Columbus, Ohio. The regular production dates from 1814.[1]

The phenomenal growth of the coal mining industry is well shown by the diagram (Fig. 24).

The production of the individual states since 1910 is given on page 55.

Grouping the output by regions, the overwhelming importance of the Appalachian region is well seen.

PRODUCTION OF COAL IN UNITED STATES BY REGIONS FROM 1910–1914 IN SHORT TONS

| | 1910 | 1911 | 1912 | 1913 | 1914 |
|---|---|---|---|---|---|
| Anthracite (Pa.) . . | 84,485,236 | 90,464,067 | 84,361,598 | 91,524,922 | 90,821,507 |
| Triassic . . . . . | — | 120 | 200 | a | — |
| Appalachian . . . | 287,816,446 | 275,212,234 | 307,410,102 | 330,737,079 | 284,813,462 |
| Northern . . . . | 1,534,967 | 1,476,074 | 1,206,230 | 1,231,786 | 1,283,030 |
| Eastern . . . . . | 72,634,356 | 75,041,014 | 83,044,272 | 87,302,055 | 82,129,925 |
| Western and South-western . . . . . | 22,276,364 | 24,502,107 | 26,580,416 | 27,875,292 | 26,396,916 |
| Rocky Mountain and and Northern Great Plains . . . . . | 28,857,413 | 26,044,387 | 28,449,860 | 27,338,220 | 24,952,567 |
| Pacific Coast and Alaska . . . . | 3,991,596 | 3,631,123 | 3,413,902 | 3,950,865 | 3,128,070 |

a. Va. production included in Appalachian region.

*Price per Ton.* — The average price per short ton of coal fluctuates somewhat from year to year, and yet not as much as one might imagine. The figures below show the prices for the last ten years.

AVERAGE PRICE PER SHORT TON OF COAL IN THE UNITED STATES SINCE 1903

| YEAR | ANTHRA-CITE | BITUMI-NOUS | YEAR | ANTHRA-CITE | BITUMI-NOUS |
|---|---|---|---|---|---|
| 1903 . . . . | $2.04 | $1.24 | 1909 . . . . | $1.84 | $1.07 |
| 1904 . . . . | 1.90 | 1.10 | 1910 . . . . | 1.90 | 1.12 |
| 1905 . . . . | 1.83 | 1.06 | 1911 . . . . | 1.94 | 1.11 |
| 1906 . . . . | 1.85 | 1.11 | 1912 . . . . | 2.11 | 1.15 |
| 1907 . . . . | 1.91 | 1.14 | 1913 . . . . | 2.13 | 1.18 |
| 1908 . . . . | 1.90 | 1.12 | 1914 . . . . | 2.07 | 1.17 |

*Exports and Imports.* — The exports consist of anthracite and bituminous coal, the quantity of bituminous being the greater in the last few years. They are made principally by rail over the international bridges and by lake and sea to the Canadian

[1] Parker, E. W., Min. Res. U. S. Geol. Surv., 1908.

QUANTITY AND VALUE OF COAL PRODUCED IN THE UNITED STATES, 1910–1914, IN SHORT TONS

| STATE | 1910 Quantity | 1910 Value | 1911 Quantity | 1911 Value | 1912 Quantity | 1912 Value | 1913 Quantity | 1913 Value | 1914 Quantity | 1914 Value |
|---|---|---|---|---|---|---|---|---|---|---|
| Alabama | 16,111,462 | $20,236,853 | 15,021,421 | $19,079,949 | 16,100,600 | $20,829,252 | 17,678,522 | $23,083,724 | 15,593,422 | $20,849,919 |
| Arkansas | 1,905,958 | 2,979,213 | 2,106,799 | 3,396,849 | 2,100,819 | 3,582,769 | 2,234,107 | 3,923,701 | 1,836,540 | 3,158,168 |
| California and Alaska | 12,164 | 33,336 | 11,647 | 23,297 | 11,333 | 26,441 | 26,911 | 95,173 | [3]13,974 | [3]39,821 |
| Colorado | 11,973,736 | 17,026,934 | 10,157,383 | 14,747,764 | 10,977,824 | 16,345,336 | 9,232,510 | 14,035,090 | 8,170,559 | 13,601,718 |
| Georgia and North Carolina | [1]1,177,245 | [1]1,259,122 | 165,330 | [2]246,448 | 227,703 | 338,926 | 255,626 | 361,319 | 166,498 | 239,462 |
| Idaho | 4,448 | 17,426 | [2]1,821 | [2]4,872 | 2,964 | 9,313 | 2,177 | 5,285 | | |
| Illinois | 45,900,246 | 52,405,897 | 53,679,118 | 59,519,478 | 59,885,226 | 70,294,338 | 61,618,744 | 70,313,605 | 57,589,197 | 64,693,529 |
| Indiana | 18,339,815 | 20,813,859 | 14,201,355 | 15,326,808 | 15,285,718 | 17,480,546 | 17,165,671 | 19,001,881 | 16,641,132 | 18,290,928 |
| Iowa | 7,923,120 | 13,903,913 | 7,331,648 | 12,663,507 | 7,289,529 | 13,152,088 | 7,525,936 | 13,496,710 | 7,451,022 | 13,364,070 |
| Kansas | 4,921,451 | 7,914,709 | 6,178,728 | 9,473,572 | 6,986,182 | 11,324,130 | 7,202,210 | 12,036,292 | 6,860,988 | 11,228,253 |
| Kentucky | 14,623,319 | 14,403,887 | 14,049,703 | 14,008,458 | 16,490,521 | 16,854,207 | 19,616,600 | 20,516,749 | 20,382,763 | 20,852,463 |
| Maryland | 5,217,125 | 5,835,058 | 4,685,795 | 5,197,066 | 4,964,038 | 5,839,079 | 4,779,839 | 5,927,046 | 4,133,347 | 5,234,796 |
| Michigan | 1,534,967 | 2,930,771 | 1,476,074 | 2,791,461 | 1,206,230 | 2,399,451 | 1,231,786 | 2,455,227 | 1,283,030 | 2,559,786 |
| Missouri | 2,982,433 | 5,328,285 | 3,836,107 | 6,603,066 | 4,339,856 | 7,633,864 | 4,318,125 | 7,468,308 | 3,935,980 | 6,802,325 |
| Montana | 2,920,970 | 5,329,322 | 2,976,358 | 5,342,168 | 3,048,495 | 5,558,195 | 3,240,973 | 5,653,539 | 2,805,173 | 4,913,191 |
| New Mexico | 3,508,321 | 4,877,151 | 3,148,158 | 4,525,925 | 3,536,824 | 5,037,051 | 3,708,806 | 5,401,260 | 3,877,689 | 6,230,571 |
| North Dakota | 399,041 | 595,139 | 502,628 | 720,449 | 499,480 | 765,105 | 495,320 | 750,652 | 506,685 | 771,379 |
| Ohio | 34,209,668 | 35,932,288 | 30,759,936 | 31,810,123 | 34,528,727 | 37,085,363 | 36,200,527 | 39,948,058 | 18,843,115 | 21,250,642 |
| Oklahoma | 2,646,226 | 5,867,947 | 3,074,242 | 6,291,494 | 3,675,418 | 7,867,331 | 4,165,770 | 8,542,748 | 3,988,613 | 8,204,015 |
| Oregon | 67,533 | 235,229 | 46,661 | 108,083 | 41,637 | 108,276 | 46,063 | 116,724 | 51,558 | 143,556 |
| Pennsylvania, bituminous | 150,521,526 | 153,029,510 | 144,561,257 | 146,154,952 | 161,865,488 | 169,370,497 | 173,781,217 | 193,039,806 | 147,983,294 | 159,006,296 |
| South Dakota | | | | | | | 10,540 | 20,648 | 11,850 | 26,456 |
| Tennessee | 7,121,380 | 7,925,350 | 6,433,156 | 7,209,734 | 6,473,228 | 7,379,903 | 6,860,184 | 7,839,721 | 5,943,258 | 6,776,573 |
| Texas | 1,892,176 | 3,160,965 | 1,974,593 | 3,273,288 | 2,188,612 | 3,655,744 | 2,429,144 | 4,288,920 | 2,323,773 | 3,922,459 |
| Utah | 2,517,809 | 4,224,556 | 2,513,175 | 4,248,666 | 3,016,149 | 5,046,451 | 3,254,828 | 5,384,127 | 3,103,036 | 4,935,454 |
| Virginia | 6,507,997 | 5,877,486 | 6,864,667 | 6,254,804 | 7,846,638 | 7,518,576 | 8,828,068 | 8,952,653 | 7,959,535 | 8,032,443 |
| Washington | 3,911,899 | 9,764,465 | 3,572,815 | 8,174,170 | 3,360,932 | 8,042,871 | 3,877,891 | 9,243,137 | 3,064,820 | 6,751,511 |
| West Virginia | 61,671,019 | 56,665,061 | 59,831,580 | 53,670,515 | 66,786,687 | 62,792,234 | 71,254,136 | 71,822,804 | 71,707,626 | 71,391,408 |
| Wyoming | 7,533,088 | 11,706,187 | 6,744,864 | 10,508,863 | 7,368,124 | 11,648,088 | 7,393,066 | 11,510,045 | 6,475,293 | 10,033,747 |
| Total bituminous | 417,111,142 | 469,281,719 | 405,907,059 | 451,375,819 | 450,104,982 | 517,083,445 | 478,435,297 | 565,234,952 | 422,703,970 | 493,309,244 |
| Pennsylvania anthracite | 84,485,236 | 160,275,302 | 90,464,067 | 175,189,392 | 84,361,598 | 177,022,626 | 91,524,922 | 195,181,127 | 90,821,507 | 188,181,399 |
| Grand total | 501,596,378 | 629,557,021 | 496,371,126 | 626,565,211 | 534,466,580 | 695,606,071 | 569,960,219 | 760,416,079 | 513,525,477 | 681,490,643 |

[1] Georgia only.    [2] Includes Nev.    [3] Cal., Idaho and Nev.

provinces. Exports are also made by sea to the West Indies, to Central and South America and elsewhere.

The imports are principally from Australia and British Columbia to San Francisco, from Great Britain to the Atlantic and Pacific coasts, and from Nova Scotia to Atlantic coast points.

The statistics since 1909 are given below:—

COAL OF DOMESTIC PRODUCTION EXPORTED FROM THE UNITED STATES 1909–1914, IN LONG TONS

| YEAR | ANTHRACITE | | BITUMINOUS AND SHALE | |
|------|-----------|-------|---------------------|-------|
| | Quantity | Value | Quantity | Value |
| 1909 . . . . . . | 2,842,714 | $14,141,468 | 9,693,843 | $24,300,050 |
| 1910 . . . . . . | 3,021,627 | 14,785,387 | 10,784,239 | 26,685,405 |
| 1911 . . . . . . | 3,553,999 | 18,093,285 | 13,878,754 | 34,499,989 |
| 1912 . . . . . . | 3,688,789 | 19,425,263 | 14,459,978 | 36,817,633 |
| 1913 . . . . . . | 4,154,386 | 21,959,850 | 17,986,757 | 45,449,664 |
| 1914 . . . . . . | 3,830,244 | 20,211,072 | 13,801,850 | 34,104,903 |

COAL IMPORTED AND ENTERED FOR CONSUMPTION IN THE UNITED STATES. 1909–1914, IN LONG TONS

| YEAR | ANTHRACITE | | BITUMINOUS AND SHALE | |
|------|-----------|-------|---------------------|-------|
| | Quantity | Value | Quantity | Value |
| 1909 . . . . . . | 3,191 | $12,918 | 1,274,903 | $3,628,533 |
| 1910 . . . . . . | 8,196 | 42,244 | 1,986,258 | 4,761,223 |
| 1911 . . . . . . | 2,463 | 12,550 | 1,234,998 | 3,604,797 |
| 1912 . . . . . . | 1,670 | 8,329 | [1] 1,605,873 | 4,509,066 |
| 1913 . . . . . . | 896 | 5,620 | [1] 1,412,997 | 3,853,930 |
| 1914 . . . . . . | 15,800 | 25,380 | 1,380,204 | 3,902,881 |

[1] Includes 455,587 long tons of slack or culm (value $901,051) passing $\frac{1}{2}$ inch screen in 1912; 352,007 tons (value $689,864) in 1913; and 164,672 tons (value $303,348) in 1914.

PRODUCTION OF COAL IN CANADA, 1912–1913, BY PROVINCES

|  | 1913 | | 1914 | |
|---|---|---|---|---|
|  | TONS | VALUE | TONS | VALUE |
| Nova Scotia . . . . | 7,980,073 | $17,812,663 | 7,338,790 | $16,381,228 |
| British Columbia . . | 2,714,420 | 8,482,562 | 2,238,339 | 6,994,810 |
| Alberta . . . . . . | 4,014,755 | 10,418,941 | 3,667,816 | 9,367,602 |
| Saskatchewan . . . | 212,897 | 358,192 | 232,541 | 375,438 |
| New Brunswick . . . | 70,311 | 166,637 | 104,055 | 260,270 |
| Yukon Territory . . | 19,722 | 56,945 | 13,443 | 53,760 |
| Total . . . . . | 15,012,178 | $37,334,940 | 13,594,984 | $33,433,108 |

The Canadian exports in 1914 amounted to 1,423,126 tons, valued at $3,880,175. The imports for 1914 were 14,721,057 tons, valued at $39,801,498.

STATISTICS OF THE MANUFACTURE OF COKE IN THE UNITED STATES IN 1880, 1890, 1900, 1910–1914

| YEAR | ESTAB-LISH-MENTS | OVENS | | COAL USED (SHORT TONS) | PER-CENTAGE YIELD OF COAL IN COKE | COKE PRO-DUCED (SHORT TONS) | TOTAL VALUE OF COKE AT OVENS | VALUE OF COKE AT OVENS PER TON |
|---|---|---|---|---|---|---|---|---|
|  |  | BUILT | BUILD-ING |  |  |  |  |  |
| 1880 | 186 | 12,372 | 1159 | 5,237,741 | 63.0 | 3,338,300 | $ 6,631,267 | $1.99 |
| 1890 | 253 | 37,158 | 1547 | 18,005,209 | 64.0 | 11,508,021 | 23,215,302 | 2.02 |
| 1900 | 396 | 58,484 | 5804 | 32,113,553 | 63.9 | 20,533,348 | 47,443,331 | 2.31 |
| 1910 | 578 | 104,440 | 2567 | 63,088,327 | 66.1 | 41,708,810 | 99,742,701 | 2.39 |
| 1911 | 570 | 103,879 | 2254 | 53,278,248 | 66.7 | 35,551,489 | 84,130,849 | 2.37 |
| 1912 | 559 | 102,230 | 2783 | 65,577,862 | 67.1 | 43,983,599 | 111,805,113 | 2.54 |
| 1913 | 551 | 102,650 | 1321 | 69,239,190 | 66.9 | 46,299,530 | 128,922,273 | 2.78 |
| 1914 | 536 | 99,755 | 1249 | 51,623,750 | 66.9 | 34,555,914 | 88,334,217 | 2.56 |

The quantity of coal consumed in manufacture of coke in 1914 was 51,623,750 short tons, valued at $74,949,565, while the value of the coke made therefrom was $128,922,273.

There were, in 1914, 536 establishments, operating 99,755 ovens.

There were 5809 by-product ovens in 1914 with 644 building.

Of the 1914 production 32.47 per cent of the quantity and 43.11 per cent of the value was from by-product ovens.
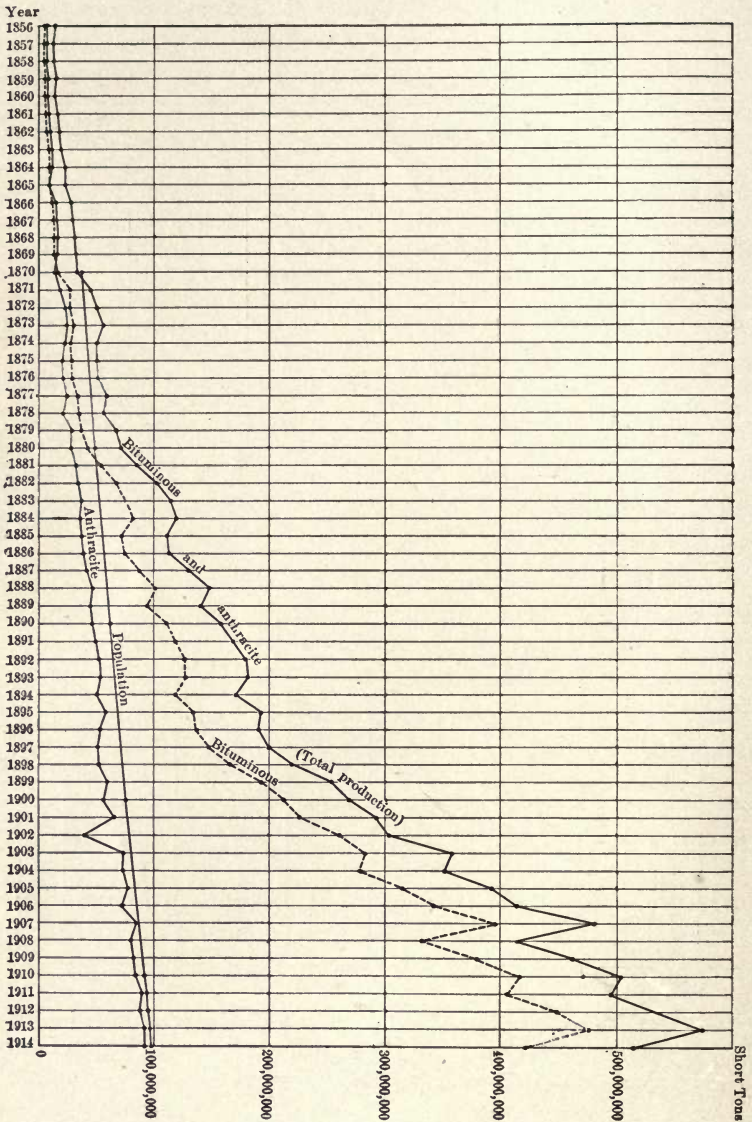
Fig. 24.—Curve showing relation of increase in population in the United States to production of coal, 1856–1914.  (*U. S. Geol. Surv., Min. Res.* 1914.)

## Value of Products Obtained in Manufacture of Coke in Retort Ovens in 1913 and 1914

|  | 1913 | | 1914 | |
|---|---|---|---|---|
|  | Quantity | Value | Quantity | Value |
| Gas . . . . . . . M cubic feet | 64,553,941 | $5,694,691 | 61,364,375 | $6,009,583 |
| Tar . . . . . . . gallons | 115,145,025 | 2,830,158 | 109,901,315 | 2,867,274 |
| Ammonia, sulphate or reduced to equivalent in sulphate pounds | 173,342,349 | 5,324,444 | 170,763,906 | 4,696,590 |
| Ammonia liquor . . gallons | 4,102,448 | 537,413 | 5,938,223 | 658,497 |
| Anhydrous ammonia . pounds | [1]28,663,936 | [1]2,135,656 | [1]25,370,509 | [1]2,300,137 |
| Other by-products . . . . . | — | 403,579 | — | [2]997,007 |
| Total value of by-products . . | — | 16,925,941 | — | 17,529,088 |
| Coke . . . . . . short tons | 12,714,700 | 48,637,852 | 11,219,943 | 38,080,167 |
| Grand total . . . . . . . | — | 65,563,793 | — | 55,609,255 |

[1] Mainly ammoniacal liquor sold on pound basis of NH₃.

[2] Mainly benzol.

*World's Production.* — The following figures are those given by the U. S. Geol. Survey, and compiled from various sources:—

### The World's Production of Coal, in Short Tons

| Country | Production | Country | Production |
|---|---|---|---|
| United States (1914) . . | 513,525,477 | Dutch East Indies (1913) | 453,136 |
| Great Britain (1914) . . | 297,698,617 | Indo-China (1912). . . | 471,259 |
| Germany (1914) . . . . | 270,594,952 | Servia (1912). . . . . | 335,000 |
| Austria-Hungary (1913) . | 59,647,957 | Sweden (1913) . . . . | 401,199 |
| France (1914) . . . . | 45,108,544 | Western Australia (1913) . | 351,687 |
| Russia (1913) . . . . | 35,500,674 | Peru (1913) . . . . . | 301,970 |
| Belgium (1913) . . . | 25,196,869 | Formosa (1912) . . . | 306,941 |
| Japan (1914) . . . . | 21,700,572 | Bulgaria (1912). . . . | 324,511 |
| India (1913) . . . . | 18,163,856 | Rhodesia (1913) . . . | 237,728 |
| China (1913) . . . . | [1]15,432,200 | Roumania (1911) . . . | 266,784 |
| Canada (1914) . . . . | 13,597,982 | Cape Colony (Cape of Good | |
| New South Wales (1914) | 11,644,476 | Hope) (1913) . . . . | 67,481 |
| Transvaal (1913) . . . | 5,225,036 | Korea (1911) . . . . | 138,508 |
| Spain (1913) . . . . | 4,731,647 | Tasmania (1914) . . . | 68,130 |
| Natal (1913). . . . . | 2,898,726 | British Borneo (1913). . | 49,762 |
| New Zealand (1913) . . | 2,115,834 | Spitzbergen (1911). . . | 44,092 |
| Holland (1913) . . . . | 2,064,608 | Brazil (1911) . . . . | 16,535 |
| Chile (1913) . . . . . | 1,362,334 | Portugal (1913) . . . | 27,653 |
| Queensland (1914) . . | 1,180,825 | Venezuela (1913) . . . | 13,355 |
| Mexico (1912) . . . . | 982,396 | Switzerland (1911). . . | 8,267 |
| Bosnia and Herzegovina | | Philippine Islands (1912) | 2,998 |
| (1913) . . . . . | 927,244 | Unspecified . . . . . | [1]1,016,947 |
| Turkey (1912) . . . . | 909,293 | | |
| Italy (1913) . . . . . | 772,802 | Total . . . . . . | [2]1,346,000,000 |
| Victoria (1912) . . . . | 668,524 | | |
| Orange Free State (Orange River Colony (1913). . | 609,973 | | |

[1] Estimated. [2] Approximate.

QUANTITY (SHORT TONS) AND VALUE OF COKE PRODUCED IN UNITED STATES FROM 1912-1914

| STATE | 1912 | | 1913 | | | 1914 | | |
|---|---|---|---|---|---|---|---|---|
| | QUANTITY | VALUE | QUANTITY | VALUE | PER CENT YIELD OF COKE FROM COAL | QUANTITY | VALUE | PER CENT YIELD OF COKE FROM COAL |
| Alabama | 2,975,489 | $8,098,412 | 3,323,664 | $9,627,170 | 63.6 | 3,084,149 | $8,408,443 | 65.9 |
| Colorado | 972,941 | 3,043,994 | 879,461 | 2,815,134 | 65.1 | 666,083 | 2,203,031 | 63.5 |
| Georgia | 43,158 | 161,842 | 42,747 | 186,304 | 51.5 | 24,517 | 100,529 | 54.1 |
| Illinois | 1,764,944 | 8,069,903 | 1,859,553 | 8,593,581 | 74.9 | 1,425,168 | 5,858,700 | 73.8 |
| Indiana | 2,616,339 | 12,528,685 | 2,727,025 | 13,182,136 | 77.1 | 2,276,652 | 9,055,937 | 72.8 |
| Kentucky | 191,555 | 513,734 | 317,084 | 753,897 | 61.9 | 443,959 | 971,060 | 66.0 |
| New Jersey | — | — | 255,792 | 695,041 | 75.4 | 255,283 | 680,972 | 77.6 |
| New Mexico | 413,906 | 1,356,946 | 467,945 | 1,548,536 | 59.4 | 362,572 | 1,228,045 | 54.9 |
| New York | 794,618 | 3,203,133 | 758,486 | 3,301,400 | 71.1 | 457,370 | 1,726,133 | 69.0 |
| Ohio | 388,669 | 1,365,905 | 351,846 | 1,231,554 | 69.3 | 521,638 | 1,672,686 | 70.0 |
| Pennsylvania | 27,438,693 | 56,336,255 | 28,753,444 | 67,929,864 | 66.6 | 20,258,393 | 42,447,886 | 66.9 |
| Tennessee | 370,076 | 951,853 | 364,578 | 925,430 | 52.5 | 246,127 | 642,573 | 54.2 |
| Virginia | 967,947 | 1,815,975 | 1,303,603 | 2,840,275 | 64.7 | 780,984 | 1,582,419 | 59.2 |
| Washington | 49,260 | 279,105 | 76,221 | 432,770 | 64.2 | 84,923 | 472,531 | 63.7 |
| West Virginia | 2,465,986 | 4,692,393 | 2,472,752 | 5,504,416 | 61.3 | 1,427,962 | 2,847,284 | 61.6 |
| Other states | 2,530,018 | 9,386,978 | 2,345,329 | 9,354,765 | — | 2,222,134 | 8,429,988 | — |

## PEAT

**Origin.** — So much attention has been attracted to this material in the last few years that it seems desirable to treat it as a separate topic, and partly so because it can be used for other purposes than fuel.

Peat (128) may be defined as "vegetable matter in a partly decomposed and more or less disintegrated condition," and represents much of the "dark-colored or nearly black soil found in bogs and swamps."[1] The dry peat may be very fibrous and light colored, or compact, structureless, and dark brown or black. If wet, it contains as much as 89 to 91 per cent or even more water. As previously mentioned (p. 1) it is produced by the slow decay, under water, of accumulated plant remains.
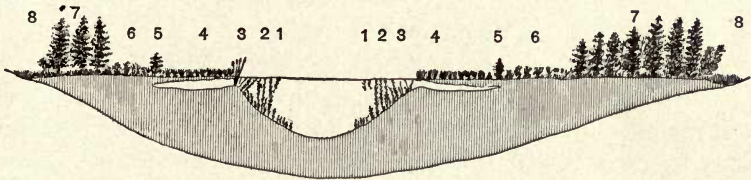


FIG. 25.— Diagram showing how plants fill depressions from the sides and top, to form a peat deposit. — 1. Zone of Chara and floating aquatics. 2. Zone of Potamogetons. 3. Zone of water lilies. 4. Floating sedge mat. 5. Advance plants of conifers and shrubs. 6. Shrub and Sphagnum zone. 7. Zone of Tamarack and Spruce. 8. Marginal Fosse. (*After Davis, Mich. Geol. Surv., Ann. Rept. for 1906.*)

The two essential conditions for peat formation are (1) restricted access of air to impede growth of decay-producing organisms, and (2) abundance of water to permit profuse plant growth.

This decay is accomplished mainly through the agency of fungi and air-requiring bacteria which break down the tissues, the decay involving decrease in bulk, darkening in color, and liberation of gaseous constituents. Both moisture and air are essentials to this process.

Since an abundance of water is essential to peat formation, and as it is formed by accumulation of plants in the spot where they grew, it requires plants of a water-loving nature. But peat may form in lakes or ponds, or in moist depressions or flat areas, and hence plants adapted to these different sets of conditions being differ-

[1] If this material contains too much mineral matter to burn freely, it is technically known as muck.

ent, it follows that the product may come from more than one kind.

Peat may be formed in lakes or similar depressions by aquatic plants, including minute algæ, building up a deposit from the bottom and around the sides, in water shallower than 15 feet. The extension of this deposit into deeper water and building up of the bottom permits growth of aquatic seed plants, resulting in establishment of characteristic zones. These are characterized (127) by (1) the pond weeds, *Potamogeton*, next to the deepest water; (2) shoreward of this the pond lilies; (3) the lake bulrush, *Scirpus;* and (4) the amphibious sedges, especially the turf-forming slender sedge. In some localities some of the zones may be absent. The sedges may also extend outward from the shore, forming a floating mat, which may cover the entire surface of the pond, and become covered by a growth of shrubs and even large trees, although the mat may not be more than 4 or 5 feet thick.

Peat may also form on moist, flat, or sloping surfaces, in depressions from which standing water is naturally absent, provided the plant remains are kept saturated with water, which they hold there partly by capillarity. In such situation plants of the rush, grass, sedge type, or *sphagnum* are important. This type of peat accumulation flourishes best in regions of heavy rainfall and moist atmosphere, and the deposit shows an irregularly stratified structure, but more uniform character than the filled-basin type first described, whose structure is more uniform below the original water level, but whose upper 3–5 feet is nearly always of different structure and composition from that below. Some bogs may be of composite origin.

The present surface vegetation of the bog does not necessarily indicate the kind of plant from which the peat was formed.

An interesting type of peat is that found in salt marshes, of which there are thousands of acres along the Atlantic coast, these marshes being poorly-drained plains subject to frequent overflow by the sea-water. Studies by Davis of the Maine marshes (128) indicate that the peat is either of " fresh-water origin below a relatively thin stratum of salt-water peat, or else made up entirely of plants similar to those growing on the marshes to-day at about high tide level." The suggested explanation is that the fresh-water peat has been formed in fresh-water bogs situated on a slowly sinking coast, while the upper or salt-water peat formed when the land was low enough to permit an influx of salt water, thus permitting the growth of only such plants as could stand it.

The fresh-water peat may be of fuel value, but that formed wholly by the growth of salt-marsh plants is too full of fine silt and mud tidal deposits to be of marketable character. (See analyses, p. 9.)

**Uses of Peat** (119, 126, 127). — The main use of peat is for fuel, but it has never been extensively used in America for this purpose. A number of experimental plants have been built in Canada, but most of them have not been successful nor have any been so in the United States. The failure may have been due to lack of capital, improper machinery, or lack of experience. Since a detailed discussion of peat-fuel technology is beyond the limits of this work, those wishing to follow it up are referred to Nos. 126, 127, 128, of the bibliography.

For fuel purposes the peat may be used in air-dried form as it comes from the bog, pressed into blocks (machine peat), in briquettes with or without binder, or in gas producers. There is only one peat briquetting plant in Europe (1913), but peat powder has been successfully used in special burners. Peat fuel has been used in European glass factories.

Of importance is the use of the more fibrous kinds of peat as a material for bedding for stock and for packing, as well as for deodorizing and disinfecting. Those varieties of powdered peat which are rich in nitrogen are dried and sold for filler in certain kinds of artificial fertilizer, and although a use of recent origin it seems to be growing. " Mull " is the finer matter separated from moss litter by screening, and sold for deodorizing, filtering, disinfecting, and packing purposes.

The manufacture of fertilizer filler is at present the largest industry based on peat in the United States.

Those peats having a strong fiber can be used in the manufacture of cloth and paper, but there is only one American plant turning out this class of product. Peat can also be utilized for making ethyl alcohol, and also for pressing into a structural material resembling wood.

Peat baths have long been used for medicinal purposes in Germany and Austria,[1] but only recently have they been tried in the United States.

**Distribution in the United States.** — Those regions possessing peat beds of sufficient size and depth to be of commercial value lie mostly outside of the coal-producing territory.

[1] H. Schreiber, Moorkulturstation in Sebastiansberg, Vol. XII, 1910.

Davis states that workable beds are found in many states lying north of the Ohio and east of the Missouri rivers, in the coastal portions of the Middle and South Atlantic and Gulf States, and in the narrow strip along the Pacific coast from southern California northward to the Canadian boundary.

**Production of Peat.** — Few statistics showing the production of peat in the United States are available.

The production and imports for 1913 and 1914 are given by the United States Geological Survey as follows:

PRODUCTION, IMPORTS, AND CONSUMPTION OF PEAT IN THE UNITED STATES IN 1914, IN SHORT TONS

| USE | PRODUCTION | | IMPORTS | | CONSUMPTION | |
|---|---|---|---|---|---|---|
| | QUANTITY | VALUE | QUANTITY | VALUE | QUANTITY | VALUE |
| Fertilizer filler. | 22,767 | $136,994 | . . . . . . | . . . . . . | 22,767 | $136,994 |
| Fertilizer . . | 14,962 | 112,905 | . . . . . . | . . . . . . | 14,962 | 112,905 |
| Fuel . . . . | 1,925 | 6,540 | . . . . . . | . . . . . . | 1,925 | 6,540 |
| Miscellaneous [1] | 7,439 | 53,253 | . . . . . . | . . . . . . | 7,439 | 53,253 |
| Peat moss litter | . . . . . . | . . . . . . | 9921 | $57,542 | 9,921 | 57,542 |
| Total . . . | 47,093 | 309,692 | 9921 | 57,542 | 57,014 | 367,234 |

[1] Only 1 producer each of peat for stock food, mud baths, and paper pulp.

PRODUCTION, IMPORTS, AND CONSUMPTION OF PEAT IN THE UNITED STATES IN 1913, IN SHORT TONS

| USE | PRODUCTION | | IMPORTS | | CONSUMPTION | |
|---|---|---|---|---|---|---|
| | QUANTITY | VALUE | QUANTITY | VALUE | QUANTITY | VALUE |
| Fertilizer . . | 28,460 | $169,600 | . . . . . . | . . . . . . | 28,460 | $169,600 |
| Stock food . . | 4,800 | 27,600 | . . . . . . | . . . . . . | 4,800 | 27,600 |
| Stable litter . | . . . . . . | . . . . . . | 10,983 | $55,719 | 10,983 | 55,719 |
| Total . . . | 33,260 | 197,200 | 10,983 | 55,719 | 44,243 | 252,919 |

The 1913 production of peat in Canada was estimated at 2600 short tons, valued at $10,100, and came from Quebec and Ontario.

## REFERENCES ON COAL

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# CHAPTER II

## PETROLEUM, NATURAL GAS, AND OTHER HYDROCARBONS

**Introductory.** — Under this head are included four well-known substances, viz. natural gas, petroleum, mineral tar or maltha, and asphaltum, all essentially compounds of carbon and hydrogen — hydrocarbons — or mixtures of such compounds. In addition they may contain many impurities, such as sulphur compounds, oxidized and nitrogenous substances, etc., whose exact nature may be doubtful.

The hydrocarbons are divisible primarily into a number of regular series, each of which has a generalized formula as indicated below.

| | | | |
|---|---|---|---|
| 1. $C_nH_{2n+2}$ | | 6. $C_nH_{2n-8}$ |
| 2. $C_nH_{2n}$ | | 7. $C_nH_{2n-10}$ |
| 3. $C_nH_{2n-2}$ | | 8. $C_nH_{2n-12}$ |
| 4. $C_nH_{2n-4}$ | | | |
| 5. $C_nH_{2n-6}$ | | 18. $C_nH_{2n-32}$ |

Members of the first eight series have been discovered in petroleum. Of the above formulas, the first represents the paraffin hydrocarbons, beginning with marsh gas or methane, $CH_4$, and ranging at least as high as the compound $C_{35}H_{72}$. Methane is gaseous, the middle members of the series are liquids, while the higher members are solids, like ordinary paraffin. Members of the second series are also important in petroleums, especially the olefine subseries. The third or acetylene series is represented in some petroleums by its higher members. The fifth or benzine series occurs in nearly all petroleums, but not in large amounts.

**Properties of Petroleum** (4, 10, 12). — Crude petroleum is a liquid of complex composition and variable color and density. It consists of a mixture of hydrocarbons, mainly liquid, with some gaseous and solid ones, the last being in solution.[1]

Oils which contain chiefly paraffin hydrocarbons, and which usually yield paraffin scales when the heavier distillates are subjected to a freezing temperature, may be said to have a *paraffin base*. Those containing asphaltic bodies, and yielding on evaporation a residue consisting essentially of as-

[1] For a résumé of the different hydrocarbons discovered in American and Canadian oils, see F. W. Clarke, U. S. Geol. Surv., Bull. 491. Much general information also in Johnson and Huntley, Principles of Oil and Gas Production, New York, 1916.

phalt, are said to have an *asphaltic base*.   These two terms, though much used formerly, are rapidly falling into disuse; because some asphaltic oils may also yield paraffin wax.

Sulphur may be present as a constituent of hydrogen sulphide, as free sulphur, or as organic sulphur compounds.   The first two, which occur for example in the Mexican, and in the Gulf Coast oils of Texas and Louisiana, are not difficult to remove.   Organic sulphur, such as occurs in the Lima, Ohio, and the Ontario limestone oils, is more difficult to eliminate, even though in small amounts.

Most petroleum contains some nitrogen, but it rarely exceeds 2 per cent, except in some California oils, where it may reach 10 or 20 per cent.[1]

The following are analyses of several petroleums from American and foreign localities: —

ELEMENTARY ANALYSES OF PETROLEUM

| | PER CENT | | | SPECIFIC GRAVITY $H_2O = 1$ |
|---|---|---|---|---|
| | C | H | O | |
| Heavy oil, W. Va.   .   . | 83.5 | 13.3 | 3.2 | .873 |
| Light oil, W. Va.   .   . | 84.3 | 14.1 | 1.6 | .8412 |
| Heavy oil, Pa.   .   .   . | 84.9 | 13.7 | 1.04 | .886 |
| Light oil, Pa. .   .   .   . | 82.0 | 14.8 | 3.2 | .816 |
| Parma, Italy  .   .   .   . | 84.0 | 13.4 | 1.8 | .786 |
| Hanover, Germany .   . | 80.4 | 12.7 | 6.9 | .892 |
| Galicia, Austria  .   .   . | 82.2 | 12.1 | 5.7 | .870 |
| Light oil, Baku, Rus.   . | 86.3 | 13.6 | 0.1 | .884 |
| Heavy oil, Baku, Rus.  . | 86.6 | 12.3 | 1.1 | .938 |
| Java  .   .   .   .   .   .   . | 87.1 | 12.0 | 0.9 | .923 |
| Beaumont, Texas   .   . | 86.8 | 13.2 | — | .920 |

Most crude oils are opaque by transmitted light, except in thin layers.   Some of the thinner grades of Pennsylvania oils, and some Alberta ones may show pale straw, yellow, red, and brown colors.

Crude oils usually have a green cast by reflected light, but otherwise vary in color from yellow to black.

Oils from different fields vary in their refractive indices (2b), and this property may be of use for purposes of identification.

They also show double refraction.   As a rule crude oil rotates

the plane of polarization to the right, but some rotate it to the left, while others may be optically inert.

Petroleums commonly vary in specific gravity between about .8 and .98, the following being some of the limits shown by American oils:—

SPECIFIC GRAVITY OF SOME AMERICAN PETROLEUMS

| STATE | SPECIFIC GRAVITY | GRAVITY BEAUMÉ[1] |
|---|---|---|
| California (Placerita Cañon) . | .777 + | 50 + |
| Pennsylvania . . . . . . . | .801–.817 | 46.2–42.6 |
| Ohio . . . . . . . . . | .816–.860 | 42.8–32.5 |
| Kansas . . . . . . . . . | .835–1.000 | 38.8–10.0 |
| West Virginia . . . . . . | .841–.873 | 37.6–30.0 |
| Beaumont, Texas . . . . . | .904–.925 | 24.8–31.1 |
| Wyoming . . . . . . . . | .912–.945 | 23.3–11.9 |
| California . . . . . . . . | .920–.983 | 21.9–12.3 |

The viscosity of the oil increases with the specific gravity.

The temperature at which crude petroleum solidifies ranges from 82° F. in some Burma oils to several degrees below zero in certain Italian oils. The flashing point, or the lowest temperature at which inflammable vapors are given off, may be as low as zero degrees in the Italian oils to as high as 370° F. in an oil found on the Gold Coast of Africa, but these are extreme limits. There is also a great range in the boiling point, which is 180° F. in some Pennsylvania oils and 338° F. in oils found at Hanover, Germany.

The various liquid hydrocarbons making up crude petroleum vary in their specific gravity and boiling point. The more important oils which can be separated from crude petroleum by distillation are gasoline, benzine, heavy naphthas, and residuum. Those with a paraffin base are generally lighter and more valuable on account of the higher quantity and quality of the naphthas, illuminating oils, and lubricating oils which they produce. Those with an asphalt base are of inferior quality and chiefly valuable for fuel. Their transportation by pipe lines is also more difficult.

The percentage of the different distillates varies.

The following average percentages of distillates were yielded by the oils of several fields in 1902 (Oliphant) : —

[1] A specific gravity of 1, compared with water, is 10° on the Beaumé scale. Conversion from one scale to the other may be made by the following formula:—

$$\text{Beaumé} = \frac{140}{\text{Sp. Gr.}} - 130; \text{ or Sp. gr.} = \frac{140}{130 + \text{Beaumé}}.$$

|  | APPALACHIAN FIELD | LIMA, IND., FIELD | KANSAS FIELD |
|---|---|---|---|
| Naphthas . . . . . . . | 20.1 | 10.9 | 18 |
| Illuminating oils . . . . . | 61.4 | 48.8 | 30 |
| Lubricating and heavy oils . | 7.1 | 17.2 | 25 |
| Residuum . . . . . . . | 6.3 | — | — |
| Loss from uncondensed products and water . . . . | 5.1 | 23.0 | 27 |

In the following table (p. 74) there are given a number of determinations of distillates, etc., published by Dr. David T. Day, of the United States Geological Survey, and in part made by him.

**Properties of Natural Gas.** — This consists chiefly of marsh gas — fire damp — $CH_4$. It is colorless, odorless, burns often with a luminous flame, and when mixed with air it is highly explosive.

Ethane ($C_2H_6$), the next member of the marsh-gas series, may exist in considerable quantities in natural gas. Ethylene, or olefiant gas ($C_2H_4$), burns with a much more luminous flame than the two preceding, but it rarely exists in American gas in amounts greater than a small fraction of 1 per cent. Carbon monoxide occurs only in very small quantities, and the same is true of carbon dioxide· Nitrogen is found in variable amounts, and oxygen is not uncommon, but when present in large quantity in an analysis, it may be due to contamination of the sample analyzed with air.

The analyses given on p. 78 represent a number of American occurrences. It will be seen that marsh gas is the predominating constituent in nearly all of them.

The gas from Dexter, Kansas (No. 4 of the table on page 78), is interesting because of its high content of nitrogen. Of 47 samples of gas examined [1] by Cady and McFarland, all except one showed helium, in amounts averaging .10 per cent. One Kansas sample contained 1.84 per cent more than the others, and this same one carried the high nitrogen contents referred to above. The rare element neon was also discovered.

[1] Jour. Amer. Chem. Soc., XXIX: 1524.

| LOCATION OF WELL | DEPTH OF WELL (FEET) | LOCATION OF POOL | Gravity at 60° F. Specific | Gravity at 60° F. Degrees Baumé | Color | Begins to Boil at (°C.) | Distillation — To 150° C. cc | To 150° C. Sp. Gr. | 150° to 300° C. cc | 150° to 300° C. Sp. Gr. | Residuum cc | Residuum Sp. Gr. | Total (Cubic Centimeters) | Unsat. Crude % | Unsat. 150°–300° % | Paraffin % | Asphalt % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Katalla Bay., Alas.[1] | | | .828 | 39.5 | Dark Green | 230° C. | 21.0 | .7573 | 51.0 | .8204 | 28.0 | | | | | | 21.0 |
| Oil Bay, Alas.[2] | | | .9557 | 16.5 | Dark Green | | | | 13.2 | .8777 | 86.8 | | | | | | 10.0 |
| Contra Costa, Fresno County, Cal.[3] | | | .9667 | 14.8 | Black | | 3.7 | | [1]54.5 | | 42.8 | | | | | | |
| Fresno County, Coalinga, Cal.[4] | | | .7609 | 54 | | 49° C. | [1]30.0 | | [2]60.0 | | 10.0 | | | | | | |
| Oil City, Coalinga, Cal.[5] | | | .8584 | 33.1 | Black | | 28.0 | | [1]50.0 | | 22.0 | | | | | | |
| Kern County, Kern River, Cal.[6] | 1052 | | .9609 | 15.7 | | | 0 | | 20.2 | .8626 | 79.8 | | | | | | 21.4 |
| McKittrick, Cal.[7] | | | .9480 | 17.7 | | | 0 | | [1]39.9 | | 60.1 | | | | | | 14.25 |
| Sunset, Cal.[8] | | | 1.00 | 9.9 | | | | | 15.0 | | 95.0 | | | | | | 51.0 |
| East End Field, Los Angeles City, Cal.[9] | | | .9774 | 13.2 | | | 0 | | 12.0 | .8912 | 88.0 | | | | | | 19.8 |
| Newhall Dist., Cal.[10] | 1275 | | .8758 | 29.9 | | | 20.3 | .7686 | 34.1 | .8424 | 45.6 | | | | | | 10.9 |
| Puente Dist., Cal.[11] | 750 | | .8775 | 29.5 | | | 23.4 | .7564 | 33.1 | .8442 | 43.5 | | | | | | 13.1 |
| Santa Barbara, County Lompoc, Cal.[12] | 1425 | | .9574 | 16.2 | | | 5.2 | | 31.5 | .8417 | 63.3 | | | | | | |
| Santa Maria field, Cal.[13] | 2500 | | .8882 | 27.6 | | 122 | 25.9 | .7460 | 30.6 | .8469 | 44.5 | | | | | | 20.6 |
| United Oil Co., Florence, Colo. | 1600 | | .8750 | 30.0 | | | 1.5 | | 27.0 | .7988 | 70.2 | | | | | | 12.0 |
| Boulder County, Colo. | 2445 | | .8304 | 38.6 | | | 16.0 | .7368 | 40.0 | .8000 | 44.0 | .9079 | 98.7 | | | 9.23 | |
| W. C. Jones, Robinson, Ill. | 1140 | | .8490 | 34.9 | Dark Green | 95 | 13.0 | .7386 | 37.0 | .8028 | 50.2 | .9235 | 97.2 | | | 3.71 | 1.56 |

| Location of Well | Depth of Well (feet) | Location of Pool | Gravity at 60° F. Specific | Gravity Degrees Baumé | Color | Begins to Boil at (° C.) | To 150° C. Cubic Centimeters | To 150° C. Specific Gravity | 150° to 300° C. Cubic Centimeters | 150° to 300° C. Specific Gravity | Residuum Cubic Centimeters | Residuum Specific Gravity | Total (Cubic Centimeters) | Unsaturated Crude (per cent) | Unsaturated 150° to 300° (per cent) | Paraffin (per cent) | Asphalt (per cent) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S. Spellbring farm, sec. 7, Ohio Oil Co., Ill.[14] | 330 | | .846 | 31.5 | Light Green | 63° C. | 14.0 | .7745 | 31.0 | .8145 | | | | | | | |
| J. Turner lease, sec. 33, Ohio Oil Co., Ill.[15] | 300 | | .879 | 29.3 | Brown | 65° C. | 8.0 | .7008 | 27.0 | .8268 | | | | | | | |
| M. Misner lease, Pure Oil Co., Ill.[16] | 606 | | .863 | 32.2 | Light Green | 75° C. | 18.0 | .7193 | 32.0 | .8065 | | | | | | | |
| Z. E. Brant farm, sec. 26, Ohio Oil Co., Ill.[17] | 480 | | .868 | 31.3 | Light Green | 75° C. | 10.5 | .7261 | 30.5 | .8141 | | | | | | | |
| Chanute Pool, Beach lease, Rex Oil and Gas Co., Chanute, Kas. | 751 | | .8647 | 31.9 | Dark Green | 109 | 5.0 | .7350 | 36.0 | .7993 | 57.8 | .9223 | 98.8 | | | 4.25 | 1.23 |
| Webb lease, Northland Oil and Gas Co., Erie, Kas. | | | .8739 | 30.2 | Black | 135 | 1.0 | | 34.0 | .8000 | 64.1 | .9115 | 99.1 | | | 4.78 | 3.20 |
| M. Davis lease, Dunkley & Odell, Coffeyville, Kas. | 625 | Coffeyville Pool | .8717 | 30.6 | Black | 100 | 6.0 | .7289 | 33.0 | .8030 | 58.3 | .9241 | 97.3 | 24.4 | | 5.31 | 0.17 |
| F. G. Hill's lease, Interstate Oil and Gas Co., Peru, Kas. | 1070 | Peru Pool | .8557 | 33.6 | Dark Green | 110 | 7.0 | .7310 | 37.0 | .7975 | 63.2 | .9150 | 97.2 | 24.8 | | 5.79 | 1.53 |
| McKinley Crude Oil Co., Humboldt, Kas. | | Humboldt Pool | .8878 | 27.7 | Dark Green | 123 | 1.0 | | 29.0 | .8152 | 68.9 | .9247 | 98.9 | 32.8 | 2 | 3.93 | 2.33 |
| Springer lease, Hardison & Streeter, Rantoul, Kas. | 350 | Rantoul Pool | .8557 | 33.6 | Black | 76 | 11.5 | .7116 | 29.5 | .7950 | 54.9 | .9272 | 95.9 | 34.0 | | 3.45 | 2.29 |

| Locality | Well / Pool | Sp. gr. | Baumé | Color | ° C. | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Warren County and Sunnyside, Ky. | | .8426 | 36.2 | Dark Green | 67 | 19.0 | .7148 | 37.0 | .9979 | 44.0 | .9150 | 94.7 | | | 4.93 | .41 |
| H. M. Caldwell, Monticello, Ky. | | .8211 | 40.5 | Black | 67 | 16.0 | | 37.5 | | 41.2 | .8805 | 99.6 | | | | .25 |
| Caddo Oil and Mineral Co., Gilbert well, La. | | .8264 | 39.4 | | 136 | 1.5 | .700 | 49.0 | .7778 | 49.1 | | | | | | |
| St. Martin's Parish, Anse-Le-Butte, La.[18] | 600 | .9392 | 19.1 | | 240° C. | | | 16.0 | | 84.0 | | | | | | |
| Calcasieu Parish, Jennings, La.[19] | 1000 | .9093 | 21.0 | Dark Green | 200° C. | | | 41.0 | | 59.0 | | | | | | 5.0 |
| St. Claire County, Port Huron, Mich. | | .8333 | 38.0 | Dark Green | 23° C. | 15.0 | | 55.0 | | 30.0 | | | | | | |
| Lima, Ohio | | .791 | 47.0 | Green | | 16.0 | .788 | 68.0 | | 16.0 | | | | | | |
| Washington County, Macksburg, O. | From 140 feet sand | .8118 | 42.5 | Light Amber | | 15.47 | | 45.81[2] | | | | | | | | |
| New field, Evans lease, Julia Oil Co., Muskogee, Okla. | 1553 | .8328 | 38.1 | Green | 97 | 11.0 | .7332 | 36.0 | .7960 | 52.8 | .8866 | 99.8 | | | 7.64 | .0 |
| Bartlesville pool, lot 32, Illuminating Oil Co., Bartlesville, Okla. | 1500 | .8547 | 33.8 | Dark Green | 113 | 3.5 | .7514 | 44.0 | .7868 | 52.4 | .9009 | 99.9 | | | 7.90 | 1.12 |
| J. I. Yorgee lease, Robt. Galbreath, Tulsa, Okla. | Red Fork Pool 601 | .8323 | 38.2 | Dark Green | 93 | 9.0 | .7220 | 40.5 | .7814 | 48.5 | .9038 | 98.0 | 17.6 | 1 | 4.39 | .0 |
| Thos. Berryhill lease, Indiana Oil and Gas Co., Kiefer, Okla. | Glenn Pool 1518 | .8439 | 35.9 | Black | 105 | 8.0 | .7508 | 44.5 | .8008 | 48.0 | .9091 | 100.5 | 20.8 | 6 | 7.53 | .90 |
| W. B. Self lease, Prairie Oil and Gas Co., Tulsa, Okla. | Glenn Pool 1523 | .8373 | 37.2 | Black | 94 | 10.0 | .7328 | 41.0 | .7968 | 47.6 | .9021 | 98.6 | 16.8 | 5 | 3.12 | .21 |
| Prairie Oil and Gas Co., Morris, Okla. | Morris Pool | .8459 | 35.5 | Light Green | 112 | 3.0 | | 34.0 | .7924 | 62.1 | .8866 | 99.1 | 10.0 | 1 | 11.90 | .0 |
| Buchanan lease, Burns & Caton, Morris, Okla. | Bald Hill Pool 1680 | .8531 | 34.1 | Dark Green | 110 | 5.5 | .7515 | 36.0 | .8018 | 58.0 | .9003 | 99.5 | 20.0 | 8 | 3.43 | .15 |
| Fort Worth Development Co., lease of Richmond Dev. Co., Muskogee, Okla. | Muskogee Pool new field 1702 | .8333 | 38.0 | Green | 90 | 11.0 | .7090 | 37.0 | .7986 | 51.2 | .8861 | 99.2 | 16.4 | 8 | 1.52 | .0 |
| Prairie Oil and Gas Co., Bartlesville, Okla. | Bartlesville Pool | .8521 | 34.3 | Dark Green | 103 | 8.0 | .7378 | 37.0 | .8090 | 54.5 | .9038 | 99.5 | 24.4 | 4 | 3.75 | .23 |
| Venango County, Pa.[20] | | .882 | 28.7 | Green Dark | | 8.55 | | 42.78[1] | | 48.67[2] | | | | | | |
| Jefferson County, Beaumont, Tex. | | .9217 | 21.9 | Dark Brown | | 1.8 | | 17.1 | | 81.1 | | | | | | 7.5 |

| Location of Well | Depth of Well (feet) | Location of Pool | Physical Properties — Gravity at 60° F. Specific | Physical Properties — Degrees Baumé | Color | Begins to Boil at (°C.) | Distillation by Engler's Method, 100 cc. at 60° F. Taken, By Volume — To 150° C. Cubic Centimeters | To 150° C. Specific Gravity | 150° to 300° C. Cubic Centimeters | 150° to 300° C. Specific Gravity | Residuum Cubic Centimeters | Residuum Specific Gravity | Total (Cubic Centimeters) | Unsaturated Hydrocarbons — Crude (per cent) | Unsaturated Hydrocarbons — 150° to 300° (per cent) | Paraffin (per cent) | Asphalt (per cent) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jefferson County, Beaumont, Tex. | | | .9206 | 22.1 | Brown | 77° C.[1] | 6.45 | | 35.0 | .872 | 58.55 | | | | | | 6.34 |
| Navarro County, Corsicana, Tex.[21] | | | .8604 | 32.7 | Opaque Dark Brown | | [1]24.78 | .755 | [2]59.94 | | 15.28 | | | | | | .00 |
| Smith Bros. & Sweeney, St. Mary's, W. Va. | 1234 | | .7883 | 47.6 | Green | 73 | 15.0 | .7076 | 43.5 | .7688 | 39.4 | .8578 | 97.9 | | | 9.00 | .00 |
| J. D. Dinsmore & Co., Big Injun Sand, St. Mary's, W. Va. | | | .7870 | 47.9 | Green | 70 | 16.5 | .7111 | 41.0 | .7694 | 34.5 | .8573 | 92.0 | | | 5.00 | .00 |
| Ohio and W. Va. Oil Co., 1st Cow Run Sand, St. Mary's, W. Va. | 1673 | | .8041 | 44.1 | Green | 89 | 18.0 | .7256 | 39.5 | .7818 | 42.8 | .8653 | 100.3 | | | 8.92 | .00 |
| Dinsmore Oil Co., 1st Cow Run Sand, St. Mary's, W. Va. | 590 | | .7982 | 45.4 | Green | 74 | 8.0 | .7165 | 43.5 | .7086 | 42.4 | .8613 | 94.0 | | | 6.93 | .00 |
| Uinta County, Spring Valley, Wyo. | | | | | | | 28.0 | | 24.0 | | 48.0 | | | | | | |
| Oil Spring reserve, No. 12 Shale Spring, Wyo. | | | .8573 | 33.3 | Light Green | 143 | tr. | | 51.0 | .8271 | 48.7 | .8929 | 99.7 | | | | .00 |

(1) Sulphur trace; paraffin base. (2) S, .098. (3) [1], 150°–350° C. (4) [1], 49°–141° C.; [2], 141°–275° C. (5) Asphaltic base. [1], 150°–270° C. (6) S, .94. (7) S, .87; [1], 150°–350° C. (8) S, 1.253; [1], 150°–270° C. (9) S, .49. (10) Gravity at 15° C. (11) S, .36; gravity at 15° C. (12) S, 4.43; gravity at 15° C. (13) S, 1.56; (14) S, .48. (15) S, .30. (16) S, .30; lower sand oil. (17) S, 27; upper sand oil. (18) S, 20; asphaltio base. (19) S, 39; asphaltic base. (20) [1], 150°–270° C.; [2], includes loss and water. (21) [1], portion of fraction 77–203° F., lost before measured; [2], 150°–280° C.

ANALYSES OF NATURAL GAS

| No. | Methane (CH₄) | Ethane (C₂H₆) | Olefine (C₂H₄) | Carbon Dioxide (CO₂) | Carbon Monoxide (CO) | Oxygen | Nitrogen | Hydrogen | Helium | Hydrogen Sulphide |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 . . . . | 94.40 | — | — | — | — | .23 | 5.08 | — | .183 | ← |
| 2 . . . . | 96.20 | .78 | — | — | .11 | tr. | 2.46 | .18 | .27 | — |
| 3 . . . . | 82.25 | — | .12 | .61 | — | tr. | 16.40 | — | .616 | — |
| 4 . . . . | 14.85 | .41 | — | — | — | .20 | 82.70 | tr. | 1.84 | — |
| 5 . . . . | 62.93 | — | — | .50 | tr. | .70 | 24.36 | 11.51 | undet. | — |
| 6 . . . . | | 95.35 | | 1.60 | 2.50 | .55 | — | | undet. | — |
| 7 . . . . | 13.97 | — | — | .10 | .05 | .05 | 85.83 | — | undet. | — |
| 8 . . . . | 73.81 | — | — | .81 | — | 3.46 | 21.92 | — | undet. | — |
| 9 . . . . | 92.67 | — | .25 | .25 | .45 | .35 | 3.53 | 2.35 | undet. | .15 |
| 10 . . . . | 92.61 | — | .30 | .26 | .50 | .34 | 3.61 | 2.18 | undet. | .20 |
| 11 . . . . | | 90.01 | | .20 | — | tr. | 9.79 | — | undet. | — |
| 12 . . . . | | 98.90 | | .40 | — | — | .70 | — | undet. | — |
| 13 . . . . | 80.94 | 14.60 | — | — | .40 | .20 | 3.46 | tr. | undet. | — |
| 14 . . . . | 86.48 | 7.65 | — | — | .50 | .30 | 4.87 | — | undet. | — |
| 15 . . . . | 98.40 | — | — | — | .95 | tr. | .40 | tr. | undet. | tr. |
| 16 . . . . | 94.20 | — | .39 | 1.06 | 1.13 | .92 | 3.31 | — | tr. | — |
| 17 . . . . | 92.20 | — | — | 1.40 | .21 | tr. | 5.59 | .40 | — | .20 |
| 18 . . . . | 96.57 | — | — | — | — | — | 2.69 | — | — | .74 |
| Minima . . | 14.33 | — | — | .05 | — | .10 | .60 | — | — | — |
| Maxima . . | 98.30 | — | — | 30.40 | — | 9.00 | 85.83 | — | — | — |

1. Iola, Kas., p. 270; 2. Buffalo, Kas., p. 270; 3. Fredonia, Kas., p. 270; 4. Dexter, Kas., p. 270; 5. Stockton, Cal., p. 252; 6. From glacial drift, Dawson, Ia., p. 252; 7. Princeton, Ill., p. 251; 8. Pittsfield, Ill., p. 251; 9. Muncie, Ind., p. 249; 10. Trenton limestone, Findlay, O., p. 248; 11. Kane, McKean Co., Pa., p. 247; 12. Pittsburg, Pa., p. 247; 13. Big Injun sand, Shinnston, W. Va., p. 242. 14. Fifty-foot sand, same locality, p. 242; 15. Trenton limestone, Baldwinsville; N. Y., p. 241; 16. Gas from coal mine, Scranton, Pa., 1–16, quoted by Kas. Geol. Surv., IX on page given after each; 17. Kent County, Ont.; 18. Welland, Ont.

For additional analyses of gas used in different cities, see Burrell, G. A., and Oberfell, G. G., Bur. Mines, Tech. Pap. 109, 1915.

The following table brings out the essential differences between natural gas and other fuel or illuminating gases.

Analyses of natural and manufactured gases.

| | Aver. Pa. & W. Va. | Aver. O. & Ind. | Aver. Kas. | Aver. Coal Gas | Aver. Water Gas | Aver. Producer Gas Bit. Coal |
|---|---|---|---|---|---|---|
| Marsh gas, $CH_4$ | 80.85 | 93.60 | 93.65 | 40.00 | 2.00 | 2.05 |
| Other hydrocarbons | 14.00 | .30 | .25 | 4.00 | .00 | .04 |
| N | 4.60 | 3.60 | 4.80 | 2.05 | 2.00 | 56.26 |
| $CO_2$ | .05 | .20 | .30 | .45 | 4.00 | 2.60 |
| CO | .40 | .50 | 1.00 | 6.00 | 45.00 | 27.00 |
| H | .10 | 1.50 | .00 | 46.00 | 45.00 | 12.00 |
| $H_2S$ | .00 | .15 | .00 | .00 | .00 | .00 |
| O | tr. | .15 | .00 | 1.50 | 1.50 | .05 |
| Lbs. in 1000 cu. ft. | 47.50 | 48.50 | 49.00 | 33.00 | 45.60 | 75.00 |
| Sp. gr. | .624 | .637 | .645 | .453 | .600 | .985 |
| B.T.U. per 1000 cu. ft. | 1,145,000 | 1,095,000 | 1,100,000 | 755,000 | 350,000 | 155,000 |

**Origin of Oil and Gas.** — That the solid, liquid, and gaseous hydrocarbons are more or less closely related is evident from the fact that the gases given off by petroleum are similar to those predominating in natural gas, while the exposure of many petroleums to the air results in a change to a viscous mass and finally to a solid asphalt or paraffin-like substance. It is a well-known fact that petroleum is rarely free from natural gas, although this gas may sometimes form alone, as in coal mines, or from decaying vegetation in stagnant pools. The origin of the hydrocarbon compounds has been the subject of much speculation among both chemists and geologists, the former for a time arguing for an inorganic or mineral origin, the latter for an organic derivation, the same evidence curiously enough being sometimes used by persons holding opposite views.

It cannot be said that the matter has yet been settled to the satisfaction of all, although it is probable that the majority of observers admit the organic origin of petroleum. One cause of uncertainty is that oils, unlike coals, do not usually contain visible traces of their original constituents. Moreover, we had until recently few undoubted known instances of the recent formation of petroleum under conditions similar to those found in the older rocks.

**Inorganic Theories** (1, 2a, 2d, 3a, 10). — Several theories have been advanced to account for an inorganic origin of oil. Humboldt was the first to propose it, in 1804, although it was later more definitely stated by Berthelot,[1] and still later elaborated by Mendeljeff,[2] under whose name it is frequently referred

[1] Comptes Rendus, LXII: 949, 1866.
[2] Ber. Deutsch. Chem. Gesell., X: 229, 1877, and Jour. Chem. Soc., XXXII: 283.

to. The general substance of these, and several others' hypotheses is that surface water has percolated downward through the earth's crust, where on reaching the heated interior it becomes converted into steam, which, attacking the carbide of iron, forms hydrocarbons, which make up the oil and gas.

From a purely chemical standpoint, this theory is reasonable, and the production of hydrocarbons by this method has been done experimentally, but it does not accord with geologic facts. If petroleum were formed in this manner, we should expect to find it widely distributed through the oldest rocks of the earth's crust.

On the contrary, hydrocarbon compounds like oil, gas, and asphalt are practically unknown in crystalline rocks. In Ontario, a hard compressed asphalt is found in them, but it is significant that this material (Anthraxolite) which was probably original petroleum, occurs in rocks which may be metamorphosed sediments. A second case is found in California (17), where oil occurs in a much-folded crystalline schist, but its associations are such that it may have been derived from neighboring sediments.

A possible point in favor of the derivation of oil and gas from carbides has been noted by Becker (1), who has called attention to the fact that the irregularities of the curves of equal magnetic declination are strongly marked in the principal oil regions. While the agreement is not a very close one, it is most marked in the Appalachian field. There are, however, some systematic irregularities, as in the New Jersey magnetite regions, which are not known to contain any oil. Becker believes that the coincidence between the petroleum occurrences and local disturbances of the compass are too numerous to be attributable to mere accident, and that there must be a direct or indirect historical connection between the two phenomena in the regions of coincidence, thus suggesting the possibility of the oil being derived from iron carbides.

Tarr (12a), however, disputes Becker's conclusions, pointing out: (1) That the isoclinals or lines of magnetic dip do not show any evidence of disturbances due to magnetic masses in the oil regions; (2) that the secular variation is a shifting of the isogonics or lines of magnetic declination, indicating that the origin of this variation is not due to a stationary mass; and (3) the magnetism of iron is lost at high temperatures, hence it must exist at comparatively shallow depths to be magnetically effective.

*Volcanic Theory.* — A second inorganic theory advocated by several, and in recent years expounded with great vigor and detail by E. Coste (2d, 3a), is the theory of volcanic origin of the hydrocarbons.

Mr. Coste believes that all hydrocarbons cannot be of animal or vegetable origin, but must be of volcanic derivation for the following reasons: 1. Animal remains are never entombed in rock formations. 2. Vegetable remains in rocks decompose into carbonaceous matter. 3. Further distillation of carbonaceous matter has not taken place in nature. 4. Gaseous

liquid, and solid hydrocarbons are products of volcanic emanations.   5. Oil and gas are under strong pressure, and hence must be of volcanic origin, for nothing else could produce this pressure.   6. In some oil fields heated gas and water are met with.   7. Oil and gas fields are located along faulted and fissured zones of the earth's crust, parallel to great orogenic (mountain-making) and volcanic dislocations.   8. Oil, gas, and bituminous matter are never indigenous to the strata in which they are found.   9. The density of the rocks precludes possibility of anything but volcanic pressure having forced them upward.

The arguments against some of these points may be mentioned under the same numbers: 1. Animal remains are entombed in rocks, otherwise we could not have fossils of those lacking hard parts.   2. Vegetable remains in rock have been proven to decompose into hydrocarbons, as evidenced by natural gas supplies found in glacial drift; moreover, some coal seams have oil seepages.   3. While hydrocarbons are known to occur in some volcanic emanations, they might be formed by the direct union of carbon and hydrogen of th gases, or have been distilled out of sedimentary rocks through which t lava passed.   Moreover, they are frequently formed from decaying vegetable matter.   5. The pressure may be due to the natural expansive force of the gas.   7. Oil and gas fields are sometimes found in regions of but little disturbance, as Illinois, Medicine Hat, Alberta, etc.   8. This may be true, but they are often clearly shown to have come from adjoining beds. 9. If volcanic pressure forced this oil and gas up through many feet of dense rock, why were they not forced all the way to the surface?

One may also add that the restriction of oil and gas to sedimentary rocks is not in accordance with a volcanic origin, neither is the decrease in pressure which most wells show with time.

**Organic Theory.** — This considers that petroleum has been formed by the decomposition of organic matter buried in the rocks, although the exact changes involved are somewhat uncertain.

But even though many are in agreement on the theory of organic origin, they differ as to whether the oil came from animal or vegetable matter.

Adherents of the former view include Höfer,[1] Newberry,[2] Hunt, Zaloziecki,[3] Engler,[4] and others, while among those of the latter are numbered Lesquereux, Phillips, Kramer, Spilker, and others.

Perhaps the majority of geologists and even others have unconsciously assumed that petroleum has been derived from land plants, and while in some cases this may be so, some rather

[1] Proc. Manchester Lit. Phil. Soc., III: 136, and Das Erdöl, p. 118.

[2] Geol. Surv. Ohio, 1878, Pt. I: 125 and 174.

[3] Dingler's Polytech. Jour., CCLXXX: 69, 85 and 133;   Chem. Zeit., XV: 1203.

[4] Redwood, Petroleum and its Products, 1906, p. 259.

weighty objections can be urged against it. These are the following:—

1. There is a general lack of association of coal or lignite and oil. 2. Where lignite or carbonized wood is found with oil it has lost none of its essential constituents. 3. There is a great chemical difference between lignite tar oils and natural petroleums. 4. It requires a high temperature (geologically speaking) to convert wood into liquid bitumen, and leave no trace of its original structure.[1] 5. An argument of doubtful weight is that limestones, being of marine origin, the oil in them could not be derived from land plants.

The following arguments may be mentioned in favor of the derivation of petroleum from marine plants such as seaweeds: 1. Saline water associated with some oils carries iodine.[2] 2. Certain seaweeds found on the coast of Sardinia become covered with an oily coating while decomposing.[3] 3. In some localities the diatom cases found in rocks are known to contain small globules of oil, which have in some regions been regarded as a source of petroleum (19). 4. The so-called algal remains of bog-head coals were formerly regarded as evidence of marine origin, but these minute bodies are now recognized as spores, the coals rich in them being petroliferous or highly bituminous, and according to Jeffrey [4] in some form or other are the mother substance of oil or gas.[5]

Some have also considered that the oil may have been derived, in part at least, from animal remains, the oil thus having a dual origin.

Some have claimed that the optical activity of oil shows it to be of undoubted organic origin (1), for the reason that mary petroleum products have the power of rotating the plane of polarization of light, as is done by sugar, lactic acid, and other organic compounds. These optical phenomena are not shown by inorganically synthesized petroleum,[6] and hence it is argued that the substances to which it is believed to be due are only of organic derivation. These substances are cholesterol, found in the fatty parts of animals, and phytosterol, found in plants.

[1] Such a process would be likely to occur only where a bed of land plants was approached by an intrusive.

[2] Watts, Calif. State Min. Bur., Bull. 19: 202.

[3] Redwood, Petroleum and its Products, 2d edition, I: 126, 142.

[4] Econ. Geol., IX: 741, 1914.

[5] C. A. Davis has recently identified algæ in Utah oil shales.

[6] Some natural petroleums are now found to be inert optically.

If the oils are derived from animal and plant remains of marine character, it is possible that the nitrogenous portions were eliminated by bacterial action soon after the death of the organism, and before it became buried under sediments.   Subsequently the oil was produced by decomposition of the fatty matter of the plants and animals.   Some geologists, including Orton (4) and Newberry (Ohio State Agric. Rept. 1859) believed that the formation of petroleum has taken place at lower temperatures; but others, including Peckham (6), have considered heat necessary.   In the case of Appalachian oils the folding of the strata is supposed to have supplied this heat.

**Mode of Occurrence.** (6, 8, 9, 13). — Oil is rarely found without some gas, but gas may occur without oil, and in either case saline water may be present.
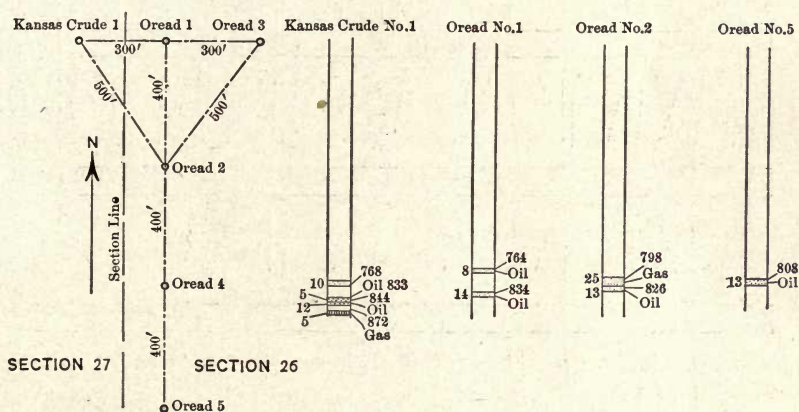


Fig. 26.— Showing positions and vertical sections of wells southeast of Humboldt, Kas., and differing thickness and number of sands in neighboring wells. (*Kas. Geol. Surv., IX*.)

In the first discovered fields, the oil and gas were found in porous sandy strata, varying from fine-grained sandstones to conglomerates.   These rocks were termed *sands*, and the area of porous oil sand was called the *pool*.   Later discoveries in Ohio and Indiana showed that the gas and oil might occur in limestone also, while in a few fields (Florence, Colorado, and parts of California) the oil has accumulated in fissures in shale, produced by earth movement.

The number and thickness of the oil and gas sands may some-

times vary in different parts of the same field (Figs. 26 and 27), thereby making correlation difficult.
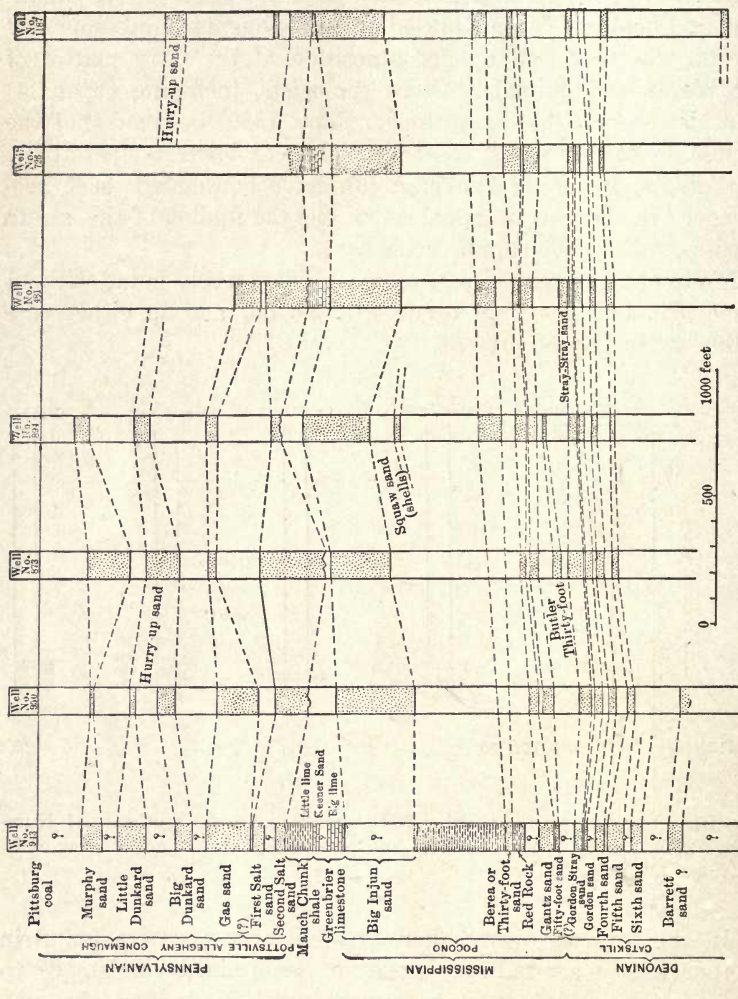


Fig. 27. — Sections of deep wells in the Clayville, Pa., quadrangle, showing irregularity in thickness and number of the oil and gas sands. (After Griswold and Munn.)

The thickness of the producing rock ("pay sand") varies in the different fields. White, referring to West Virginia, regards 5 feet of sand as sufficient for good productive territory, but thicker ones are found in the Appalachian field. The Illinois sands range from 2 to over 30 feet in thickness, while that estimated for Spindle Top in Texas averages 75 feet. The

Kern River field of California is said to have pay sands as much as 100 feet thick.[1]

The quantity of oil which a cubic foot of apparently dense rock can hold is often surprising. White estimated that fairly productive sands may hold from six to twelve pints of oil per cubic foot, but that probably not more than three-fourths of the quantity stored in the rock is obtainable. According to Day (53) it has been customary to consider 10 per cent as near the average porosity of the pay sand, with a latitude of variation from practically nothing in damp shales to over 30 per cent in the most porous strata. The degree of openness of the pores will, however, govern the rate of flow of oil from the rock.[2]

*Pressure of Oil and Gas Wells.* — Since both oil and gas usually occur in the earth under pressure, any break in the porous rock or reservoir which contains them allows them to escape, frequently giving rise to surface indications, and the force with which oil and gas oftentimes issue from a well indicates the pressure under which they are confined. It is sometimes sufficient to blow out the drilling tools and casing, as well as to cause the oil to spout many feet into the air.

There are several remarkable cases of the amount spouted by these gushing wells. One of these is the famous Lucas well at Beaumont, Texas, which in 1901 for nine days gushed a 6-inch stream to a height of 160 feet, at the rate of 75,000 barrels per day. This, however, is small compared with the records of some Mexican oil wells. Although many wells flow when first drilled, this does not usually continue long, and the oil then has to be brought to the surface by pumping. The depth of the wells drilled in the United States ranges from 250 to 4000 feet.

The maximum pressure which a well develops when closed has been called *rock pressure*. As a result of his studies in the Ohio-Indiana field, Orton (42) found that the rock pressure was the same as that of a column of water whose height was equal to the difference in elevation between the level of Lake Erie and that of the oil or gas-bearing stratum. He therefore considered it to be hydrostatic pressure. This theory, while apparently applicable in many localities, was found to be inadequate to explain the great pressure shown in many shallow wells. In these, as also in deep ones, the pressure is thought by many to be due to the expansive force of the imprisoned gas.

Either the drilling of additional wells or a drain by excessive use

[1] U. S. G. S., Bull. 394: 34, 1909.
[2] Washburne, Amer. Inst. Min. Engrs., Bull., Feb. 1915.

# ECONOMIC GEOLOGY

PRESSURE OF NATURAL GAS IN VARIOUS FIELDS AT VARIOUS DATES
(In pounds per square inch)

| | ILL. | IND. | KAS. | KY. | N.Y. | O. | OKLA. | PENN. | TEX. | W. VA. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885 | 400–450 | 325–400 | 110 | | | 450 | | 150–575 | | 550–680 |
| 1886 | 125 | 320–340 | | | | 400 | | 200–460 | | |
| 1887 | 300 | | | 125 | | {[1]750 / [2]650 / [2]450} | | 200–380 | | |
| 1888 | | 325 | | | | 250–390 | | | | 1000 |
| 1889 | | 325 | | | 400 | 170–275 | | | | |
| 1890 | | 280 | | | 240 | | | | | |
| 1893 | | 260 | | | | | | | | |
| 1894 | 60 | 240 | | {[8]60 / [4]250–300} | | [2]50–150 | | 250 | | |
| 1895 | 40 | 220 | 200 | | | | | 150 | | |
| 1896 | 25 | 195 | 100 | 285–300 | 1500 | {[1]750 / [2]45 / [2]30} | | 85 | | 600–900 |
| 1897 | | 165 | 250 | | | | | | | 100–1100 |
| 1898 | | 150 | | | | | | | | 600–1200 |
| 1899 | [5]3–30 | 110 | {[6]300–325 / [7]150} | | 200 | | | | | 1200 |
| 1900 | | 80 | | | | {[1]300–400 (2,8)} | | | | 1200 |
| 1901 | | 50 | | | | {[1]1100 / [10]800} | | | [9]250 | 1000–1300 |
| 1902 | | | | | | | | | | 1000–1250 |
| 1903 | | | | | | | | 400 | | 850–1250 |
| 1904 | | {[11]305–400 / 155} | 550–650 | | | | | | | |
| 1906 | 150–435 | 22–156 | 90–282 | | 45–335 | 121–352 | 217–468 | 41–486 | | 144–516 |

[1] Lancaster.  [2] Northwestern Ohio.  [3] Western Kentucky.  [4] Eastern Kentucky.  [5] Bureau County.  [6] Allen County.  [7] Neosho County.

[8] Reduced to almost no pressure.  [9] Beaumont.  [10] Homer.  [11] Southern Indiana.

from wells already bored commonly causes a slow decrease in pressure in an oil or gas field.   Thus in the natural gas region of Findlay, Ohio, the rock pressure in 1885 was 450 pounds per square inch; 400 in 1886; 360–380 in 1887; 250 in 1889; 170–200 in 1890.   Some West Virginia wells have shown a measured rock pressure of 1110 pounds per square inch and an estimated pressure of 2000 pounds.

It has been not infrequently noticed, however, that the opening up of one or more wells close to a good producer may have little or no effect on it.

The table on page 86 (53) gives the closed or rock pressure in various fields, in different years.   They are interesting, but lose their comparative value as they do not probably in all cases represent the same well.

**Classification of Oil and Gas Sands.** — As early as 1861 T. Sterry Hunt. the Canadian geologist, and A. Höfer, the Austrian
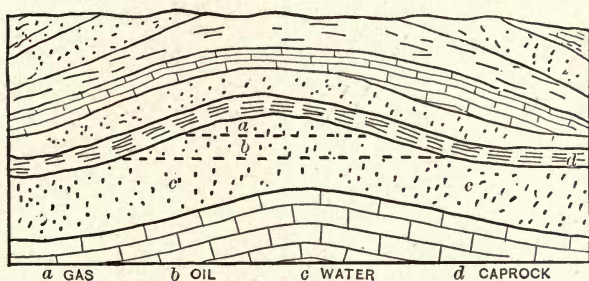


Fig. 28. — Section of anticlinal fold showing accumulation of gas, oil, and water.
(*After Hayes. U. S. Geol. Surv., Bull.* 212.)

geologist, called attention to the fact that oil and gas occurrences appeared to be associated with anticlinal folds, but the *anticlinal theory,* as it came to be called, was most fully developed by I. C. White (13).   According to this theory, in folded areas the gas collects at the summit of the fold, with the oil immediately below, on either side, followed by the water (Fig. 28). It is, of course, necessary that the oil-bearing stratum shall be capped by a practically impervious one.

If the rocks are dry, then the chief points of accumulation of the oil will be at or near the bottom of the syncline, or lowest portion of the porous bed.   If the rocks are partially saturated with water, then the oil accumulates at the upper level of saturation.

In a tilted bed which is locally porous and not so throughout, the oil, gas, and water may arrange themselves according to their gravity in this porous part.

While the anticlinal theory has been found to apply in many oil regions, some doubt has been raised regarding its possible application in parts of southwestern Pennsylvania (6), and even other localities.

Many occurrences of oil and gas appear to be associated with anticlines, but there are others which are either related to modifications of this structure, or to totally unrelated structures.
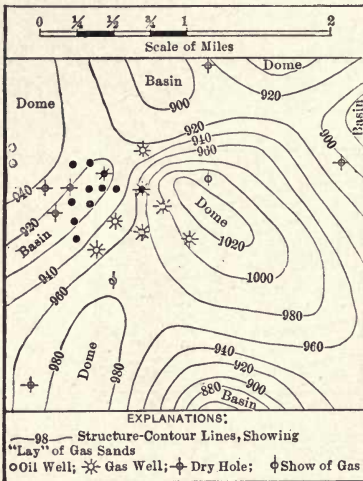


Fig. 29. — Contour map of " sand," showing occurrence of gas on a structural dome in Oklahoma. (*Clapp, Econ. Geol. VIII.*)
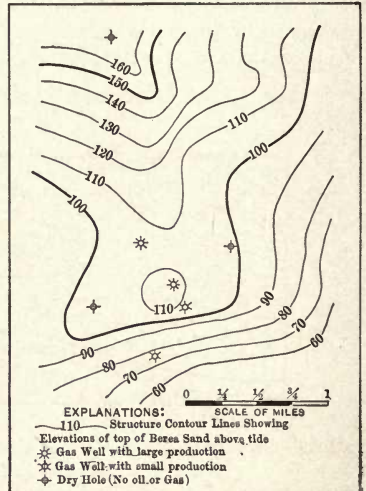
Fig. 30. — Gas pool coincident with a structural terrace. Class 1*d*. (*Clapp, Econ. Geol. V.*)

The following classification has been suggested by Clapp (2*c*).

I. Where anticlinal and synclinal structure exists.
    *a.* Strong anticlines standing alone.
        (Eureka-Volcano Burning Springs anticline in West Virginia.)
    *b.* Alternating, well-defined anticlines and synclines.
        (Appalachians, southern Indiana, and Illinois, etc.)
    *c.* Monoclinal slopes with change in dip.
        (Southeast Ohio pools.)

 *d.* Terrace structures.
   (Southwest Ohio.)
 *e.* Broad geanticlinal folds.
   (Trenton limestone, Ohio.)

II. Domes or quaquaversal structures.
 *a.* Anticlinal bulge type.
   A variation of I and merges into it.
   (Rogersville, Pa., Geol. Atl. Fol. 146, a type case.)
 *b.* Saline dome type.
   (Southern Louisiana and Texas.)
 *c.* Volcanic neck type.
   (Northeast Mexico.)

III. Along sealed faults.
   (Lompoc field, Calif.)

IV. Oil and gas sealed by asphaltic deposits.
   (Trinidad.)

V. At contact of sedimentary and crystalline rocks.
   (Some Quebec and Ontario occurrences.)

VI. In joint cracks.
   (Florence, Colorado, and some California fields.)

VII. In crystalline rocks.

Of these the representatives of Group **I** are by far the most important.

**Mode of Accumulation.** — While the oil and gas are not necessarily, and perhaps rarely are, indigenous to the rock containing them, a difference of opinion exists as to whether they have been transported long distances; indeed their source is often indicated in some under- or over-lying bed of shale.

According to the original anticlinal theory, the oil, gas, and water were supposed to arrange themselves readily according to their specific gravities, but this postulates a somewhat free movement of these materials through the pores of the rocks, to which many modern investigators hesitate to agree.

Capillary action and great rock pressure have been suggested as possible operating forces, while Munn believes it is caused by hydraulic action. According to his hydraulic theory (6), the diffused oil and gas are concentrated into pools or pay streaks by the action of currents of underground water. These collect the oil and gas and push them along. Since these under-

ground currents circulating through the rocks vary in the direction of their flow, there may be places where the meeting of conflicting currents forms eddies or places of no movement. It is at such points that the accumulated oil and gas are held.
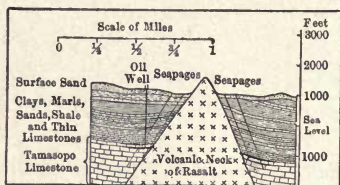


FIG. 31. — Hypothetical cross-section through a volcanic neck in the oil fields of Vera Cruz and Tamaulipas, Mexico, showing one mode of occurrence of oil in formations having a quaquaversal structure. (*After Clapp, Econ. Geol. VII.*)

If the water is flowing through the rocks under the influence of capillarity alone, and conflicting currents are absent, there will be a tendency to force the oil and gas into the more porous beds where the capillarity is too weak for the water to follow.

The pressure of the oil is ascribed to the expansive force of the gas, which cannot diffuse because of the saturation of the surrounding rocks. The association of oil with anticlines is thought to be due to the influence which these structures exert on the water currents. The difference in specific gravity of oil and water is considered insufficient to account for the widespread movement of oil against the friction developed by its passage through rock pores.

The oil and gas are, then, held in the rock, not because of an impervious cap rock, but by the overlying and surrounding water mantle.

Washburne (12c), in discussing the effect of capillary action, points



FIG. 32. — Hypothetical section in same district as Fig. 31, showing a second and probably less common mode of occurrence of oil in quaquaversal structures. (*After Clapp, Econ. Geol., VII.*)

out that the force drawing liquids into pores varies directly as the surface tension of the liquid and inversely as the diameter of the pore. Water having a greater surface tension than oil, capillary action will exert a greater pull on it, and there will be a tendency to draw it into the finest openings and

displace oil or gas. This results in concentrating the last two in the coarsest spaces available.

Surface tension collects the small bodies of oil and gas in a sand into larger ones, which in case of gas are capable of gravitative displacement by water, so that the gas is lifted to the highest position it can reach. If circulatory movements of the water bring oil to the water-gas surface, it is held there by surface tension, and the mass of oil may grow by accretion. It is claimed that in the absence of such conditions, oil might accumulate below water as it does in some fields.

*Yield of Sands.* — The yield of an oil sand depends on the porosity, degree of saturation and quantity extractible. Washburne uses a saturation factor of 15 per cent for the average oil sand, but assumes that only 75 per cent of the sand in a large pool is saturated and that only 60 to 75 per cent of this can be recovered. The last two factors must be varied to suit conditions. The figures given above mean 524 barrels of oil per acre foot, which is high. The yield per acre foot calculated for example, by Washburne, for the different sands of the Midway, California, field ranges from 32 to 1020.[1]

It is a difficult matter to estimate closely the average yield of oil in any field.

*Life of a Well.* — This may vary with the amount of supply, compactness of pay sand, and gas pressure accompanying the petroleum. It varies from a few months to 20 years or more. Some wells may gush forth tremendous quantities of oil and gas for a short period and then die down to almost nothing. Others may yield moderate quantities, or perhaps only a few barrels daily, for a period of years. The average life of Pennsylvania wells is seven years.

In all fields the production increases at first and then begins to drop off, and the increasing production of the United States is due to the discovery and development of new fields, whose production more than offsets the decrease of the older ones.

As examples, the daily average production per well per day of New York and Pennsylvania has fallen from a maximum of 207 barrels to 1.7 barrels. The West Virginia production has dropped to 56 per cent of its maximum, and Ohio and Indiana have shown a still greater decline.

On the other hand, Oklahoma and California are still increasing their output.

Arnold in 1915 has figured the probable future supply from the United States and Alaska at 5,763,100,000 barrels.

**Distribution of Petroleum in the United States** (Pl. X). — The fields as figured by Arnold in 1915 together with their proven areas and per cent exhaustion are as follows:

[1] Johnson and Huntley, Principles of Oil and Gas Production, 1916.

| | STATE. | PROVEN AREA. | PER CENT EXHAUST. |
|---|---|---|---|
| Appalachian [1] . . . . | N. Y.-Pa. . . . . . . . . . | 1400 | 85 |
| | W. Va. . . . . . . . . . | 350 | 55+ |
| | Ky.-Tenn. . . . . . . . | 100 | 47 |
| | Ohio . . . . . . . . . | 115 | 67 |
| Ohio-Indiana . . . . | Ohio . . . . . . . . . | 535 | — |
| | Indiana . . . . . . . . | 500 | 83+ |
| Illinois . . . . . . | . . . . . . . . . . | 400 | 36+ |
| Mid-Continental . . . | Kansas . . . . . . . . . | 70 | 42 |
| | Oklahoma . . . . . . . . | 297 | 22 |
| Gulf . . . . . . . | Louisiana . . . . . . . . | 87 | 34 |
| | Texas . . . . . . . . . | 50 | 33+ |
| California . . . . . . . . . . . . . . . . . . . | | 156 | 24 |
| Colorado . . . . . . . . . . . . . . . . . . . | | 17 | $33\frac{1}{2}$ |
| Michigan . . . . . . . . . . . . . . . . . . . | | 1 | 58 |
| Wyoming . . . . . . . . . . . . . . . . . . | | 31 | 2 |
| Alaska . . . . . . . . . . . . . . . . . . . | | 15 | 0 |

[1] Arnold, Econ. Geol., X, 1915.

These figures of course represent only the areas actually underlain by known pools, and not the entire area of the field.

*Appalachian Field.* — This is the largest oil field in the United States, and includes portions of New York, Pennsylvania, Ohio, West Virginia, Kentucky, and Tennessee.

The rocks are chiefly sandstones, with a few limestones, embedded in and underlain by a great thickness of shales, while below these are probably limestone beds. The sandstones have a thickness of probably 2000 feet or more, and in the middle and northern end of the field range from the Conemaugh series nearly to the base of the Devonian, and still lower in Tennessee and Kentucky. Their deposition represents a period of continuous sedimentation, with the exception of the period between the Mauch Chunk and the Pottsville, where an unconformity indicates an interval of uplift and erosion.

It may be said of the Appalachian field as a whole that the oil-bearing rocks occupy the bottom and west side of a large structural trough, whose rim passes through central Ohio, then eastward south of the Great Lakes and then south along the western base of the Appalachians. It therefore crosses western Pennsylvania where petroleum has been found in large quantity. While the total area outlined is probably over 50,000 square miles, the area actually un-

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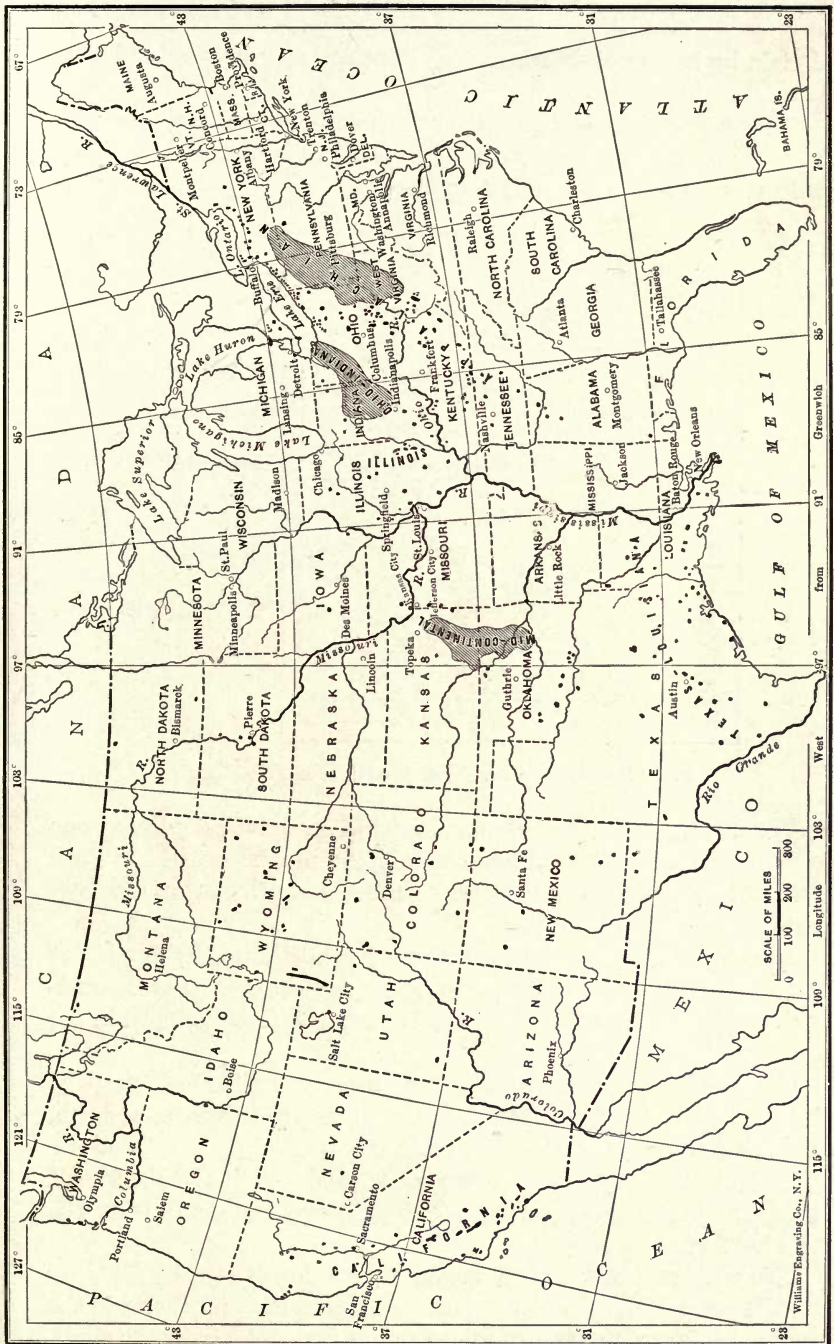
derlain by known oil-bearing sands does not appear to exceed 3500 (53).

Within this great trough there are a number of subordinate folds whose trend is northeast southwest, while still minor ones are found with their axes at right angles to these.
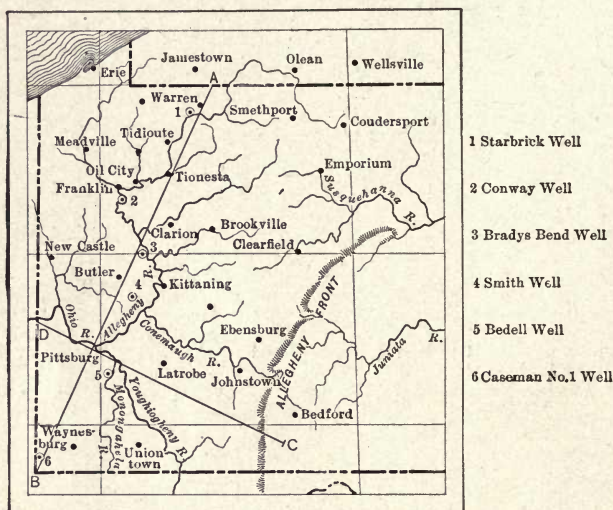


FIG. 33.—Map showing lines of sections in Plate XI.

The sandstones are, moreover, found at increasing depths as one goes southward, so that those outcropping in Ohio and New York may be 2000 or 3000 feet below the surface in southwestern Pennsylvania or West Virginia.

In this region there are a number of sandstones, the important ones individually underlying many square miles. These sandstones are most numerous and attain their greatest thickness in the center of the region.

The upper or younger sands are usually white, and may be conglomeratic locally, while the older beds are brown or reddish, and generally more uniform in texture.

At some localities two or more sands produce oil, and the lowest then may be the most prolific. The wells range in depth from 100 to 4000 feet.

The character of the oil found in this region is said by Dr. Day to differ essentially from any other petroleum thus far found in the world. It is practically free from sulphur and usually from asphalt,

PLATE XI
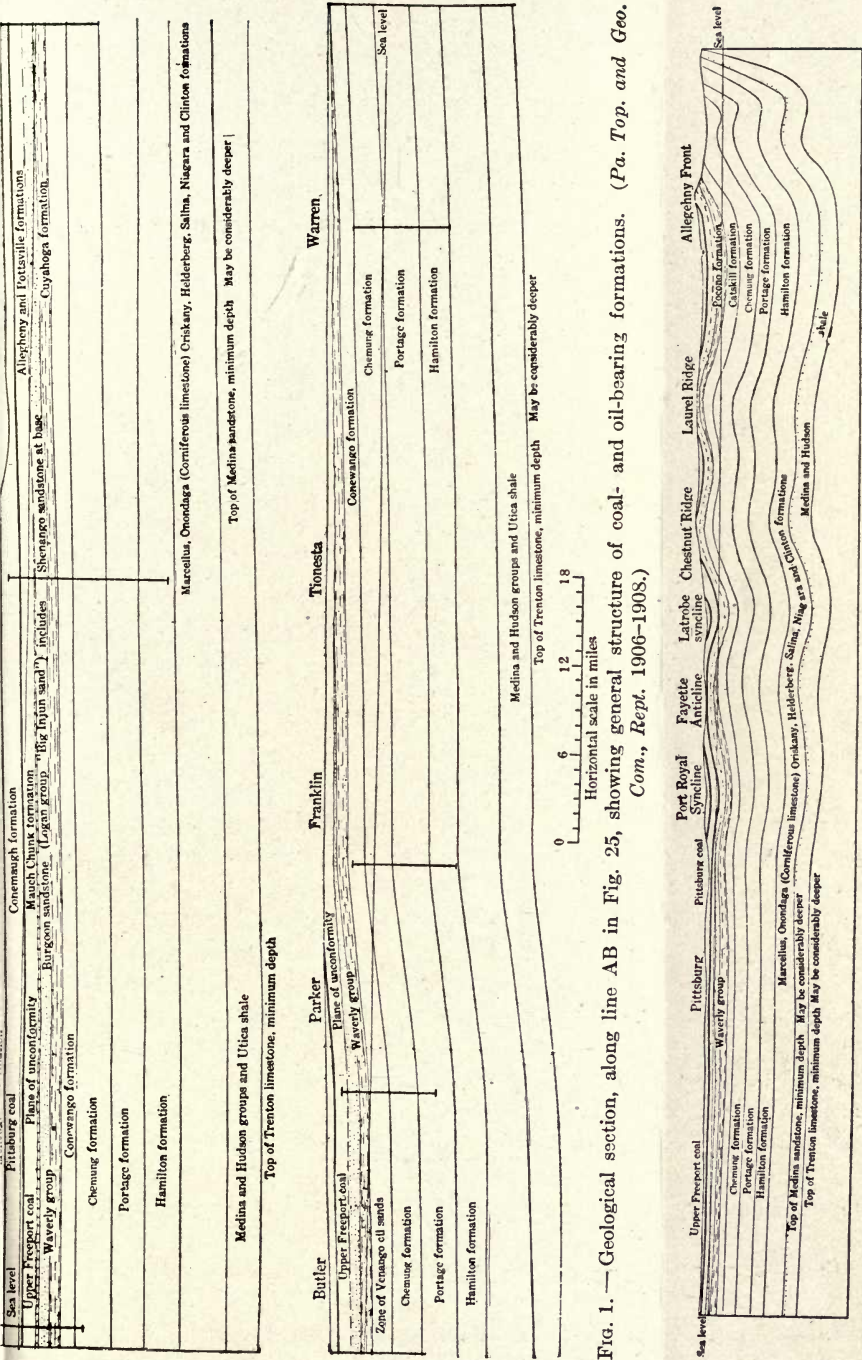
Fig. 1. — Geological section, along line AB in Fig. 25, showing general structure of coal- and oil-bearing formations. (*Pa. Top. and Geo. Com., Rept.* 1906–1908.)

but is rich in paraffin wax. Added to this is its easy conversion into lamp oil, of which product it yields the greatest percentage, being far ahead of all others except the Lima and Ohio petroleums, which, however, are more expensive to refine.

The Kentucky and Tennessee product, while inferior to that found in Pennsylvania, is much better than the Russian or any other of the foreign products with which it has to compete.
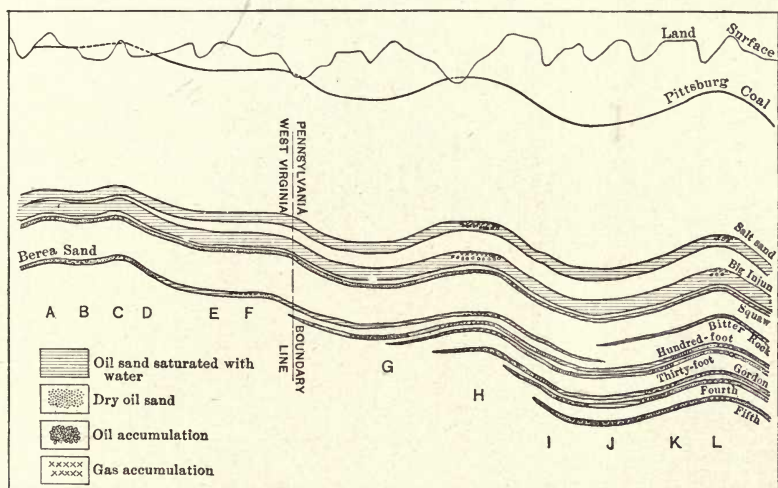


Fig. 34.—Diagrammatic section of sands in the central Appalachian region. (*After Griswold and Munn, U. S. Geol. Surv., Bull.* 318.)

The Appalachian region, however, has passed the zenith of its production, that of Pennsylvania having been reached seventeen years ago; and yet some of the wells show a remarkably persistent, though small, production.

In New York State petroleum is obtained from the fine-grained sandstones of Chemung age in parts of Cattaraugus, Allegany, and Steuben counties. The wells range from 600 to 1800 feet in depth, and while of small capacity, they yield a product of good quality, which ranges from amber to black in color.

The petroleum-producing belt extends across Pennsylvania, in a southwesterly direction, leaving it in the southwestern corner. Within this area (whose general structure has been referred to above) there are a number of oil pools, occurring in rocks ranging from the Conemaugh series of the Carboniferous down to and including the Chemung division of the Devonian. In the space permitted here, it is not possible to go into detail regarding all the pools.

CORRELATION OF OIL AND GAS SANDS IN APPALACHIAN FIELDS

| | PENNSYLVANIA | WEST V[IRGI]NIA | OHIO | KENTUCKY | NEW YORK |
|---|---|---|---|---|---|
| Monongahela. | | Carroll. | Horseneck. | | |
| Conemaugh. | Murphy. Little Dunkard. Big Dunkard. Cow Run or Hurry Up. | Morgantown. Moundsville. First Cow Run. Upper Dunkard. Lower Dunkard. | Mitchell. First Cow Run. Mahoning. | | |
| Allegheny. | Gas sand. | Second Cow Run. "Gas" sand of Marion and Monongalia Counties. | Dunkard or 300 foot. | | |
| Pottsville. | Salt sand, sixty foot. | "Gas" sand of Cairo. Salt sand, Cairo. (?) | Macksburg, 500 foot sand. Second Cow Run. Salt sand. Maxton. | Beaver, Horton, Pike — Of Floyd, Pike, etc., Cos. Salt, Wages, Jones, Epperson — Knox Co. | |
| Mauch Chunk. | Little lime, Salvation or Maxton sand. | Maxton, Cairo. (?) | | Big Injun. Cloverport. Berea. Stray. Mt. Pisgah — Wayne Co. Beaver. Otter. Cooper. Slickford. Amber ore. | |
| Mountain or Greenbrier Limestone. | | No oil or gas horizons except as part of the "Big Injun," below, unless the Beckett Sand of Milton Field belongs here. | | | |
| Pocono Sandstone. | Mountain or Big Injun. Squaw. Pappoose. Butler gas, Butler, 30 ft. Gas, Salt, Murrysville or Berea. (?) Gantz. Fifty foot. Hundred foot. | Keener. Big Injun. Squaw. Berea. Gantz. Fifty foot. | Keener. Big Injun. Squaw. Berea. | | |

| | | Thirty foot. | Ohio Black shale (gas). | | Oil and gas sands of southwestern New York. |
|---|---|---|---|---|---|
| Catskill. | Ninevah or thirty foot. Snee, Blue Monday or Stray Boulder, Gordon Stray or Campbell Run. (?) Gordon or Third. Fourth. Fifth (McDonald). Bayard or Sixth. | Stray. Campbell's Run or Garden. Whetstone Run. Gordon sand. Flat Run. Gordon or Fourth. Fifth (McDonald). Bayard or Sixth. | | | Oil and gas sands of southwestern New York. |
| Chemung. | Elizabeth Warren 1st sand. (?) Warren 2d sand. (?) Speechley. Tiona. Bradford first and second. Elk (?) sand. Kane (?) sand. | | | | |
| Corniferous. | | | | Ragland oil sand. Irvine oil sand. Menefee gas sand. | |
| Lower Helderberg. | | | Lower Helderberg. | | |
| Clinton. | | | Clinton sand. | Clinton (Morgan Co.). | |
| Medina. | | | | | Gas sands of Erie Livingston Chautauqua Genesee } Counties. |
| Hudson. | | | | Caney Creek. Upper Sunnybrook. Deep. Shallow. | Utica shale gas. |
| Trenton. | | | Trenton. | Lower Sunnybrook. Lower sands of Barren Wayne Clinton Cumberland } Counties. Deep sand (Wayne Co.). | Limestone of Oswego and Onondaga Counties. Gas. |
| Calciferous. | | | | Salt water sand at top. Gas sand (Estill Co.). | |
| Potsdam. | | | | | Some gas. |

Suffice it, therefore, to say, that the oil is obtained from a number of different sands, some of which are of high importance, as the Berea, Hundred Foot, Fifth, etc.

Although the Appalachian field is on the wane, some new pools are being discovered in West Virginia (56, 57), central Ohio (39a and b) and Kentucky (32, 32a), but no definite results have been obtained in Tennessee (48a).

In recent years the Bremen field (39b) of southeastern Ohio has become of interest and importance, because of its yield of oil from the Clinton sandstone (39a). This formation dips southeasterly, but there are occasional reversals of dip, which develop local basins, in which according to Bownocker, the oil occurs. The sand is dry and has a thickness of about 30 feet.

In the table given on pp. 96 and 97, an attempt has been made to show the oil (and gas) sands known in the different formations, but they are correlated only so far as occurring in the same formation.[1]

*Ohio-Indiana Field* (24–26, 39–44). — The discovery of oil and gas in the Trenton rocks of western Ohio in 1884 caused considerable excitement, since it showed the existence of petroleum in limestone, an exception to previously known conditions, and at a much lower geological horizon than any in which oil or gas had hitherto been found. This field extends from Findlay in northwestern Ohio southwestward into Indiana.
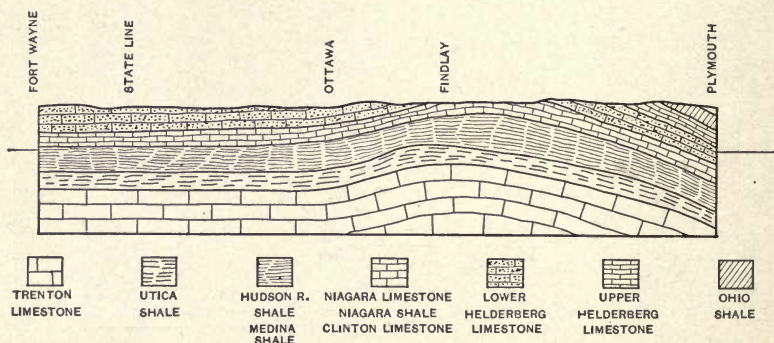


Fig. 35. — Geological section of Ohio-Indiana oil and gas fields. (*After Orton, U. S. Geol. Surv., 8th Ann. Rept., II.*)

Most of the Trenton oil has been found in the upper 50 feet of the formation, in one of two thin streaks; but at several localities in both

[1] These tables are those given by the respective state surveys.

Ohio and Indiana, a productive horizon lying from 100 to 200 feet deeper has been discovered. The oils of this field contain sufficient sulphur to require special treatment for its elimination, but the oil is of paraffin base like that of the Appalachian region.

Outside of the main field, oil has been found in the Clinton formation of Ohio, the most important occurrence being in Vinton County (39). In Indiana oil has been obtained from the Corniferous limestone (Devonian) and from the Huron sandstone (Lower Carboniferous) in Gibson County. The latter occurrence is exceedingly pockety, and the oil, which is darker and thicker than the Trenton oil, has a low percentage of illuminants.

Ohio and Indiana show a much smaller production than formerly.

*Illinois Field* (23, 23a and b). — Oil and gas have been known in Illinois for some years, but the important discoveries were not made until 1904, and the production since then has increased at such a rapid rate that in 1913 it ranked third in the list of producing states.

The oil fields, of which there are two—the eastern and the western, are associated with the spoon-shaped basin of the Eastern Interior Coal Region. On the eastern slope of this syncline is a somewhat persistent ridge, the La Salle anticline, whose extension is traceable across southwestern Indiana to Hartford, Ky., and it is in this arch that the sands have proved very productive, especially in Clark, Crawford, and Lawrence counties, a distance of about 66 miles. Seven sands, ranging from 450-1985 feet in depth, are known in Lawrence County.

On the western slope there are a number of separate anticlines, which have yielded oil at a number of points from Morgan to Jackson Counties (Fig. 35).

The principal horizons at which oil and gas have thus far been discovered are in the Carboniferous rocks, the sands occurring in both the Upper and Lower Coal Measures, the Pottsville group, and the Birdsville and Tribune of the Mississippian.

Most of the Illinois oils are above 30° B., have a paraffine base, and are essentially free from sulphur. The average gasoline content is 15 per cent.

In general the depth of the wells increases from north to south as follows: Oilfield pool, 300-350; Siggins pool, 400 and 570; Johnson township, 470 and 610; Crawford County, 900 to 1000; Lawrence County, 950, 1300, 1500.

ILLINOIS OIL
AND GAS FIELDS

1. Plymouth oil field
2. Pike County gas field
3. Jacksonville gas field *
4. Carlinville oil and gas field
5. Litchfield oil and gas field*
6. Greenville gas field
7. Carlyle oil field
8. Sparta oil and gas field*
9. Sandoval oil field
10. Main oil fields
11. Allendale oil field
12. Staunton oil and gas field
    *abandoned

SCALE OF MILES

0   10   20   30   40   50              100

FIG. 36. — Map of Illinois showing distribution of oil fields. (*After De Wolf.*)

The Illinois field is no longer included in the Ohio-Indiana region, because the oils are of different horizon. Moreover, the product carries less sulphur and much of it is refined without

PLATE XII
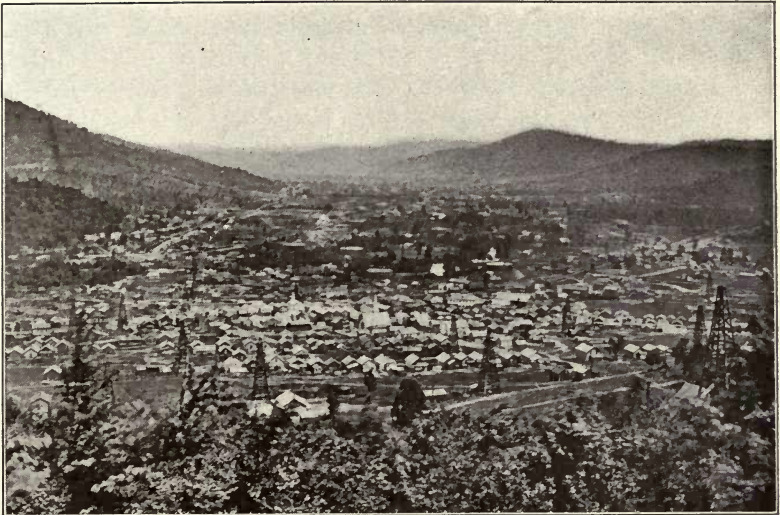


FIG. 1. — General view of Tuna Valley, in Pennsylvania oil field. (*Photo. by F. H. Oliphant.*)
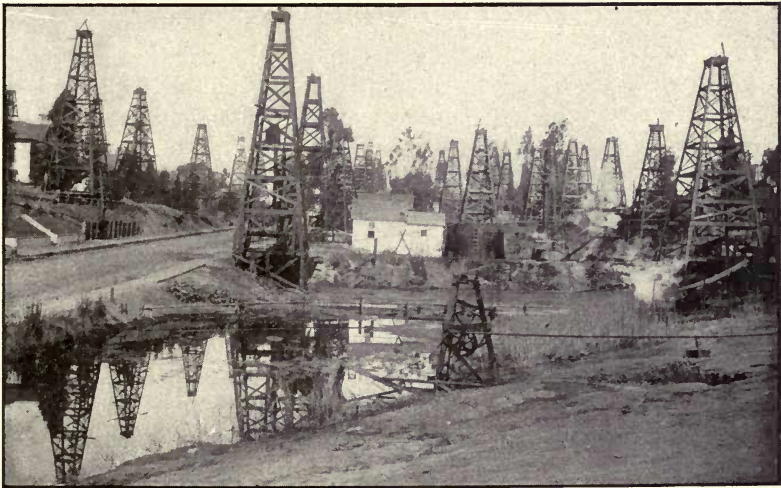


FIG. 2. — View in Los Angeles, Cal., oil field. Such close spacing of oil derricks tends to hasten the exhaustion of the oil supply.

special treatment. Some of it contains asphalt as well as paraffin, and the oils vary within wide limits of gravity and distillation products.

*Mid-Continental Field* (28, 45, 45a–d). — This region underlies a portion of southeastern Kansas and northeastern Oklahoma, and extends roughly from Paola, Kansas, to Colgate, Oklahoma. The Pennsylvanian rocks which outcrop in this area dip westward in Kansas, and in northern Oklahoma from 50 feet per mile, to less than 20 feet per mile, as they are followed to the west, but in the southern part of the field they appear to be folded into anticlines and synclines. Three-fourths of the oil has come from the Cherokee formation at the base of the Pennsylvanian, a little from the Fort Scott Limestone member above it, and in the western part of the field the beds still higher in the section have yielded oil.

The sands outcrop in southeastern Kansas and eastern Oklahoma are 300 to 800 feet deep in Nowata County, 1200 to 2000 near Bartlesville and Tulsa, and 2700 feet in the Cleveland Pool.

The sands, which are usually lenticles capped by shale and sometimes limestone, may vary from 20 to 100 feet in thickness, and while there are usually not more than one or two in a pool, the Glen Pool, one of the most important, contains at least four.

Most of the Kansas oils are asphaltic, but in Oklahoma oils of both asphaltic and paraffin types are found, those from near Muskogee resembling the Pennsylvania oils.

This field is the second largest producer in the United States, but the output is supplied mainly by Oklahoma.

*California* (15–20). — While all the commercially productive oil fields lie in the southern half of the state, along the flanks of the Coast Ranges, they are divisible unto two groups (Fig. 37) as follows: (1) Valley districts, including the Coalinga, Lost Hills, McKittrick, Midway, Sunset, and Kern River; and (2) coast districts, lying on the west flank of the Coast Ranges, and including Santa Maria, Summerland, Santa Clara Valley, Los Angeles, Puente Hills, and others.

The oil is found at one or another place in every important geologic horizon from the Chico of the Upper Cretaceous to the Fernando of the Pliocene, and the structure is quite varied. In the San Joaquin Valley districts the oil is generally associated

with monoclines, but in the coastal counties, anticlines and faults are more effective factors of accumulation. Sandstones commonly form the reservoir rock, but exceptionally, as in the Santa Maria field, the oil occurs in cracks in hard flinty shales or in the pores of softer ones.



FIG. 37. — Map of California oil fields and pipe lines. (*After Arnold and Garfias, Amer. Inst. Min. Engrs., Bull.* 87, 1914.)

Where the oil sand outcrops, it is often sealed by asphalt.

Arnold believes that the oil has been derived from both animal and vegetable matter, but chiefly diatoms.

Nearly all of the California oils have an asphalt base, and about 40 per cent of the output is heavy oil, used for fuel or road dressing, while the remaining 60 per cent is refined, the residuum being used for fuel.

In the Kern River field, which is the most important, the well records indicate a great body of Miocene (Tertiary) sands and clays in which the general westerly dip away from the Sierra granites has been locally interrupted by anticlines, on the flanks of which the oil has been found.

The oil occurs in sands interbedded with the clays which underlie one heavy clay bed and overlie another. The thickness of the oil-bearing sands may vary from 200 or 300 to 400 or 500 feet.

The Santa Maria field comprises the Santa Maria, Lompoc, and Cat Canyon fields, in northern Santa Barbara and southern San Luis Obispo County. The formations involved in the productive region range from Lower Miocene to Quaternary, involving beds of shale, sandstone, diatomaceous earth, and volcanic ash.

The region contains long sinuous folds of a peculiar type, and most of the wells are located along or near anticlines, ranging in depth from 1500
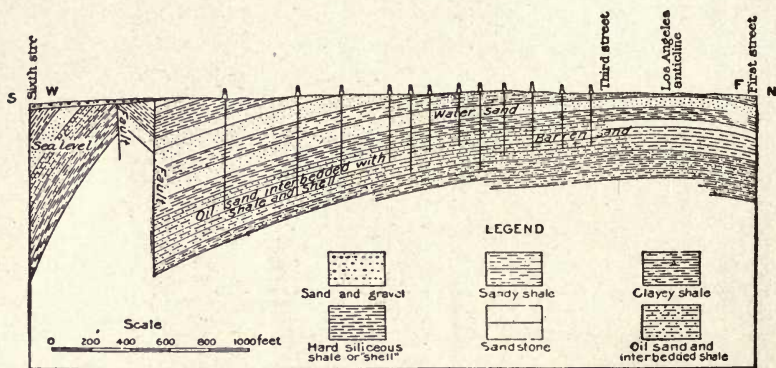


Fig. 38. — North-south section, showing structure of western field of Los Angeles district. (*After Eldridge and Arnold, U. S. Geol. Surv., Bull, 309.*)

to over 4000 feet. In the Santa Maria and Lompoc fields the oil is obtained from zones of fractured shale, or sandy layers in the lower portion of Monterey (Middle Miocene), and has an average gravity of 25° B.

Although the Kern River field leads in point of production, the Santa Maria leads in the production per well, and supplies most of the oil exported, its situation giving it command of the coast trade from Alaska to Chile, as well as foreign trade with Japan and Hawaii.

The Summerland field is of interest, for the reason that Arnold believes the oil to have been derived from diatoms (19), and other organisms found in the Monterey shale. It has subsequently migrated upward into the overlying Fernando, and to some extent Pleistocene formations, urged along probably by gas or hydrostatic pressure. A similar origin is also ascribed to the oil in the Coalinga district.

The California oils are generally characterized by much asphalt and little or no paraffin, although in recent years there has been a considerable yield of lighter grade oils from the Santa Maria and Monterey districts. Since these are well adapted to refining, they will probably be in strong demand.
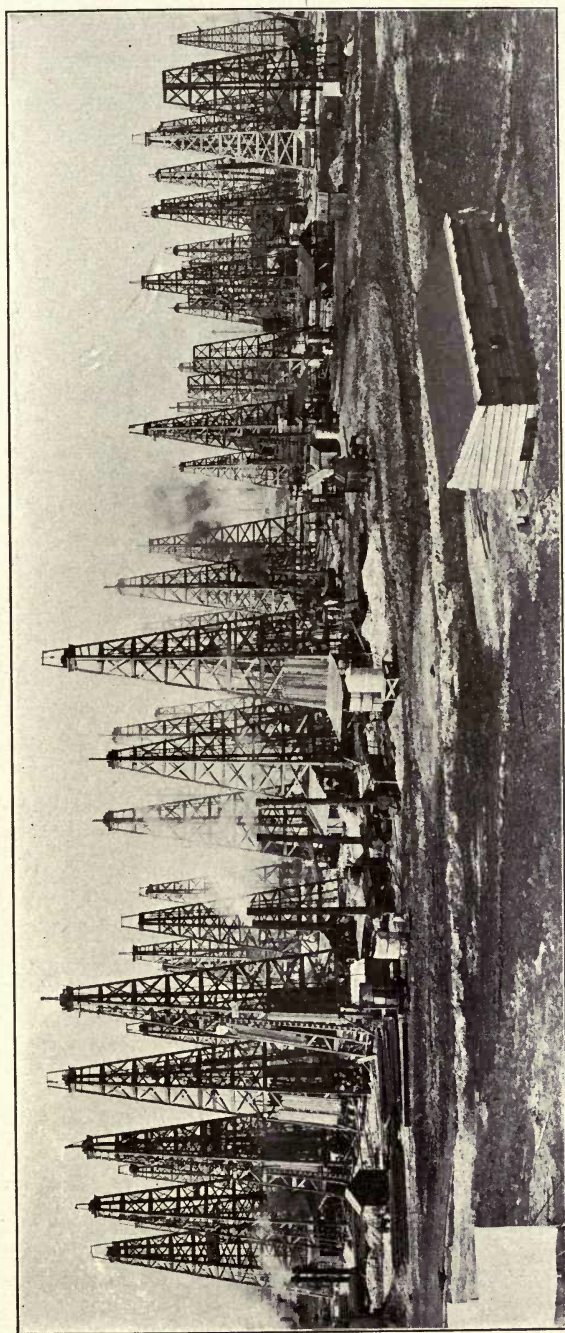
PLATE XIII. – General view of Spindle Top oil field, Beaumont, Tex. (*Photo. by Troost.*).

(105)

*Texas-Louisiana Oil Fields* (34, 35, 49–51). — This includes a series of small scattered fields lying mostly in the coastal plain region of Texas and Louisiana (Pl. X). Underlying the coastal plain there is a series of Quaternary, Tertiary, and Cretaceous clays, sands, and gravels, with occasional limestones, having in general a gentle southeastern dip, interrupted by low



LEGEND

SALT    DOLOMITE    CLAY    SAND    SHALE,    GYPSUM
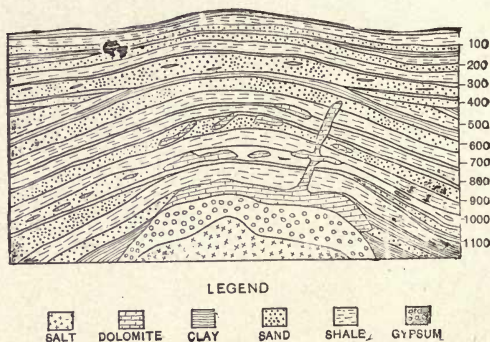
Fig. 39.—Section of Spindle Top oil field near Beaumont, Tex.    (*After Fenneman, Min. Mag., XI.*)

domes, which, in parts of Louisiana at least, appear to be due to the upthrust caused by the growth of salt and gypsum masses.

Under these domes, or mounds, and underlying the sediments mentioned above, there are usually found deposits of marly or crystalline limestone (often dolomitic), sulphur, gypsum, and rock salt, which in most cases are at considerable depth, but occasionally lie at or near the surface. Thus at Avery Island, Louisiana, the heavy deposit of rock salt comes within 15 feet of the surface, but at Spindle Top, Texas, the limestone is 800 or 900 feet deep.

The oil is most frequently found in or near the limestones.

The oil pools are of small size, and that discovered at Beaumont, Texas, may serve as a type of many. This pool, which covers an area of about 200 acres (Pl. XIII), was discovered in 1901, and within a year and a half 280 successful wells had been drilled. The oil rock, which lies from 900 to 1000 feet below the surface, is a very porous, crystalline, dolomitic limestone, and the cap rock is clay. The occurrence of gypsum and salt

underlying the oil rock in some of the wells is unique (Fig. 39). Many of the wells in this pool were gushers, but so great was the drain on this field that by the end of the first year after its discovery the pressure was considerably reduced, and in 1903 many of the wells had practically ceased producing, while others were yielding a mixture of salt water and oil. The production, however, is still considerable, although the supply is no doubt exhaustible. The coastal-plain oils have an asphaltic base, or are " heavy," and at times contain considerable sulphur.

In 1903 many wells were being developed in the Sour Lake district about 20 miles northwest of Beaumont. The oil is heavy like that of Beaumont, but runs lower in sulphur. In Louisiana active drilling operations have been carried on in the region around Jennings, and one well yielded 20,000 barrels per day while it was gushing. The oil resembles that of Beaumont.

The belt of Cretaceous rocks of central Texas has yielded both oil and gas at several localities, but the only important one is at Corsicana, where both a light and heavy oil have been found in sands interbedded with dense clay shales. The two kinds of oil occur at different horizons.
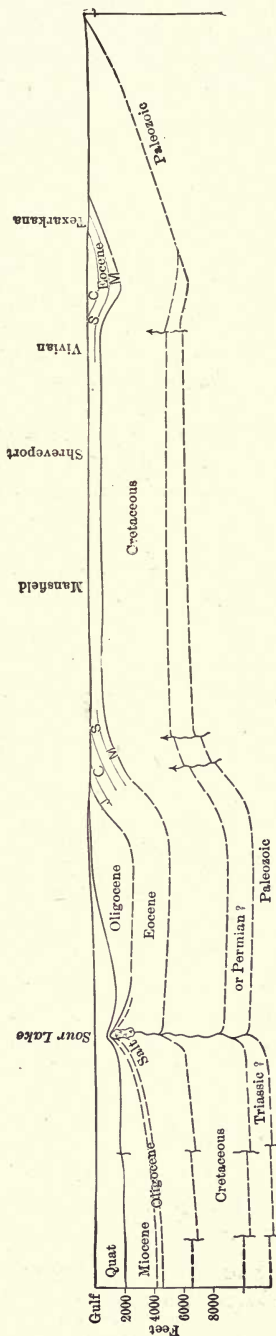


FIG. 40.—Generalized section from Paleozoic outcrop in Arkansas through Caddo oil field and Sour Lake to Galveston, Tex  (After Harris, La. Geol. Surv., Bull. 9.)

In northwestern Louisiana, both oil and gas are found in the more or
less consolidated Cretaceous rocks, which underlie the Tertiary and Quater-
nary.    Here the Cretaceous rocks which dip to the southward show a dome-
like uplift of considerable dimensions, which brings them within 700 feet
of the surface.    This includes the Caddo field, and although the oil and
gas occur separately or together at four horizons, viz. the Nacatoch,
Austin, Eagle Ford, and Woodbine, of the Upper Cretaceous, most of the
gas is obtained from the first or upper, and the oil from the fourth or lower
division.    The main oil sand is about 2200 feet deep.    The oil from this
field is light, similar to that of the Appalachian region, and thus differs
strongly from the Beaumont and Jennings oils (Harris).

Most of the oils of the Gulf region contain considerable quantities of sul-
phur, largely in the form of hydrogen sulphide, and therefore easily removed
by steam before refining, or for use as fuel.    They make a good fuel oil,
which because of the location of the field can be easily exported, but they
also yield a good grade of lubricating oil.    Moreover, the gasolene derived
from them is acceptable as a substitute for turpentine.

The Corsicana and Caddo field oils are lighter and run lower in sulphur.

*Colorado.* — Florence (21) and Boulder (22) are the two important
oil-producing localities.    At the former the oil is found in beds of
Cretaceous age, at depths of from 1000 to 2000 feet, and, unlike
many occurrences, appears to have accumulated in fissures, although
the rocks of the region as a whole form a syncline.

At Boulder, the oil is found associated with broad low anticlines in
sandstones and shales of the Pierre (Cretaceous) formation, and is
now being obtained at depths ranging from 2100 to 2350 feet.[1]    The
oil does not vary much in quality.
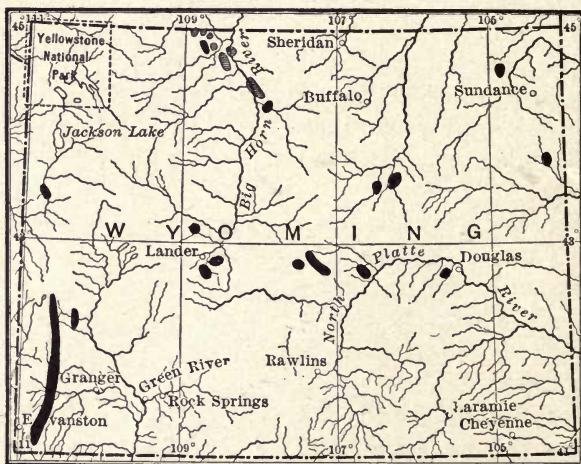


Fig. 41.—Map of Wyoming, showing approximately the areas underlain by oil and
gas.   (*After Day.*)

[1] R. D. George, private communication.

*Wyoming* (58–63). — This state contains a number of oil and some gas districts (Fig. 41), most of which are but slightly developed. The oil is obtained chiefly from the Cretaceous, and many of the occurrences appear to be associated with anticlines (62), but, in one field (Spring Valley, Uinta County) at least (63), the oil occurs in a synclinal basin (Fig. 42), whose bounding fault on the northwest seems to have permitted somewhat abundant seepage.

The oils vary in their gravity, but, according to published data, are mainly of medium gravity.
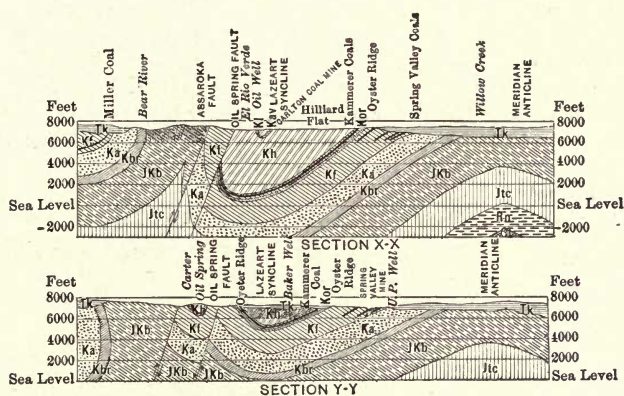


Fig. 42.—Section across portion of oil district of southwestern Wyoming. (*After Veatch, U. S. Geol. Surv., Prof. Pap.* 56.)

The Salt Creek field is the most important producer, its product being piped to Casper for refining.

*Alaska* (14). — Oil has thus far been found in Alaska at only four localities, at which the indications were sufficient to warrant drilling. Wells have been driven at three, and disclosed the presence of oil similar to that of Pennsylvania. All of the fields lie in the Pacific coast region, but none have been extensively developed, as the low price of imported oil and high cost of drilling in Alaska have discouraged attempts towards development.

In the Katalla field, located near the mouth of the Copper River, the oil is found in complexly folded and faulted Tertiary shales and sandstones. At Cook Inlet, folded and faulted Jurassic shales and sandstones form the petroliferous horizon. At Cold Bay, where seepages are found as in the other fields, the structural conditions

and age of the oil-bearing strata are similar to those at Cook Inlet. Seepages are found in Tertiary rocks near Cape Yakataga, but no wells have been drilled.
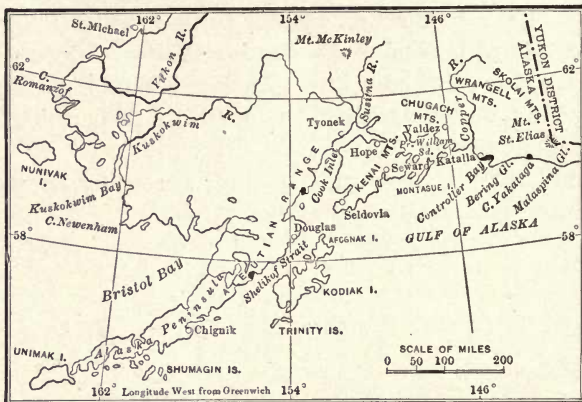


FIG. 43. — Map of Alaska, showing areas in which oil or gas are known to occur. (*After Day.*)

*Summary.* — The following table summarizes very briefly the mode of occurrence in the several fields:—

SUMMARY OF OIL OCCURRENCE IN THE PRINCIPAL UNITED STATES FIELDS

| FIELD | STRUCTURE | GEOLOGIC AGE | KIND OF ROCK | KIND OF OIL |
|---|---|---|---|---|
| Appalachian. | Geosyncline with subordinate anticlines. | Ordovician to Carboniferous. | Mostly sandstone. | Paraffin base. |
| Lima-Indiana. | Anticlines. | Ordovician. | Mostly limestone. | Paraffin base. Sulphur. |
| Illinois. | Low anticlines (?) | Carboniferous. | Sandstones. | Paraffin and mixed oils. |
| Michigan. | Probably anticlines. | Silurian. | Sandstones. | Paraffin base. |
| Mid-Continental. | Westerly dip, with some anticlines. | Carboniferous. | Shales, sandstones mostly. | Both paraffinic and asphaltic. |
| Wyoming. | Usually folded. | Carboniferous to Tertiary. | Mostly sandstone. | Paraffinic and asphaltic. |
| Colorado. | Folded. | Cretaceous. | Sandstone and shale. | Paraffinic. |
| Gulf Coast. | Domes. | Tertiary and Cretaceous. | Dolomite and sandstone. | Mainly asphaltic, sometimes high sulphur. |
| California. | Folded and faulted. | Tertiary. | Sandstones, shales, conglomerates. | Mainly asphaltic. |
| Alaska. | Folded and faulted. | Jurassic to Tertiary. | Sandstones and shales. | Paraffin. |

**Canada** (63*e*–*i*). — Oil is obtained in Canada in Ontario, New Brunswick and Alberta, but only the production from the first named is important, although it has been decreasing since 1906.

In Ontario the important wells are confined to the Paleozoic rocks of the area lying west and southwest of a line connecting Georgian Bay and Toronto. The flat-lying undisturbed sediments of this series have a thickness of nearly 3800 feet in Lambton County, but their thickness decreases as the pre-Cambrian rocks to the north are approached. The oil occurs in the Onondaga, Oriskany, Guelph, Niagara, Medina, and Trenton, the first named being the most important, and supplying the oil in the Petrolia or most important field. The depths to which the wells penetrate vary on the average from about 350 to 1300 feet.

In New Brunswick oil is obtained from the Albert shales of the Subcarboniferous.

Considerable prospecting has been done recently along the foothills west of a line connecting Calgary and Edmonton, and while small quantities of oil have been struck here and there in the Dakota sandstone, no large producers have been developed.

**Mexico.**[1] — The Mexican oil field is located in a rectangle 50 miles wide and 160 miles long, extending from Tampico west to Panuco and thence south to Tuxpam. Its growth can be seen by the increase from a recorded production of 200,000 barrels in 1904, to 25,725,403 barrels in 1914. The main districts are Ebano, Panuco, Tuxpam, and Huasteca, the first-named being the oldest and the last-named the most important.

The geologic formations include: (1) Tamasopa limestone (Upper(?) Cretaceous); (2) San Felipe limestones and shales (Upper Cretaceous); (3) Mendez marls and shales (Eocene); (4) Tertiary limestones, sandstones and clays, and Pleistocene deposits of no importance in the oil occurrence; (5) Igneous intrusions of late Tertiary or early Quaternary, in the form of dikes, sills, or stocks. The general gentle easterly dip of the sediments is interrupted by domes and basins, the beds being also fractured by joints and faults. The intrusive stocks show a close association with the oil, but the exact significance of this is not settled to the satisfaction of all, though they doubtless by deformation of the sedimentaries may have been an influencing factor in the oil accumulation.

The oil in general seems to come from near the top of the Tamasopa limestones, but it may have originated in the Mendez marls. It is usually heavy, with an asphaltic base, the thickness sometimes interfering with its transportation through pipe lines. Some of the wells have shown an enormous yield. One, the Juan Casiano No. 7, has been making about 700,000 barrels per month, with about 40,000,000 barrels to its credit, while another, the Dos Bocas gusher, blew a crater in the ground, and after producing 200,000 barrels a day for 57 days, went to salt water.

[1] Garfias, Econ. Geol., X, No. 3, 1915; Ordonez, Amer. Inst. Min. Engrs., L: 859, 1914; De Golyer, *Ibid.*, Bull. 105: 1899, 1915; Huntley, *Ibid.*, Bull. 105: 2067, 1915.
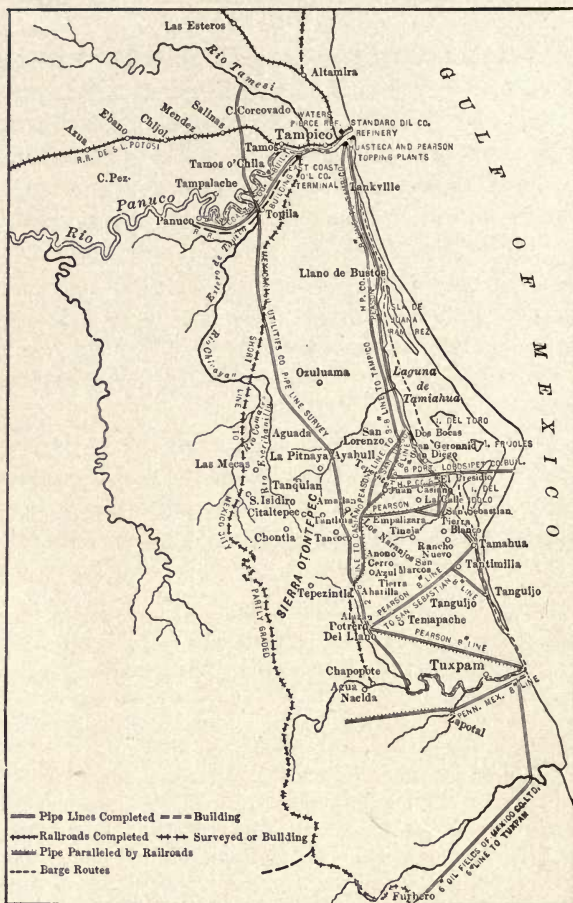
FIG. 44. — Sketch Map of the Mexican Oil Fields, showing Pipe Lines and Railroads. (*After Huntley, Amer. Inst. Min. Engrs., Bull.* 105, 1915.)
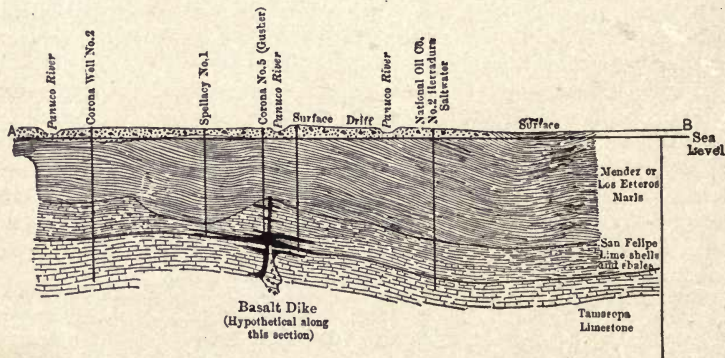


FIG. 45.—Hypothetical Section through the Panuco Field, Mexico, showing anticlinal terrace and fracture. (*After Huntley, Amer. Inst. Min. Engrs., Bull.* 105, 1915.)

**Other Important Foreign Fields.** — Among the foreign producers, Russia Galicia and Rumania have contributed considerably to the world's supply of petroleum. In Russia,[1] the Baku region on the Apsheron peninsula of the eastern Caucasus, yields 75 per cent of the country's output. The rocks involved are Pliocene, Miocene, and Oligocene sediments, with some volcanic ash, and the whole series has been strongly folded and faulted, mud volcanoes and seepages being distributed along the main line of uplift. The oil series, which has a thickness of 5000 feet, consists of Miocene clays, sands and marls. Of the three divisions found in the largest or Balakhany-Sabunchy field, the upper is productive with the wells ranging from 300 to 2400 feet in depth. Another small but productive district is the Bibi-Eibat on the Caspian shore.

In the Galician[2] oil field on the north flanks of the Carpathians, the oil is obtained from strongly folded Eocene rocks, while in the Rumanian field, which is continuous with that of Galicia, the Miocene and Pliocene formations are the petroliferous ones. The only other region producing over 2 per cent of the world's output is the Dutch East Indies, where, in southeastern Borneo, the oil is found in Miocene sandstones.

**Distribution of Natural Gas in the United States.** — The distribution of gas is practically coextensive with that of petroleum, and most oil wells yield some gas; but the regions from which supplies are obtained and utilized are fewer than those of petroleum.

Day (53) gives the following estimate of the area in square miles of gas pools in the several fields.

| | | |
|---|---|---|
| Appalachian | Kentucky | 290 |
| | New York | 550 |
| | Ohio | 110 |
| | Pennsylvania | 2730 |
| | West Virginia | 1000 | 4680 |
| Ohio-Indiana | Indiana | 2460 |
| | Ohio | 165 | 2625 |
| Illinois | | 50 |
| Michigan | | 40 |
| Mid-Continental | Oklahoma | 1000 |
| | Missouri | 70 |
| | Kansas | 550 | 1620 |
| Colorado | | 80 |
| Wyoming | | 120 |
| California | | 310 |
| Texas-Louisiana | | 240 |
| Others | | 290 |
| | | 10,055 |

[1] Adiassevich, Amer. Inst. Min. Engrs., XLVIII: 613, 1915; Dalton, Econ. Geol., IV: 89, 1909.

[2] Dalton, loc. cit.

Natural gas shows a wide geologic distribution, for in the United States and Canada it is found at one place or another in formations ranging from Cambrian to Tertiary, exclusive of Jurassic and Triassic.

## UNITED STATES

The five most important natural gas producing regions are: (65a): 1. Appalachian, including New York, Pennsylvania, southeastern Ohio, West Virginia, Kentucky, and Alabama; 2. Ohio and Indiana, Trenton rock area; 3. Clinton sand area of central Ohio; 4. Mid-continental area; 5. Caddo field of northwestern Louisiana.

*Appalachian Field.* — Gas is obtained in New York (74) from the Corniferous, Guelph, Niagara, and Trenton limestones, and from the Medina and Potsdam sandstones. The depths range from 150 to 3000 feet, with a general monoclinal structure.

In Pennsylvania (78) the gas lies west of the Allegheny Mountains in comparatively undisturbed strata, the productive horizons ranging from the Conemaugh to Middle Devonian. It may occur in others lower down, but the formations productive in New York lie pretty deep in Pennsylvania, the Corniferous for example, having been encountered in Washington county at a depth of 6000 feet.

In West Virginia (56) gas is obtained in the northwestern half of the state at depths of from 500 to 4000 feet, associated with anticlines and synclines as in Pennsylvania, but, owing to the greater thickness of the formations, the drill has not reached below the Speechley (Chemung) sand.

The southeastern Ohio gas field is a continuation of the West Virginia one, while some Devonian gas is found in northeastern Ohio, even west of the Appalachian belt.

Kentucky has productive gas areas obtaining a supply from the Pottsville, Berea, Devonian shales, and Trenton limestone. The supply comes chiefly from the northeastern portion of the state.

*Ohio-Indiana Fields* (67, 68, 76, 77). — Gas is obtained from the Trenton limestone along the Cincinnati anticline, but the supply is much less than formerly. Aside from this the Devonian shales and limestone supply some gas in southern and western Indiana.

*Clinton Sand Area, Ohio* (65a, 39 and 39a, under Oil). — Gas is obtained from the Clinton sand in a belt parallel with the Cincinnati arch, and extending from western Ontario to the Ohio River.

*Mid-Continental Field.* — In southeastern Kansas (70) gas is obtained from the Carboniferous, the same as the oil, at depths ranging from 80 to 1300 feet, while in Oklahoma the sands of Carboniferous age are now strongly productive. The general structural features were referred to under oil.

*Louisiana* (65a, 73). — The Caddo field of northwestern Louisiana, located on a broad anticline known as the Sabine Uplift, is the most important producer, although some gas is found with the salt domes in the southern part of the state. The product is all from the Cretaceous.

*Other Localities.* — Not a little gas is obtained from the different oil fields, not located in the strata above mentioned, as in Illinois and California.

**Distribution of Natural Gas in Canada.** — Natural gas occurs in Ontario (79a–b) in the Onondaga, Guelph, Clinton, Medina and Trenton formations. Less important occurrences are found in the glacial drift. The most important area is the Kent field of Tilbury and Romney townships, where the gas is obtained from the Onondaga dolomite. In New Brunswick gas has been obtained in Albert County from Subcarboniferous rocks, at depths ranging from 1200 to 2000 feet.

In the western provinces (79c) natural gas was developed at Carlstadt, Alberta, as early as 1885, but the active development at Medicine Hat, Alberta, began about 1905. At this locality gas is encountered in the Belly River formation at about 600 feet depth, but the main supply comes from the Niobrara in wells ranging from 1000 to 1300 feet, and having an open flow pressure of two to three million cubic feet per 24 hours.

The second important gas field of the western provinces is around Bow Island, Alberta. Here the gas is obtained from the Dakota formation at depths of about 2000 feet. The first well driven in 1909 showed 810 pounds pressure and seven million cubic feet flow. The gas from here is piped to Lethbridge and Calgary.

Gas has been found in limited quantities at a number of other points in the Great Plains area, that from Dunmore Junction, Suffield and Vegreville, occurring in the Niobrara formation.

**Uses of Petroleum.** — The three most important uses are for light, heat, and lubrication; but the various distillates have special uses. Rhigolene is used as a local anæsthetic, gasoline is used as fuel, and naphtha as a solvent for resins in making varnish and in oilcloth manufacture, while benzine is of value for cleaning and as a substitute for and an adulterant of turpentine. Astral oil and mineral sperm oil are special grades of illuminating oil with high flashing points. Crude petroleum is now much used for fuel purposes in engines, as along the Pacific coast and in the southwest, where good coal is so scarce that many of the locomotives are run by the use of crude oil.

The paraffin residue is placed on the market for medicinal purposes under the name of vaseline, petroleum ointment, and cosmoline. It is also used as an adulterant of candy and for electrical insulation.

**Uses of Natural Gas.**[1]—Natural gas is widely employed as a fuel in factories, metallurgical establishments, glass works, cement plants, etc. For domestic purposes, such as heating, cooking, and lighting, it is also widely used. Its cheapness, cleanliness, and high calorific power, and the ease with which it can be used, have been important factors in insuring its widespread selection for the above purposes. Some is used in the manufacture of carbon black.[2]

The term *carbon black* as used in the trade is applied to lampblack made upon the surfaces of metal or stone, by direct impact of flame, while *lamp black* is a soot deposited by the smudge process and made from oil, resin, or some other solid or liquid raw material.

A profitable industry now is the separation of the more volatile grades of gasoline from natural gas issuing from oil wells. The gas from different regions yields from 0 to 8 or 10 gallons of gasoline per thousand feet of gas.[3]

The former wasteful use of natural gas, and its allowed escape from oil wells helped greatly to deplete the supply in some fields, so that energetic measures have been taken to combat this.[4]

[1] Johnson and Huntley, Principles of Oil and Gas Production, **1916.**
[2] U. S. Geol. Surv., Min. Res. 1913, II: 1488, 1914.
[3] Bureau Mines, Technical Paper No. 10.
[4] U. S. Geol. Surv., Min. Res., 1911, II: 280, 1912.

## SOLID AND SEMI-SOLID BITUMENS

Under this heading are included (1) bitumens of a more or less solid character which are found filling fissures in the rocks, or sometimes occupying basin-shaped depressions on the surface, and (2) bitumen of viscous character, or *maltha*, which is found oozing from fissures or pores of the rocks and sometimes collecting in pools on the surface.

Both of these are usually of rather high purity, and those belonging to the first-named group may have a rather wide geologic and geographic (Fig. 46) range.



FIG. 46. — Map of asphalt and bituminous rock deposits of the United States. (*After Eldridge, U. S. Geol. Surv., 22d Ann. Rept., IX.*)

Those of the first group were termed *asphaltites* by Eldridge, but since they are not all true asphalts, it seems best perhaps to avoid this term. They are most commonly found filling fissures, usually in sedimentary rocks,[1] and might perhaps be termed *vein bitumens*.

**Vein Bitumens.** — There are several varieties of these, all black or dark brown in color, commonly with a pitchy odor, burning readily with a smoky flame, and insoluble in water, but soluble to a

[1] The anthraxolite of Ontario occurs in slate, and an asphalt vein in quartz-porphyry has been described from near Heidelberg, Germany. (Geol. Zentralbl., XIII: 547, 1909.)

varying degree in ether, oil of turpentine, and naphtha.    Their specific gravity ranges from 1 to 1.1.    They are closely related chemically and in their mode of occurrence, but differ somewhat in their behavior toward solvents, as well as in their fusibility, so that their identification is often somewhat uncertain.    The most important varieties are described below.

*Albertite* (91).    A black bitumen with a brilliant luster and conchoidal fracture, a hardness of 1 to 2, and specific gravity 1.097.    It is barely soluble in alcohol, and dissolves to the extent of 4 per cent in ether and 30 per cent in oil of turpentine.

Some American occurrences of vein bitumens are thought to belong here, but the most important occurrence is at Albert Mines, New Brunswick (91) where a vein of albertite is found in the Subcarboniferous shales. The vein had a length of about half a mile and was followed down its steep dip to a depth of 1500 feet.    Its thickness varied from 15 feet to zero, and branch veinlets ran off into the wall rock.    It was worked for thirty years and proved to be one of the most profitable mineral industries of New Brunswick.

*Anthraxolite* (93) is a coaly, lustrous, black mineral, with a hardness of 3 to 4, and specific gravity of 1.965.    It is found at Sudbury, Ontario, forming veins in a black fissile slate, but has also been described from other localities.

*Ozokerite* (98, 106), also termed *mineral wax* or *native paraffin*, is a waxlike hydrocarbon, yellow brown to green, translucent when pure, and of greasy feel.    Its specific gravity ranges from .845 to .97.    It is easily soluble in petroleum, benzine, benzole, turpentine, and carbon disulphide, but more difficultly so in ether and ethyl alcohol.

It is known to occur in Utah (106) where the material is found filling fissures in zones of crushed Tertiary shales, sandstones, and limestones, near Midway, Soldiers Summit, and Coulters station on the Rio Grande and Western Railway.    The conditions are not regarded as very favorable for working.    The most important deposit of Ozokerite is in Galicia.    There it is found forming veins from a few millimeters up to several feet in thickness, in much-disturbed Miocene shales and sandstones.

*Grahamite* (97, 105, 108). — This has a hardness of 2, and a specific gravity of 1.145.    It is pitch-black, slightly soluble in alcohol, partly so in ether, petroleum, and benzole, but almost completely in turpentine.    Carbon disulphide and chloroform dissolve it completely.

Grahamite was originally found in the Carboniferous sandstones of Ritchie County, W. Va.    There it occurred in a deep vertical fissure 1 to 5 feet wide at the surface, and nearly a mile in length, which was opened up at right angles to the direction of an anticlinal fold (Fig. 47).    Through this the oil escaped upwards from an oil pool, known to occur below, and was oxidized to grahamite.    The vein has long since been worked out.

Deposits of grahamite are also known in southeastern Oklahoma, where the material occurs in steeply pitching veins, in sandstones, and shales. The wall rocks, which are of Ordovician to Carboniferous age, vary from
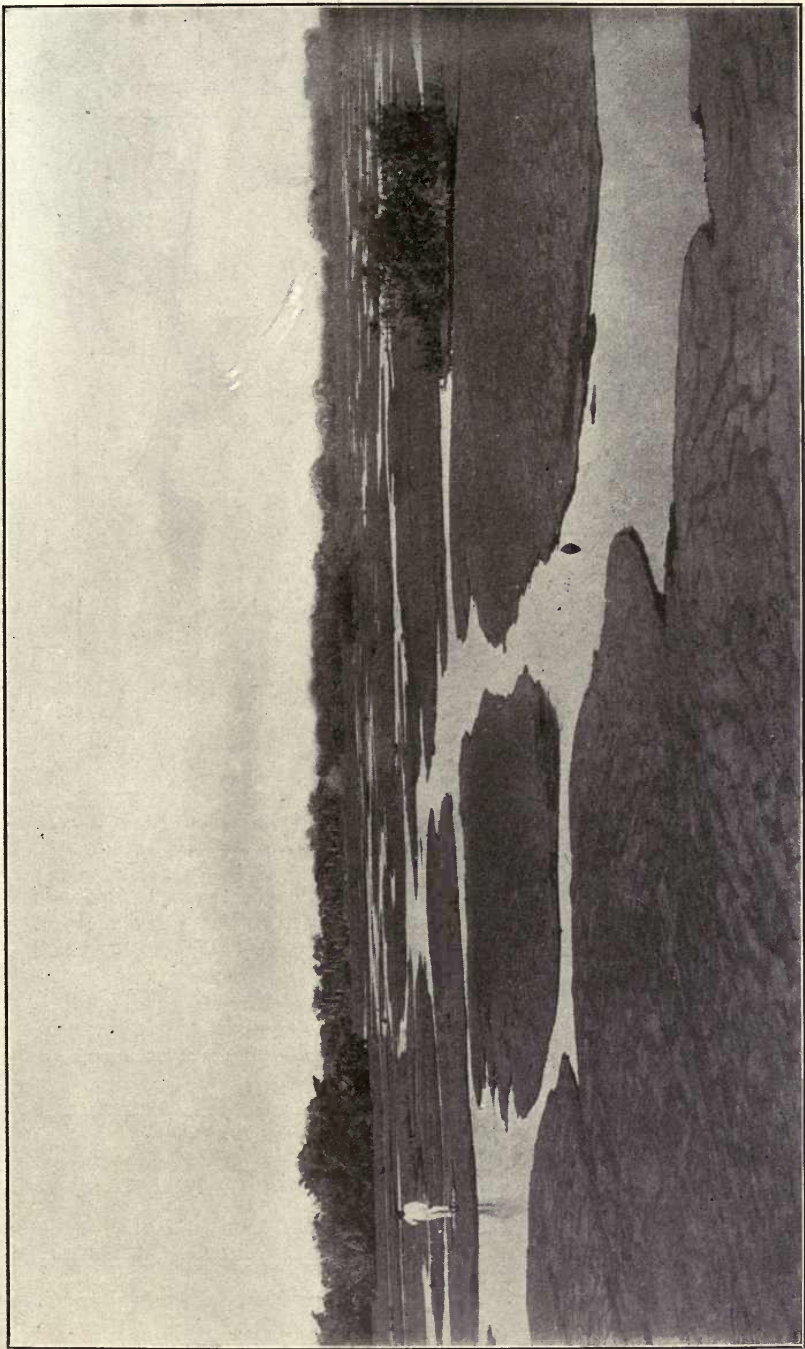
PLATE XIV.—General view of Trinidad asphalt lake. The clumps of bushes in the center are "floating" islands. *(Photo. loaned by Barber Asphalt Company.)*

(119)

flat to highly folded, and the grahamite shows corresponding fluctuations in composition which are due no doubt to differences in the degree of meta-



FIG. 47.—Map showing relation of grahamite fissure to anticlinal fold, in Ritchie County, W. Va. (*After White, Bull. Geol. Soc. Amer., X.*)

morphism which the rocks have undergone. The veins are uncertain in extent, and with two exceptions have not warranted extensive development.

Other deposits are located in western Arkansas but the material is badly crushed and more highly metamorphosed (105).

PROXIMATE ANALYSES OF OKLAHOMA AND ARKANSAS BITUMEN

|  | I | II | III |
|---|---|---|---|
| Moisture . . . . . . . . | .25 | .09 | 2.51 |
| Volatile bitumen . . . . . | 43.33 | 23.06 | 17.78 |
| Fixed Carbon . . . . . | 55.97 | 75.90 | 79.15 |
| Ash . . . . . . . . | 1.45 | .95 | .56 |
| Sulphur . . . . . . . | 1.47 | 1.69 | 1.38 |

I. Impson Valley grahamite.  II. Black Fork Mountain vein bitumen. III. Fourche Mountain vein bitumen.  Nos. II and III occur in the more highly folded rocks, and show effects of metamorphism.

*Wurtzilite* (97) is a bitumen related possibly to gilsonite, but distinguished from it by its behavior towards solvents, and by its elastic and sectile properties. It has a hardness of 2–3, and specific gravity of 1.03; is black, with pitchy luster, and petroleum-like odor. *Tabbyite* is regarded by some as similar. Wurtzilite is found filling fissures in Tertiary calcareous shales and limestones in the western part of the Uinta Basin, Utah. It has been but little mined.



FIG. 48.— Plan of Trinidad pitch lake. (*After Peckham.*)

*Lake Asphalt* (103) is not found in the United States, but occurs in the famous pitch lake on the island of Trinidad, off the coast of Venezuela.

The deposit Pl. XIV, and Pl. XV, Fig. 1, appears to occupy a basin-shaped depression of about 100 acres and nearly circular outline (Fig. 48) lying 138 feet above the sea level. The material evidently arises from some source below, as excavations made in the pitch fill up again in a short time. Two forms of the asphalt are recognized, viz., the lake pitch and the land pitch, the latter being asphalt which has overflowed from the lake at a low point on its rim, and run down to the sea. Up to the present time over 3 million short tons of asphalt have been exported from the island.

*Manjak* (100 a) is the name applied to a bitumen resembling Uintaite, found on the island of Barbados. It is a hydrocarbon of high purity, black color, brilliant luster, and conchoidal fracture.

The Manjak is found in veins cutting obliquely across the upper strata of the oil series (Oligocene) and disseminated through the clays. The largest vein is over 27 feet thick and often shows unusually rich pockets. The close association of this asphalt with the petroleum has led most geologists to assume its derivation from the latter.

*Uintaite*, or *Gilsonite* (97), is a black, brilliant bitumen, with conchoidal fracture, hardness 2 to 2.5, and specific gravity of 1.065 to 1.07. It is partly soluble in alcohol (45.4 per cent), more so in ether, and completely in chloroform and warm oil of turpentine. It is found filling a series of fissures (Figs. 49 and 50), termed veins, in the Bridger beds of the Tertiary



FIG. 49.— Section of Gilsonite vein, Utah. (*After Eldridge, U. S. Geol. Surv., 17th Ann. Rept., I*).

of Uintah and Wasatch counties, northeastern Utah, and, to a less extent, in

western Colorado. The veins strike usually northeast-southwest, and vary greatly in width, extremes of 18 feet being reported. They are traceable for long distances, but their vertical depth appears to be unknown.

*Maltha.* — This is usually found issuing from crevices or pores of the rocks, the latter being sometimes of bituminous character. It can also be extracted from bituminous rock and asphaltic oils.

Maltha is not known to occur in large deposits in the United States, although it is somewhat widely distributed in some of the California oil fields, where the petroleum exudes from the rocks, and on exposure to the air becomes converted into maltha by the loss of its more volatile constituents. In the Santa Barbara (18) and Kern County oil fields it is found in fissures of limited extent. Its occurrence has also been noted in Oklahoma.

Oil asphalt is obtained from the distillation of certain asphaltic oils of California and Texas, and some of these are said to contain over 35 per cent of it.[1]
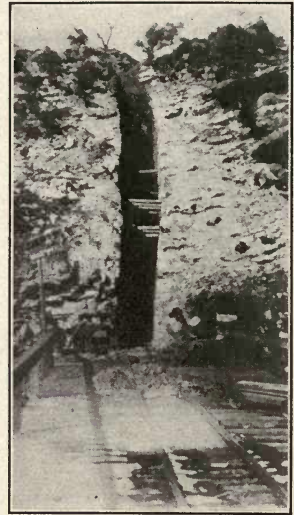


Fig. 50. — Gilsonite mine at Dragon, Utah. The cut represents position of vein. (*Rept. of Coal Mine Inspector, Utah,* 1905–1906.)

ELEMENTARY ANALYSES OF BITUMENS AND MALTHA

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | OZOKERITE, UTAH | MALTHA, CARPINTERIA, CAL. | IMPSOMITE, IND. TY. | GRAHAMITE, W. VA. | GRAHAMITE, W. VA. | ALBERTITE, NOVA SCOTIA | ALBERTITE, NOVA SCOTIA | GILSONITE, UTAH | GILSONITE, UTAH | WURTZILITE, UTAH | LAKE PITCH, TRINIDAD |
| C . . | 85.25 | 85.72 | 86.57 | 76.45 | 59.20 | 86.04 | 85.53 | 88.30 | 89.28 | 80.00 | 83.68 |
| H . . | 15.09 | 11.83 | 7.26 | 7.83 | 5.77 | 8.96 | 13.20 | 9.96 | 8.66 | 12.23 | 10.84 |
| N . . | — | 1.21 | 1.48 | tr | 1.01 | 2.93 | .42 | .32 | .79 | 1.78 | .45 |
| O . . | — | — | 2.00 | 13.46 | 14.68 | 1.97 | | | | | |
| S . . | — | 1.32 | 1.38 | tr | — | tr | 1.20 | 1.32 | 1.79 | 5.83 | 5.10 |
| Ash . | — | — | 1.31 | .10 | 19.34 | .10 | — | .10 | — | — | — |
| Moisture | — | — | — | — | — | | | | | | |

1, 9, 10, 11. Richardson, "Nature and Origin of Asphalt," 1898. 2. Munic. Eng. Mag. June–August, 1897. 3. Amer. Jour. Sci., Sept. 1899, p. 221. 4. Wurtz, analyst, Amer. Jour. Sci., iii, VI: 415, 1873. 5. Hite, analyst, Geol. Soc. Amer., Bull. X: 283, 1899. A proximate analysis made on another sample gave 1.13 sulphur. 6. Trans. Amer. Philos. Soc., Phila.: 853, 1852. 7. Richardson, Modern Asphalt Pavement: 209, 1905. 8. Jour. Frankl. Inst., CXL, No. 837, Sept. 1895.

[1] Taff, U. S. Geol. Surv., Min. Res., 1908.

PLATE XV
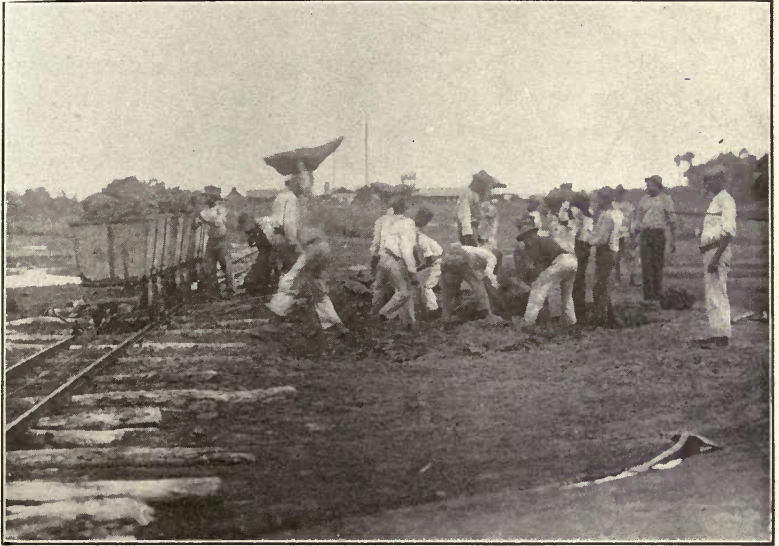


FIG. 1. — View of portion of Trinidad asphalt lake, showing digging operations. (*Photo. loaned by Barber Asphalt Company.*)
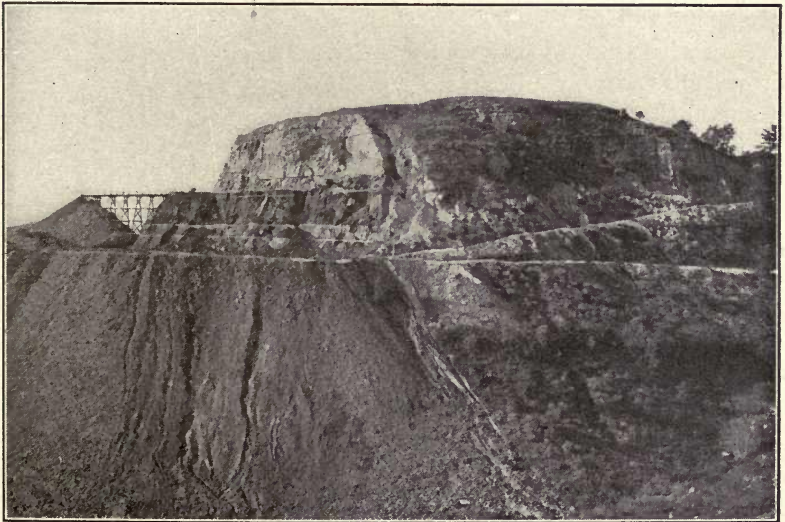


FIG. 2. — Quarry of bituminous sandstone, Santa Cruz, Cal. (*After Eldridge, U. S. Geol. Surv., 22d Ann. Rept., I.*)

## BITUMINOUS ROCKS

Under this heading are included consolidated and unconsolidated rocks, whose pores are more or less completely filled with bituminous matter, often of asphaltic character (97).

They are commonly classified according to the character of the containing rock as bituminous sands or sandstones, bituminous limestones, shales, or schists.

Bituminous rocks vary not only in their richness, but also in their value for paving purposes, for while in some the bituminous matter is purely asphalt proper, in others it may consist wholly or in part of maltha or some liquid bitumen, which may interfere with its use for paving purposes.

Deposits of bituminous rock are more widely distributed than the vein bitumens, being found in several geological horizons, and are worked in Kentucky (97a), Oklahoma (97a), and California (97).

In California deposits of asphaltic shale and sandstone are not of rare occurrence in the oil regions from Santa Cruz southward. The bituminous sandstone quarried near the above named place (Pl. XV, Fig. 2) is of blackish or brownish-black color, weathering to gray, and occurs beneath the Monterey shales; it sometimes rests directly on the granites. The bitumen impregnates the heavy-bedded sandstone immediately under the shale, and also the sand that fills cracks which extend up into the shale. These cracks, which vary in width from very minute size up to 25 or 30 feet, are sometimes traceable for several hundred feet, being at times of value as guides in finding the main bed.

ANALYSES OF BITUMINOUS ROCKS

| LOCALITY | MOISTURE | SOLUBLE IN CS₂ | CaCO₃ | MgCO₃ | SAND OR CLAY |
|---|---|---|---|---|---|
| California . . . . . | 2.50 | 20.20 | 3.00 | — | 74.00 |
| Kentucky . . . . . | — | 5.76 | — | — | 94.22 |
| Seyssel, France . . . | — | 8.15 | 91.70 | — | — |
| Limmer, Germany . . | — | 18.26 | 56.50 | 27.01 | 4.98 |

The Kentucky rock asphalt is found principally along the southern and eastern outcrop of the western Kentucky coalfield, where it occurs in the Chester sandstone, and the lower sandstones of the Coal Measures. The beds are 3 to 30 feet thick,

with a bituminous content ranging from 5 to 21 per cent, but 7 per cent is claimed to be sufficient for commercial purposes (96a).

In Oklahoma deposits have been found in a belt extending from the Arkansas boundary westward to the Wichita Mountains. The material includes bituminous sandstone of Permian and also Pennsylvanian age, and Ordovician limestones (100a).

Large quantities of bituminous rock are obtained from the Jurassic limestones of France, from Tertiary limestones of Italy, as well as other localities in Europe.[1]

## OIL SHALES

Shale containing sufficient petroleum to permit its extraction by a process of distillation is known as *torbanite* or *kerosene shale* (80–84). Such shales are found in the Carboniferous of New South Wales, Australia, New Zealand, and Scotland, and in the Cretaceous of Brazil. Those in New South Wales have been worked, and in Scotland the industry has thrived under careful management for a number of years (83).

In the last named country the crude oil extracted by distillation from a ton of shale varies from 16 to 35 gallons, while the ammonium sulphate ranges from 30 to 75 pounds.

Highly bituminous shale is known to occur in the Green River (Tertiary) formation of the Uinta Basin in Colorado and Utah (84a). It forms lenticular beds from one-half inch to 80 feet in thickness, is light to dark brown in color, and gives a petroleum odor when struck with the hammer. The shale turns gray on prolonged weathering.

The amount of oil obtained varied from 10.4 to 61.2 gallons, with an average of 30.4 gallons. Much of the bituminous material is in the form of liquid oil, semisolid and solid asphalt. The oil distilled in the field had a gravity of 26.5 to 16.0 Beaumé. The occurrence of a considerable proportion of unsaturated carbons in these as well as the Scotch shales, may involve some loss in refining.

In Albert and Westmoreland counties of New Brunswick, Canada, there is a considerable area underlain by black, brown, and gray shales of Subcarboniferous age, which contain a number of bands of oil shale. Tests of some of these have yielded

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[1] Dammer and Tietze, Die Nutzbaren Mineralien, II: 493, 1914.

63 gallons of crude oil per ton, and in 1909 investigations were under way looking towards their development (84).

The following analysis indicates the composition of an oil shale:

| | MOIS-TURE | VOLATILE HYDRO-CARBON | FIXED CARBON | ASH | SULPHUR |
|---|---|---|---|---|---|
| Rich shale, Joadja, N.S.W. . | .16 | 89.59 | 5.27 | 4.96 | .384 |

The oil can be obtained by distillation in retorts; but in view of the large available supplies of petroleum, obtainable in many parts of the world, the material at present has but little commercial value.

**Origin of Solid Bitumens and Bituminous Rocks.** — A study of the deposits leads to the conclusion that these solid bituminous compounds have been derived from petroleum (87, 88, 89, 90), for the following reasons: In the vein deposits the solid bitumens are often associated with petroleum springs, or with fissures leading down to or toward petroleum-bearing strata. In some cases the material not only fills such a fissure, but impregnates the wall rock to a distance of a foot or more on either side of the vein, indicating that the material came up through the fissure in a liquid condition, filling it, and even penetrating the wall rock.

The bitumen in bituminous rocks may either have originated from organic remains within the rock itself or have seeped into it from some neighboring pool. In either case the material seems originally to have been liquid petroleum, some of which later solidified.

**Uses of Asphalt.** — Trinidad asphalt mixed with powdered rock and tar is much in use for pavements, and the bituminous rocks are employed for similar purposes. Ozokerite, known as Ceresin in its purified form, is used in the manufacture of candles, ointments, powders, as an adulterant of beeswax, and for bottles to hold hydrofluoric acid. Ichthyol is obtained from an Austrian bituminous rock filled with fossil fish.

Uintaite and Manjak are used for making low-grade and dipping varnishes, for iron work and baking Japans. Other uses of Uintaite are for preventing electrolytic action on iron plates of ship bottoms, coating masonry, acid-proof lining for chemical tanks, roofing pitch, insulating electric wires, as a substitute for rubber in common garden hose, and as a binder pitch in making coal briquettes.

**Production of Petroleum and Natural Gas.** — Petroleum has long been known in many parts of the world because of its



1 Appalachian Field } Both these fields are on the decline.
2 Indiana-Ohio Field }
3 Illinois Field. Production less than 200,000 Barrels before 1905.
4 Mid-continental Field. Production very small prior to 1896.
5 Gulf Field. Production very slight prior to 1898.
6 California Field. Production under 100,000 Barrels before 1882.
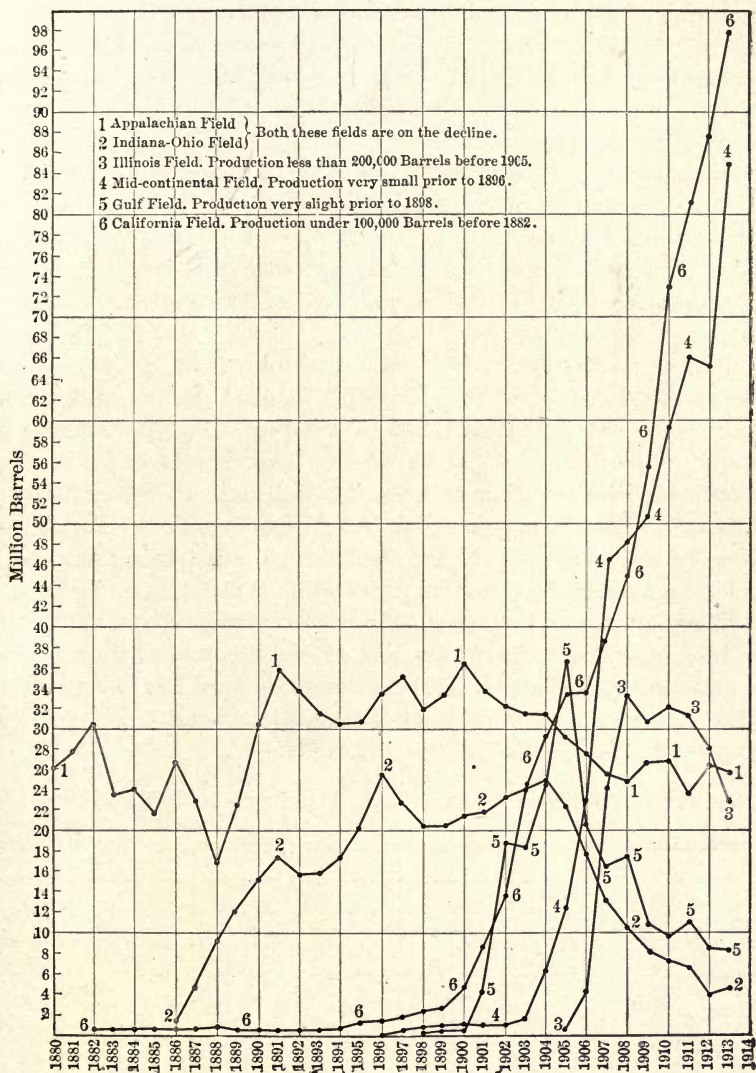
FIG. 51.

presence in bituminous springs or as a floating scum on the surface of pools. It was used at an early date on the walls of Babylon and Nineveh, and was obtained by the Romans from Sicily for use in their lamps.

In the United States petroleum was mentioned by French missionaries even in 1635, and the early Pennsylvania settlers obtained small quantities by scooping out the oil from dug wells. Its discovery at a greater depth on the western slope of the Alleghanies was made during the drilling of brine wells; but its early use was chiefly a medicinal one until 1863, when attempts were made to purify it for use as a lubricant and illuminant. The beginning of the oil industry is usually considered to date from the sinking of a successful well by Colonel Drake on Oil Creek, Pennsylvania, in 1860. From this center prospectors spread out in all directions, making valuable discoveries, until now petroleum production and refining rank among the leading industries of the country, the supply coming from many states.

Natural gas was discovered and first employed for economic purposes at Fredonia, New York, in 1821. In 1841 it was used in the Great Kanawha Valley as a fuel in salt furnaces, but its first extensive use began in 1872 at Fairview, Pennsylvania. It was used in 1885 for iron smelting at Etna Borough near Pittsburg, and in 1886 was piped nineteen miles from Murraysville to Pittsburg. Now natural gas is piped long distances to cities, being used as a fuel in many industries, as well as for domestic heating and lighting.

The following tables give the production of oil and gas from 1909 to 1914 inclusive. The production of oil since 1884 is shown diagrammatically in Fig. 51. Where the production has fallen below 200,000 barrels no attempt has been made to show it. This affects only the Gulf and Mid-Continental fields.

QUANTITY AND VALUE OF PETROLEUM MARKETED IN UNITED STATES, 1909–1911

| | 1909 | | 1910 | | 1911 | |
|---|---|---|---|---|---|---|
| | Quantity, bbl. | Value. | Quantity, bbl. | Value. | Quantity, bbl. | Value. |
| California . . | 55,471,601 | $30,756,713 | 73,010,560 | $35,749,473 | 81,134,391 | $38,719,080 |
| Colorado . . | 310,861 | 318,162 | 239,794 | 243,402 | 226,926 | 228,104 |
| Illinois . . | 30,898,339 | 19,788,864 | 33,143,362 | 19,669,383 | 31,317,038 | 19,734,339 |
| Indiana . . | 2,296,086 | 1,997,610 | 2,159,725 | 1,568,475 | 1,695,289 | 1,228,835 |
| Kansas . . | 1,263,764 | 491,633 | 1,128,668 | 444,763 | 1,278,819 | 608,756 |
| Kentucky . | 639,016 | 518,299 | 468,774 | 324,684 | 472,458 | 328,614 |
| Louisiana . . | 3,059,531 | 2,022,449 | 6,841,395 | 3,574,069 | 10,720,420 | 5,668,814 |
| New York . | 1,134,897 | 1,878,217 | 1,053,838 | 1,414,668 | 952,515 | 1,248,950 |
| Ohio . . . | 10,632,793 | 13,225,377 | 9,916,370 | 10,651,568 | 8,817,112 | 9,479,542 |
| Oklahoma . | 47,859,218 | 17,428,990 | 52,028,718 | 19,922,660 | 56,069,637 | 26,451,767 |
| Pennsylvania . | 9,299,403 | 15,424,554 | 8,794,662 | 11,908,914 | 8,248,158 | 10,894,074 |
| Texas . . . | 9,534,467 | 6,793,050 | 8,899,266 | 6,605,755 | 9,526,474 | 6,554,552 |
| West Virginia . | 10,745,092 | 17,642,283 | 11,753,071 | 15,723,544 | 9,795,464 | 12,767,293 |
| Wyoming [1] . | 20,056 | 34,456 | 115,430 | 93,536 | 186,695 | 124,037 |
| Other States . | 5,750 | 7,830 | 3,615 | 4,794 | 7,995 | 7,995 |
| United States . | 183,170,874 | $128,328,487 | 209,557,248 | $127,899,688 | 220,449,391 | $134,044,752 |

[1] Includes Utah.

QUANTITY AND VALUE OF PETROLEUM MARKETED IN UNITED STATES,
1909–1914—*Continued*

|  | 1912 | | 1913 | | 1914 | |
|---|---|---|---|---|---|---|
|  | Quantity, bbl. | Value. | Quantity, bbl. | Value. | Quantity, bbl. | Value. |
| California . . | [1] 87,272,593 | $[1] 39,624,501 | 97,788,525 | $45,709,400 | 99,775,327 | $48,066,096 |
| Colorado . . . | 206,052 | 199,661 | 188,799 | 174,779 | 222,773 | 200,894 |
| Illinois . . . | 23,601,308 | 24,332,605 | 23,893,899 | 30,971,910 | 21,919,749 | 25,426,179 |
| Indiana . . . | 970,009 | 885,975 | 956,095 | 1,279,226 | 1,335,456 | 1,548,042 |
| Kansas . . . | 1,592,796 | 1,095,698 | 2,375,029 | 2,248,283 | 3,103,585 | 2,433,074 |
| Kentucky . . | 484,368 | 424,842 | 524,568 | 675,748 | 502,441 | 498,556 |
| Louisiana . . | 9,263,439 | 7,023,827 | 12,498,828 | 12,255,931 | 14,309,435 | 12,886,897 |
| New York . . | 874,128 | 1,401,880 | 948,191 | 2,284,307 | 933,974 | 1,760,868 |
| Ohio . . . . | [2] 8,969,007 | [2] 12,085,998 | 8,781,468 | 17,538,452 | 8,536,352 | 13,372,729 |
| Oklahoma . . | 51,427,071 | 34,672,604 | 63,579,384 | 59,581,948 | 73,631,724 | 57,253,187 |
| Pennsylvania . | 7,837,948 | 12,886,752 | 7,917,302 | 19,690,502 | 8,170,335 | 15,573,822 |
| Texas . . . . | 11,735,057 | 8,852,713 | 15,009,478 | 14,675,593 | 20,068,184 | 14,942,848 |
| West Virginia . | 12,128,962 | 19,927,721 | 11,567,299 | 28,828,814 | 9,680,033 | 18,468,540 |
| Wyoming . . | 1,572,306 | 798,470 | 2,406,522 | 1,187,232 | 3,560,375 | 1,679,192 |
| Other States . | . . . . . . . . . | . . . . . . . . . | 10,843 | 19,263 | 7,792 | 14,291 |
| United States . | 222,935,044 | $164,213,247 | 248,446,230 | $237,121,388 | 265,762,535 | $214,125,215 |

[1] Includes Alaska.        [2] Includes Michigan.

The average price per barrel of petroleum naturally varies
somewhat from year to year. In 1885 it was $87\frac{7}{8}$¢; in 1890,
$86\frac{3}{4}$¢; in 1900, $1.194; in 1903, $94\frac{1}{4}$¢; in 1906, 73.1¢; in 1908,
72.2¢ in 1912, 73.7¢; in 1913, 95.4¢; in 1914, 80.6¢.

The total number of barrels of petroleum produced in the
United States from 1859 to the end of 1914 was 3,335,457,140, with
a value of $2,789,829,745, while the total value of natural gas
produced in the United States from 1882 to the end of 1908 was
approximately $1,060,590,712.

MARKETED PRODUCTION OF PETROLEUM IN THE UNITED STATES,
1910–1914, BY FIELDS, IN BARRELS.

| Field. | 1910 | 1911 | 1912 | 1913 | 1914 |
|---|---|---|---|---|---|
| Appalachian. . . . . . . . . | 26,892,579 | 23,749,832 | 26,338,516 | 25,921,785 | 24,101,048 |
| Lima-Indiana. . . . . . . . | 7,253,861 | 6,231,164 | [1] 4,925,906 | 4,773,138 | 5,062,543 |
| Illinois. . . . . . . . . . . . . | 33,143,362 | 31,317,038 | 28,601,308 | 23,893,899 | 21,913,749 |
| Mid-Continent. . . . . . . | 59,217,582 | 66,595,477 | 65,473,345 | 84,920,225 | 97,995,400 |
| Gulf. . . . . . . . . . . . . . . | 9,680,465 | 10,999,873 | 8,545,018 | 8,542,494 | 13,117,528 |
| California. . . . . . . . . . | 73,010,560 | 81,134,391 | [2] 87,272,593 | 97,788,525 | 99,775,327 |
| Colorado and Wyoming | [3] 358,839 | [3] 421,616 | 1,778,358 | 2,595,321 | 3,783,148 |
| Other fields. . . . . . . . . | — | — | — | [4] 10,843 | [5] 7,792 |
| Total. . . . . . . . . . | 209,557,248 | 220,449,391 | 222,935,044 | 248,446,230 | 265,762,535 |

[1] Includes Michigan.    [3] Includes Michigan and Missouri.
[2] Includes Alaska.      [4] Includes Alaska, Michigan, Missouri, and New Mexico.
[5] Includes Alaska, Michigan, and Missouri.

The world's production of petroleum from 1911 to 1914 was as
follows:—

WORLD'S PRODUCTION OF CRUDE PETROLEUM, 1911–1914, BY
COUNTRIES

(Barrels of 42 gallons)

| COUNTRY. | 1911 | 1912 | 1913 | | 1914 | | Percentage of Total Production. 1914 |
|---|---|---|---|---|---|---|---|
| | | | Barrels. | Metric tons. | Barrels. | Metric tons. | |
| United States . | 220,449,391 | 222,113,218 | 248,446,230 | 33,126,164 | 265,762,535 | 35,435,005 | 66.36 |
| Russia . . . | 66,183,691 | 68,019,208 | 60,935,482 | 8,124,731 | 67,020,522 | 8,936,070 | 16.74 |
| Mexico . . . | 14,051,643 | 16,558,215 | 25,696,291 | 3,426,172 | 21,188,427 | 2,825,124 | 5.29 |
| Roumania . . | 11,107,450 | 12,991,913 | 13,554,768 | 1,885,225 | 12,826,579 | 1,783,947 | 3.20 |
| Dutch East Indies | 12,172,949 | 10,845,624 | 11,966,857 | 1,534,223 | 12,705,208 | 1,634,403 | 3.17 |
| Galicia . . . | 10,519,270 | 8,535,174 | 7,818,130 | 1,087,286 | 5,033,350 | [1] 700,000 | 1.26 |
| India . . . | 6,451,203 | 7,116,672 | [1] 7,500,000 | 1,000,000 | [1] 8,000,000 | 1,066,667 | 2.00 |
| Japan . . . | 1,658,903 | 1,671,405 | 1,942,009 | 258,934 | 2,738,378 | 365,117 | .68 |
| Peru . . . | 1,368.274 | 1,751,143 | 1,857,355 | 247,647 | 1,917,802 | 255,707 | .48 |
| Germany . . | 1,017,045 | 995,764 | [1] 995,764 | 132,769 | 995,764 | [1] 140,000 | .25 |
| Egypt . . . | — | — | | | 777,038 | 103,605 | .19 |
| Canada . . . | 291,096 | 243,614 | 228,080 | 30,410 | 214,805 | 28,641 | .05 |
| Trinidad . . | | | | | 643,533 | 85,804 | .16 |
| Italy . . . | 74,709 | [1] 86,286 | [1] 50,334 | 7,000 | 39,548 | [1] 5,500 | .01 |
| Other . . . | [1] 200,000 | 250,000 | 517,616 | 69,015 | — | — | — |
| Total . . . | 345,512,185 | 351,178,236 | 381,508,916 | 50,929,576 | 400,483,489 | 53,448,257 | |

[1] Estimated.

APPROXIMATE VALUE OF NATURAL GAS PRODUCED IN THE UNITED STATES,
1909–1914

| STATE | 1909 | 1910 | 1911 | 1912 | 1913 | 1914 |
|---|---|---|---|---|---|---|
| Pennsylvania . | $20,475,207 | $21,057,211 | $18,520,796 | $18,539,672 | $21,695,845 | $20,401,295 |
| New York . . | 1,222,666 | 1,678,720 | 1,418,767 | 2,343,379 | 2,425,633 | 2,600,000 |
| Ohio . . . | 9,966,938 | 8,626,954 | 9,367,347 | 11,891,299 | 10,416,699 | 14,667,790 |
| West Virginia . | 17,538,565 | 23,816,553 | 28,435,907 | 33,324,475 | 34,164,850 | 35,515,329 |
| Illinois . . | 644,401 | 613,642 | 687,726 | 616,467 | 574,015 | 437,275 |
| Indiana . . | 1,616,903 | 1,473,403 | 1,192,418 | 1,014,295 | 948,278 | 755,407 |
| Kansas . . | 8,293,846 | 7,755,367 | 4,854,534 | 4,336,635 | 3,288,394 | 3,340,025 |
| Missouri . . | 10,025 | 12,611 | 10,496 | 11,576 | 6,795 | 5,319 |
| California . . | 446,933 | 476,697 | 800,714 | 1,134,456 | 1,883,450 | 2,910,784 |
| Texas . . . | | | 1,014,945 | 1,405,077 | 2,073,823 | 2,469,770 |
| Alabama . . | 453,253 | 956,683 | 858,145 | 1,747,379 | 2,119,948 | 2,227.999 |
| Louisiana . . | | | | | | |
| Kentucky . . | 485,192 | 456,293 | 407,689 | 522,455 | 509,846 | 490,875 |
| Tennessee . | 350 | 300 | 300 | 375 | 600 | 300 |
| Arkansas and Wyoming . . | 226,925 | 301,151 | 295,858 | 309,816 | 269,421 | [1] 214,103 |
| Oklahoma . | 1,806,193 | 3,490,704 | 6,731,770 | 7,334,599 | 7,436,389 | 8,050,039 |
| South Dakota . | 16,164 | 31,999 | 16,984 | 30,412 | 31,166 | 27,220 |
| North Dakota . | 3,025 | 7,010 | 5,738 | | | |
| Oregon . . . | 50 | | | | | |
| Iowa . . . | 50 | 40 | 70 | 120 | 120 | 200 |
| Michigan . . | 255 | 820 | 1,330 | 1,470 | 1,405 | 1,442 |
| Total . . . | $63,206,941 | $70,756,158 | $74,621,534 | $84,563,957 | $87,846,677 | $94,115,524 |

[1] Includes Colorado.

No imports or exports of natural gas have been reported during
the period 1909–1913.

EXPORTS OF MINERAL OILS FROM UNITED STATES, 1911–1914

| Kind. | 1911 | 1912 | 1913 | 1914 |
|---|---|---|---|---|
| Crude . . . . . . . . | $6,165,403 | $6,770,484 | $8,448,294 | $4,958,838 |
| Naphtha . . . . . . | 11,482,761 | 20,459,378 | 28,091,608 | 25,288,414 |
| Illuminating . . . . . | 61,055,095 | 62,084,022 | 72,042,107 | 64,112,772 |
| Lubricating and Paraffin . | 23,337,126 | 28,297,467 | 29,608,549 | 26,316,313 |
| Residuum . . . . . . | 3,882,463 | 6,599,031 | 11,125,851 | 19,224,250 |
| Total . . . . . . | $105,922,848 | $124,210,382 | $149,316,409 | $139,900,587 |

PRODUCTION OF PETROLEUM IN ONTARIO AND NEW BRUNSWICK, 1911–1914

| Year. | Barrels. | | Value. |
|---|---|---|---|
| | Ontario. | New Brunswick. | Canada. |
| 1911 . . . . . . . | 288,635 | 2,461 | $357,073 |
| 1912 . . . . . . . | 240,935 | 2,679 | 345,050 |
| 1913 . . . . . . . | 226,166 | 2,111 | 406,439 |
| 1914 . . . . . - . | 212,495 | 1,725 | 343,124 |

VALUE OF NATURAL GAS PRODUCED IN CANADA BY PROVINCES, 1911–1914

| Year. | New Brunswick. | Alberta. | Ontario. | Total. |
|---|---|---|---|---|
| 1911 . . . . . | —— | $ 110,165 | $1,807,513 | $1,917,678 |
| 1912 . . . . . | $ 36,549 | 289,906 | 2,036,245 | 2,362,700 |
| 1913 . . . . . | 174,147 | 1,079,466 | 2,055,768 | 3,309,381 |
| 1914 . . . . . | 54,249 | 1,250,320 | 2,346,687 | 3,651,256 |

**Production of Asphalt and Bituminous Rock.**—The production of these two substances by kinds and by states as well as the imports and exports are given below.

MARKETED PRODUCTION OF ASPHALT, 1910–1914, BY VARIETIES, IN SHORT TONS

| Variety. | 1910 | | 1911 | |
|---|---|---|---|---|
| | Quantity. | Value. | Quantity. | Value. |
| Bituminous Rock . . . | 64,554 | $ 400,557 | [1] 42,654 | $ [1] 159,670 |
| Maltha. . . . . . . | 1,252 | 12,742 | 8,574 | 125,966 |
| Wurtzilite (elaterite) . . | | | 610 | 30,500 |
| Gilsonite . . . . . . | [2] 33,087 | [2] 440,935 | 30,236 | 486,114 |
| Grahamite . . . . . | | | 5,000 | 15,000 |
| Ozokerite and Tabbyite . | | | | |
| Oil asphalt or manufactured | 161,187 | 2,225,833 | 277,192 | 3,173,859 |
| Total . . . . . . | 260,080 | $3,080,067 | 364,266 | $3,991,109 |

[1] Includes small output of mastic.
[2] Includes gum.

MARKETED PRODUCTION OF ASPHALT, 1910–1914, BY VARIETIES,
IN SHORT TONS—*Continued*

| Variety | 1912 | | 1913 | | 1914 | |
|---|---|---|---|---|---|---|
| | Quan-tity. | Value. | Quan-tity. | Value. | Quan-tity. | Value. |
| Bituminous Rock . . | [1] 54,762 | $ [1] 173,018 | } 57,549 | $173,764 | 48,771 | $ 151,122 |
| Maltha . . . . . | 474 | 3,518 | | | | |
| Wurtzilite (elaterite) . | 8,452 | 115,620 | | | { 19,148 | 405,966 |
| Gilsonite . . . . | 31,478 | 573,069 | } 35,055 | 576,949 | 9,669 | 73,535 |
| Grahamite . . . . | ([2]) | ([2]) | | | — | — |
| Manufactured or oil asphalt. . . . | 354,344 | 3,755,506 | 436,586 | 4,531,657 | 360,683 | 3,016,969 |
| Total . . . . | 449,510 | $4,620,731 | 529,190 | $5,282,370 | 438,271 | $3,647,692 |

[1] Includes small output of mastic.
[2] Included under wurtzilite.

Since deposits of the purer type, such as lake asphalt, are very
scarce in the United States, the supply for domestic consumption
is obtained from foreign countries.   The imports for the last five
years are given below:—

ASPHALT IMPORTED FOR CONSUMPTION INTO THE UNITED STATES, 1910–1914,
IN SHORT TONS

| YEAR. | CRUDE. | | DRIED OR ADVANCED. | | BITUMINOUS LIMESTONE. | | TOTAL. | |
|---|---|---|---|---|---|---|---|---|
| | Quan-tity. | Value. | Quan-tity. | Value. | Quan-tity. | Value. | Quan-tity. | Value. |
| 1910 . . | 162,435 | $588,206 | 20,180 | $178,704 | 3,696 | $ 9,301 | 186,311 | $[1]785,963 |
| 1911 . . | 167,681 | 572,198 | 20,461 | 184,954 | 8,180 | 23,468 | 196,322 | 789,236 |
| 1912 . . | 193,645 | 726,345 | 20,707 | 177,992 | 3,976 | 15,808 | 218,328 | 921,145 |
| 1913 . . | [2]207,033 | 738,452 | [3] 14,750 | 133,336 | 6,395 | 38,823 | 228,178 | 910,611 |
| 1914 . . | 137,352 | 664,558 | — | — | 1,705 | 11,060 | 139,057 | 675,618 |

[1] Imports for 1909 include $8,988 of manufactures;  1910, $9,752.
[2] Includes dried or advanced asphalt for last three months of 1913.
[3] Last three months of 1913 included in crude asphalt.

Most of the asphalt imported from foreign countries comes from
the island of Trinidad, but other important sources are Venezuela
(Bermudez), Cuba, Germany, Italy, and Mexico.   Small amounts
are also brought from Switzerland, France, the United Kingdom.
Turkey in Asia, Colombia, and Netherlands.

The ozokerite imported for consumption in 1913 amounted
to 7,141,514 pounds, valued at $549,992; in 1914 the quantity
imported rose to 8,191,529 pounds valued at $498,655.

The imports of ichthyol in 1914 amounted to 61,416 pounds, valued at $56,415.

During the fiscal year 1914, asphalt and manufactured asphaltic material to the value of $1,247,020 were exported from the United States to other countries as against similar exports valued at $1,679,411 during 1913.

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## CHAPTER III

### BUILDING STONES

UNDER this term are included all stones for ordinary masonry construction, as well as for ornamentation, roofing, and flagging. The number of different kinds used is very great, and includes practically all varieties of igneous, sedimentary, and metamorphic rocks, but a few stand out prominently on account of their widespread occurrence and durability.

The cost of a building stone naturally exerts decided influence on its use. Since the ease of splitting and dressing a stone influences its cost, the texture is also of importance. Color is another factor in determining the value of a building stone, and this, together with other considerations, sometimes gets a fashion leading to the widespread use of certain stones. This has been well illustrated in the eastern cities of the United States, where, for many years, Connecticut brownstone was in such great demand for use in building private dwellings that much inferior stone was put on the market. More recently Indiana limestone and Ohio sandstone have met the popular fancy, and these two are now used in vast quantities.

**Properties of Building Stones**[1] (1–10). — The following properties have an important bearing on the value of a building stone: —

*Color.* — The color of rocks varies greatly, and those shown by common building stones include white, black, brown, red, yellow, and buff, while some are green, blue, or mottled. The color may vary in the same quarry.

In igneous rocks the color may be that of the prevailing mineral, as in pink granite, where there is an excess of pink feldspar; or it may be a composite due to the blending of the colors of several minerals, as in the case of ordinary gray granite, where the color results from the mixture of black mica and whitish quartz and feldspar. Sedimentary rocks commonly owe their color to ferruginous cements, or to carbonaceous matter. The former give brown, yellow, red, or green colors depending on the condition of oxidation and form of combination of the iron, while the latter produces gray, black, and bluish tints depending on the amount present. Sandstone and limestone free from either of these coloring agents are nearly if not quite white.

[1] Only the more important ones are here considered. Excellent detailed discussions will be found in Refs. 2, 9, 30, 41, 43a, 51.

Some stones change color on exposure to the air. For example, lime-stones or sandstones containing carbonaceous matter may bleach; some black marbles fade to a white or gray; and some red and green roofing slates, as well as a few red granites, change color. Oxidation of evenly distributed pyrite may change gray or bluish-gray sandstones to buff color. If the minerals responsible for such change in color are not uniformly distributed, the stone assumes a blotchy appearance, but such changes are not necessarily an indication of deterioration.



Fig. 52. — Photomicrograph of a section of Granite. (Photo loaned by A. B. Cushman.)

*Texture.* — Building stones vary in their texture from coarse-grained granites and conglomerates to fine-grained sandstones, lime-stones, and porphyries.

Texture is an important property, for it influences both the dura-bility and the cost of stone. Other things being equal, a fine-grained rock is not only more durable, but splits better and dresses more evenly, than a coarse-grained rock. Uneven texture, whether due to mineral grains or cement, is undesirable, since it often causes uneven weathering.

*Density.* — On the whole, dense stones resist weather better than porous ones, but there is great difference in the density of building stones.

In general, though with some exceptions, igneous and metamorphic rocks have high density because of the close interlocking of the crystalline grains. Sedimentary rocks of clastic origin, on the other hand, have less closely fitting grains, and unless the latter are very small, or the pores well filled with cement, they are apt to be porous.

The specific gravity of a stone indicates its density; and from the specific gravity the weight per cubic foot may often be approximately estimated by multiplying it by 62.5, the weight of an equal volume of water. While sufficiently accurate for very dense stones, this method is liable to lead to incorrect results when applied to very porous rocks. Following are some average specific gravities of common building stones, as given by Hirschwald (1): granite, 2.65; syenite, 2.80; diabase, 2.80; gabbro, 2.95; serpentine, 2.60; gneiss, 2.65; limestone, 2.60; dolomite, 2.80; sandstone, 2.10; slate, 2.70.
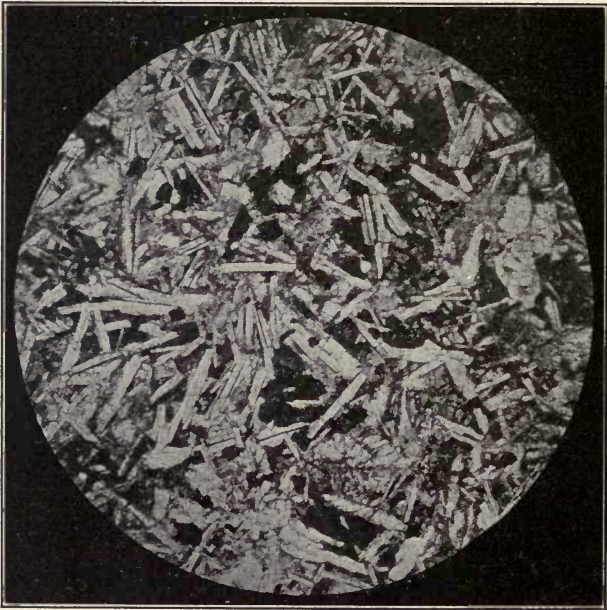


Fig. 53. — Photomicrograph of a section of Diabase.   (Photo loaned by A. B. Cushman.)

*Hardness.* — The hardness of a building stone is not necessarily dependent on the hardness of its component minerals, but is largely influenced by their state of aggregation, and to some extent their hardness.

For example, a sandstone composed of quartz grains, but with little cementing material, may be so soft as to crumble easily in the fingers; while a limestone, whose grains of soft carbonate of lime fit closely and

are firmly cemented, may be difficult to break with a hammer. The nature of the cement in sedimentary rocks, that is, whether it is lime, silica, or iron, will also affect the hardness of the stone.    Crystalline rocks owe their great hardness to the firm interlocking of the mineral grains. The abrasive resistance (10) of a stone will depend in part on the state of aggregation of the mineral particles, and in part on the hardness of the grains themselves.    Some stones wear very unevenly because of their irregularity of hardness, and such may be less desirable than one which is uniformly soft.

No standard form of abrasion test exists, and yet one should be applied to those stones which are used for paving, steps, or flooring, as well as to those placed in situations where they may be subjected to the attacks of wind-blown sand, or the rubbing action of running water.

*Strength.* — Two kinds of strength, compressive and transverse, are to be considered in building stones.

The compressive or crushing strength, which is expressed in pounds per square inch, is the resistance which the rock offers to a crushing force, and is dependent chiefly on the size of the grains, state of aggregation, and mineral composition.    Because of the close interlocking of the grains of igneous rocks they are stronger than those of sedimentary origin, in which the strength is due chiefly to the cement which binds the grains together.    Sedimentary rocks show greatest strength when dry, or when pressure is applied at right angles to the bedding.

Few building stones when in use are subjected to pressures even approximately equal to their crushing strength.    No domestic building stone at present used in the eastern market has a crushing strength of less than 6000 pounds, yet the pressure even in the tallest buildings does not require a stone with a crushing strength exceeding 314.6 pounds, and this includes the factor of safety of twenty usually allowed by architects.    Computations show that a stone at the base of the Washington monument sustains a maximum pressure of 6292 pounds per square inch, which includes the usual factor of safety of twenty; the crushing strength of the stone used in the base of the monument is however not less than 10,000 to 12,000 pounds per square inch.

The crushing strength of some soft limestones or sandstones may be but little above 3000 pounds per square inch, while that of diabase often exceeds 30,000 pounds per square inch.    The accompanying table gives the crushing strength of a number of stones.    (Many others are given in the state reports.)

### CRUSHING STRENGTH OF BUILDING STONES

| | |
|---|---:|
| Granite, Vinal Haven, Me. | 13,381 |
| Granite, East Saint Cloud, Minn. | 28,000 |
| Granite, Port Deposit, Md. | 19,750 |
| Dolomite marble, Tuckahoe, N.Y. | 13,076 |
| Limestone, Caen, France | 3,550 |
| Sandstone, Portland, Conn. | 13,310 |
| Sandstone, E. Long Meadow, Mass. | 8,812 |

Wide variations sometimes exist in stones from different parts of the same quarry, or in stones from the same locality tested at different times. The published crushing tests of different stones cannot really be fairly compared because all have not been tested under exactly the same conditions.

*Transverse Strength.* — The transverse strength is the load which a bar of stone, supported at both ends, is able to withstand without breaking. It is measured in terms of the *modulus of rupture,* which represents the force necessary to break a bar of one square inch cross section, resting on supports one inch apart, the load being applied in the middle.
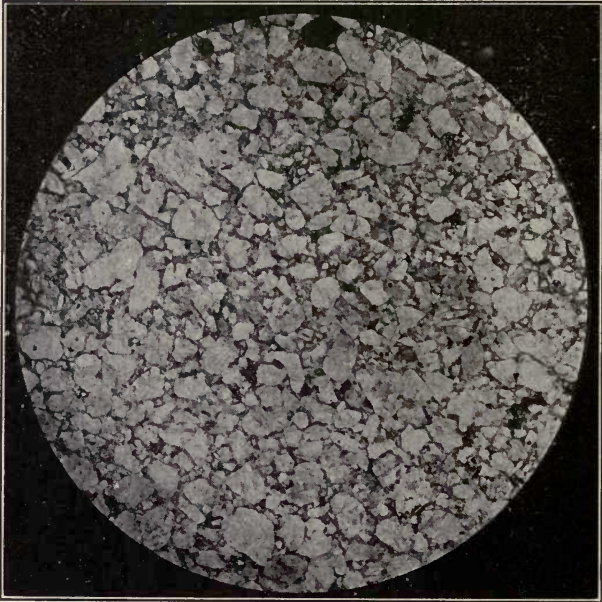


FIG. 54. — Photomicrograph of a section of quartzitic sandstone.
(Photo loaned by A. B. Cushman.)

Although stones in buildings are rarely, if ever, crushed, they are frequently broken transversely, and therefore a knowledge of the transverse strength is of more importance than the crushing strength. A high crushing strength does not necessarily mean a high transverse strength. Unfortunately few stones have been tested in this manner.

*Porosity and Ratio of Absorption.* — The porosity of building stones varies widely. Most igneous rocks have little pore space and hence absorb little water; but sedimentary rocks, especially sandstones, are often very porous.

Many rocks, especially those of the sedimentary class, contain water in their pores when first quarried. This is known to quarrymen as *quarry*

*water*, and it is present in some porous sandstones in sufficient quantities to interfere with quarrying during freezing weather. Mineral matter in solution in the quarry water is deposited between the grains when the water evaporates, often in sufficient quantities to perceptibly harden the stone.

Water is also present in the joint planes, and by its passage along these planes causes oxidation and rusting of the iron of the rock-forming minerals. This discolors the stone along and on either side of the joint planes, giving rise to a yellow color known as *sap*.

*Resistance to Frost.* — Building stones show a varying degree of resistance to frost.

Dense rocks, like granites, quartzites, and many limestones, and even some very porous rocks, are little affected; but many porous and laminated rocks, like open sandstones and schists, disintegrate under frost action. This is due to the fact that moisture absorbed in the warmer weather, on freezing in the pores, expands, and either forces off small pieces or disrupts the stones. Since clay readily absorbs water, clayey rocks are sometimes similarly affected.

*Resistance to Heat.* — All rocks expand when heated, and contract when cooled, but do not shrink down to their original dimensions. This permanent increase in size is termed *permanent swelling*, and though small when figured for one linear foot, is appreciable in long pieces.

The following figures give the average of a number of tests of permanent swelling in stone bars 20 inches long, heated from 32° F. to 212° F., and then cooled to the original temperature: granite, .009 inch; marble, .009 inch; limestone and dolomites, .007 inch; sandstone, .0047.

The most severe test of a stone's resistance to rapid changes of temperature is to heat it to about 800° C. and then immerse it in cold water. Quartzites and hard sandstones withstand such treatment best; some granites crack and crumble, and the carbonate rocks change to lime.

*Chemical Composition.* — Many chemical analyses of building stones have been made, but most of them are of little value, largely because they tell us nothing regarding the physical properties of the stone. They are perhaps of most value in the case of sedimentary rocks. The chemical analysis of a limestone will indicate whether it is dolomitic or not, also whether it is clayey in its character. So too the analysis of a sandstone will indicate whether it is siliceous or clayey.

*Life of a Building Stone.* — This may be considered as the period of time a stone will stand exposure to the weather without showing signs of decay. Even for the same stone, it may vary with location

and climate. Julien makes the following deductions from observations made on stones in use: —

| | |
|---|---|
| Coarse brownstone . . . . . . . . . . . . . | 5–15 years |
| Fine-laminated brownstone . . . . . . . . . . | 20–50 years |
| Coarse fossiliferous limestone . . . . . . . . . | 20–40 years |
| Coarse dolomitic marble . . . . . . . . . . . | 40 years |
| Fine-grained marble . . . . . . . . . . . . | 50–100 years |
| Granite . . . . . . . . . . . . . . . . | 75–200 years |
| Quartzite . . . . . . . . . . . . . . . | 75–200 years |

**Structural Features affecting Quarrying.** — All rocks are traversed by planes of separation of one sort or another. In sedimentary rocks these consist of bedding and joint planes; in igneous rocks, the latter alone are present; and in metamorphic rocks, joint planes, a banding of minerals and, very often, cleavage planes.

*Bedding planes.* — (Pl. XVII, and Pl. XXII, Fig. 1.) These may be either an advantage or a disadvantage to the quarryman. They are desirable because they facilitate the extraction of the stone; but if numerous and closely spaced, the layers may be too thin for any purpose except flagging. They often serve as a means of entrance for the agents of weathering, and the stone may be disintegrated along the bedding planes while elsewhere fresh.

Incipient planes of weakness, due either to the arrangement of minerals or to microscopic fractures in them, often give rise to planes of easy splitting which are of great value in quarrying, notably of granite. The most prominent plane is called *rift;* and a less prominent vertical plane, approximately at right angles to the rift, is called the *grain.* Granites often show a sheeted (Pl. XVI, Fig. 1) structure, due to the presence of horizontal joints. These are slightly curved, and hence tend to separate the granite mass into a series of lenses.

The position of the beds exerts an important influence on the cost of quarrying. When horizontal and of different quality, it may often be necessary to strip off worthless rock in order to reach the beds of good quality. In such cases, there is often less stripping to do in quarries opened on gently sloping ground. In regions of steep dip, it is sometimes possible to work the quarry as a cut, extracting the desired beds and leaving useless ones standing.

## GRANITES

**Characteristics of Granites** (9, 43*a*). — As commonly used by quarrymen, the term *granite* includes all igneous rocks and gneiss; but in this book it is used in the geological sense, which is more restricted. From the geological standpoint a granite is a holocrystalline, plutonic igneous rock consisting of quartz, orthoclase feldspar, and either mica or hornblende, or both. There are also varying but usually small quantities of other feldspars, and there may be

Plate XVI
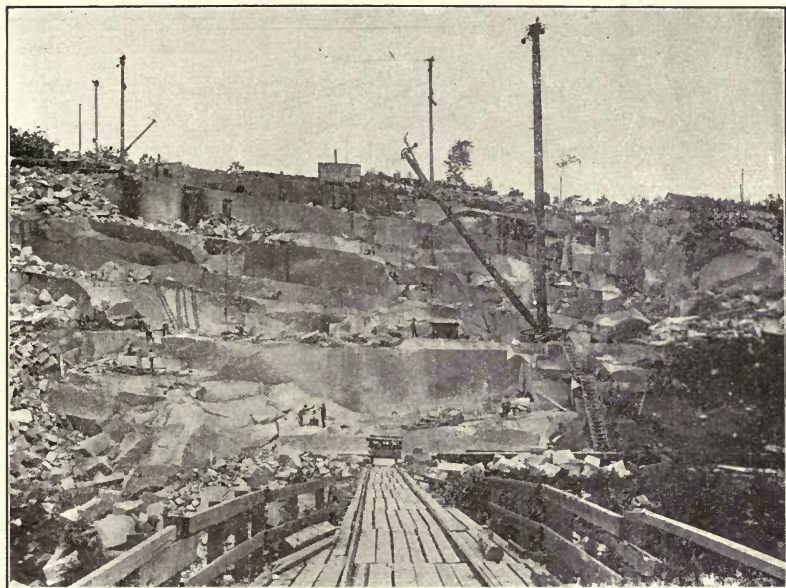


Fig. 1. — Granite quarry, Hardwick, Vt.    (*Photo. by G. H. Perkins.*)
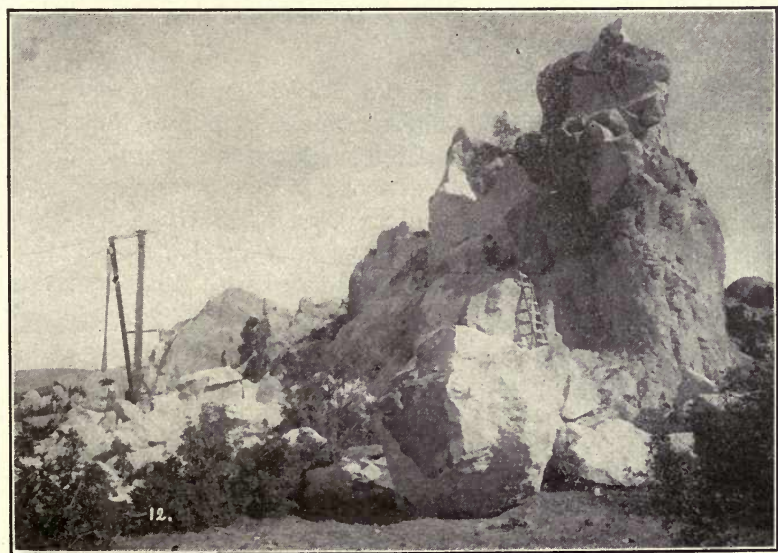


Fig. 2. — Quarry in volcanic tuff, north of Phœnix, Ariz.

(145)

subordinate accessory minerals, such as pyrite, garnet, tourmaline, and epidote.

Granites vary in texture from fine to coarse grained, and in some cases are porphyritic. They pass into gneisses by such insensible gradations that no sharp line can be drawn between the two. In color they vary, being, most commonly, gray, mottled gray, red, pink, white, or green, according to the color or abundance of the component minerals. Most granites are permanent in their color, but some of bright red color bleach on continuous exposure to sunlight.

The average specific gravity of granites is 2.65, which corresponds to a weight of 165.6 pounds per cubic foot. They commonly contain less than 1 per cent of water, and often absorb two or three tenths more. Their crushing strength varies, but is apt to lie between 15,000 and 30,000 pounds per square inch.

Granites are among the most durable of building stones, but there is some variation in the durability of the different kinds. Other things being equal, fine-grained granites are more durable than coarse-grained, being less easily affected by changes of temperature. One of the most beautiful granites known, the Rapikivi granite of Finland, lacks in durability on this account. Pyrite and marcasite are injurious minerals, since they rust rapidly and may discolor the stone in an unsightly manner. Very few granites now in use show signs of decay; but in those that do, the darker silicates are rusted, the luster of the feldspar is dulled, and, in some cases, the stone has begun to disintegrate.

**Distribution of Granites in the United States** (9). — Granite usually occurs in batholytic masses sometimes forming the cores of mountain chains. Removal of the overlying strata by denudation has revealed the granite, which, owing to its greater durability, is often left standing as peaks or domes by the farther removal of the surrounding, weaker strata. Granites show a wide geologic range, but most known occurrences are associated with the older formations.

Granite forms an important source of durable building stone widely distributed in the United States (Fig. 55); but nearly 70 per cent of that quarried comes from the Atlantic states. There are several areas which will be briefly considered.

*Eastern Crystalline Belt* (2, 11, 19, 26, 31, 44, 45). — From northeastern Maine southwestward to eastern Alabama there is an important belt of granites and gneisses, mostly of pre-Cambrian age. Those at the northeastern end of the belt, as far south as New York, are most extensively quarried, largely because of their pecul-

iarly favorable location. In this belt those of Quincy, Massachusetts (28), Barre, Vermont (44), and Westerly, Rhode Island (41), are of value for monumental work. Many large quarries have also been opened up in Maine (25a), but their output is employed mainly for structural work. A gneissic granite quarried at Port Deposit, Maryland (26), a white granite from Mt. Airy, North Carolina (36), as well as a pinkish granite worked at Stone Mountain, Georgia (20), are also of some importance. Another important granite area is located near Richmond, Virginia. (46).



FIG. 55. — Map showing distribution of crystalline rocks (mainly granites) in United States. (*After Merrill, Stones for Building and Decoration.*)

*Minnesota-Wisconsin Area* (51). — There are several detached areas in these two states, some of which supply granites of value for ornamental work. That from Montello, Wisconsin, bears a high reputation, and those from Wausau, Wisconsin, and Ortonville, Minnesota, are favorably known.

*Southwestern Area.* — This includes portions of Missouri, Arkansas, Oklahoma, and Texas.

These four states contain small areas, worked mainly to supply a local demand. Those of southeastern Missouri vary from light gray to red in color and fine grained to porphyritic in texture. Some of the rock is rhyolite. The region around Fredericktown is important (30). Important granite deposits are known in the Arbuckle and Wichita Mountains of Oklahoma (38), but their development thus

far has been slight.    Arkansas contains quarries of syenite west of Little Rock (2), and for purposes of convenience it is mentioned under granite.    In Texas quarries have been opened in Llano County, and yield both pink and gray granite (2, 43a).

*Western States.* — There are many areas of true granite, and closely allied rocks such as grano-diorite and rhyolite in the western states.    The central portion of the Black Hills of South Dakota is a great granite mass, but little of it is quarried.    Granites are known in Colorado (17), and quarried to some extent, and the rhyolites of Castle Rock are of considerable importance.    In California the grano-diorite mass forming the central portion of the Sierra Nevada Mountains yields an inexhaustible supply, which is quarried at several points.    Montana, Washington (48), and Oregon also contain granites which are quarried for local use.    On the whole, however, the Cordilleran granite industry is somewhat restricted because of lack of demand.

**Uses of Granite.** — On account of its massive character and durability, granite is much employed for massive masonry construction, while some of the granites that take and preserve a high polish, and are susceptible of being carved, are in great demand for ornamental and monumental work.    Because of its greater durability, granite has in recent years largely replaced marble for monumental purposes.

The refuse of the quarries is often dressed for paving blocks or crushed for roads and railroad ballast.    The size of the blocks which can be extracted from a granite quarry depends in part on the spacing of the joint planes, in part on the perfection of development of the rift, some of the monoliths that have been quarried being of immense size: for example, one from Stony Creek, Connecticut, measured 41 ft. × 6 ft. × 6 ft.; one from Vinal Haven, Maine, 60 ft. × 5½ ft.; one from Barre, Vermont, 60 ft. × 7 ft. × 6 ft.

**Miscellaneous Igneous Rocks** (9). — But little space need be given to these, for they are of minor importance as compared with the granites.    In the eastern states the diabase or trap rock is quarried at several points in Connecticut, New York, New Jersey, and Pennsylvania.    Owing to its great hardness it is only occasionally used for dimension blocks, its chief value being for paving blocks and road metal.    The basaltic rocks of the western states, especially those of Washington and California, are often employed for similar purposes.    Anorthosites and gabbros, some of the former being of highly ornamental character when polished, occur in the

Adirondack Mountains, New York; they are, however, but little utilized. Gabbros have been quarried for local use in Maryland and Minnesota, and diorites have been quarried to a small extent at scattered localities. Some of the porphyries and rhyolites of the Atlantic states possess considerable beauty when polished. A handsome porphyry is quarried in Wisconsin (51), and in the Cordilleran region both rhyolite and porphyry occur in numerous localities. Andesite tuffs are quarried in Colorado, and consolidated volcanic tuffs have also been used to some extent for building in Arizona.

## LIMESTONES AND MARBLES

**General Characteristics** (1, 9). — A great series of sedimentary and metamorphic rocks, composed chiefly of carbonate of lime, or, in the case of dolomite, of carbonate of lime and magnesia, is included under the term *limestone and marble*. These rocks also contain varying, but usually small, amounts of iron oxide, iron carbonate, silica, clay, and carbonaceous matter. When of metamorphic character various silicates, such as mica, hornblende, and pyroxene, etc., may be present.

These calcareous rocks vary in texture from fine-grained, earthy, to coarse-textured, fossiliferous rocks, and from finely crystalline to coarsely crystalline varieties. There is, also, great range in color, the most common being blue, gray, white, and black, but beautiful shades of yellow, red, pink, and green, usually due to iron oxides, are also found. Their crushing strength commonly ranges from 10,000 to 15,000 pounds per square inch, while their absorption is generally low.

The mineral composition of limestone exerts a strong influence on its durability. Those limestones which are composed chiefly or wholly of carbonate of lime are liable to solution in waters containing carbon dioxide; but dolomite limestones, especially coarse-grained ones, disintegrate rather than decompose. Streaks of mineral impurities cause the stone to weather unevenly. Pyrite is an especially injurious constituent, not only on account of its rusting, but also because the sulphuric acid set free by its decomposition attacks the stone. Tremolite, which is found in some dolomitic marbles, is also liable to cause trouble by its decay. Black or gray limestones will sometimes bleach on exposure.

**Varieties of Limestones.** — In the geological sense limestones are of sedimentary origin, while marbles are of metamorphic character, but in the

trade the term *marble* is applied to any calcareous rock capable of taking a polish. In addition to the different varieties of marble and the ordinary limestones, there are certain kinds of calcareous rock to which special names are given, as follows: —

*Chalk* is a fine, white, earthy limestone, composed chiefly of foraminiferal remains.

*Coquina* is a loosely cemented shell aggregate, like that found near St. Augustine, Florida.

*Dolomite*, or *dolomitic limestone*, composed of carbonate of lime and magnesia, and to the eye alone often is indistinguishable from limestone.

*Fossiliferous limestones* is a general term applied to those limestones which contain many fossil remains. Under this heading are included crinoidal limestone and coral-shell marble.

*Hydraulic limestone*, an argillaceous limestone containing over 10 per cent of clayey impurities. Used mainly for cement manufacture (p. 188).

*Lithographic limestone* is an exceedingly fine grained, crystalline limestone, of gray or yellowish hue. It is used for lithographic and not structural work.

*Oölitic limestone*, composed of small, rounded grains of concretionary character.

*Stalactitic* and *stalagmitic deposits*, formed on the roofs and floors of caves, respectively, are often of crystalline texture and beautifully colored, and, when of sufficient solidity, are known as onyx marble.

*Travertine*, or *calcareous tufa*, a limestone deposited from springs. The Roman deposits are sufficiently hard for building purposes, but those occurring in the United States, as in Virginia, are not so, even though the deposits are large.

**Distribution of Limestones in the United States.** — Limestones are found in many states, and in all geological formations from Cambrian to Tertiary, but those of the Paleozoic, which are much used in the eastern and central states, are more extensive and more massive than those of later formations. Although many large quarries have been opened to supply a local demand, the product is shipped to a distance from only a few localities. At present the Subcarboniferous Bedford (22) oölitic limestone of Indiana (Pl. XVII) is, perhaps, the most widely used limestone in the United States. It occurs in massive beds from 20 to 70 feet thick, and is said to underlie an area of more than 70 square miles. Although soft and easily dressed, it has good strength, and has been used in many important cities of the United States. The same rock is quarried at Bowling Green, Ky. (23c).

In the eastern and central states the Paleozoic limestones are worked at many points, mainly to supply a local demand (3).

Cretaceous limestones are worked in Kansas, Nebraska, and Iowa, although the most important sources are in the Paleozoic formations.
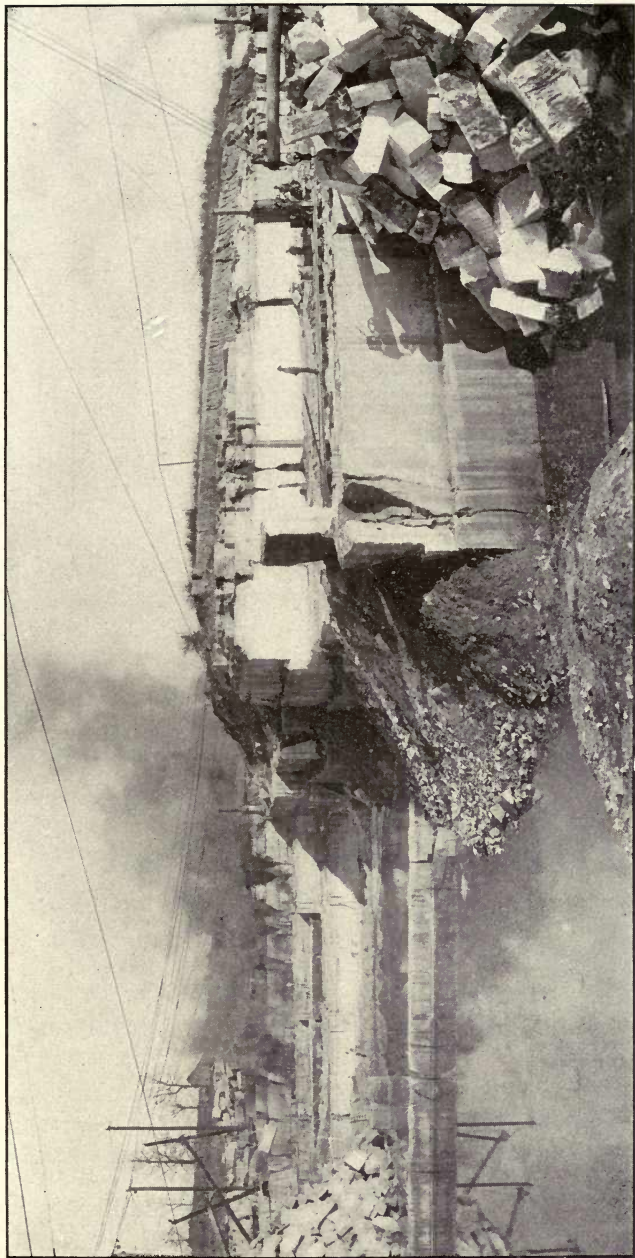
PLATE XVII. — Quarry in limestone, Bedford, Ind. (*Photo., Bedford Quarries Co.*) A horizontally bedded limestone, showing some weathering along the vertical joint planes.

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**Distribution of Marbles in the United States** (2).—While some variegated marbles are produced in the United States, still most of those quarried are white, the greater part of the variegated stones
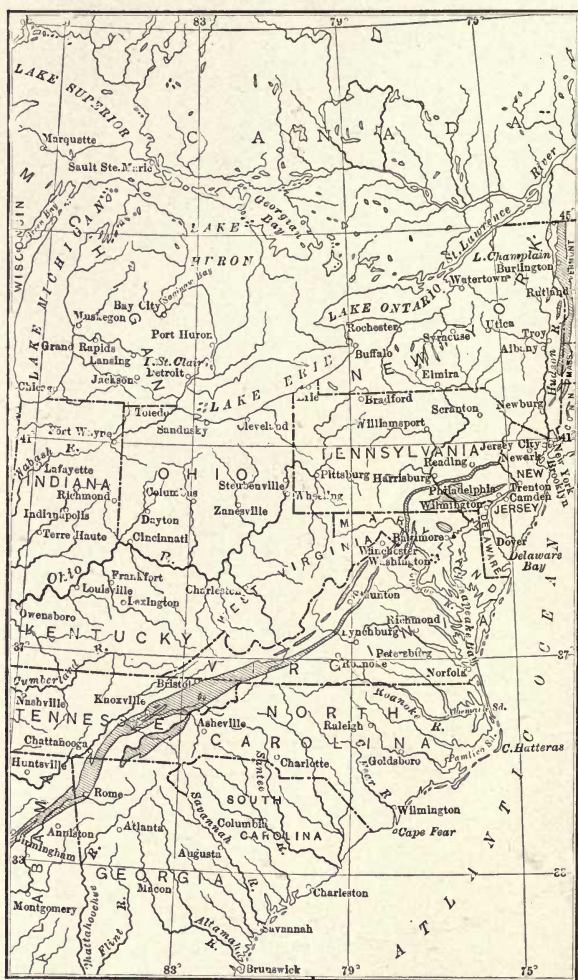


Fig. 56. — Map showing marble areas of eastern United States. (*After Merrill, Stones for Building and Decoration.*)

being imported. The main supply comes chiefly from regions of metamorphic rock, the eastern crystalline belt being the principal producer (Fig. 56). Vermont (44, 45) leads all other states in marble production, supplying a large per cent of all the marbles

I

used for ornamental work in the country.  The most important and largest quarries are those at Proctor (Pl. XVIII) and West Rutland. At the latter locality the marble bed has a thickness of 150 feet at the top of the quarry, narrowing to 75 feet at the bottom, and is divisible into a series of well-marked layers of varying thickness, quality, and color (45).

The Vermont marbles usually show a bluish-gray or whitish ground, the latter often showing a pinkish or creamy shade, and traversed by veins or markings of a green or brown color.

A beautifully colored series of variegated marbles[1] is quarried at Swanton, Vt. (45), and much used throughout the United States for flooring and wainscoting.  Owing to their highly siliceous character they show excellent wearing qualities.  White marbles for structural work are quarried at Lee, Massachusetts (2), and at South Dover and Gouverneur, New York (2, 35), but gray ones are also obtained from the last-named locality.  In Maryland important quarries have been opened up at Cockeysville (26). Large quantites of white and also gray marble are quarried in Pickens County, Georgia (19) (Pl. XIX, Fig. 1).

The Trenton limestone in eastern Tennessee (9) supplies marble of gray, and of pinkish chocolate color with white variegation. It is used chiefly for interior decoration.  The Napoleon gray from Phenix, Missouri, is very similar to the Knoxville, Tenn., gray.

Marble has been reported from various other states west of the Mississippi, but as yet little quarrying has been done.  A large deposit of white marble is said to occur at Marble, Colorado, and that quarried in Inyo County, California, has attracted considerable attention in recent years (16).

Most of the variegated marble used for interior decoration in this country is obtained from foreign countries, especially France, Belgium, Greece, etc.  Many of these imported stones are of rare beauty, but are usually unfitted for exterior use in severe climates, a fact often ignored by architects. Although ornamental stones of this class occur in the United States, up to the present time few attempts have been made to place them on the market. This may be due to the fact that most quarrymen do not care to assume the temporary expense which their introduction might involve.

**Onyx Marbles** (53–56). — Under this term are included two types of calcareous rock, one a hot-spring deposit, or travertine, formed at the surface, the other a cold-water deposit formed in limestone caves in the same manner as stalagmites and stalactites.  Cave onyx is more coarsely crystalline and less translucent than travertine onyx.  The beautiful

[1] These should perhaps be more properly classed as calcareous sandstones.

banding of onyx is due to the deposition of successive layers of carbonate of lime, while the colored cloudings and veinings are caused by the presence of metallic oxides, especially iron.

Neither variety of onyx occurs in extensive beds, though both are widely distributed. Onyx is found in Arizona, California, and Colorado, but it has not been developed in any of these states except on a small scale. Most of the onyx used in the United States is obtained from Mexico, though small quantities are obtained from Egypt and north Algeria.

The value of onyx varies considerably, the poorer grades selling for as little as 50 cents per cubic foot, while the higher grades bring $50 or more. The earliest-worked deposits were probably those of Egypt, which were used by the ancients for the manufacture of ornamental articles and religious vessels; and the Romans obtained onyx from the quarries of northern Algeria. Many of the travertine onyx deposits occur in regions of recent volcanic activity, and all of the known occurrences are of recent geological age.

**Uses of Limestones and Marbles.** — The limestones are used mainly for ordinary dimension blocks, though some, as the Bedford stone, lend themselves well for carved work. The refuse from the quarry may be of value for road material, lime, or Portland cement manufacture. (See reference under Cement.)

Marbles are used in increasing quantities for ordinary structural work, although many of the lighter-colored ones soon become soiled by dust and smoke. The output of many quarries, especially the Vermont ones, is well adapted to monumental purposes, and these, together with those from Georgia, Tennessee, and California, are much used for wainscoting and paneling. That from Swanton is also well adapted to flooring. Electrical switchboards are now frequently made of marble. The demand for marble tops for tables, washbasins, and similar uses is probably decreasing. The refuse from marble quarries is sometimes utilized for the same purposes as limestone. Special tests are applied to marbles (45a).

## SERPENTINE

Pure serpentine is a hydrous silicate of magnesia; but beds of serpentine are rarely pure, usually containing varying quantities of such impurities as iron oxides, pyrite, hornblende, and carbonates of lime and magnesia. The purer varieties are green or greenish yellow, while the impure types are various shades of black, red, or brown. Spotted green and white varieties are called ophiolite or ophicalcite.

Serpentine is sometimes found in sufficiently massive form for use in structural or decorative work; but, owing to the frequent and irregular joints found in nearly all serpentine quarries, it is difficult to obtain other than small-sized slabs. Its softness and beautiful color have led to its extensive use for interior decoration; but since it weathers irregularly and loses luster, it is not adapted to exterior work.
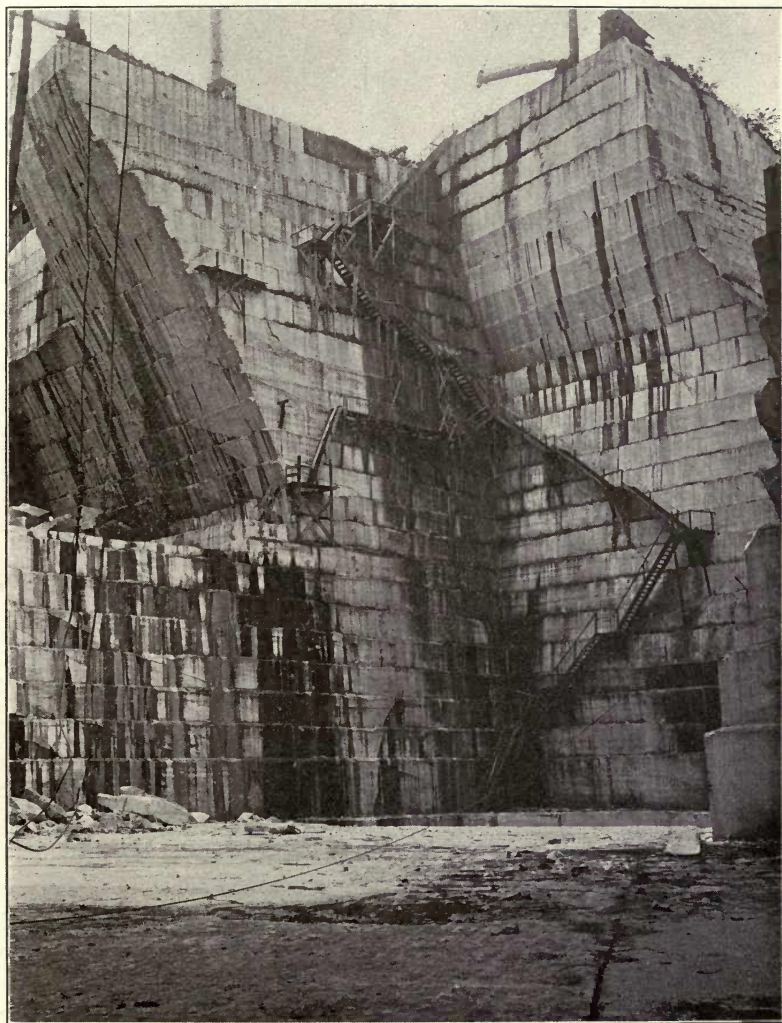
PLATE XVIII. — Marble quarry, Proctor, Vt. The banding of the rock is vertical
The horizontal lines are caused by the stone being quarried in benches.
(*Photo., Vermont Marble Co.*)

(155)

Though found in a number of states, most of the numerous attempts to quarry American serpentine have been unsuccessful. Considerable serpentine for ordinary structural work has been quarried in Chester County, Pennsylvania, and a variety known as verdolite has been worked near Easton, Pennsylvania (32). Quarrying operations have also been carried on in the state of Washington (48), Maryland and Georgia.

## SANDSTONES

**General Properties** (1, 9). — While most sandstones are composed chiefly of quartz grains, some varieties contain an abundance of other minerals, such as mica, or, more rarely, feldspar, which in rare cases may even form the predominating mineral. Pyrite is occasionally present, and varying amounts of clay frequently occur between the grains, at times in sufficient quantity to materially influence the hardness and dressing qualities of the stone. The hardness of sandstones, however, usually depends on the amount and character of the cement, varying from those having so small an amount of silica or iron oxide cement that the stone crumbles in the fingers to those quartzites whose grains are so firmly bound by silica that the rock resembles solid quartz. With these differences the chemical composition varies from nearly pure silica to sandstone with a large percentage of other compounds. (For analyses, see Kemp's " Handbook of Rocks.")

There are many colors among sandstones, but light gray, white, brown, buff, bluish gray, red, and yellow are most common. In density sandstones range from the nearly impervious quartzites to the porous sandrocks of recent geologic formations, and consequently they show a variable absorption. Most sandstones contain some quarry water, and those with appreciable amounts are softer and more easy to dress when first quarried; but they cannot be quarried in freezing weather. The average specific gravity of sandstone is 2.7, and accordingly a cubic foot weighs about 160 to 170 pounds.

On the whole, sandstones resist heat well and are usually of excellent durability, since they contain few minerals that decompose easily. When they disintegrate, it is commonly by frost action. The injurious minerals are pyrite, mica, and clay. Pyrite is likely to cause discoloration on weathering; the presence of much mica may cause the stone to scale off if set on edge; and clay may cause injury to the stone in freezing weather on account of its capacity for absorbing moisture. A slight quantity of clay, however, makes

PLATE XIX



FIG. 1. — Marble quarry, Pickens County, Ga.   (*Photo. loaned by S. W. McCallie.*)
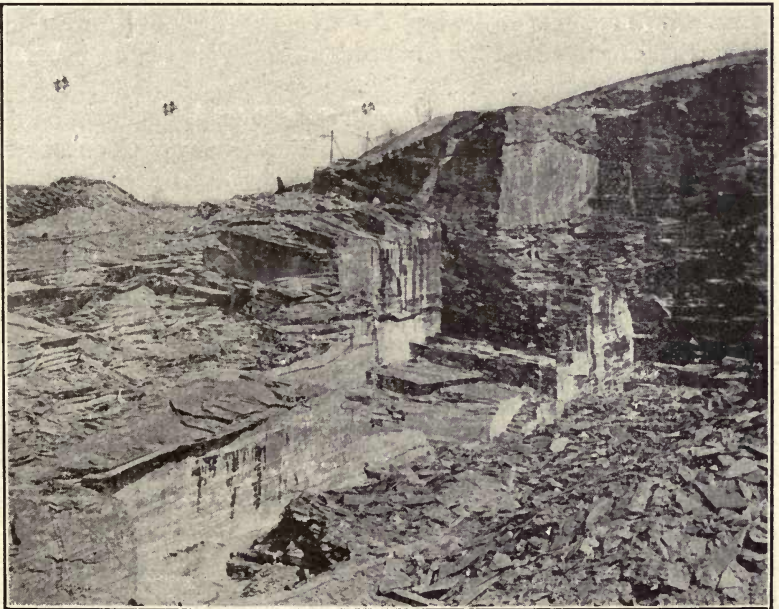


FIG. 2. — Slate quarry at Penrhyn, Pa.   (*H. Ries, photo.*)
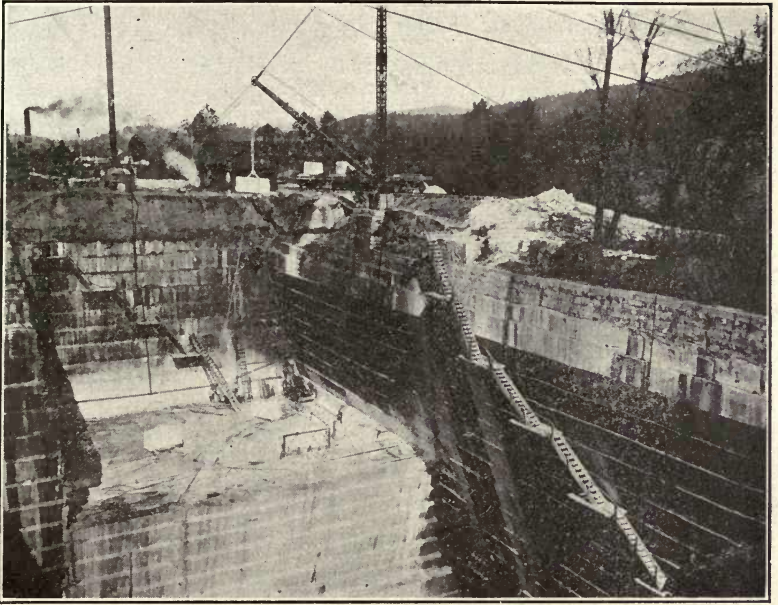
(157)

the stone easier to dress. The value of a sandstone is often lessened by careless quarrying, or by placing it on edge in the building, thus exposing the bedding planes to the entrance of water.

**Varieties of Sandstone.** — With an increase in the size of their grains, sandstones pass into conglomerates on the one hand and with an increase in clay into shales. By an increase in the percentage of carbonate of lime they may also grade into limestones.

On account of these variations, as well as the difference in color and the character of the cement, a number of varieties of sandstone are recognized, of which the following are of economic value: *arkose*, a sandstone composed chiefly of feldspar grains; *bluestone*, a flagstone much quarried in New York; *brownstone*, a term formerly applied to sandstones of brown color, obtained from the eastern Triassic belt, and since stones of other colors are now found in the same formation, the term has come to have a geographic meaning and no longer refers to any specific physical character; *flagstone*, a thinly bedded, argillaceous sandstone used chiefly for paving purposes; *freestone*, a sandstone which splits freely and dresses easily.

**Distribution of Sandstones in the United States.** — Sandstones occur in all formations from pre-Cambrian to Tertiary. They are so widely distributed that for local supply there are numerous small quarries in many states, but there are several areas which have been operated on an extensive scale, some of them for many years. Of these, one of the best known is the Triassic Brownstone belt, which extends from the Connecticut Valley, in Massachusetts, southwestward into North Carolina.

This is a red, brown, or even bluish sandstone, of moderate hardness, and somewhat variable texture. That from the Connecticut Valley district was formerly used in enormous quantities.

Among the Paleozoic strata there are many sandstones, often massive, and usually dense and hard. Of these the Medina and Potsdam are specially important and much quarried in New York State (34, 35). The same formations extend southward along the Appalachians and are available at several points. Devonian flagstones are extensively quarried at several localities in New York and Pennsylvania. At the present time the Lower Carboniferous Berea sandstone of Ohio (37) is in great demand because of its light color, even texture, and the ease with which it is worked. Moreover, it has the peculiar property of changing to a uniform buff on exposure to the air. There are numerous other Paleozoic sandstones in the central states, among them the Potsdam, which covers a wide area in Michigan and Wisconsin (51). Some of this stone is bright red in color.

The Mesozoic and Tertiary strata of the West contain an abundance of good sandstone, and quarries opened in many of them yield a durable quality of stone. Though usually less dense and hard than the Paleozoic sandstones, they serve admirably for buildings in the mild or dry climates of the West.

**Uses of Sandstones.** — The wide distribution of sandstones makes them an important source of local structural material. They are chiefly used for ordinary building work, and but little for massive masonry or monuments. The thin-bedded flagstones are much used for flagging, and some of the harder sandstones are split up for paving blocks. For other uses, see Abrasives.

## SLATES

**General Characteristics** (9, 25). — Slates are metamorphic rocks derived from clay or shale or more rarely from igneous rocks (14). Their value depends upon the presence of a well-defined plane of splitting, called *cleavage* (Fig. 57), developed by metamorphism through the rearrangement and flattening of the original mineral grains and the development of micaceous minerals. The cleavage usually develops at a variable angle to the bedding planes which are often completely obliterated by the metamorphism. When not com-
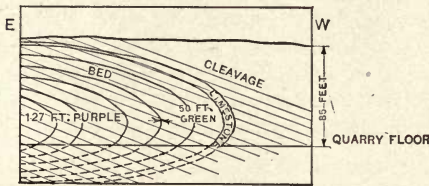


Fig. 57. — Section showing cleavage and bedding in slate. (*After Dale, U. S. Geol. Surv., 19th Ann. Rept., III.*)

pletely destroyed, the bedding planes are marked by parallel bands, called ribbons, cutting across the planes of cleavage, but so perfect is the cleavage in the best slates that the rock readily splits into thin sheets with a smooth surface.

Slates are commonly so fine grained that the mineral composition is not evident to the eye, but the microscope reveals the presence of many of the varied mineral grains found in shale, and in addition much chlorite, developed by metamorphism. Owing to the presence of carbonaceous particles, most slates are black or bluish black, but green, purple, and red slates are also known. The specific gravity of slate is about 2.7, and a cubic foot weighs between 170 and 175 pounds.

Most slates are fairly durable, though the presence of pyrite

along the ribbons may lead to their decay.  Lime carbonate if
present in any quantity is injurious, and if the slate is to be used
for switchboards, it should be as free
from magnetite grains as possible.
Some colored slates fade on exposure to
the weather, but this change, which is
due to the bleaching of certain mineral
grains, does not necessarily result in loss
of strength or disintegration.



Fig.  58. — Section in slate
quarry with cleavage paral-
lel to bedding.  *a*, purple
slate; *b*, unworked; *c* and *d*,
variegated; *e* and *f*, green; *g*
and *h*, gray-green; *i*, quartz-
ite;  *j*, gray with black
patches.  (*After Dale.*)

In slate quarrying it is of importance to
distinguish between bedding and cleavage.
The following criteria may be used (43*a*).
Quartzite and limestone bands of some per-
sistence indicate bedding, but care must be
taken not to mistake vein quartz for quartz-
ite.   Fossil impressions are always on the
bed surface.  A microscopic section, trans-
verse to cleavage, may be used, if other
means fail, to indicate divergence between
bedding and cleavage, although in some places the two may agree.

Special tests are necessary for determining the quality of slate.  They
include the determination of its sonorousness, cleavability, abrasive resist-
ance, absorption, elasticity, and presence of injurious minerals.  The chemi-
cal analysis is of limited value, but Merriman concludes that the strongest
slate runs highest in silica and alumina but not necessarily lowest in lime
and magnesium carbonates.

Dale divides slates into the following groups:
I. Aqueous sedimentary.
   A. Clay slates: cemented by clay, lime carbonate, or magnesium
      carbonate.  Fissility, strength, and elasticity low.
   B. Mica slates: 1. fading; with sufficient iron carbonate to dis-
      color on exposure.   2. Unfading; without sufficient iron
      carbonate to produce any but very slight discoloration on
      prolonged exposure.
   Under each group we may have the following types: Graphitic
      (gray-black); chloritic (greenish); hematitic and chloritic (pur-
      plish).  The second group may also include hematitic (reddish).
II. Igneous.
   A. Ash slates.
   B. Dike slates.

**Distribution of Slates in the United States** (Fig. 59). — Since
slates are of metamorphic origin, they are limited to those regions
in which the rocks are metamorphosed, and at present the greater
part of our supply comes from the Cambrian and Silurian strata of
the eastern crystalline belt of the Atlantic states.
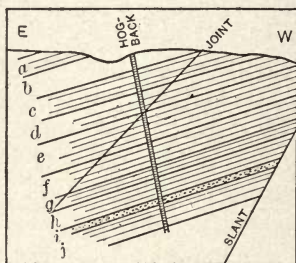
● Productive districts
■ Prospective deposits

A series of quarries producing, red, green, purple, and variegated slates are located in a belt of Cambrian and Hudson River strata along the border of New York (33) (Pl. XX) and Vermont (33, 45).

Black slates are quarried in Maine (3), New Jersey (32), Pennsylvania (3), (Pl. XIX, Fig. 2), Maryland (26), Georgia (3), and Virginia (46). Other producing states are Minnesota, California (14, 43a), and Arkansas (12).

**Uses of Slate.** — Slate is best known as a roofing material, but it is also used for mantels, billiard-table tops, floor tiles, steps, flagging, slate pencils, acid towers, washtubs, etc. The process of marbleizing slates for mantles and fireplaces was formerly carried on at several localities.

In quarrying slate there is from 60 to 80 per cent waste, which is greater than in any other building stone; but the introduction of channeling machines in quarrying has done much to reduce this. The discovery of a use for this waste has been an important problem, which has thus far been only partially solved. It is sometimes ground for paint, and attempts have been made to utilize it in the manufacture of bricks and Portland cement.

**Building Stones in Canada** (52a). — The Canadian building stones are developed chiefly in the eastern provinces, including Ontario, and in the far West, as along the Pacific Coast.

**Igneous Rock** (52a). — Nova Scotia and New Brunswick contain a number of granite areas, yielding stone of varying texture and color, the red variety quarried near St. George, N. B., being well known. There is also considerable local development around Halifax. Nova Scotia has much fine-grained, dense volcanic rock, susceptible of decorative use. Some diorite and diabase for monumental work is also quarried in New Brunswick.

In Quebec granites and gneisses are worked at scattered points in the northern area, but the gray granite of the Stanstead district in the eastern townships is the best known, while so-called black granite (essexite) for monumental purposes is quarried in the Monteregian Hills.

Ontario granites and gneisses though abundant are little developed.

Not a little granite is quarried along the Pacific Coast north of Vancouver, and the andesite from Vancouver Island is quite extensively used.
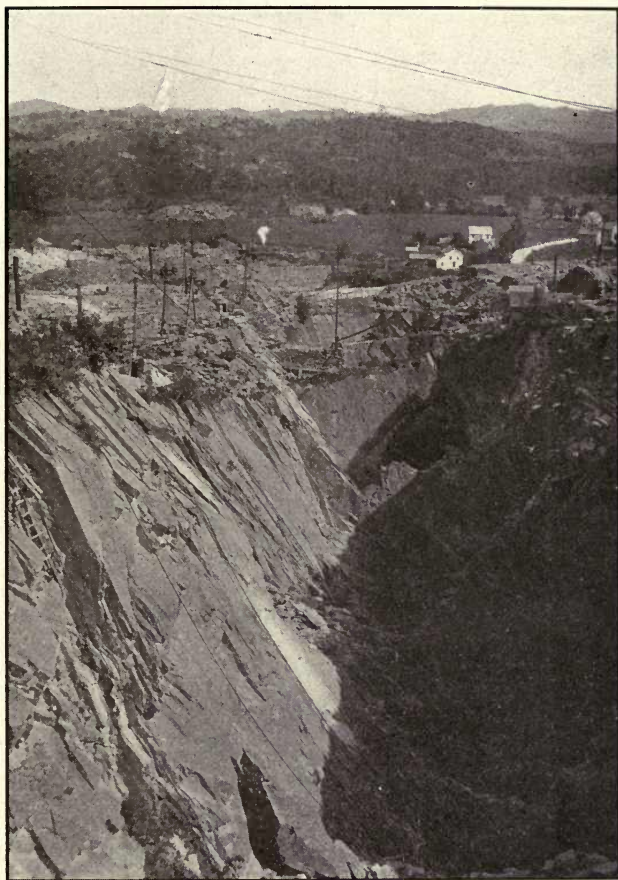
PLATE XX. — View of green-slate quarry, Pawlet, Vt.   (*Photo. by H. Ries.*)

(163)

**Limestones.** — Limestones of Paleozoic age are extensively quarried in Quebec, notably around Montreal and Hull, and at many points in southern Ontario. West of Winnipeg a peculiar mottled limestone is quarried, and much used in Manitoba.

**Sandstones.**—The Carboniferous sandstones of New Brunswick and Nova Scotia, and the Ordovician and Silurian sandstones of Quebec and Ontario have been developed at many points. Occasionally sandstone deposits are worked in the Cretaceous and Tertiary beds of the Western Provinces, and also on Vancouver Island.

**Marble.** — Highly decorative marbles of pre-Cambrian age are quarried at South Stukely, Quebec. Paleozoic ones of gray and green color, with veins and cloudings, are obtained near Phillipsburg in the same province. Crystalline limestones are abundant in Ontario, but the best known variegated marble is that quarried near Bancroft. A gray and white marble is obtained in the Kootenay district of British Columbia.

**Slate.** — Little good slate is obtained in the Dominion, this coming from the eastern townships of Quebec.

*Other Foreign Building Stones.* — Granites are quarried at a number of localities in Europe, but those exported to the United States, and used more or less for monumental purposes, come chiefly from Scotland and Sweden.

Of the many foreign sandstones quarried, the bright-red Scotch ones have been used in some quantity in the United States.

Volcanic tuffs are widely distributed and abundantly used in central Mexico, and these, together with lava rock, have been frequently quarried in Italy, the Auvergne region of France, and even other localities.

The roofing slates found in the Cambrian and Ordovician of North Wales are among the best known deposits of the world.

Many limestones are quarried, especially in the post-Carboniferous formations. Among these may be mentioned the Portland stone of the Jurassic on the Isle of Portland, near Weymouth, and the soft French limestones, of which the Caen stone, often used in America for interior work, are well known. Another soft, but dense limestone, capable of taking a polish, and frequently employed here, is that of Hauteville, France.

Marbles of great beauty are quarried in many foreign countries, and widely exported. Among the best known are: White statuary marble from Carrara, Italy; yellow, black-veined Sienna, and whitish, veined Pavonazzo, from the same country; Skyros breccia from Greece; Griotte or red from France; Parian white from Greece; banded Cippolino from Switzerland, and a host of others. Many of them are of highly decorative character, but of low weather-resisting qualities.

The same is true of the beautiful serpentine marbles, which may be obtained from Ireland, Italy, and Greece.

**Production of Building Stones.** — The production of building stones by kinds for the last 5 years was as follows:—

PRODUCTION OF BUILDING STONES IN THE UNITED STATES FROM 1910 TO 1914

| KIND. | 1910 | 1911 | 1912 | 1913 | 1914 |
|---|---|---|---|---|---|
| Granite . . . | $20,541,967 | $21,194,228 | $19,223,302 | $20,733,217 | $20,028,919 |
| Trap rock . . | 6,452,141 | 6,739,141 | 7,560,049 | 9,134,494 | 7,865,998 |
| Sandstone [1] . . | 7,930,019 | 7,730,868 | 6,893,611 | 7,248,965 | 7,501,808 |
| Marble . . . | 6,992,779 | 7,546,718 | 7,786,458 | 7,870,890 | 8,121,412 |
| Limestone . . | 34,603,678 | 33,897,612 | 36,729,800 | 38,745,429 | 33,894,155 |
| Slate . . . . | 6,236,759 | 5,728,019 | 6,043,318 | 6,175,476 | 5,706,787 |
| Total . . . | $82,757,343 | $82,836,586 | $84,236,538 | $89,908,471 | $83,119,079 |

[1] Includes bluestone.

It should be noted that the stone statistics compiled by the United States Geological Survey include not only building stone, but stone used for monuments, road material, etc. Some idea of the quantity used for each of these purposes can be gained from the following table:

VALUE OF STONE USED FOR DIFFERENT PURPOSES IN 1914

| KINDS. | BUILDING (ROUGH AND DRESSED). | MONU-MENTAL (ROUGH AND DRESSED). | FLAG-STONE. | CURB-STONE. | PAVING STONE. | CRUSHED STONE. |
|---|---|---|---|---|---|---|
| Granite . . . | $6,481,091 | $4,744,088 | $ 13,849 | $760,952 | $2,831,568 | $ 3,975,575 |
| Trap rock . . | 45,134 | ——— | ——— | ——— | 112,246 | 6,225,805 |
| Sandstone . . | 1,825,179 | ——— | 519,957 | 988,317 | 713,692 | 1,898,505 |
| Limestone . . | 3,896,854 | ——— | 7,134 | 120,407 | 114,877 | 18,061,881 |
| Marble [1] . . . | 5,548,294 | 2,303,484 | ——— | ——— | ——— | ——— |
| Total . . . | $17,796,552 | $7,047,572 | $540,940 | $1,869,676 | $3,772,383 | $30,161,766 |

[1] Marble for both exterior and interior building.

The value of the building stones produced by the several more important states, together with the kind of stone produced chiefly in 1914, is given below:—

PRODUCTION OF BUILDING STONES IN CANADA 1911 TO 1914

| KIND. | 1911 | 1912 | 1913 | 1914 |
|---|---|---|---|---|
| Granite . . . . . | 1,119,865 | 1,373,119 | 1,653,791 | $2,179,930 |
| Limestone . . . . | | 2,762,936 | 3,204,091 | 2,730,430 |
| Marble . . . . . | 162,783 | 260,764 | 249,975 | 192,533 |
| Sandstone . . . . | | 329,352 | 396,782 | 490,584 |

PRODUCTION OF BUILDING STONES IN MORE IMPORTANT STATES IN 1914

| STATE. | TOTAL VALUE. | PER CENT OF TOTAL, U. S. PRODUCTION. | KIND PRODUCED CHIEFLY. |
|---|---|---|---|
| Pennsylvania. | $8,153,413 | 10.53 | Limestone |
| Vermont | 6,635,477 | 8.57 | Marble and Granite |
| New York | 6,575,079 | 8.49 | Limestone |
| Ohio | 5,655,713 | 7.13 | Limestone |
| California. | 4,610,781 | 5.96 | Granite |
| Indiana | 4,136,132 | 5.34 | Limestone |
| Massachusetts | 3,438,556 | 4.44 | Granite |
| Illinois. | 2,934,078 | 3.79 | Limestone |
| Wisconsin | 2,413,435 | 3.12 | Granite |
| Missouri | 2,294,103 | 2.96 | Limestone |
| Georgia | 2,238,789 | 2.89 | Marble and granite |
| Virginia | 2,152,378 | 2.78 | Limestone |
| Tennessee | 1,932,462 | 2.50 | Marble |
| Maine | 1,723,032 | 2.23 | Granite |
| Washington | 1,600,615 | 2.07 | Trap |

IMPORTS OF STONE INTO THE UNITED STATES IN 1913 AND 1914

| KIND. | 1913 | 1914 |
|---|---|---|
| Marble: | | |
| In block, rough, etc. | $1,024,595 | $878,284 |
| Sawed or dressed | 606 | ——— |
| Slabs or paving tiles | 50,788 | 62,828 |
| All other manufactures | 242,674 | 153,920 |
| Mosaic cubes (loose) | 48,944 | 30,566 |
| Attached to paper | ——— | 1,541 |
| Total | $1,367,607 | $1,127,139 |
| Onyx: | | |
| In blocks, rough, etc. | 34,518 | 31,368 |
| All other manufactures | 1,803 | 2,026 |
| Total | $ 36,321 | $ 33,394 |
| Granite: | | |
| Dressed | 110,451 | 155,777 |
| Rough | 5,074 | 2,280 |
| Total | $ 115,525 | $158,057 |
| Stone (other): | | |
| Dressed | 23,422 | 15,944 |
| Rough | 63,260 | 25,978 |
| Rough (other) | 9,017 | 28,911 |
| Total | $95,699 | $70,883 |
| Grand Total | $1,615,152 | $1,389,473 |

*Exports and Imports.* — The following figures show the value of the exports for the years 1913 and 1914:

EXPORTS OF STONE FROM THE UNITED STATES IN 1913 AND 1914

| KIND | 1913 | 1914 |
|---|---|---|
| Marble and stone, unmanufactured . . . . . | $ 606,745 | $ 559,556 |
| All others . . . . . . . . . . . . . . | 1,250,147 | 803,686 |
| Total . . . . . . . . . . . . . . | $1,856,892 | $1,363,242 |

The exports from Canada in 1914 were: Ornamental stone, 231 tons, valued at $5,607; and building stone, 63,009 tons, valued at $46,198.

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# CHAPTER IV

## CLAY

**Definition.** — Clay may be defined as an earthy substance of fine texture containing a mixture of hydrous aluminum silicates, with fragments of other minerals, such as silicates, oxides, carbonates, etc., and colloidal material which may be of either organic or mineral character. The mass possesses plasticity (usually) when wet, and becomes rock-hard when fired to at least a temperature of redness.

Two important classes of clays are the residual and the transported ones.

**Residual Clays** (8). — Clays are derived primarily and principally from the decomposition of crystalline rocks, more especially feldspathic varieties, and deposits thus formed will be found overlying the parent rock and often grading down on to it. From its method of origin and position it is termed a *residual clay* (Fig. 60).
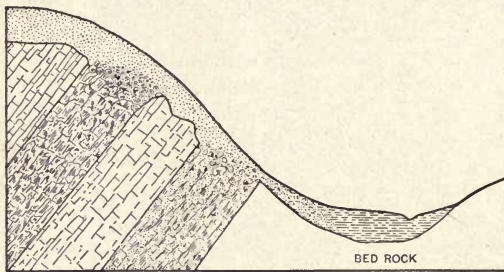


FIG. 60. — Section showing formation of residual clay. (*After Ries, U. S. Geol. Surv., Prof. Pap.* 11.)

All residual clays probably contain a variable amount of kaolinite (8) or clay substance. This mineral, which is white in color, results from the decomposition of feldspar, either by weathering, or, less often, by the action of volcanic vapors. The decay of a large mass of pure feldspar would therefore yield a mass of white clay, but, in most instances, the feldspar is associated with other minerals, such as quartz, mica, and hornblende, all of which, except the quartz, and muscovite, decay with greater or less rapidity, and some of these, such as the hornblende, may likewise yield a hydrous aluminum silicate. Any ferruginous minerals in the rock will, in decomposing, yield limonite, which stains the mass.

Large masses of pure feldspar are rare, but feldspathic rocks, such as granite or syenite, are more common, and these will also decompose to clay; but, since the parent rock contains other minerals, such as quartz or mica, these will either remain as sand grains in the clay, or, by decom-

position, will form soluble compounds, or iron stains. Sedimentary rocks as well as crystalline ones may produce residual clay. That derived from limestone is the insoluble clayey impurities left after the carbonates are dissolved.

The extent of a deposit of residual clay will depend on the extent of the parent rock and the topography of the land, which also influences its thickness. On steep slopes much of the clay may be washed away; and residual clays are also rare in glaciated regions, for the reason that they have been swept away by the ice erosion. They are consequently wanting in most of the Northern states, but abundant in many parts of the Southern states, where the older formations appear at the surface.

**Transported Clays** (8). — With the erosion of the land surface the particles of residual clay become swept away to lakes, seas, or the ocean, where they settle down in the quiet water as a fine aluminous sediment, forming a deposit of *sedimentary clay* (Fig. 61). Such beds are often of great thickness and vast extent. With the accumula-



Fig. 61. — Section of a sedimentary clay deposit.
(*After Ries, U. S. Geol. Surv., Prof. Pap.* 11.)

tion of many feet of other sediments on top of them, they become consolidated either by pressure or by the deposit of a cement around the grains. Consolidated clay is termed *shale*, and this upon being ground and mixed with water often becomes as plastic as an unconsolidated clay.

Residual materials may also have been transported by wind or glacial action, to form clayey deposits.

The following are important types of transported clays: —

*Marine Clays.* — Formed by the deposition on the ocean floor of the finer particles derived from the waste of the land. Such ancient sea-bottom clays have been elevated to form dry land in all the continents, in many cases forming consolidated clay strata, but elsewhere, especially in coastal plains, in unconsolidated condition. Extensive clay deposits are also formed in protected estuaries and lagoons along the seacoast.

*Flood-plain Clays.* — Formed by the deposition of clayey sediment on the lowlands bordering a river during periods of flood. Layer upon layer, this deposit builds a flood plain often of great extent and depth. Such areas of flood-plain clays are most extensive along the greater rivers and in the deltas which they have built in the sea.

*Lake Clays.* — Clay is deposited on the bottom of many lakes and ponds in the same manner as on the ocean bottom. Where the streams
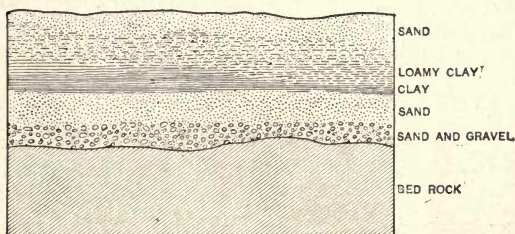
bring only fine particles the filling of a lake may be entirely of clay. Many lakes have been either drained or completely filled and their clays therefore made available. This is especially true of small, shallow lakes formed during the Glacial Period.

*Glacial Clays*, commonly known as till or bowlder clay, a rock flour ground in the glacial mill in which rock fragments were worn down to clay by being rubbed together or against the bed rock over which the ice moved. When the ice melted, this deposit was left in a sheet of varying thickness and characteristics over a large part of the area which the ice covered. It is not always, strictly speaking, a sedimentary deposit.

*Æolian Clays.* — Wind drifts dry clay about, and in favorable positions causes its accumulation in beds. This is true of the Chinese loess, a wind-blown deposit derived from residual soils and drifted about in the arid climate of interior China. Some at least of the loess clays of the Mississippi Valley seem to have a similar origin, the source of the clay being glacial deposits; in other cases loess seems to be a water deposit either in shallow lakes or else in broad, slowly moving streams.

**Properties of Clay.** — These are of two kinds, physical and chemical, and since they exercise an important influence on the behavior of the clay, the most important ones may be described.

*Physical Properties* (8, 1). — These include plasticity, tensile strength, air and fire shrinkage, fusibility, and specific gravity.

*Plasticity* may be defined as the property which clay possesses of forming a plastic mass when mixed with water, thus permitting it to be molded into any desired shape, which it retains when dry. This is an exceedingly important character of clay. Clays vary from exceedingly plastic, or "fat" ones, to those of low plasticity which are "lean" and sandy. Plasticity is probably due in part to fineness of grain, and in part to the presence of colloids (1, 6a, 8).

*Tensile strength* is the resistance which a mass of air-dried clay offers to rupture, and is probably due to interlocking of the particles and set colloids. Tests show that the tensile strength of clays varies from 15 to 20 pounds per square inch up to 400 pounds or more per square inch. Many common brick clays range from 100 to 200 pounds.

*Shrinkage* is of two kinds — air shrinkage and fire shrinkage. The former takes place while the clay is drying after being molded, and is due to the evaporation of the water, and the drawing together of the clay particles. The latter occurs during firing, and is due to a compacting of the mass as the particles soften under heat. Both are variable. In the manufacture of most clay products an average total shrinkage of about 8 or 9 per cent is commonly desired. Excessive air or fire shrinkage causes cracking or warping of the clay. To prevent this a mixture of clays is often used.

*Fusibility* is one of the most important properties of clays. When subjected to a rising temperature, clays, unlike metals, soften slowly, and hence fusion takes place gradually. In fusing, the clay passes through three stages, termed, respectively, incipient fusion, vitrification, and viscosity.

In the lower grades of clay, that is, those having a high percentage of fluxing impurities, incipient fusion may occur at about 1000° C., while in refractory clays, which are low in fluxing impurities, it may not occur until 1300° or 1400° C. is reached. The temperature interval between incipient fusion and vitrification may be as low as 30° C. in calcareous clays, or as much as 200° C. in some others. The recognition of this variation is of considerable practical importance, and vitrified products, such as paving bricks and stoneware, have to be made from a clay in which the three stages of fusion are separated by a distinct temperature interval. The importance of this rests on the fact that it is impossible to control the temperature of a large kiln within a few degrees, and there must be no danger of running into a condition of viscosity in case the clay is heated beyond its point of vitrification.

*Specific gravity* varies commonly from about 1.70 to 2.30.

*Chemical Properties* (8). — The number of common elements which have been found in clays is great, and even some of the rarer ones have been noted; but in a given clay the number of elements present is usually small, being commonly confined to those determined in the ordinary chemical analyses, which show their existence in the clay, but not always the state of the chemical combination. The common constituents of a clay are silica, alumina, ferric or ferrous oxide, lime, magnesia, alkalies, titanic acid, and combined water. Organic matter, and sulphur trioxide, though often present, are usually in small amounts. Carbon dioxide is always found in calcareous clays. The effect of these may be noted briefly.

*Silica* if present in the form of quartz or other crystalline grains, aids in lowering the plasticity and shrinkage at low temperatures. Silica in colloidal form probably increases the plasticity (6a). *Alumina,* which is most abundant in white clays, is a refractory ingredient. *Iron oxide* acts as a coloring agent in both the raw and burned clay, small quantities usually coloring a burned clay buff, and larger amounts (4 to 7 per cent), if evenly distributed, turning it red. It also acts as a flux in burning. Whatever the iron compound present in the raw clay it changes to the oxide in burning. *Lime, magnesia,* and *alkalies* are also fluxing ingredients of the clay. The combined percentage of fluxing impurities is small in a refractory clay, and often high in a low-grade one. Lime, if present in considerable excess over the iron, will, in burning, exert a bleaching effect on the latter. For this reason, highly calcareous clays, such as those in the Great Lake region, burn cream or buff. When lime is present in large amounts, it also causes clay to soften more rapidly in firing than it otherwise would.

*Chemically combined water* passes off chiefly between 450° and 650° C., and carbonaceous matter mostly between 800° and 900° C. This loss leaves the clay temporarily porous until fire shrinkage sets in. *Titanic acid,* though rarely exceeding 1 per cent, acts as a flux at high temperatures at

least. *Sulphur trioxide* is rarely present in sufficiently high amounts to interfere with the successful burning of the clay.

Carbon colors a raw clay gray or black, and several per cent may give much trouble in burning, unless driven out of the clay before it becomes dense.

*Chemical Composition.* — As might be expected from their diverse modes of origin, clays vary widely in their chemical composition. There is every gradation from those which, in composition, closely resemble the mineral kaolinite, to those, like ordinary brick clays, in which there is a high percentage of impurities. This variation is shown in the opposite table.

The absence of ferrous oxide, titanic oxide, sulphur trioxide, organic matter, and manganous oxide in many of the analyses (p. 175) does not necessarily indicate their non-existence in these clays. Probably all contain at least small percentages of these substances, but they are rarely determined.

**Classification of Clay.** — It is possible to base a classification of clays either on origin, chemical and physical properties, or uses. But since the subdivisions which can be made are not sufficiently distinct, each of these gives rise to a more or less unsatisfactory grouping. The following classification is based partly on mode of origin and partly on physical characters (8): —

A. Residual clays. (By decomposition of rocks *in situ*.)

    I. Kaolins or china clays (white-burning).

        (*a*) Veins, derived from pegmatite, rhyolite, etc.

        (*b*) Blanket deposits, from areas of igneous or metamorphic rocks.

        (*c*) Pockets in limestone, as indianaite (24). (Origin doubtful.)

        (*d*) Bedded deposits from feldspathic sandstones.

    II. Red-burning residuals, derived from different kinds of rocks.

B. Colluvial clays, representing deposits formed by wash from the foregoing, and of either refractory or non-refractory character.

C. Transported clays.

    I. Deposited in water.

        (*a*) Marine clays or shales. Deposits often of great extent.
            White-burning clays. Ball clays and plastic kaolins.
            Fire clays or shales. Buff-burning.
            Impure clays or shales. $\begin{cases} \text{Calcareous.} \\ \text{Non-calcareous.} \end{cases}$

        (*b*) Lacustrine clays (deposited in lakes or swamps).
            Fire clays or shales.
            Impure clays or shales, red-burning.
            Calcareous clays, usually of surface character.

        (*c*) Flood-plain clays. Usually impure and sandy.

        (*d*) Estuarine clays (deposited in estuaries). Mostly impure and finely laminated.

ANALYSES SHOWING VARIATION IN COMPOSITION OF CLAYS

|  | I | II | III | IV | V |
|---|---|---|---|---|---|
| Silica (SiO$_2$) . . . . . . . . | 46.3 | 45.78 | 57.62 | 59.92 | 68.62 |
| Alumina (Al$_2$O$_3$) . . . . . . | 39.8 | 36.46 | 24.00 | 27.56 | 14.98 |
| Ferric oxide (Fe$_2$O$_3$) . . . . | — | .28 | 1.9 | 1.03 | 4.16 |
| Ferrous oxide (FeO) . . . . | — | 1.08 | 1.2 | — | — |
| Lime (CaO) . . . . . . . | — | .50 | .7 | tr | 1.48 |
| Magnesia (MgO) . . . . . | — | .04 | .3 | tr | 1.09 |
| Potash (K$_2$O) . . . . . . | — | .25 | .5 | .64 | 3.36 |
| Soda (Na$_2$O) . . . . . . | — | | .2 | | |
| Titanic oxide (TiO$_2$) . . . . | — | — | — | — | — |
| Water (H$_2$O) . . . . . . | 13.9 | 13.40 | 10.5 | 9.70 | 3.55 |
| Moisture . . . . . . . | — | 2.05 | 2.7 | 1.12 | 2.78 |
| Carbon dioxide (CO$_2$) . . . . | — | — | — | — | — |
| Sulphur trioxide (SO$_3$) . . . | — | — | .35 | — | — |
| Organic matter . . . . . . | — | — | — | — | — |
| Manganous oxide (MnO) . . | — | — | — | — | .64 |
| Total . . . . . . . . . | 100.00 | 99.84 | 99.97 | 99.97 | 100.66 |

|  | VI | VII | VIII | IX | X |
|---|---|---|---|---|---|
| Silica (SiO$_2$) . . . . . . . | 82.45 | 54.64 | 38.07 | 90.00 | 47.92 |
| Alumina (Al$_2$O$_3$) . . . . . | 10.92 | 14.62 | 9.46 | 4.60 | 14.40 |
| Ferric oxide (Fe$_2$O$_3$) . . . . | 1.08 | 5.69 | 2.70 | 1.44 | 3.60 |
| Ferrous oxide (FeO) . . . . | — | — | — | — | — |
| Lime (CaO) . . . . . . . | .22 | 5.16 | 15.84 | .10 | 12.30 |
| Magnesia (MgO) . . . . . | .96 | 2.90 | 8.50 | .10 | 1.08 |
| Potash (K$_2$O) . . . . . . | — | 5.89 | 2.76 | tr. | 1.20 |
| Soda (Na$_2$O) . . . . . . | — | | | tr. | 1.50 |
| Titanic oxide (TiO$_2$) . . . . | 1.00 | — | — | .70 | 1.22 |
| Water (H$_2$O) . . . . . . | 2.4 | 3.74 | 2.49 | 3.04 | 4.85 |
| Moisture . . . . . . . | — | .85 | | — | — |
| Carbon dioxide (CO$_2$) . . . | — | 4.80 | 20.46 | — | 9.50 |
| Sulphur trioxide (SO$_3$) . . . | — | — | — | — | 1.44 |
| Organic matter . . . . . | — | — | — | — | 1.34 |
| Manganous oxide (MnO) . . | — | .76 | — | — | — |
| Total . . . . . . . . . | 99.03 | 99.05 | 100.28 | 99.98 | 100.35 |

I. Kaolinite.

II. Washed kaolin, Webster, N. Ca.

III. Plastic fire clay, St. Louis. Mo.

IV. Flint fire clay, Salineville, O.

V. Loess clay, Guthrie Center, Ia.

VI. Pressed-brick clay, Rusk, Tex.

VII. Brick shale, Mason City, Ia.

VIII. Calcareous brick clay, Milwaukee, Wis.

IX. Sandy brick clay, Colmesneil, Tex.

X. Blue shale clay. Ferris, Tex.

K

II. Glacial clays, found in the drift, and often stony. May either be red- or cream-burning.

III. Wind-formed deposits (some loess).

D. Chemical deposits (some flint clays?).

**Kinds of Clays.** — Many kinds of clays are known by special names, which in some cases indicate their use, but in others refer partly to certain physical properties. The more important ones are the following : —

*Adobe.* A sandy, often calcareous, clay used in the west and south-west for making sun-dried brick. *Ball clay.* A white-burning, plastic, sedimentary clay, employed by potters to give plasticity to their mixture. *Brick clay.* Any common clay suitable for making ordinary brick. *China clay.* A term applied to kaolin (*q.v.*). *Earthenware clay.* Clay suitable for the manufacture of common earthenware, such as flower pots. *Fire clay.* A clay capable of resisting a high degree of heat. *Flint clay.* A peculiar flint-like fire clay, which when ground up and wet develops no plasticity. Chemically, it differs but little, if at all, from the plastic fire clays. Moreover, the two often occur in the same bed, either in separate layers or irregularly mixed. *Gumbo.* A very sticky, highly plastic clay, occurring in the central states, and used for making burned-clay ballast (2). *Kaolin.* A white-burning residual clay, employed chiefly in manufacture of white earthenware and porcelain. The term is also applied by some to the white-burning sedimentary clays of Georgia and South Carolina. *Loess.* A sandy, calcareous, fine-grained clay, covering thousands of square miles in the central states, and of wide use in brick making. *Paper clay.* Any fine-grained clay, of proper color, that can be employed in the manufacture of paper. *Pipe clay.* A loosely used term applied to any smooth plastic clay. Strictly speaking, it refers to a clay suited to the manufacture of sewer pipe. *Pot clay.* A dense-burning fire clay, used in the manufacture of glass pots. The domestic supply comes mainly from St. Louis, Missouri, but much is imported. *Pottery clay.* Any clay suitable for the manufacture of pottery. *Retort clay.* A plastic fire clay, used in making gas retorts. The term is a local one used chiefly in New Jersey. *Sagger clay.* A loose term applied to clays employed in making saggers; they are of value for other purposes as well. *Sewer-pipe clay.* A term applicable to any clay that can be used for manufacture of sewer-pipe. It is usually vitrifiable and red-burning. *Slip clay.* Under this term are included those clays which are easily fusible, and form a natural glaze, when applied to ware (such as stoneware) and burned at the proper temperature. The best-known variety comes from Albany, N. Y. *Stoneware clay.* A very plastic clay, which burns to a vitrified or stoneware body. It may be refractory. *Terra-cotta clay.* Clay suitable for the manufacture of terra cotta. The term has no special significance, as a wide variety of clays are adapted to this purpose.

**Geological Distribution.** — Clays have a wider distribution than most other economic minerals or rocks, being found in all forma-
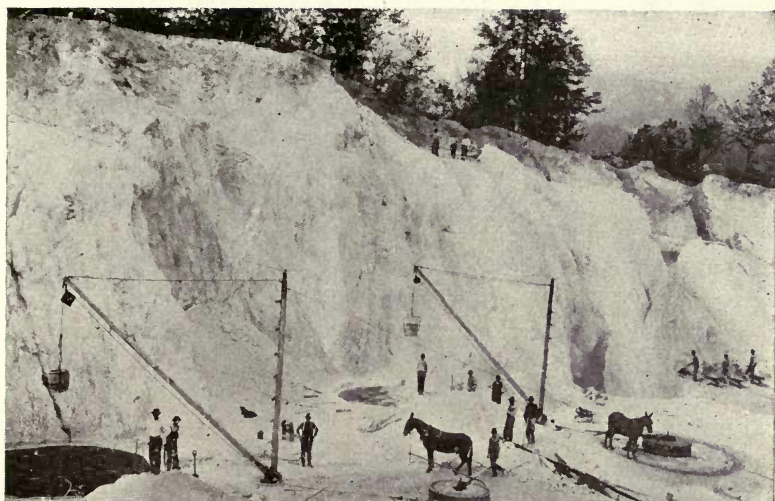
PLATE XXI



FIG. 1.—Kaolin deposit, North Carolina, shows circular pits for mining, sunk in clay. (*Photo loaned by Southern Railway Company.*)



FIG. 2. — Bank of sedimentary clay, Woodbridge, N. J. This section affords at least five kinds of clay. (*Photo., H. Ries.*)

tions from the oldest to the youngest. The pre-Cambrian crystallines yield both white and colored residual clays, usually the result of weathering, though more rarely of solfataric action. In the Paleozoic rocks, deposits of shale, and sometimes of clay, are found in many localities; and, since they are usually marine sediments, the beds are often of great extent and thickness. The weathered outcrops of these may yield a residual clay. With the exception of certain Carboniferous deposits, the Paleozoic clays are mostly impure. The Mesozoic formations contain large supplies of clays and shale suitable for the manufacture of bricks, terra cotta, stoneware, fire brick, etc.

The Pleistocene clays are all surface deposits, usually impure, and individually of limited extent, although they are thickly scattered all over the United States. Their chief value is for brick and tile making. They have been accumulated by glacial action, on flood plains, in deltas, or in estuaries and lakes.

**Distribution of Clays by Kinds in the United States.** — *Kaolins* (67). — Kaolins proper are derived only from crystalline or igneous rocks, hence their distribution is limited, and the only deposits worked are in the eastern states. Being commonly formed by the weathering of pegmatite veins, kaolin deposits have great length as compared with their width, which may be anywhere from 5 to 300 feet. Their depth ranges from 20 to 120 feet, depending on the depth to which the feldspar has been weathered.

|  | CRUDE KAOLIN | WASHED KAOLIN |
|---|---|---|
| $SiO_2$ . . . . . . . . . . . . . | 62.40 | 45.78 |
| $Al_2O_3$ . . . . . . . . . . . . | 26.51 | 36.46 |
| $Fe_2O_3$ . . . . . . . . . . . . | 1.14 | .28 |
| FeO . . . . . . . . . . . . . | — | 1.08 |
| CaO . . . . . . . . . . . . . | .57 | .50 |
| MgO . . . . . . . . . . . . . | .01 | .04 |
| Alkalies . . . . . . . . . . . | .98 | .25 |
| $H_2O$ . . . . . . . . . . . . . | 8.80 | 13.40 |
| Moisture . . . . . . . . . . . | .25 | 2.05 |
|  | 100.66 | 99.84 |
| Clay substance . . . . . . . . | 66.14 | 93.24 |

Quartz and white mica are often present in kaolin, and it is then frequently necessary to put the clay through a washing process to remove these minerals. The difference between a washed and unwashed kaolin is well shown by the two preceding analyses, from which it is seen that the quartz

contents have been considerably lowered, and that the washed product approaches more closely to the composition of kaolinite.

North Carolina (52) and Pennsylvania (58, 56) are the most important residual kaolin-producing states, but deposits are also worked in Connecticut (17 a), Maryland (36), and Virginia (67). It is known to occur in Alabama (10). All of these deposits except that in Connecticut are found south of the limit of the glacial drift. Kaolins occur in southeastern Missouri, but they have never become of great importance (45).

The Cretaceous of Georgia (20), and South Carolina (61) contains important deposits of white-burning sedimentary clays, which might perhaps be termed plastic kaolins to distinguish them from the residual ones.

The output from the American deposits is insufficient to supply the domestic clay-working industry, and consequently many thousand tons are annually imported from England. Since this can be brought over as ballast, it is possible to put it on the American market at a low price. The best grades of kaolin sell for $10 to $12 per ton at Trenton, New Jersey, and East Liverpool, Ohio, these being the two most important pottery centers of this country.

*Fire Clays.* — Fire clays are found in the rocks of all systems, from the Carboniferous to the Tertiary, inclusive, with the exception of the Triassic.

The most extensive, and among the most important, beds of fire clay are those found in the Carboniferous strata of Pennsylvania (56, 60), Ohio (54, 55), Kentucky (29, 30, 33), West Virginia (72), Maryland (36), Indiana (24), Missouri (45), and Illinois (21, 22). Those of the first two named states are on the average the most refractory. Here the fire clays are usually found underlying coal seams and often at well-marked horizons, especially in the Upper Productive Measures.

The section given in Fig. 2 is fairly representative of their mode of occurrence.

Those of Indiana and Illinois are so placed that one mine shaft may be used for extracting coal, fire clay, stoneware clay, and shale.

The beds of refractory clay, found in the Carboniferous strata near St. Louis (45), are not only used in the manufacture of fire brick, but are, in some cases, found suitable, after washing, for mixture with imported German clays for the manufacture of glass pots.

In the Lower Cretaceous of New Jersey (49) there are many beds
of refractory clay, variable in thickness and closely associated with
beds of less refractory character. They not only support a thriving
local fire-brick industry, but serve also as a source of supply for fac-
tories in other states. Similar, but less extensive and less refractory,
beds occur in strata of Cretaceous Age in the coastal plain of Mary-
land (36), Georgia (20), South Carolina (61), and Alabama (10).

The Tertiary formations of Texas (64) and Mississippi (44) hold
abundant deposits of refractory material, but many are undeveloped.
The Missouri Tertiary also supplies some fire clays (45).

Fire clays are found in the Black Hills of South Dakota (62), in the
Laramie beds of Colorado (14–17), and in California (13); but, excepting
near Denver, where used for making fire brick and assayer's apparatus,
these deposits are as yet slightly developed.

*Pottery Clays.* — Under this heading are included several grades
of clay, the kaolins, already described, being the purest and best
suited to the manufacture of high grades of pottery.

Another high-grade pottery clay of more plastic character, the
ball clay, is of limited distribution in the United States. A small
quantity is found in the Cretaceous (Pl. XXI) of New Jersey (49),
and a much larger amount in the Tertiary of western Kentucky
(29, 31) and Tennessee (63), and southeastern Missouri (45) and
Florida (19, 67). As in the case of kaolin, the domestic supply is
not sufficient to meet the demand, and large quantities of ball clay
are imported from England.

Stoneware clays form a third grade of pottery clays. They are
usually of at least semirefractory character, but differ from fire
clays proper in burning dense at a much lower temperature. Their
distribution is essentially coextensive with that of fire clays; in-
deed, the two are often dug from the same pit or mine. Large
quantities are obtained in the Carboniferous of western Pennsyl-
vania (56, 57) and eastern Ohio (55) and smaller amounts in the
New Jersey Cretaceous formations (49).

Stoneware clays, usually in the same area as the fire clays, are also ob-
tained in Illinois (21), Indiana (24), Kentucky (29, 31), Tennessee (63),
Alabama (10), and Texas (64); and they occur also in Missouri (45), Iowa
(26), Colorado (15), and California (13).

Many of the Pleistocene surface clays in various states are suffi-
ciently dense-burning to be used locally by small stoneware
factories.

*Brick and Tile Clays* (67). — None of our states lack an abundant supply of good brick and tile clays, and in many areas there are extensive deposits near the large markets, and often near tide water. In such cases the clay beds are exploited to an enormous extent.

In the northeastern states the Pleistocene surface clays are found almost everywhere in great abundance, and are made use of in many places, especially near the large cities.

In the middle Atlantic states Columbian loams and clay marls are an important source of brick material.

In Ohio, Illinois, and Indiana Pleistocene clays, in part of glacial, and in part of flood-plain origin, are much used for brick and tile. Impure Paleozoic shales are also used in places, especially in the manufacture of vitrified paving brick, thousands of which are made annually in Ohio. Northern Illinois, Michigan, and Wisconsin draw their main supply of brick clays from the calcareous lake deposits.

Although glacial clays and flood-plain deposits are much used in the states west of the Mississippi, the loess which occurs over a wide area is probably even more important as a source of brick, while in the southwestern states loess and adobe are important. Residual clays, river silts, glacial clays, and other forms of clay are employed in brick making along the Pacific coast.

*Miscellaneous Clays of Importance.* — Paper clays of good quality are much sought for by paper manufacturers. Much English kaolin is used for this purpose, but the domestic kaolins are also drawn upon, especially those of Georgia, South Carolina, North Carolina, southeastern Pennsylvania, and Connecticut. A small amount of *glasspot clay* (45) comes from western Pennsylvania, but much more from eastern Missouri, and our chief supply is imported. Terra-cotta clays are obtained from the same areas that supply fire clays, New Jersey being the principal producer.

**Distribution of Clays in Canada.** — *Kaolins.* — Deposits are hardly expected in the glaciated area, but one deposit formed from feldspathic veins in quartzite has been worked near Huberdeau, Que. (80).

*Fire Clays.* — Extensive deposits occur in the Laramie of southern Saskatchewan (79), and the Eocene delta deposits of the Frazer Valley, British Columbia. The same materials are utilized for pressed brick, terra cotta, and certain beds for stoneware.

*Red-burning Clays and Shales.* — The Carboniferous shales of
Nova Scotia and New Brunswick (78, 81), the Ordovician and
Silurian shales of Ontario (77, 82), and the Cretaceous and
Tertiary shales of the Western Provinces (79) afford abundant
material for making building and paving brick, drain tile, fire-
proofing, and in some cases, sewer pipe.

*Surface Clays.* — These are widely distributed through the
Dominion, and may be of the estuarine, lacustrine, floodplain
or glacial type according to their location and origin (77–82).
Those found in the Great Plains region are not infrequently
buff or cream burning, because of their calcareous nature.

**Other Foreign Deposits.** — The kaolin or china clay deposits
of the Cornwall, England,[1] district are the most important of
this type worked in the world, and supply a large export trade.
Equally well known, but of less extent, are similar deposits in
France, Denmark, Bohemia, and Germany.[2] Fireclays are
worked at a number of localities for domestic use, but the glass-
pot clays of Belgium and Germany have not only been used at
home, but also exported. So, too, have German clays employed
in making graphite crucibles.

**Uses of Clay.** — So few people have even an approximate
idea of the uses to which clays are put that it seems desirable
to call attention to them briefly. In the following table an attempt
has been made to do this:[3]—

**Domestic.** — *Pottery of various grades; Polishing brick,* often known as
*bath bricks; Fire kindlers; Majolica stoves.*

**Structural.** — *Brick; Tiles and Terra cotta; Chimney pots; Chimney flues;
Door knobs; Fireproofing; Copings; Fence posts.*

**Hygienic.** — *Closet bowls; Sinks,* etc.; *Sewer pipes; Ventilating flues; Foun-
dation blocks; Vitrified bricks.*

**Decorative.** — *Ornamental pottery; Terra cotta; Majolica; Garden furni-
ture.*

**Minor Uses.** — *Food adulterants; Paint filler; Paper filling; Electrical insu-
lations; Pumps; Fulling cloth; Scouring soap; Packing horses' hoofs;
Chemical apparatus; Condensing worms; Ink bottles; Ultramarine
manufacture; Emery wheels.*

**Refractory Wares.** — *Crucibles* and *other assaying apparatus; Refractory
bricks* of various patterns; *Glass pots.*

**Engineering Work.** — *Puddle; Portland cement; Railroad ballast; Water
conduits; Turbine wheels.*

[1] Searle, British Clays, Shales and Sands, London, 1911.
[2] Dammer and Tietze, Die Nutzbaren Mineralien, II: 379, 1914.
[3] Table compiled by R. T. Hill and modified by the author.

**Production of Clay and Clay Products.** — Owing to the fact that clays are usually manufactured by the producer, it is necessary to give the value of the product, no record being kept of value of the raw material.

VALUE OF CLAY PRODUCTS PRODUCED BY THE NINE LEADING STATES, AND TOTAL UNITED STATES PRODUCTION, 1910–1914

| STATE. | 1910 | 1911 | 1912 | 1913 | 1914 |
|---|---|---|---|---|---|
| Ohio | $31,525,948 | $32,663,895 | $34,811,508 | $38,388,296 | $37,166,768 |
| Pennsylvania | 22,094,285 | 20,270,033 | 21,537,221 | 24,231,482 | 21,846,996 |
| New Jersey | 17,834,309 | 18,178,228 | 19,838,553 | 19,705,378 | 16,484,652 |
| Illinois | 15,176,161 | 14,333,011 | 15,210,990 | 15,195,874 | 13,318,953 |
| New York | 11,871,949 | 10,184,376 | 12,058,858 | 11,469,476 | 9,078,933 |
| Indiana | 8,100,010 | 7,000,771 | 7,935,251 | 8,498,646 | 7,655,285 |
| Missouri | 7,087,766 | 6,274,353 | 6,412,861 | 6,602,076 | 6,077,284 |
| Iowa | 5,328,241 | 4,432,874 | 4,522,326 | 5,573,681 | 6,401,745 |
| California | 4,842,391 | 4,915,866 | 5,912,450 | 5,344,958 | [1] 5,761,411 |
| Total of all states | $170,115,974 | $162,236,181 | $172,811,275 | $181,289,132 | $164,986,983 |

[1] West Virginia in 1914 was ninth in rank.

VALUE OF CLAY PRODUCTS, BY KINDS, IN THE UNITED STATES, 1910–1914

| KIND. | 1910 | 1911 | 1912 | 1913 | 1914 |
|---|---|---|---|---|---|
| Common brick | $55,219,551 | $49,885,262 | $51,796,266 | $50,134,757 | $43,769,524 |
| Vitrified paving brick | 11,004,666 | 11,115,742 | 10,921,575 | 12,138,221 | 12,500,866 |
| Front brick | 8,590,057 | 8,648,877 | 9,455,297 | 9,614,138 | 9,289,623 |
| Ornamental brick | 179,505 | 177,015 | 225,367 | 109,703 | 124,459 |
| Enameled brick | 832,225 | 1,038,865 | 1,027,314 | 1,225,708 | 1,075,026 |
| Firebrick | 18,111,474 | 16,074,686 | 17,877,629 | 20,627,122 | 16,427,547 |
| Stove linings | 503,806 | 614,116 | 516,874 | 535,667 | 520,585 |
| Drain tile | 10,389,822 | 8,826,314 | 8,010,250 | 8,558,320 | 8,522,039 |
| Sewer pipe | 11,428,696 | 11,454,616 | 12,147,677 | 14,872,103 | 14,014,767 |
| Architectural terra cotta | 6,976,771 | 6,017,801 | 8,580,436 | 7,733,306 | 6,087,652 |
| Fireproofing | 5,110,597 | 5,660,172 | 7,174,148 | 8,620,216 | 8,385,337 |
| Tile (not drain) | 5,240,644 | 5,356,184 | 5,809,495 | 6,109,180 | 5,705,583 |
| Pottery | 33,784,678 | 34,518,560 | 36,504,164 | 37,992,375 | 35,398,161 |

Much clay is mined and sold, especially to manufacturers of high-grade clay products who do not own deposits themselves. The value of production of such clays is given below.

VALUE OF CLAYS MINED AND SOLD IN THE UNITED STATES, 1910–1914

| KIND. | 1910 | 1911 | 1912 | 1913 | 1914 |
|---|---|---|---|---|---|
| Kaolin | $ 255,873 | $ 211,045 | $ 220,747 | $ 235,457 | $ 284,817 |
| Paper clay | 420,476 | 454,435 | 522,924 | 567,977 | 558,334 |
| Slip clay | 29,962 | 16,770 | 27,573 | 24,505 | 17,731 |
| Ball clay | 257,265 | 220,710 | 227,545 | 237,672 | 255,767 |
| Fire clay | 2,157,720 | 2,112,827 | 2,363,357 | 2,592,591 | 2,147,277 |
| Stoneware clay | 153,044 | 165,751 | 115,522 | 143,587 | 116,610 |
| Brick clay | 128,039 | 123,900 | 204,504 | 137,976 | 161,852 |
| Miscellaneous | 223,106 | 165,325 | 263,848 | 240,694 | 214,180 |
| Total | $3,625,485 | $3,480,763 | $3,946,020 | $4,180,459 | $3,756,568 |

PRODUCTION OF CLAY PRODUCTS IN CANADA, 1912–1914

| | 1912 | | 1913 | | 1914 | |
|---|---|---|---|---|---|---|
| | NUMBER | VALUE | [1] NUMBER | VALUE | [2] NUMBER | VALUE |
| Brick, common | 769,191,532 | $7,010,375 | 668,426,675 | $5,917,373 | 457,513,762 | $3,653,861 |
| Brick, pressed . | 125,180,422 | 1,609,854 | 116,802,053 | 1,458,733 | 93,634,858 | 1,115,556 |
| Brick, paving . | 4,579,500 | 85,989 | 4,208,295 | 75,669 | 2,707,000 | 49,627 |
| Brick, moulded & ornamental . | 371,356 | 8,595 | 875,355 | 15,423 | 1,554,496 | 23,592 |
| Firebrick and fire-clay shapes, etc. | —— | 125,585 | —— | [1] 142,738 | —— | [1] 107,568 |
| Fireproofing and architectural terra-cotta . | —— | 448,853 | —— | 461,387 | —— | 405,543 |
| Kaolin (tons) . | 20 | 160 | 500 | [1] 5,000 | —— | 10,000 |
| Pottery . . | —— | 43,955 | —— | 53,533 | —— | 35,371 |
| Sewer pipe . . | —— | 884,641 | —— | 1,035,906 | —— | 1,104,499 |
| Tile, drain . . | —— | 357,862 | —— | 338,552 | —— | 366,340 |
| Total . . | —— | 10,575,869 | | 9,504,314 | | $6,871,957 |

[1] Production from Canadian clay.          [2] Number sold.

The total value of the exports of Canadian clay products in 1914 was $48,073.

The imports of Canadian clays and clay products in 1914 were valued at $4,467,140. Both imports and exports less than 1913.

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# CHAPTER V

## LIMES AND CALCAREOUS CEMENTS

**Composition of Limestones** (2, 43). — Limes and calcareous cements form an important class of economic products, obtained from limestones by heating them to a temperature ranging from that of decarbonation to clinkering. The term *limestone* is applied to one of the main divisions of the stratified rocks so widely distributed, both geologically and geographically, and formed under such different conditions, that its composition varies greatly, this range of variation becoming appreciable from an inspection of the following table, which contains a few selected types: —

|  | I | II | III | IV | V | VI | VII | VIII |
|---|---|---|---|---|---|---|---|---|
| Silica (SiO₂) . . . | .54 | 2.22 | .48 | 4.9 | 14.30 | 15.05 | 16.99 | 12.13 |
| Alumina (Al₂O₃) . . | .42 | .92 | .20 | 6.5 | .70 | 9.02 | 5.00 | 4.17 |
| Ferric oxide (Fe₂O₃) . | | .18 | | | .80 | 1.27 | 1.79 | 3.28 |
| Lime (CaO) . . . | 54.73 | 54.08 | 31.31 | 27.3 | 46.50 | 39.26 | 23.15 | 42.04 |
| Magnesia (MgO) . | .19 | .10 | 21.03 | 14.6 | n.d. | 1.90 | 16.60 | .44 |
| Sulphur trioxide (SO₃) | — | — | — | — | — | — | — | n.d. |
| Carbon dioxide (CO₂) | 43.22 | 42.50 | 46.98 | 44.8 | 36.54 | 32.90 | 36.47 | 33.51 |
| Water (H₂O) . . . | — | — | — | — | — | — | — | — |
| | 99.10 | 100.00 | 99.99 | 98.1 | 98.84 | 99.40 | 100.00 | 95.57 |

I. Pure limestone, Ilasco, Mo. II. Chalk, Marinas, Cuba. III. Dolomite, E. Canaan, Conn. IV. Magnesian limestone, Clinton, Hunterdon Co., N. J. V. Siliceous limestone for hydraulic lime, Teil, France. VI. Argillaceous (cement rock) limestone, Lehigh district, Pa. VII. Argillaceous magnesian limestone, Milwaukee, Wis. VIII. Clayey chalk.

From this table it will be seen that limestones vary from rocks composed almost entirely of carbonate of lime, or of carbonate of lime and carbonate of magnesia, to others which are high in clayey or siliceous impurities. The presence of such impurities in large quantity usually imparts an earthy appearance to the limestone, and sometimes even gives it a shaly structure.

Marked variations in composition may at times be found even in a single quarry (50), while in other cases a limestone formation may show remarkable uniformity of composition over a wide area.

**Changes in Burning** (2). — When limestones are calcined or "burned" to a temperature sufficiently high to drive off volatile constituents, such as carbon dioxide, water, and sulphur (in part), or, in other words, to the point of decarbonation, the rock is left in a more or less porous condition. If heated to a still higher temperature, the rock clinkers or fuses incipiently, but the temperature of clinkering depends on the amount of siliceous and clayey impurities in the rock.

**Lime** (2, 43). — Limestone free from or containing but a small percentage of argillaceous impurities is, by decarbonation, changed to quicklime, a substance which has a high affinity for water, and which, when mixed with water, "slakes," forming a hydrate of lime. This change is accompanied by the evolution of heat and by swelling, and this action becomes the more marked the higher the percentage of lime carbonate in the rock, for the slaking activity is retarded by the presence of magnesia and especially by argillaceous impurities. Limes may, therefore, be divided into "fat" limes and "meager" limes, depending on the rapidity with which they slake and the amount of heat they develop in doing so.

**Hydraulic Cements.** — With an increase in clayey and siliceous impurities, the burned rock shows a decrease in slaking qualities, and develops hydraulic properties, or sets when mixed with water, and even under the same. Products of this type are termed cements, and owe their hydraulic properties to the formation during burning of silicates and aluminates of lime. On mixing the burned ground rock with water, these take up the latter and crystallize, thereby producing the set of the cement.

Hydraulic cements can be divided into the following classes: Pozzuolan cements, hydraulic limes, natural cements, and Portland cements.

*Pozzuolan Cement* (2, 53). — This is produced from an uncalcined mixture of slaked lime and a silico-aluminous material, such as volcanic ash or blast-furnace slag.

This process was known to the ancients, and is named from its early use around Pozzuolano, Italy. The composition of an Italian Pozzuolano earth may vary between the following limits:[1] $SiO_2$, 52–60; $Al_2O_3$, 9–21; $Fe_2O_3$, 5–22; $CaO$, 2–10; $MgO$, up to 2; alkalies, 3–16; $H_2O$, up to 12.

[1] Schoch, Die Moderne Aufbereitung u. Wertung der Mörtel Materialien, Berlin. 1896.

No deposits of volcanic ash, for use in Pozzuolan cement, are worked in the United States, although extensive deposits of the material are known to occur in the Rocky Mountain and Pacific Coast states. It is said, however, that a mixture of Portland cement and volcanic ash was extensively and satisfactorily used in the construction of the Los Angeles aqueduct.

The manufacture of slag cement has been started at several localities in the United States (2), but the industry is at present showing a contraction instead of an expansion. Moreover, the cement hardly meets the specifications for Portland cement.

*Hydraulic limes* (2) are formed by burning a siliceous limestone to a temperature not much above that of decarbonation. Owing to the high percentage of lime carbonate, considerable free lime appears in the finished product. Hydraulic limes generally have a yellow color, and a gravity of about 2.9. They slake and set slowly, and have little strength unless mixed with sand. This class is of little importance in the United States, although small quantities have, in the last few years, been produced in Maryland, Georgia, and New York. They are, however, of great importance in Europe, and it may be of interest to give a few analyses of the raw material used abroad (2):

ANALYSES OF HYDRAULIC LIME ROCKS

|  | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Silica (SiO$_2$) . . . . . . . | 14.30 | 11.03 | 7.60 | 17.00 |
| Alumina (Al$_2$O$_3$) . . . . . . | .70 | 3.75 | .75 | 1.00 |
| Iron oxide (Fe$_2$O$_3$) . . . . | .80 | 5.07 | | —— |
| Lime (CaO) . . . . . . . | 46.50 | 43.02 | 50.05 | 44.80 |
| Magnesia (MgO) . . . . . | undet. | 1.34 | .30 | .71 |
| Carbon dioxide (CO$_2$) . . . . | 36.54 | 35.27 | 41.30 | 35.99 |
| Water | | | | |

1. Teil, France.  2. Hausbergen, Germany.  3. Malain, France.  4. Senonches, France.

In the best types of hydraulic limestones, silica varies between 13 and 17 per cent, while alumina and iron oxide together rarely exceed 3 per cent.

*Natural Rock Cements* (2, 43). — These, known also as Roman cement, quick-setting cement, and Rosendale cement, are made by burning a silico-aluminous limestone (containing from 15 to 40 per cent clayey impurities) at a temperature between decarbonation and clinkering. The product shows little or no free lime. The following analyses will give some idea of the range in composition of natural cement rocks quarried in the United States: —

ANALYSES OF NATURAL CEMENT ROCKS

|  | UTICA, ILL. | LOUIS-VILLE DISTRICT | FORT SCOTT, KAN. | HANCOCK, MD. | HANCOCK, MD. | MANKA-TO, MINN. |
|---|---|---|---|---|---|---|
| $SiO_2$ . . . . . . . . | 17.01 | 15.21 | 17.26 | 19.81 | 24.74 | 10.10 |
| $Al_2O_3$. . . . . . . . | 3.35 | 4.07 | 2.05 | 7.35 | 16.74 | 2.78 |
| $Fe_2O_3$ . . . . . . . | 2.39 | 1.44 | 5.45 | 2.41 | 6.30 | 1.34 |
| CaO . . . . . . . . | 32.85 | 33.99 | 34.45 | 35.76 | 23.41 | 25.96 |
| MgO . . . . . . . . | 8.45 | 7.57 | 5.28 | 2.18 | 4.09 | 14.91 |
| Alk. . . . . . . . . | n.d. | — | — | n.d. | 6.18 | 3.50 |
| $SO_3$ . . . . . . . . | 1.81 | — | — | n.d. | 2.22 | .26 |
| $CO_2$ . . . . . . . . | 34.12 | 35.03 | 32.87 | 31.74 | 22.90 | 41.29 |
| $H_2O$ . . . . . . . . | | | | | — | — |

|  | LAW-RENCE-VILLE, N. Y. | LAW-RENCE-VILLE, N. Y. | HOWES CAVE, N. Y. | JAMES-VILLE, N. Y. | AKRON-BUFFALO DISTRICT | MIL-WAUKEE, WIS. |
|---|---|---|---|---|---|---|
| $SiO_2$ . . . . . . . . | 10.90 | 23.80 | 12.89 | 10.97 | 9.03 | 17.56 |
| $Al_2O_3$ . . . . . . . | 3.40 | 4.17 | 11.15 | 4.46 | 2.25 | 1.40 |
| $Fe_2O_3$ . . . . . . . | 2.28 | 4.71 | | 1.54 | .85 | 2.24 |
| CaO . . . . . . . . | 29.57 | 22.27 | 30.90 | 27.51 | 26.84 | 27.14 |
| MgO . . . . . . . . | 14.04 | 12.09 | 9.38 | 16.90 | 18.37 | 13.89 |
| Alk. . . . . . . . . | n.d. | n.d. | — | — | .85 | — |
| $SO_3$ . . . . . . . . | .61 | .90 | — | — | n.d. | — |
| $CO_2$ . . . . . . . . | 37.90 | 31.00 | 34.60 | 37.94 | 40.33 | 36.45 |
| $H_2O$ . . . . . . . . | n.d. | n.d. | — | — | .98 | — |

Natural cements differ from lime in possessing hydraulic properties, and refusal to slake unless ground very fine. They differ from Portland cements in lighter weight, lower temperature of burning, quicker set, lower ultimate strength, and greater latitude of composition. Magnesia is not regarded as a detrimental impurity in natural cements as it is in Portland cement.

The following are some analyses of the burned material: —

ANALYSES OF SOME NATURAL ROCK CEMENTS

| | CaO | MgO | SiO$_2$ | Al$_2$O$_3$ | Fe$_2$O$_3$ | Na$_2$O,K$_2$O | IGNITION |
|---|---|---|---|---|---|---|---|
| Natural rock cement, Rosendale, N. Y. | 34.38 | 18 | 30.5 | 6.84 | 2.42 | 3.98 | 3.78 |
| Natural rock cement, Akron, N. Y. . . | 40.68 | 22 | 22.62 | 7.44 | 1.40 | 2.23 | 3.63 |
| Natural rock cement, Cumberland, Md. | 43.97 | 2.21 | 22.38 | 11.71 | 2.29 | 9.00 | 2.44 |
| Roman cement, Rüdersdorf, Germany | 56.45 | 4.84 | 27.88 | 6.19 | 4.64 | — | — |

*Portland Cement* (2). — Portland cement is the product obtained by burning a finely ground artificial mixture consisting essentially of lime, silica, alumina, and some iron oxide, these substances being present in certain definite proportions. Portland cement was first made by Joseph Apsdin, of Leeds, England, who desired to make an artificial cement that would replace natural hydraulic cements. It received its name because it hardened under water to a mass resembling the Portland stone of England.

The following combinations of raw materials are at present used in the manufacture of true Portland cement in the United States: *bog lime and clay; limestone and clay, or shale; chalk and clay; pure limestone and argillaceous limestone.*

In these combinations it is evident that the substances first named supply most of the lime and the second most of the silica, alumina, and iron. In the fourth the argillaceous limestone supplies some lime, as well as the silica and alumina. The nature of the raw materials chosen depends to a large degree on the location of the plant, whether in a limestone- or a bog-lime-producing region. Where both of these raw materials are available, as in parts of New York, questions of manipulation in the process of manufacture govern the selection of one or the other.

Bog limes, for example, though easier to excavate and reduce than limestones, contain so much more organic matter and water than limestones that they are more expensive to handle and prepare. Bog lime beds are likewise apt to be of limited extent and irregular, while limestone beds are, so far as the needs of a manufacturing plant are concerned, practically limitless.

Comparing clay and shale,[1] the former is often easier to excavate, but, on account of the water it contains, has to be dried before it can be ground and mixed. The fossils in shales are sometimes an important source of calcium carbonate, and then careful grinding and mixing is neces-

[1] It is probable that the refuse of many slate quarries could also be used in place of shale.

sary to bring about a uniform distribution of the lime through the mass. Shale is, however, used by only a few works.

Argillaceous limestone, mixed with a much smaller quantity of purer limestone, as in Pennsylvania and New Jersey, is superior to a limestone and clay mixture, because less thorough mixing and fine grinding are required. In such cements, even when grinding and mixing are incompletely done, the particles of argillaceous limestone so closely resemble the proper mixture in chemical composition as to affect the result but little.

The following table gives the analyses of some of the raw materials used in manufacture of Portland cement: —

ANALYSES OF RAW MATERIALS USED FOR PORTLAND CEMENT

| LOCALITY | MATERIAL | SiO$_2$ | Al$_2$O$_3$ | Fe$_2$O$_3$ | CaCO$_3$ | MgCO$_3$ | H$_2$O + Org. Matter | MISCEL. |
|---|---|---|---|---|---|---|---|---|
| Lehigh Valley, Penn. | Calc. shale or cement rock | 15.40 | 4.26 | 1.38 | 74.66 | 2.66 | 1.88 | CaSO$_4$ .86 |
|  | Limestone mixture | 5.87 | 1.59 | | 88.00 | 4.00 | | |
|  | mixture | 13.97 | 5.07 | 1.88 | 74.1 | 2.04 | 1.82 | |
| Glens Falls, N.Y. | Limestone | 3.3 | 1.3 | | CaO 52.15 | MgO 1.58 | | SO$_3$ .3 |
|  | Clay | 55.27 | 28.15 | | CaO 5.84 | MgO 2.25 | 8.37 | SO$_3$ .12 |
| Warners, N.Y. | Bog lime | .26 | .10 | | 94.39 | .38 | 4.64 | |
|  | Clay | 40.48 | 20.95 | | 25.80 | .99 | 8.50 | |
| Sandusky, Ohio | Bog lime | Insol. 1.28 | 1.72 | | 92.70 | .50 | 1.13 | CaSO$_4$ 2.06 |
|  | Clay | 64.70 | 11.9 | 9.9 | CaO .90 | MgO .70 | 11.9 | |
| White Cliffs, Ark. | Chalk | 7.97 | 1.09 | | 88.64 | .73 | | |
|  | Clay | 53.3 | 23.29 | 9.52 | CaO .36 | MgO 1.49 | 5.16 | |

In the selection of the raw materials the aim of the manufacturers is to produce a raw mixture which runs approximately 75 per cent carbonate and the balance clay. In the burning of this mixture, which must be done at a high temperature, a fused mass termed clinker is formed. This consists largely of 3CaO·SiO$_2$, 2CaO·SiO$_2$, 3CaO·Al$_2$O$_3$, 5CaO·3Al$_2$O$_3$, with a little free lime.[1] The finely ground clinker, which is the Portland cement, is blue to gray in color, and has a specific gravity of 3 to 3.25.

In some localities argillaceous limestones are found which approach so closely to the proper composition, that but little additional material has to be added to make a mixture of the proper composition.

[1] Rankin and Wright, Amer. Jour. Sci., Jan., 1915.

The raw materials must not only have the proper composition, but they also must show proper physical character, extent, and location, with respect to market and fuel supplies. As regards composition, 5 or 6 per cent magnesium carbonate is about the permissible limit. Chert, flint, or sand are also undesirable impurities, and alkalies and sulphates should not exceed 3 per cent. The clay used, if non-calcareous, should not contain less than 55 per cent silica nor more than 70 per cent, and the ratio of $(Al_2O_3 + Fe_2O_3)$ to $SiO_2$ should be about 1 : 3. High alumina clays are undesirable because they raise the vitrification temperature and quicken the set of the cement.

The following are analyses of Portland cement mixtures before burning: [1] —

<div align="center">ANALYSES OF PORTLAND CEMENT MIXTURES</div>

| | | | | |
|---|---|---|---|---|
| $SiO_2$ . . . . . . . . | 12.85 | 12.92 | 13.52 | 14.94 |
| $Al_2O_3$ . . . . . . . | 4.92 | 4.83 | 6.56 | 2.66 |
| $Fe_2O_3$ . . . . . . . | 1.21 | 1.77 | — | 1.10 |
| $CaCO_3$ . . . . . . | 76.36 | 75.53 | 75.13 | 75.59 |
| $MgCO_3$ . . . . . . | 2.13 | 4.34 | 4.32 | 4.64 |
| | 97.47 | 99.39 | 99.53 | 98.93 |

The following analyses will serve to illustrate the composition of some American Portland cements: —

<div align="center">ANALYSES OF CEMENTS</div>

| | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | $CaO$ | $MgO$ | $SO_3$ |
|---|---|---|---|---|---|---|
| Empire brand . . . . | 22.04 | 6.45 | 3.41 | 60.92 | 3.53 | 2.73 |
| Sandusky . . . . . . | 23.08 | 6.16 | 2.90 | 62.38 | 1.21 | 1.66 |
| Alpha . . . . . . . | 22.62 | 8.76 | 2.66 | 61.46 | 2.92 | 1.53 |

**Distribution of Lime and Cement Materials in the United States.** *Limestone for Lime.* — Limestones of suitable composition for making lime are so widely distributed that no particular regions or states require special mention.[2] In the New England states, crystalline limestones are the chief source of supply. In the Appalachian states, from New York to Alabama, there are many Paleozoic limestones of high purity, notably the Trenton, Lower Helderberg, and Carboniferous limestones (see state references). The same

[1] U. S. Geol. Surv., Min. Res., 1907.

[2] Analyses and detailed descriptions will be found in the areal reports, mentioned in the list of References.

L

series of rocks are also of importance in the Mississippi Valley
states from Tennessee (52) to Michigan (35). Lime of excellent
quality is obtained from the Subcarboniferous in Iowa (23, 24),
Kansas (25), and Missouri (53), and from the Cretaceous in Texas
(53). Limestones suitable for lime manufacture are also found in
numerous localities in the Pacific coast states (53).

*Hydraulic Limes* (2). — Largely because of the great abundance
of natural-rock cements, which are of superior value, these materials,
though much used abroad, are of no importance in the United
States.

It was stated that in 1906 and 1907 [1] several natural cement
plants had been making and marketing a true hydraulic lime, but
little or none is made now.

*Natural Rock Cements* (2, 43, 53). — Calcareous rocks for making
natural cement are found at a number of points, the more impor-
tant ones being given in summarized form in the following table: —

GEOLOGIC AGE OF NATURAL CEMENT ROCKS IN THE UNITED STATES

| STATE | GEOLOGIC AGE | STATE | GEOLOGIC AGE |
|---|---|---|---|
| Georgia | Cambro-Ordivician | Ohio | Devonian |
| Illinois | Ordovician | Pennsylvania | Ordovician |
| Indiana-Kentucky | Devonian | Texas | Cretaceous |
| Kansas | Carboniferous | Virginia | Cambrian |
| Maryland | Silurian | West Virginia- | |
| Minnesota | Ordovician | Maryland | Cambrian |
| New York | Silurian | Wisconsin | Devonian |
| North Dakota | Cretaceous | | |

In many districts the cement rocks occur in more than one
bed, and may be interstratified with limestones or shales of no
economic value for cement making (Fig. 64).

Some of the important occurrences may be briefly referred to.

*New York* (43). — This state contains four localities in which
natural cement rock is found, these in the order of their impor-
tance being: 1. Rosendale District in Ulster County; 2. Akron-
Buffalo District in Erie County; 3. Fayetteville-Manlius District
in Onondaga County (mostly); 4. Howe's Cave, Schoharie County.
The following chart shows their occurrence at different horizons in
the Silurian: —

[1] U. S. Geol. Surv., Min. Res., 1907 : 490, 1908.

PLATE XXII



FIG. 1. — Quarry of natural cement rock, Cumberland, Md. (*H. Ries, photo.*)
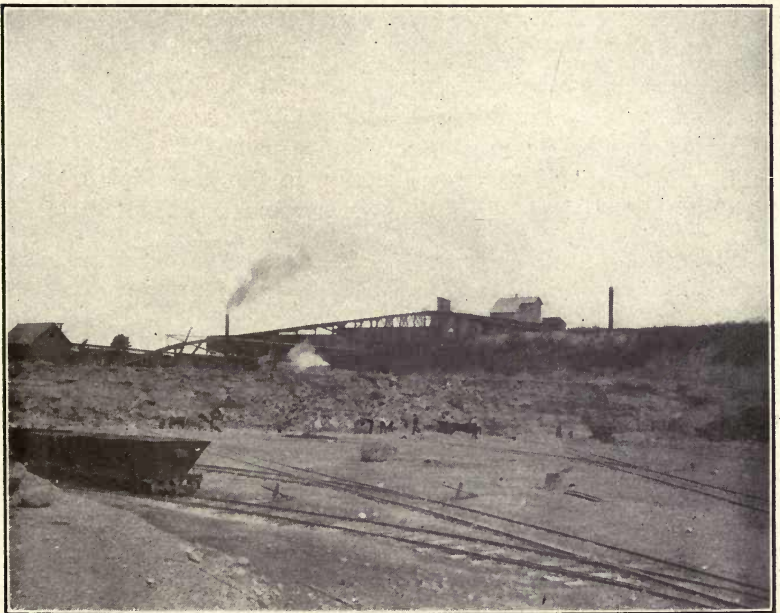


FIG. 2. — Natural cement rock quarry, Milwaukee, Wis. (*H. Ries, photo.*)

(195)

| FORMATION | ULSTER CO. | SCHOHARIE | ONONDAGA | ERIE |
|-----------|------------|-----------|----------|------|
| Manlius | Present, not worked for cement | Worked at Howe's cave | Worked for cement at Manlius, etc | Absent |
| Rondout | Upper cement bed of Rondout district | Worked for cement at Howe's Cave | Present, but not worked | Absent |
| Cobleskill | Present | Not used for cement | | |
| Bertie | Lower cement bed of Rondout district | Absent | Present in Onondaga Co., but rarely used | Worked around Akron and Buffalo |
| Wilber | Limestones | No cement | | |

In Rosendale district (Figs. 62 and 63), two distinct beds are worked usually, which differ in chemical composition and geologic age. The lower or dark bed, according to Darton, averages about 21 feet, while the upper or light bed is about 11 feet, the two being separated by 14–15 feet of worthless limestone.

The lower bed rests directly on Clinton quartzite.

The folding and faulting are intense in the Rosendale district (Fig. 63), but the beds show little disturbance in the others.

*Other States.* — Southward from New York natural cement rock is quarried at a number of points along the Appalachians, but owing to the folded character of the beds the extraction is often difficult (Pl. XXII, Fig. 1). The Lehigh district of Pennsylvania is an important producer of natural cement, but still more so of Portland cement (p. 198).

Several beds are worked in the Cumberland-Hancock area of Maryland (32, 33), while in Virginia (55) limestones of suitable composition for natural cement manufacture occur at several horizons, but only the argillaceous magnesian limestones found in the lower part of the Shenandoah (Cambro-Ordovician) limestone will probably prove of economic value. Others are worked in Georgia (14, 15, 53.)

Natural cement has been made at Utica, Ill. (53), from dolomitic limestone (Fig. 64), for nearly fifty years.

Near Milwaukee, Wisconsin (53), the cement beds occur interstratified with Devonian limestone (Pl. XXII, Fig. 2). Farther west near Fort

Scott, Kansas (25), slightly magnesian Carboniferous argillaceous limestones, are worked.

Cement rock is also obtained in southeastern Ohio (44), and at Louisville, Kentucky (29), probably the second most important center in the United States.
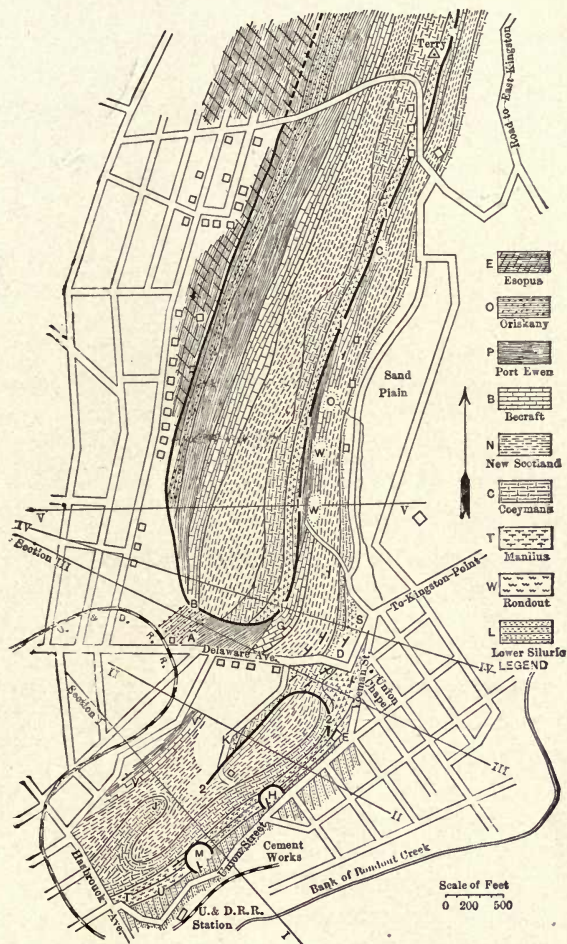


Fig. 62. — Geologic map through the Vlightberg at Rondout, N. Y.   (*After van Ingen, N. Y. State Mus., Bull.* 69.)

*Portland Cements.* — Clay and limestone, in one form or another, are so widely distributed throughout the United States that it is possible to manufacture Portland cement at many localities,
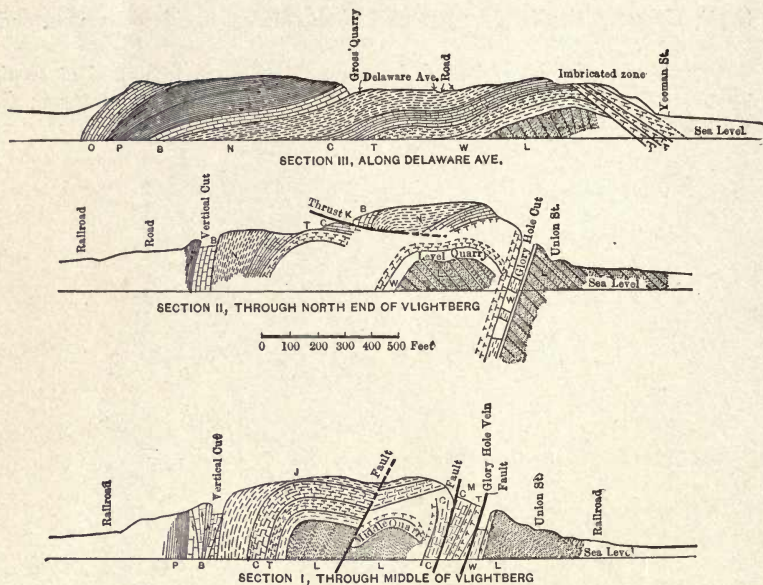
FIG. 63. — Geologic sections through the Vlightberg, showing position of natural rock cement beds. (*After van Ingen, N. Y. State Mus., Bull. 69.*)

and the geologic age of the materials used ranges from Ordovician to Pleistocene (53), (Refs. under different states). Twenty-six states were making this cement in 1914, the factories being spread over the country from the Atlantic to the Pacific (Fig. 68).

*Pennsylvania.* — By far the most important district is the Lehigh Valley in Pennsylvania, which supplies about 30 per cent of the domestic product.

The cement belt lies in Northampton and Lehigh counties, Pennsylvania (Fig. 65), and the geologic section involved is as follows (50): —
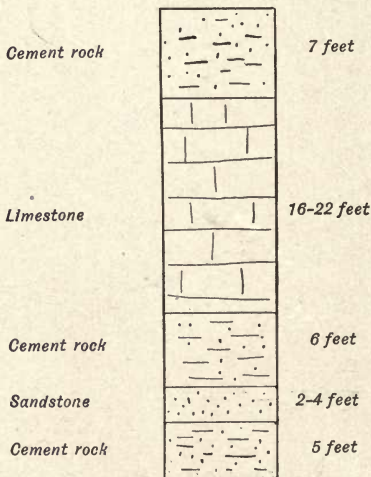


FIG. 64. — Section in cement quarries at Utica, Ill. (*After Eckel.*)

Hudson River slate.  Probably 500 feet thick.  No limestone.  Sharp boundary.

Trenton limestones. { More or less argillaceous slaty limestone, the cement rock.
Nearly pure limestones with some dolomitic beds.

Cambrian { Kittatinny dolomites and dolomitic limestones.
3000′± . Some beds flinty, and lowest are siliceous.
Basal conglomerates or quartzite.

Pre-Cambrian rocks.  Mainly gneisses.

The lower member of the Trenton varies in its physical character, and furnishes material to raise the lime content of the cement rock for Portland cement manufacture.  Its lime carbonate content varies from 80 to 97 per cent, but occasionally drops to 70 per cent, while the magnesian carbonate runs from 1.5 to 3 per cent.  In a few it reaches 20 per cent, and these highly magnesian layers cause trouble in quarrying.  The upper or slaty member of the Trenton grades into the lower one.  The rocks of this region have, by post-Carboniferous folding, been bent into a complex series of folds (Figs. 66 and 67),
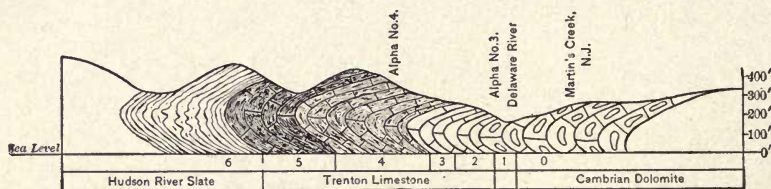


Fig. 66.—Diagrammatic section two miles long extending northwest from Martin's Creek, N. J., showing overturned folds.  0 and 1 = Cambrian dolomite; 2 and 3 = Lower Trenton, rocks high in lime; 4 = cement rock, Upper Trenton, averaging 70 to 80 per cent CaCO₃; 5 = Upper Trenton cement rock with less than 70 per cent CaCO₃; 6 = Hudson River slate. (*After Peck, Econ. Geol.*, III.)

whose axes trend northeast and southwest, and while the folds are in many cases overturned, there is comparatively little faulting.

The cement rock extends as a continuous zone or belt of varying width southwest across Northampton County from the Delaware to the Lehigh River (Fig. 65), crosses into Lehigh County,
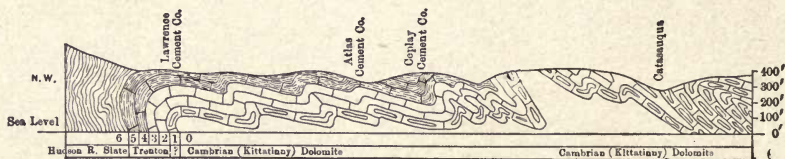


Fig. 67.—Diagrammatic section five miles long extending northwest from Catasauqua.  Numbers same as in Fig. 66. (*After Peck, Econ. Geol.*, III.)

Fig. 68. — Map of United States, showing location of cement plants. (*After Eckel, U. S. Geol. Surv., Min. Res. 1911.*)

and ends abruptly at a point four and a half miles west of Coplay.

The same beds are found in the adjacent territory of New Jersey (38).

*Other States.* — In the eastern half of New York (43) the Ordovician and Silurian limestones form an inexhaustible supply of material to mix with Pleistocene surface clays. In the south central part of New York the Tully limestone and Hamilton shales are employed, while in the central and southwestern portion beds of bog lime (Pl. XXIII, Fig. 2), associated with surface clays, are utilized.

Ohio (46, 74), Indiana (18–21) and Michigan (34–36) are important Portland cement producing states. The abundance of bog lime and Pleistocene clays makes them the favorite materials, notwithstanding the fact that beds of Paleozoic limestones occur in each of the states. Bog lime, although especially abundant in Michigan, is found in many states lying east of the Mississippi and north of the terminal moraine. It is precipitated from the waters of ponds through the agency of minute plants, especially *Chara* (35).

In Kansas Carboniferous shales and limestones are used for making Portland cement (25, 26, 28), and in Texas and Arkansas the Cretaceous shales and chalky limestones are employed (13, 14, 53); Alabama has a Cretaceous limestone of such composition that very little clay or shale has to be added to it (12). Portland cement is also manufactured in North Dakota (53), South Dakota (51), Utah (53), Colorado (53), and California (15, 53).

**Cement Materials in Canada.** — Portland cement plants are scattered over the Dominion from east to west. In Quebec and Ontario the Paleozoic limestones are used, and mixed with shales or surface clays, but a number of the Ontario plants are employing bog lime for the calcareous ingredient of the cement. As limestones are scarce on the Great Plains, there are few cement plants in this area, but between Calgary and the Pacific Coast, where Paleozoic and Mesozoic limestones are plentiful, some half dozen plants have been established. There is also at least one in operation on Vancouver Island, which is using a mixture of Cretaceous limestone and a metamorphosed dacite or andesite.[1]

[1] C. H. Clapp, private communication.

PLATE XXIII



FIG. 1. — Limestone quarry in Lehigh cement district, Pennsylvania. (*H. Ries*, *photo.*)



FIG. 2. — Marl pit at Warners, N. Y. The dark streaks are peat, and the marl is underlain by clay. (*H. Ries*, *photo.*)
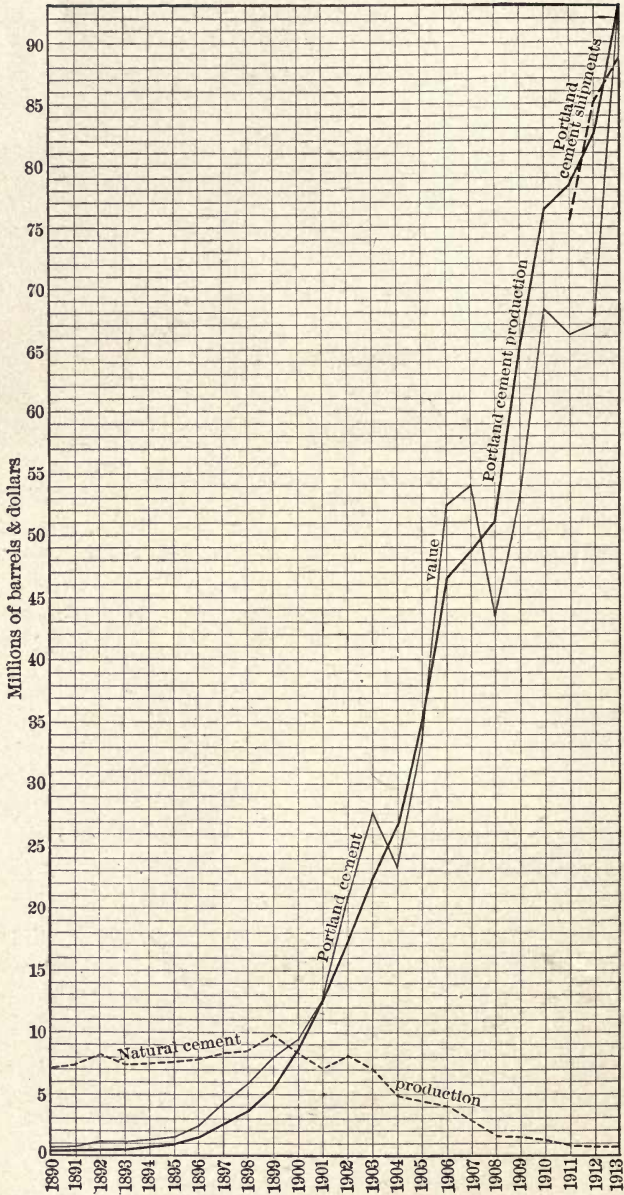
FIG. 69. — Chart showing production of Portland and natural cements and value of Portland cement in the United States, 1890 to 1913, and shipments of Portland cement, 1911 to 1913. (*After Burchard, U. S. Geol. Surv., Min. Res., 1913.*)

**Uses of Lime** (43, 2). — The most important single use of lime is for mixing with sand to form mortar, and many thousands of tons are used annually for this purpose. In addition to this use lime is employed for a great variety of purposes, of which the following are the most important: as a purifier in basic steel manufacture; in the manufacture of refractory bricks, ammonium sulphate, soap, bone ash, gas, potassium dichromate, paper, pottery glazes, and calcium carbide; as a disinfectant; as a fertilizer; as a polishing material; for dehydrating alcohol, preserving eggs, and in tanning.

**Uses of Cement** (2, 5). — The use of hydraulic cement is constantly increasing in the United States, this being specially true of Portland cement, which is superseding natural cement to a great extent, and is finding an increasing use in building and engineering operations. For pavements, Portland cement is probably more extensively used in America than in any other country; and as an ingredient of concrete it is widely employed. Blocks weighing as much as 65 to 70 tons have been made for harbor improvements at New York City (5).

*The Production of Cement.*—The tables on pp. 205–207 give the production of natural-rock and Portland cement. Those given for the latter cover a greater period than those of the former, and are grouped with figures of import and consumption in order to show more clearly the tremendous growth of the American Portland cement industry.

The diagram (Fig. 69) shows most clearly the remarkable increase in the production of Portland cement, and the rapid decrease in the natural cement production, the latter being now of small importance in the cement industry.

The Portland-cement curve shows a rapid rise after 1895, this year marking the introduction of powdered coal fuel in the rotary kiln. The sag in 1907 was due to financial troubles.

PRODUCTION OF PUZZOLAN CEMENT IN THE UNITED STATES, 1909–1914

| YEAR | QUANTITY (BARRELS) | VALUE | YEAR | QUANTITY (BARRELS) | VALUE |
|---|---|---|---|---|---|
| 1909 . . | 160,646 | $99,453 | 1912 . . . | 91,864 | $77,363 |
| 1910 . . . | 95,951 | 63,286 | 1913 . . . | 107,313 | 97,663 |
| 1911 . . . | 93,230 | 77,786 | 1914 . . . | 68,311 | 63,358 |

PRODUCTION OF NATURAL CEMENT IN THE UNITED STATES, 1910 TO 1914

| STATE | 1910 QUANTITY (BARRELS) | 1910 VALUE | 1911 QUANTITY | 1911 VALUE | 1912 QUANTITY | 1912 VALUE | 1913 QUANTITY | 1913 VALUE | 1914 QUANTITY | 1914 VALUE |
|---|---|---|---|---|---|---|---|---|---|---|
| New York | 304,598 | $150,952 | 429,832 | $178,937 | 366,236 | $162,376 | 255,709 | $114,067 | 287,714 | $131,593 |
| Pennsylvania | 196,331 | 56,777 | | | | | | | | |
| Indiana | 315,823 | 115,471 | 257,859 | 86,370 | 229,901 | 91,787 | 266,949 | 121,422 | 197,071 | 90,852 |
| Illinois | | | | | | | | | | |
| Ohio | [1]37,487 | 18,931 | 46,400 | 26,586 | 11,594 | 8,434 | [2] | [2] | [3] | [3] |
| Georgia | | | | | | | | | | |
| Texas | 285,000 | 140,875 | 192,000 | 86,640 | 213,500 | 104,625 | 222,000 | 110,400 | 266,500 | 128,925 |
| Kansas | | | | | | | | | | |
| Minnesota | | | | | | | | | | |
| Total | 1,139,239 | $483,006 | 926,091 | $378,533 | 821,231 | $367,222 | 744,658 | $345,889 | 751,285 | $351,370 |

[1] Includes Kentucky.    [2] No production for Texas; the Ga. production is included with Ind., Ill. and Ohio.    [3] No production reported for Ga. and Texas

PRODUCTION OF PORTLAND CEMENT IN THE UNITED STATES, 1910 TO 1914

| | 1910 QUANTITY | 1910 VALUE | 1911 QUANTITY | 1911 VALUE | 1912 QUANTITY | 1912 VALUE | 1913 QUANTITY | 1913 VALUE | 1914 QUANTITY | 1914 VALUE |
|---|---|---|---|---|---|---|---|---|---|---|
| United States production | 76,549,951 | $68,205,800 | 78,528,637 | $66,248,817 | 82,438,096 | $67,016,928 | 92,097,131 | $92,557,617 | 88,230,170 | $81,789,368 |
| Imports | 306,863 | | 164,670 | | 68,503 | 93,558 | 84,630 | 138,187 | 120,906 | 194,053 |
| Total | 76,856,814 | | 78,693,307 | | 82,506,599 | $67,110,586 | 92,181,761 | $92,695,804 | 88,351,076 | $81,983,421 |
| Exports (domestic and foreign) | 2,475,957 | 3,477,981 | 3,135,409 | 4,632,215 | 4,215,532 | 6,160,341 | 2,964,358 | 4,270,666 | 2,140,197 | 3,088,809 |
| Apparent consumption | 74,380,857 | | 75,557,898 | | 78,291,067 | $60,950,245 | 89,217,403 | $88,425,138 | 86,210,879 | $78,894,612 |

PRODUCTION OF PORTLAND CEMENT IN THE UNITED STATES IN 1914, BY STATES

| STATE | PRODUCING PLANTS | QUANTITY (BARRELS) |
|---|---|---|
| Pennsylvania | 20 | 26,570,151 |
| Indiana | 5 | 9,595,923 |
| California | 7 | 5,075,114 |
| New York | 8 | 5,886,124 |
| Illinois | 5 | 5,401,605 |
| Missouri | 5 | 4,723,906 |
| New Jersey | 3 | 3,674,800 |
| Michigan | 11 | 4,285,345 |
| Iowa | 3 | 4,233,707 |
| Kansas | 9 | 3,431,142 |
| Washington | 5 | 2,017,344 |
| Texas | 4 | 2,100,341 |
| Ohio | 5 | 1,962,047 |
| Utah | 3 | 981,100 |
| Other states [1] | 17 | 8,291,521 |
| Total | 110 | 88,230,170 |

[1] Includes Alabama, Arizona, Colorado, Georgia, Kentucky, Maryland, Montana, Oklahoma, Tennessee, Virginia, West Virginia and Nebraska.

PRODUCTION, EXPORTS, AND IMPORTS OF PORTLAND CEMENT IN CANADA, 1912–1913

| | 1912 | | 1913 | |
|---|---|---|---|---|
| | BARRELS | VALUE | BARRELS | VALUE |
| Production | 7,132,732 | $9,106,556 | 8,658,805 | $11,019,418 |
| Imports | 1,434,413 | 1,969,529 | 254,093 | 409,303 |
| Exports | ———— | 2,436 | ———— | 1,739 |

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# CHAPTER VI

## SALINES AND ASSOCIATED SUBSTANCES

UNDER the heading of salines are included the substances, salt, borax, sodium sulphate, sodium carbonate, sodium and potassium nitrate. They are all easily soluble substances, which are either found dissolved in the waters of lakes, seas or oceans, or may be present at times in the rocks or soils. As a result of the leaching of the last-named by underground waters, they may be brought to the surface and deposited there as an incrustation, often found in arid regions; or they may be carried into bodies of water, where they remain in solution until the waters by evaporation leave them behind as residues. Either mode of deposition would be characteristic of an arid climate.

The above outlines in general their manner of formation, although there may be exceptions, as will be seen in subsequent pages.

Bromine, calcium chloride, and iodine are also treated in this chapter, because of the association of the first two with sodium chloride, and of the third with sodium nitrate.

From what has been said above, it will be readily seen that bodies of saline water may not only vary in their degree of concentration, but also in the kind and relative amounts of the different saline substances which they contain in solution.

The analyses on p. 211 will show this variation.

### SALT

**Types of Occurrence.** — Common salt, the chloride of sodium (NaCl), is a widely distributed mineral, being found: (1) in solution in sea water or salt lakes; (2) as solid masses termed rock salt; (3) as natural brine in cavities or pores of the rocks, from which it may exude as salt springs or be tapped by wells; and (4) in marshes and soils.

Although all four of these types of occurrence may serve as commercial sources of salt, it is only the second that is of great economic importance.

ANALYSES OF LAKE AND SEA WATERS

|  | I | II | III | IV | V | VI | VII | VIII | IX |
|---|---|---|---|---|---|---|---|---|---|
| Cl | 55.292 | 55.69 | 70.25 | 67.66 | 42.04 | 53.32 | 3.18 | 23.34 | 32.27 |
| Br | .188 | tr. | 1.55 | 1.98 | .05 | .06 | — | — | .04 |
| SO$_4$ | 7.692 | 6.52 | .21 | .22 | 23.99 | 17.39 | 7.47 | 12.86 | .13 |
| CO$_3$ | .207 | — | tr. | tr. | .37 | — | 38.73 | 23.42 | 22.47 |
| Na | 30.593 | 32.92 | 6.33 | 10.20 | 24.70 | 11.51 | 10.10 | 37.93 | 38.10 |
| K | 1.106 | 1.70 | 1.70 | 1.62 | .54 | 1.83 | 4.56 | 1.85 | 1.52 |
| Ca | 1.197 | 1.05 | 5.54 | 1.51 | 2.29 | — | 12.86 | .04 | .03 |
| Mg | 3.725 | 2.10 | 14.42 | 16.81 | 5.97 | 15.83 | 4.15 | .10 | .35 |
| SiO$_2$ | — | — | tr. | tr. | — | — | 18.95 | .14 | .01 |
| PO$_4$ | — | — | — | — | — | — | — | — | .02 |
| B$_4$O$_7$ | — | — | — | — | — | — | — | .32 | 5.05 |
| Salinity | 3.301[1] | 23.036[1] | 20.709[1] | 24.573[1] | 1.294[1] | 28.50[1] | .73[2] | 51,170[2] | 76,560[2] |

[1] Salinity per cent.        [2] Salinity parts per million.

I. Mean of 77 analyses of sea water. II. Great Salt Lake, the same type as ocean water, but having no carbonates, higher sodium, and lower magnesium. III. Dead Sea water from depth of 20 meters. IV. The same, depth of 120 meters. This lake derives its chlorides and sulphates from leaching of surrounding deposits containing salt and gypsum, but carbonates and gypsum are deposited when the Jordan, its main feeder, enters the lake, hence the dissolved substances are largely chloride. V. Caspian Sea. VI. Karaboghaz Gulf. Note the quantity of Mg and SO$_4$. VII. Lake Tahoe, Calif. VIII. Mono Lake, Calif. This yields trona (Na$_2$CO$_3$·HNaCO$_3$·2H$_2$O), on evaporation, and is typical of lakes occupying closed basins, in regions of great volcanic activity, the products of eruption having been leached, and the waters showing an abundance of sulphate and carbonates of sodium, as well as some chloride. Waters of this type may on evaporation also yield glauber's salt, borates and perhaps even nitrates. IX. Borax Lake, Calif. This is said to derive its boron from hot springs. Analyses I–IX from Clarke, United States Geological Survey, Bulletin 616, 1916.

**Occurrences of Salt in Sea and Lake Waters.** — Salt is present in all ocean water, and also in that of most inland lakes or seas having no outlet, as can be seen from the analyses in the preceding table.

Salt is sometimes obtained by artificial evaporation of the water of either the ocean or salt lakes; but in the United States this plan is profitable only under exceptional conditions, as around San Francisco Bay, California (8), or Great Salt Lake, Utah (21).

**Natural Brines.** — These, sometimes found in porous layers of the rocks, may result either from sea water imprisoned in the layers of sediment or from the solution of rock salt by percolating waters.

**Salt Marshes and Soils.** — When away from the ocean, these owe their salinity to the infiltration of brine from neighboring

saliferous formations. They sometimes represent the site of former salt lakes.

**Rock Salt.** — Rock salt, which is the most important source of commercial salt, occurs commonly in beds of variable thickness and purity interbedded with sedimentary rocks, such as shales or sandstones. It is frequently associated with gypsum, and less commonly with limestone, or easily soluble compounds of magnesia, potash, and lime. Less often, the rock salt is found in domelike masses in stratified rocks, but not conformable with them. Rock salt deposits vary in thickness from a few inches up to as much as 3600 feet (Sperenberg, Germany); and while found in all geological formations from the Cambrian to the Pleistocene, except the Cretaceous, the rock salt of the United States is not found in formations older than the Upper Silurian.

**Origin of Rock Salt** (1–7a). — One of the interesting problems of geology has been to find a correct theory to account for the origin of salt deposits. Such a problem is not as simple as it may appear at first sight, for it must explain (1) the formation of salt deposits of extraordinary thickness, (2) the association of gypsum, either above or below the salt, and (3) the presence of other minerals, which may or may not be saline ones.

*Evaporation Theory.*—It is generally believed that most deposits of rock salt, or of rock salt and gypsum, have been formed by the evaporation of oceans and lakes, this process having gone on during a number of periods from the Silurian to the present.

If a body of salt water is evaporated until precipitation begins, the least soluble salts will generally separate out first, while the most soluble ones do not precipitate until the last.

Assuming then a basin filled with sea water, similar in composition to that of the present oceans, the order of precipitation would be: (1) iron hydroxide; (2) calcium carbonate; (3) calcium sulphate; (4) sodium chloride; and (5) easily soluble compounds, such as sulphates and chlorides of potash and magnesia, etc., these being often of quite complex composition.

This order of precipitation was demonstrated as early as 1849, by J. Usiglio,[1] who made an elaborate series of evaporation tests of Mediterranean water.

The four following analyses, reduced to ionic form and to

[1] Ann. chim. phys., 3d. ser., XXVII: 92, 192, 1849.

percentages of total solids, represent the composition of the sea water evaporated to different densities.[1]

ANALYSES OF MEDITERRANEAN WATER AND BITTERNS

| CONSTITUENTS | A | B | C | D |
|---|---|---|---|---|
| Cl . . . . . . | 54.39 | 56.18 | 49.99 | 49.13 |
| Br . . . . . . | 1.15 | 1.22 | 2.68 | 3.03 |
| SO₄ . . . . . . | 7.72 | 5.78 | 14.64 | 17.36 |
| CO₃ . . . . . . | .18 | ——— | ——— | ——— |
| Na . . . . . . | 31.08 | 32.06 | 20.39 | 12.89 |
| K . . . . . . | .71 | .78 | 2.25 | 3.31 |
| Ca . . . . . . | 1.18 | .26 | ——— | ——— |
| Mg . . . . . . | 3.59 | 3.72 | 10.05 | 14.28 |
| Salinity . . . | 3.766 | 27.546 | 33.712 | 39.619 |

A. The water itself, density 1.0258.  B. Bittern of density 1.21.  C. Bittern of density 1.264.  D. Bittern of density 1.32.

Clarke considers that the bromine determinations are excessive, and that the potash is too low. However, the analyses show: (1) the elimination of calcium as carbonate, and later as sulphate: (2) the subsequent deposition of sodium chloride, and (3) the still later accumulation of the more soluble substances in the mother liquors.

Simple as the phenomena of concentration of sea water would appear, they may yet be complex, and it is possible as well as probable that the order of precipitation is not always in the order of solubility, this being governed to some extent at least by other salts present, degree of concentration  and temperature.

*The Stassfurt Section.*—There are few salt deposits in the world that show such a complete series of precipitates as Usiglio obtained in his experiments, and the most nearly perfect one is that found at Stassfurt, in Prussia, where more than thirty saline minerals are known to occur.

The section which occurs in strata of Upper Permian age is as follows:[1]

    1. Lower Buntsandstein (capping rock)
    2. Red clay and concretions of anhydrite and salt cavities    20 m.
    3. Anhydrite Layer (No. IV) . . . . . . . . .    4 m.

[1] Quoted by F. W. Clarke, U. S. G. S., Bull. 616: 219.
[2] Grabau, Principles of Stratigraphy, p. 371, quoted from Walther.

| | | |
|---|---|---:|
| 4. Rock salt . . . . . . . . . . . . . . | | 40 m. |
| 5. Anhydrite No. III (Pegmatite anhydrite) . . . . | | 5 m. |
| 6. Red clay . . . . . . . . . . . . . . . | | 10 m. |
| 7. Younger rock salt, with about 400 annual rings of polyhalite . . . . . . . . . . . . . | | 80 m. |
| 8. Main anhydrite, No. II . . . . . . . . . . | | 30–80 m. |
| 9. Salt clay, averaging . . . . . . . . . . | | 5–10 m. |
| 10. Carnallite (KCl, $MgCl_26H_2O$) zone . . . . . . | | 15–40 m. |
| 11. Kieserite ($MgSO_4$, $H_2O$) . . . . . . . . | | 18 m. |
| 12. Polyhalite ($K_2SO_4$, $MgSO_4$, $2CaSO_4$, $2H_2O$) zone . | | 35 m. |
| 13. Older rock salt with about 3000 annual rings averaging | | 245 m. |

Nos. 11, 12, 13 have a combined thickness, ranging from 150 to perhaps 1000 meters. (Due perhaps to subsequent thickening.) The annual rings of anhydrite form layers averaging 7 mm. thick, separating the salt into sheets of 8 or 9 mm.

| | | |
|---|---|---:|
| 14. Older anhydrite (I) and gypsum, averaging . . . | | 100 m. |
| 15. Zechstein limestone or dolomite . . . . . . . | | |
| 16. Copper slates . . . . . . . . . . . . | | |
| 17. Zechstein conglomerate . . . . . . . . . . | | |

The lower members, beginning with anhydrite I and ending with the carnallite zone, form one depositional series. Above this, and separated from it by a clay member, is a second series, which lacks the more soluble salts.

Assuming then that the evaporation of a body of sea water may give a graded series as shown above, we must in order to apply it consider the following: (1) The most soluble salts are often wanting; (2) salt and gypsum may occur singly; and (3) many salt and gypsum deposits exhibit great thickness.

The absence of the mother-liquor salts may be explained by assuming that the water never was sufficiently concentrated to cause their precipitation, or if this did occur they may have been redissolved, before a protective covering, such as a clay sediment, was deposited on them.

It is not difficult to conceive that evaporation went on far enough to deposit gypsum, and not enough to precipitate salt, but it is more difficult to explain why salt was sometimes deposited, without any gypsum under it, unless we assume that some of the earlier oceans were of a different composition than existing ones.

The most difficult problem, however, is to explain the formation of very thick deposits of salt between stratified rocks, on the basis of simple evaporation of a body of water.

We can easily understand the formation of a thin bed of salt (or gypsum) in this way, but the insufficiency of this explanation appears, when we find that the formation of 15 feet of gypsum would require the evaporation of 35,000 feet of existing ocean water, and since salt is more soluble, a much greater depth would be required.

*Bar Theory.* — This theory, which seeks to explain the origin of salt deposits of great thickness, was first suggested by G. Bischof,[1] and later elaborated by Ochsenius (1, 4). It assumes a barrier partly shutting out the ocean water. Evaporation on the inclosed area of the sea exceeds the supply of water from inflowing rivers and from the open ocean. Therefore the water on the surface of the sea becomes more dense and settles to the bottom of the basin, being prevented from escape into the open ocean by the barriers at the entrance. As the surface of the bay is lowered by evaporation, ocean waters enter, furnishing a constant supply of salt. If the barrier is complete, forming a bar, sea water may enter only at times of high tide or storm. Eventually evaporation will so concentrate the solution in the bay as to cause the precipitation of sodium chloride and other salts. So long as these conditions lasted, salt would be precipitated, but beds of clayey material would be deposited wherever fine-grained sediment was supplied from the land.

This theory has appealed to many, and the case of Karaboghaz Gulf on the eastern side of the Caspian Sea, is often quoted as illustrative of the deposition of salts according to the hypothesis mentioned above. The Gulf referred to is connected with the sea by a shallow channel through which it is continually supplied by water, the latter delivering a daily estimated load of 350,000 tons of dissolved salts.

Analyses V and VI, p. 211, show the composition of the waters of the sea and the gulf respectively.

The Karaboghaz water contains 285 parts per million of salts, while gypsum will precipitate when the concentration is 202 parts per million. It is a sulphate chloride bittern, in which magnesium replaces lime. We find, then, that while some gypsum is deposited around the margins, the bottom is covered by magnesium sulphate, which in places is 7 feet thick, the total deposit being estimated at 1,000,000,000 tons. The salinity, although

[1] Allgemeine Chemische u. Physikalische Geologie, II: 48, 1864.

increasing, is not yet sufficient to precipitate salt, but the water is sufficiently saline to prevent marine life, so that any animals carried into the gulf die.

Of more interest are the Suez Bittern Lakes, which were formerly a continuation of the present Gulf of Suez, and the Red Sea.

When the gulf became silted up to such an extent that the supply of water from the Red Sea just balanced the evaporation from the surrounding surface of the Gulf, and the salinity was of corresponding magnitude, salt began to deposit and continued until some time after the complete separation from the Gulf of Suez and transformation into the Bittern Lakes. When the Suez Canal was cut, a salt mass 13 km. long, 7 km. broad, and averaging 8 meters in thickness was found. It showed parallel layers separated by thin layers of earthy matter and gypsum.

The operation of the bar theory is probably restricted to arid regions, where there will be little inflow of fresh water into the bay, and where evaporation will be accelerated.

Grabau points out that: (1) the bay must be connected with a large sea; (2) that there should be a contemporaneous fossiliferous series in the sea; and (3) that the salt deposits themselves, as shown by Karaboghaz and Bittern Lakes, should be fossiliferous. If these criteria fail, he believes that the deposit could not have been formed by the evaporation of sea water.

More recently Branson (1a) has suggested a modified bar theory, which postulates overflow basins connected with a main one, the precipitation of the salts taking place in the former.

*Desert Theory.*—This theory has been specially urged by Walther, who saw the objections to the bar theory mentioned above. According to the desert theory, extensive salt deposits might be formed by the leaching of the salt from an older more or less saliferous formation. This salt might be contained in connate waters or in the rocks. If brought to the surface either by evaporation or erosion, it may perhaps first form a crust there, and be later removed by wind or rain. If in a drainless basin, it may accumulate in a body of water within the depression. As the water evaporates, and leaves any of the salt on the drainage slopes, it may still be washed down into the contracting sea or lake, whose salinity gradually increases to such an extent that the salt begins to deposit.

Grabau [1] thinks that the Siluric salt of North America has been derived from connate waters of the Niagara formation, of which a vast amount has been eroded, for he says, " the fact that all around the Salina area, the Upper Siluric strata rest on Niagaran except where the continental deposits of Salina time intervene, and the further fact that no undoubted marine equivalents of the Salinan are known in North America, greatly strengthen the argument for the wholly continental origin of these salt deposits."
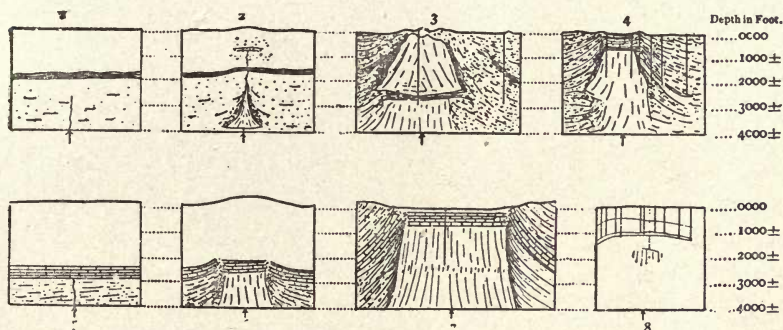


FIG. 70. — Figures representing the origin of dome structure by crystalline growth.
(*After Harris, Econ. Geol. IV.*)

*Dome Theory* (Fig. 70). — In Louisiana and Texas as well as some other localities, there are found great domelike masses of rock salt, accompanied at times by gypsum, limestone, and even sulphur.  G. D. Harris (6) believes they have been formed as follows: Heated waters coming up through underlying formations have become saturated with salt from deposits occurring in them. These waters found a pathway in fissures related to the differential uplifting of the rocks in the Mississippi embayment, and marking the position of anticlines.   Cooling of the uprising solutions caused them to deposit the salt in these fissures.   It is thought that the force exerted by the crystallizing salt was sufficient to lift up the overlying Tertiary and Quaternary beds, as the accumulation went on.[2]   These cores of salt have been pushed up through Cretaceous, Eocene, and even Quaternary strata.

R. T. Hill likewise thought the salt domes due to deposition by ascending solutions, but that the upraising of the surrounding strata was caused by the hydrostatic pressure of the salt solu-

[1] Principles of Stratigraphy, p. 376.
[2] See Day and Becker, Wash. Acad. Sci. Proc., Vol. 7: 288, 1905.

tions and to oil rising through the fractures in the rocks. On the other hand, Hager and Veatch suggested laccolithic intrusions as the cause of the uplift, and recently it is claimed that a hard rock, possibly of igneous origin, has been struck by the drill below one of these domes.

**Distribution of Salt in the United States.** — Salt deposits are found in a number of states, as shown on the map, Fig. 71, but nearly



Fig. 71. — Map showing distribution of salt-producing areas in United States, compiled from various geological survey reports.

63 per cent of the production in 1914 came from two states, New York and Michigan. Most of the domestic production is obtained either in the form of artificial brine obtained by forcing water through wells to the salt, which is then brought up in solution, or else as rock salt, raised through shafts from underground workings.

The range of geologic age of the United States deposits is shown in the following table: —

TABLE SHOWING GEOLOGIC DISTRIBUTION OF SALT IN THE UNITED STATES

| STATE | AGE | STATE | AGE |
|---|---|---|---|
| California | Present | Oklahoma | Permian (?) |
| Kansas | Permian | Pennsylvania | Carboniferous |
| Louisiana | Tertiary | Texas | Cretaceous |
| Michigan | Silurian | Utah | Recent |
|  | Mississippian | Virginia | Mississippian |
| New York | Silurian | West Virginia | Middle Carboniferous |
| Ohio | Silurian |  | (Pottsville) |
|  | Mississippian |  |  |

PLATE XXIV



FIG. 1. — Interior view of salt mine, Livonia, N. Y.    Both roof and pillar are rock salt.
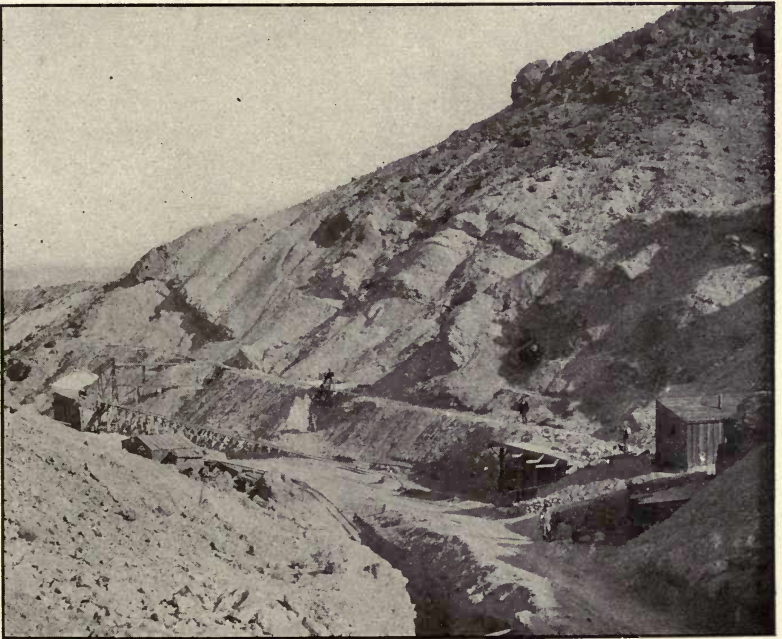


FIG. 2. — Borax mine near Daggett, Cal.    (*Photo. loaned by G. P. Merrill.*)

*New York* (15). — Salt was manufactured from brine springs at Onondaga Lake as early as in 1788; but the presence of rock salt beds was not suspected until 1878, when a bed seventy feet thick was struck in drilling for petroleum in Wyoming County. Since then the development of the salt industry has been so rapid that for some years New York has been one of the two leading salt-producing states.

The salt occurs in lenticular masses interbedded with soft shales of the Salina series (Fig. 72), which also carry gypsum deposits. The outcrop of the formation coincides approximately with the line of the New York Central Railroad, but owing to its soluble character, no salt is found along the outcrops. The beds dip southward from 25 to 40 feet per mile, so that the depth of the salt beneath the surface increases in this direction.

At Ithaca, salt is struck at 2244 feet, and there are seven beds. The thickness of the individual beds varies, but the greatest known thickness is in a well near Tully, where 325 feet of solid salt was bored through. Salt has also been struck by a deep boring in the oil field of southwestern New York at a depth of about 3000 feet. Though most of the New York product is obtained from artificial brines, a small quantity is mined by shafts.

*Michigan* (13). — Salt in Michigan is obtained both from natural brines and from brines obtained by dissolving rock salt, as in New York. The natural brines occur in the sandstones of the Mississippian, the most important locality being in the Saginaw Valley, where the brines are found in the Napoleon or Upper Marshall sandstone. They are remarkable for the large amount of bromine contained, more than half the bromine produced in the United States being obtained here. The vast beds of rock salt which occur in the Salina (Monroe) are exploited along the Detroit and St. Clair rivers and at Manistee and Ludington. The salt is dissolved by lake water pumped down and then re-evaporated, and soda ash (sodium carbonate) is made from the salt to a very great extent, by forced reaction with calcium carbonate.[1]

*Ohio* (16). — Natural brines are obtained from the " Big Salt Sand " (Mississippian) at Pomeroy, Meigs County, but the profit in pumping them lies in the bromine and calcium chloride which they contain. In northeastern Ohio the wells pierce a bed of rock salt in the Salina (Silurian), which is 148 feet thick and interbedded with limestones and shales. The wells are about 1900 feet deep at Cleveland and 2800 feet at Kenmore, Summit County.

[1] Private communications from Dr. A. C. Lane.
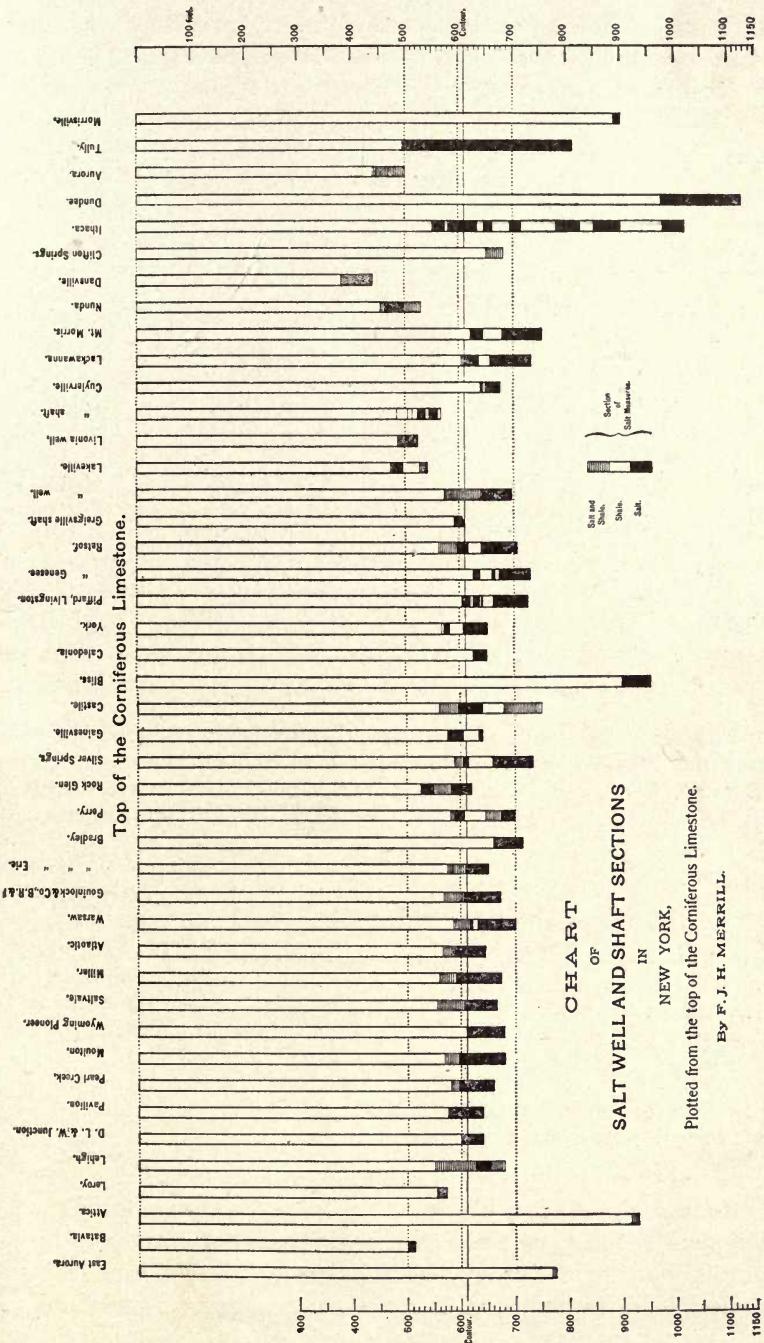
Fig. 72. — Section showing number and thickness of salt beds at different localities in New York State. (After Merrill, N. Y. State Mus. Bull. 11, 1893.)

The two following analyses are of interest, partly on account of their completeness. The absence of sulphate in the first is noticeable.

ANALYSES OF OHIO BRINES

|  | | GRAMS PER LITER | |
|---|---|---|---|
|  | | I | II |
| SiO₂ . . . . . . . . . . . . . . . | | .012 | .000 |
| Fe₂O₃, Al₂O₃ . . . . . . . . . . . | | .083 | .000 |
| CaCl₂ . . . . . . . . . . . . . . | | 14.340 | 1.033 |
| MgCl₂ . . . . . . . . . . . . . | | 5.59 | .462 |
| NaCl . . . . . . . . . . . . . . | | 84.3 | 310.977 |
| KCl . . . . . . . . . . . . . . . | | .114 | .713 |
| MgBr₂ . . . . . . . . . . . . . | | .155 | .012 |
| BaCl₂ . . . . . . . . . . . . . . | | .343 | .000 |
| NaI . . . . . . . . . . . . . . . | | .004 | .000 |
| SrCl₂ . . . . . . . . . . . . . . | | .000 | .089 |
| CaSO₄ . . . . . . . . . . . . . | | .000 | 4.857 |
| LiO₂ . . . . . . . . . . . . . . | | tr. | tr. |
| Sp. gr. . . . . . . . . . . . . . | | 1.075 | 1.204 |

I. Natural brine, Pomeroy, O.   II. Artificial brine, Cleveland, O.

*Virginia* (23). — Salt, associated with gypsum, is obtained by wells from the Mississippian shaly limestones in the Holston Valley near Plasterco, Washington County (Fig. 73). The product is used entirely in the manufacture of alkali (22). The geology is referred to under Gypsum (p. 252).
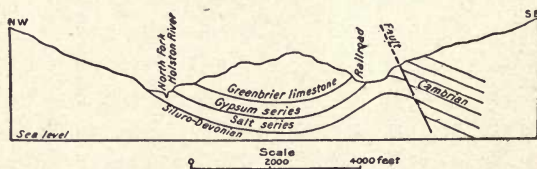


FIG. 73. — Section across Holston and Saltville valleys, midway between Saltville and Plasterco, Va. (*After Eckel, U. S. Geol. Surv., Bull.* 223.)

*West Virginia* (24). — Brine is obtained from the Carboniferous (Pottsville) and Mississippian (Berea) in that portion of the state adjoining the Meigs County salt district of Ohio. Pennsylvania supplies similar brines.

*Kansas* (9). — Salt is found in this state under the following conditions: (1) in the northern and central parts of Kansas as brine in salt marshes derived by leaching from the saliferous Dakota shales; (2) a limited amount in eastern Kansas from wells sunk in

the Carboniferous; (3) in the Permian of south central Kansas as beds of rock salt (Fig. 74). At the present time the rock salt is the most important commercial source, being obtained in part as artificial brines and in part as rock salt. The thickness of the salt varies, the greatest aggregate thickness recorded in any well being 324 feet. The deposits thin out to the eastward, and the north and
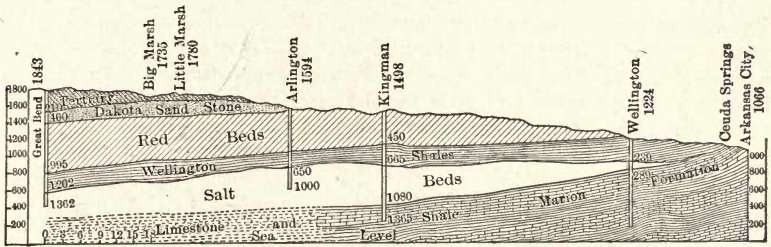


FIG. 74.—Geologic section from Arkansas City to Great Bend, Kas., showing occurrence of rock salt. (*Kas. Geol. Surv., Min. Res. Bull.*, 1898.)

south limits are fairly well known, but the western boundary remains undefined. The absence of gypsum in close association with the salt is a significant fact, but farther south it is found at a lower horizon, and the separation of the two is explained by a shifting sea bottom, during deposition.

*Louisiana* (10, 11, 12). — Brine occurs in springs and wells in the Cretaceous area of northern Louisiana, but the most important source of salt is in the extensive beds of rock salt found in the southern portion of the state. These underlie a series of low knolls, called the Five Islands (Fig. 75), and are covered by a series of clay, sand, and gravel beds. The salt occurs as great dome-like masses which Harris thinks have been pushed up into Cretaceous, Tertiary, and Quaternary beds (p. 217). Salt is mined on Grande Côte or
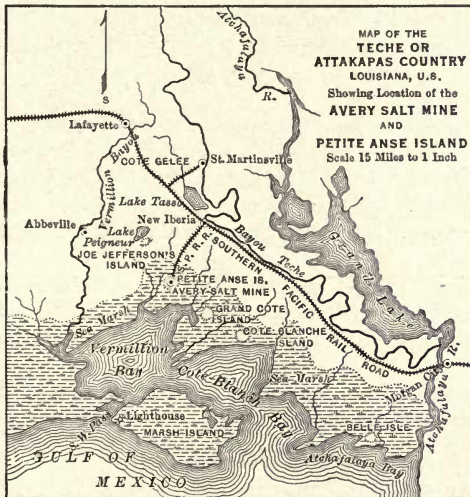


FIG. 75. — Map showing location of Petite Anse and other " salt islands," Louisiana. (*After Pomeroy.*)

Weeks Island and also on Avery Island.   The age of the salt beds is
pre-Pleistocene.   Although the amount of rock salt present is
evidently great, borings in one case revealing a thickness of 1756
feet of solid salt, these deposits yield but a small percentage of
the country's output.

*Other Western States.* — In California the main supply of salt is obtained
by evaporating sea water (8), an elaborate system of ponds, covering thou-
sands of acres, having been built on San Francisco Bay.   These are filled
at high tide, and the brine evaporated by solar heat, although artificial heat
is used at some of the plants.   A large deposit of salt was formerly worked
at Salton Lake.   This is a depression 27 miles long, $3\frac{1}{2}$ to 9 miles wide, and
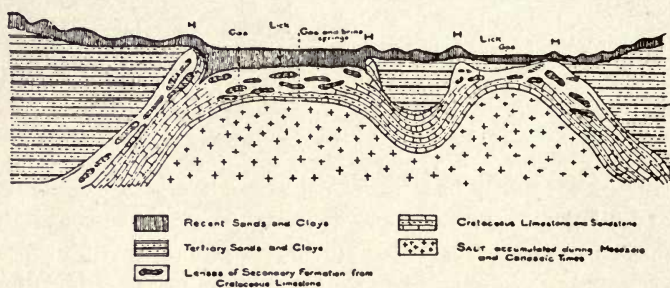


FIG. 76.—Section illustrating dome salt occurrence, under Cedar Lick, La.   (*After
Harris, La. Geol. Surv., Bull. 7.*)

at its lowest point 280 feet below sea level.   The deposit is formed by evapo-
ration of the lake waters, which are fed by saline springs from the surround-
ing foothills.   The salt, which has accumulated to a depth of 6 inches, is
gathered by scrapers.   Salt is also found in marshes, springs, or wells in a
number of other localities in California (8).

In Idaho brine salt is obtained in Bear Lake and Bannock counties,
near the Wyoming line; some also is produced in Churchill and Washoe
counties, Nevada, Torrance County, New Mexico, and from saline lakes
in several parts of Texas.   Rock salt has been found at several localities in
Texas, notably in Mitchell County, and under the oil beds at Beaumont,
but none is yet produced.

In Utah, some salt is obtained by evaporating the waters of Great Salt
Lake (21), and brines from several other localities.   An enormous deposit
of pure salt is reported from the west side of the Utah desert, near the
Nevada state line.[1]

Throughout the Red Beds area of western Oklahoma, and in parts of
eastern Oklahoma, there are numerous salt springs and seepages, but Fer-
guson is the only locality of importance where salt is made (18).

[1] U. S. Geol. Surv., Min. Res., 1908.

**Canada** (27). — The only salt deposits now being exploited in Canada are those of southwest Ontario, where the material is obtained from the Salina formation. There appear to be a number of beds of varying thickness, interstratified with dolomite and shale. The average depth of the salt is over 1000 feet, and increases gradually to the south.

In the other Canadian provinces salt springs are known to occur at many points, but no deposits of rock salt have been found except at two points, viz., near McMurray, Alberta, and at Kwinitza, B. C.

**Other Foreign Deposits** (12). — Rock salt deposits are widely distributed, but only the most important world's producers need be mentioned.

In England it is found in the Upper Triassic marls, the Cheshire district having two important deposits lying respectively from 120 to 210 feet, and 240 to 300 feet, below the surface. Many large deposits are also found in the Triassic as well as the Permian of Germany. Those of Stassfurt, are specially well known. The German deposits may occur as lenses, beds or domes. France is another important producer, rock salt occurring as flattened lenses in saline clays of the Lorraine Triassic, and in rocks of the same age in the Pyrenees.

In Galicia the Miocene deposits of Wieliczka are among the most curious known. The upper part of the mass consists of irregular bodies of salt with blocks of sandstone, limestone and granite in saline clays, while below it is stratified salt associated with clay and anhydrite. Russia contains abundant supplies in the southeastern and southern part of the country. Of the Asiatic deposits the most important, perhaps, are those lying along the Salt Range of northwestern Punjab, where the beds, underlying gypsum, have been much disturbed by tilling and folding.

**Analyses of salt.** —

ANALYSES OF ROCK SALT FROM VARIOUS LOCALITIES

| LOCALITY | SODIUM CHLORIDE | CALCIUM CHLORIDE | MAGNESIUM CHLORIDE | CALCIUM SULPHATE | MAGNESIUM SULPHATE | ALUMINA, SILICA, IRON | WATER | AUTHORITY |
|---|---|---|---|---|---|---|---|---|
| Retsof, N. Y. . . . | 98.701 | Tr. | — | .446 | — | .743 | Tr. | F. E. Englehardt |
| Pearl Creek, N. Y. . | 96.885 | .157 | .103 | .437 | — | 1.21 | 1.21 | F. E. Englehardt |
| Petite Anse, La. . . | 98.90 | .146 | .022 | .838 | — | .014 | .08 | P. Collier |
| Saltville, Va. . . . | 99.084 | Tr. | — | .446 | — | .47 | — | C. B. Hayden |

**Extraction.** — When salt forms underground deposits, it has to be extracted either by a process of solution or mining. In the former case water is forced down to the salt bed through a well, for

ANALYSES OF SOLID MATTER OF BRINES FROM VARIOUS LOCALITIES

| LOCALITY | SODIUM CHLORIDE | CALCIUM CHLORIDE | MAGNESIUM CHLORIDE | CALCIUM SULPHATE | MAGNESIUM SULPHATE | ALUMINA, SILICA, IRON | PERCENTAGE SOLIDS IN BRINE | SPECIFIC GRAVITY OF BRINE | AUTHORITY |
|---|---|---|---|---|---|---|---|---|---|
| Warsaw, N. Y. | 97.60 | .51 | .20 | 1.68 | — | — | 26.34 | 1.204 | Englehardt |
| Syracuse, N.Y. | 95.966 | .90 | .69 | 2.54 | — | .004 | 18.50 | 1.142 | G. H. Cook |
| Saginaw, Mich. | 82.14 | 12.39 | 5.01 | .46 | — | — | 21.32 | — | C. A. Goessman |
| Bay City, Mich. | 91.95 | 3.19 | 2.48 | 2.39 | — | — | 16.61 | — | C. A. Goessman |
| Kanawha, W. Va. | 79.45 | 16.48 | 4.07 | — | — | — | 9.20 | 1.073 | G. H. Cook |
| Pittsburg, Pa. | 81.27 | 13.93 | 4.80 | — | — | — | 2.80 | 1.019 | G. H. Cook |
| Saltville, Va. | 97.792 | .033 | — | 2.17 | — | Tr. | 24.60 | — | C. B. Hayden |
| Great Salt Lake | 98.10 | .322 | .000 | .364 | .021 | .214 | — | — | J. E. Talmadge |

the purpose of dissolving the salt, the brine being brought to the surface and evaporated, sometimes by solar heat, but more commonly by artificial means. In the latter case a shaft is sunk to the salt bed, and the material mined like coal and brought to the surface in lumps, known as rock salt. Natural brines are pumped to the surface for evaporation. In the evaporation of brine care has to be taken to separate the gypsum and other soluble impurities present, which precipitate before the salt does.

**Uses.** — Salt is largely used in the meat-packing business and the manufacture of dairy products, as well as for domestic purposes. Therefore a number of different grades are called for, known under various names, such as table, dairy, common, fine, packers, solar, rock, milling, etc. Large quantities of salt are also consumed in the manufacture of soda ash, sodium carbonate, caustic soda, and other sodium salts. The chlorination of gold ores calls for an additional large amount.

**Production of Salt.** — The increase in the amount of salt produced has been very marked, but it has been accompanied by a decrease in price, as shown in the statistics given below: —

PRODUCTION OF SALT IN UNITED STATES, 1885 TO 1910

| YEAR | BARRELS | VALUE | YEAR | BARRELS | VALUE |
|---|---|---|---|---|---|
| 1885 . . | 7,038,653 | $4,825,345 | 1900 . . | 20,869,342 | $6,944,603 |
| 1890 . . | 8,876,991 | 4,752,286 | 1905 . . | 25,966,122 | 6,095,922 |
| 1895 . . | 13,699,649 | 4,423,084 | 1910 . . | 30,305,656 [1] | 7,900,344 |

[1] Includes production of Hawaii and Porto Rico.

PRODUCTION OF SALT BY STATES FROM 1910 TO 1914, IN BARRELS

| STATE | 1910 | | 1911 | | 1912 | |
|---|---|---|---|---|---|---|
| | QUANTITY | VALUE | QUANTITY | VALUE | QUANTITY | VALUE |
| New York . . | [1]11,642,520 | $2,585,739 | [1]11,234,928 | $2,538,151 | 10,527,221 | $2,615,334 |
| Michigan . . | 9,452,022 | 2,231,262 | 10,320,074 | 2,633,155 | 10,946,739 | 2,974,429 |
| Ohio . . . . | 3,673,850 | 951,963 | 4,302,507 | 1,100,453 | 5,269,179 | 1,364,136 |
| Kansas . . . | 2,811,448 | 947,369 | 2,159,859 | 806,027 | 2,573,626 | 844,292 |
| Louisiana . . | [2] | [2] | [2] | [2] | [3] | [3] |
| California . . | 937,514 | 519,667 | 1,086,163 | 555,359 | 1,090,000 | 620,196 |
| West Virginia . | 155,625 | 62,955 | 183,379 | 78,805 | 139,121 | 66,023 |
| Texas . . . . | 382,164 | 272,568 | 385,200 | 299,537 | 373,064 | 290,328 |
| Utah . . . . | 249,850 | 185,869 | 272,420 | 171,268 | 283,293 | 154,734 |
| Hawaii . . . | 11,450 | 9,570 | 8,463 | 11,850 | 8,286 | 9,180 |
| Idaho . . . . | 885 | 1,127 | 314 | 532 | [3] | [3] |
| Porto Rico . . | [3] | [3] | [3] | [3] | [3] | [3] |
| Nevada . . . | 17,535 | 10,600 | 12,856 | 16,952 | 12,536 | 15,752 |
| Oklahoma . . | 2,564 | 881 | 500 | 431 | [3] | [3] |
| Other states . | [4]968,229 | 120,774 | [4]1,217,305 | 133,172 | [5]2,101,743 | 448,368 |
| Total . . | 30,305,656 | $7,900,344 | 31,183,968 | $8,345,692 | 33,324,808 | $9,402,772 |

| STATE | 1913 | | 1914 | |
|---|---|---|---|---|
| | QUANTITY | VALUE | QUANTITY | VALUE |
| New York . . | 10,780,514 | $2,865,187 | 10,389,314 | $2,824,733 |
| Michigan . . | 11,528,800 | 3,293,032 | 11,670.976 | 3,299,005 |
| Ohio . . . . | 5,310,135 | 1,318,156 | 5,482,826 | 1,320,554 |
| Kansas . . . | 2,698,079 | 860,404 | 2,967,864 | 924,550 |
| Louisiana . . | [3] | [3] | [3] | [3] |
| California . . | 1,082,993 | 759,485 | 1,100,443 | 856,861 |
| West Virginia . | 113,921 | 63,803 | 145,429 | 78,036 |
| Texas . . . . | 355,529 | 278,008 | 334,979 | 251,493 |
| Utah . . . . | 330,443 | 191,686 | 375,457 | 231,512 |
| Hawaii . . . | 6,071 | 5,950 | — | — |
| Idaho . . . . | [3] | [3] | 300 | 520 |
| Porto Rico . . | [3] | [3] | [3] | [3] |
| Nevada . . . | 8,971 | 7,947 | 4,436 | 2,448 |
| Oklahoma . . | [3] | [3] | [3] | [3] |
| Other States . | [5]2,183,842 | 479,481 | [6]2,332,649 | 481,646 |
| Total . . | 34,399,298 | $10,123,139 | 34,804,683 | $10,271,358 |

[1] Includes Louisiana.

[2] Included in New York.

[3] Included in other states.

[4] Includes New Mexico, Pennsylvania, Porto Rico, and Virginia.

[5] Includes Idaho, Louisiana, New Mexico, Oklahoma, Pennsylvania, Porto Rico, and Virginia.

[6] Louisiana, New Mexico, Oklahoma, Pennsylvania, Porto Rico, Virginia.

The exports in 1914 were 164,589,012 lb., valued at $586,055. The imports for the same year amounted to 261,609,200 lb., valued at $380,083, this being less than any year since 1902.

*Canada.* The production of salt in Canada in 1913 was 100,791 short tons, valued at $491,280, and in 1914, 107,038 short tons, valued at $493,648. The entire product came from Ontario.

The exports from Canada in 1914 amounted to 952,700 lb.,

valued at $5,229, while the imports for the year 1913 were
144,446 tons, valued at $565,283.

PRODUCTION OF SALT IN PRINCIPAL COUNTRIES OF THE WORLD

| COUNTRY | YEAR | METRIC TONS |
|---|---|---|
| United States . . . . . . . . . . | 1912 | 4,200,000 |
| Great Britain . . . . . . . . . | 1912 | 2,156,000 |
| Germany . . . . . . . . . . | 1911 | 2,087,000 |
| Russia . . . . . . . . . . . | 1910 | 2,047,000 |
| British India . . . . . . . . . | 1911 | 1,495,000 |
| France . . . . . . . . . . . | 1912 | 1,098,000 |
| Japan . . . . . . . . . . . | 1911 | 568,000 |
| Austria . . . . . . . . . . . | 1911 | 342,000 |
| Hungary . . . . . . . . . . | 1911 | 239,000 |
| Canada . . . . . . . . . . . | 1912 | 86,200 |
| Italy . . . . . . . . . . . | 1912 | 524,000 |
| Spain . . . . . . . . . . . | 1912 | 627,000 |
| Greece . . . . . . . . . . . | 1911 | 60,000 |
| Algeria . . . . . . . . . . . | 1912 | 27,000 |

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## BROMINE

**Sources.** — Bromine occurs in nature combined with some metals, as in the minerals Embolite, Ag (Cl, Br), Bromyrite (Ag Br), and Iodobromite (2 Ag Cl, 2 Ag Br, Ag I), which theoretically contain 25, 42.6, and 17.8 per cent respectively of bromine. None of these are commercial sources. Sea water contains about .06 gram per liter, and at Stassfurt, Germany, the mother liquor obtained from salt refining contains from 15 to 35 per cent bromine.

In the United States bromine is extracted from natural brines found at several geological horizons, but not all rock brines contain it, some, as those of New York State, being very low in it.

At the present time Ohio, West Virginia, Pennsylvania, and Michigan brines are used, the first bromine having been manufactured in 1846 at Freeport, Pennsylvania.

At Pomeroy and Syracuse, Meigs County, Ohio, and at Hartford and Mason, Mason County, West Virginia, it is obtained as a by-product of the salt industry, the brine coming from the Pottsville horizon (Big Salt Sand).

A plant has been operated also at Pittsburg, Pennsylvania, obtaining the bromine from brines in the Pocono sandstone. That manufactured in Michigan comes from the Marshall sandstone of the Lower Carboniferous, the brine containing from .1 to .3 per cent bromine.

**Uses.** — Bromine is used for making bromides of potash, soda, and ammonia, for medicinal purposes and photographic reagents. A small amount is employed in the preparation of coal-tar colors known as Eosine and Hoffman's Blue. As a chemical reagent, it is utilized for precipitating manganese from acetic acid solutions, for the conversion of arsenious into arsenic acid, etc. It may also be used as a disinfectant when dissolved in water, and has been employed in gold extraction.

PRODUCTION OF BROMINE IN UNITED STATES

| Year | Pounds | Value | Year | Pounds | Value |
|---|---|---|---|---|---|
| 1895 | 517,421 | $134,343 | 1909 | 569,725 | $ 57,600 |
| 1900 | 521,444 | 140,790 | 1910 | 245,437 | 31,684 |
| 1905 | 1,192,758 | 178,914 | 1911 | 651,541 | 110,902 |
| 1906 | 1,283,250 | 165,204 | 1912 | 647,200 | 145,805 |
| 1907 | 1,379,496 | 195,281 | 1913 | 572,400 | 115,436 |
| 1908 | 760,023 | 75,783 | 1914 | 576,991 | 203,094 |

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## CALCIUM CHLORIDE

A considerable quantity of calcium chloride is obtained from natural brines in connection with the salt and bromine industry of Michigan, Ohio, and West Virginia. The figures of production since 1909 are given below, but these do not include the calcium chloride obtained in connection with the manufacture of soda, for, in that case, it is not an original constituent of the brine.

The following are partial analyses of brines supplying calcium chloride:

|  | I | II | III |
|---|---|---|---|
| Sodium chloride . . . . . . . . . . . | 60.172 | 84.30 | 141.00 |
| Calcium chloride . . . . . . . . . . | 15.0103 | 14.34 | 83.00 |
| Potassium chloride . . . . . . . . . | .5700 | 0.114 | —— |
| Magnesium chloride . . . . . . . . . | 4.9692 | 5.50 | 31.00 |
| Barium chloride . . . . . . . . . . | .7447 | 0.343 | |
| Strontium chloride . . . . . . . . . | .2013 | .257 | |
| Sodium iodide . . . . . . . . . . . | .0009 | .004 | |
| Sodium bromide . . . . . . . . . . . | .2238 | [1].155 | |

[1] Magnesium bromide.

I. Malden, W. Va., Parts per 1000 by weight (Ref. 3);  II. Pomeroy, O., Grams, per liter of brine (Ref. 1);  III. Napoleon sandstone brine, Saginaw Valley, Mich.

QUANTITY AND VALUE OF CALCIUM CHLORIDE MARKETED IN UNITED STATES, 1909–1914, IN SHORT TONS

| YEAR | QUANTITY | VALUE | YEAR | QUANTITY | VALUE |
|---|---|---|---|---|---|
| 1909 . . | 12,853 | $63,198 | 1912 . . | 18,550 | $117,272 |
| 1910 . . | 10,971 | 74,713 | 1913 . . | 19,611 | 130,030 |
| 1911 . . | 14,606 | 91,215 | 1914 . . | 19,403 | 121,766 |

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## SODIUM SULPHATE

**Occurrence and Distribution.**—The hydrous sulphate, mirabilite or Glauber salt ($Na_2SO_4 + 10 H_2O$), is a white saline material, which is collected on or near the surface of some alkaline marshes in desert regions.    It may also be extensively deposited in some saline lakes, its precipitation preceding that of salt, and being affected more or less by the season of the year; for since it is much more soluble in warm than in cold water, the difference in temperature between summer and winter may cause its separation and re-solution (5).    The phenomenon has been noticed in Great Salt Lake (4).    Exposure to warm, dry air causes the mirabilite to lose its water and change to thenardite.

No production of sodium sulphate is recorded by the United States Geological Survey.    It is known to occur at several localities in Wyoming (3), and some of the deposits at least owe their origin to the leaching of sediments.    The deposit, which may be as much as 15 feet thick, consists chiefly of mirabilite, epsomite, natrona, and halite (7).    Deposits of some extent have also been noted in the lowest portion of the Carriso Plain, along the northeast boundary of San Luis Obispo County, California (6). In this lake, which remains practically dry, except in very wet seasons, there have been deposited a series of saline beds, whose chief constituent is sodium sulphate.    The salt has been derived from the leaching of soft beds of conglomerate, sandstone, and shale in the surrounding hills.

There is little present demand for sodium sulphate or " salt cake."    It is used in glass making, ultramarine manufacture, dyeing and coloring, as well as to some extent in medicine (Glauber's salt).

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    428, 1914.    (Calif.)

## SODIUM CARBONATE

Sodium carbonate, or natural soda, is obtained by the evaporation of the waters of alkali lakes, or is found as a deposit on or near the surface of alkaline marshes in arid regions. It is usually a mixture of sodium carbonate and bicarbonate in varying proportions, as well as impurities such as sodium chloride, sodium sulphate, borax, and sodium nitrate.

Sodium carbonate has been obtained from Owens Lake in California. An analysis of the waters by Chatard yielded: $SiO_2$, .220; $Fe_2O_3$, $Al_2O_3$, .038; $CaCO_3$, .055; $MgCO_3$, .479; $KCl$, 3.137; $NaCl$, 29.415; $Na_2SO_4$, 11.080; $Na_2CO_3$, 26.963; $NaHCO_3$, 5.725. The soda is purified by fractional crystallization. Soda is also known to occur in Oregon and Nevada.

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## SODA NITER [1]

Soda niter, or Chile saltpeter ($NaNO_3$, with 63.5 per cent $N_2O_5$ when pure), is found in San Bernardino and Inyo counties, California, along the shore lines marking the boundary of Death Valley in Eocene times (1). It occurs in peculiar rounded hills of Eocene clay, the niter being found as a layer near the surface or distributed through the clay. Very little soda niter is obtained from this source, and the main supply of this country continues to come from Chile, where extensive deposits are found in the desert region west of Iquique. There the niter (*caliche*) forms a bed 6 to 12 feet thick, under a cap of conglomerate (*costra*) 1 to 18 feet thick. The origin of this deposit is interesting, and has caused considerable discussion. One theory quite generally accepted is that the niter was formed primarily by the slow oxidation in air of guano or other nitrogenous organic matter in contact with alkali; a second theory refers its origin to the oxidation of organic materials and ammonia, by microscopic organisms known as nitrifying germs.

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[1] The term *niter*, when used alone, refers to potash niter.

## BORATES

Various compounds of boron are known in nature. When contained in complex borosilicates the material is of no commercial value as a source of borax. It may also be present in volcanic emanations and hot spring waters, but while in the United States these are of no importance, in Tuscany, Italy, the gases, steam and hot waters are of value, the waters being caught in basins to evaporate, while the borax crystallizes out.

In the United States the chief minerals containing boron are borax, tincal, or sodium biborate, $Na_2B_4O_7, 10 H_2O$; colemanite, $Ca_2B_6O_{11}, 5 H_2O$; ulexite, $CaNaB_5O_9, 8 H_2O$; boracite, $2 Mg_3B_8O_{15}, MgCl_2$. These minerals are found usually as incrustations in alkaline marshes, in lake waters of arid regions, or as massive deposits.

**Distribution in the United States.** — Deposits of borax (Fig. 77) have up to the present time been discovered only in California (1, 2, 5), Nevada, and Oregon (3, 8). Borax was originally obtained by evaporation from the waters of Clear Lake,[1] north of San Francisco, being produced in commercial quantities in 1864, and the solution was enriched by crystalline borax obtained from the marshes surrounding the lake. This and other lakes of California were worked until the discovery of large deposits of nearly pure borax in alkaline marshes of eastern California and western Nevada in the early seventies, the mineral most characteristic of these being ulexite. Still later there came the development north of Daggett, Calif., of bedded muds and clays with low grade borates of lime, but even these had to give way to the subsequently developed colemanite deposits.

Colemanite was first discovered in Death Valley, Inyo County, Calif., in 1882, and in the following year 12 miles north of Daggett, San Bernardino County, Calif., this being followed by its discovery at many places in similar formations in the same general regions where the marsh and mud borax had been worked.

The colemanite, which has been referred to as a bedded deposit, between sands and clays, was supposed by Campbell to have been deposited in a series of Tertiary lakes (2), but the beds are in many instances tilted, due to violent crustal movements, and

[1] An analysis of the solids of hot spring from sulphur bank on margin of Clear Lake yielded Cl, 16.49; I, .03; $CO_2$, 21.96; $B_4O_7$, 25.61; Na, 24.99; $NH_4$, 7.88; $Al_2O_3$, .40; $SiO_2$, 2.64. (U. S. Geol. Surv., Bull. 330: 154.)
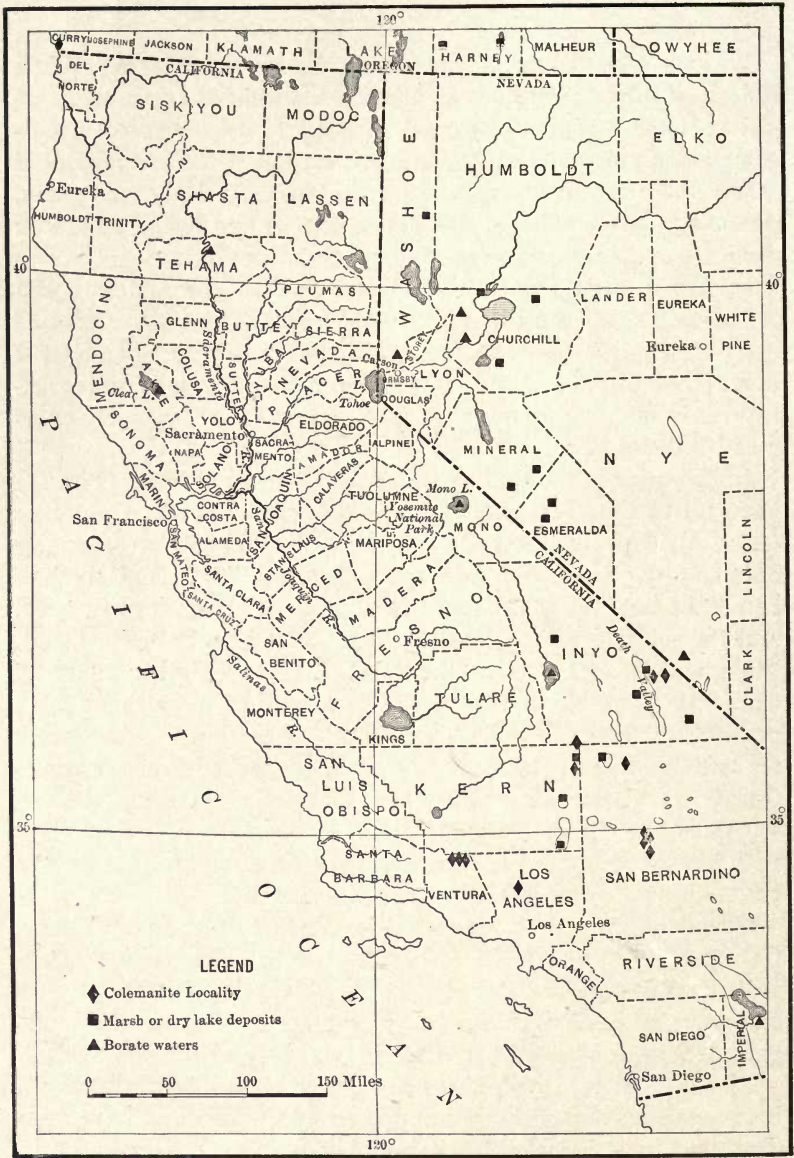
Fig. 77. — Map showing borax deposits in the United States. (*After Yale and Gale, U. S. Geol. Surv., Min. Res., 1913.*)

sedimentation was supposed to have been interrupted at intervals.

A more recent study of the deposits in Ventura County, Calif., by Gale (3a), gives the following general section:

Shale and some sandstone.................. 300 feet
Basaltic lava flows, with intercalated lenses of
    shale and limestone..................... 600    "
Shale......................................... 600    "
Conglomerate, bowlders, or cobbles of light
    granitic rock cemented.................. 600    "
Other sedimentary rocks below.

The beds, which are believed to be of Miocene age, are folded and faulted, and the most valuable borate deposits are included
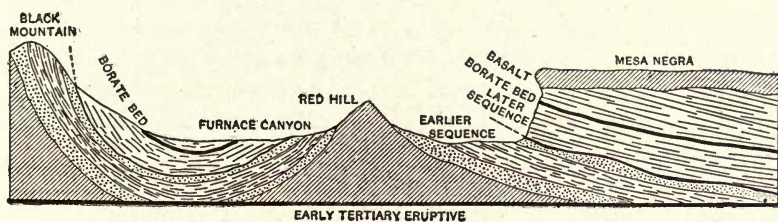


FIG. 78. — Cross section of Furnace Cañon, Calif., borate deposits. (*After Keyes, Amer. Inst. Min. Engrs.*, 1909.)

in the layers of shale and limestone found within the basalt, though some may be found in the shales above and below the latter.

The colemanite is in somewhat irregular masses, lacking a stratified structure, and associated with travertine-like limestone. Selenite of vein-like character is also present, and there is a practical absence of any other salines.

Gale does not therefore believe the colemanite to have been precipitated in lake basins, but suggests that emanations of boric acid both contemporaneous with, and, possibly, subsequent to the basalt extrusion, attacked the limestone, replacing carbonic acid with boric acid, thus forming the colemanite.

The material mined showed varying degrees of purity ranging from 20–25 per cent $B_2O_3$, to nearly 40 per cent as shipped.

In this connection it is interesting to refer to an occurrence of

the boron mineral pandermite, found in layers and stocks in beds of gypsum, in Asia Minor, and to which a fumarolic origin has been assigned.[1]

The reduction of colemanite to borax and boric acid is accomplished by reaction with sodium carbonate, forming the soluble borax, which is crystallized in vats.

In 1913, small quantities only were produced in Ventura County, the supply coming mainly from a few mines in Inyo and Los Angeles counties, California.

**Uses.** — The borax-bearing minerals are utilized chiefly for the manufacture of borax and boracic acid. Borax is used in industrial chemistry, in medicine, and as a laboratory reagent. It is also employed in the assaying of gold and silver ores, in soldering brass, and welding metals.

Boric acid is used in the manufacture of borax, in colored glazes for decorating iron, steel, and metallic objects, in enamels and glazes for pottery, in making flint glass, as an antiseptic, and as a preservative for food. Chromium borate makes a green pigment used in calico printing, and manganese borate is sometimes employed as a drier in paints and oils. Borax is also extensively used in numerous cosmetics.

The chief refiners are the Pacific Coast Borax Company with works at Bayonne, New Jersey, and Alameda, California, and the Sterling Borax Company of San Francisco, California.

**Production of Borax.** — The California colemanite deposits form the main source of domestic supply, the output being derived from the counties of Los Angeles, Inyo, and Ventura. The marsh deposits of Nevada are no longer productive.

The production of borax in California from 1909 to 1914 was as follows, the values being based on the boric-acid content of the corresponding number of crude tons of colemanite or borate of lime:

PRODUCTION OF BORAX IN CALIFORNIA

| Year | Short Tons | Value | Year | Short Tons | Value |
|------|-----------|-------|------|-----------|-------|
| 1909 . . | 41,434 | $1,534,365 | 1912 . . | 42,315 | $1,127,813 |
| 1910 . . | 42,357 | 1,201,842 | 1913 . . | 58,051 | 1,491,530 |
| 1911 . . | 53,330 | 1,569,151 | 1914 . . | 62,400 | 1,464,400 |

[1] Coulbeaux, M., Ann. Mines, Onz. ser, II: 294, 1912.

IMPORTS FOR CONSUMPTION OF BORAX AND BORATES INTO THE UNITED
STATES, 1910-1914, IN POUNDS

| YEAR | BORAX | | BORATES, CALCIUM AND SODIUM (CRUDE) AND REFINED SODIUM BORATE | | BORIC ACID | |
|---|---|---|---|---|---|---|
| | QUANTITY | VALUE | QUANTITY | VALUE | QUANTITY | VALUE |
| 1910 . . . . | 6860 | $1170 | 563 | $  66 | 336,466 | $11,164 |
| 1911 . . . . | 9580 | 732 | 28,815 | 5230 | 458,900 | 17,666 |
| 1912 . . . . | 9280 | 636 | 16,091 | 1861 | 232,545 | 8,752 |
| 1913 . . . . | 4215 | 477 | 7,900 | 1025 | 423,215 | 16,932 |
| 1914 . . . . | 220 | 29 | 3,862 | 546 | 425,241 | 18,837 |

*World's Production.* Chile and the United States are the
world's leading producers, each producing in round numbers
from 40,000 to 50,000 metric tons, mainly calcium borates.
Turkey is probably third, with a reported average production of
14,000 tons boracite. Peru, Bolivia and Italy are next with
2000 to 3000 tons each.

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I, No. 4: 6, 1904. (Oregon.) 9. Yale and Gale, U. S. Geol. Surv.,
Min. Res. 1913: 523, 1914. (Good bibliography.)

### IODINE

**Sources.** — This element is known to occur in sea water, in min-
eral springs, and in a few rare minerals, such as the iodides of
silver, copper, and lead. In the Chilean nitrate deposits it exists as
lautarite $[Ca(IO_3)_2]$ and as a double salt of calcium iodate and
chromate $[Ca(IO_3)_2, CaCrO_4]$. Some Silesian zinc ores and some
of the phosphate rocks of France show small percentages of the
element. It has been found in the ashes of sea weeds, and in some

oil-well waters, certain Pennsylvania ones carrying .5587 gram of calcium iodide per liter.

At present the entire production of iodine comes from two sources, viz., the ashes of sea weeds and the niter deposits of Chile.

REFERENCES ON IODINE

1. Clarke, U. S. Geol. Surv., Bull. 616: 17, 119, 183, 1916. (Many references.) 2. Min. Indus., XVI: 582, 1907.

## POTASH

The occurrence of this substance is referred to in this chapter, because the world's main source of supply at the present time is obtained from deposits of salines. The element potassium is, however, a constituent of other minerals not to be classed as salines, but for purposes of convenience they will be discussed here.

Practically all the potash salts of mineral origin consumed in North American industries are at present imported from abroad, chiefly from Germany. In 1913 the U. S. imports of potash salts, not including kainit and manure salts, amounted to 612,514,916 pounds, valued at $10,805,720. The 1914 imports were naturally smaller, due to the war.

**Potash in Saline Deposits.** — A section of the remarkable salt deposits at Stassfurt, Prussia, has been given on p. 213. While this locality had been a producer of salt for some time, the true nature and value of the potash and magnesia salts overlying the rock salt was not fully realized until 1860. Since then the potash industry has assumed large proportions, and in addition to those at Stassfurt, other deposits are known at Hanover, South Harz mountain, and West Alsatia. Mines are also operating near Hamburg and Bremen, while lean deposits with poor cover are said to occur in Holland.[1]

Small, partly developed deposits exist near Kaluz in Galicia, and about 1912 others were discovered near Sauria, Spain [2] These last may in time become important producers.

The United States has not only been dependent on Germany, but has taken a large portion of its output, and its dependence on that country became keenly recognized during the German-American potash war of 1909–10.

[1] MacDowell, C. H., Amer. Inst. Min. Engrs., Trans., LI: 424, 1916.
[2] Inst. Geol. de Espana, Bol. 34: 173, 1914.

This led to a search for potash in the United States, attention being first turned to the saline deposits, of which there are several possible sources.

**Brines and Bitterns** (6, 7). — A study of these shows that none of the artificial brines, natural brines, or rock-salt deposits of many examined contain sufficient potash salts to render them of commercial value for this purpose. The following table gives the composition of some.

COMPOSITION OF SOLID MATTER IN BRINES FROM SALT WELLS

Parts per Million

|        | 1     | 2     | 3     | 4     | 5     | 6     |
|--------|-------|-------|-------|-------|-------|-------|
| K . . .| 11.8  | 3.0   | 9.4   | 5.8   | 4.2   | 2.7   |
| Na . . | 104.4 | 122.0 | 73.7  | 48.0  | 78.2  | ——    |
| Ca . . | 4.8   | 0.2   | 20.2  | 45.6  | 36.4  | 135.8 |
| Mg . . | 1.6   | tr.   | 1.6   | 9.8   | 11.0  | 48.4  |
| Cl . . | 179.1 | 189.4 | 135.0 | 187.0 | 202.2 | 355.2 |
| $SO_2$ . | 1.6  | 1.8   | 2.2   | 0.0   | 0.8   | 4.8   |
| Br . . | 1.1   | tr.   | ——    | 0.4   | 3.3   | 11.0  |

1. Watkins, N. Y., artificial brine;  2. Wadsworth, O., artificial brine; 3. Rock Glen, N. Y., bittern, 6 weeks' evaporation in grainer, taken at time of run-off;  4. Fairport Harbor, O., natural brine;  5. Saginaw, Mich., bittern from grainer, 14 days' evaporation;  6. Mason, W. Va. bittern, before going to bromine still.

Cook, has, however, noted some brines from Michigan, one of which from the Monroe formation contains 179.24 grams per liter KCl, and another from the Dundee limestone containing 158.17 grams per kilogram.[1]

**Saline Lake Beds** (8–13). — It is well known that many of the depressions found in the Great Basin were formerly occupied by lakes, whose waters have entirely disappeared, and that during their existence they did not overflow. Some of these like the former Lake Bonneville and Lake Lahontan had considerable depth. Large quantities of soluble saline and alkaline substances were carried into them by streams.

In addition to the two lakes mentioned, other important ones were Mono, Owens, Searles and Panamint of Southern Cali-

[1] Mich. Acad. Sci., 13th Rept.: 81, 1911.
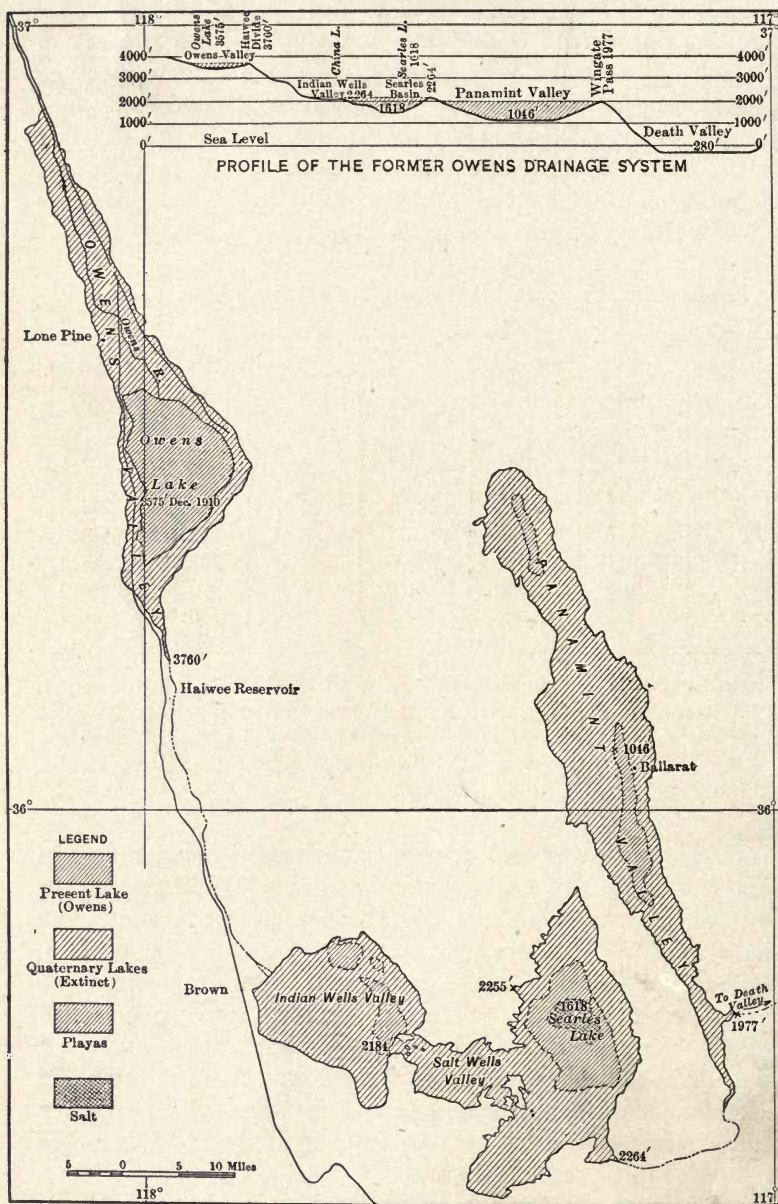
Fig. 79. — Map showing Owens and neighboring lakes of California. (*After Gale, U. S. Geol. Surv. Bull.* 530, 1915.)

fornia; and Lake Le Conte in the Imperial Valley of the Colorado Desert, California.

If now such a large body of water evaporated, the assumption is that the salts would be left as a crust on the basin floor or be absorbed by the sands and clays underlying it. Another possibility is that residual brines may be found in the sands beneath the basin floor.

Attractive as this theory apparently is on first thought, a careful study of the subject tends to the belief that the outlook for finding potash or other salts under such conditions is not very promising, so that most of the saline crusts, dry-lake areas, salt flats, sinks or playas of the desert region offer little inducement as a source of potash. Two cases may, however, be mentioned.

*Searles Lake, Calif.* (8). In the evaporation of a natural saline solution, containing both soda and potash, the latter would normally remain in solution much longer, and hence become concentrated in the residual brine, after most of the sodium chloride had crystallized out, and theoretically we might expect to find these potash-enriched brines in the sediments underlying former lake basins.

The only important case of this sort thus far discovered is that of Searles Lake (Fig. 79). This lake, so-called, which is known also as Borax Flat, is a dry-lake basin of the ordinary type, occupying a depression which could be filled to a depth of 640 feet above the present salt flat before it would overflow into the Panamint Valley to the south and east. This it evidently did in the past, and, moreover, the water that contributed to this former high level was the overflow from Owens Lake.

At the present day we find the bottom of this desert basin covered by a great sheet of solid white salts, unique in the variety of its saline minerals. This forms a central area of firm, crusted salt, covering about 11 square miles, surrounded by a zone of salt-incrusted mud and sand, composed of salts and mixed alluvial material washed into the basin from the surrounding valley slopes.

The salt of the central area is said to vary from 60–100 feet in thickness, and it consists of " a consolidated mass crystallized from an evaporating mother-liquor brine in which the salts are still immersed, evaporation being about balanced by the influx of ground water from the hill slopes."

Analyses of the brine from six wells gave the following averages in the ignited residue: $SiO_2$, .02; As, .06; Mg, 0; Ca, 0; Na, 33.19; K, 6.22; $CO_3$, 7.11; $SO_4$, 12.76; Cl, 36.39; $B_4O_7$, 2.45. A works for treating the brine was being built in 1914, which was expected to handle 20,000 gallons of brine, turning out daily: Borax, 225 tons; soda ash, 508 tons; salt, 1507 tons; sodium sulphate, 593 tons; and potassium chloride, 489 tons.

*Deep Drilling* (9–13). Assuming that soluble potash salts might be found in old lake bottoms, segregated as layers in such, or in mother liquors of high concentration, attempts have been made to discover these by drilling. Holes were put down by the United States Geological Survey near Fallon, Nevada, and in the Columbus Marsh, near Coaldale, Nevada. At the latter place samples taken from 20-foot sections, averaged 5.96 per cent water-soluble salts in the dried material, of which nearly one-third is potassium chloride, but the practical value of such saline muds is considered problematical.

In bore holes in Railroad Valley, Nye County, Nevada, one of the wells encountered considerable quantities of gaylussite ($Na_2CO_3 \cdot CaCO_3 \cdot 5H_2O$) but no potash.

## Sources of Potash, not Saline Deposits

**Alunite.** — This mineral, which has the formula $K_2O \cdot 3Al_2O_3 \cdot 4SO_3 \cdot 6H_2O$, has been regarded as among future possibilities, provided a sufficient quantity exists and a proper method of extraction can be employed.

Several other localities have been recorded, as follows: 1. At Marysvale, Utah (1). 2. In San Cristobal quadrangle, Colo. (2), where there are several areas of alunitized granite, consisting of quartz, pyrite and alunite, the latter in some cases forming 29 per cent of the rock. 3. Near Patagonia, Ariz. (3); and 4, at Bovard, Nev. (4). The last two are probably not of commercial value.

**Igneous Rocks.** (14–17). — Potash is an abundant constituent of some igneous rocks, in such minerals as orthoclase and leucite, but the extraction of potash from these has not yet been worked out on a commercial scale; moreover, it is doubtful whether it could compete successfully with that obtained from salines.

The possibility of working feldspar dikes or veins for this

purpose has also been suggested, but the total available quantity from this source would not be large.

It has also been suggested that the vast quantities of tailings derived from the concentration of the monzonite and other disseminated copper-bearing rocks may some day serve as a source of potash (18).

**Other Sources.** — The suggestion has been made that since potash volatilizes in the burning of Portland cement, it may be caught while passing up the stack along with the dust which is precipitated by special means, such as an electrical treater.

The extraction of potash from the kelp (18, 19) deposits along the Pacific coast has also been suggested.

### REFERENCES ON POTASH

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# CHAPTER VII

## GYPSUM

**Properties and Occurrence.** —*Gypsum* (1, 4), the hydrous sulphate of lime ($CaSO_4$, $2 H_2O$), occurs most frequently in sedimentary rocks, interbedded with shales, sandstones, and limestones, and often more or less closely associated with rock salt. It is also found as surface deposits mixed with clay (*gypsite*) (11), or in the form of sand (5 Ariz.). The first two types are the most important commercially. It also occurs as efflorescent deposits, periodic lake deposits, in lumps and plates scattered through clays or shales, in veins, and in limited quantities in volcanic regions, especially in lavas (4). When occurring in bedded deposits (Pl. XXV, Fig. 2). it is often massive, of crystalline texture or earthy appearance, and of variable color, although most commonly white and gray.

Transparent, colorless forms, known as *selenite*, are found as veins or crystals in the massive gypsum, or as plates and crystals in many clays, shales, and limestones. This variety by itself never forms deposits of commercial importance, although selenite scales are sometimes plentifully scattered through the purer varieties. *Alabaster* is a pure white, fine-grained, massive variety, which is sometimes used for ornamental work.

Gypsum when pure contains 46.6 per cent sulphur trioxide, 32.5 per cent lime, and 20.9 per cent water. It has a specific gravity of 2.3, and a hardness of 1.5 to 2. It is therefore sufficiently soft to be easily scratched with a knife or even by the thumb nail.

*Anhydrite* differs from gypsum chemically in the absence of water, but changes to it on exposure to the air and moisture. In some cases it may have been derived from gypsum. When present, it may occur as veinlets, beds or masses in the gypsum deposit; indeed, its irregularity of occurrence is at times puzzling (Pl. XXV, Fig. 1).

Anhydrite contains 41.2 per cent lime, 58.8 per cent sulphur trioxide. Its specific gravity is 2.8 to 2.9 and its hardness 3 to 3.5. As it is of no commercial value, it may cause trouble in quarrying, if present in large quantities.

Anhydrite has not usually been regarded as very abundant in the gypsum deposits of the United States. It is not uncommon in the Virginia mines, and Lane notes its occurrence in the deeper-

PLATE XXV
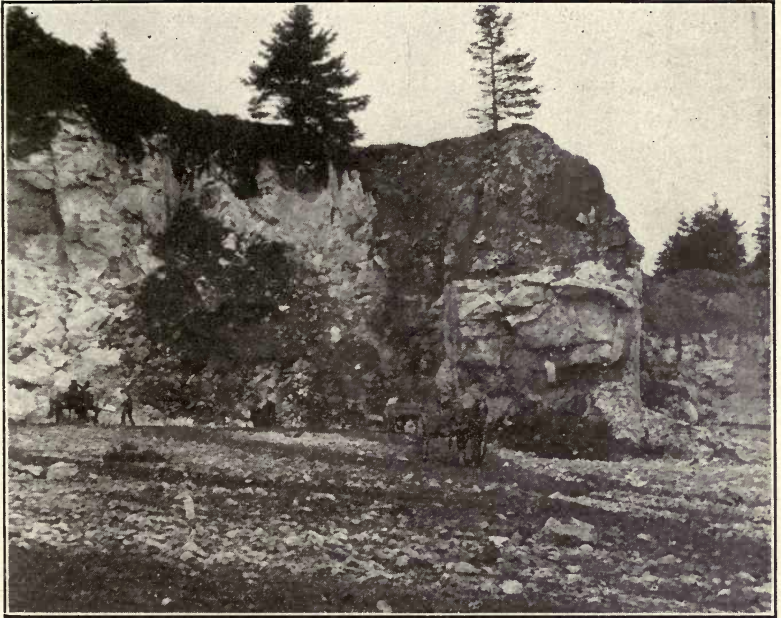


FIG. 1. — View in a Nova Scotia gypsum quarry, showing large mass of anhydrite. The anhydrite forms the buttress on right of quarry face, and is not removed. Good gypsum occurs on either side of it.   (*H. Ries, photo.*)



FIG. 2. — Gypsum quarry, Linden, N Y.   (*Photo. loaned by D. H. Newland.*)

(245)

lying parts of the Michigan gypsum series. It is also found with gypsum on top of the Texas and Louisiana salt deposits. Some extensive beds also occur in Oklahoma and a large mass has been found in Lyon County, Nevada. Scattered irregular masses and beds are abundant in some of the New Brunswick and Nova Scotia gypsum areas.

Anhydrite may be overlooked because of its resemblance to gypsum and limestone, but although closely similar to gypsum, the two can easily be distinguished by the following tests (21)..

| Anhydrite | Gypsum |
|---|---|
| Orthorhombic. | Monoclinic. |
| Cleavage, pseudo-cubic. | Cleavage, perfect in one direction. |
| Sp. gr., about 2.9. | Sp. gr., about 2.3. |
| Hardness, $3-3\frac{1}{2}$. | Hardness, $1\frac{1}{2}$ to $2\frac{1}{2}$. |
| Fragments are square or rectangular, with parallel extinction. | Fragments are platy with oblique extinction. |
| Soluble with difficulty in dilute hydrochloric acid. | Easily soluble in dilute hydrochloric acid. |
| Little or no water in closed tube. | Abundant water (20.9%) in closed tube. |
| Double refraction rather strong. | Double refraction rather weak. |

**Impurities in Gypsum.** — Clay is probably the commonest impurity, and occurs either uniformly distributed through the gypsum, giving it an earthy appearance and gray or brown color, or else it may be in layers. Lime carbonate is often present, though rarely in large amounts, although at times the gypsum is interbedded with layers of limestone. Magnesia, silica and iron oxide may also be present, though not usually in large amounts.

Owing to its solubility, massive gypsum sometimes contain sink holes and underground solution channels, that not only permit surface dirt to wash into the deposit, but interfere at times with the mining.

**Origin of Gypsum** (4, 12b, 28).—Gypsum is widely distributed both geographically and geologically, being found in various horizons from the Silurian to the Recent. Most beds of this substance have no doubt been formed by the evaporation of salt water either in inland seas or else in arms of the ocean, the process of precipitation having been discussed in the chapter on *Salt*. As gypsum separates from sea water after 37 per cent of the water is evaporated, while salt precipitates only after 93 per

cent has been removed, it is evident that gypsum beds may be deposited without salt. This may also explain why gypsum is more widely distributed than salt; and the fact that the percentage of gypsum in salt water is much less than that of salt probably accounts for its usual occurrence in the thinner deposits.

Thin beds of gypsum may be formed by water percolating through gypsum-bearing beds, and subsequently depositing the gypsum so dissolved, by evaporation on the surface; or again, crusts may accumulate from the drying up of the gypsiferous waters of playas or temporary lakes.

Gypsum may also be formed by the decomposition of sulphides, such as pyrite, and the action of the sulphuric acid thus liberated on lime carbonate. Small quantities are formed in volcanic regions through the action of sulphuric vapors on the lime of volcanic tuffs or other rocks (4).

The conditions under which anhydrite forms do not appear to be thoroughly understood. According to Van 't Hoff and Weigert, anhydrite forms from gypsum in sodium chloride solutions at 30° C., while in sea water the transformation takes place at 25° C. (Quoted by Clarke, 4). Lane (12) believes that all calcium sulphate precipitated at a greater depth than 500 feet is really anhydrite rather than gypsum. Indeed, some believe that perhaps much of the gypsum now found was originally anhydrite.

Vater has pointed out that at ordinary temperatures calcium sulphate separates from a saturated salt solution as gypsum. The temperatures noted above are not likely to be found in sea water, although the Persian Gulf (1a) has a mean temperature of 24° C. owing to its shallowness, and Grabau suggests that if in such a warmed body of water the deeper layers had become a concentrated brine, the successive influxes of calcium sulphate, brought in by waters during the rainy period would, on passing through these brine layers, be deposited directly as anhydrite, in alternating layers with the salts.

If the change of gypsum to anhydrite was brought about by penetrating surface waters, it might account for the irregularity of occurrence of the anhydrite in the gypsum. That such a transformation may extend to a considerable depth is shown by the deposits at Bex, Switzerland (4), where the alteration has reached a thickness of 60 to 100 feet.

But if the anhydrite represents the original mineral, then its change to gypsum must be accompanied by increase of volume

in the mass, and one might expect to find a shattering or deformation of the surrounding beds, a condition actually found in some of the Paleozoic gypsum bearing-strata.[1]

Another suggestion is that originally precipitated gypsum (28) may change to anhydrite when buried to depths of 1500 feet or more. It is more than probable that in some cases gypsum has been the original mineral, and in others anhydrite, especially if either occurs alone. Where the two are irregularly associated or mixed, the one may be derived from the other, but where they occur in separate beds with sharp and even lines of separation, both may be original.
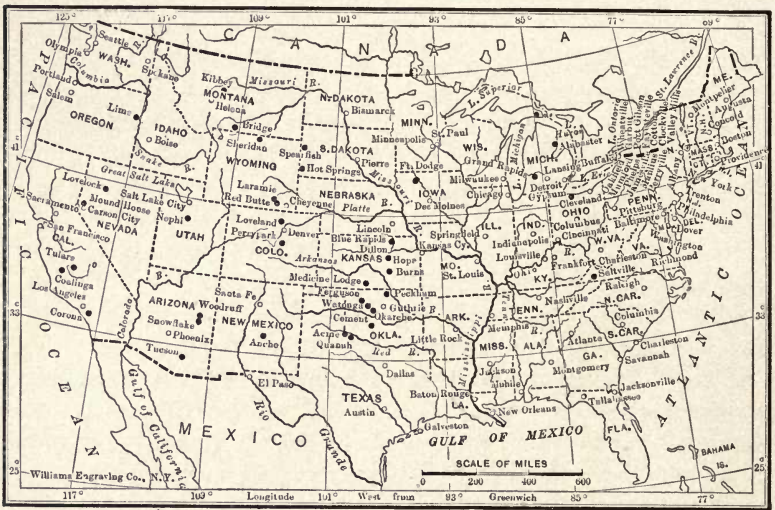


Fig. 80.— Map showing gypsum-producing localities of the United States. (*After Adams, U. S. Geol. Surv., Bull.* 223.)

**Gypsite,** or gypsum dirt, is an earthy or sandy variety of gypsum forming a surface deposit in Kansas (11), and other western states (20, 24), which in spite of its impure appearance, may run high in calcium sulphate. It is believed to be a deposit either in the soil or in shallow lakes supplied by springs whose water has dissolved the calcium sulphate from gypsum beds or other rocks. During its precipitation by the second method, its impure character is caused by its becoming mixed with clay or sand washed in from the land.

[1] Grabau and Sherzer, Mich. Geol. and Biol. Surv., Pub. 2.

**Distribution in the United States** (Fig. 80). — Nineteen states and territories are producers of gypsum, although three of these— New York, Michigan, and Iowa—produce nearly 50 per cent of the total quantity mined.

The wide geologic range of gypsum deposits in the United States can be seen from the following table: —

| STATE OR TERRITORY | AGE | STATE OR TERRITORY | AGE |
|---|---|---|---|
| Alaska | Permian or Triassic | Nevada | Triassic |
| | | New Mexico | Permian |
| Arizona | Triassic and Tertiary (Pliocene) | New York | Silurian |
| Arkansas | Tertiary | Ohio | Silurian |
| California | Tertiary | Oklahoma | Pleistocene |
| Colorado | Permian | | Permian |
| Iowa | Permian | South Dakota | Permian |
| Kansas | Pleistocene | Texas | Permian |
| | Permian | Utah | Jurassic |
| Michigan | Lower Carboniferous | Virginia | Carboniferous |
| Montana | Lower Carboniferous | Wyoming | Triassic |



FIG. 81. — Map of New York showing outcrop of gypsum-bearing formations.
(*U. S. Geol. Surv., Bull.* 223.)

*New York* (13, 14) — In this state, which is one of the three largest producers, the gypsum occurs as rock gypsum, interbedded with shales and shaly limestones of Salina (Silurian) age. The beds,

several of which may occur in the same section, are lenticular in shape, but of such horizontal extent that in any one quarry they appear of uniform thickness (Pl. XXV, Fig. 2). In most quarries they range from 4 to 10 feet, and their general dip is southward, but there are local irregularities. The main gypsum deposits occur in the upper part of the Salina, while the salt beds lie lower down in this formation. The area of outcrop of the Salina is shown in Fig. 81. The gypsum deposits, which occur mostly in the central part of the state, are usually impure, except in Genesee County. Fig. 82 shows a not uncommon mode of occurrence.

| | |
|---|---|
| Even bedded limestone | 18' |
| Water lime | 6' |
| Marlite | 10' |
| Gypsum | 5' |
| Shale | 1' |
| Gypsum | 5' |
| Shale | 1' |
| Light gypsum | 10' |
| Dark-gypsum | 1' |
| Gypsum | 14' |
| Shale | 2' |
| Gypsum | 10' |
| Shale | 1' |
| Gypsum | 4' |
| Shale | 1' |
| Gypsum | 6' |
| Limestone | |

Linden, N.Y.

FIG. 82.—Section in gypsum deposit at Linden, N.Y. (*After Eckel, U. S. Geol. Surv., Bull.* 223.)

*Michigan* (12). — All the Michigan gypsum is rock gypsum and of high purity. There are two important areas, one being in the vicinity of Grand Rapids, and the other at Alabaster on Saginaw Bay (Plate XXVI, Fig. 1), both in beds of Lower Carboniferous age. These beds, known as the Grand Rapids formation, surround the Michigan coal basin,[1] and carry the gypsum in their lower part. At Grand Rapids, the gypsum beds, which are interstratified with shale and limestone, run from 6 to 12 feet in thickness, and are worked either by quarrying or underground chambers. At Alabaster, Iosco County, the gypsum, which immediately underlies the glacial drift, is 23 feet thick.

A third, possibly productive, area is near St. Ignace on the upper peninsula, but there the gypsum occurs in the Salina or Monroe group (Silurian).

*Iowa* (10). — Important deposits are found in this state in an area of about 25 square miles in Webster County, especially near Fort Dodge. The gypsum, which is presumably of Permian age, rests on the Coal Measures, or the St. Louis limestone (Lower Carboniferous),

[1] It is interesting to note that wells sunk in the central portion of the basin show that the gypsum passes into anhydrite, indicating that if the gypsum is of primary character it was deposited around the borders of the old interior sea.

PLATE XXVI



FIG. 1. — Gypsum quarry, Alabaster, Mich. Shows gypsum overlain by glacial drift. The dump in foreground is overburden removed from gypsum. (*Photo.*, *A. C. Lane.*)



FIG. 2. — View in scythestone quarry, Pike Station, N. H. (*Photo. loaned by Pike Mfg. Co.*)

(251)

and is covered by glacial drift, but in places is overlain conformably
by red shales. It varies from 3 to 30 feet in thickness, with an
average of 16 feet, and much of it is sufficiently white for stucco.

*Kansas.* — Gypsum (11) is found occurring as rock gypsum, or
as gypsite, the deposits forming a belt extending across the central
part of the state in a northeast-southwest direction, and includes
three important areas, viz. Northern, or Blue Rapids, in Marshall
County, Central, or Gypsum City, in Dickinson and Saline counties,
and Southern, or Medicine Lodge, in Barber and Comanche coun-
ties. The beds of rock gypsum are of Permian age, interbedded
with red shales, those at the southern end of the belt being strati-
graphically 1000 feet higher than those at the northern end.

The gypsite or gypsum dirt, which is of more recent age, is found in the
central area, as well as at a number of other localities. The spring waters
which have supplied it have leached the calcium sulphate either from
the gypsum beds or the red shales. The gypsite is found especially in the
central area, and the deposits were the first of their kind worked in
the United States.

The product is used for fertilizer and cement plaster, and much is also
used for making Keene's cement.[1] The rock, which is quarried especially
in the northern and southern areas, is white in color, and may range from
8 to 16 feet in thickness.

*Virginia.* — Gypsum is also found in beds of Lower Carbonif-
erous age in the Holston Valley of southwestern Virginia (22),
the deposits occurring in shales, between Carboniferous (Green-
brier limestone) and Siluro-Devonian sandstones (Fig. 73). The
section is faulted up against the Cambro-Silurian limestones, on
the southeast, and both the gypsum and salt deposits seem to be
limited to a narrow belt bordering on this fault.

The gypsum occurs in bowlder masses in gray and red clays, and is
interesting because of the abundant but irregular occurrence of anhydrite,
which grades into the gypsum. The rock is mined partly by underground
workings, and some of the beds are fully 30 feet thick. The product is used
for land and wall plaster.

In Ohio gypsum has been obtained from the lower Helderberg beds of
Ottawa County, 10 miles west of Sandusky. The material occurs at differ-
ent horizons, the beds being bent into rolls, the main ones having a thickness
of about 12 feet (15, 20).

*Other Occurrences.* — Additional occurrences are known in Wyoming
(24, 25), Utah (21), Nevada (20), California (8), Montana (20), Idaho (20),
Colorado (9, 20), South Dakota (17–19), Oklahoma (16), Texas (20), and
Arizona (7, 20). In the last, as well as in New Mexico, there are found

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[1] A cement made by burning gypsum at high temperatures, and then treating
it with alum or other chemicals.

important deposits of gypsum sand, composed of gypsum grains broken down by stream action and water from rock gypsum outcrops, and then gathered into hills or dunes by wind action. Some of these dunes are more than 100 feet high. The utilization of these sands in Otero County, New Mexico, was begun in 1908.

Gypsum (6) of Permian or Triassic age is known to occur on Chichagof Island in southeastern Alaska. The beds, which are folded and steeply tilted, have been extensively developed during the last few years and shipped to Tacoma for preparation. It comes into competition with similar material from the western states.

**Analyses of Gypsum.** — The following analyses indicate the composition of gypsum from different localities in the United States and Canada. They cannot all be guaranteed as being of average character, and serve mainly to show variation in composition:—

| | Pure Gypsum | Dillon Kas. | Ala- baster Mich. | Grand Rapids Mich. | Salt- ville Va. | Gyp- site Mar- low I. T. | Gypsite Burns Kas. | Gypsite Salina Kas. | Gyp- site Dillon Kas. |
|---|---|---|---|---|---|---|---|---|---|
| $CaSO_4$ . . . . | 79.10 | 78.40 | 78.51 | 76.26 | 72.06 | 59.46 | 67.91 | 34.38 | 56.58 |
| $H_2O$ . . . . . | 20.90 | 19.96 | 20.96 | 20.84 | 21.30 | 16.59 | 17.72 | 8.50 | 15.16 |
| $SiO_2$ . . . . . | — | .35 | .05 | tr. | 1.68 | 10.67 | 2.31 | 34.35 | 17.10 |
| $Al_2O_3$ and $Fe_2O_3$ . | — | .12 | .08 | .54 | 1.95 | .60 | .37 | 4.11 | 2.04 |
| $CaCO_3$ . . . . | — | .56 | — | n.d. | — | 10.21 | 11.71 | 8.14 | 7.71 |
| $MgCO_3$ . . . . | — | .57 | .11 | n.d. | — | 1.10 | .52 | 10.52 | 1.24 |
| | 100.00 | 99.96 | 99.71 | 97.64 | 96.99 | 98.63 | 100.53 | 100.00 | 99.83 |

| | Onon- daga, N. Y. | Fort Dodge, Ia. | San- dusky O. | Grand Etang Harbor, N. S. | Hills- bor- ough, N. B. | Mag- dalen Is- lands | York, Ont. | Gyp- sum- ville, Man. | Sal- mon River, B. C. |
|---|---|---|---|---|---|---|---|---|---|
| CaO . . | 73.92 | 73.44 | 78.73 | 32.11 | 33.00 | 32.93 | 32.70 | 30.90 | 32.60 |
| $SO_3$ . . . | | 45.88 | 46.80 | 44.93 | 46.88 | 42.52 | 46.67 |
| $H_2O$ . . . | | 20.76 | 19.70 | 20.52 | 20.80 | 20.00 | 20.66 | 20.00 | 20.40 |
| Insol. . . | | | .91 | .26 | tr. | .60 | .06 | 3.04 | .04 |
| $Fe_2O_3$ . . | 4.64 | | | .42 | — | .24 | | | |
| $Al_2O_3$ . | | .65 | .60 | | | | | | |
| MgO . . | — | | .54 | .23 | — | tr. | | | |
| $CO_2$ . . . | 21.44 | — | — | — | — | .86 | | | |
| CaO . . . | | — | — | | | | | | |

**Distribution of Gypsum in Canada** (26, 27). — Canada ranks third in the world's production of gypsum, the United States and France being first and second respectively, but over 65 per cent of the crude gypsum is exported. The map, Fig. 83, shows a

number of occurrences, those of Nova Scotia and New Brunswick being the most important, followed by Ontario, Manitoba
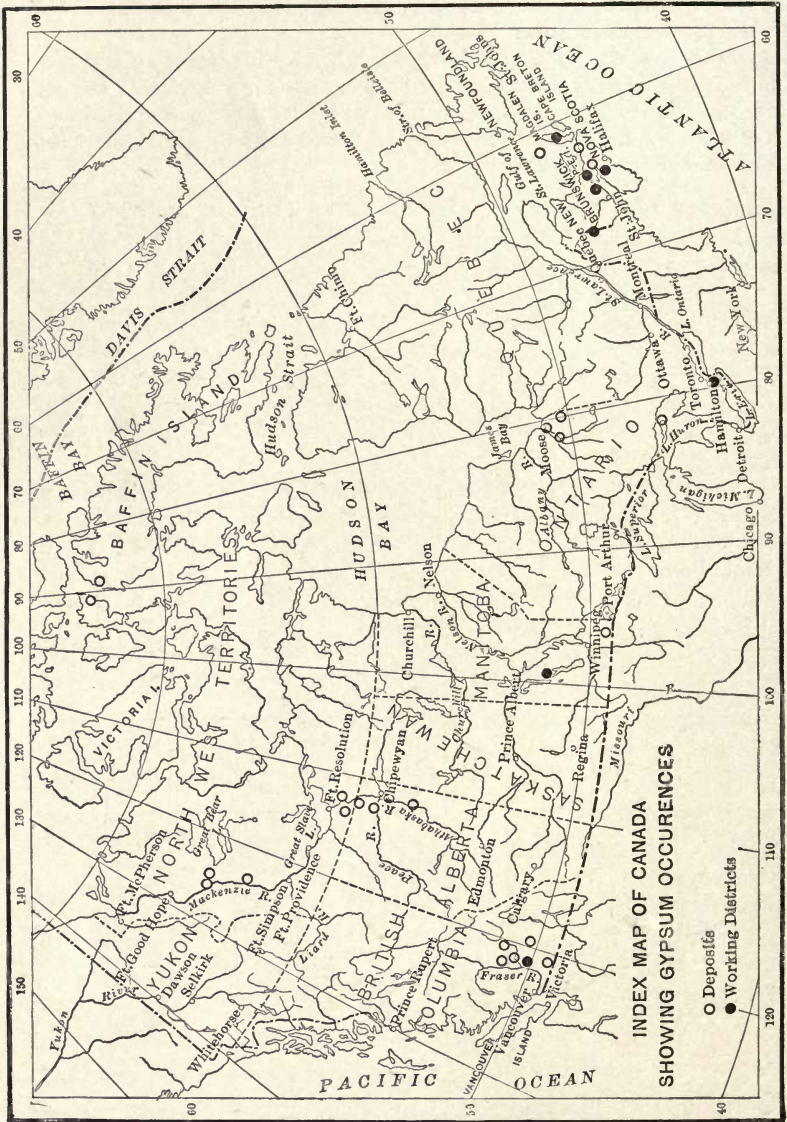


FIG. 83. — Map showing location of gypsum areas in Canada. (*After Cole, Mines Branch Rep. 245.*)

and British Columbia. In Nova Scotia there are many deposits, distributed over the northern half of the province from Windsor

to Cape Breton, while in New Brunswick the deposits are located chiefly in the southern part of the province, with Hillsborough and Plaster Rock as the two important localities.

The gypsum of these two provinces is of Lower Carboniferous age, and appears to form more or less lens-shaped deposits, associated with shales and limestones. Anhydrite is a common accompanying rock (Pl. XXV, Fig. 1), and while in many cases it is said to underlie the gypsum, it often occurs in it, in the form of irregular masses and veinlets. Considerable high-grade white gypsum is quarried near Hillsborough, N. B. Gypsum also of Lower Carboniferous age is known on the Magdalen Islands in the Gulf of St. Lawrence.

At York in southern Ontario, the Onondaga formation carries gypsum, interstratified with limestone, dolomite and shale. The material is white, and forms lenticular masses averaging 4 feet in thickness, with some as much as 11 feet thick. The northern Ontario deposits are not worked.

Gypsum is actively worked in northern Manitoba northwest of Lake St. Martin. The thinly-bedded deposits, which are sometimes overlain by gypsum earth, may be 10 feet thick, and appear to be of Upper Silurian or Lower Devonian age.

British Columbia contains several localities. That near Spatsum on the Thompson River is interbedded with crystalline limestone, argillites and volcanic rocks, while a second, east of Grand Prairie, shows one bed over 100 feet thick, and a second 30 feet thick, associated with gray schists and crystalline limestone.

**Other Foreign Deposits.**[1] — Of these France is the most important, the extensive Oligocene deposits of the Paris basin being a most important source of supply. The gypsum contains 10–20 per cent of calcium carbonate, and soluble silica, which is said to increase the hardness of the set plaster. England is the only other important European producer, the chief deposits being found in the Triassic of Cumberland, Nottinghamshire and Staffordshire.

A number of other countries contribute to the World's supply (See table p. 258), but they are far behind the countries mentioned.

**Uses** (1, 12). — Gypsum is sold either in the ground, uncalcined condition, or after calcining and screening.

Uncalcined gypsum is used in large quantities as a retarder for Portland cement, and in the past much was employed for

[1] For résumé see Dammer and Tietze, Nutzbaren Mineralien, II: 64, 1914.

fertilizing purposes under the name of *land plaster*. Other applications are for crayon manufacture, as an ingredient of steam pipe coverings, as a body for some paints, and as a food adulterant under the name of *terra alba*. The pure white rock gypsum, known as *alabaster*, has been used for statuary, basins, vases and other objects for interior decoration.

**Calcining Gypsum.** — When heated to 250° F., gypsum loses a portion of its water of hydration, but if finely ground has the property of recombining with it. If heated to 300° F. to 400° F., it is said to lose this power and is called *dead-burned*.[1] In addition to dehydration, burning also breaks up the crystals into minute particles. The *set* is due to the formation of a crystalline network of the rehydrated grains.

Since calcined gypsum sets in from 6 to 10 minutes, some retarding material, such as organic matter from slaughter-house refuse, is often added to it, and thus the setting process may be delayed from 2 to 6 hours. Those plasters which set slowly are termed *cement plasters*.

The following analyses show the composition of (1) uncalcined gypsum; (2) the calcined rock; and (3) the plaster after it has taken up water and set. From these it will be seen that the plaster takes up the amount of water lost in calcination.

SERIES OF ANALYSES SHOWING CHANGES IN GYPSUM DURING BURNING AND AFTER SETTING

|  | CRUDE | FINISHED | SET |
|---|---|---|---|
| $SiO_2$ and Insol. res. . . . . . . | 12.29 | 14.31 | 12.03 |
| $Fe_2O_3$ and $Al_2O_3$ . . . . . . . | 2.27 | 2.16 | 1.62 |
| CaO . . . . . . . . . . . | 29.67 | 33.53 | 30.05 |
| MgO . . . . . . . . . . . | .78 | .91 | .61 |
| $SO_3$ . . . . . . . . . . . | 34.87 | 39.85 | 35.73 |
| $CO_2$ . . . . . . . . . . . | 3.52 | 4.11 | 3.55 |
| $H_2O$ . . . . . . . . . . . | 16.07 | 4.81 | 16.38 |

In its calcined form, gypsum comparatively free from impurities is known as *plaster of paris*, and has the following uses dependent on its property of hardening or setting when mixed with water: stucco, plastering for walls, whitewash, pottery molds, statuary, dental purposes, and as a bed for polishing plate glass. Hard finish plasters, such as Keene's Cement, etc., and partition blocks consisting of plaster of paris with other substances are being used in increasing quantity.

**Production of Gypsum.** — Michigan, New York, and Iowa are the leading producers, but other states contribute considerable amounts.[1]

[1] Recent experiments show that " dead-burned " gypsum if ground to .005 mm. sets readily with water. W. D. Bancroft, personal communication.

MARKETED PRODUCTION OF GYPSUM IN THE UNITED STATES, 1913 AND 1914, BY STATES AND USES, IN SHORT TONS

**1913**

| STATE | TOTAL MINED | Ground for Land Plaster — Quantity | Ground for Land Plaster — Value | For Portland Cement, Paint, Bedding Plate Glass and other Purposes — Quantity | For Portland Cement, Paint, Bedding Plate Glass and other Purposes — Value | Sold as Calcined Plaster — Quantity | Sold as Calcined Plaster — Value | TOTAL VALUE |
|---|---|---|---|---|---|---|---|---|
| Alaska, Arizona, Colorado, Illinois,[1] Minnesota,[1] Montana, Nevada, Oregon, South Dakota, Utah, Virginia, Washington,[1] Wisconsin[1] | 392,788 | 17,120 | $35,624 | 54,839 | $156,177 | 285,290 | $1,335,074 | $1,526,875 |
| California | 49,015 | 6,209 | 15,700 | 18,211 | 47,166 | 29,690 | 168,070 | 230,936 |
| Iowa | 456,031 | 8,757[2] | 10,266[2] | 43,300 | 35,285 | 333,357 | 1,112,388 | 1,157,939 |
| Kansas | 110,510 |  |  | 32,696[3] | 26,992 | 64,236 | 281,316 | 308,308 |
| Michigan | 423,896 | 9,604[2] | 10,222[2] | 51,102 | 45,747 | 278,368 | 665,356 | 721,325 |
| New Mexico | 43,180 |  |  | [4] | [4] | 539,532 | 102,564 | 102,564 |
| New York | 529,627 | 9,418[2] | 17,232[2] | 179,064 | 259,723 | 282,187 | 1,003,744 | 1,280,699 |
| Ohio | 254,863 | [2] | [2] | 37,174[3] | 11,793 | 208,421 | 683,356 | 695,149 |
| Oklahoma | 147,876 |  |  | 12,093[3] | 10,723 | 110,418 | 319,693 | 330,416 |
| Texas | 161,090 | [4] | [4] | [4] | [4] | [5]133,946 | 345,749 | 345,749 |
| Wyoming | 30,632 |  |  |  |  | 21,453 | 74,862 | 74,862 |
| Total | 2,599,508 | 54,815 | $95,953 | 408,321 | $601,113 | 1,773,849 | $6,077,756 | $6,774,822 |

**1914**

| STATE | TOTAL MINED | Ground for Land Plaster — Quantity | Ground for Land Plaster — Value | For Portland Cement, Paint, Bedding Plate Glass and other Purposes — Quantity | For Portland Cement, Paint, Bedding Plate Glass and other Purposes — Value | Sold as Calcined Plaster — Quantity | Sold as Calcined Plaster — Value | TOTAL VALUE |
|---|---|---|---|---|---|---|---|---|
| Alaska, Arizona, Colorado, Illinois,[1] Minnesota,[1] Montana, Nevada, New Mexico, Oregon, South Dakota, Virginia, Washington,[1] Wisconsin[1] | 358,363 | 14,193 | $34,922 | 47,301 | $122,741 | 238,497 | $1,162,584 | $1,320,247 |
| California | 27,376 | 5,199 | 14,344 | 12,921 | 30,710 | 24,787 | 139,842 | 184,886 |
| Iowa | 480,404 | 12,251[2] | 14,920[2] | 52,934 | 45,566 | 335,065 | 1,260,971 | 1,321,457 |
| Kansas | 80,774 |  |  | 23,796[3] | 22,531 | 47,877 | 255,812 | 278,343 |
| Michigan | 393,006 | 9,322[2] | 10,761[2] | 51,905 | 40,481 | 249,648 | 654,599 | 705,841 |
| New York | 523,368 | 6,540[2] | 12,535[2] | 172,279 | 247,307 | 279,449 | 977,350 | 1,237,192 |
| Ohio | 265,091 |  |  | 38,189[3] | 13,156 | 220,126 | 760,257 | 773,413 |
| Oklahoma | 113,103 |  |  | [4] | [4] | [5]91,419 | 312,856 | 312,856 |
| Texas | 158,814 |  |  |  |  | [5]133,478 | 490,937 | 490,937 |
| Utah | 44,950 | [2] | [2] | [3]7,639 | 14,741 | 33,401 | 169,880 | 184,621 |
| Wyoming | 31,216 |  |  |  |  | 21,537 | 86,196 | 86,196 |
| Total | 2,476,465 | 52,945 | $97,716 | 390,742 | $549,083 | 1,656,066 | $6,249,190 | $6,895,989 |

[1] Produces no crude gypsum.  
[2] Included with crude gypsum for Portland cement, etc.  
[3] Includes some land plaster.  
[4] Included with calcined gypsum.  
[5] Includes some crude gypsum.

MARKETED PRODUCTION OF GYPSUM IN THE UNITED STATES, 1910–1914, IN SHORT TONS

| YEAR | SOLD WITHOUT CALCINING | | | SOLD AS CALCINED PLASTER | | | TOTAL VALUE |
|------|----------|-------|---------------------|----------|-------|---------------------|-------------|
| | Quantity | Value | Average Price per Ton | Quantity | Value | Average Price per Ton | |
| 1910 | 421,829 | $669,497 | $1.59 | 1,583,669 | $5,853,532 | $3.70 | $6,523,029 |
| 1911 | 387,480 | 589,479 | 1.52 | 1,598,418 | 5,872,556 | 3.67 | 6,462,035 |
| 1912 | 441,608 | 623,522 | 1.41 | 1,731,674 | 5,940,386 | 3.43 | 6,563,908 |
| 1913 | 463,136 | 697,066 | 1.51 | 1,773,849 | 6,077,756 | 3.43 | 6,774,822 |
| 1914 | 443,687 | 646,799 | 1.46 | 1,656,066 | 6,249,190 | 3.77 | 6,895,989 |

The imports of gypsum for 1914 were valued at $444,841.

WORLD'S PRODUCTION OF GYPSUM

| COUNTRY | SHORT TONS | VALUE | COUNTRY | SHORT TONS | VALUE |
|---------|-----------|-------|---------|-----------|-------|
| Algeria (1912) . . | 59,965 | $125,064 | Germany (1912) . | 62,957 | $24,683 |
| Australia (1912) . | 15,767 | 60,145 | Greece . . . | 2,475 | |
| Canada (1913). . | 636,370 | 1,447,739 | India (1912) . . | 23,557 | |
| Cyprus (1912) . | 5,571 | 13,865 | United Kingdom | | |
| France (1912) . . | 1,979,595 | 3,330,311 | (1913) . . . | 319,579 | 440,174 |
| | | | United States (1913) | 2,599,508 | 6,774,822 |

PRODUCTION OF GYPSUM IN CANADA, 1912–1914, IN SHORT TONS

| PROVINCE | 1912 | | 1913 | | 1914 | |
|----------|------|-------|------|-------|------|-------|
| | TONS | VALUE | TONS | VALUE | TONS | VALUE |
| Nova Scotia . . . . | 376,082 | $481,493 | 404,801 | $479,515 | 303,155 | $368,931 |
| New Brunswick . . . | 82,757 | 185,821 | 103,954 | 279,395 | 79,083 | 200,680 |
| Ontario . . . . . | 53,119 | 176,056 | 62,315 | 208,029 | 81,219 | 204,033 |
| Manitoba . . . . . | 66,500 | 481,250 | 65,100 | 479,500 | 53,423 | 382,563 |
| Br. Columbia . . . | — | — | 200 | 1,300 | — | — |
| Total . . . . . | 578,458 | $1,324,620 | 636,370 | $1,447,739 | 510,663 | $1,137,157 |

IMPORTS AND EXPORTS OF GYPSUM FOR CANADA

| IMPORTS, 1913 | | | EXPORTS, 1914 | |
|---------------|--------------|------------------|---------------|-------|
| Crude Gypsum | Ground Gypsum | Plaster of Paris | Short Tons | VALUE |
| $21,763 | $11,770 | $154,719 | 345,830 | $404,234 |

### REFERENCES ON GYPSUM

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# CHAPTER VIII

## FERTILIZERS

Under this term are included a number of mineral substances, limestone (p. 187), marl (p. 191), gypsum (p. 244), phosphate of lime, greensand, guano, kainite ($K_2SO_4$, $MgSO_4$, $MgCl_2$, 6 $H_2O$) (p. 213), and niter (p. 232), which are of value for adding to the soil to increase its supply of plant food and also in some cases correct its physical condition. Some of these have other uses as well, and have been discussed elsewhere on those pages indicated by the numbers following them in the foregoing lines.

**Phosphate of Lime.** — This occurs both as crystalline phosphate of lime, or apatite, associated with crystalline rocks and rock phosphate usually associated with stratified rocks.

**Apatite** (6, 8). — This mineral when pure contains about 90 per cent tricalcic phosphate, and 10 per cent calcium fluoride, which may be replaced by calcium chloride. It is widely distributed in some igneous and metamorphic rocks, especially granites, gneisses, and some crystalline limestones, but rarely in sufficient quantity or in sufficiently concentrated masses to render its extraction profitable, at least while the supply of amorphous phosphate lasts. So, competition with rock phosphate has restricted mining to a few localities where it is associated with other valuable minerals.

In the United States apatite has been produced for several years at Mineville, N. Y. (7) where it occurs disseminated in small grains through the magnetite, forming sometimes as much as 5 per cent of the ore. In the process of magnetic separation the apatite is removed as tailings, the first grade of these carrying about 60 per cent tricalcium phosphate, and the second about 30 per cent. They are used in fertilizer manufacture.

A unique as well as extensive occurrence of phosphatic material is found at two localities in Nelson (figured under Titanium) and Roanoke counties, Virginia. The rock which Watson has named *Nelsonite* (8 a) consists of a hard granular aggregate of white apatite and black ilmenite, and forms dike-like masses in metamorphic igneous rocks. The commercial value of this material as a source of phosphate remains to be proven.

Large quantities of crystalline apatite were formerly produced in Ontario and Quebec, where the material is found in pegmatites associated with much pyroxene, phlogopite, hornblende, etc. The output at present is very limited, as the material cannot compete with the cheaper and more easily ground rock phosphate. That produced is a by-product from mica mining.

**Rock Phosphates** (4, 4a, 8). — These, though composed chiefly of phosphate of lime, also carry variable quantities of other substances as will be explained below. They are sometimes called *phosphorites*, although this term should probably be restricted to the purer, denser, fine-grained forms.[1]

Rock phosphates may be roughly classified as follows:

I. Bedded deposits, consisting of, (a) beds of massive phosphate, of continuous or lens-shaped character, and varying purity; (b) nodules in sedimentary rocks; (c) bone beds mixed with more or less phosphatic material.

II. Replacement deposits, formed by the leaching of phosphate from guano or higher-lying phosphatic formations, and its deposition in lower-lying calcareous rocks.

III. Cavity fillings deposited from solution, and including; (a) irregular cavities in limestones, or (b) fissures in limestones or other rocks. These represent phosphates of high purity, and some replacement may accompany the filling.

IV. Residual deposits.

V. Mechanically formed deposits (placers), of marine or stream origin.

**Minerals in Phosphate Rock.** — The chief minerals in phosphate rock are calcium phosphates. According to Rogers (13) phosphate rock appears to be a mixture of two minerals, amorphous collophanite, largely a solid solution of calcium carbonate in calcium phosphate, and crystalline dahllite, a calcium carbonophosphate with the formula $Ca_6(PO_4)_4CaCO_3\frac{1}{2}H_2O$, analogous to fluorapatite. The amorphous collophanite gradually changes to dahllite. Hydroapatite is sometimes present in mammillary masses resembling chalcedony.

Phosphates of iron or aluminum may be present in small amounts, and calcium carbonate is not rare, though never present in large quantity. Other substances may include quartz, clay and even small amounts of fluorine, titanium, manganese, etc.

[1] See Dana, Syst. Min., p. 762; Dammer and Tietze, Nutzbaren Mineralien, II: 106, 1914; Merrill, Non-Metallic Minerals, p. 268; Stutze, Nicht-Erze, p. 266.

*Objectionable Impurities.* — These may be objectionable because they take the place of just so much phosphate, or because they interfere with the process of manufacturing acid phosphate. Iron and alumina are the most objectionable from the latter viewpoint, and hence phosphate is sold under a guarantee not to exceed 2 to 4 per cent of iron. Alumina if present as silicate is said to be more injurious than aluminum phosphate.

A small amount of calcium carbonate is beneficial, since its reaction with the acid added generates heat which promotes subsequent reactions among the other constituents, and the carbon dioxide gas given off facilitates drying. Fluorine if present in any quantity is objectionable because of the obnoxious gas generated, when the phosphate is treated with sulphuric acid. This trouble is met with more in using apatite than with rock phosphate.

**Origin of Phosphate Deposits** (2, 4, 8). — Considering the somewhat varied mode of occurrence of amorphous phosphate it is obvious that different deposits may have been formed in different ways.

We may perhaps regard the igneous and other crystalline rocks as the ultimate source of the element phosphorus. The phosphate minerals, of which apatite is the commonest, may on the weathering of the rock be attacked by the soil waters, different inorganic phosphates showing different degrees of solubility, and their solubility varying also with the conditions.

Thus the presence of decaying organic matter in water seems to increase the solubility of phosphate minerals, and carbonated water appears to exert a similar influence, as does also sodium chloride.[1] Surface waters gather carbon dioxide from the air, or from the soil, where they also collect organic acids. These then attack the phosphate compounds found in the rocks.

While a part of this dissolved phosphate of lime is no doubt taken up by plants or held in the soil, other portions may be carried to the sea. There a portion of it may be abstracted by marine animals in the construction of their shell covering or skeletons. The actual percentage of calcium phosphate in these hard parts is not high, but it is not to be overlooked.

It has been found in the case of certain swamp waters in South Carolina, that calcium phosphate was dissolved when organic matter was present to furnish organic acids. If these same

[1] Patten and Waggaman, Dept. Agric., Bur. Soils, Bull. 52.

solutions stood for a time over marl, the phosphate was precipitated. Phosphate may also be precipitated on the sea floor, either as grains or nodules, or sometimes apparently by replacement of calcium carbonate of shells by calcium phosphate.

A marine deposit might therefore contain phosphate formed by chemical precipitation, as well as that contained in bones and shells, and such a deposit might or might not be sufficiently rich to work.

These primary deposits, however, may become the source of richer ones of a secondary nature by: (1) Leaching out of calcium carbonate from phosphatic limestones, leaving the phosphate behind; (2) removal of the phosphate by solution, and its redeposition by replacement at a lower horizon; or (3) erosion of the phosphate formation, and mechanical concentration of nodules and bones, in streams.

We can, therefore, see that phosphate deposits may in some cases exhibit considerable complexity of origin, involving in some cases several shifts of the phosphatic material.

## ROCK PHOSPHATES OF THE UNITED STATES

**Florida** (13, 14, 15). — This state is at present the most important phosphate producer, although the full extent and value of the deposits were unsuspected until the discovery of large beds along the Peace River in 1887. Three distinct types have been recognized, viz., hard rock, land pebble, and river pebble, but the last is no longer important, or even worked. Their mode of occurrence, origin and location is different.

The hard rock phosphate lies in a general north-south belt, about 100 miles long, roughly paralleling the Gulf Coast, while the land-pebble deposits are found farther south, chiefly in Polk and Hillsboro counties (Fig. 84).

The hard rock phosphate, rests on and replaces the porous and cavernous Ocala limestone (Lower Oligocene). It consists of boulders and lumps of phosphate rock, mixed with sands, clays, flint nodules, etc., the phosphate often forming more than 10 to 25 per cent of the entire mass.

There have been different opinions expressed regarding the origin of the hard-rock formation, but Sellards (14) especially, has shown that the Ocala limestone was formerly covered by the

Chattahoochee limestone and Alum Bluff sands. These have disintegrated *in situ*, and the Alum Bluff formation, which is
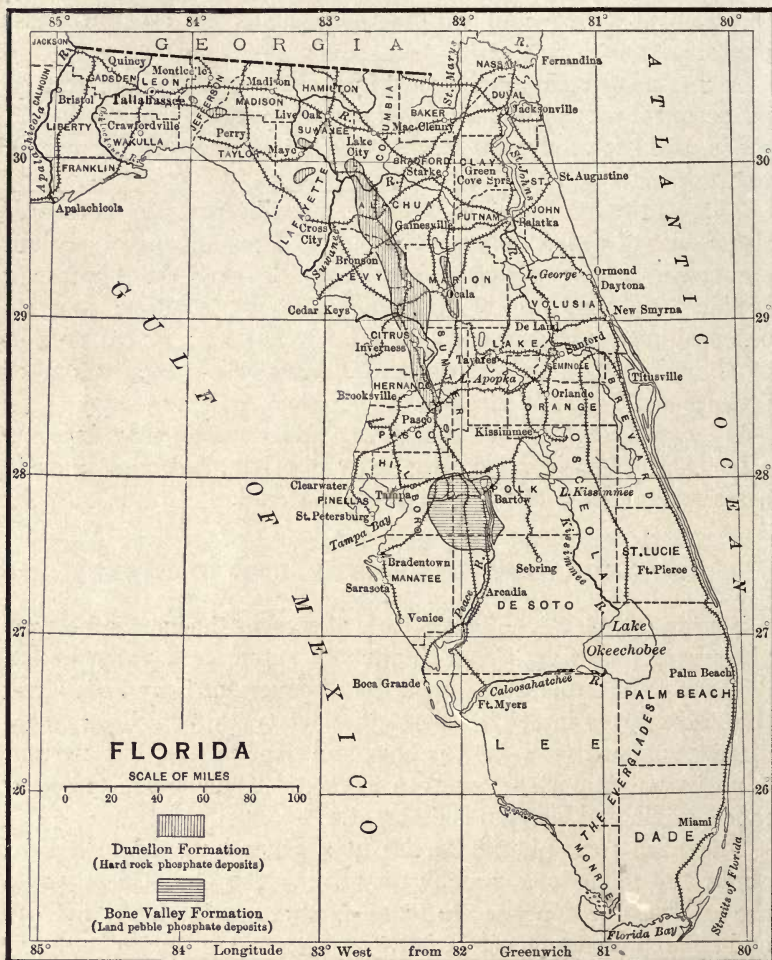


Fig. 84. — Map showing phosphate areas of Florida. (*After Sellards, Fla. Geol. Surv.,* 7th *Ann. Rept.*)

distinctly phosphatic, has by leaching supplied the phosphate which was carried downward and redeposited at a lower level, often by replacement of the limestone, the shells of which were in some cases completely phosphatized. There was also some

PLATE XXVII



FIG. 1. — Rock phosphate mine near Ocala, Fla.    (*Photo., A. W. Sheafer.*)



FIG. 2. — Phosphate beds, Montpelier, Ido.    Shows the alternating layers of limestone and phosphate.    (*W. F. Ferrier, photo.*)

(265)

precipitation of the phosphate in cavities, as shown by the botryoidal and stalactitic forms.

The thickness of the hard-rock phosphate formation is often from 30 to 50 feet, and in exceptional cases 100 feet (14), the high-grade material averaging 77 to 80 per cent tricalcic phosphate.

The land pebble phosphate (Fig. 84) is a conglomerate of pebbles, sands and clay, formed by the sea advancing, probably with minor oscillations in level, across the exposed surface of a great phosphatic marl, the Alum Bluff formation, while the overburden sands represent that part of the formation deposited following the accumulation of the pebble conglomerate. Within the phosphate bed, the rock has been improved by secondary enrichment by downward- and lateral-moving waters, because the pebbles of the phosphate carry considerably more $P_2O_5$ than those of the parent rock.

The pebble phosphate appears to be 8 to 12 feet thick, with a maximum of 18 to 20 feet. In the workable deposits the phosphate makes up 10 to 25 per cent of the whole, while the marketed material runs from 60–74 per cent tricalcic phosphate.

Hard-rock phosphate, if in large lumps, is first crushed, after which, it, together with finer material, passes through a log washer to separate dirt and sand. Land pebble is put through a similar washing process, sometimes preceded by screening. After leaving the cleanser, hard rock is sorted on a picking table.

Both kinds of phosphate must be dried before shipment. Not a little phosphoric acid is to be regarded as lost in the low-grade material which is thrown on the dump, and methods for saving this are needed.

**South Carolina.** — Phosphate is found both on the land and in the river bottoms in a belt about 60 miles long lying inland from Charleston and Beaufort (8, 20, 21). The phosphate, which rarely averages much over 1 foot in thickness, is commonly of nodular character, and often contains many bones and teeth. The presence of these animal remains, including both land and marine forms, has given rise to the belief that the deposits were caused by the accumulation of bones and excrements along a shore line, probably of Upper Miocene (Tertiary) age. Leaching of these remains may have permitted a later replacement of limestone or the formation of phosphatic concretions in swamp bottoms.

Two forms are recognized, viz., land rock (the type now mined) and river rock. The former ranges from 1 to 3 feet in thickness and is overlain by green sand marl. The river rock is little more than water-worn fragments of the first type, and is mined from the river channels. The rock now shipped averages about 61 per cent bone phosphate.

The South Carolina phosphate rock was worked as early as 1867, and the production increased up to 1893, but since then it has fallen off almost steadily.

**Tennessee** (22–28). — Since the recognition, in 1893, of considerable quantities of high-grade phosphates in western middle Tennessee (Fig. 85), there have been important developments of the deposits.

Three types of phosphate deposits are recognized, viz.: brown, blue and white.

*Brown Phosphate* (26). This is more or less confined to the southwestern portions of the Central Basin of Tennessee, with
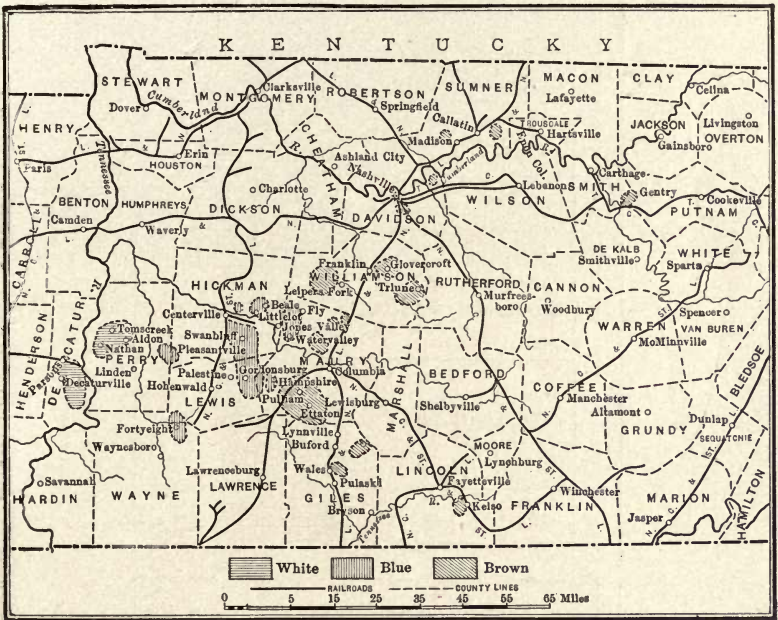


FIG. 85. — Map showing distribution of phosphates in Tennessee. (*Adapted from Ruhm, Eng. and Min. Jour., LXXXIII.*)

Mount Pleasant as the most important producing district (Fig. 85).

It occurs as a residum filling solution cavities or pockets in phosphatic limestone (Fig. 87), which have been formed by the leaching action of surface waters, that removed the lime carbonate. Where the parent rock has not been exposed to weathering action no concentration has occurred.

Two types of deposit are recognized, viz.: (1) *Rim* or *collar* deposits (Plate XXVIII, Fig. 2) in which a more or less connected

group encircles a hill, and (2) *Blanket* deposits formed where the limestone is exposed to weathering action over a considerable area. The two types grade into one another.
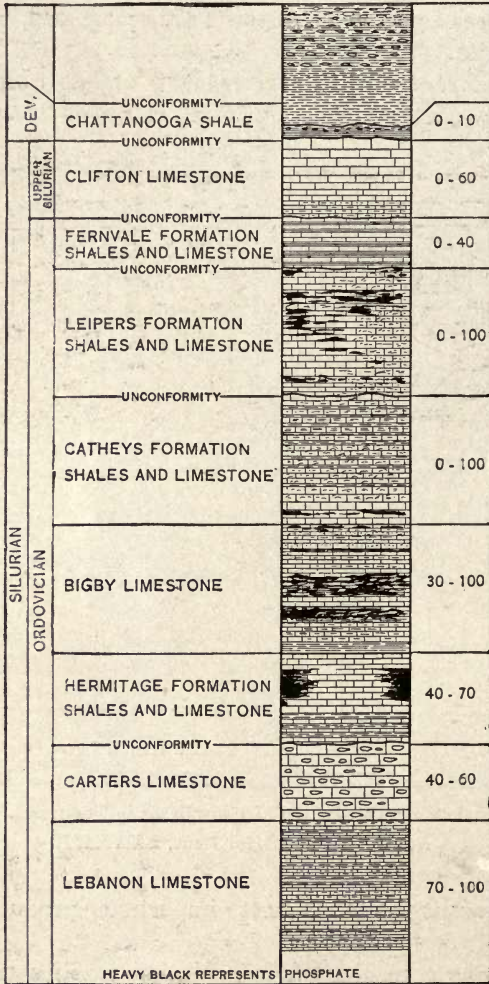


Fig. 86. — Vertical section showing geologic position of Tennessee phosphates. (*After Hayes.*)

A dominant factor is the presence of major joints striking N. 60° W., and it is along these that the weathering proceeds (Fig. 87), resulting in long narrow trenches, called *cutters* (Plate XXVIII, Fig. 1), filled with the commercially valuable phosphate.

PLATE XXVIII



FIG. 1. — View showing phosphate cutters, Mt. Pleasant, Tenn. (*J. S. Hook, photo.*)
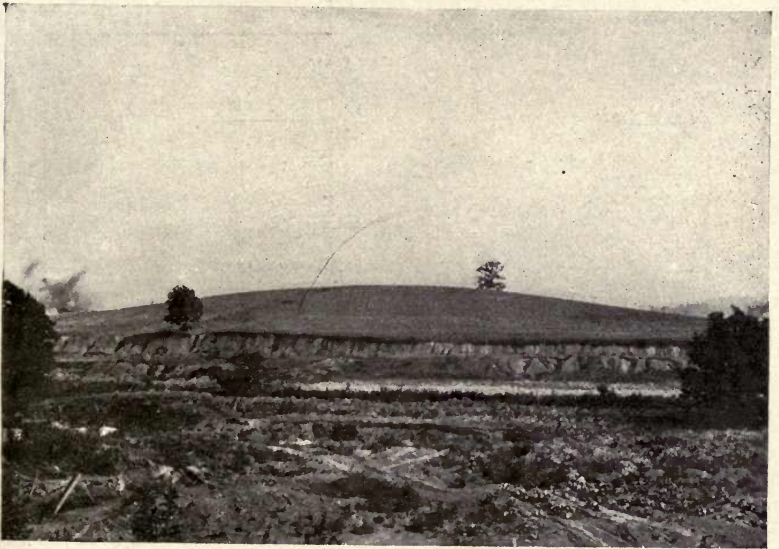


FIG. 2. — Collar deposit of brown Tennessee phosphate around base of hill. (*J. S. Hook, photo.*)

(269)
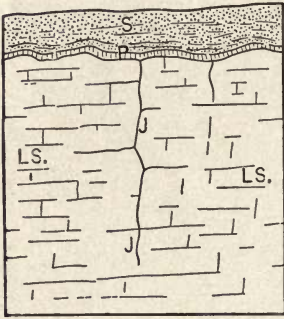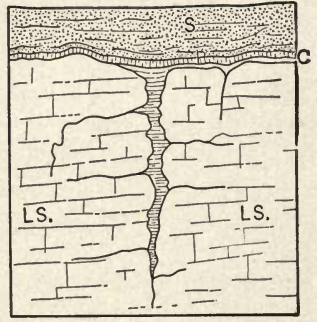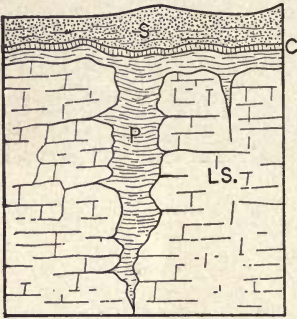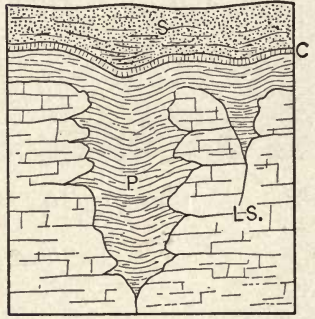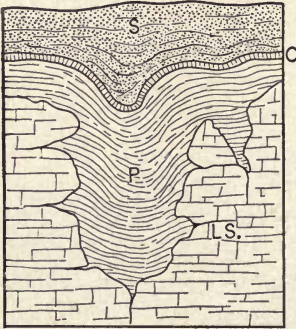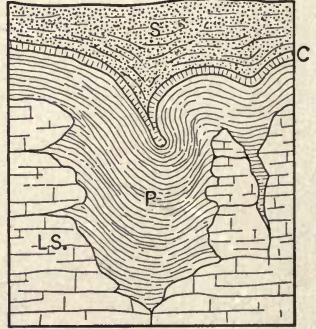
FIG. 87. — Sections, showing development of " cutters " of brown phosphate. (*After Hook, Min. Res. Tenn., IV, No. 2, 1914.*)

These average about 15 feet in depth, and 10 feet in width, with maxima of 45 feet and 20 feet respectively.

The commercial rock is either of a porous, platy, coherent structure, or of a loose, sandy nature.

The Bigby limestone (Ordovician) from which the phosphate is derived, is when fresh, of dense, crystalline nature, usually banded with thin black layers, which are more phosphatic than the rest of the rock, and produce the best quality of platy phosphate.

After mining, the brown phosphate is put through a washer to eliminate clay, iron oxide, chert, limestone lumps, and other foreign matter. The washed product is sold under a guarantee of from 70 to 80 per cent bone phosphate, the maximum specified amounts of combined iron and alumina in each case being $6\frac{1}{2}$ and 4 per cent.

*Blue Rock* (26). In Hickman, Lewis, Maury, and Perry counties, especially, there occurs a phosphatic stratum, just below the Chattanooga shale in the Devonian, which varies from a few inches up to 2 or 3 feet in thickness. The more purely phosphatic portion, known as *blue rock*, grades into non-phosphatic sandstone or shale. Structurally it may be oolitic, compact, conglomeratic or shaly. Just above it in the Chattanooga shale is a layer of flat phosphate nodules.

The blue rock appears to be a sediment, which has not been altered since its deposition, the phosphatic material having been supposedly derived from the subaerial decay of phosphatic Ordovician limestones, and mechanically concentrated by ocean currents into the lenticular deposits from which it is now mined.

The blue rock after mining is crushed fine.

*White Phosphate.* — (23, 25, 27, 28). This is found in Perry and Decatur counties, and is directly associated with Silurian limestone and with breccias of Camden chert. Three varieties of phosphate are recognized, all of which are clearly the result of transportation and deposition by underground water. They are: (1) *Stony*, representing an originally siliceous limestone, from which the calcium carbonate has been dissolved, and calcium phosphate deposited in its place. The phosphate, which forms 27 to 33 per cent of the rock is therefore a replacement; (2) *Breccia*, forming irregular masses of surface character, and consisting of small angular fragments of chert, embedded in a matrix of phosphate; (3) *Lamellar*, consisting of thin parallel layers or

plates, deposited from solutions, and filling pre-existing solution channels, or as a matrix around chert fragments. This is the most important type.

The Phosphatic material has probably been derived from the formerly overlying Devonian rock, but since its deposition is closely associated with the movement of water through irregular solution channels, its distribution must be regarded as more or less uncertain.

ANALYSES OF PHOSPHATE

| | FLORIDA HARD ROCK PHOSPHATE | | | | FLORIDA LAND PEBBLE | |
|---|---|---|---|---|---|---|
| | WHITE HARD ROCK, NODULAR | WHITE HARD PLATE ROCK | WHITE, SOFT, EARTH-LIKE | WASHINGS FROM PHOSPHATE | WHITE PEBBLES | BROWN PEBBLES |
| Bone phosphate . . | 84.40 | 75.6 | 67.5 | 39.42 | 75.77 | 68.55 |
| $Fe_2O_3$ . . . . . | .32 | .8 | 11.68 | 2.25 | .80 | 2.24 |
| $Al_2O_3$ . . . . . | .82 | .73 | 4.68 | 19.17 | .60 | .84 |
| $CaCO_3$ . . . . . | —— | —— | —— | —— | —— | —— |
| $FeS_2$ . . . . . . | —— | —— | —— | —— | —— | —— |
| $SiO_2$ . . . . . . | —— | —— | .87 | 38.40 | 4.16 | 3.81 |
| $H_2O$ . . . . . . | 1.32 | —— | —— | —— | —— | —— |

| | TENNESSEE | | | | SOUTH CAROLINA | | |
|---|---|---|---|---|---|---|---|
| | BROWN ROCK | BROWN ROCK | BLUE | BLUE LOW GRADE | | LAND ROCK | RIVER ROCK | RIVER ROCK |
| Bone phosphate . . | 77.77 | 63.5 | 73.90 | 26.16 | $Ca_3(PO_4)_2$ | 58.25 | 54.88 | 59.51 |
| $Fe_2O_3$ . . . . . | 3.12 | 1.12 | —— | 2.63 | Insol. | 11.89 | | |
| $Al_2O_3$ . . . . . | 2.08 | 2.00 | 1.00 | 7.79 | $CaCO_3$ | 7.98 | 8.20 | 8.61 |
| $CaCO_3$ . . . . . | 0.20 | .88 | 10.90 | 1.70 | | | | |
| $FeS_2$ . . . . . . | —— | —— | 1.49 | 54.48 | | | | |
| $SiO_2$ . . . . . . | —— | —— | 3.19 | 1.90 | $H_2O$ | }6.58 | 5.80 | 4.31 |
| $H_2O$ . . . . . . | —— | —— | 3.11 | | Org. | | —— | —— |

**Western States** (31–39). — Large areas of phosphate rock have been discovered in the western states (Fig. 88), within the last few years. The deposits, which are said to be the most extensive thus far discovered in the world, will no doubt prove to be of great importance in the future, although at present their development has been retarded, partly by lack of transportation facilities and limited demand.
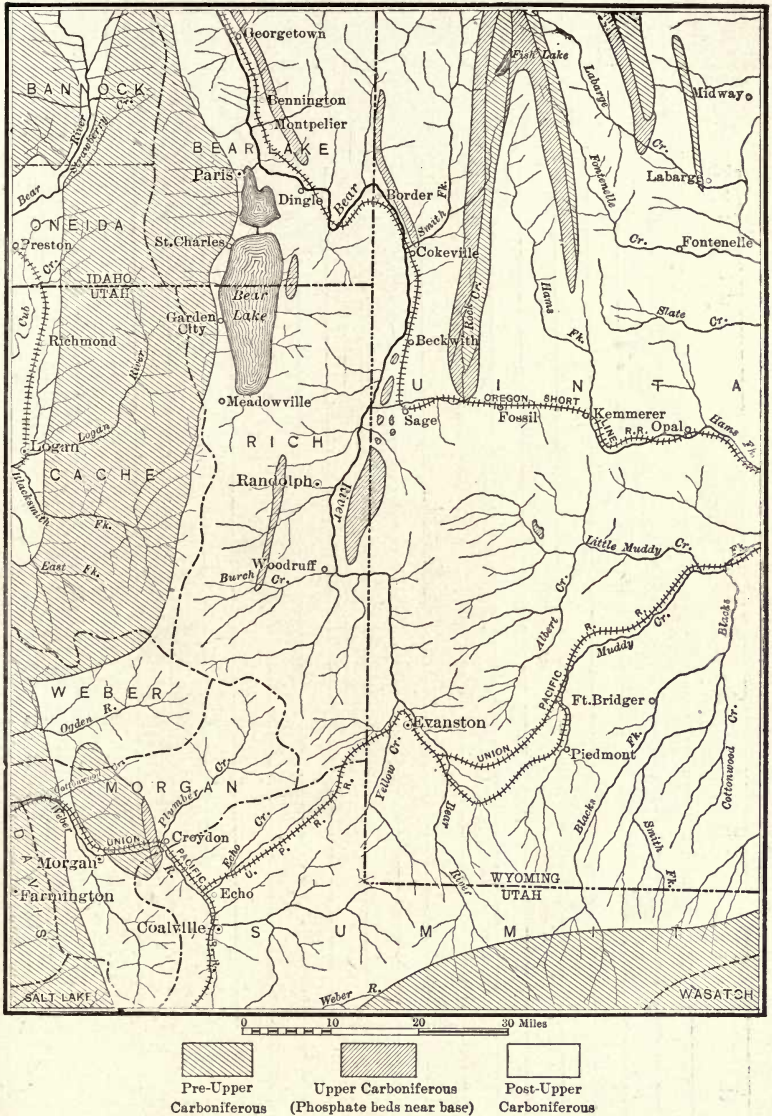
Fig. 88. — Map of parts of Idaho, Wyoming, and Utah, showing localities of Upper Carboniferous rocks containing phosphate beds.   (*After Weeks and Ferrier, U. S. Geol. Surv., Bull.* 315, 1906.)
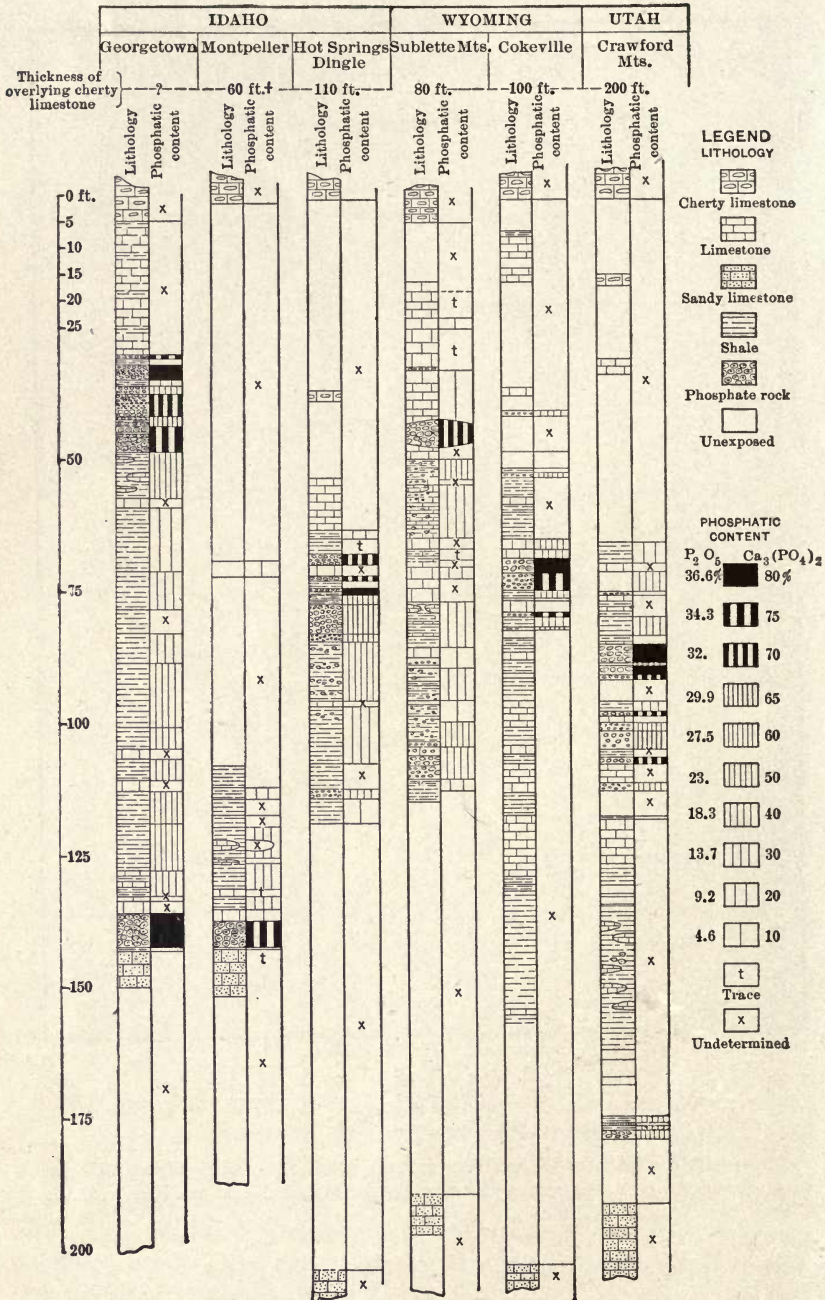
Fig. 89. — Columnar sections showing position and richness of phosphate beds in western states. (*U. S. Geol. Surv., Bull.* 430, 1910.)

They extend for a distance of 200 miles north of Ogden, Utah, into Idaho and Wyoming, and have also been found near Ellis-
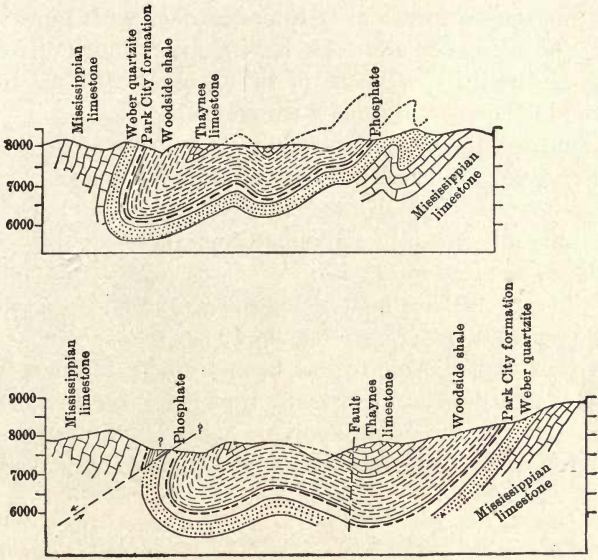


Fig. 90. — Section showing structure of phosphate bearing formations in Wyoming. (*U. S. Geol. Surv.*)
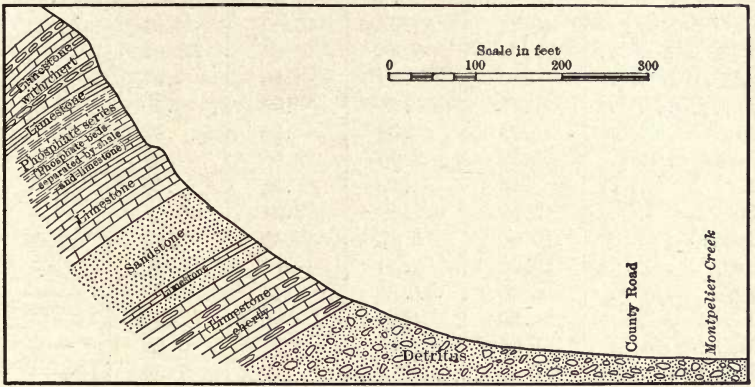


Fig. 91. — Section of Carboniferous strata on north side of Montpelier Creek, Ida (*After Weeks and Ferrier, U. S. Geol. Surv., Bull.* 315, 1906.)

ton, Melrose, and other places in Montana. The earlier reports place them in the Park City formation of the Permian, but some of the later ones assign the phosphate beds to the Phosphoria

formation, which is regarded as the equivalent of the two upper members of the Park City, and also of the phosphatic beds above the Quadrant formation of the Melrose and Elliston district.

The phosphate forms beds interstratified with limestones and shales, the series in all cases having been much disturbed by folding and faulting. Those of the Georgetown area have been involved in the great Bannock thrust fault.[1]

In hand specimens the phosphate is seen to be dense, with an oolitic texture. It is dark brown when fresh, but becomes bluish white on weathering. Under the microscope it shows an isotropic mineral, possibly collophanite, and a doubly refracting phosphate, possibly quercyite.

The lime phosphate content of the workable beds varies from 65 to 80 per cent with an average of 70 per cent.

Just how the phosphate has been formed is not conclusively settled, the only certain fact being that it has been precipitated in some manner on the ocean floor.

The following analyses will serve to show its composition:

ANALYSES OF WESTERN PHOSPHATES

|  | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| CaO . . . . | 45.34 | 50.97 | 46.80 | 48.91 | 51.15 |
| $P_2O_5$ . . . . | 27.32 | 36.35 | 32.05 | 33.61 | 35.09 |
| $Al_2O_3$ . . . | .89 | .50 | .90 | .97 | 2.20 |
| $Fe_2O_3$. . . | .73 | .26 | .33 | .40 | .10 |
| MgO . . . | .28 | .22 | .26 | .33 | —— |
| $Na_2O$ . . . | 1.10 | 2.00 | 2.08 | .97 | —— |
| $K_2O$ . . . . | .48 | .47 | .58 | .34 | —— |
| $SO_3$ . . . . | 1.59 | 2.98 | 2.34 | 2.16 | —— |
| Insol. . . . | 10.00 | 1.82 | 9.40 | 2.62 | 4.49 |
| $SiO_2$ . . . . | 0.00 | .30 | —— | .46 | —— |
| $CO_2$ . . . . | 6.00 | 1.72 | 2.14 | 2.42 | —— |
| F . . . . . | .60 | .40 | .66 | .40 | —— |
| $H_2O$ (110° C.). | 1.04 | .48 | .61 | 1.02 | —— |
| $H_2O$ . . . . | 1.14 | .57 | .75 | 1.34 | —— |

1. Main bed, Cokeville, Wyo.; 2. Crawford Mts., Utah; 3. Between Morgan and Devil's Slide, Utah; 4. Eight miles E. of Georgetown, Idaho; 5. Melrose, Mont.; Nos. 1–4, U. S. G. S., Bull. 430; No. 5, Bull. 470.

[1] Richards and Mansfield, Jour. Geol. XX: 681, 1912.

Although the western phosphate beds seem to lie chiefly in the Permian, still others are known to occur in the Mississippian of Utah.[1]

*Arkansas* (10, 11, 12). — Phosphate deposits have been developed on Lafferty Creek, on the western edge of Independence County, but the beds



Fig. 92a. — Oolitic phosphate, Cokeville, Wyo. ×30.
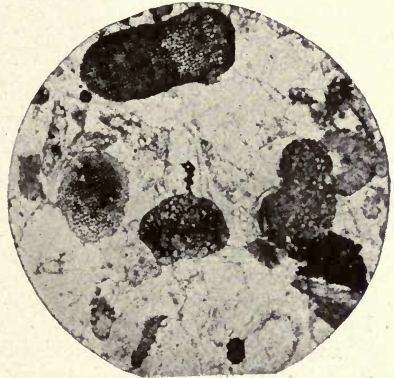
Fig. 92b. — Bigbee limestone, Mt. Pleasant, Tenn. Oolitic bodies largely phosphate; light ground calcite with phosphate grains. ×30.

extend from about 10 miles northeast of Batesville, to St. Joe in Searcy County, a distance of about 80 miles. The phosphate which forms a bed 2 to 6 feet thick in the Cason shale of the Ordovician is light gray, homogeneous and conglomeratic with small pebbles. It carries from 25 to 73 per cent lime phosphate. The following section is shown on Lafferty Creek (Fig. 93).

| | FEET | INCHES |
|---|---|---|
| St. Clair limestone . . . . . . . . . . . . . . . . . . . . . . . . . . . . | — | — |
| Brown to black shale . . . . . . . . . . . . . . . . . . . . . . . . . | 2 | 0 |
| Low-grade manganese iron ore . . . . . . . . . . . . . . . . . | 1 | 3 |
| Green to dark gray shale . . . . . . . . . . . . . . . . . . . . . . | 1 | 2 |
| High-grade phosphate . . . . . . . . . . . . . . . . . . . . . . . . | 4½–6 | — |
| Manganese-iron ore . . . . . . . . . . . . . . . . . . . . . . . . . | — | 2 |
| Low-grade phosphate . . . . . . . . . . . . . . . . . . . . . . . . | 4 | — |
| Polk Bayou limestone . . . . . . . . . . . . . . . . . . . . . . . . | — | — |

The Arkansas phosphates were discovered in 1895, but were not developed until 1900. The field will be of doubtful importance until low and medium-grade rock is marketable.

[1] Petersen, W., Science, No. 20, 1914, p. 755.

Clay and Chert

3 inches  Clay shale

13 "  39.65% $Ca_3 P_2 O_8$

14 "  Phosphatic shale

9 "  41.27% $Ca_3 P_2 O_8$

30 "  55.27% " " "

6 "  50.67% " " "

10 "  50.66% " " "

Phosphatic sandstone
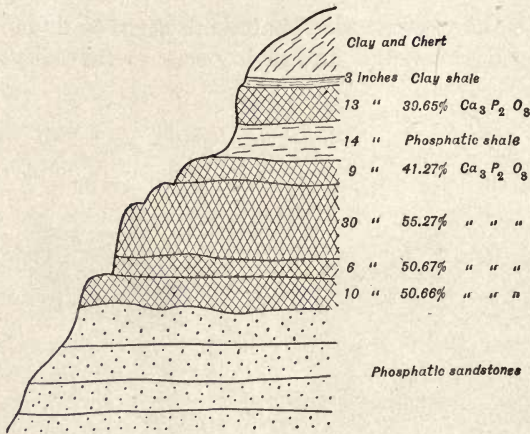
FIG. 93. — Section in Lafferty Creek, Ark., Phosphate district.  *After Branner and Newsom, Ark. Agric. Exp. Sta., Bull.* 74.)

The true nature of these phosphate deposits does not appear to have been recognized for some years.

Branner and Newsom considered them to be deep-sea (though not abysmal) deposits, formed from the droppings of fishes and other marine animals, and to accumulations of organic matter that settled to the bottom of the quiet waters.

Purdue believed the beds to have been laid down near shore as the sea advanced landward, and the phosphatic nature as due mainly to fragments of organic matter, but may have been in part the droppings of marine animals. The conglomerate character is thought by him to confirm the shallow-water theory.

*Other Phosphate Occurrences.* — Phosphate, in the form of nodules, white vesicular rock, and in limestone fragments, occurs along the contact of Oriskany (Devonian) sandstone and Lower Helderberg (Silurian) limestone in Juniata County, Pennsylvania (19). It contains 30 to 54 per cent bone phosphate. Nodular phosphate, although not worked for fertilizer, is known to occur in Cretaceous and Tertiary strata in Alabama (9), Georgia (16), North Carolina (18), and Virginia (29, 30). Phosphate is now being obtained also from the Trenton of central Kentucky (17).

**Canada.** (39a).—The finding of phosphates at a definite geologic horizon in the western United States has encouraged the Canadian geologists to make a search for this material in the continuation of the phosphate-bearing formations to the north of the international boundary, resulting in the finding of phosphate rock in the Upper Carboniferous a short distance north of Banff, in the Rocky Mountains. The finds consist of " float " phosphate and also a phosphatic quartzite at the contact between the Upper Banff limestone and the Rocky Mountain quartzite.

The latter, which contains 7.6 per cent. $P_2O_5$, is not rich enough to work, but its discovery warrants further search.

**Guano** (45, 46). — Under this name are included surface deposits of excrement, chiefly of birds. Penrose (8) recognizes two classes: (1) soluble guano, of recent origin, usually found in sheltered places, and containing not only phosphoric acid in readily available form, but also considerable nitrogen. (2) Leached guano, which has lost its soluble constituents by the action of rain or sea water, and which contains practically no nitrogen, while the phosphoric acid content, though usually high, is relatively insoluble. Most of the soluble guano of commerce was formerly obtained from Peru, where, it is said, the Incas, as well as the early Spaniards, valued it so highly that a death penalty was imposed for killing the birds which produced it. These deposits, from which many thousand tons have been obtained, are now exhausted. No large deposits of bird guano are known in the United States. Leached guanos occur on islands in the southern Pacific and in the West Indies.

Bat guano has been found in the caves of Kentucky, Texas (46), and many other states, but few of the deposits have proved large enough to work, and none are of great extent, although one cave in Texas was known to yield 1000 tons. The following analysis is representative: ammonia, 9.44 per cent; available phosphoric acid, 3.17 per cent; potash, 1.32 per cent.

**Greensand.** — This term is applied to beds of marine origin, made up in large part of the green sandy grains of glauconite, the hydrated silicate of iron and potash. It also contains small amounts of phosphoric acid. Greensand (29) is found at many localities in the Cretaceous and Tertiary formations of the Atlantic Coastal Plain, but New Jersey (43) and Virginia are the two important producers. The New Jersey greensand is spread on the soil in its raw condition, but that from Virginia is dried and ground for use in commercial fertilizers.

The following analyses show its variable composition, and the comparatively small amount of $P_2O_5$ and $K_2O$ necessary to make it of value as a fertilizer.

ANALYSES OF GREENSAND

| | $P_2O_5$ | $SO_3$ | $SiO_2$ | $CO_2$ | $K_2O$ | $Na_2O$ | CaO | MgO | $Al_2O_3$ | $Fe_2O_3$ | $H_2O$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Pemberton, N. J. | 1.02 | .27 | 50.23 | — | 6.32 | 1.59 | 1.40 | 3.45 | 7.94 | 20.14 | 9.00 |
| Aquia Creek, Va. | .09 | — | 21.58 | 29.79 | .37 | .59 | 36.78 | 1.05 | 7.70 | — | .76 |

**Uses.** — Fertilizers are used either in their raw condition or after undergoing preparation. Lime carbonate may be calcined first, or ground raw, and then spread on the soil. Gypsum is first pulverized before being sold as land plaster.

Phosphate is converted into *acid phosphate* by treatment with sulphuric acid, and the manufacture of this product has increased enormously

in the United States.[1] The raw materials which can be used for this purpose are guano, bone, apatite, and phosphate rock. Of these the last is the most important. Only guano that is easily obtained and high in nitrogen can compete with phosphate rock, while the chief objection to apatite is, the cost of mining, and the evolution of fluorine gas when treated with sulphuric acid.

**Foreign Deposits** (4). — Next to the United States, North Africa ranks as an important producer, the deposits of Algiers and Tunis being of considerable extent. These lie chiefly on the boundary between the Cretaceous and Tertiary, and consist of phosphatic beds, with phosphate nodules, teeth, and bones, and gypsum, interstratified with phosphatic marls and limestones. Some of the deposits are 3 meters thick.

In France there are a number of producing localities, most of which yield phosphate from bedded deposits of Cretaceous age, or in the Pyrenees, beds of upper Devonian age. An exception is formed by the Quercy phosphates, which occur as veins in limestone.

The Belgian deposits are also bedded and found in the Cretaceous.

**Production of Fertilizers.** — The production of phosphate in the United States for several years was as shown in the table on page 281.

*Exports and Imports.*—The following table shows what a large percentage of the phosphate rock produced in the United States is exported:

PRODUCTION AND EXPORTATION OF PHOSPHATE ROCK IN THE UNITED STATES, 1909–1914, IN LONG TONS

| YEAR | PRODUCTION | EXPORTATION | YEAR | PRODUCTION | EXPORTATION |
|---|---|---|---|---|---|
| 1909. . . | 2,338,264 | 1,020,556 | 1912 . . | 2,973,332 | 1,206,520 |
| 1910. . . | 2,654,988 | 1,803,037 | 1913 . . | 3,111,221 | 1,366,508 |
| 1911. . . | 3,053,279 | 1,246,577 | 1914 , . | 2,734,043 | 964,11 |

These exports are sent to all parts of Europe, Germany being the largest consumer. The imports since 1910 have been as follows:—

FERTILIZERS IMPORTED AND ENTERED FOR CONSUMPTION IN THE UNITED STATES, 1910–1914, IN LONG TONS

| YEAR | GUANO | | KAINIT | | ALL OTHER | | TOTAL |
|---|---|---|---|---|---|---|---|
| | Quantity | Value | Quantity | Value | Quantity | Value | |
| 1910 | 33,565 | $667,870 | 582,197 | $2,798,198 | 428,232 | $6,054,006 | $9,520,074 |
| 1911 | 36,869 | 774,315 | 563,957 | 2,748,140 | 428,549 | 7,240,017 | 10,762,472 |
| 1912 | 19,128 | 329,624 | 511,976 | 2,386,362 | 468,234 | 6,117,104 | 8,893,090 |
| 1913 | 16,674 | 518,429 | 465,336 | 2,201,730 | 473,426 | 8,099,094 | 10,819,253 |
| 1914 | 25,335 | 761,562 | 313,898 | 1,551,115 | 422,663 | 7,608,762 | 9,921,439 |

[1] U. S. Dept. Agric., Bull. 144, 1914.

PRODUCTION OF PHOSPHATES IN THE UNITED STATES, 1910-1914

| | 1910 Long Tons | 1910 Value | 1910 Average Price Per Ton | 1911 Long Tons | 1911 Value | 1911 Average Price Per Ton | 1912 Long Tons | 1912 Value | 1912 Average Price Per Ton | 1913 Long Tons | 1913 Value | 1913 Average Price Per Ton | 1914 Long Tons | 1914 Value | 1914 Average Price Per Ton |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Florida: | | | | | | | | | | | | | | | |
| Hard rock | 438,347 | $3,051,827 | $6.96 | 443,511 | $2,761,449 | $6.23 | 493,481 | $3,293,168 | $6.67 | 489,794 | $2,987,274 | $6.10 | 309,689 | $1,912,197 | $6.17 |
| Land pebble | 1,629,160 | 5,595,947 | 3.43 | 1,992,737[2] | 6,712,189[2] | 3.37 | 1,913,418[2] | 6,168,129[2] | 3.22 | 2,055,482[2] | 6,575,810 | 3.20 | 1,829,202[2] | 5,422,547[2] | 2.98 |
| River pebble | 0 | 0 | — | | | | | | | | | | | | |
| Total | 2,067,507 | 8,647,774 | 4.18 | 2,436,248 | 9,473,638 | 3.89 | 2,406,899 | 9,461,297 | 3.93 | 2,545,276 | 9,563,084 | 3.76 | 2,138,891 | 7,354,744 | 3.44 |
| South Carolina: | | | | | | | | | | | | | | | |
| Land rock | 179,659[1] | 733,057[1] | 4.08 | 169,156 | 673,156 | 3.98 | 131,490 | 524,760 | 3.99 | 109,333 | 440,588 | 3.99 | 106,919 | 415,039 | 3.88 |
| River rock | 0 | 0 | — | 0 | 0 | — | 0 | 0 | — | 0 | 0 | — | 0 | 0 | — |
| Total | 179,659 | 733,057 | 4.08 | 169,156 | 673,156 | 3.98 | 131,490 | 524,760 | 3.99 | 109,333 | 440,588 | 3.99 | 106,919 | 415,039 | 3.88 |
| Tennessee: | | | | | | | | | | | | | | | |
| Brown rock | 329,382 | 1,262,279 | 3.83 | 365,068 | 1,450,063 | 3.97 | 359,692 | 1,420,726 | 3.95 | 451,559 | 1,774,392 | 3.95 | 483,203 | 1,822,770 | 3.77 |
| Blue rock | 468,806 | 241,071 | 3.50 | 472,302[2] | 263,954 | 3.65 | 63,639[2] | 219,750 | 3.45 | 0 | 0 | — | 0 | 0 | — |
| White rock | 0 | 0 | — | 0 | 0 | — | 0 | 0 | — | | | | | | |
| Total | 398,188 | 1,503,350 | 3.78 | 437,370 | 1,714,017 | 3.92 | 423,331 | 1,640,476 | 3.88 | 451,559 | 1,774,392 | 3.93 | 483,203 | 1,822,770 | 3.77 |
| Western States | 9,634 | 32,819 | 3.41 | 10,505[3] | 39,882 | 3.80 | 11,612[3] | 49,241 | 4.24 | 5,053 | 18,167 | 3.60 | 5,030 | 15,488 | 3.08 |
| Grand Total | 2,654,988 | 10,917,000 | 4.11 | 3,053,279 | 11,900,693 | 3.90 | 2,973,332 | 11,675,774 | 3.93 | 3,111,221 | 11,796,231 | 3.79 | 2,734,043 | 9,608,041 | 3.51 |

[1] Small amount included in land rock.
[2] Small amount included with land pebble.
[3] Includes Idaho, Utah, Wyoming; 1913: Idaho and Wyoming.
[4] Includes small quantity of rock from Arkansas.

*World's production.*—The table given below is of interest, since it brings out clearly the leading position of the United States as a producer of phosphates.

WORLD'S PRODUCTION OF PHOSPHATE ROCK, 1910–1912, BY COUNTRIES, IN METRIC TONS

| COUNTRY | 1910 | | 1911 | | 1912 | |
|---|---|---|---|---|---|---|
| | QUANTITY | VALUE | QUANTITY | VALUE | QUANTITY | VALUE |
| Algeria. . . . . | 412,319 | $1,193,664 | 738,935 | $2,139,217 | [1] | [1] |
| Australia . . . . | 5,283 | 25,306 | 5,893 | 28,226 | [1] | [1] |
| Belgium . . . . | 202,880 | 366,015 | 196,780 | 319,039 | 203,110 | $316,703 |
| Canada . . . . | 1,341 | 12,578 | 563 | 5,206 | 148 | 1,640 |
| Christmas Islands (Straits Settlements) | [2]139,903 | [3] | [2]155,311 | [3] | [1] | [1] |
| Dutch West Indies: | | | | | | |
| Aruba . . . . | [2]20,337 | 106,216 | [2]27,658 | 88,430 | [1] | [1] |
| Curaçao . . . . | [2]2,165 | 3,621 | [2]1,836 | 3,071 | [1] | [1] |
| France . . . . | 333,506 | 1,253,708 | 312,204 | 1,172,404 | [1] | [1] |
| French Guiana . . | [2]6,925 | 53,074 | [1] | [1] | [1] | [1] |
| French Oceanica, So. ciety Islands . . | [2]40 | 209 | [2]12,102 | 46,378 | [1] | [1] |
| South Africa, Natal | 280 | 1,007 | —— | —— | [1] | [1] |
| Tunis . . . . . | 1,334,264 | 5,714,011 | 1,592,000 | 6,824,974 | 1,882,100 | 8,370,000 |
| United States . . | 2,697,648 | 10,917,000 | 3,102,131 | 11,900,693 | 3,020,905 | 11,675,774 |

[1] Statistics not yet available.      [2] Exports.      [3] Value not reported.

PRODUCTION OF APATITE IN CANADA

| YEAR | SHORT TONS | VALUE |
|---|---|---|
| 1912 . . . . . . . . . . . . . | 164 | $1,640 |
| 1913 . . . . . . . . . . . . . | 385 | 3,643 |
| 1914 . . . . . . . . . . . . . | 954 | 7,275 |

EXPORTS AND IMPORTS OF PHOSPHATE FOR CANADA IN 1913

| KIND | IMPORTS | EXPORTS |
|---|---|---|
| Phosphate rock . . . . . . . . . . | $ 16,070 | —— |
| Phosphorus . . . . . . . . . . | 5,856 | $73,395 |
| Manufactured fertilizers . . . . . . | 505,904 | —— |

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## ABRASIVES

**Introductory.** — Under this heading are included those natural products which are employed for abrasive purposes. Since the main use of some is not for work of abrasion, they are simply referred to briefly in this chapter, the detailed description of them being given on another page. Brief reference will also be made to some artificial compounds which come into serious competition with the natural ones.

While some abrasive substances occur as constituents of veins, or in disseminated form, the great majority form a part of rocks of either sedimentary, igneous, or metamorphic origin, and of various degrees of consolidation. They are widely distributed both geologically and geographically, but since the localities of production change from time to time, their distribution can be better illustrated by the table on page 286 than by a map.

**Millstones and Buhrstones** [1] (2) are stones of large diameter used for grinding cereals, paint ores, cement rock, barite, fertilizers, etc. The American stones are either coarse sandstone or quartz conglomerate, and are quarried at several points along the eastern side of the Appalachian Mountains from New York to North Carolina, the most important being the Shawangunk Grit (Silurian) quarried in the Shawangunk Mountains of eastern New York (20, 21). Some are also quarried in Pennsylvania, North Carolina, and Virginia (22). The material adapted to millstones is very limited in extent. Some of the stone is also cut into chasers, used for grinding quartz and feldspar. Owing to the use of improved grinding machinery the demand for millstones has fallen off greatly in recent years.

Many buhrstones are imported from France, Belgium, and Germany. Those from the first two localities are hard, cellular rocks,

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[1] The term buhrstone belongs properly to those millstones made of a chalcedonic rock, full of cavities, some of them representing casts of shells.

PLATE XXIX



FIG. 1. — Grindstone quarry, Tippecanoe, Ohio. (*J. H. Pratt, photo.*)



FIG. 2. — Corundum vein between peridotite and gneiss, Corundum Hill, Ga. (*After Pratt, U. S. Geol. Surv., Bull.* 180.)

(285)

TABLE SHOWING ABRASIVES OBTAINED FROM DIFFERENT STATES IN 1913 AND 1914

| | Millstones | Oilstones | Scythestones | Grindstones | Pulpstones | Rottenstone | Garnet | Emery | Diat. Earth | Tripoli | Pumice |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alabama | × | | | | | | | | | | |
| Arkansas | — | × | | | | | | | | | |
| California | — | — | — | — | — | — | — | — | × | — | × |
| Connecticut | — | — | — | — | — | — | — | — | × | | |
| Georgia | — | — | — | — | — | — | — | — | — | ¹× | |
| Florida | — | — | — | — | — | — | — | — | — | ¹× | |
| Illinois | — | — | — | — | — | — | — | — | × | | |
| Indiana | — | × | | | | | | | | | |
| Kansas | — | — | — | — | — | — | — | — | — | — | × |
| Kentucky | — | × | | | | | | | | | |
| Maryland | — | — | — | — | — | — | — | — | × | | |
| Massachusetts | — | — | — | — | — | — | — | — | ²× | | |
| Michigan | — | — | × | × | | | | | | | |
| Missouri | — | — | — | — | — | — | — | — | — | × | |
| Nebraska | — | — | — | — | — | — | — | — | — | — | × |
| Nevada | — | — | — | — | — | — | — | — | × | | |
| New Hampshire | — | — | × | — | — | — | × | | | | |
| New York | × | — | — | — | — | — | × | × | × | | |
| North Carolina | × | — | — | — | — | — | × | | | | |
| Ohio | — | × | × | × | × | | | | | | |
| Oklahoma | — | — | — | — | — | — | — | — | — | ¹× | |
| Pennsylvania | × | — | — | — | — | ²× | | | | | |
| Tennessee | — | — | — | — | — | — | — | — | — | ¹× | |
| Utah | — | — | — | — | — | — | — | — | — | — | ¹× |
| Vermont | — | — | × | | | | | | | | |
| Virginia | × | — | — | — | — | — | — | — | ²× | | |
| Washington | — | — | — | — | — | — | — | — | × | | |
| West Virginia | — | — | — | × | | | | | | | |

¹ Recorded only for 1913.      ² Recorded only for 1914.

consisting of a mixture of fine quartz particles and calcareous material; but the German buhrstone is basaltic lava.

**Grindstones** (2, 13). — These are made from sandstones of homogeneous texture and sufficient cementing material to hold the quartz grains together, but not enough to so fill the pores as to make the rock wear smooth under use. Most of the grindstones produced in the United States are obtained from the Berea grit of Ohio (Pl. XXIX, Fig. 1) and Michigan, certain layers of which are highly

prized for this purpose. West Virginia also contributes to the output.

Pulpstones, which have a diameter of 48 to 56 inches, a thickness of 16 to 26 inches, and a weight of 2300 to 4800 pounds, are a thicker variety of grindstone. They are used for grinding wood pulp in paper manufacture, and hence have to withstand continual exposure to hot water. On account of their superior quality, pulpstones from Newcastle-upon-Tyne, England, supply most of the American demand; but it is probable that certain beds of the Ohio sandstones will be found suited for this purpose (2).

**Whetstones, Oilstones** (2, 13, 17), etc. — The term " whetstone " includes those stones used for sharpening tools, the term " oilstone " being often applied when oil is placed on the stone to prevent heating and clogging of the pores by grains of steel. The stones used for making whetstones are either sedimentary or metamorphic in character, and include sandstone, quartzite, mica schist, and novaculite. The stone selected will naturally vary somewhat with the exact use to which it is to be put, but even texture and comparatively fine grain are essentials. A small amount of clayey matter adds to the fineness of grinding, but an excess lowers the abrasive efficiency of the stone. In the schists used, abrasive action is due to the grains of quartz, or sometimes garnet, which are embedded among the fine-grained scales of mica.

Rocks suitable for whetstone manufacture are found in many states, especially east of the Mississippi (2, 13), but, on account of keen competition and limited demand, only the better grades from the best-located deposits are employed. Most of the supply is therefore obtained from a few states, especially Arkansas, Indiana, Ohio, New York, Vermont, and New Hampshire.

Among the whetstones quarried in the United States, the Hindostan or Orange stone of Indiana and the Deerlick oilstone of Ohio are much used for oilstones. Scythestones are made from schistose rock in Grafton County, New Hampshire, and Orleans County, Vermont. At Pike Station, N. H. (Pl. XXVI, Fig. 2), the raw material quarried for scythestones is a fine-grained, thinly laminated, micaceous sandstone, whose quartz grains occur in definite layers, separated by thin layers of mica flakes. Those portions of the rock in which the quartz grains are coarse or irregularly disposed, as well as argillaceous portions, are unfit for abrasive purposes.[1]

The novaculite quarried in Garland and Saline counties, Arkansas (17), represents a unique type, much prized for high-grade

[1] Min. Res., U. S. Geol. Surv., 1908.

oilstones for sharpening small tools, and in demand both at home and abroad.    It is an extremely fine-grained sandstone made up of
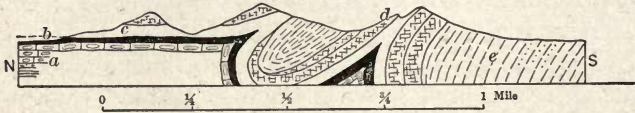


FIG. 94. — North-south section through Missouri and Statehouse Mountains showing folded character of novaculite and slate-bearing formations of Arkansas.    *a.* Bigfork chert; *b.* Pclk Creek shale; *c.* Missouri Mountain slate; *d.* Arkansas novaculite; *e.* Stanley shale.    (*After Purdue, Ark. Geol. Surv.*, 1909.)

finely fragmental quartz grains, visible under the microscope.    The rock is chertlike in superficial appearance and has a conchoidal fracture.    While the deposits, which are stratified, have a total thickness of over 500 feet, the commercial novaculite is found only in thin beds varying from a few inches to 15 feet in thickness.    The beds have a steep dip (Pl. XXX and Fig. 94), and are cut by several series of joints, which greatly interfere with the extraction of large blocks, and sometimes even with small ones.    There are also structural irregularities and almost invisible flaws, so that much waste is caused in quarrying the rock.    The rock has been variously regarded as a metamorphosed chert, a siliceous silt, or a silicified limestone.

**Pumice and Volcanic Ash.** — The term " pumice," as used in the geological sense, refers to the light spongy pieces of lava, whose peculiar texture is due to the rapid and violent escape of steam from the molten lava.    It is put on the market either in lump form, or ground to powder, or in compressed cakes of the ground-up material.    In the commercial sense the term " pumice " includes volcanic ash (Fig. 95) as well as true pumice.

Most of the pumice used in the United States is obtained from the island of Lipari, north of Sicily.    The stone, after being freed from the volcanic ash with which it is mixed, is sorted according to color, weight, and size, before it is shipped to market.
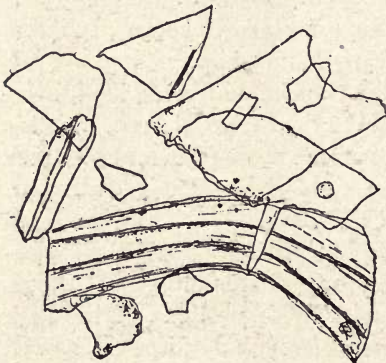


FIG. 95. — Volcanic ash from Madison County, Mont.    (*After J. P. Rowe.*)

PLATE XXX.— View in Arkansas novaculite quarry. (*Photo. loaned by Pike Manufacturing Co.*)

Deposits of volcanic ash are abundant in many western states, for example, in Nebraska (10), Utah (13), Montana (14), Oregon (12), Wyoming (11), Colorado (15), etc., but owing to their inaccessibility these materials cannot compete with Lipari pumice, which is imported as ballast, and sells in its prepared form for 2 to $2\frac{1}{2}$ cents per pound. The pumice produced in the United States in 1913 came from Kansas, Utah and Nebraska. The deposits are very abundant in the last named state, as Barbour remarks that nearly the whole of it is underlain by pumice beds as far east as Omaha.

**Diatomaceous Earth.**[1] — This material has been used to some extent for abrasive purposes, either in the form of polishing powder or in scouring soap. Since it has many other and more important possible applications, it is described separately on a later page.

**Tripoli.** (See p. 412.) — Some of the Missouri tripoli is ground and sold as tripoli flour, whose value f.o.b. is $6–$7 per ton. This flour is employed as an abrasive for general polishing, burnishing, and buffing, as well as an ingredient of scouring soaps.

The so-called " silica " obtained in Union County, Illinois, is similar to tripoli, and may have had the same origin.

Both of these run high in silica, and in that respect are different from a so-called tripoli, obtained in Johnson County, Tenn., and representing a leached Cambrian limestone. It carries about 68 per cent silica (Ref. p. 414).

**Crystalline Quartz** (2, 13). — Some of the vein quartz quarried in the United States, and also quartzite, is pulverized and used for abrasive purposes. Considerable quartz sand is employed by stone cutters as an abrasive in sawing stone, and a small quantity is utilized in making sandpaper. (See further, p. 390.)

**Feldspar** (13). — This also is used to a small extent for abrasive purposes, but since it has other and more important uses it is discussed separately on p. 321.

**Garnet** (13, 16). — The garnet group includes several mineral species which are essentially silicates of alumina with iron or lime, magnesia, manganese, and chromium. They crystallize in the isometric system, have a hardness of 6.5 to 7.5 and a specific gravity of 3.55 to 4.30.—Their color is variable, but commonly a shade of red or brown. The two commonest species are *Almandite* [$Fe_3Al_2(SiO_4)_3$] and *Grossularite* [$Ca_3Al_2(SiO_4)_3$].

[1] Infusorial earth and tripoli are terms sometimes applied to Diatomaceous earth. Both are incorrect.

Garnet is a common mineral in many metamorphic rocks, and though ordinarily a subordinate constituent of these, it may in some cases become the chief one.

Garnet is of value as an abrasive because of its hardness, toughness and cleavage. The best material is that which is well crystallized and relatively free from impurities, for it has greater strength and stands up better under conditions of service than finely granular material, or that containing inclusions of other minerals. The common impurities found in garnet are hornblende, chlorite, mica, and pyroxene. The parting or imperfect cleavage which garnet possesses causes it to break with smooth surfaces and sharp edges, the latter adding to its abrasive value.

Although garnet is a common mineral in many metamorphic rocks, especially gneisses and schists, few deposits of economic value are known, and in the United States the most productive deposits are found in the Adirondacks, while others are worked in New Hampshire and North Carolina.

*New York* (16, 16a). — The garnet industry is an important one in the Adirondack region, a steady production having come from Warren and Essex Counties. The garnet, which is Almandite, may occur in several different ways, viz.: 1. As crystals or grains in Grenville gneisses, and representing a crystallization product of the metamorphism of sediments; 2. As distinct crystals in intrusive rocks. 3. As large, more or less rounded masses with distinct hornblende reaction rims, occurring in long, lens-like inclusions of Grenville hornblende gneiss in syenite or granite; 4. As more or less distinct crystals, without hornblende rims, in a certain special basic syenite like an acidic diorite-like rock.

At the largest mine the garnets form 7 to 8 per cent of the gneiss mined. The rock is crushed, and the garnet concentrated by jigs and pneumatic separators.

*Other Localities.* — Garnet is also produced in New Hampshire (15a) and North Carolina. In the former state, the rock quarried at Wilmot consists of garnet, biotite, quartz and albite, of which the first named forms about 60 per cent.

Some garnet has been imported from Spain, and is said to be obtained by washing the sands of certain streams in the province of Almeria.

*Uses.* — Garnet is used in the manufacture of garnet paper, being a valuable abrasive for leather and wood. It has also been

employed in polishing and grinding brass. Attempts have been made to use it as a substitute for corundum in the manufacture of emery wheels, for, although softer, it possesses the advantage of having a splintery fracture, which prevents it from wearing smooth.

**Corundum and Emery** (3-9). — *Corundum* ($Al_2O_3$) is, next to diamond, the hardest of the natural abrasives known, having a hardness of 9, but varying slightly from this.

Its fracture is irregular to conchoidal, and gives a good cutting surface, but the presence of parting planes decreases its value. A specific gravity of 4 helps to distinguish it from other light-colored minerals found in the corundum regions. Corundum shows a variable behavior when heated, some forms crumbling when exposed to a high temperature. Such kinds are worthless for the manufacture of emery wheels, all of which must be fired in order to fuse the clay bond used in their manufacture.

Nearly all corundum analyses show $SiO_2$, $Fe_2O_3$, and $H_2O$, and it must be remembered that in analyses of commercial corundum the alumina percentage does not indicate the quantity of corundum present, as some of it may belong to aluminous silicates.

The following analyses represent selected rather than commercial samples: —

ANALYSES OF CORUNDUM

|  | $Al_2O_3$ | $Fe_2O_3$ | $SiO_2$ | $H_2O$ | INS. RES. | TOTAL |
|---|---|---|---|---|---|---|
| Hastings Co., Ont. . . . . | 96.92 | | | 2.43 | 1.36 | 100.71 |
| Corundum Hill, N. Ca. . . . | 98.79 | .75 | .90 | .78 | — | 101.22 |
| Laurel Creek Mine, Ga. . . . | 95.51 | .88 | 1.45 | .74 | — | 98.58 |
| Ruby from India . . . . . | 97.32 | 1.09 | 1.21 | — | — | 99.62 |
| Sapphire from India . . . . | 97.51 | 1.89 | .80 | — | — | 100.20 |

Corundum may occur in masses, crystals, or irregular grains. It is found in both igneous and metamorphic rocks, as well as in alluvial deposits derived from them, although the last supply but little abrasive corundum.

Corundum forms a primary constituent (sometimes an important one) of feldspathic igneous rocks, both high and low in silica. It is found in granite, syenite, nephelite-syenite, and coarse pegmatites. It is also known to occur in crystalline schists and metamorphosed limestones.

A number of other minerals may be associated with it as follows (5):
*Associated minerals.*

In gneiss and granite: Besides essentials, garnet magnetite, pyrite, zircon, rarely monazite and sodalite.

In peridotites and other basic rocks: Olivine, magnesian amphibole, pyroxenes, rarely plagioclase; chromite and spinel, accessory primaries.

In contact zones: Corundum, biotite, muscovite, garnet, staurolite, tourmaline, rutile, etc.

In regionally metamorphosed rocks: biotite, muscovite, amphibole, sillimanite, cyanite.

*Distribution.* — With the exception of a few localities in Montana, two in Colorado, one in Idaho, and one or two in California, all the known United States occurrences are confined to the Appalachian region, the commercially valuable deposits for abrasive purposes being found in a belt of basic magnesian r o c k s , extending from Massachusetts t o A l a b a m a . These rocks reach their greatest development in North Carolina (5) and Georgia (3). Most of the corundum is



FIG. 96. — Section showing occurrence of corundum around border of dunite mass. (*After Pratt, U. S. Geol. Surv., Bull.* 180.)

found there, in peridotite, especially near its contact with the surrounding gneiss.

It is believed that the corundum which was one of the earliest minerals to crystallize out from the cooling peridotite was concentrated around the borders of the mass by convection currents. This zone of corundum sent off tongues toward the interior of the mass, and now that erosion has removed the main zone of corundum, these tongues remain as apparently separate veins within the peridotite (Fig. 96).

In North Carolina (5) the greatest development of corundum is in a belt in Macon County. Some is also found east of the Blue Ridge. Georgia (3) contains scattered deposits, the most important being at Pine Mountain, Rabun County. Some mining has been done in South Carolina and Geor-

gia, and deposits in garnetiferous mica schists cut by granite have been recorded from Patrick County, Virginia (9).

No corundum production is recorded in the United States since 1906.

*Corundum in Canada* (2a). — Important deposits of this mineral are worked at Craigmont, Ontario. The northern part of this hill is composed of granite gneiss of the Laurentian batholith, which appears to merge into the overlying corundum-bearing series that forms the summit and southern slope. This latter series is a complex of different but closely related rock types representing differentiation products of one highly alkaline and aluminous magma, containing nepheline. These rocks are intersected by syenite pegmatite, which contains the largest and most abundant crystals and masses of corundum. These dykes sometimes attain a width of 18 feet, and usually run parallel with the foliation of the series.

*Emery.* — This is a mechanical mixture of corundum, magnetite or hematite, and sometimes spinel. Peekskill, New York (6–8), is now the most important sources of production, Massachusetts having discontinued.

At the former locality, the deposits which lie southeast of the town, and were first opened for iron ore, occur along the contact of basic intrusions belonging to the gabbro series. The emery deposits, according to G. H. Williams, are simply segregations of the basic oxides in the norite, and the ore is made up of corundum, magnetite, and hercynite (an iron-aluminum-spinel). In some specimens the corundum forms over 50 per cent of the mass, while in others the hercynite may make up nearly 100 per cent of it. The Peekskill material is very serviceable when made into wheels with a bond. The following are analyses of it.

|  | I | II | III |
|---|---|---|---|
| $Al_2O_3$ . . . . . . . . . . . . . | 20.95 | 38.78 | 46.53 |
| $SiO_2$ . . . . . . . . . . . . . | 13.97 | — | — |
| $TiO_2$ . . . . . . . . . . . . . | 4.15 | .62 | .51 |
| Fe . . . . . . . . . . . . . | 40.32 | — | — |
| $Fe_2O_3$ . . . . . . . . . . . . . | — | 24.35 | 32.31 |
| MgO . . . . . . . . . . . . . | — | 7.92 | 9.43 |
| $P_2O_5$ . . . . . . . . . . . . . | — | tr. | tr. |
| Si residue . . . . . . . . . . . . . | — | 11.19 | 2.42 |
| $Fe_3O_4$ . . . . . . . . . . . . . | — | 17.37 | 8.98 |
| S . . . . . . . . . . . . . | — | .02 | .01 |

I. Am. Chemist, 1874, 4: 321.   II and III. A. J. S., March, 1887, p. 197.

At Chester, Massachusetts (13), the emery occurs in a local widening of a belt of amphibolite schists, and forms a vein traceable for nearly five miles. The emery-bearing vein varies in width from a few feet up to 10

or 12 feet, while the emery streak in it averages about 6 feet, it being bordered on both sides by chlorite seams. The emery is in pockets, but these are traceable by a small vein of chlorite. The Massachusetts output has been diminishing and none has been reported since 1912.

After mining, both corundum and emery need to be cleaned and concentrated by special mechanical processes. The chief use of this material is as an abrasive, and for this purpose it is used in the form of wheels and blocks, emery paper, and powder.

Practically all the corundum and emery used in the United States is imported. The emery is imported crude as ballast from Turkey and Greece. Corundum is imported mainly from Canada in pulverized form.

**Diamonds.** — Black diamonds, known as *borts* and *carbonados*, which are of no value for gem purposes, are much sought after for use in drilling, being set in the end of the cylindrical drill tube. They are often of rounded form, translucent to opaque, and lack the cleavage possessed by the gem diamonds. Brazil, Africa, Borneo and India serve as sources of supply, but the first-named country is said to yield the best ones. The ordinary sizes for drills weigh from $\frac{1}{2}$ to 1 carat, but in special cases pieces weighing 4 to 6 carats are used. The price ranges from $50 to $75 per carat.

Diamond powder is also used as an abrasive for cutting other diamonds, gems, glass, and hard materials which cannot be cut by softer and cheaper substances.

**Pebbles for Grinding** (23–25). — These are used for grinding minerals, ores, cement clinker, etc., and those employed in the United States have been chiefly flint pebbles obtained from the chalk formations of Denmark and France, but not a few have been imported from other foreign countries. The value of flint pebbles lies in their hardness and uniform character; moreover, they contain little else but silica, and hence there is little danger of the material worn off contaminating the ground product, as for example in grinding feldspar, which must be free from iron oxide.

The decrease in foreign supply, due to the European war, has stimulated search for domestic sources of supply with some results. Pebbles of granite and quartzite have been imported into the United States from Newfoundland and Ontario for some time, and similar ones could be found here. Stream pebbles of quartz have been tried in California gold mills; dense silicified

rhyolite has given satisfactory results in some of the metallurgical mills of Nevada, and basalt has been tried in Oregon.

**Artificial Abrasives.** — Several artificial abrasives are now much manufactured. Prominent among these is carborundum, which is produced by fusion in the electric furnace of a mixture of silica, coke, and sawdust; the reaction being $SiO_2 + 3\ C = CSi + 2\ CO$. The sawdust is added to give porosity to the mixture. Other forms of carborundum are aloxite and samite.

Artificial corundum or alundum, whose introduction is of more recent date, is made by fusing bauxite in the electric furnace. It is put on the market in the form of wheels, etc., while carborundum is either made into wheels or sold in powdered form. Borocarbone is similar to alundum.

**Production of Abrasives.** — The value of the abrasives produced in the United States during the last five years, together with the imports and artificial abrasives, was as follows:—

VALUE OF ALL ABRASIVE MATERIALS CONSUMED IN THE UNITED STATES, 1910–1914

| KIND OF ABRASIVE | 1910 | 1911 | 1912 | 1913 | 1914 |
|---|---|---|---|---|---|
| Millstones | $28,217 | $40,069 | $71,414 | $56,163 | $43,316 |
| Grindstones and pulpstones | 796,294 | 907,316 | 916,339 | 855,627 | 689,344 |
| Oilstones and scythestones | 228,694 | 214,991 | 232,218 | 207,352 | 167,948 |
| Emery | 15,077 | 6,778 | 6,652 | 4,785 | 2,425 |
| Garnet | 113,574 | 121,748 | 163,237 | 183,422 | 145,510 |
| Abrasive quartz and feldspar | [1] | [1] | [1] | [1] | [1] |
| Infusorial earth and tripoli | 130,006 | 147,462 | 125,446 | 285,821 | 142,428 |
| Pumice | 94,943 | 88,399 | 86,687 | 55,408 | 59,172 |
| Total | $1,406,805 | $1,526,763 | $1,601,993 | $1,648,578 | $1,200,143 |
| Artificial abrasives | 1,604,030 | 1,493,040 | 1,747,120 | 2,017,458 | 1,685,410 |
| Imports | 977,718 | 815,854 | 898,892 | 916,913 | 728,710 |
| Grand total | $3,988,553 | $3,835,657 | $4,248,005 | $4,582,949 | $3,614,263 |

[1] Value of abrasive quartz and feldspar is not available as it is included with other uses of those minerals.

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# CHAPTER X

## MINOR MINERALS.  ASBESTOS

**Asbestos Minerals** (1, 13). — The minerals which have been mined and sold under this name include:  Chrysotile, the fibrous form of serpentine ($H_4Mg_3Si_2O_9$), Actinolite [$Ca(MgFe)_3(SiO_3)_4$], and Anthophyllite ($MgFe)SiO_3$.  Crocidolite ($NaFeSi_2O_6 \cdot FeSiO_3$) is also mentioned by some.

The following table gives the chemical composition of the different ones:

ANALYSES OF ASBESTOS MINERALS

|  | I | II | III | IV | V | VI | VII | VIII |
|---|---|---|---|---|---|---|---|---|
| SiO₂ . . . . | 40.30 | 39.05 | 40.87 | 55.81 | 61.82 | 57.12 | 52.11 | 39.97 |
| Al₂O₃ . . . | 2.27 | 3.67 | .90 | 1.66 | 1.12 | .75 | 1.01 | } 7.27 |
| FeO . . . . | .87 | 2.41 | 2.81 | 6.81 | 6.55 | 6.36 | 16.75 | |
| Fe₂O₃ . . . | — | — | — | — | — | — | 20.62 | |
| MgO . . . | 43.37 | 40.07 | 41.50 | 21.09 | 23.98 | 29.44 | 1.77 | 40.78 |
| CaO . . . . | — | — | — | 12.74 | 1.63 | — | — | .50 |
| Na₂O . . . | — | — | — | — | — | — | 6.16 | |
| Ignition . . | 13.72 | 14.48 | 13.55 | 1.81 | 5.45 | 5.47 | 1.58 | 12.51 |

I. Chrysotile,  Italy;  
II. Chrysotile, Thetford, Que.;  
III. Chrysotile, Broughton, Que.;  
IV. Amphibole, Roanoke County, Va.;  
V. Actinolite, Hastings County, Que.;  
VI. Anthophyllite, Sall Mtn., Ga.;  
VII. Crocidolite, S. Afr.;  
VIII. Chrysotile, Vermont.

**Mode of Occurrence.** — Asbestos may occur in three different ways, viz.:

1. Cross fiber found in fissures  with the fibers transverse to the wall.  It consists usually of chrysotile and rarely of anthophyllite.

2. Slip fiber lying in slipping planes with the fibers parallel to the walls. It may be either chrysotile or amphibole.

3. Mass fiber with the fiber occurring in bundles or groups. This is always anthophyllite.

**Comparison of Types.** — Of the three asbestos minerals, chrysotile is the most important and anthophyllite next. The commercial value of asbestos depends on the fineness, length, flexibility, and strength of its fiber. Chrysotile asbestos is



FIG. 97. — Map showing asbestos districts of the United States. (*After Diller*, *U. S. Geol. Surv., Min. Res.* 1913.)

1. Lowell, chrysotile; 2. Thetford, Que., chrysotile; 3. Rocky Mount, Va., Amphibole slip fiber; 4. Sall Mountain, Ga., anthophyllite; 5. Llano, Tex. amphibole; 6. Casper Mountain, Wyo., chrysotile; 7. Grand Canyon, and Globe, Ariz., chrysotile; 8. Kamiah, Ido., anthophyllite; 9. Towle, Calif., amphibole.

generally taken as the standard. Anthophyllite equals it in resistance to acid, heat, and insulating properties, but is far inferior in regard to flexibility, fineness of fiber and tensile strength. Crocidolite is inferior to chrysotile in its fire-resisting properties. but equals it in other respects.

Anthophyllite because of its mode of occurrence is cheaper to mine than chrysotile, since the latter forms but a small percentage of the entire rock mass, and has to be crushed and freed from impurities. Hopkins gives the Canadian extraction as 6.45 per cent and that of Georgia as 90 to 95 per cent.

**Distribution in the United States.** — The ancient crystalline rocks in which the famous Quebec deposits occur, extend southwestward through the eastern states, as far as Alabama, and while a number of small deposits of asbestos are known, yet nowhere are there any large ones, moreover, most of the deposits are of the amphibole type.

*Vermont* (8, 9). — The only chrysotile deposit worked in the eastern belt is in Lamoille and Orleans counties, Vermont, where the material is found occupying a rather limited area in a large serpentine area (9). Two types of chrysotile are found, one form-
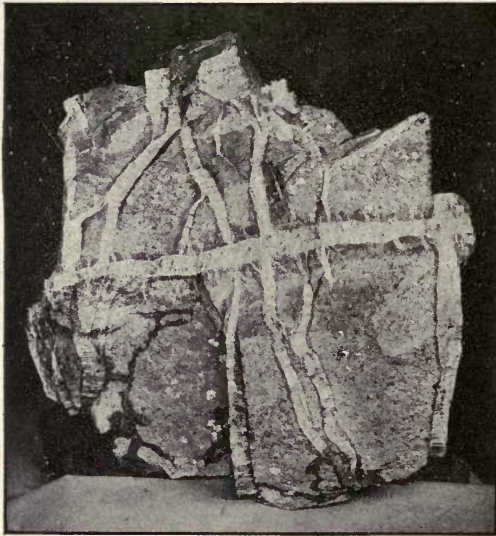


Fig. 98. — Asbestos vein in serpentine. (*Photo. by G. P. Merrill.*)

ing branching veins similar in character and quality to the Canadian fiber, the other, of inferior quality, occurring as short fibers on slickensided surfaces. In 1908 a mill was erected near Lowell, Vermont, for separating the fiber, but the district had up to 1913 not entered the list of steady producers.

*Georgia* (4).—Sall Mountain, Georgia, has been the main source of supply of asbestos in the United States for some years. The anthophyllite forms lens-shaped masses in peridotites and pyroxenites, which are associated with pre-Cambrian gneisses, the largest lens exploited being 70 by 50 by 50 feet. The fibers are $1\frac{1}{4}$ inches or less in length, but break into shreds of $\frac{1}{4}$ to $\frac{1}{16}$ inch. Pyrite, magnetite, talc, calcite and dolomite are the im-

purities. It is supposed that the anthophyllite has been formed by the alteration of olivine and enstatite of the igneous rocks. By hydration and oxidation both the anthophyllite and any unaltered olivine may be converted into serpentine, and the latter partly into talc.

The rock is crushed, fiberized and screened, the product being used chiefly as a cement for boiler covering.
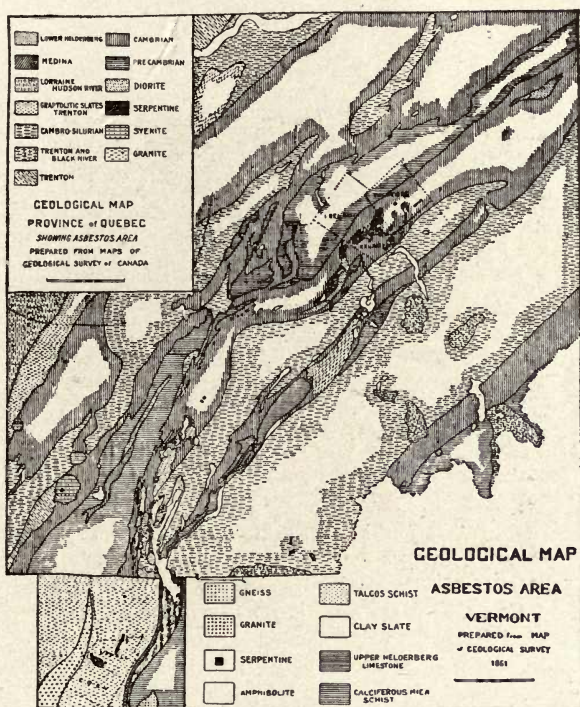


FIG. 99. — Geologic map of Vermont asbestos area. (*After Marsters, Geol. Soc. Amer., Bull. XVI,* 1905.)

*Virginia* (2, 16). — Amphibole asbestos is found in slip-fiber veins near Bedford, Va. The prevailing rock, which consists of hornblende and olivine, or in some cases pyroxene and olivine, is cut by occasional shear planes along which the slip fiber has developed.

*Arizona* (2). — Asbestos was discovered about 25 miles northeast of Globe in 1913. It forms cross-fiber veins in limestone, overlying diabase, the higher-grade veins being associated with a diabase dike.

Somewhat similar is the occurrence in the Grand Cañon of the Colorado River, near Grand View, where the asbestos forms veins in a serpentinous layer, enclosed in limestone, not far from a diabase sill. Diller has suggested that the serpentine is derived from some mineral in the limestone,

while the asbestos veins post-date the serpentine, and may represent a phase of contact metamorphism.

*Idaho* (2). — Near Kamiah, the anthophyllite asbestos forms ledges, within mica schist, and may represent an altered intrusive. It is shipped to Spokane, Wash., where it is sawed up and also ground.

*Wyoming* (2). — South and southeast of Casper are pre-Cambrian intrusives consisting of hornblende schist, diorite, granite and serpentine, the last-named being much crushed and sheared, and containing both cross and slip-fiber veins of chrysotile.
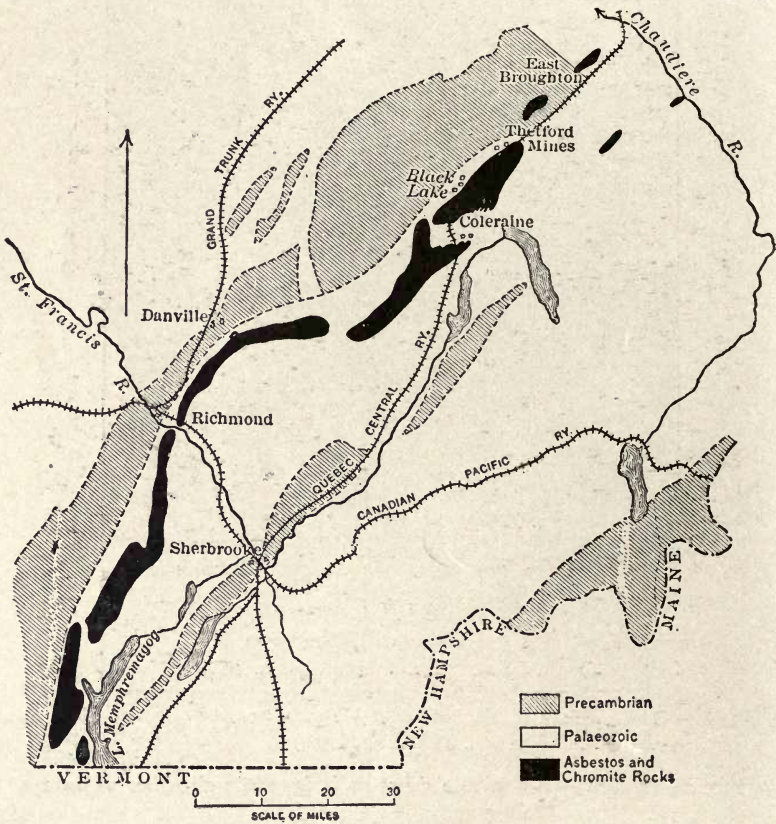


Fig. 100. — Map of Quebec asbestos area. (*After Dresser, Can. Min. Inst., Trans. XII.*)

**Quebec, Canada.** — The main source of the world's supply is obtained from southern Quebec, and as it is the best known occurrence it may be properly referred to here.

The geologic relations (Fig. 100) of the serpentines and associated rocks are imperfectly known, but it appears certain that they
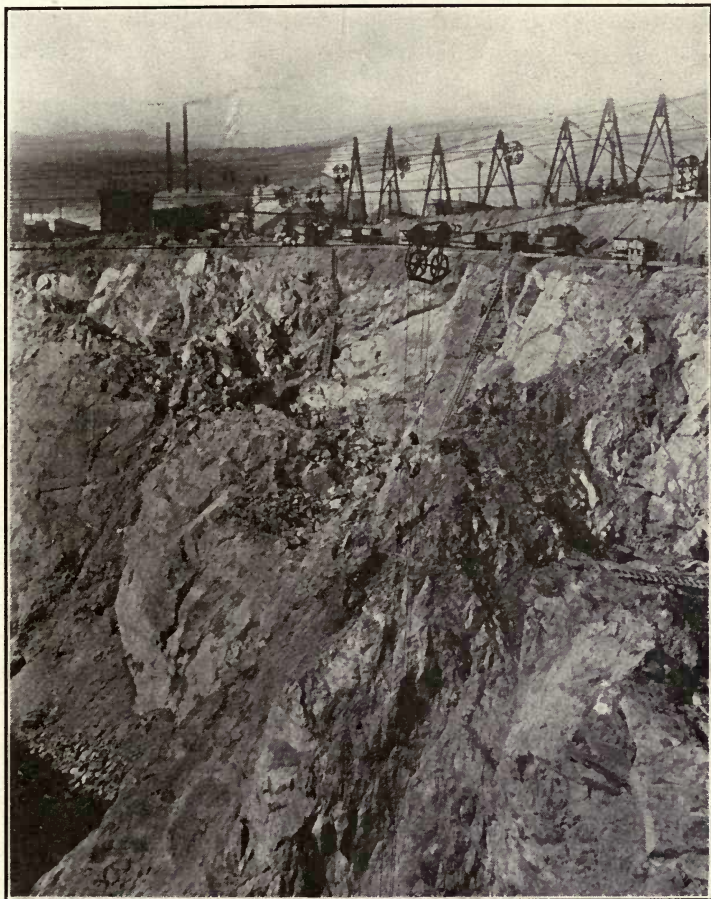
PLATE XXXI. — General view of asbestos quarry, Thetford Mines, Que.
(*H. Ries, Photo.*)

(303)

represent a series of stocks and sills, cutting rocks of Cambrian, Ordovician and Silurian age. The rocks of the asbestos belt are peridotite, generally much altered to serpentine; pyroxenite, frequently altered to talc; gabbro; diabase; and a breccia, in part of volcanic material.

The serpentine is an alteration product of peridotite, it and the pyroxenite being of laccolithic character, while the granite, which



c                              a                    b           a              c
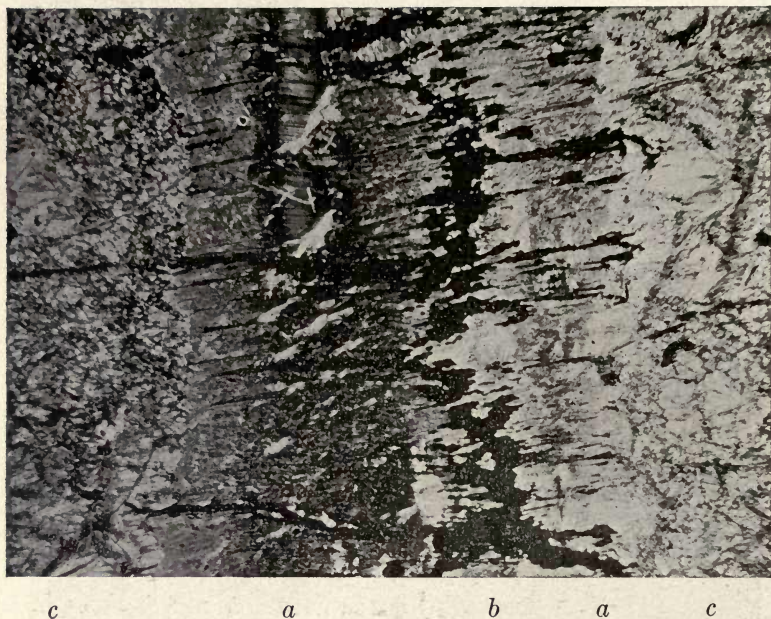
FIG. 101. — Photomicrograph showing vein of asbestos (a), with irregular margins, and mid streak of magnetite (b). Serpentinized rock (c) on either side. (*After Dresser, Can. Geol. Surv., Mem. 22.*)

forms dikes and isolated masses, may be a final and extremely acid product of differentiation of the general magma of which the basic equivalent is the olivine-rich portion of the peridotite.

The asbestos is found forming veins in the serpentine, the width of these varying from a mere line to two or three inches. It developed probably first in joint planes, and afterwards in other cracks, forming thus a network (Fig. 102). An interesting and suggestive feature is the band of pure serpentine on either side of the vein (Fig. 102), the ratio of the asbestos vein to the entire band of serpentine and asbestos being 1:6.6. The veins are formed by the
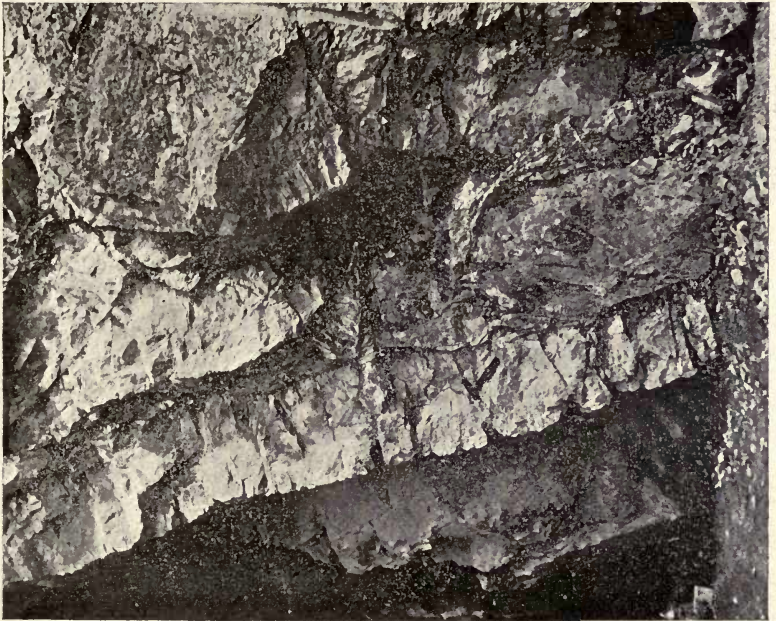
PLATE XXXII.  FIG. 1. — Granite dike cutting peridotite near
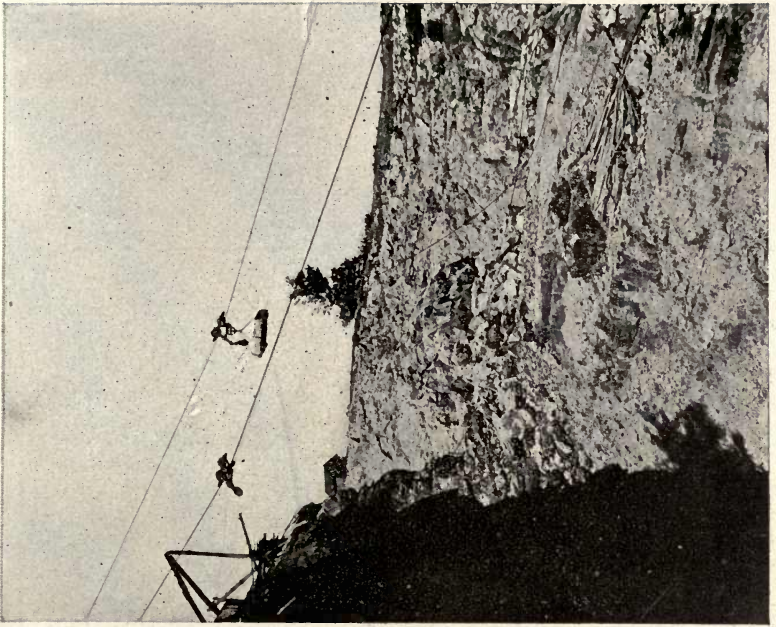
FIG. 2. — Richardson feldspar quarry, near Godfrey, Ont.

(305)

growth of minute crystals of chrysotile, perpendicular to the walls, and there is in most cases a central parting marked by a film of chromite or magnetite. The principal mines are near Thetford Mines (Pl. XXXI), Black Lake, East Broughton, and Danville. The first-named locality is of great importance.



Peridotite □    Asbestos ▥
Serpentine ▦    Scale: *The largest vein is two inches wide*
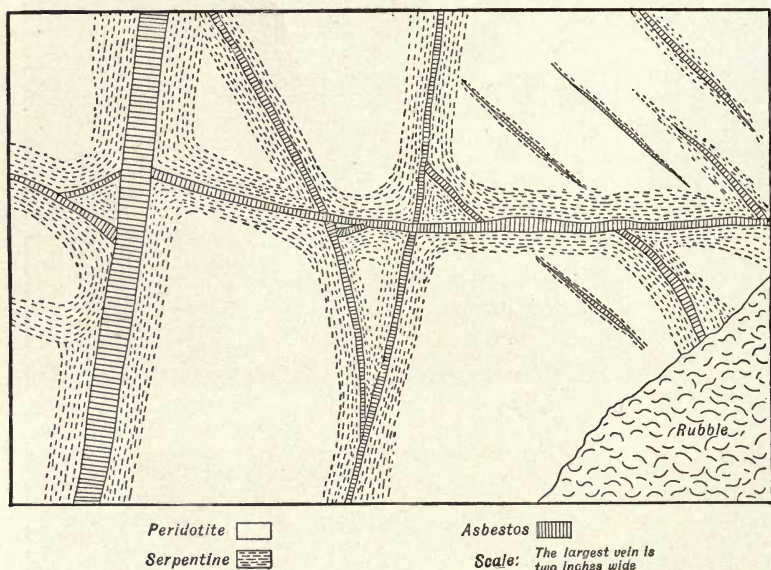
FIG. 102.—Diagram showing asbestos and serpentine in peridotite. (*After Dresser, Econ. Geol., IV.*)

The asbestos milling rock forms from 30 to 60 per cent of the quantity quarried, and 6 to 10 per cent of this is fiber.

There has been some difficulty in explaining satisfactorily the origin of the chrysotile veins in serpentine, for we have here two quite different forms of the same mineral. Pratt, in attempting to explain the origin of the vein filling, believes that the fissures represent contraction cracks formed around the edge of the peridotite mass while cooling, and which were then filled by aqueous solutions from which the chrysotile crystallized. Merrill, on the other hand, believes the fissures to have been caused by shrinkage incident to a partial dehydration of the rocks and subsequent filling by crystallization extending from the walls inward (11, 5). As suggested by Kemp, a loss of silica may also have produced some shrinkage.

Cirkel (1), believes the vein crevices to have been formed by

partial dehydration, and in part by fracturing resulting from the intrusion of the granite.

All investigators agree on the wall rock being the source of the chrysotile. Dresser (3), while admitting the filling of the veins by infiltration, suggests that they have been enlarged by replacement of the walls (Fig. 101). He points out that the veins usually show a middle parting of ore minerals, and furthermore, that microscopic study indicates that the fibers have grown outward from each side of the seam of ore, indicating alteration and re-crystallization of the serpentine to chrysotile *in situ.* It is furthermore thought that the depth at which the chrysotile formed probably precluded the existence of open fissures in which the material could have crystallized.

It is still to be regarded as doubtful whether meteoric or magmatic water was operative in bringing about the change, although most geologists favor the latter.

**Other Foreign Deposits.** — Outside of Canada, Russia is the only other important producer. The chief deposits are in the Urals (1) near the station of Baskenovo, and the asbestos occurs as cross fiber in serpentine. Other deposits occur in the Orenburg district. The Russian production for 1913 was 18,594 short tons. Asbestos of the hornblende variety is obtained in Italy, but the production is small. Crocidolite has been mined in West Griqualand, Africa, but the industry has not been established on a permanent basis.

**Uses of Asbestos.** — The usefulness of asbestos depends mainly on the flexibility of its fibers, and fibrous structure, and to a less extent on its low conduction of heat and electricity, and on its moderate refractoriness. Asbestos is used in fire-proof paints, boiler coverings, for packing in fire-proof safes, and for electric insulation where some heat resistance is necessary. Chrysotile is also used in making fire-proof rope, felt, tubes, cloth, boards, blocks, etc. *Asbestic* is a name given to short-fibered chrysotile mixed with serpentine. *Asbestine* is a pigment of which asbestos is an important ingredient, and serves to hold up other heavier pigments. Asbestos is also used for filtering in chemical work, and for this purpose the amphibole asbestos is better adapted. Many patented mixtures of asbestos and other materials, such as Portland cement, etc., are now used for making such products as asbestos wood, asbestos slate, asbestolith, etc. Asbestos roofing tile, roofing felt and shingles are now also made in large quantities.

ECONOMIC GEOLOGY

**Production of Asbestos.** — The United States is the largest producer of manufactured asbestos products, but less than one per cent of the raw material is mined in this country. Canada is the main source of supply, and will no doubt continue so for a long time. Next to Canada, Russia is the largest producer, and exports much of its product to the United States.

The production and imports from 1910 to 1914 were as follows:—

ANNUAL PRODUCTION AND ANNUAL VALUE OF IMPORTS OF ASBESTOS INTO THE UNITED STATES, 1910–1914

| YEAR | PRODUCTION | | VALUE OF IMPORTS | | |
| | SHORT TONS | VALUE | UNMANU- FACTURED | MANU- FACTURED | TOTAL |
| --- | --- | --- | --- | --- | --- |
| 1910 . . . . | 3693 | $ 68,357 | $1,235,170 | $308,078 | $1,543,248 |
| 1911 . . . . | 7604 | 119,935 | 1,413,541 | 290,098 | 1,703,639 |
| 1912 . . . . | 4403 | 87,959 | 1,456,012 | 363,759 | 1,819,771 |
| 1913 . . . . | 1100 | 11,000 | 1,928,705 | 378,961 | 2,307,666 |
| 1914 . . . . | 1247 | 16,810 | 1,407,754 | 371,469 | 1,779,223 |

VALUE OF CANADIAN PRODUCTION, EXPORTS AND IMPORTS, 1912–1914

| YEAR | PRODUCTION | EXPORTS | IMPORTS |
| --- | --- | --- | --- |
| 1912 . . . . . . . . . | $3,117,572 | $2,349,353 | $461,449 |
| 1913 . . . . . . . . . | 3,830,909 | 2,848,047 | 520,082 |
| 1914 . . . . . . . . | 2,892,266 | 2,298,646 | — |

RANGE OF NEW YORK PRICES PER SHORT TON FOR CANADIAN CHRYSOTILE FIBER, 1912–1914

| | 1912 | 1913 | 1914 |
| --- | --- | --- | --- |
| No. 1 crude . . . . . | $300–$325 | $320–$350 | $350–$375 |
| No. 2 crude . . . . . | 175– 200 | 200– 225 | 225– 250 |
| No. 1 fiber . . . . . | — | 100– 125 | 100– 125 |
| No. 2 fiber . . . . . | — | 75– 100 | 75– 100 |
| Shorter fibers . . . . . | — | 10– 30 | 10– 30 |

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mont.) 9. Marsters, Geol. Soc. Amer., Bull. XVI: 419, 1905. 10. Merrill, Non-metallic Minerals: 183, 1910. (General.) 11. Merrill, Geol. Soc. Amer., Bull. XVI: 416, 1905. (Origin.) 12. Pratt, Mineral Census, 1902, Report on Mines and Quarries: 973, 1904. 13. Merrill, Proc., U. S. Nat. Mus., XVIII: 281. (Asbestos and asbestiform minerals.) 14. Pratt, Min. World, July 8, 1905. (Ariz.) 15. Richardson, Vt. State Geologist, Rept., 1909–10; 315, 1910; *Ibid.*, 1911–12: 269, 1910. (Vt.) 16. Watson, Min. Res. Va.: 285, 1907.

## BARITE

**Properties and Occurrence.** — Barite, the sulphate of barium, contains when pure, BaO 65.7 per cent, and $SO_3$ 34.3 per cent. Its specific gravity is 4.3 to 4.6 and its hardness 2.5 to 3.5. It is commonly white, opaque to translucent, and crystalline, while the texture is granular, fibrous, or more rarely earthy. Barite is a common mineral which may be found in many kinds of rocks—igneous, sedimentary, and metamorphic. It has in nearly all cases been formed by deposition from aqueous solutions, and is not found as an original constituent of igneous rocks, nor in contact metamorphic zones, or pegmatite veins. Furthermore it is not a product of dynamo-metamorphism.

Analyses of many rocks show at least small amounts of barium, and it has also been noted in orthoclase feldspars and some micas.

It has frequently been found in spring and mine waters, where it may be in solution as the chloride, carbonate, or perhaps even as sulphate.[1] Contact of solutions containing the first two with sulphate waters will form barium sulphate, although its precipitation may be retarded by the presence of chlorides. Travertine deposits containing varying amounts of barite are also known, one described from Doughty Springs, Colo., showing from a small percentage up to 95 per cent [2] barium sulphate.

These facts indicate that barite is deposited from solution, and probably most deposits are formed in this manner.

**Form of Deposits.** — Commercially important deposits of barite may include the vollowing types:

I. Veins formed by the filling of fissures, by replacement, or by cementing of fault breccias, the wall rocks being lime-

[1] Barium sulphate has a solubility of 1 part in 400,000 of water, but the natural compound is said to be six times more soluble than the artificial.

[2] Headden, Col. Sci. Soc., Proc., VIII: 1, 1905.

stone, quartzite, sandstone, schist, gneiss or volcanic rocks in the different occurrences (3, 5a, 8a, 11).

II. Bedded deposits (so called), formed by replacement of pyrite (1a).

III. Irregular masses, occurring as replacements of limestone (11).

IV. Lumps in residual clays (11).

V. Filling the interstices of brecciated masses (11, 12).

**Associated Minerals** (3, 5a, 11). — These vary with the individual deposit. The vein and replacement types often contain metallic sulphides, especially galena, but sometimes sphalerite, chalcopyrite, and pyrite. Galena is harmful, since it discolors the ground product, and other sulphides may cause similar trouble. Quartz, calcite, and fluorite are also at times abundant, the last-named being especially noted in Kentucky and Tennessee veins as well as in some of the Great Valley occurrences of Virginia.

Residual deposits especially may carry considerable iron and manganese oxides, as well as quartz. Small amounts of iron oxide can be removed by treating the ground product with $H_2SO_4$, but the manganese is more difficult to eliminate (11).

Barite veins have not been sufficiently worked in the United States to determine whether there is much change with depth, but this has been noted in several European ones (1a).

**Geologic Age of Associated Rocks.** — This, in the case of the deposits of the United States and Canada, may be briefly summarized as follows:—

Triassic. Virginia.

Mississippian. Western Kentucky.

Devonian. Five Islands, N. S.

Ordovician. Missouri.

Cambro-Ordovician. Central Kentucky, Tennessee, Appalachian Valley region of Virginia, Georgia, Alabama, Maryland, and Pennsylvania.

Of these the deposits of the Cambro-Ordovician are the most important, practically all the United States production coming from Missouri and the Appalachian states.

**Distribution of Barite in the United States.** — The location of the deposits in the eastern half of the country is shown on the map, Fig. 103, and the more important ones at least may be briefly referred to since they represent several different types of occurrence.

*Missouri* (3).—Barite forms scattered deposits in Washington and adjacent counties, though many of the occurrences are clus-

FIG. 103. — Map of barite deposits of Appalachian states. (*After Watson and Grasty, Amer. Inst. Min. Engrs., Bull.* 98, 1915.)
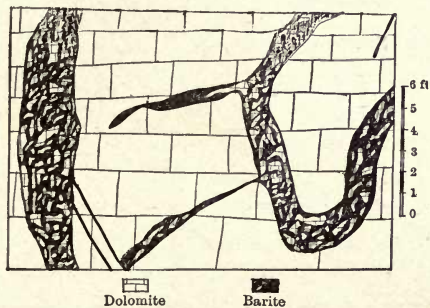


FIG. 104. — Barite veins in Potosi dolomite, southeastern Missouri. (*After Buckley, Mo. Bur. Geol. and Mines, IX.*)

tered around Mineral Point, Washington County. The material is obtained from the Potosi (Ordovician) limestones, in which it occurs as replacement veins (Fig. 104) mixed with lead, or in residual clay with chert and drusy quartz, the whole forming a sheet-like deposit, at no great depth (Fig. 105).
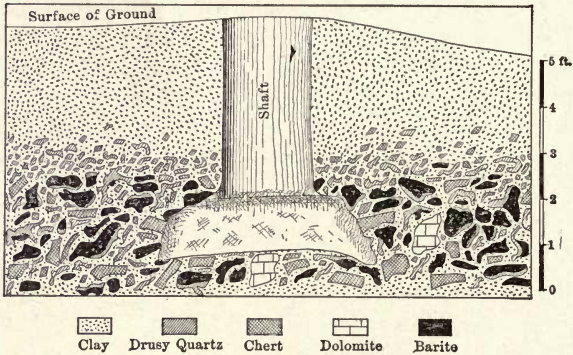


FIG. 105. — Barite deposit in residual clay near Mineral Point, Mo.
(*After Buckley, Mo. Bur. Geol. and Mines, IX.*)

*Virginia* (11).—Barite occurs in many parts of the state (Fig. 106), but the industry has been confined mainly to a few localities. The barite deposits may be grouped into three areas, as follows: 1. Deposits of the Triassic red shale-sandstone series, in which the barite is associated with red shales and impure limestones. It has been deposited from solution in fractures in the red shales, or
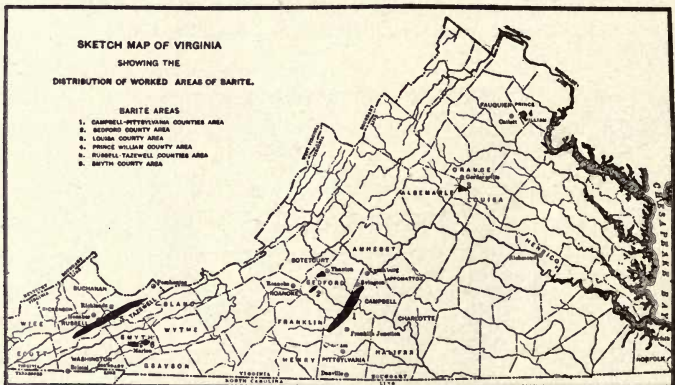


FIG. 106.— Map of Virginia showing location of worked areas of barite.
(*After Watson, Min. Res. Va.*, 1907.)

more rarely as thin, tabular replacement masses in the limestone. 2. Deposits of the crystalline metamorphic area, probably for the most part of pre-Cambrian age, and in which the barite occurs either as irregular lenses of 100–200 feet diameter in limestone, or as nodules in a residual limestone-schist clay (Fig. 107). In one locality the barite fills a vein in siliceous schists, remote from calcareous rocks. 3. The mountain region of southwestern Virginia. Here the barite, which is
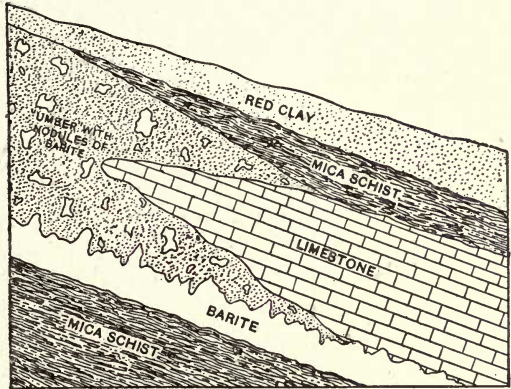


FIG. 107.—Ideal section in Bennett Barite Mine, Pittsylvania County, Va. (*After Watson, Min. Res. Va.*, 1907.)

associated with the Shenandoah limestone (Cambro-Ordovician), is found either as lumps in the residual clay, or in the fresh rock.

The frequent association of the barite with limestone in all the areas is quite noticeable.

The second region is the most important producer.

Watson believes that the source of the barite is the rocks in which the deposits are now found. Thus in the Valley region it was no doubt derived from the Shenandoah limestone, while in the Piedmont area it may have come either from the crystalline schists or limestone mass. That of the Thaxton area was doubtless obtained from the silicates of the granite. The liberation and removal of the barium in solution is considered to have been accomplished by shallow circulations. The barite is always crystalline in texture.

*Kentucky* (5a, 8, 11). — The vein type of occurrence is well developed in this state, there being two areas. Those veins in the central part of the state (Figs. 108, 109) are confined to the Ordovician, and are found filling simple fissures, or fault fractures, the chief associates being calcite, fluorite, sphalerite and galena. They are from 1 to 3 feet in width, with a maximum of 24 feet, and have been mined to depths of 100 to 325 feet. In the western area, fluorspar is the chief mineral, with barite of second-
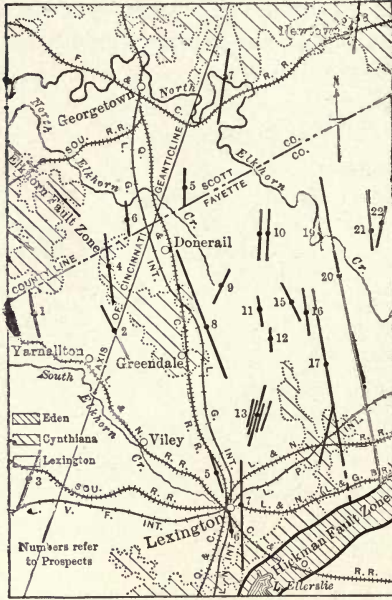
Fig. 108. — Map of barite veins near Lexington, Ky.    (*After Fohs, Ky. Geol. Surv.,* *4th ser., I:* 441, 1913.)
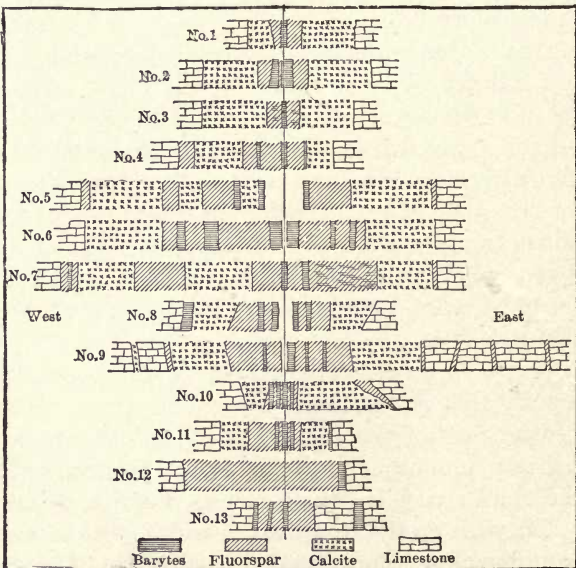


Fig. 109. — Sections of a Kentucky barite vein.    (*After Fohs.*)

ary importance, and the veins occurring in Mississippian limestone.

*Georgia* (6). — Barite deposits are known to occur near Cartersville, Ga., associated with the Beaver (Cambrian) limestone and Weisner (Cambrian) quartzite (Fig. 110).

It is thought that the barite was originally deposited by the replacement of certain beds of the shaly limestone overlying the quartzite, but it now forms nodules and masses scattered through a residual clay, and mixed with some quartzite fragments. Gravity has probably aided in concentrating the barite into workable deposits.



FIG. 110. — Sketch section showing relations of barite and limonite to underlying formations near Cartersville, Ga. (*After Hayes and Phalen, U. S. Geol. Surv., Bull.* 340.)

*Other Occurrences.* — The barite of Gaston County, North Carolina, occurs as lenticular fissure fillings in schist, associated with quartz, galena, sphalerite, and pyromorphite, while that of South Carolina is in similar rocks; that in Tennessee is either in residual clay overlying the Knox dolomite (Cambro-Ordovician) as in the Sweetwater district, or as veins in schist, as in the French Broad district (7, 11).

ANALYSES OF BARITE

| | I | II | III | IV | V | VI | VII |
|---|---|---|---|---|---|---|---|
| BaO . . . . | 64.72 | 54.95 | 98.54 [1] | 94.20 [1] | 98.82 [1] | 93.59 [1] | 97.56 [1] |
| Fe$_2$O$_3$. . . . | .06 | .06 | —— | .11 | .33 | .32 | .42 |
| SiO$_2$ . . . . | .25 | .55 | .95 | .05 | .27 | 4.76 | .41 |
| CaO . . . . | tr. | .20 | .02 | 4.44 [2] | —— | —— | —— |
| SrO . . . . | tr. | 6.75 | — | — | — | — | — |
| SO$_3$ . . . . | 33.82 | 34.22 | — | — | — | — | — |
| ZnO . . . . | — | 1.23 | — | — | — | — | — |
| MgO . . . | — | — | .22 | — | — | — | — |
| F . . . . . | — | .14 | — | — | — | — | — |

[1] BaSO$_4$    [2] CaCO$_3$

I. Mexico, Ky.; II. Danville, Ky.; III. Five Islands, N. S.; IV. Lake Ainslee, Cape Breton; V. Eton, Murray Co., Ga.; VI. Cherokee Co., S. Ca.; VI. Sweetwater district, Tennessee. All from Reference 11.

**Canada** (8a, 12). — The only productive district is at Lake Ainslié, Cape Breton, where barite is found in veins in the pre-Cambrian felsite. Calcite and fluorite are occasional associates. Other veins are found in schists of the Louisburg shale formation at North Cheticamp.

Near Five Islands, Nova Scotia, barite has been found filling fissures and brecciated zones in Devonian slate and quartzite, but the deposits have not been worked steadily. The barite here is believed to have been deposited by vadose waters, as small amounts of it are shown to occur in the surrounding rocks.

**Other Foreign Deposits.**[1] — Barite deposits are widely distributed, but those of Germany (1a) are probably the most important. They include: 1. A curious bituminous barite deposit, near Meggen, Westphalia, supposed to have originated by the replacement of portions of a bedded Devonian pyrite which in turn grades into limestone. 2. Vein deposits closely associated often with the Permian, and showing a considerable variety of metallic minerals. The barite is of higher grade than the Meggen product. Among other European deposits may be mentioned the replacement ones in Carboniferous limestone of Belgium, as well as minor vein deposits of France, Italy, Austria, and Great Britain.

**Origin of Barite.** — Sulphate of barium is but slightly soluble, but is perceptibly decomposed by a dilute solution of carbonated alkali. If present in one of the silicates (feldspar) in granite it might be decomposed by sulphates of the alkalies, lime sulphate, or magnesium sulphate, resulting in precipitation of barium sulphate.

Buckley (3) believes that the Missouri barite was possibly derived from solutions of the bicarbonate, precipitated with alkaline sulphates.

Watson (11) suggested that in the case of the Virginia barite it was probably taken into solution as the soluble bicarbonate, and precipitated under favorable conditions as the insoluble sulphate. Laboratory experiments by Dickson (4) with solutions of barium carbonate on selenite crystals and pure anhydrite in presence of $CO_2$, and on pyrite crystals in presence of an oxidizing agent, water, caused precipitation of barium sulphate in each case.

**Mining, Preparation, and Uses** (9a, 11). — Barite deposits may be worked by open cuts, shafts or pits. The greatest depth reached in mining is probably not over 200 feet.

The removal of impurities from merchantable barite includes

[1] Dammer und Tietze, Nutzbaren Mineralien, II: 7, 1914.

hand cobbing, sorting or grading, washing and crushing. Ground barite requires bleaching with sulphuric acid to remove iron, drying and grinding.

Since the barite deposits are usually small and pockety, the mill must be located to permit its drawing on numerous and changing sources of supply.

Washed barite is used in the manufacture of paper, for coating canvas ham sacks, in pottery glazes, and in the manufacture of barium hydroxide. Its main use perhaps is in white pigments to mix with white lead, zinc white, or a combination of both of these pigments. Although formerly regarded as an adulterant of white pigments, it is now considered to make the mixture more permanent, less likely to be attacked by acids, and freer from discoloration. *Lithophone* paint is a mixture of barium sulphate (68 per cent), zinc oxide (7.28 per cent), and zinc sulphide (24.85 per cent).

Barium hydrate is used chiefly in the beet-sugar industry; barium chloride in the color industry and the manufacture of wall paper; barium carbonate as a chemical reagent, in glass manufacture, and to prevent scumming of clay products. Other uses are in the manufacture of rubber, asbestos, tanning leather, enameling iron and oilcloth, poker chips, boiler compounds, insecticides, hydrogen peroxide, etc.

**Production of Barite.** — The production of barite for several years is given below.

PRODUCTION OF CRUDE BARITE IN THE UNITED STATES, 1912–1914, BY STATES

| STATE | 1912 | | | 1913 | | | 1914 | | |
|---|---|---|---|---|---|---|---|---|---|
| | SHORT TONS | VALUE | AVERAGE PRICE PER TON | SHORT TONS | VALUE | AVERAGE PRICE PER TON | SHORT TONS | VALUE | AVERAGE PRICE PER TON |
| Missouri . | 24,530 | $117,035 | $4.77 | 31,131 | $117,638 | $3.78 | 33,317 | $112,231 | $3.37 |
| Tennessee } Kentucky } | 13,718 | 8,682 | 2.34 | 12,098 | 3,568 | 1.70 | 8,932 | 14,393 | 1.61 |
| Other states[2] | 9,230 | 27,596 | 2.99 | 12,069 | 35,069 | 2.91 | 9,298 | 27,091 | 2.91 |
| Total . | 37,478 | $153,313 | $4.09 | 45,298 | $156,275 | $3.45 | 51,547 | $153,715 | $2.98 |

[1] Tennessee alone.

[2] Includes 1912: Georgia, North Carolina, and Virginia; 1913: Georgia, North Carolina, South Carolina, and Virginia; 1914: Alabama, California, Georgia, North Carolina, South Carolina, and Virginia.

*Imports.*—The imports of barium compounds for 1912 to 1914 were as follows:—

VALUE OF THE IMPORTS OF BARIUM COMPOUNDS, 1912–1914

|  | 1912 | 1913 | 1914 |
|---|---|---|---|
| Barium carbonate { Natural | $ 15,777 | $ 13,116 | $ 8,084 |
| Manufactured | 9,938 | 38,949 | 36,305 |
| Barium binoxide | 252,320 | 239,000 | 332,709 |
| Barium chloride | 27,655 | 37,620 | 68,866 |
| Blanc-fixe, or artificial barium sulphate | 70,327 | 62,785 | 32,619 |
|  | $376,017 | $391,470 | $478,583 |

PRODUCTION OF BARITE IN CANADA, 1912–1914

| YEAR | QUANTITY, SHORT TONS | VALUE |
|---|---|---|
| 1912 | 7654 | $32,410 |
| 1913 | 5987 | 41,774 |
| 1914 | 612 | 6,129 |

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## DIATOMACEOUS EARTH (KIESELGUHR)

**Properties and Occurrence** (1, 8). — This material when pure is made up of the siliceous tests of diatoms (Fig. 111).   Chemically it is a variety of opal.   It resembles chalk or clay in appearance, but is very much lighter than either of these, and can also be distinguished from the former substance by the fact that it does not effervesce with acid.   A microscopic examina-

tion serves to identify it at once.  Diatomaceous earth is commonly white or light gray in color, but may be brownish, dark gray, or even black, due to the presence of organic matter.  It is exceedingly porous.  If pure, it should show little else than silica and water on analysis, but most earths have at least small amounts
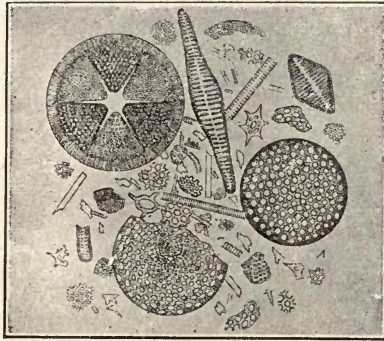


FIG. 111. — Diatomaceous earth from Lompoc, Calif.  (*Calif. State Min. Bur., Bull.* 38.)

of other substances, and some contain a large amount of clayey impurities (see analysis VI below).

The following analyses represent the composition of a number of American earths: —

ANALYSES OF DIATOMACEOUS EARTH

|  | I | II | III | IV | V | VI | VII | VIII |
|---|---|---|---|---|---|---|---|---|
| $SiO_2$ . . . | 86.92 | 72.50 | 86.89 | 80.53 | 81.53 | 63.17 | 82.85 | 86.515 |
| $Al_2O_3$ . . | 4.27 | 11.71 | 2.32 | 5.89 | 3.43 | 19.30 | 6.76 | .449 |
| $Fe_2O_3$ . . | — | 2.35 | 1.28 | 1.03 | 3.34 | 6.32 | 2.34 | .374 |
| CaO . . . | 1.60 | .32 | .43 | .35 | 2.61 | .06 | .35 | .120 |
| MgO . . . | tr. | .83 | tr. | — | — | .69 | 1.06 | 12.000 |
| Alkalies . . | 2.48 | 1.88 | 3.58 | — | 2.59 | 3.14 | 2.06 | — |
| $TiO_2$ . . . | — | — | — | — | — | .88 | 1.09 | — |
| Ign. loss . . | 5.13 | 9.54 | 4.89 | 12.03 | 6.04 | 6.39 | 3.40 | — |
|  | 100.40 | 99.13 | 99.39 | 99.83 | 99.54 | 99.95 | 99.91 | 98.458 |

I. Porcelain diatomaceous shale, Point Sal, Santa Barbara Co., Calif.  II. Soft shale, Orcutt, Santa Barbara Co., Calif.  III. Monterey, Santa Barbara Co., Calif.  IV. Lake Umbagog, N. H.  V. Pope's Creek, Md.  VI. Wilmot, Virginia; very clayey.  VII. Richmond, Virginia.  VIII. Herkimer, N. Y.

**Distribution in the United States.** — Diatomaceous earth occurs as deposits of comparatively small extent in the bottoms of ponds, lakes, and swamps, sometimes mixed with organic matter, or it may form bedded deposits of marine origin and showing at times great extent as well as thickness. A few localities may be mentioned.

*California* (1, 2, 4). — Important deposits of diatomaceous earth are known to occur at a number of points in the Coast Ranges of California, but the most important, perhaps, are those found in northern Santa Barbara County. There it occurs mainly in the Monterey (Middle Miocene) and in the lower part of the Fernando (Upper Miocene) formations.

The deposits range from those of high purity, through impure shaly beds, to flinty deposits. The earth is found interbedded with volcanic ash at some localities (south of Lompoc), and with limestones at others. The thickness of the diatom deposits is often remarkable, being 2400 feet south of Harris, and 4700 feet between the Santa Ynez and Los Alamos valleys.

*New York* (3, 5). — Although diatomaceous earth is known to occur at several localities, the only one recently worked is near Hinckley, Herkimer County, where it forms a bed 2 to 30 feet in White Head Lake. It is purified by washing and pressed into cakes.

*Virginia* (8). — In the Atlantic Coastal Plain, deposits of diatomaceous earth are not uncommon in the Miocene (Tertiary) formations, and those around Richmond have long been known. Along the Rappahannock River, especially below Wilmot, there are long exposures, the bluffs of the material standing out prominently in the sunlight.

*Maryland.* — Beds of diatomaceous earth occur at the base of the Calvert (Tertiary) formation, deposits being known in Anne Arundel, Calvert, and Charles counties. Few of them are worked, although some attain a thickness of at least 25 or 30 feet.

*Other States.* — Connecticut, Massachusetts, Florida, Nevada, and Washington are also producers, but the deposits are of limited extent.

**Foreign Deposits.** — Diatomaceous earth is known to occur at a number of Canadian localities, but the only production recorded is from Nova Scotia. Many deposits are known in Europe.[1]

**Uses.** — Diatomaceous earth, on account of its porous character, was formerly used as an absorbent of nitroglycerine in dynamite, but little or none appears to be now employed for this purpose in the United States. It can be used for polishing powders, and as a nonconductor of heat it has been occasionally utilized for steam boiler backing, for wrapping steam pipes, and for fireproof cement.

[1] Dammer and Tietze, Nutzbaren Mineralien, I: 202, 1913.

Mixed with clay, or even alone, it can be used for making porous partition brick or tile. Some of the California material can be cut into any desired shape, and used as a filter stone, or even for building purposes. Recently it has been used in talking machine records.

In Europe, especially in Germany, it has of late years found extended application. It has been used in the preparation of artificial fertilizers, especially in the absorption of liquid manures, in the manufacture of water glass, of various cements, of glazing for tiles, of artificial stone, of ultramarine and various pigments, of aniline and alizarine colors, of paper, sealing wax, fireworks, gutta-percha objects, Swedish matches, solidified bromine, scouring powders, papier-maché, and a variety of other articles. There is said to be a large and steadily growing demand for it.

The production is given under Abrasives, where it is included with Tripoli.

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## FELDSPAR

**Properties and Occurrence.** — The feldspar group includes several species, all silicates of alumina, with one or more of the bases—potash, soda, and lime. These species may be divided into two groups, viz., the potash feldspars, and the lime-soda feldspars, a division which is not without practical value, since the two groups differ somewhat in their fusibility and mineral associates.

Orthoclase and microcline, whose composition is expressed by the formula $KAlSi_3O_8$, are the chief representatives of the first group. Expressed in percentages their composition is $SiO_2$, 64.7 per cent; $Al_2O_3$, 18.4 per cent; $K_2O$, 16.9 per cent. Soda may partly or wholly replace the potash. If the latter occurs, anorthoclase results. Potash-soda feldspars are usually pinkish to nearly white, but some, as that mined in Ontario, is a distinct reddish color. Nevertheless, even the strongly colored ones may calcine

to a pure white color, and show a sufficiently low iron oxide content to permit their use in pottery manufacture.

The lime-soda feldspars, or plagioclases, present a series of compounds ranging from the soda feldspar, albite, through soda-lime feldspars, to the pure lime spar, anorthite, at the other end.

Albite, whose formula is $NaAlSi_3O_8$, has $SiO_2$, 68.7 per cent; $Al_2O_3$, 19.5 per cent; $Na_2O$, 11.8 per cent. Anorthite, $CaAl_2Si_2O_8$, has $SiO_2$, 43.2 per cent; $Al_2O_3$, 36.7 per cent; $CaO$, 20.1 per cent.

All feldspars in melting pass gradually from a solid condition to that of a very stiff fluid (5), complete fusion occurring usually about Seger cone 9 (1310° C.). A mixture of soda and potash spar seems to have a slightly lower fusing point, while the lime spar, anorthite, does not melt until 1532° C. (5).

Most of the feldspar quarried in the United States is the potash-soda type, but in some localities the soda spar, albite, may be present. If plagioclase is present in feldspar used for pottery, it is generally albite.

Feldspars are widely distributed in many igneous and metamorphic rocks, but in most cases they are so intimately mixed with other minerals, that their extraction is not commercially practicable, and it is only when found in pegmatites that they are worked. Of these rocks, two types are recognizable, viz. the granite pegmatites, which are very coarse-grained and carry quartz, potash feldspar, muscovite, biotite, tourmaline, etc., and the soda pegmatites, which consist mainly of albite with a little hornblende. Most of the deposits worked in the United States belong to the first type, only a few from southeastern Pennsylvania and northeastern Maryland falling in the second class.

It may be mentioned here that all pegmatite deposits are not worked for their feldspar contents, some serving as sources of other minerals, such as mica, quartz, or gems. Their value as spar deposits depends on the quantity and purity of the material present.

The pottery trade demands that the spar be free from iron-bearing minerals. Muscovite is also undesirable on account of the difficulty encountered in grinding it, while the permissible limits for quartz range from 5 to 20 per cent.

In quarrying or mining some sorting is often necessary, and in those states lying south of the glaciated area the deposit may be capped with residual clay.

**Distribution of Feldspar in the United States.** — In the United States feldspar quarries are operated in New York, Connecticut,

Maine, Pennsylvania, and Maryland. The general form of deposit is similar in all the states, but those worked in Pennsylvania and Maryland are albite spar, while the others are potash spar. The wall rock is gneiss or schist.

In recent years feldspar deposits have also been developed in California, Colorado, and Minnesota.[1]

The following table gives the composition of feldspar from a number of localities:—

ANALYSES OF FELDSPARS

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| $SiO_2$ . . . . | 64.7 | 64.98 | 65.40 | 65.23 | 69.63 | 63.11 | 65.95 |
| $Al_2O_3$ . . . | 18.4 | 19.18 | 18.80 | 20.09 | 12.30 | 21.65 | 18.00 |
| $Fe_2O_3$ . . . | — | .33 | tr. | .71 | — | — | .12 |
| $CaO$ . . . . | — | tr. | none | none | .95 | — | 1.05 |
| $MgO$ . . . . | — | .25 | none | none | none | — | tr. |
| $K_2O$ . . . | 16.9 | 12.79 | 13.90 | 11.60 | 14.96 | 14.10 | 12.13 |
| $Na_2O$ . . . | — | 2.32 | 1.95 | 2.00 | .79 | 1.46 | 2.11 |
| Loss on ignition | — | .48 | .60 | .36 | .43 | .40 | — |
| Total . . . | 100.0 | 100.33 | 100.65 | 99.99 | 99.06 | 100.72 | 99.36 |

1. Theoretical composition of pure orthoclase or microcline. 2. Norwegian feldspar, used for porcelain. 3. Pink orthoclase-microcline feldspar, from Bedford, Ont. Much used by American potters. 4. Cream-colored orthoclase-microcline feldspar, Georgetown, Me. 5. White orthoclase-microcline feldspar, South Glastonbury, Conn. 6. Pearl-gray orthoclase-microcline feldspar, near Batchellerville, N. Y. 7. Pink orthoclase-microcline feldspar, Bedford Village, N. Y.

ANALYSES OF FELDSPARS

|  | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|
| $SiO_2$ . . . . | 65.33 | 64.62 | 63.50 | 65.96 | 68.60 | 48.25 | 76.37 |
| $Al_2O_3$ . . . | 20.96 | 20.57 | 22.39 | 19.53 | 19.10 | 34.11⎫ | 13.87 |
| $Fe_2O_3$ . . . | .71 | tr. | .36 | .24 | .14 | ⎬ | |
| $CaO$ . . . . | none | .14 | 2.15 | .18 | tr. | 15.63 | .26 |
| $MgO$ . . . . | none | 2.36 | none | — | .28 | — | none |
| $K_2O$ . . . | 10.65 | 1.94 | 3.40 | 12.92 | 9.03 | — | 5.24 |
| $Na_2O$ . . . | 1.37 | 10.27 | 6.27 | 1.13 | 2.09 | 1.98 | 3.74 |
| $H_2O$ . . . . | — | — | — | — | — | — | .30 |
| Loss on ignition | — | — | 1.00 | — | — | — | — |
| Total . . . | 99.02 | 99.90 | 99.07 | 99.96 | 99.24 | 99.97 | 99.78 |

8. Light yellow orthoclase-microcline feldspar, North Castle, N. Y. 9. Soda feldspar, Chester County, Pa. 10. White feldspar, Embreeville, Pa. 11. Potash feldspar, Woodstock, Md. 12. Potash-soda feldspar, Henryton, Md. 13. Lime-soda feldspar (bytownite), Point Corundum, near Duluth, Minn. Used for abrasives and filters, but not for pottery. (All analyses from Min. Res., U. S., 1906 : 1257, 1907.) 14. Kinkle's quarry, Bedford, N. Y., No. 3 grade, used in glass, but not for pottery. U. S. G. S., Bull. 420.

[1] U. S. Geol. Surv., Min. Res. 1913: 149, 1914.

**Canada.** — Most of the Canadian production is derived from the province of Ontario, the principal mines being located in Frontenac County, about 20 miles north of Kingston (Pl. XXXII, Fig. 2). The feldspar, which is often of a deep pink color and high purity, occurs as veins in the pre-Cambrian gneiss of that region. Quartz horses and veins are sometimes present, and tourmaline is likewise found in patches. While the spar veins are very abundant, not all are of sufficient purity to be workable. Other deposits have been worked in Ottawa County, Quebec, one mine near Villeneuve having yielded a very white albite.

**Other Foreign Deposits.** — Many feldspar deposits are worked in Europe, for use in the pottery industry. Those of Norway and Sweden are the largest producers, the product being exported in considerable quantity. In this connection mention may be made of *Cornish stone*, a partly weathered, coarse-grained granite, quarried in Cornwall, England, and used in some quantity by the potters of Europe and America.

**Uses** (1). — Feldspar is used chiefly as a flux in the manufacture of pottery, electrical porcelain, and some enameled wares. For all these purposes it should be as free from iron as possible, but some of the ground commercial spar carries as much as 15 to 20 per cent free quartz.

Feldspar is also employed as a flux or binder in emery and carborundum wheels, and to some extent in the manufacture of opalescent glass. For the last purpose it can carry more quartz and muscovite than pottery spar, and does not have to be as finely ground, 50 to 60 mesh being sufficient.

As an ingredient of scouring soap, feldspar possesses advantages over quartz, because it is softer and less liable to scratch glass. Selected feldspar is used in the manufacture of artificial teeth.

The possibility of using feldspar as a fertilizer, because of its potash contents, has been suggested; but no commercially practicable means of extracting the desired element has as yet been found (2).

**Production of Feldspar.** — The production of feldspar from 1909 to 1914 is given below. The crude refers to that sold in the unground state, but all spar is crushed before use.

PLATE XXXIII
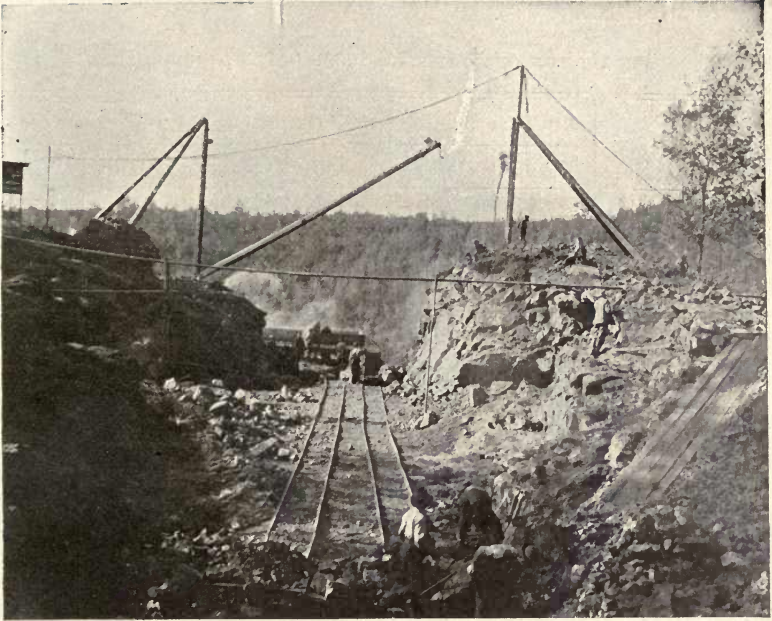


FIG. 1. — Stewart graphite mine, near Buckingham, Que. Rock on right, graphitic gneiss. On left at farther end of cut, a basic igneous rock. (*H. Ries, photo.*)
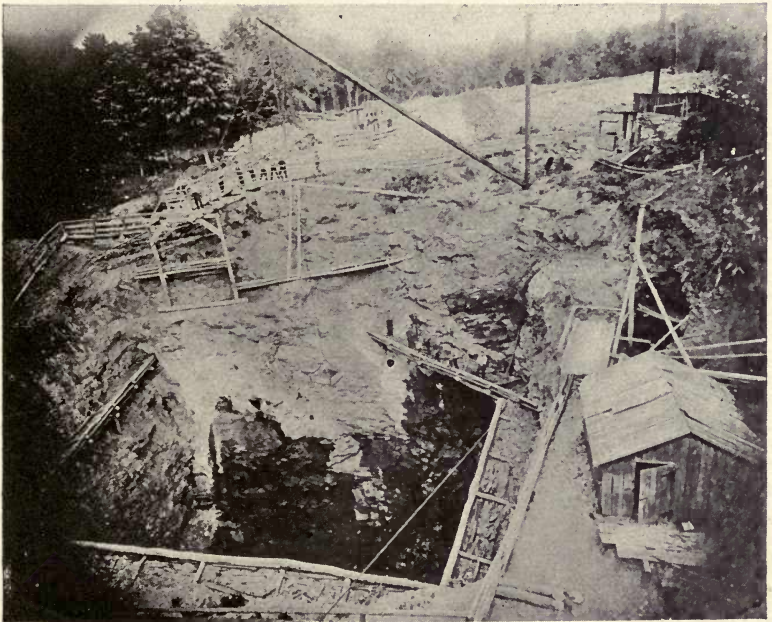


FIG. 2. — Lacey mica mine, Ontario. (*Photo loaned by Can. Dept. Mines.*)

PRODUCTION OF FELDSPAR, 1909–1914, IN SHORT TONS

| YEAR | CRUDE | | GROUND | | TOTAL | |
|---|---|---|---|---|---|---|
| | Quantity | Value | Quantity | Value | Quantity | Value |
| 1909 . . . . | 25,506 | $ 70,210 | 51,033 | $354,392 | 76,539 | $424,602 |
| 1910 . . . | 24,655 | 81,965 | 56,447 | 420,487 | 81,102 | 502,452 |
| 1911 . . . . | 28,131 | 88,394 | 64,569 | 490,614 | 92,700 | 579,008 |
| 1912 . . . . | 26,462 | 89,001 | 60,110 | 431,561 | 86,572 | 520,562 |
| 1913 . . . . | 45,391 | 148,549 | 75,564 | 628,002 | 120,955 | 776,551 |
| 1914 . . . | 85,905 | 263,476 | 49,514 | 366,397 | 135,419 | 629,873 |

MARKETED PRODUCTION OF FELDSPAR IN 1914, BY STATES, IN SHORT TONS

| STATE | CRUDE | | GROUND | | TOTAL | |
|---|---|---|---|---|---|---|
| | Quantity | Value | Quantity | Value | Quantity | Value |
| California . . | 2,778 | $ 10,715 | —— | —— | 2,778 | $ 10,175 |
| Connecticut . | 11,099 | 42,965 | 5,414 | $ 40,326 | 16,513 | 83,291 |
| Delaware . . | [1] | [1] | | | [1] | [1] |
| Maine . . | 12,553 | 30,925 | 17,510 | 163,635 | 30,063 | 194,560 |
| Maryland . . | 5,867 | 19,224 | 42 | 210 | 5,909 | 19,434 |
| New Hampshire | [1] | | | | [1] | [1] |
| New York . . | 289 | 1,032 | 19,290 | 100,995 | 19,579 | 102,027 |
| North Carolina. | 15,420 | 43,153 | —— | —— | 15,420 | 43,153 |
| Pennsylvania . | 2,843 | 10,162 | 7,258 | 61,231 | 10,101 | 71,393 |
| Virginia . . . | [2] 35,056 | [2] 105,300 | —— | —— | 35,056 | 105,300 |
| Total . . | 85,905 | $263,476 | 49,514 | $366,397 | 135,419 | $629,873 |

[1] Included in Virginia.  [2] Virginia includes Delaware and New Hampshire.

PRODUCTION OF FELDSPAR IN CANADA, 1912–1914

| YEAR | QUANTITY, SHORT TONS | VALUE |
|---|---|---|
| 1912 | 13,733 | 30,916 |
| 1913 | 16,790 | 60,795 |
| 1914 | 18,060 | 70,824 |

The world's production was supplied by the United States, Canada, Belgium, Italy, Madagascar, Norway, Sweden, and Germany.

The preceding figures do not include feldspar used for all purposes.

Dealers usually divide feldspar into the following three grades:

No. 1, which is free from iron-bearing minerals, mostly free from muscovite, and contains less than 5 per cent quartz.

No. 2, which is largely free from iron-bearing minerals, and in the potash spar usually carries 15 to 20 per cent quartz.

No. 3, which is less carefully selected and may carry enough iron-bearing minerals to render it unfit for pottery purposes.

Feldspar free from quartz is much sought after and difficult to obtain in large quantities in the United States.

The average price in 1914 of crude feldspar used for pottery and enamel ware was about $3.07 per short ton f.o.b. ,while the average price of the ground was about $7.40 per short ton f.o.b. mills.

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## FLUORSPAR

Fluorspar, or fluorite ($CaF_2$), contains 48.9 per cent fluorine and 51.1 per cent calcium. Its hardness is 4, its specific gravity, 3.18, and it has a pronounced octahedral cleavage. Fluorite shows a variety of colors, including white, green, purple, etc. The mineral is commonly found in veins which may be fissure fillings or replacements, and is often associated with ore minerals, especially lead and tin. Limestone is the most important wall rock of the American deposits, but in some districts granites, gneisses, or volcanic rocks may form the vein wall.

**Distribution in the United States.** — In the United States fluorite is found at a number of points in the Piedmont and Appalachian areas from Maine to Virginia, and is likewise noted (usually in small amounts) in many metalliferous veins of the west; but the most important producing districts are in Kentucky and Illinois. Colorado, Arizona, and Tennessee are also to be included in the producing states.

*Kentucky* (3, 4). — In the western Kentucky district, which is one of the largest producers of the world, the fluorite occurs as vein deposits in fault fissures cutting limestones (Pl. XXXIV, and Fig. 112), sandstones, and shales of Carboniferous age. The minerals

have been deposited by (1) a filling of the fissure cavity, (2) replacing the wall rock of the fissure, or (3) cementing a breccia of the same.    Associated with the fluorspar are barite, calcite, galena, and sphalerite, as well as other minerals in smaller amounts.    The different minerals may occur in the veins, either intimately intergrown or in separate bands; in some cases, however, only one mineral may be present in the vein.    The fault fissures strike northeast and northwest, but the former carry more fluorite.
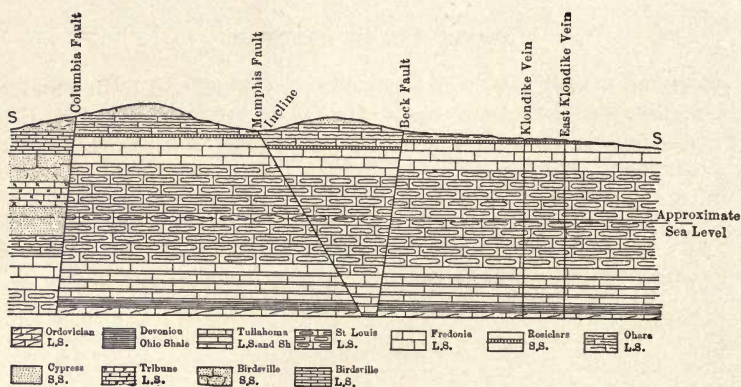


Fig. 112. — Section of Memphis mine group, along line *SS* of Pl. XXXIV.
(*After Fohs, Ky. Geol. Surv., Bull.* 9.)

It is supposed that the fluorite has been deposited by thermal waters, which were given off during cooling by the dikes of mica peridotite which are found in the district.    The fissures, fault planes, and dike contacts served as trunk channels along which the waters ascended, and from which they also spread out into the adjacent rocks.    Weathering has produced a disintegration of the fluorite.    The veins show a maximum width of 36 feet for gravel ore and 16 feet for lump ore.

The product of the veins is divided into lump, representing the coarse product; gravel, which is the naturally or artificially disintegrated spar, and ground fluorspar.    Washing and jigging are necessary to separate clay and associated minerals.    Number 1 fluorite is usually white and carries 96 per cent or more of calcium fluoride; Number 2 grade has at least 90 per cent calcium fluoride and under 4 per cent silica; while Number 3 carries from 60 to 90 per cent calcium fluoride.

*Illinois.* — Until 1898 the mines of Hardin and Pope counties, Illinois, were the only domestic source (1), and this area continues

to be an important producer. There the deposits fill fault fissures in Lower Carboniferous limestones or sandstones. Dikes of mica peridotite also occur in the district, but not in contact with the veins. These latter in some places attain a width of 45 feet and a proven depth of 200 feet. This great width is due partly to enlargement of the fissure by solution, and partly to a replacement of the limestone walls. In the limestone footwall, the fluorspar sometimes forms a solid mass from 2 to 12 feet thick, but that on the hanging wall is less pure. The vein filling is chiefly fluorite and calcite, while associated with these are smaller amounts of galena, sphalerite, and occasionally pyrite or chalcopyrite. It is significant that the galena is slightly argentiferous.

The origin of the fluorite is somewhat doubtful, but Bain (1) believes that it has probably been derived from heated waters of either meteoric or magmatic origin which leached the mineral from some large mass of low-lying igneous rocks of which the dikes are offshoots. These heated ascending solutions are thought to have carried fluosilicates of zinc, lead, copper, iron, barium, and calcium. The dissolved compounds were probably broken up by cold descending waters, which possibly also furnished the sulphur to combine with the metals.

*Colorado* (2). — In eastern Colorado fluorspar occurs in considerable quantities in a belt extending from Boulder County to Custer County. The veins, in most cases, cut granites and gneisses of pre-Cambrian age that have been intruded by later dikes, especially of quartz porphyry. Metalliferous minerals are associated with the fluorite, but in several instances the latter forms most of the vein filling. The deposits have thus far not been extensively developed, and much of the material lies rather far from the railroad. The three producing localities are Jamestown, Boulder County; Evergreen, Jefferson County; and near Rosita, Custer County.

In 1913 shipments were made from an interesting vein at Wagon Wheel Gap (2b). The fluorite here occupies a fissure averaging 3 feet in width in rhyolitic tuffs and breccias. It is associated with hot springs, and contains small quantities also of barite, calcite, quartz, and altered pyrite, the latter mostly in the altered wall rock. Even small amounts of gold and silver occur in the fluorite.

*New Mexico* (2a).—Ten miles north of Deming, fluorspar is found in steeply dipping veins cutting monzonite porphyry, the

latter being intrusive in Paleozoic and Cretaceous sediments, Fig.
113. The veins range from 2 to 5 feet in width, with a maximum
of 12 feet and may show a distinctly banded structure, or at other
times consist of massive spar with pockets of quartz. Brecciation
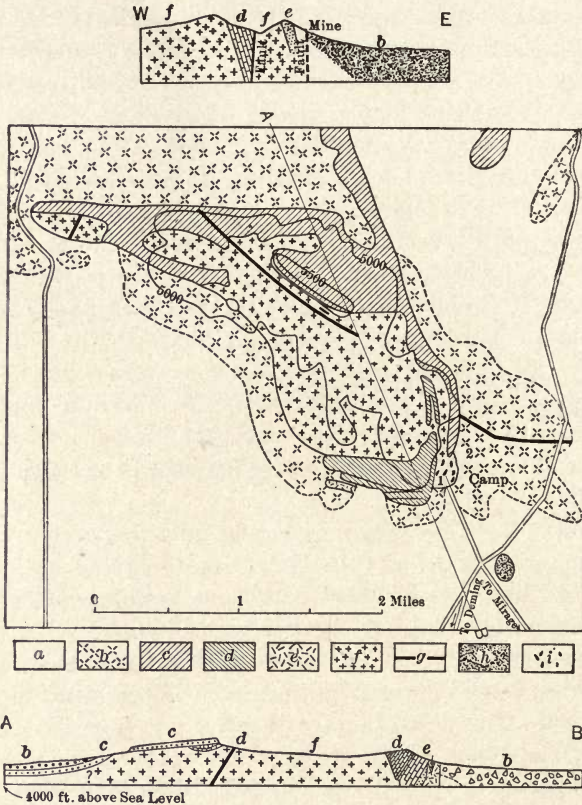


FIG. 113. — Map and sections of fluorspar deposits, Deming, N. Mex. *a*, Desert fill;
   *b*, andesitic agglomerate; *c*, sandstone; *d*, limestone; *e*, intrusive granite;
   *f*, monzonite; *g*, basalt dikes; *h*, rhyolite; *i*, fluorite veins, marked 1 and 2 on
   map. (*After Darton and Burchard, U. S. Geol. Surv., Bull.* 470.)

is also common. The partly siliceous veins are slightly more
resistant than the surrounding porphyry, but at the surface the
fluorspar is in places altered to calcium carbonate.

*Other States.* — Tennessee (3, 5) fluorspar comes from Smith,
Trousdale, and Wilson counties of that state; while that obtained
in Arizona (5) is mainly from the Castle Dome district, Yuma
County.
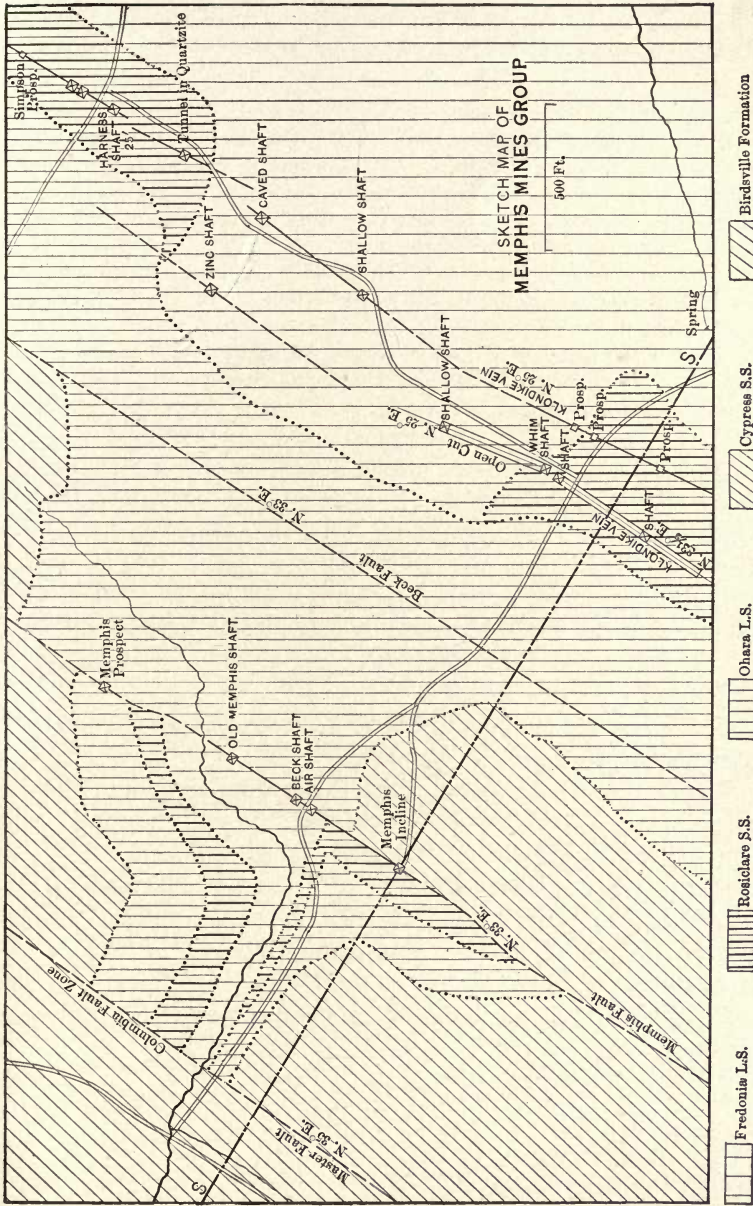
PLATE XXXIV. — Map of portion of Kentucky fluorite district. (*After Fohs, Ky. Geol. Surv., Bull. 9.*) (331)

**Canada.** — Fluorspar is known to occur near Madoc, Hastings County, Ont., and also in Huntingdon township, but the output is small.

**Other Foreign Deposits.** — Next to the United States, Great Britain is the largest producer, the fluorspar of Derbyshire and Durham, associated with lead-zinc ores of the Carboniferous, serving as an important source of supply. Most of the mineral comes from the tailings of lead mines, and the gob of abandoned workings.

Some idea of the importance of the industry is gained from the fact that the 1913 production amounted to 53,663 long tons, of which over 37 per cent was shipped to the United States.

In Germany fluorspar veins are worked, especially in the southern Harz district, Bavaria, Black Forest and Thuringian Forest. The veins may be large, and contain the common associates.

*Imports.* — Considerable gravel spar is produced as tailings from the English lead mines and shipped as ballast to the United States, thus competing with the American product as far west as Pittsburg. It is high in silica and is almost entirely consumed by open hearth steel makers. The estimated imports for 1913 were not over 22,682 short tons, valued at $71,463, while those for 1914 were 10,205 short tons valued at $38,943.

These imports amount to about 22.3 per cent of the domestic gravel spar production.

**Cryolite.** — This mineral, which is a sodium-aluminum fluoride, is not produced in the United States, the entire supply being imported from Ivigtut on the south coast of Greenland.[1] The quantity imported for consumption in the United States in 1914 was 4612 long tons, valued at $94,424, or an average price of $20.47 per ton. Canada imported $33,487 worth in 1913.

**Analyses of Fluorspar.** — The analyses (2, 3), given on page 333, will indicate the variation in composition of the American product.

**Uses.** — Fluorspar was formerly used chiefly for making hydrofluoric acid, but not more than 5 to 10 per cent of the domestic product is now employed for this purpose, while increasing quantities are sold for the manufacture of opalescent glass. The greatest demand for it, however, is as a flux in iron manufacture, since it saves from 3 to 5 per cent more iron than limestone flux, reduces the sulphur and phosphorus contents, and

[1] Mining Magazine, Apr., 1916.

ANALYSES OF FLUORSPAR

| LOCALITY | CaF$_2$ | SiO$_2$ | CaCO$_3$, MgCO$_3$ | Fe$_2$O$_3$, Al$_2$O$_3$ |
|---|---|---|---|---|
| Hodge Mines, Ky. . . . . | 98.30 | .21 | .98 | —— |
| Nancy Hanks Mines, Ky. . . | 96.00 | .71 | 3.29 | tr. |
| Gravel Fluorspar . . . . . | 95.08 | 1.90 | —— | —— |
| Rosita, Colorado . . . . . | 86.75 | 9.3 | —— | 4.2 |
| Jamestown, Colorado. . . . | 60.9 | 27. | —— | n.d. |
|  | 76.05 | 19.8 | —— | 4.2 |
|  | 86.75 | 8.60 | —— | 4.46 |
| Marion, Ky. . . . . . . | 96.01 | 1.9 | —— | 1.88 |
|  | 84.25 | 2.98 | 10.28 | 1.28 |
| Fairview, Ill. . . . . . . | 88.85 | 3.4 | —— | 1.45 |
| Mirage, N. Mex. . . . . . | 93.68 | 4.68 | .76 | .74 |

increases the tensile strength of the metal. On account of its valuable reducing properties, it is also used in making spiegeleisen, in foundry work, and in cupola furnaces. It is also used as a flux in silver, lead, and copper smelters; in the electrolytic refining of antimony and lead; in the manufacture of enamels, glazes, and fireproof ware, for apochromatic lenses, for gems, cheap jewelry, paper weights, and for carbon electrodes for flaming arc lamps. Its use as a flux in cement manufacture has been discontinued. Fluorspar for iron and steel making should contain at least 80 per cent CaF$_2$, and for most chemical purposes at least 95 per cent CaF$_2$.

**Production of Fluorspar.** — The table on page 334 gives the quantity and value of fluorspar marketed from 1912 to 1914.

The fluorspar is prepared for market by hand sorting, crushing, jigging, and sometimes fine grinding. The grades produced are:—

1. American lump No. 1, with under 1 per cent silica, and sold mainly to glass, enameling, and chemical industries.

2. American lump No. 2, which includes colored spar and may run as high as 4 per cent silica, though usually sold under a 3 per cent guaranty. It is used by blast furnaces in the production of ferrosilicon and ferromanganese, and in basic open hearth steel furnaces.

3. Gravel spar, including all with over 4 per cent silica, and spar mixed with calcite. It is used in iron and brass foundries.

FLUORSPAR MARKETED IN 1912–1914, IN SHORT TONS

| STATE | GRAVEL | | LUMP | | GROUND | | TOTAL QUAN-TITY | TOTAL VALUE |
|---|---|---|---|---|---|---|---|---|
| | Quantity | Value | Quan-tity | Value | Quan-tity | Value | | |
| **1912** | | | | | | | | |
| Illinois . . . | } 97,150 | $565,784 | 5315 | $36,553 | 11,945 | $154,316 | 114,410 | 756,653 |
| Kentucky . . | | | | | | | | |
| Other states [1] . | 2,135 | 12,510 | —— | —— | —— | —— | 2,135 | 12,510 |
| Total. . . | 99,285 | $578,294 | 5315 | $36,553 | 11,945 | $154,316 | 116,545 | $769,163 |
| **1913** | | | | | | | | |
| Illinois . . . | } 91,663 | 525,456 | 5676 | 39,059 | 8,137 | 100,203 | { 85,854 | 550,815 |
| Kentucky . . | | | | | | | 19,622 | 113,903 |
| Other states [1]. | 10,104 | 71,568 | —— | —— | —— | —— | 10,104 | 71,568 |
| Total . . . | 101,767 | $597,024 | 5676 | $39,059 | 8,137 | $100,203 | $115,580 | $736,286 |
| **1914** | | | | | | | | |
| Illinois . . . | } 77,048 | 397,913 | 8842 | 74,708 | 6,998 | 82,428 | { 73,811 | 426,063 |
| Kentucky . . | | | | | | | 19,077 | 128,986 |
| Other states . | [2] 2,228 | 14,992 | [2] | [2] | —— | —— | 2,228 | 14,992 |
| Total . . . | 79,276 | $412,905 | 8842 | $74,708 | 6,998 | $82,428 | 95,116 | $570,041 |

[1] Includes Colorado, New Hampshire, New Mexico; 1913: Arizona in addition; 1914: Colorado and New Hampshire.

[2] Lump spar included with gravel.

### REFERENCES ON FLUORSPAR

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## FOUNDRY SANDS

**Definition.** — Under the term *foundry sand* there are included (1) sands for making the mold proper into which the metal is cast, and (2) core sand, utilized for making the cores which occupy the hollow spaces of the cast piece.

The molding sands proper are usually of finer texture and more loamy character than the core sands, still the two grades overlap, and both show considerable range of texture. In selecting molding sands, the fine-grained ones are used for small castings, while the

coarser grades are employed for heavy castings. The core sands have but little cohesiveness, owing to their lack of clayey matter, and hence require the addition of an artificial binder.

**Requisite Properties.** — The requisite physical qualities of foundry sands are: 1. sufficient cohesiveness to make the grains cohere when pressed together to form the parts of the mold, the deficiency in this respect in core sands being supplied by artificial binders; 2. sufficient refractoriness to prevent extensive fusion in the sand when exposed to the heat of the molten metal; 3. texture adapted to the grade of casting to be poured in it; 4. sufficient porosity and permeability to permit the escape of the gases given off by the cooling metal; 5. durability, or sufficient length of life, to permit as much of the sand as possible being used over again.

The laboratory examination of a molding sand might properly include the determination of (1) its texture (by mechanical analysis), (2) porosity, (3) permeability (by aspirator method), (4) average fineness (by aspirator method),[1] (5) tensile strength, and (6) refractoriness.

Chemical analyses of foundry sands are in most cases of little value, mainly because they shed no light on the physical properties. A few are, however, given below: —

CHEMICAL ANALYSES OF FOUNDRY SANDS

| | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $K_2O$ | $Na_2O$ | $TiO_2$ | $H_2O$ | MOIST |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 81.59 | 6.46 | 4.94 | .14 | .22 | 1.19 | .59 | 1.90 | 1.63 | 1.46 |
| 2. | 66.12 | 16.54 | 4.46 | .40 | .22 | 2.67 | .35 | .14 | 4.90 | 4.15 |
| 3. | 79.36 | 9.36 | 3.18 | .44 | .27 | 2.19 | 1.54 | .34 | 2.02 | .74 |
| 4. | 79.38 | 9.38 | 3.98 | 1.40 | .54 | 1.80 | 1.04 | .44 | 2.50 | .80 |
| 5. | 71.60 | 11.49 | 7.81 | .65 | .95 | 1.42 | 1.27 | — | 4.00 | |
| 6. | 86.80 | 3.05 | 5.32 | .15 | .65 | .83 | .04 | — | 3.25 | |
| 7. | 84.28 | 4.50 | 6.10 | tr. | .72 | .91 | .39 | — | 3.10 | |
| 8. | 79.41 | 12.47 | .80 | .99 | .81 | 1.56 | | — | 3.96 | |
| 9. | 57.63 | 10.03 | .88 | 11.16 | 5.63 | .01 | | — | 14.66[2] | |
| 10. | 84.86 | 7.03 | 2.18 | .62 | .98 | Undet. | | — | 2.20 | |
| 11. | 82.90 | 8.21 | 2.90 | .62 | .00 | Undet. | | — | 2.85 | |
| 12. | 81.57 | 11.52 | 2.74 | 1.49 | .18 | — | | — | 2.50 | |

1. Fine sand for light castings, Richmond, Va. 2. Coarse, gravelly core sand, Richmond, Va. 3. Stove plate sand, Albany, N. Y. 4. Stove plate sand, Newport, Ky. 5. " Philadelphia" brass sand. 6. Lumberton, N. J., brass sand (mild). 7. Lumberton, N. J., brass sand (strong). 8. Upper sand bed, Rockton, Ill. 9. Lower sand bed, Rockton, Ill. 10. Sand for medium weight castings. 11. Coarse sand for heavy castings. 12. Stove plate sand, Conneaut, O. All quoted from Ref. 6.

[1] The average fineness may be determined in other ways, but these are less accurate. See Ref. 6.　　[2] Includes $CO_2$.

The following table gives the mechanical analysis, specific gravity, and porosity of a number of samples of foundry sand.

PHYSICAL TESTS OF FOUNDRY SANDS

| No. | 20 MESH | 40 MESH | 60 MESH | 80 MESH | 100 MESH | 250 MESH | CLAY | SPECIFIC GRAVITY | PER CENT PORE SPACE | AVERAGE SIZE OF GRAIN IN TERMS OF SIEVES, ASPIRATOR METHOD |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 6.84 | 6.61 | 40.09 | 8.98 | 23.82 | 12.56 | 1.06 | 2.68 | 36.2 | 91 |
| 2. | .96 | 12.42 | 34.41 | 4.31 | 7.50 | 18.29 | 22.06 | 2.61 | 38.8 | 714 |
| 3. | .30 | .77 | 4.52 | 1.63 | 5.35 | 57.95 | 29.44 | 2.59 | 40.9 | 770 |
| 4. | 4.69 | 13.34 | 23.96 | 5.01 | 11.95 | 18.22 | 22.79 | 2.66 | 45.0 | 222 |
| 5. | .09 | .45 | 1.51 | .31 | .74 | 66.79 | 30.08 | 2.67 | 42.2 | 1429 |
| 6. | .13 | .59 | 20.10 | 5.81 | 15.89 | 33.35 | 24.09 | 2.62 | — | — |
| 7. | .33 | .18 | .55 | .24 | 5.47 | 87.92 | 5.36 | 2.65 | 43.0 | 344 |
| 8. | 2.51 | 6.16 | 16.49 | 4.74 | 11.30 | 32.37 | 26.39 | 2.62 | 42.9 | 361 |
| 9. | .27 | .54 | 1.21 | .32 | 1.21 | 69.46 | 26.97 | — | — | — |
| 10. | .08 | .20 | .17 | .00 | .14 | 87.56 | 11.82 | 2.7 | 46.7 | 714 |
| 11. | 1.51 | 1.26 | 1.27 | .56 | 6.27 | 71.69 | 16.52 | — | — | — |
| 12. | 42.48 | 12.90 | 6.16 | .85 | 1.70 | 8.58 | 26.44 | — | — | — |
| 13. | 3.03 | 1.41 | .97 | .40 | 2.61 | 48.32 | 41.87 | — | — | — |
| 14. | — | .36 | 6.56 | 3.52 | 21.22 | 64.84 | 2.56 | — | — | — |
| 15. | .4 | 16.54 | 56.24 | 5.60 | 5.20 | 2.60 | 13.34 | 2.58 | 40.41 | — |
| 16. | 1.32 | 14.02 | 28.68 | 5.62 | 10.24 | 14.12 | 25.02 | 2.55 | 39.52 | — |
| 17. | .04 | .06 | .12 | .06 | .12 | 80.12 | 19.22 | 2.66 | 43.43 | — |
| 18. | 4.5 | 32.0 | 23.0 | 16.0 | 9.5 | 15 | | 2.613 | 45.1 | — |
| 19. | 5.5 | 25.5 | 11.5 | 14.5 | 12.0 | 31 | | — | 39.5 | — |

1. Fine core sand, Jackson, Mich. 2. Sand for general work, Zanesville, O., district. 3. Riverside, Mich. 4. Core sand, Niles, Mich. 5. Stove plate sand, Conneaut, O. 6. Sand for general work, Vineland, Mich. 7. Leoni, Mich. 8. Sand for heavy work, Battle Creek, Mich. 9. No. 5 sand, Newport, Ky. 10. No. 3 sand, Akron, O. Nos. 1–10 quoted from Ref. 6. 11. Sand for general work, Manchester, Va. 12. Coarse sand, Richmond, Va. 13. Petersburg, Va. Nos. 11–13 quoted from Ref. 6. 14. Sand for small castings, Berlin, Wis. 15. Core sand for heavy castings, Janesville, Wis. 16. Sand for heavy castings, Kenosha County, Wis. 17. No. 4 sand, for malleable and gray iron, and brass, Waterford, Ill. Nos. 14–17 quoted from Ref. 4. 18. Lumberton, N. J. 19. Strong sand, Hainesport, N. J. Nos. 18–19, Ref. 2.

**Distribution in the United States.** — Many thousands of tons of foundry sand are used annually by foundries, scattered all over the United States. In most cases these represent natural mixtures, but for some grades of work, especially steel casting, artificial mixtures of quartz, clay, etc., are used.

Sands for cores and molds for general work are widely distributed and obtainable from many surface formations, usually of recent age; but the finer-grained sands, such as are required for stove plate and brass casting, are of rarer occurrence. The regions around Albany, New York, Conneaut, Ohio, Newport, Kentucky, Valparaiso, Indiana, etc., are noted for their supplies of the finer grades of molding sands. New Jersey is also an important producer, but there the sand is obtained largely from Cretaceous and Tertiary deposits. In the digging of molding sand, careful sorting is sometimes necessary, the deposit of good sand being often thin, or of irregular thickness, and interbedded with other sands of no value, although closely resembling the good material.

The literature on molding sands is not extensive.

The value of molding sand produced in the United States in 1914 is reported as $1,756,383, but these figures are probably only approximate.

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## FULLER'S EARTH

**Properties.** — Fuller's earth (7) may be regarded as a peculiar type of clay which has a high absorbent power for many substances, on which account it is of value for decolorizing oil and other liquids. Its color and chemical composition are variable, and its specific gravity ranges from 1.75 to 2.5. The quantitative analysis shows it to differ chiefly from common clay in having a relatively higher percentage of combined water.

The following analyses represent the composition of fuller's earth

from different localities, but it should be emphasized that they are of little value in judging the quality of the earth:—

CHEMICAL ANALYSES OF FULLER'S EARTH

|              | I      | II    | III   | IV    | V     | VI    | VII    |
|--------------|--------|-------|-------|-------|-------|-------|--------|
| $SiO_2$ . . | 47.10  | 62.83 | 67.46 | 58.72 | 74.90 | 54.32 | 63.19  |
| $Al_2O_3$ . . | 16.27  | 10.35 | 10.08 | 16.90 | 10.25 | 18.88 | 18.76  |
| $Fe_2O_3$ . . | 10.00  | 2.45  | 2.49  | 4.00  | 1.75  | 6.50  | 7.05   |
| $CaO$ . . | 2.63   | 2.43  | 3.14  | 4.06  | 1.30  | 1.00  | .78    |
| $MgO$ . . | 3.15   | 3.12  | 4.09  | 2.56  | 2.30  | 3.22  | 1.68   |
| $K_2O$ . . | —      | .74   | —     | 2.11  | 1.75  | 4.21  | .21    |
| $Na_2O$ . . | —      | .20   | —     | —     | —     | —     | 1.50   |
| $H_2O$ . . | 20.85  | 7.72  | 5.61  | 8.10  | 5.80  | —     | 7.57   |
| Moisture . | —      | 6.41  | 6.28  | 2.30  | 1.70  | 11.86 | —      |
| Total .. | 100.00 | 96.25 | 99.15 | 98.45 | 99.75 | 99.99 | 100.74 |

I. Woburn sands, Eng. (Yellow.)  II. Gadsden County, Fla.  III. Decatur County, Ga.  IV. Fairburn, S. Dak.  V. Sumter, S. Ca.  VI. Bakersfield, Calif.  VII. Alexander, Ark.  All quoted from Ref. 7.

The cause of the bleaching power of fuller's earth still remains to be explained, but Parsons (3) has suggested that the phenomenon is one of simple adsorption. Lime carbonate seems to injure the bleaching power of the earth, and in some cases appears to be counteracted somewhat by acid treatment. A practical test affords the only satisfactory method of determining the value of fuller's earth.

**Distribution in the United States** (1, 3, 7). — In former years nearly all of the fuller's earth used in the United States was imported from England, where large deposits of this material exist; but occurrences are now known in a number of states, including Florida, Georgia, Alabama, Arkansas, Colorado, South Carolina, etc.

At most localities the earth is found interbedded with sands or clays, which may sometimes differ from it but little in appearance.

Fuller's earth is not confined to any particular formation, but the known deposits occur in sedimentary rocks ranging from the beginning of the Mesozoic up to the Pleistocene. In Gadsden County, Florida (5, 8) and in Decatur County, Georgia (8), for example, it is obtained from the upper Oligocene of the Tertiary, the former locality being the most important in the country. The earth from this region is used for bleaching mineral oils.

**Foreign Deposits.**[1] — The best known foreign deposits are those of England. They are worked chiefly in the Lower Cretaceous at Woburn Sands, and in the Lower Oolite (Jurassic) at Bath. The German deposits, though

[1] Dammer and Tietze, Nutzbaren Mineralien, II: 419, 1913.

of low yield, are interesting because those of the most important or Westerwald district are a weathering product of basalt, while some of the Saxon ones come from the decay of gabbro and amphibolite.

**Uses.** — Fuller's earth was originally used for fulling cloth, but in this country its employment for this purpose is small, the chief use being for bleaching, clarifying, or filtering, fats, greases, and oils. It has also been employed in the manufacture of pigments for printing wall papers, for the detection of certain coloring matters in some food products, and as a substitute for talcum powder.

For treating mineral oils the carefully dried earth is placed in cylinders, and the oil allowed to filter slowly through it, the result being that the first oil comes out water white. In the treatment of vegetable oils, these are heated in large tanks to above 212° F., from 5 to 10 per cent oil added, and after strong stirring, the mixture put in a filter and the discolored oil strained out.

**Production of Fuller's Earth.** — Fuller's earth was dixcovered in the United States in 1891 near Alexander, Ark. It was subsequently accidentally discovered near Quincy, Fla., and this state has remained the leading producer. The domestic output has never been large, and much is still imported from England.

PRODUCTION OF FULLER'S EARTH IN UNITED STATES, 1912–1914

| YEAR | SHORT TONS | VALUE | AVERAGE PRICE PER TON |
|---|---|---|---|
| 1912 . . . . . . . . | 32,715 | $305,522 | $9.34 |
| 1913 . . . . . . . . | 38,594 | 369,750 | 9.58 |
| 1914 . . . . . . . . | 40,981 | 403,646 | 9.85 |

FULLER'S EARTH IMPORTED FOR CONSUMPTION INTO UNITED STATES, IN SHORT TONS

| YEAR | UNWROUGHT OR UNMANUFACTURED | | | WROUGHT OR MANUFACTURED | | | TOTAL | | |
|---|---|---|---|---|---|---|---|---|---|
| | Quantity | Value | Average Price per Ton | Quantity | Value | Average Price per Ton | Quantity | Value | Average Price per Ton |
| 1912 . . | 1970 | $11,619 | $5.90 | 17,139 | $133,718 | $7.80 | 19,109 | $145,337 | $7.61 |
| 1913 . . | 1916 | 12,344 | 6.44 | 16,712 | 133,657 | 8.00 | 18,628 | 146,001 | 7.84 |
| 1914 . . | 1468 | 9,283 | 6.32 | 23,509 | 185,800 | 7.90 | 24,977 | 195,083 | 7.81 |

REFERENCES ON FULLER'S EARTH

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## GLASS SAND

Glass sand is obtained from quartzose sands, sandstones, or quartzites. When sand is employed, it is sometimes necessary to put it through a washing process in order to separate the impurities, while in the case of sandstone or quartzite, at least a preliminary crushing and screening are usually necessary.

**Chemical Composition.**[1]—Since silica is the major ingredient of the sand, it influences the character of the ware to a marked degree. Sand with impurities is therefore to be avoided, especially if it is to be used for the higher grades of glassware. Chemical analysis of almost any sand may show at least traces of iron oxide, alumina, titanium oxide, lime, magnesia, and organic matter, but most of these are included in mineral grains other than quartz.

Iron oxide, even in small amounts, colors the glass green, and is avoided by a selection of the whitest sand, although whiteness does not necessarily indicate freedom from impurities. Washing may remove much of the iron, and the iron color may also be counteracted to some extent by the addition of arsenic. Magnesia causes trouble by rendering the batch less fusible, but it is more apt to be

[1] Frink (Ref. 14) believes that many of the views held regarding allowable limit of MgO and Al₂O₃ are incorrect, and these substances are less harmful than is commonly imagined.

introduced through the limestone than the sand. Clay is undesirable, since it tends to cloud the glass.

CHEMICAL ANALYSES OF GLASS SANDS

| | SiO$_2$ | Al$_2$O$_3$ | Fe$_2$O$_3$ | CaO | MgO | | TOTAL |
|---|---|---|---|---|---|---|---|
| 1. Ottawa, LaSalle County, Ill. . . . . . . | 99.45 | .30 | | .13 | tr. | — | 99.88 |
| 2. Utica, Ill. . . . . . | 99.57 | .283 | .0903 | .0197 | .002 | — | 99.97 |
| 3. Klondike, Mo. . . . . | 99.97 | .03 | — | — | — | — | 100.00 |
| 4. Grays Summit, Mo. . . | 99.839 | — | .0014 | — | — | H O .154 | 99.9944 |
| 5. Everton, Boone Co., Ark. | 99.55 | .13 | .09 | — | — | — | 99.77 |
| 6. Flora, Grant Co., Wis. . | 99.17 | .25 | .22 | — | — | | 99.64 |
| 7. Coxville, Ind. . . . . | 98.61 | .74 | .22 | .12 | tr. | Ign· .32 Und. | 100.01 |
| 8. Tip Top, Ky. (selected) . | 98.87 | .21 | .08 | .24 | .12 | .48 | 100.00 |
| 9. Massillon, O. . . . . | 97.50 | 1.50 | .50 | — | .50 | — | 100.00 |
| 10. Niles, O. . . . . . | 99.915 | .062 | .0019 | .021 | tr. | — | 99.999 |
| 11. Berkeley, W. Va. (Oriskany sandstone) . . | 98.99 | .7717 | .0383 | — | — | — | 99.80 |
| 12. 4 m. from Hancock,W.Va. (Medina sandstone) . | 99.30 | .5186 | .0314 | — | — | — | 99.85 |
| 13. Columbia, Pa. (Oriskany) | 99.5044 | .1337 | .2989 | | | Loss etc. .062 | 99.9999 |
| 14. Cheshire, Mass. (Cambrian) . . . . . . | 99.46 | .48 | | .06 | | | 100.00 |
| 15. Lewiston, Pa. (Oriskany) | 98.84 | .17 | .34 | tr. | tr. | Ign. .23 | 99.58 |
| 16. Hanover, N. J. (Tertiary) | 97.705 | .755 | .15 | .955 | .442 | | 100.007 |
| 17. Clayton, Ia. (Ordovician) | 98.85 | .46 | .995 | .21 | | Loss etc. .384 | 99.999 |
| 18. W. Vienna, N. Y. (Pleistocene) . . . . . | 98.6 | .17 | .23 | | tr. | | 99.00 |

Nos. 1–6, Ref. 3; Nos. 7–10, Ref. 4; Nos 11–12, Ref. 10.

**Physical Properties** (3). — Contrary to the belief of glass manufacturers that rounded grains are best, much good glass is made from sands of angular or subangular grain. Uniformity of grain is highly desirable, and should range between 30 and 120 mesh. If larger than 30 mesh, the sand is more difficult to fuse; while if finer than 120 mesh, it is said to " burn out " in the batch.

Few mechanical analyses of glass sands have been published, but the following will serve to show the texture of several from different localities (2, 3).

MECHANICAL ANALYSES OF GLASS SANDS

| LOCALITY | SAMPLE | PASSES 20 MESH | PASSES 40 MESH | PASSES 60 MESH | PASSES 100 MESH |
|---|---|---|---|---|---|
| Ottawa, Ill. . . | Finest grained . . | 100 | 100 | 92 | 25 |
| Ottawa, Ill. . . | Coarsest grained | 99 | 6 | 1 — | 0 |
| Ottawa, Ill. . . . | Crude, direct from pit. | 99 + | 23 | 3 | 1 — |
| Utica, Ill. . . . . | Crude from car . | 99 + | 45 | 11 | 3 |
| Klondike, Mo. . | Extra qualtiy . . | 100 | 90 | 15 | 1 |
| Grays Summit, Mo. | Finished product | 100 | 92 | 25 | 2 |
| Grays Summit, Mo. | Crude, from quarry. | 100 | 88 | 55 | 1 — |
| Crystal City, Mo. | Prepared . . . | 99 + | 23 | 13 | 1 |
| Crystal City, Mo. | Average mine run | 100 | 55 | 20 | 1 |
| Berkeley Springs, W. Va. | Crushed sandstone, finished product | 100 | 98 | 25 | 1 — |
| Everton, Ark. . | Not worked . . | 99 + | 97 | 50 | 10 |
| Flora, Wis. . . | Not worked . . | 99 + | 80 | 40 | 15 |

**Distribution of Glass Sand.** — Sand for glass making is obtained from a number of different geological formations, ranging from Cambrian to Pleistocene. Those obtained from the Pleistocene deposits, as in New York (12), are not as a rule of high purity, but those from the Tertiary and Cretaceous formations are of better quality. In New Jersey there are extensive pits in the Tertiary, around Bridgeton (11), the material being used in the glass works of southern New Jersey and southeastern Pennsylvania. Large pits have also been opened in the Raritan formation of the Cretaceous along the Severn River in Maryland. The Oriskany sandstone is found to be of high purity in West Virginia between Berkeley Springs and a point on the border near Hancock, Maryland, the locality having been worked for a number of years (10). Sandstones of the same age are also worked in Pennsylvania (6, 8).

The glass-sand industry of Illinois (2), is developed mainly in La Salle County, the rock used being the St. Peter (Ordovician) sandstone. Much of it is very soft. Sandstone of similar age is worked in Missouri (1, 2), in a belt between Klondike on the Missouri River

and Crystal City on the Mississippi River. Indiana (4) contains sandstone suitable for glass manufacture in the Silurian, Devonian, Carboniferous, and Tertiary formations, but most of it comes from the Mansfield sandstone of the Carboniferous in the southwestern part of the state. Beds of high-grade sandstone occur interbedded with Silurian limestones in northwestern Ohio (4), but the most important deposits are found in the Mississippian, Pottsville, and Lower Coal Measures in the eastern portion of the State.

In eastern Canada the Oriskany sandstone is used.

**Production of Glass Sand.** — About 19 states report a production of glass sand, but all of the material may not be used in glass manufacture. The production of the important producers as well as the total for the United States is given below:—

QUANTITY AND VALUE OF GLASS SAND IN UNITED STATES, 1912–1914

|  | 1912 | | 1913 | | 1914 | |
|---|---|---|---|---|---|---|
|  | SHORT TONS | VALUE | SHORT TONS | VALUE | SHORT TONS | VALUE |
| California | 9,535 | $8,664 | [1] | [1] | [1] | [1] |
| Illinois | 323,467 | 225,434 | 350,229 | $239,277 | 339,551 | $246,803 |
| Indiana | 26,040 | 10,641 | 1,842 | 1,861 | 36,977 | 14,138 |
| Missouri | 129,030 | 81,817 | 130,676 | 91,284 | 160,190 | 112,484 |
| Michigan | [1] | [1] | 2,938 | 3,020 | 26,035 | 32,593 |
| New Jersey | 102,782 | 79,027 | 108,560 | 82,577 | 83,927 | 62,595 |
| New York | [1] | | 35,514 | 21,416 | [1] | [1] |
| Ohio | 154,527 | 164,462 | 73,154 | 65,892 | 138,565 | 131,766 |
| Pennsylvania | 427,936 | 517,383 | 513,867 | 674,073 | 512,718 | 611,173 |
| West Virginia | 244,881 | 287,038 | 534,600 | 668,214 | 233,024 | 269,602 |
| Total United States | $1,465,386 | $1,430,471 | 1,791,800 | $1,895,991 | 1,619,649 | $1,568,030 |

[1] Included in the total.

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# CHAPTER XI

## MINOR MINERALS — GRAPHITE MONAZITE

## GRAPHITE

**Properties and Occurrence.** — Graphite, or black lead, as it is often termed popularly, is a form of carbon, of which two varieties are generally recognized, especially in the trade. The first of these, the *crystalline*, has a lamellar or flaky structure, and is of high purity, while the other form, which is classed as *amorphous*, lacks crystalline structure, and may be quite impure. However, even the purest graphite may contain at least a few tenths per cent ash and volatile matter, and commercial graphite often contains an appreciable content of impurities. Those containing 90–95 per cent graphitic carbon meet the requirements of the general trade, but for many purposes, especially paint-making, graphites with as low as 30 to 35 per cent graphitic carbon can be employed.

The following analyses of graphite from a number of localities (6) show the variation in its composition, but probably do not in all cases represent commercial samples.

### Analyses of Graphite

| Localities | Sp. Grav. | Volatile Matter | Carbon | Ash |
|---|---|---|---|---|
| Cumberland, first quality . . . . | 2.3455 | 1.10 | 91.55 | 7.35 |
| Passau, Bavaria . . . . . . . | 2.3032 | 7.30 | 81.08 | 11.62 |
| Passau, Bavaria . . . . . . . | 2.3108 | 4.20 | 73.65 | 22.15 |
| Mugrau, Bohemia . . . . . . . | 2.1197 | 4.10 | 91.05 | 4.85 |
| Ceylon crystals . . . . . . . | 2.3501 | 5.10 | 79.40 | 15.50 |
| Ceylon, commercial quality . . . . | 2.2659 | 5.20 | 68.30 | 26.50 |
| Gulf of Spencera, S. Australia . . . | 2.3701 | 2.15 | 25.75 | 72.10 |
| Gulf of Spencera, S. Australia . . . | 2.2852 | 3.00 | 50.80 | 46.20 |
| Buckingham, Can. . . . . . . . | 2.2863 | 1.82 | 78.48 | 19.17 |
| Madagascar . . . . . . . . . | 2.4085 | 5.18 | 70.69 | 24.13 |
| Pissic, Dep. Hautes Alpes . . . . | 2.4572 | 3.20 | 59.67 | 37.13 |
| Ural Mts., Russia . . . . . . . | 2.1795 | .72 | 94.03 | 5.25 |
| Ticonderoga, N.Y., vein graphite . . | 2.2647 | .818 | 97.422 | 1.76 |

Graphite is usually easily recognized by its peculiar physical properties, such as extreme softness, steel-gray to blue-black color, greasy feel and black streak. The specific gravity is 2.20 to 2.27. The luster is metallic in the leafy form, but earthy when the graphite is in a finely divided state. In such event it may be difficult to tell it from amorphous carbon, although graphite can be told by its property of forming graphitic acid, when treated with nitric acid. Molybdenite is the only mineral with which it might be confused, but this has a bluish or greenish tinge and a greenish streak.

**Mode of Occurrence.** — Graphite always occurs in eruptive or metamorphosed rocks, especially the latter. The different occurrences include schist, gneiss, quartzite, crystalline limestones, granulite, syenite, etc.

The shape of the deposit is also varied. Thus the graphite may form: (1) disseminations in metamorphic rocks; (2) pockets in metamorphic or in igneous rocks; (3) veins; and (4) bedded deposits.

The gangue minerals are important, since they affect the process of separation, and are in general those common to the c untry rock, except in the case of veins, when they may be different. Mica and chlorite are undesirable, as they are hard to separate. Both quartz and calcite may be common gangue minerals, and the less abundant may include rutile, titanite, apatite, etc.

**Genetic Occurrence.** — It seems probable that graphite may be of either igneous or sedimentary origin, although the latter is possibly the more important. The following cases are recognized:

1. *In Igneous Rocks.* — There is no doubt that graphite may form an original constituent of rocks formed by the cooling and crystallization of a magma. For examples of this we may refer to the occurrence of graphite in meteorites, in the native iron of Greenland, in the nepheline syenite of Siberia, or in pegmatite dikes.

Of course, where the intrusive rock has pierced sedimentary ones, there is always the doubt or possibility that the graphite may have been derived from these. This fact thas been pointed out in the case of a graphite-bearing pegmatite from Maine,[1] and another from New Jersey.[2]

2. *In Veins.* — This manner of graphite occurrence affords a

[1] Smith, U. S. G. S., Bull. 285: 280, 1906.
[2] Spencer, U. S. G. S., Geol. Atl. Fol. 161, 1908.

puzzling problem. The veins appear to represent fissure filling, and may be several feet in width. They are found not only in igneous rocks such as granites and pegmatites, but also in metamorphosed sediments, and while they were probably formed at considerable depths, it has been suggested that in some cases at least, the temperature did not exceed 575° C.[1]

Some believe that the graphite was derived from surrounding sediments, and deposited shortly after the pegmatitic injection. Others hold the view that the graphite has been derived from gaseous constituents of the magma, it being pointed out that if CO and H are present, they will react below 500° C. according to the equation

$$2CO + 2H_2 \rightleftarrows 2C + 2H_2O.$$
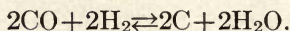
This may be the origin of the graphite in the veins of Ceylon, Montana and New York.

3. *In Metamorphic Rocks.* — These may include regionally and and contact metamorphosed rocks. It is quite generally admitted that the carbonaceous matter of sedimentary rocks may undergo a recrystallization during metamorphism resulting in the formation of graphite.

Where graphite has been produced by contact metamorphism, some writers (Weinschenk) have sought to show that it represents exhalations from the magma, but this hardly seems necessary, especially when we find that the metamorphosed formation, if traced away from the eruptive, is carbonaceous.

The intrusion of igneous rocks into or near coal appears in some cases to have produced crystalline (1, p. 41), in other instances amorphous graphite.[2] As an example of the latter we may refer to deposits in central Sonora, Mexico, where coal beds up to 24 feet in thickness, enclosed in sandstone, have been metamorphosed by granite.

**Distribution of Graphite in the United States.** — Crystalline graphite is widely distributed in the United States, occurring in contact zones between igneous and sedimentary rocks, in metamorphic rocks, etc., but the known deposits of commercial value are few in number.

Most of the domestic supply has been obtained from New York State.

*New York* (4, 11, 11a, 12). — The producing mines are located on

[1] Bastin, Econ. Geol. V: 152, 1910.    [2] Bastin, U. S. Geol. Surv., Min. Res. 1908.

Fig. 114.—Map showing principal graphite mines of northeastern states.
1. Crown Point Graphite Co.; 2. Ticonderoga mine; 3. Dixon's American
Mine; 4. Hague mine; 5. Rowland Graphite Co.; 6. Champlain, and Adiron-
dack Graphite Companies; 7. Sacandaga Graphite Co.; 8. Empire Graphite
Co.; 9. Saratoga Graphite Co.; 10. Macomb Graphite Co.; 11. Bloomingdale
Mine; 12. Raritan Graphite Mine, High Bridge; 13. Eynon Graphite Co.,
Coventryville; 14. Girard Graphite Co., Rock Graphite Mining Co., Crucible
Flake Graphite Co.; 15. Anselma Mine, Federal Carbon Mine, Chester Mine;
16. Acme, Pennsylvania and Pettinos Bros.' Mine; 17. Boyertown Mine;
18. Penn Mine, Mertztown; 19. Backenstoe Mine; 20. Sturbridge Mine.
(*U. S. Geol. Surv., Min. Res.* 1913.)

the southeastern side of the Adirondacks in Essex, Warren, Washington, and Saratoga counties, and the state leads all others in its production of graphite, partly because of the steady production of one large mine.

The graphite occurs in the following ways: 1. In pegmatite veins, forming bunches, associated chiefly with quartz, but also feldspar, pyroxene, hornblende, mica, calcite, scapolite, apatite, sphene, etc. This type of deposit is of little commercial value. 2. Veinlets of graphite with quartz in gneiss. 3. Graphitic quartzites, representing metamorphosed pre-Cambrian sediments. These are the most important type. 4. Graphitic disseminations in Algonkian limestones.

At the American Graphite Company's mine, which is representative of 3, the material worked is a medium-grained, quartz-graphite schist, which averages 6.25 per cent graphitic carbon. The associated minerals are quartz, mica, and apatite. The graphite rock varies from 3–20 feet in thickness, and is overlain by garnet gneiss.

*Rhode Island* (5). — Amorphous graphite, graphitic anthracite, or graphitic shale, as it has been variously called, has been known for many years to occur in the metamorphosed Carboniferous rocks near Providence and Tiverton, Rhode Island, but the production has been irregular. At the Cranston Mines near Providence, which are the largest, the section shows a series of interbedded, sandy, carbonaceous, and graphitic shales, something over 300 feet thick, all folded and perhaps faulted. The main graphitic bed is 30 feet thick.

The following analyses represent the range of composition of the material:—

|    | Moisture | Volatile matter | Fixed carbon | Ash |
|----|----------|-----------------|--------------|-----|
| 1. | 13.26    | 2.56            | 65.30        | 18.88 |
| 2. | 23.68    | 3.01            | 42.54        | 30.77 |

Ashley has characterized the material as a high-ash, high-moisture, graphitic anthracite coal of high specific gravity (1.65–2.45), which cannot be used successfully as a fuel, unless it can be mined and delivered at the furnace in Providence or Boston for less than one-half the wholesale price of competing coals.

The material is used chiefly for paint and foundry facings.

*Pennsylvania* (8). — Crystalline graphite has been mined at several localities in eastern Pennsylvania, where it occurs in crystalline rocks.

*Alabama* (14). — Crystalline graphite is found in granites and schists in Clay, Chilton, and Coosa counties. In Clay County, for example, the graphite is uniformly disseminated throughout a zone of mica-free weathered granite, ten miles long and several hundred feet wide. Its depth has been proven to 75 feet, with an average of 4.5 per cent graphite. A graphitic clay found in the slightly crystalline schists of the Palæozoic area of Clay and Tallapoosa counties is used as a lubricant.

*New Mexico* (10). — Amorphous graphite is known to occur in the cañon of the Canadian River, about 7 miles southwest of Raton. The bed, which is nearly horizontal, has been traced laterally into the principal bituminous coal seam of the Raton field, and that portion which is graphitized owes its character to diabase intrusions, the change being most complete where the bed was fractured and the diabase forced into it. The graphite is said to occur in pockets or irregular masses in the diabase, and is columnar normal to the faces of the igneous rock. It has been mined somewhat and sold for the manufacture of mineral paint.

*Montana* (20). — Near Dillon, Mont., there is a deposit somewhat similar to those of Ceylon, for the graphite occurs in veins. These may be irregular, forming a network, or some of the narrow ones appear persistent. They occur in schists and crystalline limestones, which have been penetrated by pegmatite. The graphite is said to be softer than the Ceylon product.

*Other States.* — Developments of graphite have been made in other states, such as Michigan, Wisconsin, Virginia (17), Wyoming (2), Maine (15), Georgia (9), etc., but the output is not steady.

**Canada** (1, 6). — Mining for graphite in Canada began in 1847, and has continued since, the production coming from rocks of the Hastings-Grenville series of eastern Ontario and the adjoining portions of Quebec. The 1913 production came from the Buckingham district, Quebec and Calabogie and Wilberforce, Ont. Canadian graphite occurs in the following three ways: (1) As disseminations in gneiss, quartzite or schist, the beds being sometimes more highly graphitic, where pierced by intrusives; (2) As usually narrow or irregular veins, in or near igneous rocks; (3) As veins or irregular masses in limestone near igneous rocks; (4) As a constituent of pegmatite veins cutting the Grenville series.

Only the first of these is of much economic importance.

**Other Foreign Deposits.** — Ceylon (1, 3) is the leading graphite-producing country of the world, the chief mines being located in the mountainous area of the southwestern and south central part of the island. The chief rocks are gneisses with some interbedded dolomites, and some intrusives, especially granite pegmatites. While some disseminated graphite is found in gneiss and limestone, the commercially important deposits are veins of irregular width, occurring along fracture planes. In small veins the graphite

forms an aggregate of parallel needles at right angles to the wall, but in the larger veins a coarse platy structure is observed. Pyrite and quartz are not uncommon, while biotite, orthoclase, pyroxene, apatite, allanite, and rutile are more rare.

Bavaria (1) is another important producer. There, in the Passau district (Fig. 115), the country rock is cordierite gneiss, surrounded by granite, and containing bands of schist, and limestone, as also some intrusive rocks.
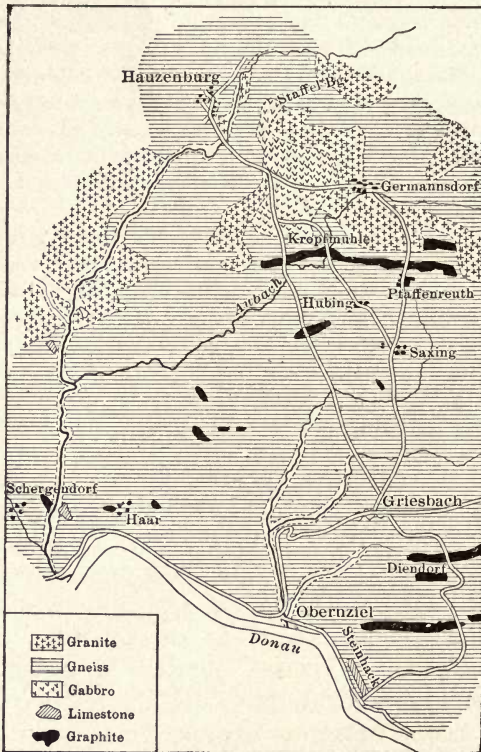


Fɪɢ. 115. — Geologic map of Passau, Bavaria, graphite district. (*After Gümbel-De Launay, from Stutzer, Die Nicht-Erze.*)

The graphite forms lenses conformable with the gneiss and schist, with often a foot wall of limestone and syenite, and a hanging wall of granite. Both the country gneiss and graphite are strongly decomposed. Weinschenk advanced the theory that the graphite was deposited by exhalations from the granite, and that the kaolinization was due to the same cause. The first is disputed by some, who consider the carbon to be original in the rock, while the latter is very unlikely, the kaolin being an ordinary product of weathering.

Austria is the largest producer in Europe, the deposits of southern Bohemia being similar to those of Bavaria. The Styrian ones form thin beds

in schist, and those of Mähren occur in crystalline limestone which is interbedded with schists, gneisses and quartzites. The Madagascar [1] deposits of crystalline graphite, and Korea [2] deposits of amorphous graphite are also important.

**Uses.** — On account of its refractoriness and high heat conductivity, graphite is employed in the manufacture of crucibles for use in the steel, brass, and bronze industries. For making these it is mixed with clay and some sand. Ceylon graphite is specially suitable for this class of work, because of its peculiar fibrous structure, but small amounts of American and Madagascar graphite are also used. Amorphous graphite has not given success in crucible work. In addition graphite is employed for making stove polish, foundry facings, paint, lead pencils, lubricating powder, glazing, electrotyping, steam piping, for adulterating fertilizers, coloring and glazing coffee beans or tea leaves, etc.

The use of graphite for paint has increased greatly in the last few years, the material employed being chiefly of the amorphous variety and rather impure. Another recent and increasing use of amorphous graphite and of fine flake graphite is for boiler compound.

Both amorphous and crystalline graphite can be used for lubricating purposes. The use of graphite for pencil manufacture, though an early one, and perhaps the best known, consumes but a small percentage (under 10 probably) of the world's supply. For this purpose amorphous graphite is demanded, and while Bohemian and Bavarian graphite were originally used, Sonora, Mexico, now supplies American manufacturers with all they need.

Graphite is also made artificially from anthracite coal, but its introduction has not seriously affected the market for the natural product.

Crystalline graphite is put through a concentrating process before shipment to market. This is necessary in order to free it from the associated minerals. Both wet and dry methods of separation are employed, while more recently air separation has been tried with some success.

**Graphite Industry.** — In spite of the importance of graphite, the United States does not produce more than about one-seventh

[1] U. S. Geol. Surv., Min. Res., 1913: 23, 1914.
[2] *Ibid.*, p. 238.

of the total quantity consumed in this country. This unsatisfactory condition of the domestic industry is due to: (1) The superiority of the Ceylon product; (2) the low cost of production of the Ceylon product; and (3) the fact that both United States and Canadian graphites are disseminated and hence require separation from the associated minerals. Considerable Madagascar graphite, which is of the flake variety, is imported into the United States. It is cleaned after being received here. Korean amorphous graphite is also imported.

**Production of Graphite.** — The domestic production of crystalline graphite does not form more than a small proportion of the entire consumption.

In 1914 the total production of crystalline graphite came from Alabama, New York, Pennsylvania, and Montana. The Alabama production amounted to 2,410,200 pounds, valued at $118,000, which was less than half of the total production of 5,220,539 pounds, valued at $285,368. Alabama showed a slight increase over the production of the previous years.

PRODUCTION OF NATURAL GRAPHITE IN THE UNITED STATES, 1910–1914

| YEAR | AMORPHOUS | | CRYSTALLINE | | TOTAL | |
|---|---|---|---|---|---|---|
| | SHORT TONS | VALUE | POUNDS | VALUE | SHORT TONS | VALUE |
| 1910 . . | 1,407 | $39,710 | 5,590,592 | $295,733 | 4,202 | $335,443 |
| 1911 . . | 1,223 | 32,415 | 4,790,000 | 256,050 | 3,618 | 288,465 |
| 1912 . . | 2,063 | 32,894 | 3,543,771 | 187,689 | 3,835 | 220,583 |
| 1913 . . | 2,243 | 39,428 | 5,064,727 | 254,328 | 4,775 | 293,756 |
| 1914 . . | 1,725 | 38,750 | 5,220,539 | 285,368 | 4,336 | 324,118 |

IMPORTS OF GRAPHITE AND PRODUCTION OF ARTIFICIAL GRAPHITE IN THE UNITED STATES, 1910–1914

| YEAR | IMPORTS OF NATURAL GRAPHITE | | PRODUCTION OF ARTIFICIAL GRAPHITE | | |
|---|---|---|---|---|---|
| | SHORT TONS | VALUE | POUNDS | VALUE | PRICE PER POUND (CTS.) |
| 1910 . . . . | 25,235 | $1,872,592 | 13,149,100 | $945,000 | 7.20 |
| 1911 . . . . | 20,702 | 1,495,729 | 10,144,000 | 664,000 | 6.55 |
| 1912 . . . . | 25,643 | 1,709,337 | 12,896,347 | 830,193 | 6.44 |
| 1913 . . . . | 28,879 | 2,109,791 | 13,633,342 | 973,397 | 7.14 |
| 1914 . . . . | 22,002 | 1,398,261 | 10,455,139 | 698,800 | 6.68 |

WORLD'S PRODUCTION OF NATURAL GRAPHITE IN 1912

| COUNTRY | SHORT TONS | VALUE | COUNTRY | SHORT TONS | VALUE |
|---|---|---|---|---|---|
| United States . | 2,694 | $211,883 | Italy . . . . | 14,517 | $   77,236 |
| Canada . . . | 2,059 | 117,117 | Japan. . . . | 163 | 10,935 |
| Mexico . . . | 3,158 | 96,668 | Chosen (Korea) | — | 82,108 |
| Germany . . | 13,814 | 81,514 | India (1911 prod.) | 4,533 | 45,867 |
| Austria . . . | 50,017 | 378,867 | Ceylon . . . | ¹36,660 | ¹2,707,973 |
| Norway . . . | 285 | 1,898 | Madagascar . | 3,011 | 239,291 |
| Sweden . . . | 87 | 2,535 | South Africa . | 42 | 5,621 |
| France . . . | 661 | 1,635 | | | |

¹ Export figures.

PRODUCTION OF GRAPHITE IN CANADA, 1912–1914, IN SHORT TONS

| YEAR | QUANTITY | VALUE |
|---|---|---|
| 1912 | 2060 | $117,122 |
| 1913 | 2162 | 90,282 |
| 1914 | 1647 | 107,203 |

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## LITHIUM

The two minerals most commonly used as a source of lithium are *Lepidolite* (KLi[Al(OH,F$_2$)]Al(SiO$_3$)$_3$)) and *Spodumene* (LiO$_2$, Al$_2$O$_3$, 4 SiO$_2$). The largest deposits of lepidolite at present known in the United States are found near Pala, California. Spodumene occurs in some quantities in the Black Hills of South Dakota and in Connecticut and Massachusetts, but none of these occurrences have yet been worked to supply lithium.

In the last few years there has been a great demand for lithium minerals for use in the manufacture of lithium carbonate. Since most of this substance now in use is made in Germany, nearly all the American mineral has been shipped to that country. The American supply of carbonate is imported from Germany, selling in New York for $4.20 a pound. The chief use of lithium salts is in the preparation of mineral waters.

The production of lithium minerals in the United States is very irregular and small.

## LITHOGRAPHIC STONE

**Properties.** — Lithographic stone (1, 3) is a very fine-grained, homogeneous limestone, used for lithographic purposes. It may be either pure lime carbonate or magnesian limestone, but so far as known this difference in composition exerts no important influence on its physical character. The two following analyses will serve to indicate this difference in composition, No. 1 being the standard Bavarian stone and No. 2 the Brandenburg, Kentucky, rock: —

| | INSOLUBLE IN HCl | | | | | SOLUBLE IN HCl | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | SiO$_2$ | (AlFe)$_2$O$_3$ | CaO | Al$_2$O$_3$ | FeO | MgO | CaO | Na$_2$O K$_2$O | Moist. | H$_2$O | CO$_2$ |
| **1.** | 1.15 | .22 | Trace | .23 | .26 | .56 | 53.80 | .07 | .23 | .69 | 42.69 |
| **2.** | 3.15 | .45 | .09 | .13 | .31 | 6.75 | 44.76 | .13 | .41 | .47 | 43.06 |

The physical character of the stone is of prime importance, for in order to yield the best results it should be fine-grained, homogeneous, free from veins or cracks, of just sufficient porosity to absorb the grease holding the ink, and soft enough to permit its being carved with the engraver's tool. Owing to these strict requirements but few localities have produced good stone.

*Sources of Supply.* — Lithographic stone is not confined to any one geologic formation, and deposits have been reported from many states both east and west. Some of these appear to be of inferior quality, while others are too far from railroads. The most promising developed deposit is that found at Brandenburg, Kentucky (2, 6), at which locality a bed of blue-gray stone three feet thick is quarried and used by some establishments in the south and southwest. Another bed of good quality has also been described from Iowa (1).

The main source of the world's supply is obtained from the Jurassic limestone of the Solenhofen district in Bavaria (4), in which the quarries have been worked for a number of years, but the supply is said to be becoming unsatisfactory and unreliable. The stones are trimmed at the quarries, and sizes of 22 or 28 by 40 inches are in the greatest demand. From these they range up to sizes 40 by 60 inches. The best quality stones sell for 22 cents per pound.

The domestic demand is not large, and it is probable that one or two well-developed and well-managed native quarries could no doubt satisfy it.

The successful substitution of zinc or aluminum plates for certain classes of lithographic work is said to have had a noticeable influence on the demand for lithographic stone. Onyx has also, in some cases, been found to make a good substitute.

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## MAGNESITE

**Properties and Occurrence.** — This mineral, which is a carbonate of magnesium with 47.6 per cent magnesia (MgO), has a hardness of 3.5 to 4.5 and a specific gravity of 3 to 3.12.

It commonly occurs in veins or in masses replacing other rocks rich in magnesia, such as serpentines, talcose schists, dolomites, etc. Its color is white or yellowish, and when massive it sometimes resembles unglazed porcelain, and is quite brittle, but when crystalline it resembles coarse-grained metamorphosed limestone.

Magnesite occurrences may be grouped into two classes, viz.: the dolomite and the serpentine type.

**Dolomite Type** (4). — The only important occurrence of this type is in a belt in Austro-Hungary, the most important district being near Veitsch in Styria. The material, which is coarsely crystalline, occurs as replacements of Carboniferous dolomite, and may not only contain an admixture of siderite, or even scattered metallic sulphides, but also veinlets of dolomite and sometimes talc. These deposits form the main source of the world's supply.

An impure magnesite containing considerable dolomite is known in Quebec, and a deposit of hydromagnesite at Atlin, B. C.

**Serpentine Type** (1, 3, 4). — This type forms veins (Pl. XXXV, Fig. 2), or lenses in serpentine, and has been derived from the latter, or possibly even from the minerals that altered to serpentine, probably by the action of surface waters. The following equations will illustrate this change:

$$H_4Mg_3Si_2O_9 + 3CO_2 = 3MgCO_3 + 2SiO_2 + 2H_2O$$

or

$$3Mg_3FeSi_2O_8 + 3CO_2 + 4H_2O + O$$
$$= 2H_4Mg_3Si_2O_9 + Fe_3O_4 + 3MgCO_3 + 2SiO_2.$$
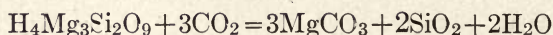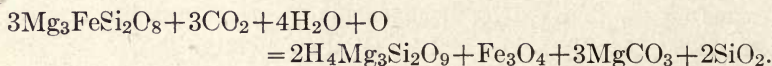
The silica formed above may be deposited with the magnesite, or in separate veins as opal or chalcedony.

Other impurities in the magnesite may be iron, alumina and lime.

In texture the serpentine magnesite is fine grained, dense or massive, and when pure, white in color.

Although this type is of almost world-wide distribution, the most important deposits are on the Island of Eubœa, Greece, where some of the lenses are 50 feet thick and 75 to 100 feet long (4).

Small ones are known in Pennsylvania and Maryland, but are not worked, as they cannot compete with the imported magnesite.

**California** (1). — Deposits of magnesite (Fig. 116) are scattered along the Coast Range from Mendocino County at least to a point south of Los Angeles, and along the western slope of the Sierra Nevada from Placer County to Kern County. The greatest production comes from near Porterville in Tulare County (Fig. 116).

Plate XXXV
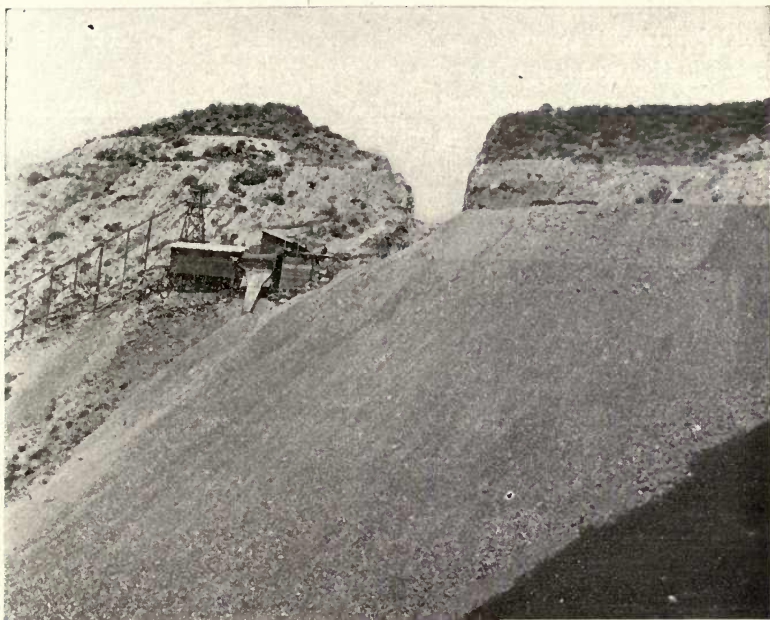


Fig. 1. — Magnesite mine near Winchester, Calif.   (*H. Ries, photo.*)
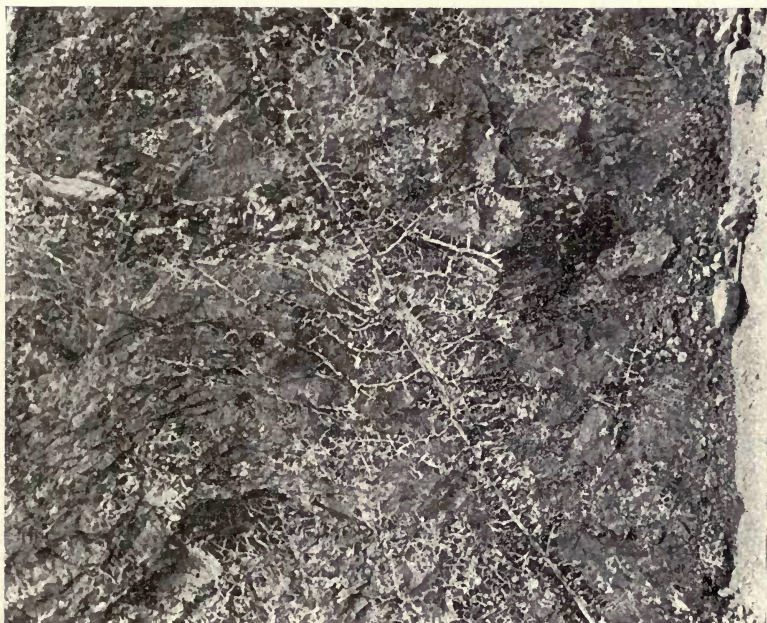


Fig. 2. — Network of magnesite veins in Serpentine, same mine.  (*H. Ries, photo.*)

(357)

The deposits all occur as veins in serpentine, the larger number being in the Coast Range.



FIG. 116. — Map of part of California showing distribution of magnesite deposits. (*After Yale and Gale, U. S. Geol. Surv., Min. Res.* 1913.)

The much-fractured and faulted serpentines of the Coast Ranges, which are probably of Lower Cretaceous age, appear to have been derived from olivine-pyroxene rocks, and the magnesite may have been formed from both the serpentine-making

minerals and the serpentine itself. In some cases the magnesite forms a network of veins in the serpentine, but since its origin is due to the action of surface waters, the deposits may be of
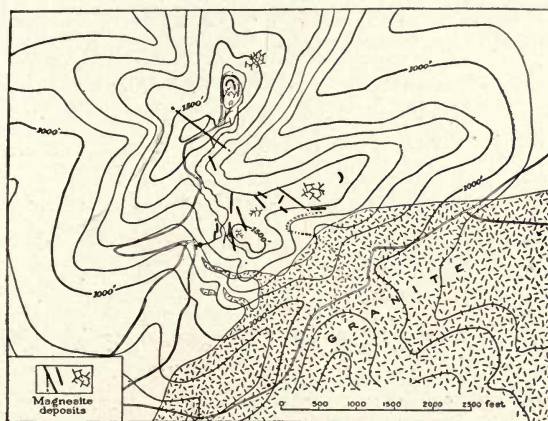


FIG. 117. — Plan of magnesite veins and workings 4 miles northeast of Porterville, Calif. (*After Hess, U. S. Geol. Surv., Bull.* 355.)

limited depth. As the magnesite weathers less readily than the serpentine, the vein outcrops often stand out in bold relief.

The following analyses show the composition of the magnesite from several localities: —

ANALYSES OF MAGNESITE

|  | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $SiO_2$ . . . . . . . | 7.67 | .73 | 2.28 | 1.67 | 2.24 |
| $Al_2O_3$ . . . . . . . | .26 | .14 | .03 | 3.47 ⎱ | 2.05 |
| $Fe_2O_3$ . . . . . . . | .29 | .21 | .26 | 4.68 ⎰ | |
| CaO . . . . . . . | .04 | .40 | 1.32 | 2.94 | 2.48 |
| MgO . . . . . . . | 43.42 | 46.61 | 45.17 | 86.90 | 93.63 |
| $CO_2$ . . . . . . . | 48.08 | 51.52 | 50.74 | | |
|  | 99.76 | 99.61 | 99.80 | 99.66 | 100.40 |

1. Siliceous Magnesite, 8 m. north of Cazadero, Sonoma County. 2. Alameda claim, Santa Clara County. 3. Four miles northeast of Porterville, Tulare County. Too high in lime for good cement. Used in wood-pulp whitening. 4. Calcined magnesite, Nyustya, Hungary. 5. Calcined magnesite, Greece. 1–5 from Ref. 1.

**Uses.** — Crude magnesite is used chiefly for making carbon dioxide, but its application for this purpose is decreasing.

Caustic magnesite is that which has not been thoroughly calcined and contains 3 to 4 per cent carbon dioxide. This is used for making *oxychloride cement* (a mixture of magnesia and magnesium chloride), and probably over 90 per cent of the serpentine magnesite is employed for this purpose. The caustic magnesite deteriorates on exposure, and after 4 or 5 months may have taken up two or three times as much carbon dioxide as was left in it.

Dead-burned magnesite has less than 1 per cent carbon dioxide, and does not take up any from the air. The dolomite variety is used almost exclusively for this purpose and goes into the manufacture of refractory bricks.

Magnesite is used as a toilet preparation, or in medicine, and as a boiler covering when mixed with asbestos.

California magnesite has been used in the paper-manufacturing industry, after conversion into bisulphite. Epsom salt, while derived chiefly from the Stassfurt salt deposits, is also manufactured from magnesite.

The metal magnesium is not made from magnesite, but from magnesium chloride obtained from the Stassfurt, Germany, and other brines.

The domestic production is obtained entirely from California and has been as follows:—

PRODUCTION OF MAGNESITE IN UNITED STATES, 1912–1914

| YEAR | QUANTITY | VALUE |
|---|---|---|
| | Short tons | |
| 1912 . . . . . . . . . . . . | 10,512 | $84,096 |
| 1913 . . . . . . . . . . . . | 9,632 | 77,056 |
| 1914 . . . . . . . . . . . . | | |

PRODUCTION OF MAGNESITE IN CANADA, 1912–1914

| YEAR | SHORT TONS | VALUE |
|---|---|---|
| 1912 . . . . . . . . . . . . | 1714 | $9645 |
| 1913 . . . . . . . . . . . . | 515 | 3335 |
| 1914 . . . . . . . . . . . . | 358 | 2240 |

Plate XXXVI



Fig. 1. — View in glass sand pit, on Severn River, Md. — The tunnel shows position of bed of glass sand. The overlying beds carry too much iron oxide. (*H. Ries, photo.*)
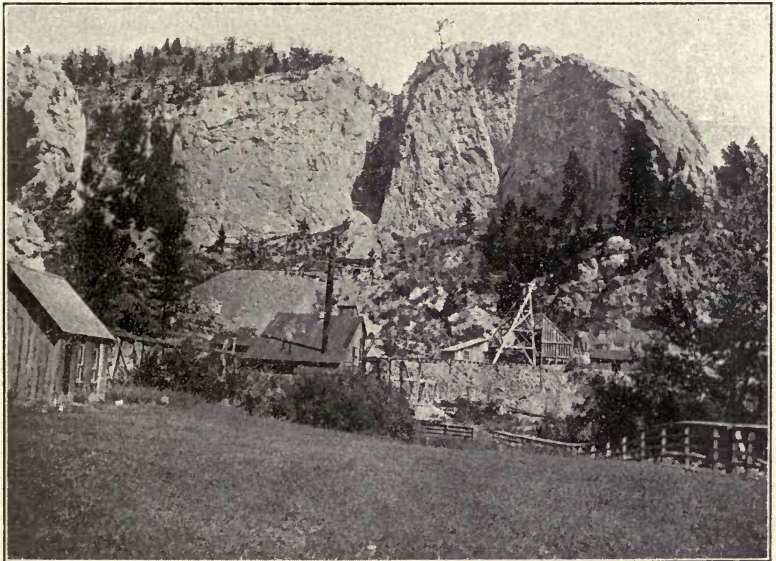


Fig. 2. — View showing sapphire workings, Yogo Gulch, Mont. (*Photo by J. P. Rowe.*) The cut indicates position of sapphire-bearing dike.

(361)

IMPORTS, FOR CONSUMPTION, OF MAGNESITE INTO THE UNITED STATES FOR CALENDAR YEARS 1912–1914, IN POUNDS

| | 1912 | | 1913 | | 1914 | |
|---|---|---|---|---|---|---|
| | QUANTITY | VALUE | QUANTITY | VALUE | QUANTITY | VALUE |
| Magnesia: | | | | | | |
| Calcined, medicinal . . . | 104,106 | $ 16,326 | 54,915 | $ 10,034 | 159,547 | $ 19,342 |
| Carbonate of, medicinal . | 62,404 | 2,812 | 70,823 | 4,880 | 46,183 | 2,527 |
| Sulphate of (Epsom salts) | 10,703,209 | 41,739 | 8,121,677 | 32,884 | 13,826,899 | 53,768 |
| Magnesite: | | | | | | |
| Calcined, not purified . . | 250,503,372 | 1,265,339 | 334,187,404 | 1,672,565 | 243,633,205 | 1,323,194 |
| Crude . . . | 35,810,752 | 104,326 | 26,479,109 | 84,911 | 26,708,381 | 54,677 |

IMPORTS OF MAGNESITE CALCINED, NOT PURIFIED, FOR FISCAL YEARS ENDING JUNE 30, 1912–1914, BY COUNTRIES, IN SHORT TONS

| COUNTRY | 1912 | 1913 | 1914 |
|---|---|---|---|
| Europe: | | | |
| Austria-Hungary . . . . . . . . . . . | 99,104 | 163,715 | 134,260 |
| Belgium . . . . . . . . . . . . . | 25 | —— | 11 |
| Germany . . . . . . . . . . . . . | 689 | 2,412 | 2,578 |
| Greece . . . . . . . . . . . . . | 114 | 1,605 | 3,232 |
| Denmark . . . . . . . . . . . . | —— | —— | 58 |
| Italy . . . . . . . . . . . . . | —— | —— | —— |
| Netherlands . . . . . . . . . . . | 2,410 | 4,508 | 4,191 |
| Norway . . . . . . . . . . . . | 163 | —— | —— |
| United Kingdom: | | | |
| England . . . . . . . . . . . | 61 | 1 | 12 |
| Scotland . . . . . . . . . . | —— | —— | 1 |
| North America: | | | |
| Canada . . . . . . . . . . . . | 234 | 350 | 404 |
| Mexico . . . . . . . . . . . | 81 | —— | —— |
| Asia: East Indies, British . . . . . . . . | 57 | —— | —— |
| Total . . . . . . . . . . . . | 102,938 | 172,591 | 144,747 |

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## MEERSCHAUM

*Meerschaum* or *Sepiolite*, which is well known on account of its use for making pipes and other smoker's articles, has for many years been obtained mainly from Asia Minor, although other occurrences are known. Deposits of promising character have

been located in Grant County, New Mexico, and although not yet commercially developed, deserve mention.

Sepiolite has a probable composition of $H_4Mg_2Si_3O_{10}$, and when pure is a white, porous mineral, with a specific gravity of about 2. It absorbs water readily, becoming somewhat plastic, but hardens again on drying. It has a hardness of 2 to 2.5, great toughness, and earthy or conchoidal fracture, the toughness being most pronounced in those forms having a leathery or fibrous texture. Its peculiar physical properties make it of great value for carving into pipes.

In New Mexico two localities are known, both of which lie in the upper Gila River valley, at points located respectively 23 miles east of north, and 12 miles northwest of Silver City.

At the Dorsey mine, northwest of Silver City, the meerschaum occurs as veins, lenses, seams, and balls in a limestone of probable Ordovician age. The veins are filled with chert, quartz, calcite, clay, and meerschaum, and the chert which is the most important gangue mineral, occurs in the veins with meerschaum in bands, lenses, and nodules.

The meerschaum itself occurs either as irregular nodules, or in massive form. Both kinds are tough, but the latter is finer grained, less leathery, and heavier.

The three following analyses represent, (1) the Dorsey mine product; (2) the theoretic composition of meerschaum; and (3) a material from another deposit, which resembles the true meerschaum, but differs from it in its high alumina content.

ANALYSES OF MEERSCHAUM

|  | 1 | 2 | 3 |
|---|---|---|---|
| $SiO_2$ . . . . . . . . . . . . | 57.10 | 60.8 | 60.97 |
| $Al_2O_3$ . . . . . . . . . . . | .58 | —— | |
| $Fe_2O_3$ . . . . . . . . . . . | tr. | —— | 9.71 |
| MgO . . . . . . . . . . . . | 27.16 | 27.1 | 10.00 |
| CaO . . . . . . . . . . . . | .17 | —— | .22 |
| $CO_2$ . . . . . . . . . . . . | .32 | —— | —— |
| $H_2O$ . . . . . . . . . . . . | 14.78 | 12.1 | 19.14 |
| Total . . . . . . . . . . | 100.11 | 100.0 | 100.04 |

The deposit cannot as yet be regarded as a commercial proposition, but may become so.

REFERENCES ON MEERSCHAUM

1. Collins, Min. Wld., XXVI: 688, 1907. (N. Mex.)  2. Sterrett, U. S.
   Geol Surv., Bull. 340: 1908. (General and N. Mex.)  3. Dammer
   and Tietze, Nutzbaren Mineralien, II: 354, 1914.

## MICA

**Properties and Occurrence.** — There are few minerals more widely distributed in crystalline rocks than mica, and yet deposits of economic value are rare because the mica flakes are either too small, or too intimately mixed with other minerals for profitable extraction. Only two of the several known varieties of mica, muscovite ($H_2KAl_3Si_3O_{12}$) and phlogopite ($H_6K_6Mg_7Al_2(SiO_4)_7$), are of economic value, the former only being found in deposits of commercial value, in the United States. Both phlogopite and muscovite are found in Canada, but only the former is of much commercial importance. The India mica, which is shipped to the United States is muscovite.

The commercial deposits of muscovite are found in pegmatites, cutting granites, gneisses, and schists. In these the mica is associated with quartz and feldspar (usually orthoclase or microcline, more rarely plagioclase), being found in rough crystals called blocks or *books*, and which are either irregularly distributed through the vein or collected near its sides.

In addition to the quartz and feldspar, other minerals such as tourmaline, beryl, zircon, columbite, samarskite, uranium minerals, garnet, etc., are sometimes present. The pegmatite, which carries the mica, and may be of igneous or gas-aqueous origin, occurs as lenses, veins, irregular masses, etc., of varying thickness and length. The value of the deposit depends more on the abundance and quality of the mica than the size of pegmatite body.

The best mica is obtained from the more coarsely crystalline rocks; but the widest veins do not necessarily contain the largest blocks. As a rule the mica does not form more than 10 per cent of the vein, and usually not more than 10 or 15 per cent of that mined can be cut into plates, the rest being classed as scrap mica.

There has been some discussion as to whether the pegmatites are true igneous dikes or veins, but the matter cannot be said to be definitely settled in all cases. It is probably that each type of origin is represented.

The phlogopite mica of Canada is found in veins or dikes of pyroxene cutting gneiss or limestone. Its chief associate is apatite, occurring in a granular form or large rough crystals. Other minerals present in smaller amounts are calcite, scapolite, tourmaline, titanite, and even sulphides. The deposits are genetically similar to the apatite scapolite veins of Norway. In these the phlogopite occurs in the same irregular manner as the muscovite in pegmatites.

The value of a mica deposit depends on the abundance and size of the books, perfection of cleavage, color and clearness. Large sheets of mica are the exception rather than the rule.

Mica may show several internal structures which affect its market value. These are:

(1) " A " structures, which are striations or slight ridges appearing on cleavage faces, and following definite crystallographic lines, meeting to form a " V." (2) Herring-bone structure, similar to the preceding, but with a third set of striations bisecting the obtuse angle of the " A." (3) Ruled mica, resulting from the development of partings, and forming a series of straight, sharp, parallel cracks which cut through the book, at an acute angle to the cleavage face.

Large mica crystals may include smaller ones, or also grains or crystals of other minerals. Mica containing minute inclusions is known as *specked mica*. These inclusions may be dendritic in character.

**Distribution in the United States.** — Deposits of mica have been worked in a number of states both east and west, and yet but few are steady producers. The more important ones may be described.

*North Carolina* (4, 9).—The mica mined in this state, which is the leading producer, comes from three belts (Fig. 118); viz., the Cowee-Black Mountain, the Blue Ridge, and the Piedmont belts. That from the first is chiefly clear and of light color (" wine " or "rum "); that from the second is dark smoky brown and often more or less speckled, while that from the third is often of good quality and similar to the Cowee-Black Mountain product. Owing to a frequent capping of residual soil, discovery of the deposits is difficult.

The mica-bearing pegmatites occur in mica, garnet, cyanite, hornblende, and granite gneisses and schists, all of Archæan age, the important formations being the Carolina and Roan gneisses.

The rocks of these two are interbanded with, and cut by, streaks of granitic or pegmatitic material, the latter forming lenticular bodies
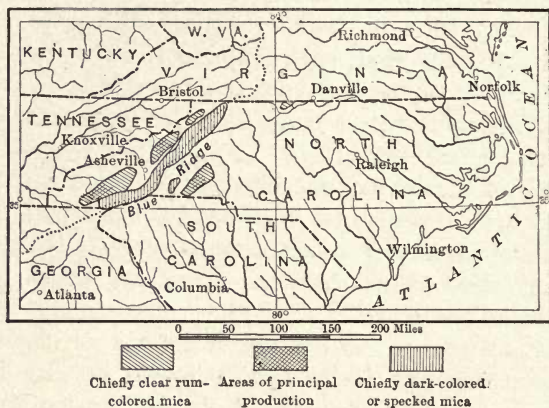


FIG. 118.—Map showing areas in North Carolina in which mica has been mined.
(*After Sterrett, U. S. Geol. Surv., Bull.* 315.)

or vein-like deposits, which may, or may not be conformable with the schistosity of the country rock.
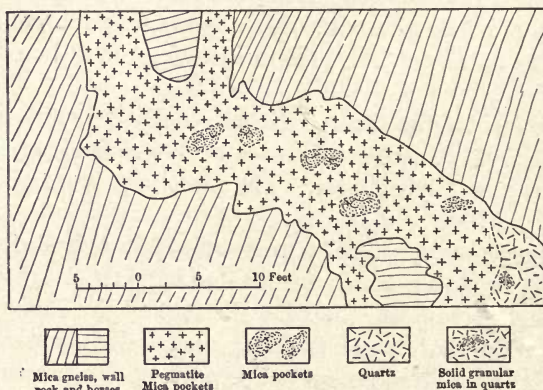


FIG. 119.—Section across pegmatite at Thorn Mountain mine, Macon Co., N. Ca.
(*After Sterrett, U. S. Geol. Surv., Bull.* 315.)

While they vary in size, 1 to 2 feet seems to be the minimum workable limit for rich and regular " veins." The muscovite, which is the main mica present (biotite being the other), shows a variable mode of occurrence. At one time it is evenly distributed

through the pegmatite, at another large crystals are found in clusters scattered through the vein (Fig. 119).

The better grades of North Carolina mica are used for the glazing industry, while the less perfect sheet material is employed for electrical work. The pegmatite veins also carry a number of rare minerals.

*South Dakota* (8).—Mica is mined in the region around Custer, South Dakota. The muscovite, as is usual, occurs in pegmatite, cutting schists and gneisses, and granite. The material is of evenly granular texture, or shows an irregular segregation of the minerals, with but little banding. This latter is sometimes
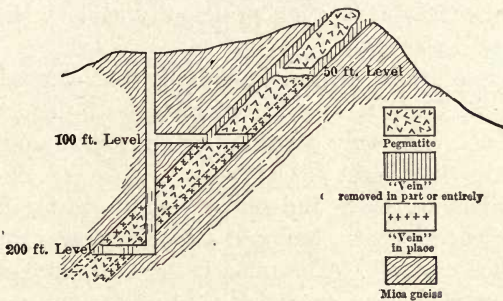


Fig. 120. — Generalized cross section of No. 1 or New York Mine, near Custer South Dakota. (*After Sterrett, U. S. Geol. Surv., Bull.* 380.)

roughly produced by a segregation of the mica along the walls of the deposit. Very few of the pegmatites around Custer, however, carry enough mica to pay for working them.

In the New York mine (Fig. 120), for example, the rough mica obtained along the walls amounts to 6 or 7 per cent, while the interior portion of the pegmatite carries about 0.5 per cent, and is not worked. The shape of the pegmatite bodies around Custer is variable, but in general they resemble the dike type, and appear to represent an end phase of the granite intrusions of that region, for they not only cut the granite itself, but in places grade into it. Their age is not definitely known.

*Other States.* — Mica in pegmatite has been worked at Mica Hill, 4 miles northwest of Cañon City, Colorado, and 6 miles north of Texas Creek. That obtained at the former locality is peculiarly adapted to grinding purposes (10). The Virginia (12) occurrences, especially those in Amelia and Henry counties, are of some importance. That found near Amelia Court House and at Ridgway, Henry County, occurs in pegmatite dikes, which inter-

sect the biotite gneiss of the district. The largest dikes are more than 50 feet wide, and the mica occurs in them as thick, highly cleavable blocks, and masses of varying size. Deposits are also known to occur in northwest Georgia (4), and while they resemble the North Carolina deposits, they have not been worked much.

**Distribution in Canada** (2). — Muscovite deposits are found quite widely distributed over the Dominion, where the pre-Cambrian crystalline rocks are exposed. They have been worked at a number of localities, but are of little commercial importance at the present time.

Phlogopite deposits are confined to two areas, viz.: (1) The Quebec area lying between the Gatineau and Lièvre rivers; and (2) the Ontario area lying principally east of the Kingston and Pembroke Railway.

The most important mine in Canada, is that worked at Sydenham, Ont. (Pl. XXXII, Fig. 2), which has attained a depth of nearly 200 feet. The only other important active one is in Templeton township northeast of Ottawa.

In the Sydenham mine the mica " lead " varies from a few inches to 25 feet in width, being at times almost a solid mass of enormous mica crystals. The mica is mottled, wine-amber, and occurs in a greenish-gray pyroxenite. Bunches of massive apatite are occasionally met, and these are mixed with white calcite.

Other Foreign Deposits. — The leading world's producer is Bengal, where muscovite mica has been obtained for many years. It is found associated with quartz, feldspar, and kaolin, in pegmatite veins cutting gneisses and schists. Much muscovite has also been obtained from the pegmatite veins of German East Africa (3).

**Mining and Uses** (2). — The irregularity of its occurrence makes mica mining somewhat uncertain. This often leads to the type of mining known as ground hogging or gophering. The rough crystals obtained from the mine range in size from small crystals to blocks several feet across. These rough crystals are cobbed and cleaned, and then split into plates about one sixteenth inch thick. The plates then have the rough edges cut off, and after grading as to size and quality are ready for further splitting and trimming. Mica can be split into sheets one five-hundredth of an inch or even less in thickness.

The chief use of sheet mica is for electrical purposes, it being employed as an insulating material in dynamos, motors, high-voltage induction apparatus, switchboards, lamp sockets, etc.

The domestic product is found to be uniformly satisfactory for electrical work, except for insulation between the copper bars of commutator segments. This use seems to be best served by the amber or phlogopite mica of Canada and that of Ceylon. The superiority of this variety is due to its easier wearing qualities, which cause it to wear down even with the copper segments. *Micanite* or mica board is sheet mica obtained by cementing small clear pieces of scrap mica together under pressure. Since it can be bent, rolled, and punched, it is utilized mostly for the same purposes as sheet mica. The use of mica for stove doors and chimneys is decreasing, although the glazing industry still demands a considerable amount of the finest grades of sheet mica. Scrap mica is ground for use in the manufacture of wall papers, lubricants, fancy paints, and *micanite*. That used for electrical work must be free from metallic minerals, and that for wall paper and paints must have sufficient luster.

Ground mica is also used in rubber goods as an adulterant, while mixed with shellac or plaster it is employed in the form of *moulded mica* for insulation of trolley wire. Tar and other roofing papers may be coated with coarse flakes of *bran* mica to prevent sticking when rolled for shipment. *Micarta* is a mica product used as a substitute for hard fiber, glass, porcelain, hard rubber, etc., for use in commutators and other parts of electrical apparatus.

**Production of Mica.** — The quantity and value of mica produced in the United States from 1910 to 1914 by kinds is given below. The complete production by states is not given by the United States Geological Survey.

PRODUCTION OF MICA IN THE UNITED STATES FROM 1910 TO 1914

|  | SHEET MICA | | SCRAP MICA | | TOTAL VALUE |
|  | Quantity | Value | Quantity | Value |  |
| --- | --- | --- | --- | --- | --- |
|  | Pounds | | Short Tons | | |
| 1910 . . . . | 2,476,190 | $283,832 | 4065 | $53,265 | $337,097 |
| 1911 . . . . | 1,887,201 | 310,254 | 3512 | 45,550 | 355,804 |
| 1912 . . . . | 845,483 | 282,823 | 3226 | 49,073 | 331,896 |
| 1913 . . . . | 1,700,677 | 353,517 | 5322 | 82,543 | 436,060 |
| 1914 . . . . | 556,933 | 277,330 | 3730 | 51,416 | 328,746 |

The value of the mica produced in Canada was: 1912, $143,-976; 1913, $194,304; 1914, $102,315.

The average price of sheet mica in the United States in 1914 was 50 cents per pound, as compared with 20.8 cents in 1913 and 33.4

cents in 1912. The average prices for the individual states vary greatly from year to year, due in part to variation between proportion of rough and trimmed mica, and size of sheets produced. The prices per pound of several sizes of 1st and 2d grade North Carolina mica in 1913 were as follows:

2×2 in., \$0.30; 2×3 in., \$.70; 3×3 in., \$1.15; 3×4 in., \$1.35; 4×6 in., \$2.25; 6×8 in., \$4.00; 8×10 in., \$6.00.

The imports of mica are given for the last five years, since to state those of one year would not clearly show the fluctuations.

MICA IMPORTED AND ENTERED FOR CONSUMPTION IN THE UNITED STATES, 1910–1914, IN POUNDS

| YEAR | UNMANUFACTURED | | CUT OR TRIMMED | | TOTAL | |
|---|---|---|---|---|---|---|
| | Quantity | Value | Quantity | Value | Quantity | Value |
| 1910 . . . . | 1,424,618 | \$460,694 | 536,905 | \$263,831 | 1,961,523 | \$724,525 |
| 1911 . . . . | 1,087,644 | 346,477 | 241,124 | 155,686 | 1,328,768 | 502,163 |
| 1912 . . . . | 1,900,500 | 649,236 | 88,632 | 99,737 | 1,989,132 | 748,973 |
| 1913 . . . . | 2,047,571 | 751,092 | [1] | 191,926 | [1] | 943,018 |
| 1914 . . . . | 360,888 | 168,591 | [1] | 456,805 | [1] | 625,396 |

[1] Quantity not reported.

The exports of mica from Canada in 1914 amounted to 669,163 pounds valued at \$178,940.

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## MINERAL PAINTS

Under this head are included a number of mineral substances which are used in the manufacture of paints. Some of these can be

used directly after cleaning and grinding, while others are roasted to give the desired color.

The substances used and considered in this chapter include ocher, umber, sienna, hematite, siderite, ground slate, and shale. Other substances used in the paint trade, but mentioned elsewhere, are asbestos (p. 298), asphalt (p. 117), barite (p. 309), clay (p. 170), graphite (p. 344), gypsum (p. 244), magnesite (p. 355), pyrite (p. 400), silica (p. 390), talc (p. 407), and whiting.

**Hematite.** — Certain kinds of hematite, such as the Clinton ore (see Iron Ores), are ground and sold under the name of metallic paints, and much used for coating wooden surfaces and coloring mortar. The ores are sometimes roasted before grinding to improve their color and durability. Although hematite deposits are widespread, and sometimes of large size, the quantity of material showing the necessary uniformity of color, freedom from grit, etc., required for mineral paint is small. Much crude material is supplied by the Clinton ore mines at Clinton and Ontario, New York (8).

At some localities in northwest Georgia and southeast Tennessee the Clinton oölitic hematite occurs in beds too thin to be now mined for iron ore, but its softness, high percentage of iron oxide and color make it available for red paint (3).

The following analyses show the composition of this material.

|  | I | II | III |
|---|---|---|---|
| $Fe_2O_3$ . . . . . . . . . . . . | 72.86 | 83.14 | 80.00 |
| $SiO_2$ . . . . . . . . . . . . | 21.00 | 11.90 | 16.45 |
| P . . . . . . . . . . . . . | .40 |  | .28 |
| Mn . . . . . . . . . . . . | .30 |  |  |

I. Estelle, Ga.   II. Ooltewah, Tenn.   III. Hinch's Switch, Tenn.

**Ochers.** — The term ocher, as commonly used, includes the earthy and pulverulent forms of the minerals hematite and limonite. More or less clayey matter is usually present.

**Properties and Occurrence.** — The ochers show a variety of colors, depending mainly on the chemical composition. Thus hematites give a deep red color, while limonites have some shades of yellow or brown, but whatever the color, uniformity of tint is necessary. Ochers may contain as much as 50 to 75 per cent iron oxide (10). Brown ocher or umber is colored by manganese, and sienna is a yellowish-brown variety.

s

Ochers may result from (5, 10): the leaching action of percolating waters and subsequent deposition; as residual products, formed by the removal or solution of the soluble parts of the original rock, leaving the insoluble portions, clay and iron oxide, to form the different ocherous colored clays; from the decomposition of rocks rich in iron-bearing silicates; by oxidation of beds of pyrite; by alteration or decomposition of hematite beds; by alteration of more compact forms of limonite; by replacement; by sedimentation.

**Distribution of Ocher.** — Georgia and Pennsylvania are the largest producers of ocher, but California, Vermont, and other states help to swell the total.

*Georgia* (5, 6, 10). — In this state the ocher deposits occur in a north-south belt, 8 miles long, lying east and southeast of Cartersville. The ocher is limited to the Weisner (Cambrian) quartzite, in which it occupies an extensively shattered zone of similar posi-
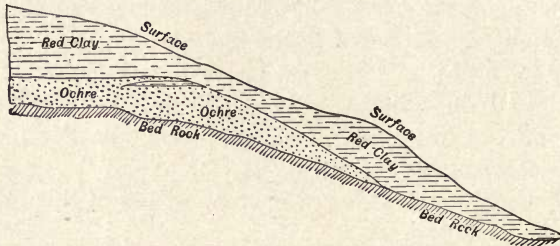


Fig. 121.—Section showing relations of ocher, quartzite, and clay, near Cartersville, Ga. (*After Watson, Ga. Geol. Surv., Bull.* 13.)

tion to that of the residual clay derived from the rock decay (Fig. 121). The following analyses represent its composition.

ANALYSES OF GEORGIA OCHER

|  | I | II | III |
|---|---|---|---|
| $Fe_2O_3$ . . . . . . . . . . . . . | 72.29 | 56.29 | 61.40 |
| $Al_2O_3$ . . . . . . . . . . . . | 5.55 | 10.15 | 7.14 |
| FeO . . . . . . . . . . . . . | .46 | .39 | |
| $MnO_2$ . . . . . . . . . . . . | .87 | .54 | 2.00 |
| $SiO_2$ (free sand) . . . . . . . | 6.65 | 8.94 | 11.89 |
| $SiO_2$ (comb) . . . . . . . . . | 3.98 | 9.49 | 5.84 |
| Moist . . . . . . . . . . . . | .55 | 2.08 | .46 |
| $H_2O$ above 105° C. . . . . . . | 9.22 | 11.34 | 9.37 |
| | 99.57 | 99.22 | 98.10 |

I. Crude ocher, Mansfield Bros., Lot. 462, 4th dist., 3d sec. Bartow Co. II. Crude ocher near Emerson, Bartow Co. III. Refined ocher, Blue Ridge Ocher Co.

The average percentage of limonite in a number of analyses was 74.15 per cent for both the crude and refined ocher. There is admixed with it about 20 per cent of clay and finely divided quartz which cleansing will not eliminate. The ocher of this district ranges from a dark to a light yellow color dependent chiefly on the amount of admixed clay.

According to Watson (10), the Bartow County ocher deposits have been formed by molecular replacement of the quartzite, and subsequent weathering has resulted in the ocher bodies being inclosed in many cases in residual clays derived from the decay of the original rock. Hayes (5) states that the ocher forms a series of irregular branching veins, extending in all directions, but often expanding into bodies of considerable size.

It is believed by Watson (10) that the iron oxide of the ocher was derived largely from the decay of surface rocks and carried downward by surface waters in the form of soluble ferrous salts, but that some was probably contributed by pyrite in the quartzite. The deposition may have been due to the carbon-dioxide solution of ferrous carbonate meeting an oxidizing solution, resulting in a precipitation of the iron and a solution of the silica of the quartzite.[1]

The main use of the Georgia yellow ocher is in the manufacture of linoleum and oilcloths, especially in England and Scotland. It is employed to a limited extent for paint manufacture.

*Pennsylvania.* — The ocher deposits of eastern Pennsylvania include the residual deposits of the Reading-Allentown district and the bedded deposits of the Moosehead district. The first named includes the principal ocher belt of Pennsylvania and lies in Berks and Lehigh counties, where the ocher deposits occur as irregular masses in a residual clay derived from the Shenandoah (Cambro-Silurian) limestone. Associated with the ochers are nodules and geodes of limonite, as well as smaller quantities of turgite, ilmenite, siderite, and pyrite. The product after washing, drying, and grinding contains from 12 to 30 per cent $Fe_2O_3$.

In the Moosehead area a bed of soft, buff-colored shale, found at the base of the Mauch Chunk shale, and resting on the Pocono sandstone (Lower Carboniferous), is mined for paint. It is of low grade, and the product carries from 6 to 7 per cent ferric oxide.

Umber and sienna have been produced in small quantities in

[1] Van Hise, Treatise on Metamorphism, p. 417.

Illinois and Pennsylvania, and sienna in addition has been obtained from New York.

ANALYSES OF MINERAL PAINTS FROM PENNSYLVANIA

|  | I | II | III | IV | V |
|---|---|---|---|---|---|
| $SiO_2$ . . . . | 39.70 | 39.00 | 57.53 | 64.24 | 75.52 |
| $Fe_2O_3$. . . . | 37.64 | 42.35 | 4.52 | 4.80 | 4.95 |
| $FeS_2$ . . . . | —— | —— | 3.76 | —— | —— |
| $Al_2O_3$ . . . | 12.36 | 13.33 | 16.72 | 22.40 | 9.85 |
| MgO . . . | 1.37 | tr. | 1.38 | —— | 1.29 |
| $CaCO_3$ . . . | —— | —— | 4.12 | —— | —— |
| CaO . . . . | —— | —— | —— | —— | 1.27 |
| $Na_2O$ . . . | —— | —— | 1.06 | —— | 2.22 |
| $K_2O$ . . . . | —— | —— | 2.12 | —— | 2.02 |
| Carbon . . . | —— | —— | 3.19 | —— | —— |
| Water . . . | 7.83 | 2.50 | —— | 5.70 | 3.14 |

I. Ocher, Easton, Pa.; II. Same after burning; III. Black shale, Muncy. Pa.; IV. Yellow shale, Moosehead, Pa.; V. Red shale, East Charleston, Pa.

**Canada** (12). — Ochers are found in many parts of Canada, but the worked deposits are confined to those found between between Champlain and Three Rivers, Quebec. In Ontario small quantities have been occasionally obtained from near Campbellville.

**Siderite** (1). — In Southern Carbon County, Pa., there occurs a somewhat extensive but not very thick bed of siderite lying between the Oriskany (Devonian) and Hamilton (Devonian) formations. The section shows

| | |
|---|---|
| Cement rock . . . . . . . . . . . . . . . . . . . | 25 feet |
| Paint " ore" . . . . . . . . . . . . . . . . . . . | 2 feet |
| Clay . . . . . . . . . . . . . . . . . . . | 8 feet |
| | 35 feet |

The brown paint " ore," which consists chiefly of iron carbonate, varies in thickness, often between 1 and $2\frac{1}{2}$ feet, and rarely reaching 4 feet. It is in places changed to limonite at the surface, and grows leaner with depth, leading to the belief that it represents a replacement of limestone by surface waters.

Below are given (I) an analysis of the crude ore (7), and (II) an analysis of the roasted product (4).

ANALYSES OF SIDERITE PAINT "ORE" FROM PENNSYLVANIA

| | I | | II |
|---|---|---|---|
| Fe . . . . . . . . | 34.60 | $Fe_2O_3$ . . . . . . | 42.70 |
| Mn . . . . . . . . | .929 | MnO . . . . . . | 1.40 |
| $SiO_2$ . . . . . . . | 16.21 | $SiO_2$ . . . . . . | 37.20 |
| $Al_2O_3$ . . . . . . | 5.492 | $Al_2O_3$ . . . . . . | 9.40 |
| CaO . . . . . . | 3.51 | CaO . . . . . . | 1.70 |
| MgO . . . . . . | 1.081 | MgO . . . . . . | 1.70 |
| S . . . . . . . . | .674 | $SO_3$ . . . . . . | 1.88 |
| P . . . . . . . . | .018 | $P_2O_5$ . . . . . . | .14 |
| Loss on roasting . . | 24.35 | $H_2O$ . . . . . . | .60 |
| | | $CO_2$ . . . . . . | 2.60 |
| | 86.854 | | 99.32 |

This paint is used mainly for freight cars, and in lesser amounts for painting steel, tin, boats, and as a filling in oilcloth and linoleum.

**Slate and Shale.** — The refuse from slate quarries is sometimes ground and sold as a pigment, and in some localities shales of the proper color and texture are utilized for the same purpose. Their value depends on their color, fineness, and amount of oil required in mixing. They are also used as fillers in the manufacture of oil cloth and linoleum.

Pennsylvania and New Jersey are the chief producers. The Hamilton (Devonian) shales have been worked for some years in Cattaraugus County, N. Y., and a product known as *mineral black* is made from the slates of the Hudson River (Ordovician) series.

Pennsylvania yields over 90 per cent of the United States production. The shales used are classed as black (mineral black), yellow and red. The refuse from slate quarries and the culm from anthracite mines has also been used by paint manufacturers.

**Gypsum,** known also as terra alba or mineral white, is used to some extent as a pigment for printing wall paper.

**Barite,** or barium sulphate, which is used as an adulterant of white lead, is purified after mining by grinding and washing.

**Asbestos** is used to some extent in paint manufacture for the so-called non-inflammable or fireproof paints, but the total quantity thus utilized is small.

**Graphite,** either natural or artificial, supplies a black pigment of permanent color which, on account of its resistance to the atmosphere and ordinary chemicals, is of much value for coating oxidizable metals, such as iron and steel.

**Calcium Carbonate,** in the form of chalk, known commercially as whiting or paris white, is used as a pigment to alter the shade of other pigments as a basis for whitewash.

Kentucky, Michigan and Missouri produced whiting in 1914, but all of it was not used as pigment. Whiting may be prepared by grinding different kinds of white limestone, but it is not as fine grained or as light in weight as the artificially prepared material. A fine-grained rhyolitic tuff has been produced in Los Angeles County, Calif., for white pigment.

*Other Paints.* — Paints sometimes classed as mineral paints are made from other crude minerals, as follows: zinc white from zinc ore; white lead, red lead, and orange mineral from lead; venetian red from iron sulphate; vermilion or artificial cinnabar from quicksilver; chrome yellow from chromite; cobalt blue from cobaltite.

**Production of Mineral Paints.** — The production of mineral paints, as well as the imports, are given below.

Production of Natural Mineral Pigments, 1909–1914, in Short Tons

| PIGMENT | 1909 | | 1910 | | 1911 | |
|---|---|---|---|---|---|---|
| | Quantity | Value | Quantity | Value | Quantity | Value |
| Ocher . . . | 12,458 | $125,349 | 11,711 | $112,445 | $11,703 | $109,465 |
| Umber . . . | 1,276 | 33,472 | 1,015 | 26,700 | 1,005 | 26,225 |
| Sienna . . . | | | | | | |
| Metallic paint . | 20,722 | 201,905 | 29,422 | 184,869 | 25,599 | 181,163 |
| Mortar colors . | 10,820 | 108,126 | 9,960 | 107,780 | 7,922 | 76,517 |
| Slate and shale (ground) . . | 14,944 | 98,176 | 16,515 | 96,001 | 16,510 | 105,451 |
| Total . . | 60,220 | $567,028 | 68,623 | $527,795 | 62,739 | $498,821 |

| PIGMENT | 1912 | | 1913 | | 1914 | |
|---|---|---|---|---|---|---|
| | Quantity | Value | Quantity | Value | Quantity | Value |
| Ocher . . . | 15,269 | $149,289 | 17,578 | $173,944 | 14,387 | $136,185 |
| Umber . . . | 805 | 21,975 | 776 | 20,790 | 790 | 21,070 |
| Sienna . . . | | | | | | |
| Metallic paint . | 28,347 | 181,352 | 30,098 | 171,264 | 30,947 | 179,653 |
| Mortar colors . | 9,272 | 87,595 | 5,357 | 35,443 | 5,371 | 47,723 |
| Slate and shale (ground) . . | 20,964 | 121,482 | 16,786 | 120,969 | 15,271 | 88,405 |
| Total . . | 74,657 | $561,693 | 70,595 | $512,410 | 66,766 | $473,036 |

Imports in 1913 and 1914, Pounds

| | 1913 | | 1914 | |
|---|---|---|---|---|
| | Quantity | Value | Quantity | Value |
| Ocher . . . . . . | 16,697,098 | $143,720 | 22,066,006 | $141,704 |
| Umber . . . . . . | 5,236,489 | 36,771 | 7,886,716 | 45,280 |
| Sienna . . . . . . | 3,273,217 | 48,535 | 7,815,323 | 63,958 |

PRODUCTION OF OCHERS IN CANADA, 1912–1914

| YEAR | SHORT TONS | VALUE |
|------|-----------|-------|
| 1912 . . . . | 7654 | $32,410 |
| 1913 . . . . | 5987 | 41,774 |
| 1914 . . . . | 5890 | 51,725 |

*World's Production.*—From the following table of ocher and umber production of the principal producing counties in short tons, it will be seen that France is the leading producer and the United States second.

| COUNTRY | QUANTITY | VALUE | COUNTRY | QUANTITY | VALUE |
|---------|----------|-------|---------|----------|-------|
| United States (1913) | 17,963 | $181,404 | Canada (1913) . | 5,987 | $41,774 |
| United Kingdom | | | Belgium (1912) . | 716 | 1,502 |
| (1913) . . . | 16,951 | 70,370 | Spain (1912) . . | 661 | 1,168 |
| France (1912) . . | 46,087 | 420,248 | Cyprus (1912) . | 5,259 | 20,945 |
| German Empire | | | | | |
| (1912) . . . | 7,668 | 14,072 | | | |

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### MONAZITE

**Properties and Occurrence.** — This mineral is an anhydrous phosphate of the rare earth metals, cerium, lanthanum, praseodymium and neodymium; but its economic value is due chiefly to the small amount of thoria which it contains. The percentage of thoria in monazite ranges from less than 1 to 20 or more, and in

commercial monazite varies between 3 and 9 per cent. Although grains of monazite are found scattered through many granites and gneisses, still no occurrences of this type have thus far proven to be of commercial value. The economically valuable deposits are all found in stream gravels, derived from the disintegration of monazite-bearing rocks. Monazite is usually light yellow to honey yellow, red, or brown in color, has a resinous luster, a specific gravity of 5.203 (Penfield and Sperry) and a hardness of 5 to 5.5. It is very brittle. Its gravity and color aid in its ready determination.

In the United States deposits of monazite sand have been found in the granite and gneiss areas of North Carolina (2, 4) and South Carolina (3), and these, together with deposits found in Brazil (1), supply nearly the entire world's demand. A small quantity is also obtained from southern Norway, as a by-product in feldspar mining. The following analyses indicate the composition of monazite: —

ANALYSES OF NORTH CAROLINA MONAZITE

|  | $P_2O_5$ | $Ce_2O_3$ | $La_2O_3$ | $ThO_2$ | $SiO_2$ | $H_2O$ |
|---|---|---|---|---|---|---|
| Burke Co., N. C. . . . | 29.28 | 31.28 | 30.88 | 6.49 | 1.40 | .20 |
| Alexander Co., N. C. . | 29.32 | 37.26 | 31.60 | 1.48 | .32 | .17 |

The deposits known in the Carolinas have been found within an area of about 3500 square miles (Fig. 122), which lies wholly within the Piedmont Plateau region. The chief rocks are gneisses of different kinds, schists, granite, pegmatite, peridotite, quartz-diorite, and diabase, but the structural conditions are complex, and metamorphism has often
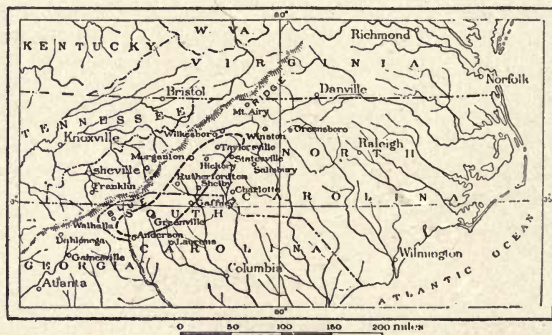
FIG. 122. — Map showing area of monazite deposits of known commercial value in southern Appalachian region. (After Sterrett, U. S. Geol. Surv., Bull. 340.)

obscured the original character of the rocks. The latter are, moreover, often concealed by a heavy mantle of residual soil.

Where the monazite has been found in the bed rock, it has been chiefly in a porphyritic pegmatized gneiss. In the ordinary gneiss, and in the highly pegmatized gneiss, the monazite is far less abundant. These occurrences in bed rock have not, however, proved to be of commercial value, and the only important deposits are the placers, and gravel beds in the streams and bottom lands, as well as some surface soils, adjoining the rich gravel deposits.

In some areas the saprolite or rotted rock underlying gravel deposits has been washed with favorable results.

The monazite-bearing gravels range in thickness from one to two feet, including overburden, up to 6 to 8 or more feet, and the monazite on account of its gravity has collected more abundantly in the lower portion. The deposits are richest in those regions containing an abundance of granitic rocks, pegmatized gneisses, and schists, while in the gravel itself, the presence of considerable quartz débris, and fragments of such rocks as pegmatite, granite, mica, and cyanite gneiss, are favorable signs.

In some cases the supply of monazite in the stream gravels may be replenished by wash from the hillsides which are underlain by residual soils containing monazite grains.

The monazite found in the pegmatized gneiss is believed to have been derived from aqueo-igneous solutions passing through the rock, and depositing and recrystallizing portions of it into the minerals of pegmatite.

**Uses.** — Monazite is usually separated from the gravels by a washing process, and in addition magnetic separation has in some cases been employed to separate it from the associated garnet, magnetite, and quartz.

The value of monazite lies in the incandescent properties of the oxides of the rare earths, cerium, lanthanum, didymium, and thorium, which it contains, and which are utilized in the manufacture of mantles for incandescent lights.

**Production of Monazite.** — The production of monazite declined from a maximum of 1,352,418 pounds, valued at $163,908 in 1905, to 99,301 pounds, valued at $12,006 in 1910, since which time there has been no production in the United States, the gas mantle industry having been supplied by imports from Brazil.

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# CHAPTER XII

## MINOR MINERALS — PRECIOUS STONES — WAVELLITE

### PRECIOUS STONES

THE names *gems* and *precious stones* (1, 2) are applied to certain minerals, which on account of their rarity, as well as hardness, color, and luster, are much prized for ornamental use. The hardness is of importance as influencing their durability, while their color, luster, and even transparency affect their beauty. A distinction is some times made between the more valuable stones, or gems (such as diamond, ruby, sapphire, and emerald), and the less valuable, or precious stones (such as amethyst, rock crystal, garnet, topaz, moonstone, opal, etc.).

Most gems are found in unconsolidated surface deposits representing either residual material or alluvium derived from it, and in the latter their concentration and preservation are due to their weight and hardness. When found in solid rock, the metamorphic and igneous types are more often the source than the sedimentary ones.

Many different minerals are used as gems (1, 2), but only a few of the important ones can be mentioned here, and the number of the more valuable kinds found in the United States is very limited (4, 12). Every year, however, discoveries of one kind or another are reported, and reference is usually made to these in the Mineral Resources of the United States published annually by the United States Geological Survey.

**Diamond.** — This mineral, which is the hardest of all known natural substances, is pure carbon, crystallizes in the isometric system, and has a specific gravity of 3.525. It occurs in many different colors, of which white is the commonest, and is found either in basic igneous rocks or in alluvial gravels.

The massive forms, known as *bort* or *carbonado*, have little or no cleavage, and are of value only as an abrasive.

The greatest number of diamonds come from South Africa, but other deposits of commercial value occur in India, Borneo, and Brazil.

In the United States a few scattered diamonds have been found in the drift or soil of the southern Alleghanies, California, Wisconsin, and Indiana, but they are all small (10, 12, 13, 15).

*Arkansas.*—The only and first locality in North America where diamonds have been found in place, is in Pike County, Ark. (9, 13), where, near Murfreesboro, several areas of peridotite are known to occur (Fig. 123). The first diamonds were found in 1906, and up to 1913, approximately 1375 stones, aggregating about 550 carats, were reported to have been recovered.

The sedimentary rocks of this area consist of strongly folded Paleozoic ones, overlain by Cretaceous beds, and these have been intruded by the peridotite. This has in most places disintegrated to a soft earth, whose topographic features, however, do not differ from those of the Trinity (Cretaceous) clay.



FIG. 123. — Map of Arkansas diamond area. (*After Miser, U. S. Geol. Surv., Bull.* 540.)

The residual clay derived from the peridotite is usually yellowish green above and bluish green below, the solid rock being in some cases as much as 30 feet deep.
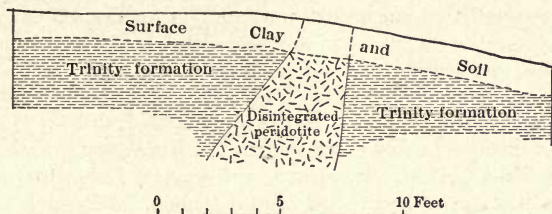


FIG. 124. — Section in Arkansas diamond area. (*After Miser.*)

*South Africa* (5a, 24a). — The Arkansas diamond occurrence resembles in some respects some of the South African ones. There the gems have been discovered at several localities, viz.: (1) In northern Cape Colony;

(2) At Jägerfontein, Orange Colony; (3) near Pretoria, Transvaal; and (4) In German Southwest Africa.

In the Kimberley field, for example, the diamonds occur in volcanic necks or "pipes" of kimberlite. These necks pierce a series of sandstones, lavas, and shales, ranging from Carboniferous to Triassic in age. The upper part of the kimberlite is weathered to the so-called *yellow ground*, while below it is the unoxidized rock or *blue ground*. The latter is the material now worked, and has to be disintegrated by weathering before the diamonds can be extracted from it.

The pipes are to be regarded as vents filled with the products of explosive eruptions, and the diamond crystals disseminated through this, may be crystallizations from the magma.

The Premier mine, where the conditions are similar to those at Kimberley, has yielded the Cullinan diamond,—the largest ever found,—weighing 3024¾ carats, and measuring 4 by 2 inches.

The German Southwest Africa deposits are unique in that the diamonds occur in a windblown sand and gravel resting on the crystalline bed rock. Their exact source, whether from the crystalline rocks of the district, or a hypothetical basic igneous rock now below sea-level, is open to doubt (5*b*, 24*a*).

*British Columbia* (7*a*). — A highly interesting, but not commercially important occurrence of diamonds has been found at Olivine Mountain, in the Tulameen district of British Columbia. The rock is a serpentinized peridotite, containing small segregations of chromite, and it is with these that the diamonds are found, forming without doubt original constituents of the igneous mass. They are all small, not larger than a pin head, of yellowish to brownish color, and partly or wholly opaque. A few have been found in the neighboring stream gravels.

*Origin*. — The origin of the diamond has provoked much discussion among scientists, and a number of successful attempts have been made to produce it artificially. These indicate its formation by crystallization from a fused magma, which in most cases has a composition resembling peridotite. As corroborative of this we have the occurrence of South African diamonds in or near volcanic pipes of peridotitic character, and Lewis has suggested that the stones were formed by the solvent action of the molten peridotite magma on carbonaceous shales. Some have disputed this idea, and believe that the diamond is an original constituent of the magma, from which it crystallized on cooling. As opposed to an igneous origin is the statement of G. F. Williams, that he found an inclusion of apophyllite (a highly hydrous mineral) in a Kimberley diamond. The occurrence in British Columbia, already referred to, seems to leave little doubt as to a possible crystallization from a magma. All diamonds do not occur in peridotite, for in Brazil hydromica schists and quartzite may contain them, while certain Indian ones appear to have been derived from pegmatite, and some Australian ones in hornblende-diabase.

The most that can perhaps be said is that, while much of the evidence indicates an igneous origin, the diamond has not necessarily been obtained in all cases from the same kind of magma.

**Emerald**. — This gem is a variety of beryl, essentially a glucinum-aluminum silicate. Its hardness is 7.5 to 8, and its specific gravity 2.5 to 2.7. Its brilliant green color is attributed by some to chromium, by others to organic matter. Brazil, Hindustan, Ceylon, and Siberia are all important sources. In the United States a few have been found in western North Carolina (12, 15) in gravel deposits. Flawless emeralds are very rare, and equal in value to diamonds.

*Aquamarine* and *oriental cat's-eye* are also varieties of beryl. *Brazilian emerald* is a green variety of tourmaline, and *lithia emerald* an emerald-green spodumene.

**Beryl.** — Gem beryl has been found at many localities in New England, and while at some of these it has been obtained as an accessory mineral in feldspar mining, at others the veins have been worked for the gem mineral alone. Thus in Connecticut golden beryl has been obtained near New Milford, and good aquamarine near East Hampton. Other localities have been worked in Maine, Massachusetts and New Hampshire.[1]

**Garnet.** — Of the several varieties of garnet, three are well known as gem stones, viz., the precious garnet, or almandite, Bohemian garnet, or pyrope, and manganese garnet, or spessartite. The first two are of deep crimson, the last of orange-red or light red-brown color. India is the main source of supply. All three varieties mentioned are found in the United States, but there is a regular production only of the pyrope from Arizona and New Mexico, and a purple-red garnet known as rhodolite from North Carolina (4, 12, 15).

Those found in the southwest (22) have for many years been collected by the Navajo Indians. Clear red garnets associated with peridot gems, which have been weathered out of basic igneous rocks, have been found at several places around and north of Fort Defiance, Arizona, but those obtained from these localities are small and not worth cutting. The supply of gem garnets comes from close to the Utah-Arizona line, at a point 12 miles southwest of the junction of the Chin See Valley and San Juan River in Utah. In this region, which is underlain by sandstone of probable Triassic age, pierced by numerous basic igneous rocks, the garnets are found chiefly in a coarse, unconsolidated drift or gravel layer, associated with feldspar, diopside, quartz, and igneous rock fragments. The garnets range in size from small

[1] Min. Res., U. S. Geol. Surv., 1913, p. 656.

grains to others over 3 centimeters in diameter, but the gem stones are not over 12 millimeters across.

**Opal,** which is hydrous silica chemically, is amorphous, with conchoidal fracture, yellow, red, green, or blue color, and often showing considerable iridescence. The varieties recognized are the precious opal, fire opal, girasol, and common opal. The finest examples of precious opal are obtained from Hungary. Others are also found at Queretaro, Mexico, and in Oregon and Washington. The United States production is small, although it is thought that there are many scattered occurrences in the igneous rocks of Washington, Idaho, Oregon, California, Nevada, and Utah (4, 12).

In 1913,[1] considerable prospecting was done in the opal field of Virgin Creek, Humboldt County, Nevada, a region that was discovered in 1908. The formations consist of tuffs, ashes and rhyolitic lavas, which have been broken by block faulting and tilting, and the opal occurs in the ash beds, mostly associated with the petrified wood. It is found as casts of different parts of the trees, and as coatings and filling in cracks in the silicified wood.

**Peridot.** — This name is applied to a deep olive-green variety of chrysolite, a silicate of magnesium and iron. Peridot has a low hardness (6.75) as compared with other gems, while its specific gravity, 3.3 to 3.4, is relatively high.

Gem peridot is found in two regions in Arizona (22) viz. north of Fort Defiance in the Navajo Indian Reservation, and near Rice in the White Mountains Apache Indian Reservation. In the former district the peridot is plentiful, and is found associated with volcanic rocks. These are monzonite porphyry, orthoclase basalt, and peridotite agglomerate. The peridot, which appears to have been derived from the agglomerate, is found in the soil, and associated with it are such minerals as garnet, diopside, quartz, calcite, titanic iron, etc. Gems of 1 to 2 carats' weight are fairly abundant, and some of 3 to 4 carats are found. Those of dark yellowish-green color are commonest.

In the Rice district peridot is found not only in the original basalt rock matrix, but also loose in the soil.

**Ruby.** — A red, transparent variety of corundum ($Al_2O_3$), having a hardness of 9 and a specific gravity of 4. The most valuable color in ruby is a deep, clear, carmine red. Rubies of large size are

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[1] Merriam, Science, n. s., XXVI: 380, 1907, and Sterrett, U. S. Geol. Surv., Min. Res., 1913, p. 677.

scarce, so that a 3-carat stone of good color and flawless is worth several times as much as a diamond of the same size. The best ones come from Burma. In the United States they have been found in the stream gravels of Macon County, North Carolina, but the production is not a steady one. Those found in Arizona and other western states are not true rubies, but a variety of garnet (4, 12, 15).

**Sapphire** is a blue, transparent variety of corundum ($Al_2O_3$). It is of slightly greater hardness and specific gravity than the ruby, though of similar composition. Sapphires of good color and size are more common than rubies and cheaper. The best sapphires come from Siam. In the United States they have been found in the gravels of Cowee County, North Carolina, but Yogo Gulch, Montana, is now the main source of domestic supply. They range in weight from under 1 up to 4 or 5 carats (4, 12, 18).

The Montana sapphires were first found in gravel bars on the Missouri River, but subsequently they were discovered in dikes of basic igneous rock cutting Carboniferous (?) limestone in southwestern Fergus County. The rock is of somewhat basic character belonging to a type known as monchiquite, and the sapphires are obtained from the somewhat decomposed portions of the dike.

There are two companies, both operating on the same dike, which has a width of 10 to 20 feet, and has been traced for a distance of 5 to 6 miles.

**Spodumene.** — A remarkable transparent lilac-colored and pale pink to white spodumene, known as *Kunzite* (14) has been found in California not far from the rubellite locality, and occurring in a pegmatite dike, where it is closely associated with gem tourmalines.

**Topaz.** — This is a fluosilicate of alumina, crystallizing in the orthorhombic system, with a hardness of 8, specific gravity of 3.5, vitreous luster, and yellow, green, blue, red, or colorless. It occurs in gneiss or granite, as well as in other metamorphic or igneous rocks, and is associated with beryl, mica, tourmaline, etc. It is also found in alluvial deposits. The best gem stones come from Ceylon, the Urals, and Brazil. In the United States they have been found in small quantities in Maine, Colorado, California (12), and Utah.

In Utah topaz (17) is found in the Thomas range of mountains about 40 miles north of Sevier Lake, at a locality known as Topaz Mountain. The transparent crystals occur in lithophysæ in rhyolite, and vary from colorless to wine color. Rough opaque crystals are scattered through the solid rhyolite. The crystals are believed to have been formed by vapors or solu-

tions contemporaneous or nearly so with the final consolidation of the rock. In the weathering of the rock the crystals fall out and become mixed with the soil, the colored ones fading on exposure to the light.

Topaz is obtained from pegmatite veins near Ramona, San Diego County, where it occurs in pockets in albite and orthoclase. The topazes are white, yellow, sea-green, and sky-blue, some of them being of large size (14).

**Tourmaline.** — This is a complex silicate, of aluminum and boron, with usually varying amounts of iron, magnesium, alkalies, and water. It has a hardness of 7 to 7.5 and a specific gravity of 2.98 to 3.20. The color is variable, and this variation may exist in the same crystal.

The opaque, black, or brown tourmaline is a somewhat common mineral in many metamorphic rocks, as well as in granite and other eruptive rocks, but this variety has no value as a gem.

Gem tourmalines are, however, rather rare, being known in Brazil, Russia, and Ceylon, and in this country in the states of Maine, Connecticut, and California. Of the gem tourmalines the red ones are most highly prized, especially the darker ones; the green ones are usually dark green.

A large number of green tourmalines have been obtained from a pegmatite granite at Paris, Maine, and many are found in a belt extending from Auburn to Newry (23). The gems here are likewise found in pegmatite, and are associated with beryl.

An interesting and important occurrence of red tourmaline (*rubellite*) has been worked at Pala, San Diego County, California. The crystals here form radiating groups in lepidolite and the earlier discovered ones were clear enough for cutting. Valuable crystals, many of gem character, have since been found in pegmatite veins near Pala, and near Mesa Grande (14).

**Turquoise** is a massive hydrated aluminum copper phosphate, of waxy luster, blue to green color, and opaque. Its hardness is 6, and specific gravity 2.75. It usually occurs in streaks and patches in volcanic rocks. The best varieties are obtained from Persia, but it is also obtained from Asia Minor, Turkestan, and Siberia. In the United States turquoises are found in the Los Cerillos Mountains near Santa Fé, New Mexico, and Turquoise Mountain, Arizona, as well as in Colorado.

It is interesting to note that turquoise was hardly known in the United States in 1890, but now a considerable supply comes from the southwestern states and territories (16a, 22, 25).

The production of turquoise in the United States has at dif-

ferent times come from New Mexico, Nevada, Arizona, California, and Colorado.

Turquoise mines have been operated in the Burro Mountains, 15 miles southwest of Silver City, New Mexico. The country rock of granite, which is cut by andesite-porphyry, andesite, and dacite, is much altered, and the turquoise is found in a vein or fissured zone, which contains kaolinized feldspar and secondary quartz.

In this strip, which is 40 to 60 feet wide, the turquoise occurs as veins and nuggets, the former filling cracks in the granite $\frac{1}{16}$ to $\frac{3}{4}$ inches wide, and the latter in the kaolin. The veinlets often cross and indicate successive periods of deposition.

A diversity of opinion exists regarding the origin of the turquoise. Silliman (Amer. Jour. Sci., 1881, July, p. 67) believes it to have been formed by heated water and vapors, which destroyed the original character of the rock and produced new compounds. Clarke and Diller suggested that the turquoise represents a replacement of the apatite of the granite. Johnson (16 a) advanced the theory that gases played a rôle in the decomposition of the rock, and called attention to the association of fluorite with the turquoise. The alumina of the turquoise, he thinks, was derived from the feldspar, the phosphorus from the apatite, and the copper from cupriferous solutions which formed the ores in that region.

Zalinski (25) believes that hot solutions, coming from below, caused a kaolinization of the granite, the silica set free in this connection being deposited in cracks and fractures with the turquoise. Solutions carrying aluminum phosphate rose along fissures parallel with the walls, while the copper solutions came along an intersecting series. Intermingling of the two solutions formed the turquoise.

In Mohave County, Arizona (22), the turquoise is found in the younger intrusive porphyries and granite, both of which have been more or less altered, especially around the turquoise deposits. This alteration consists of kaolinization, but there has also been some silicification, as shown by a deposition of quartz in joints and between the grains. Some of the turquoise seems to have been derived from the kaolin by the addition of phosphoric acid and copper, but much of it has been deposited from solution, as it occurs as seams and veinlets, as well as in patches or streaks in quartz seams and veinlets. The nodular turquoise is less common.

The Colorado turquoise deposits are associated with trachyte, but they show relations similar to the Arizona material.

In the district of northeastern San Bernardino County, California, where several large mines have been operated, the turquoise occurs in a coarse porphyritic granite, and a monzonitic (?) porphyry. These have been fractured, and then sericitized and kaolinized, as well as stained with limonite. Later solutions carrying the elements of turquoise passed through the same fissures where kaolinization occurred and deposited the turquoise in seams and veinlets, as well as in nodular masses in the kaolinized and sericitized rock.[1]

**Variscite.** — This mineral alone is not used as a gem stone, but it is cut with its associated matrix. This mixture, which is sometimes called **amatrice** (26), is composed of variscite, wardite, and probably other associated minerals such as chalcedony and quartz. The first two are hydrous phosphates of aluminum, showing varying shades of green, of compact, tough character and having a hardness of 4 and 5 respectively. The matrix consists of chalcedony and quartz with other minerals, among them yellowish gray and white phosphates. The decorative value of the material lies in the variety and arrangement of its colors.

**Production of Precious Stones.** — The United States produces a number of different kinds of gems and precious stones, but the total output is by no means large. Moreover, those kinds most used are produced in but small amounts. The collection of accurate statistics of production is, for several reasons, quite difficult and therefore the output has to be estimated in some cases. The figures of production for 1912 to 1914 are given on the opposite page.

The imports of precious stones into the United States for 1909 to 1914 as reported by the Bureau of Statistics is given below.

IMPORTS OF PRECIOUS STONES INTO THE UNITED STATES, 1909–1914 [2]

| YEAR | VALUE | YEAR | VALUE |
|---|---|---|---|
| 1909 . . . . . . . | $40,237,509 | 1912 . . . . . . | $41,363,325 |
| 1910 . . . . . . . | 40,704,487 | 1913 . . . . . . | 45,431,998 |
| 1911 . . . . . . . | 40,820,430 | 1914 . . . . . . | 18,711,084 |

[1] U. S. Geol. Surv., Min. Res., 1913, p. 695.
[2] These figures include pearls.

PRODUCTION OF PRECIOUS STONES IN THE UNITED STATES IN 1912–1914

|  | 1912 | 1913 | 1914 |
|---|---|---|---|
| Agates, chalcedony, onyx, etc. . . . | $9,978 | $8,895 | $8,312 |
| Amethyst . . . . . . . . . . | 363 | 389 | 265 |
| Benitoite . . . . . . . . . | 150 | —— | —— |
| Beryl, aquamarine, blue, pink, yellow, etc. | 1,765 | 1,615 | 2,395 |
| Californite . . . . . . . . . | 275 | 152 | 1,425 |
| Chlorastrolite . . . . . . . . | 350 | —— | —— |
| Copper ore gems, chrysocolla, malachite, etc. . . . . . . . . . . | 1,085 | 2,350 | 1,280 |
| Chrysoprase . . . . . . . . . | 220 | —— | 75 |
| Cyanite . . . . . . . . . . | 10 | —— | —— |
| Diamond . . . . . . . . . . | [1]1,475 | [1]6,315 | 765 |
| Emerald . . . . . . . . . | 2,375 | —— | —— |
| Epidote . . . . . . . . . . | 10 | —— | —— |
| Feldspar, amazon stone, sunstone, etc. | 1,310 | 1,28 5 | 449 |
| Garnet, almandine, pyrope, hyacinth, etc. | 860 | 4,285 | 1,760 |
| Gold quartz . . . . . . . . | 1,900 | 300 | 1,050 |
| Jade . . . . . . . . . . . | —— | —— | 300 |
| Jasper, petrified wood, bloodstone, etc. | 6,005 | 5,275 | 4,700 |
| Opal . . . . . . . . . . . | [1]10,925 | [1]15,130 | 1,114 |
| Peridot . . . . . . . . . . | 8,100 | 375 | 100 |
| Prase . . . . . . . . . . . | —— | 25 | —— |
| Pyrite . . . . . . . . . . | 265 | 50 | —— |
| Quartz, rock crystal, smoky quartz, rutilated quartz, etc. . . . . . . | 2,448 | 1,640 | 4,046 |
| Rose quartz . . . . . . . . | 865 | 337 | 400 |
| Rhodomite . . . . . . . . . | 550 | 165 | 1,050 |
| Ruby . . . . . . . . . . . | 2,260 | 200 | 100 |
| Sapphire . . . . . . . . . | [1]195,505 | 238,635 | 60,392 |
| Smithsonite . . . . . . . . | 650 | 50 | 50 |
| Spodumene, kunzite, hiddenite . . . | 18,000 | 6,520 | 4,000 |
| Thomsonite . . . . . . . . | 450 | —— | 21 |
| Topaz . . . . . . . . . . | 375 | 736 | 1,380 |
| Tourmaline . . . . . . . . | [1]28,200 | 7,630 | 7,980 |
| Turquoise matrix . . . . . . | 10,140 | 8,075 | 13,370 |
| Variscite, amatrice, chlorutahlite, utahlite | [1]8,450 | [1]6,105 | 5,055 |
| Miscellaneous gems . . . . . . | 4,408 | 2,920 | 2,287 |
|  | $319,722 | $319,454 | $124,651 |

[1] Estimated or partly so.

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# QUARTZ

Although this material has been briefly referred to under abrasives and glass sands, it is sufficiently important to require treatment as a special topic.

Silicon is the second most abundant constituent of the earth's crust, and quartz, of which it is an important ingredient, is the most abundant of all minerals, but varies greatly in its mode of occurrence and uses. Thus some varieties, such as rose or smoky quartz, amethyst, etc., are used as gems. Quartz in the form of sand is employed for molding (p. 335), building, glass-making (p. 340), and pottery manufacture, etc. In the form of sandstone and quartzite (p. 156) it is of value as a structural material.

The forms of quartz considered here are the massive crystalline quartz (often known as vein quartz), flint, and quartzite used for purposes other than building or paving.

*Vein Quartz* (1–3). — This form of quartz, which is white, or less often rose or smoky, occurs in veins or dike-like masses, usually in metamorphic rocks. It may be of high purity, or may be mixed with feldspar, mica, etc., as an ingredient of pegmatite, in which case it is obtained as a by-product in the mining of feldspar. Vein quartz is produced in Connecticut, New York, Pennsylvania, and Maryland. A crystalline quartz, not of vein character, obtained in southern Illinois is referred to under Tripoli (p. 412).

*Quartzite.* — This rock is quarried at a few localities for special purposes. Thus in Cherokee County, North Carolina, a vitreous Cambrian quartzite has been quarried for use as a flux in copper smelting. Large quantities of a hard brittle quartzite have also been quarried near Wausau, Marathon County, Wisconsin, the ground product being used for sandpaper and other abrasive purposes, filters, bird grit, wood filler, etc. It analyzes 99.07 per cent silica.

*Flint or Chert.* — This term is applied to lusterless quartz of very compact texture and conchoidal fracture, which often forms nodules in limestone or chalk. In some cases these concretions may represent silicified fossils. Flint nodules are found in many formations in the United States, but little of the domestic material has been utilized except for road metal. The entire supply of true flint demanded by this country for special purposes is obtained from France, England, Norway, and even Greenland, being brought over as ballast. The smaller nodules are used in tube mills, but much of the supply is calcined to whiteness and then ground for use in pottery manufacture.

**Uses of Quartz.** — Quartz is extensively used in pottery manufacture to diminish the shrinkage of the ware in burning, and for this purpose it should have under 1 per cent of iron oxide. In recent

years quartzite and sandstone have been more used than vein quartz. It is also employed in the manufacture of wood filler, paints, scouring soaps, sandpaper, filters, and tooth powders. Blocks of massive quartz and quartzite are employed as a filter for acid towers. Quartz is also used as a flux in copper smelting and in the manufacture of silicon and ferrosilicon. Much chemical ware is now made of fused quartz.

PRODUCTION OF QUARTZ IN THE UNITED STATES, 1909–1913, IN SHORT TONS

| YEAR | CRUDE | | GROUND | | TOTAL | |
|---|---|---|---|---|---|---|
| | Quantity | Value | Quantity | Value | Quantity | Value |
| 1909 . . . . . | 121,459 | $131,334 | 14,010 | $118,132 | 135,469 | $249,466 |
| 1910 . . . . . | 49,886 | 80,984 | 13,691 | 112,773 | 63,577 | 193,757 |
| 1911 . . . . . | 77,759 | 70,430 | 10,184 | 84,692 | 87,943 | 155,122 |
| 1912 . . . . . | 82,205 | 67,256 | 15,669 | 124,429 | 97,874 | 191,685 |
| 1913 . . . . . | 74,176 | 54,442 | 23,726 | 147,046 | 97,902 | 201,488 |
| 1914 . . . . . | 123,508 | 88,820 | 29,893 | 271,682 | 153,401 | 360,502 |

PRODUCTION OF QUARTZ IN CANADA, 1912–1914

| YEAR | SHORT TONS | VALUE |
|---|---|---|
| 1912 . . . . . | 100,242 | $195,216 |
| 1913 . . . . . | 78,261 | 169,842 |
| 1914 . . . . . | 54,148 | 83,583 |

The imports of flint and flint stones in 1914 were valued at $479,146 (unground). Pure crystalline quartz, for pottery, paint, and wood filler brings about $2 to $3.50 per long ton, crude, f.o.b. quarries, while the ground product sells for $6.50 to $10 per short ton f.o.b. mills. Quartzite for sandpapers sells for $1 to $2 per long ton f.o.b. mines, and $6 to $8 ground, f.o.b. mills. The finest ground quartz for tooth powders sells for as high as $20 per ton. Imported French flints are quoted at $3.50 to $4 per long ton f.o.b. Philadelphia.

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## STRONTIUM

**Sources and Occurrence.** — The two minerals serving as sources of strontium salts are celestite ($SrSO_4$) and strontianite ($SrCO_3$).

Of these two the former is the more important, but the latter is the more valuable, as the strontium salts can be more easily extracted from it.

Both celestite and strontianite have been found at a number of localities in the United States, but seldom in large quantities.   One important deposit of celestite has been found in limestone caves near Put-in Bay, Strontian Island, in Lake Erie, and in opening up the cave 150 tons of the mineral were taken out.   Similar occurrences have been found in limestones in other states, but none of them have any commercial value.

Nearly all the strontium salts now used in the United States are imported from Germany, the crude material being obtained in part from Westphalia, Germany, and also from Thuringia, Germany, and Sicily.

**Uses.** — Strontium salts are used in sugar refining, in fireworks manufacture, and to a small extent in medicine.

REFERENCE ON STRONTIUM

1. Pratt, U. S. Geol. Surv., Min. Res., 1901: 955, 1902.

## SULPHUR AND PYRITE

These two minerals are discussed in the same chapter because both serve as sources of sulphur or sulphuric acid.

### SULPHUR

Native sulphur may be formed in several different ways as follows:

*Solfataric Type.* — Sulphur is often found in fissures of lava and tuff around many active and also extinct volcanic vents.[1]   When thus formed as a volcanic sublimate it may be a product of reactions between sulphur dioxide and hydrogen sulphide.   It may also be formed by incomplete combustion of hydrogen sulphide, probably as follows:  $2 H_2S + O_2 = 2 H_2O + 2 S$.   This latter change probably occurs at least a short distance below the surface, where oxygen is deficient, as at the surface the $H_2S$ may form $H_2SO_4$.

Deposits of the solfataric type are rarely of commercial importance, but they are worked in Japan, and have also been worked in the crater of Popocatepetl in Mexico.

*Mineral Spring Deposits.* — Sulphur is not an uncommon deposit around mineral springs, its deposition being due to imperfect

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[1] Ferric chloride is sometimes deposited around fumarolic vents, and might, owing to its similar color, be at first mistaken for sulphur.

oxidation of hydrogen sulphide, the sulphur appearing in the spring waters as a whitish powder. It has been noticed, however, that the associates of this type of sulphur deposit are often some form of lime carbonate, or gypsum, and that the sulphur depositing springs sometimes rise through fissures in limestone, leading to the belief that a reaction like the following may occur:—[1]

$$2 \ CaCO_3 + 2H_2S = Ca(SH)_2 + H_2Ca(CO_3)_2.$$
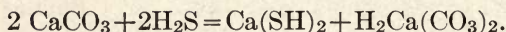
The calcium hydrosulphide formed will yield calcium carbonate or gypsum on the escape of the $H_2S$ as follows:—

$$Ca(SH)_2 + 2O_2 + 2H_2O = CaSO_4 \cdot 2H_2O + H_2S;$$

$$Ca(SH)_2 + CO_2 + H_2O = CaCO_3 + H_2S.$$
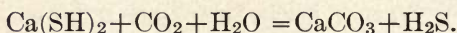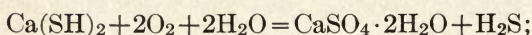
This accounts for the travertine and gypsum found with some mineral spring deposits (p. 397). It is possible also that some of the sulphur is deposited by sulphur bacteria.[2] These have the power of oxidizing $H_2S$ to $H_2SO_4$, and retaining free sulphur in their cells, if there is an excess of $H_2S$. The $H_2SO_4$ formed will in turn attack calcium bicarbonate, which the cell takes up from the water and converts it into calcium sulphate. Sulphur under favorable conditions may also be carried in the colloidal form, and be later precipitated.[3]

*Gypsum Type* (3e, 8a). — This type, which is of world-wide distribution, is so called because of its constant association with with gypsum. Limestone, marls, and bituminous matter are also found with it. The Sicilian and Louisiana deposits are well-known members of this group, and are referred to on pages 398 and 396. Because of its lack of association with volcanic activity and close relationship to sedimentary formations, the true explanation of its origin has been somewhat difficult to find. Most of the theories have been advanced in connection with a study of the Sicilian deposits, and may be briefly stated as follows:—

1. The sulphur is thought to have been formed by the reducing action of bituminous matter on gypsum according to the following reactions:—

[1] Bechamp, Ann. chim. phys., 4th ser., XVI: 234, 1869.

[2] Winogradsky, Botan. Zeit., XLV, No. 31-37, 1887.

[3] Raffo and Marncini, Zeitschr. Chemie Ind. Kolloide, IX: 58, 1911.

$$CaSO_4 + 2C = CaS + 2CO_2;$$

$$CaS + CO_2 + H_2O = CaCO_3 + H_2S;$$

$$H_2S + O = H_2O + S.$$
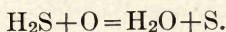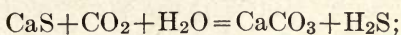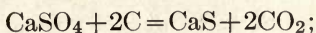
This theory was first suggested by G. Bischof,[1] and is still held by many.

2. Stutzer (8a) has suggested that the sulphur is of purely sedimentary origin. He bases his belief on: (a) Its stratified structure; (b) the interstratification with limestone, and in the Sicilian deposits at least, its absence in the gypsum; and (c) the presence of interbedded clay layers, which would prevent circulation, and preclude the deposition of the sulphur by permeating waters.

In accordance with this view he assumes that decaying organisms in the water yielded hydrogen sulphide, or that it might have been formed by the action of hydrocarbons on calcium sulphate. The oxidation of the hydrogen sulphide was brought about either by the oxygen of the air, or by sulphur bacteria (p. 394).

3. A third theory is that the hydrogen sulphide was supplied by cold springs discharging into fresh-water lakes,[2] or by hot springs flowing out over the ocean floor.[3]

4. Hunt (3a), after noting that the sulphur of Sicily forms basin-like deposits, underlying the more continuous gypsum which contains occasionally lens-shaped masses of secondary sulphur, suggests the following:—

The sulphur was collected in small basins, whose water had a comparatively high average temperature, and a high sulphate content. Bacterial reactions extending over a period of years caused a copious production of $H_2S$ from decomposition of sulphates, and reactions similar to those mentioned under *Mineral Spring Deposits* (p. 393), might cause a simultaneous precipitation of sulphur and calcium carbonate. Some of the sulphur would, however, be absorbed by the $Ca(SH)_2$, forming an unstable polysulphide, which would yield copious precipitations of free sulphur from time to time. Continued evaporation of the basin waters eventually rendered them so saline as to check bacterial action and also precipitate the overlying gypsum.

[1] Chem. u. Phys. Geol. II: 144, 1851.

[2] A. von Lasaulx, Neues Jahr. Min., 1879, p. 490.

[3] G. Spezia, Neues Jahrb. Min. 1893,, I: 38.

5. In the case of the Louisiana deposits at least, Harris has suggested ascending hot waters as the source of the sulphur.

*Metallic Sulphide Type* (4). Sulphur may result from alteration of pyrite, marcasite, or related sulphides, possibly through action of bituminous matter. Gypsum is a common associate. No deposits of economic value have been formed in this manner.

**Distribution of Sulphur in the United States.** — Louisiana and Texas are the most important producers, smaller quantities coming from other western states, especially Wyoming.

*Louisiana* (4, 5, 10). — The deposits of sulphur found in this state are the most important domestic source of this material. They occur in Calcasieu Parish, and were discovered as early as 1868 in boring for oil and gas at the head of Bayou Choupique, 15 miles west of Lake Charles.

The bed of sulphur, which is of Cretaceous age (Harris and Veatch), lies 300 to 400 feet below the surface, is over 100 feet thick, and is underlain by gypsum and salt. It is supposed by some to have been derived from gypsum, but Harris suggests the possibility of its precipitation from ascending hot waters (see under Salt, p. 210).

Owing to the quicksand-like character of the overlying beds, attempts to sink a shaft to the deposit were unsuccessful. It is now obtained by pumping superheated steam down through pipes, melting the sulphur, and drawing it to the surface, where it is discharged into vats to cool and solidify.

A similar deposit of sulphur is found near Bryan Heights, Brazoria County, Texas. It is in one of the structural domes so characteristic of the Mississippi embayment and referred to under Oil (p. 106).

*Utah* (6). — Sulphur of the solfataric type was mined at Sulphurdale in central Utah for some years. In this district there are found a series of rhyolites and andesites, overlain in places by basalts, the whole resting probably on Paleozoic sediments.

The sulphur, which occurs in a soft rhyolitic tuff (sometimes called gypsum), sometimes forms cylindrical masses or cones 10 to 15 feet in diameter, and with a rudely radial structure, but most of it is found as a dark-colored impregnation or cementing substance of the tuff.

Occasionally there are seen branching veins of nearly pure yellow sulphur, with a banding parallel to the walls, and these may repre-

sent fissure fillings from solution, since acid water partly filled with yellow sulphur issues from the fissures.

The crude material varies greatly in richness, some showing as much as 80 per cent sulphur, but rock running as low as 15 per cent is marketable. An analysis of the sulphur from the retorts yielded: S, 99.71; nonvolatile matter ($SiO_2$, $Fe_2O_3$, etc.), .23; free $SO_3$, tr.; moisture at 100° C., .06.

A volcanic origin is suggested for the sulphur, because of its close association with volcanics, and the position of the beds along a fault line. Gas now escapes from the deposits in large volumes, and hydrogen sulphide boils up through water standing in the workings. The sulphur may therefore have been precipitated by the oxidation of the hydrogen sulphide, which is presumably of volcanic origin. Oxidation of the sulphur may give $SO_3$ and this by reaction with water, $H_2SO_4$. Analysis of water issuing from the beds shows sulphuric acid.

*Wyoming.* — Native sulphur has been mined in Wyoming near Cody (12), and near Thermopolis (11), the mode of occurrence at the two localities being almost identical. At the latter locality the deposits are found in the altered Embar (middle Carboniferous) limestone which immediately underlies a travertine deposit (Fig. 125).

The sulphur occurs in small yellow crystals filling veins or cavities in the rocks, and in massive form as a replacement of calcium carbonate by sulphur, the original structure of the limestone being retained.
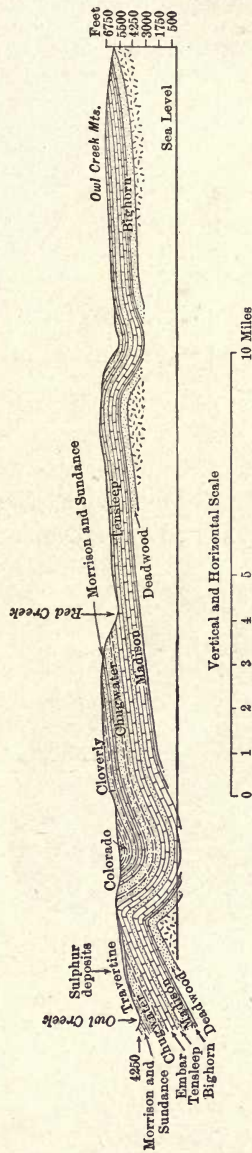


FIG. 125. — Section showing stratigraphy and structure from crest of Owl Creek Mountains to Owl Creek, and relations of sulphur deposits near Thermopolis, Wyo. (*After Woodruff, U. S. Geol. Surv., Bull.* 380.)

The distribution of the sulphur appears to be very irregular, and confined to those portions of the limestone surrounding the channels of the hot springs that deposited the travertine. The attempted explanation of the origin of the deposits is that surface
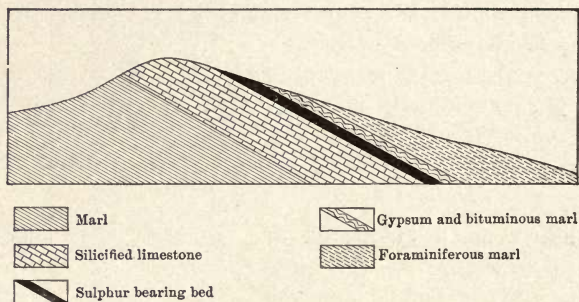


Fig. 126. — Section in Sicilian sulphur deposits. (*After Mottura, from Stutzer, Die Nicht-Erze.*)

waters worked their way downward along the sandstones from the Owl Creek Mountains (Fig. 125), and came into contact with some uncooled body of igneous rock, which not only heated them, but



Fig. 127. — Banded sulphur-bearing rocks from Sicily; black, sulphur; dotted, limestone; white, calcite. (*From Stutzer, Die Nicht-Erze.*)

also supplied them with hydrogen sulphide. Following this they passed upward through the much-fractured beds of the anticline with which the deposits are associated. As these waters approached the surface, the sulphur was precipitated by oxidation, or by other processes mentioned under *Mineral Springs Deposits* (p. 393). Hot springs carrying both $H_2S$ and $CO_2$ exist there at present.

The depth of the deposits at these two localities is not believed to be great, but in the rich pockets the sulphur may form 30 to 50 per cent of the rock.

*Other States.* — Sulphur deposits have been worked in Colorado, Nevada (1), and California (2).

**Sicily** (3a, 8a). — In the Sicilian sulphur-producing region the sedimentaries include (1) Sands, sandstones and shell breccia of Upper Pliocene; (2) Foraminiferal limestone of Lower Pliocene; and (3) Upper Miocene sulphur-bearing

series, consisting of: (a) an upper gyspum member with occasional lenses of secondary sulphur, and (b) a series of beds of sulphur-bearing limestone, separated from each other by bituminous, salty clays and shales. The individual sulphur beds may vary from one to thirty (exceptional) meters in thickness. Associated with the sulphur are celestite and calcite, less often barite, also bituminous matter. The whole series has been disturbed by folding and faulting.

**Uses of Sulphur.** — The most important use of sulphur is for the manufacture of sulphuric acid and in paper manufacture. Some is also used in making matches, for medicinal purposes, and in making gunpowder, fireworks, insecticides, for vulcanizing india rubber, etc.

In recent years pyrite has largely replaced sulphur for the manufacture of sulphuric acid, and the increase in price of Sicilian sulphur has helped this.

The greater portion of the world's supply of sulphur is obtained from Sicily, the United States consuming the largest amount.

**Production of Sulphur.** — The sulphur industry of the United States has grown rapidly in the last few years, and in 1907, for the first time in its history, the value of the importations fell below the million dollar mark, due to the great decline in the imports of crude sulphur. Louisiana continues to be a great producer, and the competition of the product from this state with imported Sicilian material has reacted somewhat disastrously on the latter.

The production for 1909 to 1913 is given below.

SULPHUR IMPORTED AND ENTERED FOR CONSUMPTION IN THE UNITED STATES, 1910–1914, BY KINDS, IN LONG TONS

| YEAR | CRUDE | | FLOWERS OF SULPHUR | | REFINED | | ALL OTHERS | | TOTAL VALUE |
|------|-------|---|--------------------|---|---------|---|------------|---|-------------|
| | Quantity | Value | Quantity | Value | Quantity | Value | Quantity | Value | |
| 1910 | 28,656 | $496,073 | 1024 | $30,180 | 1106 | $25,869 | 47 | $ 6,489 | $558,611 |
| 1911 | 24,200 | 434,796 | 3891 | 83,491 | 985 | 24,906 | 68 | 9,643 | 552,836 |
| 1912 | 26,885 | 494,778 | 1311 | 39,126 | 1665 | 40,933 | 66 | 9,137 | 583,974 |
| 1913 | 15,122 | 286,209 | 5899 | 115,574 | 1234 | 29,091 | 350 | 17,690 | 448,564 |
| 1914 | 23,610 | 398,984 | 621 | 17,214 | 1800 | 47,568 | 104 | 14,171 | 477,937 |

PRODUCTION OF SULPHUR IN THE UNITED STATES, 1910–1914

| YEAR | LONG TONS | VALUE |
|------|-----------|-------|
| 1910 . . . . | 255,534 | $4,605,112 |
| 1911 . . . . | 265,664 | 4,787,049 |
| 1912 . . . . | 303,472 | 5,256,422 |
| 1913 . . . . | 311,590 | 5,479,849 |
| 1914 . . . . | 327,634 | 5,954,236 |

The imports came mainly from Italy and Japan. The exports in 1914 amounted to 98,153 long tons, valued at $1,807,334, this being 72,018 long tons in excess of the import. These figures indicate that the country is producing more than enough sulphur to supply its own needs.

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## PYRITE

**Properties and Occurrences.** — Pyrite, $FeS_2$, when chemically pure, has 46.6 per cent iron and 53.4 per cent sulphur, and occurs in well-defined cubes or modifications of the same, in irregular grains or as granular masses, of a brassy yellow color.

It is widely distributed in nature, being found in many kinds of rocks and in all formations, and in these may occur as disseminated grains, in contact zones, as concretions in sedimentary rocks, in fissure veins, and as lenticular bodies of variable size usually in metamorphic rocks.

Pyrite as mined is never chemically pure, but contains admixtures of other sulphides, as well as non-metallic minerals.

If chalcopyrite is present in sufficient quantity to bring the copper content of the ore above 3 or 4 per cent, the material may be

sold for copper making instead of acid manufacture. Pyrrhotite is abundant in some of the Virginia deposits. In some regions the pyrite carries enough gold to render its extraction profitable, but such deposits are not worked for their sulphur contents.

Pyrite as offered to the trade rarely contains over 43 per cent sulphur, and if the content falls below 38 per cent, the acid makers object. Careful sorting and jigging of the pyrite is usually necessary. Lead, zinc, arsenic, antimony or selenium are objectionable.

The pyrite produced in the United States is obtained from (1) Massive deposits, often of lenticular form and disseminations occurring in gneisses or schists (Va., N. Y.); (2) from the lead and zinc mines of the Upper Mississippi Valley; and (3) from the coal mines of Indiana and Illinois.

When pyrite is roasted $SO_2$ is given off, which is changed to $SO_3$ by mixing with fumes given off from a mixture of $NaNO_3$ and $H_2SO_3$ in properly constructed lead chambers. In thoroughly roasted pyrite there remains a residue of iron oxide, which is known as " blue billy " or purple ore, and can be used in the blast furnace for iron manufacture. The roasted chalcopyrite is sometimes also used for copper making.

**Distribution in the United States.** — The most important domestic occurrences are found in a belt of pre-Cambrian metamorphic rocks extending from New Hampshire to Alabama (8), in which the pyrite occurs in lenticular deposits. Virginia and New York are the most important eastern producers. California is the only western state producing appreciable quantities.

*Virginia* (7, 8). — The counties of Louisa and Prince William contain workable deposits of pyrite, which have been most extensively developed, and yield a little more than half of the total domestic production.
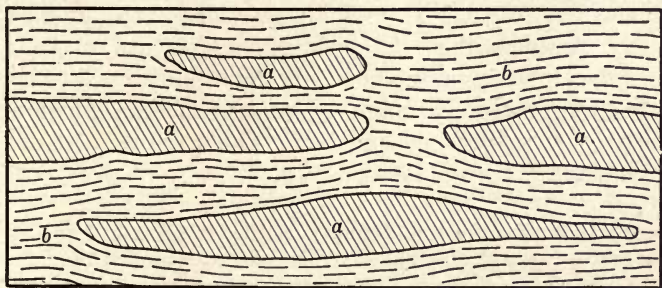


Fig. 128. — Plan of pyrite lenses at Sulphur Mines, Louisa County, Va., showing pyrite (*a*) and crystalline schists (*b*). (*After Watson, Min. Res., Va.,* 1907.)
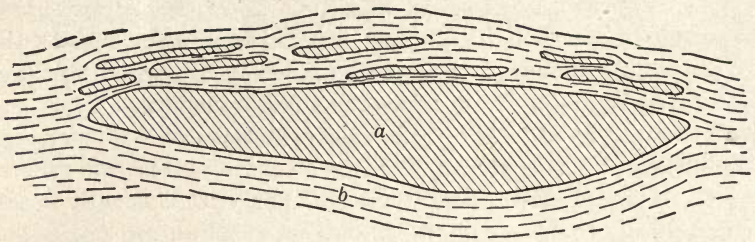
Fig. 129. — Plan of pyrite lens (*a*), showing stringers of pyrite, interleaved with schists (*b*) on hanging wall. Arminius mine, Louisa County, Va. (*After Watson, Min. Res., Va.*, 1907.)

In these counties the pyrite occurs as bodies of lenticular shape (Figs. 128, 129), in quartz-mica schists, which may contain more or less hornblende and garnet locally developed. The schists, which are completely and thickly foliated, have a general strike of N. 10 to 20° E., and a variable dip.

The pyrite is massively granular, and the associated minerals in the order of their importance are sphalerite, chalcopyrite, galena, pyrrhotite, and magnetite. Calcite, quartz, green hornblende, and red garnet are present, but the last two rather favor the margin of the ore bodies.

The lenses of pyrite follow each other along the strike, sometimes overlapping, and may also be connected by stringers of ore (Fig. 129). The main bodies may be several hundred feet long, indeed one in Louisa County has a length of 700 feet and a thickness of 60 to 80 feet. Another in Prince William County is 1000 feet long. Pinches and swells are common, and while the pyrite bodies are usually sharply defined, they may at times grade into the country rock.

An analysis of Louisa County pyrite gave: S, 49.27; Fe, 43.62; Cu, 1.50; Zn, .38; insol., 4.23; CaO and MgO, 1.32. Traces of arsenic may be present. The sulphur averages 43 to 45 per cent.

Watson considers that the inclosing schists are undoubtedly metamorphosed sedimentary limestones, as shown by the presence of bands and stringers of impure limestones and the abundant development of lime-bearing silicates. The pyrite is believed to have been formed by replacement.

The ore is worked by underground methods, the schist picked out, and the pyrite crushed and jigged. The entire output is used for acid making. The gossan of the pyrite was originally worked for iron ore.

Sulphuric acid is also obtained from the pyrrhotite-chalcopyrite deposits of Carroll County, etc. These are mentioned under Copper.

*New York* (2, 5a). — Pyrite deposits are worked near Canton and Gouverneur, St. Lawrence County. The pyrite is low grade, carrying 20 to 35 per cent sulphur which can be raised to 45 to 50 per cent by concentration. The ore deposits, which are associated with crystalline limestones and schists of the Grenville series, appear to represent impregnation zones in the schist, which by local enrichment may give lens-like accumulations.

*Massachusetts* (3, 5). — Pyrite was produced near Davis, Franklin County. The material forms a somewhat tabular deposit of irregular width in steeply dipping, northeasterly striking, crystalline schists. The deposits have been opened up along the strike for about 900 feet, and to a depth of 1400 feet on the dip. Horses of country rock occur in the pyrite. Five feet is regarded as the minimum workable thickness. Garnets and chalcopyrite are present, the latter forming either masses or veins in the pyrite. An analysis of the pyrite concentrates yielded, S, 47 per cent; Fe, 44 per cent; $SiO_2$, 3 per cent; Cu, 1.5 per cent; Zn, trace; As, none.

*Other States.* — Some pyrite is produced from deposits in crystalline schist in Clay County, Alabama (8), near Acworth and Villa Rica, Georgia, and in California (1). In Indiana, Illinois, and Ohio some is obtained as a by-product in the mining of coal (6).

Not a little pyrite (marcasite) is obtained from the Wisconsin-Illinois lead-zinc district. Some of it is a by-product of the separating plants, but the greater part is shipped as mined, and may often average 45 per cent sulphur.

ANALYSES OF PYRITE AND PYRRHOTITE

|        | I     | II     | III   | IV    | V      | VI    | VII   | VIII  | IX    |
|--------|-------|--------|-------|-------|--------|-------|-------|-------|-------|
| S . .  | 49.27 | 32.10  | 44.95 | 47.00 | 34.060 | 48.00 | 49.00 | 45.00 | 44.78 |
| Fe .   | 43.62 | 35.94  | 41.14 | 44.00 | 53.150 | 43.00 | 43.55 | 42.50 | 37.49 |
| Cu .   | 1.50  | .30    | .28   | 1.50  | .866   | 1.6   | 3.20  | 3.50  | —— |
| Zn .   | .38   | 4.68   | 3.58  | tr.   | ——  | 1.5   | .35   | .25   | 4.23  |
| Insol. | 4.23  | [1]13.42 | [2]2.54 | [3]3.00 | [2]2.99 | [5]5.0 | 1.70 | ——  | 11.08 |
| CaO .  | } 1.32 { | 1.00 | —— | —— | —— | —— | .14 | .10 | .87 |
| MgO.   |       | .59    | .70   | ——  | ——  | ——  | ——  | ——  | .20   |
| As .   | ——    | .04    | .04   | ——  | ——  | ——  | .47   | ——  | .07   |
| Pb .   | ——    | .50    | .40   | ——  | ——  | ——  | .93   | .20   | .14   |

[1] $SiO_2$.

I. Louisa County, Va. II. Crude ore, Louisa Co., Va. III. Concentrates, Louisa Co., Va. IV. Concentrates, Davis, Mass. V. Pyrrhotite, Virginia. VI. New Hampshire. VII. Rio Tinto, Spain. VIII. Sulitelma, Norway. IX. Meggen, Ger.

**Canada** (9).—Pyrite deposits are known at a number of points in Canada, especially in Ontario and Quebec, but comparatively few of them are in active operation:

According to Fraleck, the pyrite bodies are divisible into 3 classes, viz: (1) Those in gneissoid rocks; (2) those of the iron formation, including the Helen Mine deposits, where the pyrite occurs in the hematite; and those of the crystalline limestones of eastern Ontario; (3) deposits associated with crystalline schists, with eruptive greenstones near by. The ore bodies are frequently of lenticular form.

Pyrite of slightly cupriferous character is obtained from Eustis and Weedon, Quebec (1a). It is described under Copper.

**Other Foreign Deposits.** — France, Germany, Italy, Norway, Portugal, and Spain are all large producers of pyrite, but only the last-named country serves as an important source of supply for the United States.

The Huelva deposits of Spain, with Rio Tinto as an important producing town, consist of lenticular ore bodies in schist. The ore is said to rarely fall below 47 per cent sulphur.

Some of these are referred to in more detail under Copper (Chapter XVI).

**Uses of Pyrite.**—Pyrite is used chiefly and in increasing quantities for the manufacture of sulphuric acid. About 75 per cent of the production is from pyrite, marcasite and pyrrhotite, while the rest represents by-product acid made in connection with copper and zinc smelting.

This acid is used in the manufacture of superphosphates and explosives, in refining crude oil, and other ways.

**Production of Pyrite.** —

PRODUCTION OF PYRITE IN THE UNITED STATES, 1910–1911, IN LONG TONS

| STATE | 1910 | | | 1911 | | |
|---|---|---|---|---|---|---|
| | Quantity | Value | Average Price per Ton | Quantity | Value | Average Price per Ton |
| California . . . . . . . | 27,158[1] | $129,504[1] | $4.77[1] | 48,415 | $182,787 | $3.78 |
| Georgia . . . . . . . | | | | | | |
| Indiana . . . . . . . | 2[2] | 2[2] | 2[2] | 6,223 | 26,155 | 4.20 |
| Missouri . . . . . . . | | | | | | |
| Oklahoma . . . . . . | | | | | | |
| Illinois . . . . . . . | 10,502 | 33,747 | 3.21 | 17,441 | 47,020 | 2.70 |
| Massachusetts . . . . | 38,978 | 187,071 | 4.80 | 59,215 | 282,373 | 4.77 |
| New York . . . . . . | | | | | | |
| Ohio . . . . . . . | 3,766 | 12,831 | 3.41 | 6,471[3] | 18,017[3] | 2.78[3] |
| Pennsylvania . . . . | | | | | | |
| Virginia . . . . . . | 148,653 | 565,358 | 3.80 | 150,800 | 558,494 | 3.70 |
| Wisconsin . . . . . | 12,555 | 49,467 | 3.94 | 12,893 | 50,025 | 3.88 |
| Other States . . . . | | | | | | |
| Total . . . . . . . | 241,612 | $977,978 | $4.05 | 301,458 | $1,164,871 | $3.86 |

[1] Included with Virginia.          [2] Included with Illinois.
[3] Included with Massachusetts and New York.

PRODUCTION OF PYRITE IN THE UNITED STATES, 1912–1914, IN LONG TONS

| STATE | 1912 | | | 1913 | | |
|---|---|---|---|---|---|---|
| | Quantity | Value | Average Price per Ton | Quantity | Value | Average Price per Ton |
| California | 61,812 | $201,453 | $3.26 | 70,536 | $218,525 | $3.10 |
| Georgia | [1] | [1] | [1] | 11,110 | 55,094 | 4.96 |
| Indiana | 1,462 | 5,684 | 3.89 | 1,242 | 3,115 | 2.51 |
| Missouri | [1] | [1] | [1] | [1] | [1] | [1] |
| Oklahoma | | | | | | |
| Illinois | 27,008 | 62,980 | 2.33 | 11,246 | 31,966 | 2.84 |
| Massachusetts | | | | | | |
| New York | [1] | [1] | [1] | [1] | [1] | [1] |
| Ohio | 14,487 | 43,853 | 3.03 | 13,622 | 34,998 | 2.57 |
| Pennsylvania | [1] | [1] | [1] | | | |
| Virginia | 162,478 | 621,219 | 3.82 | 148,259 | 587,041 | 3.96 |
| Wisconsin | 17,898 | 70,518 | 3.94 | 25,328 | 94,727 | 3.74 |
| Other States | 65,783 | 328,552 | 4.99 | 59,995 | 260,618 | 4.34 |
| Total | 350,928 | $1,334,259 | $3.80 | 341,338 | $1,286,084 | 3.77 |

| STATE | 1914 | | |
|---|---|---|---|
| | Quantity | Value | Average Price per Ton |
| California | 71,272 | $235,129 | $3.30 |
| Georgia | [1] | [1] | [1] |
| Indiana | 1,710 | 5,281 | 3.09 |
| Missouri | [1] | [1] | [1] |
| Oklahoma | | | |
| Illinois | 22,538 | 59,079 | 2.62 |
| Massachusetts | | | |
| New York | [1] | [1] | [1] |
| Ohio | 7,279 | 19,718 | 2.71 |
| Pennsylvania | | | |
| Virginia | 141,276 | 550,091 | 3.94 |
| Wisconsin | 14,188 | 78,460 | 5.53 |
| Other states | 78,399 | 329,588 | 4.20 |
| Total | 336,662 | $1,283,346 | $3.81 |

[1] Included with other states.

WORLD'S PRODUCTION OF IRON PYRITE IN 1913

| COUNTRY | LONG TONS | COUNTRY | LONG TONS |
|---|---|---|---|
| Canada | 141,577 | Portugal | 371,588 |
| United States | 341,338 | Spain | 912,316 |
| Belgium | 264 | Sweden | 33,799 |
| Bosnia and Herzegovina | 7,580 | Turkey | [1] |
| France | 306,267 | United Kingdom | 11,427 |
| German Empire (Prussia) | 224,808 | Japan | [1] |
| Greece | [1] | | |
| Hungary | 104,950 | Total | 3,177,713 |
| Italy | 287,477 | | |
| Norway | 434,342 | Sulphur displaced (based on 45 per cent content) | 1,429,971 |

[1] Statistics not available.

*Canada.*—The production of pyrite in 1914 amounted to 224,956 short tons, valued at $735,514, while the exports were 89,999 short tons, valued at $377,985.

*Imports.*—The imports of pyrite in 1914 amounted to 1,026,617 long tons, valued at $4,797,236. They came chiefly from Spain, with some from Portugal, Canada, and Newfoundland.

PRODUCTION OF SULPHURIC ACID FROM COPPER AND ZINC SMELTERS IN 1912–1914, IN SHORT TONS

(Reduced to 60° Baumé acid)

| SOURCE | 1912 | | | 1913 | | | 1914 | | |
|---|---|---|---|---|---|---|---|---|---|
| | SHORT TONS | VALUE | PRICE PER TON | SHORT TONS | VALUE | PRICE PER TON | SHORT TONS | VALUE | PRICE PER TON |
| Copper smelters | 321,156 | $1,985,704 | $6.18 | 336,019 | $2,205,627 | $6.56 | 348,727 | $2,215,690 | $6.35 |
| Zinc smelters | 292,917 | 2,255,237 | 7.70 | 296,218 | 2,140,645 | 7.23 | 411,911 | 2,974,603 | 7.22 |
| Total | 614,073 | $4,240,941 | $6.91 | 632,237 | $4,346,272 | $6.87 | 760,638 | $5,190,293 | $6.82 |
| Total acid reduced to 50° B. | 764,237 | —— | —— | 790,296 | —— | —— | 950,798 | —— | —— |

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## TALC AND SOAPSTONE

**Properties and Occurrence.** — Talc, a hydrous magnesium silicate [$H_2Mg_3(SiO_3)_4$], is a widely distributed mineral, but rarely occurs in large quantities.

It is characterized by its extreme softness, soapy feel, and freedom from grit. The color is white, gray, or green; and though generally foliated, it may be fibrous.

*Soapstone* is a term ordinarily applied to a dark, bluish gray or greenish rock, composed essentially of talc, but containing other minerals as impurities, such as mica, chlorite, amphibole (tremolite), pyroxene (enstatite), and also quartz, magnetite, pyrrhotite, and pyrite. It too is soft enough to be easily cut with a knife, and has a pronounced soapy or greasy feel.

Talc is an alteration product of other magnesia minerals, such as tremolite, actinolite, pyroxene or enstatite, and is often associated with talcose or chlorite schists, serpentine, and such basic igneous rocks as peridotite and pyroxenite. It is also found associated with dolomite.

Soapstone, which often forms large masses, is found chiefly in association with the older crystalline rocks. In some cases, it has no doubt been derived from an altered eruptive rock, but in others probably from magnesian sediments by metamorphism.

**Distribution in the United States.** — The production of talc and soapstone is limited almost exclusively to the belt of old crystalline rocks forming the axis of the Appalachian Mountain system, and although quarried in eight or ten states, but few are important producers, and these are mentioned below.

Deposits of talc and soapstone are known in some of the western states, but commercial conditions have not been favorable for their development. Small quantities of talc have been produced in the past in both California and Washington.

*Virginia* (11).—This state is the most important producer of soapstone, and while the material is found at a number of localities in the state, nearly the entire production comes from a narrow northeast belt at least thirty miles long, extending from Nelson into Albemarle counties.

The soapstone occurs in a number of dike-like masses called " veins," 30 to 165 feet in thickness, and separated by intervals of 500 to 800 feet.

The deposits dip southeast 60°, conformable with the inclosing

crystalline schists, which vary from a mica-quartz schist to a micaceous sandstone. Occasionally the wall rock is a dark graphite schist, or an altered basic eruptive.

The soapstone varies in color from light bluish gray to dark greenish gray, the former or higher grade containing the most talc, and being the easiest and most satisfactory to work.

Under the microscope the better grade is seen to consist mostly of talc, with small quantities of chlorite, magnetite, as well as traces of amphibole and pyroxene. The dark green soapstone owes its color and greater hardness in part to chlorite and other silicates, such as hornblende and pyroxene. The product is used mainly for laundry tubs, while smaller amounts are converted into table tops, sinks, and switch boards. Much of it is shipped to foreign markets.

*New York* (10). — All of the talc mined in the state is obtained from a small area southeast of Gouverneur. The most abundant country rocks of this area are pre-Cambrian gneisses, in which there occur irregular northeast-southwest belts of crystalline limestone, the greater portion of which is impure. The schistose layers of impurities carry tremolite and enstatite as their chief constituents, and it is the alteration of these that has produced the talc, the change being indicated by the following equations: —

<div align="center">

ENSTATITE        TALC

$$4\,MgSiO_3 + H_2O + CO_2 = H_2Mg_3Si_4O_{12} + MgCO_3$$

TREMOLITE        TALC

$$CaMg_3Si_4O_{12} + H_2O + CO_2 = H_2Mg_3Si_4O_{12} + CaCO_3$$

</div>
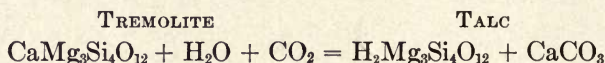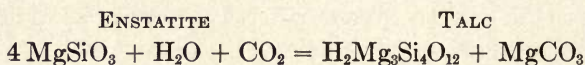
This change of the enstatite and tremolite to talc is supposed to have been accomplished by the action of water charged with $CO_2$, but whether it occurred at shallow or greater depths is uncertain. The talc layer, which varies in thickness from a few feet to over 50 feet, averaging about 20, shows either a fibrous or bladed structure. It is used mainly as a filler for writing papers, being even exported to Europe.

*North Carolina* (9). — The talc deposits of this state form an interesting contrast with those of Virginia, for here the material occurs as a series of lenticular masses and sheets in blue and white Cambrian marbles, thus indicating its probable derivation from a sedimentary rock. In other deposits the talc is found in a Cambrian conglomerate, in Archæan rocks associated with peridotite, showing an undoubted derivation from igneous rocks.

The first-mentioned group is associated with the Murphy Marble, in

Swain County, and forms lenticular bodies, with a maximum size of 50 feet thickness and 200 feet length. It crumbles down under weathering action, and the deposits are detected by float material. Most of the North Carolina talc is ground to powder, but some is sawed into slabs, or made into pencils, crayons, gas tips, etc.

*Vermont* (5). – Talc occurs at a number of localities in Vermont, some of which are worked. That worked at East Granville is a talc schist, inclosed between other schists. That at Chester and Athens occurs in gneiss.

*New Jersey* (8). — Talc has been found at a number of points in the vicinity of Phillipsburg, New Jersey, and also across the river near Easton, Pennsylvania. The talc occurs with serpentine in dolomite and near pegmatite intrusions. The latter by contact metamorphism developed tremolite, white pyroxene, and phlogopite in the limestone. Later, during break-thrust faulting, accompanying minor folding, squeezing, and faulting in this area, the magnesian silicates were altered by water to talc and other products.

The following analyses from several localities show the kind and quantity of impurities which good talc may contain: —

ANALYSES OF TALC

| | I | II | III | IV | V | VI | VII | VIII | IX |
|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 62.42 | 60.15 | 63.07 | 60.26 | 57.08 | 61.85 | 60.60 | 60.20 | 63.36 |
| $Al_2O_3$ | 1.43 | .74 | 1.56 | .31 | } 8.40 | { 2.61 | .30 | 1.25 | .46 |
| $Fe_2O_3$ | 2.38 | .09 | —— | —— | | —— | —— | 2.50 | —— |
| FeO | —— | 5.05 | .67 | .12 | —— | —— | .60 | —— | .30 |
| MgO | 30.24 | 28.71 | 28.76 | 33.04 | 27.16 | 34.52 | 35.30 | 27.98 | 27.60 |
| CaO | tr. | .04 | .30 | .28 | 1.72 | tr. | .40 | 2.60 | 3.49 |
| $Na_2O$ | —— | .22 | .79 | .24 | —— | —— | 2.80 | —— | —— |
| $K_2O$ | —— | .32 | tr. | —— | —— | .17 | —— | —— | —— |
| $H_2O$ ign. | 3.35 | 4.11 | 4.36 | 5.01 | 5.15 | .60 | —— | 5.70 | 3.92 |

I. Foliated talc, Burton, Rabun, Co., Ga.; II. Pencil grade talc, Chatsworth, Murray Co., Ga.; III. Kinsey Mine, North Carolina; IV. Fibrous talc, New York; V. Vermont; VI. Luzenach, France; VII. Valley of Pignerolles, Italy. Nos. I to VII quoted in Ref. 7. VIII. Sheep Creek, Calif.; IX. Seven miles southeast Riggs Station, Calif., Nos. VIII, IX, Ref. 3.

*Georgia* (7). — Talc formed from limestone is found in Fannin and Gilmer counties, but is not extensively worked. Deposits of greater importance, are those worked in Murray County. These occur in the Ocoee (Cambrian) series, the talc-bearing formations dipping 45° southeast. The talc occurs as lenses associated with a harder impure form known as blue john, between walls of quartz schist. It is supposed to be derived from igneous rocks.

*California* (3). — Talc deposits which occur in San Bernardino and Inyo counties, California, have recently undergone considerable development.
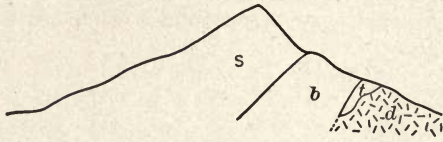
FIG. 130. — Section of talc deposit near Tecopa, Calif.,*t*, talc with some limestone tremolite, schist and serpentine; *b*, banded, somewhat cherty limestone, 125 feet; *s*, lighter colored, less ferruginous, and apparently dolomitic limestone; *d*, diorite. (*After Diller, U. S. Geol. Surv., Min. Res.*, 1913.)

The talc is usually quite white, and lies on the contact between diorite and banded limestone, but is very irregular in its thickness. Tremolite and serpentine are found in association with the talc. It has been used chiefly in the manufacture of tiles.

**Canada** (1, 4). — Talc is mined only in Madoc township, Hastings County, Ontario. The material, which is massive and white, occurs in a brown quartzose limestone of the Grenville series. It varies from 25 to 40 feet in width, and has been mined for a horizontal distance of about 500 feet. There seems to be no doubt that the talc has been formed by the alteration of magnesian limestone, although the exact process is not clear, except that the neighboring granite intrusion may have yielded silica-bearing solutions. Soapstone deposits have been worked intermittently in southern Quebec (4).

**Other Foreign Deposits** (12). — The largest European talc deposits are those on the north side of the Pyrenees in southern France. The material lies between mica schists and Ordovician slates, and contains beds of limestone, as well as scattered granite blocks. Another important occurrence is that found in Styria, where, in a saddle-shaped fold the talc lies between an underlying graphite slate, and an overlying limestone of Silurian age. The talc is supposed to have been derived by the alteration of the graphitic slate and grades into it. A similar and important occurrence of pure talc is worked near Pinerolo in northern Italy. Numerous other foreign deposits are known, but they are much less important than the above-mentioned ones.

**Uses.**—Talc is marketed as rough talc, sawed slabs, or ground talc. Its peculiar physical character, extreme fineness, softness, and freedom from grit adapt it to a number of uses, of which the following are most important: fireproof paints, foundry facing, boiler and steam-pipe coverings, soap adulterants, toilet powders, dynamite, in wall plasters, for dressing skins and leather, as a

base for lubricants, as a filling for paper, and for sizing cotton cloth. It has been used to a slight extent for adulterating food. It can, on account of its softness, be easily sawed or carved, and is extensively used for washtubs, sanitary appliances, laboratory tanks and tables, electrical switchboards, hearthstones, mantels, footwarmers, etc. Most of the New York fibrous talc is used as a paper filler, being better suited for it than the North Carolina product. The compact varieties of pure talc are employed for pencils, and for coal- and acetylene-gas tips.

The average price of rough talc in 1914 for the whole United States was $5.83 a ton, but some sold as low as $2.00 per ton, and talc worked up into pencils or crayons brought as high as $100. The average price for manufactured talc in 1914 was $27.98 per ton.

The prices of soapstone vary with the form in which it is sold, and also with the size and quality of the stone. In the rough as quarried, its value ranges from about $1.50 to $2.00 per ton. Sawed slabs of good size and quality may exceed $15.00 per ton in value, and when manufactured into laundry tubs, the average value is about $30.00 per ton.

**Pyrophyllite** differs from talc chemically, being a hydrous aluminum silicate, instead of a magnesium silicate, but when sufficiently free from grit, it is put to the same use as talc. It is sometimes incorrectly called agalmatolite, because of its resemblance to the true mineral of that name. Deposits, more extensive than those of talc, are found near Glendon, North Carolina (9). It varies from green and yellowish white to white, but in all cases becomes nearly white when dried.

**Production of Talc and Soapstone.**—The production for the last four years has been as follows:—

PRODUCTION OF TALC AND SOAPSTONE, 1911–1914, BY STATES, IN SHORT TONS

| | 1911 | | 1912 | | 1913 | | 1914 | |
|---|---|---|---|---|---|---|---|---|
| | QUAN-TITY | VALUE | QUAN-TITY | VALUE | QUAN-TITY | VALUE | QUAN-TITY | VALUE |
| Massachusetts | 7,642 | $ 36,883 | 1 | | 1 | 1 | 1 | 1 |
| New Jersey and Pennsylvania | 12,131 | 54,319 | 10,400 | $ 50,519 | 11,308 | $ 80,780 | 7,732 | $ 54,549 |
| New York . . | 62,030 | 613,286 | 66,867 | 656,270 | 81,705 | 788,500 | 86,075 | 821,286 |
| North Carolina | 3,548 | 57,101 | 3,542 | 63,304 | 4,676 | 48,817 | 1,198 | 28,413 |
| Vermont . . | 29,488 | 200,015 | 42,413 | 275,679 | 45,547 | 327,375 | 50,698 | 363,465 |
| Virginia . . | 26,759 | 660,926 | 25,313 | 576,473 | 26,487 | 615,558 | 21,687 | 527,938 |
| California . . | 1 | 1 | 1,169 | 15,653 | 952 | 6,000 | 547 | 8,786 |
| Other states 2 . | 1,953 | 23,488 | 9,566 | 69,065 | 5,153 | 41,067 | 4,359 | 60,650 |
| Total . . | 143,551 | $1,646,018 | 159,270 | $1,706,963 | 175,833 | $1,908,097 | 172,296 | $1,865,087 |

1 Included in other States.

2 Includes 1911: California, Georgia, Maryland and Rhode Island; 1912, 1913 and 1914: Georgia, Maryland, Massachusetts and Rhode Island.

The total imports of talc in 1914 amounted to 15,734 tons, valued at $177,321, an increase of 14.4 per cent in quantity and of nearly 28.8 per cent in value as compared with 1913.

PRODUCTION AND IMPORTS OF CANADIAN TALC

| YEAR | PRODUCTION | | IMPORTS |
| --- | --- | --- | --- |
| | SHORT TONS | VALUE | VALUE |
| 1912 . . . . . . . . | 8,270 | $23,132 | $ 4,414 |
| 1913 . . . . . . . . | 12,250 | 45,980 | 10,706 |
| 1914 . . . . . . . . | 10,808 | 40,418 | |

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## TRIPOLI

**Properties and Occurrence.** — The term *Tripoli* is somewhat loosely used to include many siliceous substances used for abrasive purposes, but in this place it is restricted to certain siliceous rocks found in Missouri (2, 4) Illinois (1, 3), and Tennessee.

The Missouri tripoli is a light, porous, siliceous rock which has been extensively quarried near Seneca, Missouri, but it is known at other localities in the state, and even in Oklahoma.

The deposits occur in the Boone (Lower Carboniferous) formation (4), consisting of alternating limestones and cherts having an average thickness of 350 feet, and with only an oölitic limestone as an easily recognized bed. The tripoli beds, which occur mostly above the last, are 4 to 12 feet thick, and overlain by chert, gravel, and red clay. Chert may also occur in the tripoli itself, and even form a large proportion of it.

The tripoli is an even-textured, finely porous rock, whose grains are mostly under .01 mm. in diameter, and are probably chalcedony. The following analyses represent the composition of the stone from Seneca, Missouri:—

ANALYSES OF TRIPOLI FROM SENECA, MO.

|  | 1 | 2 | 3 |
|---|---|---|---|
| SiO₂ . . . . . . . . . . . . | 98.28 | 98.10 | 98.10 |
| Al₂O₃ . . . . . . . . . . . | .17 | .24 | .24 |
| Fe₂O₃ . . . . . . . . . . . | .53 | .27 | .27 |
| CaO . . . . . . . . . . . . | tr. | .184 | .33 |
| K₂O . . . . . . . . . . . . | .17 | — | — |
| Na₂O . . . . . . . . . . . | .27 | .23 | .23 |
| Ign. . . . . . . . . . . . . | .50 | 1.16 | 1.17 |
| Org. . . . . . . . . . . . . | — | .008 | — |
|  | 99.92 | 100.192 | 100.34 |

1. R. N. Brackett, Ark. Geol. Surv., V : 267, 1892.   2. W. H. Seaman, Sci. Am. Supp., July 28, 1894 : 15487.   3. Mo. Geol. Surv., VII : 731, 1894.

A commonly accepted theory is that the tripoli results from the decomposition of chert, but while chert is in the tripoli beds, it is not possible to find a transition from tripoli laterally to unaltered rock.   It is also difficult to see how the common chert of this region could form the massive, non-fossiliferous tripoli.

Siebenthal (4) believes the tripoli to have been derived by the leaching of lime carbonate from beds like certain gray, dull, massive limestones now found in this region.

In southern Illinois, in Union and Alexander counties, there are beds of fine-grained silica, which may be similar to the Missouri tripoli.   Its origin and extent are, however, imperfectly known.   An analysis yielded SiO₂, 98.00; MgO, .20; Al₂O₃, 1.21; Moist., .15; Und., .44.   The silica consists of minute particles from .50 to .2 mm. diameter, of crystalline structure, transparent character, and irregular shape, loosely cemented by a small amount of clay.   It may be used for wood polishing and other purposes.

Another deposit of tripoli is that found near Butler, Tenn. (5). It represents leached beds of Cambrian limestone, and forms a soft chalk-like or pulverulent mass, whose grains range from .01 to .06 mm. in diameter.

The composition is: SiO₂, 67.85; Al₂O₃, 16.80; FeO, 5.06; CaO, .32; MgO, .60; K₂O, 5.40; Na₂O, 1.23; Ignition, 3.47.

**Uses.** — The rough blocks are sawed up into filter stones, while the spalls and small pieces are ground up for tripoli flour, and there has been a great increase in the production since 1885. The tripoli is worth $6 to $7 per ton f.o.b. Tripoli stone is used to some extent for blotter blocks and scouring bricks. Tripoli flour is used as an abrasive for general polishing, burnishing, and buffing, and also as an ingredient of scouring soaps.

REFERENCES ON TRIPOLI

1. Bain, Ill. Geol. Surv., Bull. 4: 185, 1907. (Illinois.)  2. Hovey, Sci. Amer. Suppl., July 28, 1894, p. 15487. (Missouri.)  3. Parr, Ernest and Williams, Jour. Indus. and Eng. Chem., I: 692, 1909. (Illinois.) 4. Siebenthal and Mesler, U. S. Geol. Surv., Bull. 340: 429, 1908. (Missouri.)  5. Glenn, Res. Tenn., IV: No. 1. (Tenn.)

## WAVELLITE

Wavellite has been used to a small extent in the United States as a substitute for rock phosphate, in making phosphorus.

This mineral does not usually occur in minable quantities, but a somewhat unique deposit has been found on South Mountain, near Mount Holly Springs, Pa. There the wavellite occurs in a white residual clay derived from talcose schists, and associated with manganese and iron ores. The iron and manganese have been concentrated during the weathering of the rocks, and deposited in the residual materials, near the contact of the limestones of the valley and the mountain sandstones. The phosphate occurs as nodules, scattered through a white clay, lying between a manganese-bearing red clay and the mountain. The width of the deposit is 40 to 50 feet. The mining of this material was reported by the United States Geological Survey for 1906, but since then no production has been recorded.

Phosphorus is used mainly for making matches as well as for fuse compositions, rat and insect poison, phosphoric acid, and for other compounds used in medicine and the arts. It is also used in the preparation of precious metals, electrotyping, and in phosphor bronze.

REFERENCES ON WAVELLITE

1. Stose, U. S. Geol. Surv., Bull. 315 : 325, 1907.   2. Hopkins, Ann. Rept. Pa. State College, 1889–1900, appendix III : 13.

PLATE XXXVII
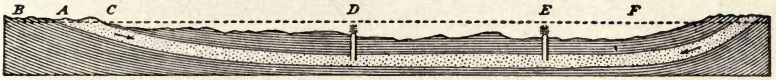


FIG. 1. — Section of an artesian basin.  A, porous stratum; B, C, impervious beds below and above A, acting as confining strata; F, height of water level in porous bed A, or, in other words, height in reservoir or fountain head; D, E, flowing wells springing from the porous water-filled bed A.
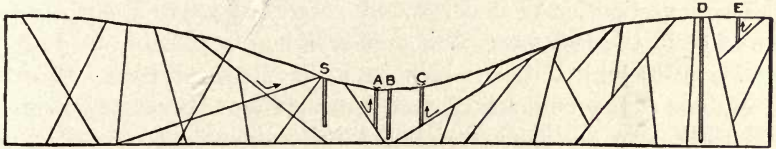


FIG. 2. — Section illustrating artesian conditions in jointed crystalline rocks without surface covering.  A, C, flowing wells fed by joints; B, intermediate well between A and C of greater depth, but with no water; D, deep well not encountering joints; E, pump well adjacent to D, obtaining water at shallow depths; S, dry hole adjacent to a spring, showing why wells near springs may fail to obtain water.
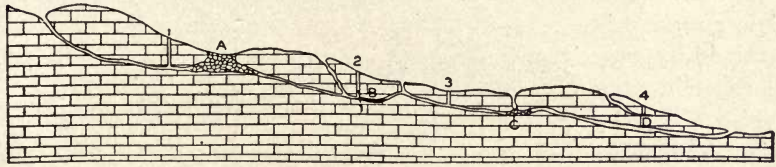


FIG. 3. — Section illustrating conditions of flow from solution passages in limestone. A, brecciated zone (due to caving roof) serving as confining agent to waters reached by well 1; B, silt deposit filling passage and acting as confining agent to waters reached by well 2; C, surface débris clogging channel and confining waters reached by well 3; D, pinching out of solution crevice resulting in confinement of waters reached by well 4.
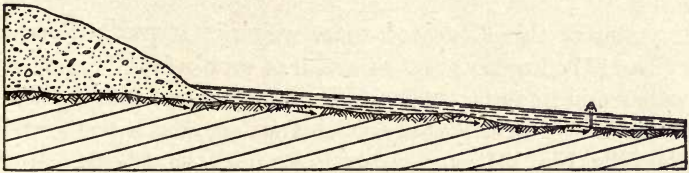


FIG. 4. — Section illustrating conditions of flow from joints, cracks, and solution passages in stratified rocks covered by impervious clays and fed from morainal drift.   (All after Fuller.)

(415)

# CHAPTER XIII

## UNDERGROUND WATERS

THE investigation of underground waters has assumed such importance in the last few years, that it is hardly possible to do it justice in the limited space which can be devoted to it here. However, some of the more salient points can perhaps be touched upon, and those who desire more detailed information are referred to the selected bibliography at the end of the topic.

While much of the water used for supplying towns and cities, for irrigation purposes, etc., is obtained from below the surface, all of it originates in rainfall. The rain water falling on the surface is disposed of in part by evaporation and surface run-off, but a variable and sometimes large percentage seeps into the ground.

**Ground Water** (5, 6) — A small part of the water soaking into the ground is retained by capillarity in the surface soil, to be returned again to the atmosphere, either by direct evaporation or through plants; but most of it



FIG. 131. — Ideal section across a river valley, showing the position of ground water and the undulations of the water table with reference to the surface of the ground and bed rock. (*After Slichter, U. S. Geol. Surv., Water Supply Bull.* 67.)

finds its way into deeper layers of the soil, which it completely saturates.

The water in this saturated zone, which is termed the *ground water* (Fig. 131), forms a great reservoir of supply for lakes, springs, and wells; and its upper surface, known as the water table, agrees somewhat closely with that of the land surface, but is farther from it under hills (Fig. 131), and nearer to it under the valleys. Under some depressions it may even reach the surface and form springs or swampy conditions (see Fig. 131). The depth of the water table is quite variable, being but a few feet below the surface in moist climates, while in arid regions it may be 100 feet or more.

In any area, however, the water table may show periodical fluctuations, due in part and mainly to variation in the supply. Near the coast line, the rise and fall of the tide may also affect it (Fig. 132). In all ground water there is a slow but constant movement from higher to lower levels, just as in the case of surface waters, so that the ground water flows toward the valleys. There it may discharge into the streams, but in some instances it follows the valley bottom below the river bed, separated from the river water by a more or less impervious layer (6). The composition of the ground water also shows a somewhat close relation to the rocks or soils in which it accumulates.

**Artesian Water.** — Under this heading are included those waters confined in rocks of consolidated or unconsolidated character, under sufficient pressure to cause the water to rise toward the surface, along an avenue of escape, but not necessarily high enough to produce an outflow.
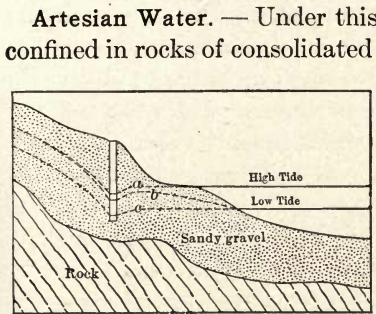


Fig. 132. — Section showing effect of tide on level of water table. (*After Ellis, U. S. Geol. Surv., W. S. Bull.* 232.)

The artesian water found in rocks may collect there in cavities of diverse size, origin, and shape, such as pores between the grains, joint cracks, bedding planes, solution cavities, cavities due to brecciation, gas cavities of lavas, etc. (Pl. XXXVII). The surface water finds its way down into these open spaces in the rocks, and if there is some confining agent, such as denser rock, or other more or less impermeable barrier, present, it may be held there. Under these conditions it may be under more or less pressure and if some avenue of escape, such as a drill hole, is opened up, the water rises towards the surface.

The requisite conditions of an artesian flow might therefore be stated as follows (2): (1) adequate source of water supply; (2) a retaining agent offering more resistance to the passage of water than the well or other opening; (3) an adequate source of pressure.

The retaining agent may be a stratum, vein, or dike wall, joint, fault, a water layer, etc., while the pressure is due primarily to variations in level in the different parts of the artesian system, although there may be numerous modifying factors. It will be understood, from what little has been stated above, that a supply of artesian water might be found under a variety of conditions. Only

two of these will be considered here, although several others are shown in Pls. XXXVII and XXXVIII.

*Stratified Beds.* — The structure sometimes found in stratified rocks closely approaches the most favorable conditions for an artesian circulation. That is, we have inclined layers of pervious rock, inclosed between beds of impermeable, or but slightly permeable, character. Water flowing down these permeable beds, either through the pores, or in the pores and joints together, may accumulate in sufficient quantity to yield a large and sometimes steady supply. While sandstones usually show the highest porosity of any of the sedimentary rocks, limestones may also yield a good flow, although in these the water must accumulate largely in the joint planes. Such a structural type, composed of water-bearing beds between denser ones, may be termed an artesian slope (Pl. XXXVII,Fig. 1),and it is of great importance. The wells tapping such a supply are sometimes many miles from the area of intake, and may be sunk to depths of as much as 2000 feet in order to reach the water-bearing bed. A more or less tight bed over the porous one is essential, but the underlying bed need not be impervious.

A not uncommon type of artesian reservoir is that found in glacial drift where water-bearing lenses of sand or gravel are overlain or more or less surrounded by clay. In this case the water seeping downward from the surface collects in the gravel pocket.

There are many areas in the United States in which the conditions are favorable to an artesian water supply in stratified rocks, as the various state and government reports will show. A few of the more important ones may be briefly referred to.

Along the Atlantic and Gulf coastal plain an abundant supply of artesian water is obtained from the Cretaceous and Tertiary beds at depths varying from 50 feet along the inland border, to 1000 feet and over along the coast (7, 10, 22, 41, 48) (Fig. 133).

A second area is that of the upper Mississippi Valley (50), in which an abundant supply of potable water is obtained from the St. Croix and St. Peters sandstone, whose outcrop in Minnesota and Wisconsin covers some 14,000 square miles.

In the Great Plains (8) region water is obtained from the Dakota sandstone, whose collecting area is around the border of the Black Hills (Fig. 134) and eastern edge of the Rocky Mountains. This source is available in South Dakota and eastern Nebraska and Kansas and Colorado. The chief use of the water in this region is for irrigation.

PLATE XXXVIII
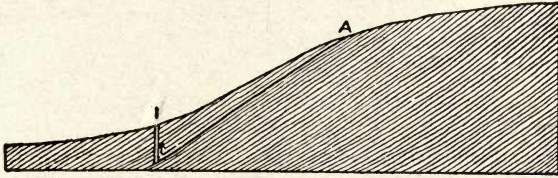


FIG. 1. — Section illustrating conditions of flow from foliation and schistosity planes. *A*, Foliation plane feeding flowing well 1. (*After Fuller.*)
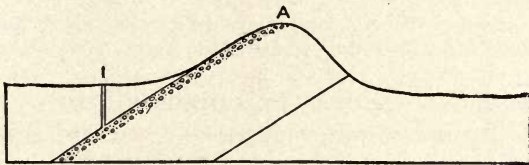


FIG. 2. — Section illustrating conditions of flow from vesicular trap. *A*, Vesicular zone feeding well 1. (*After Fuller.*)
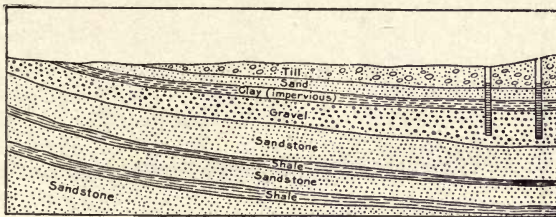


FIG. 3. — Section showing accumulation of water in stratified rocks with low intake. (*After Ellis.*)

(419)

For the arid regions of the west this source of supply has been of inestimable value, and has been the means of reclaiming many an area of hitherto useless land.
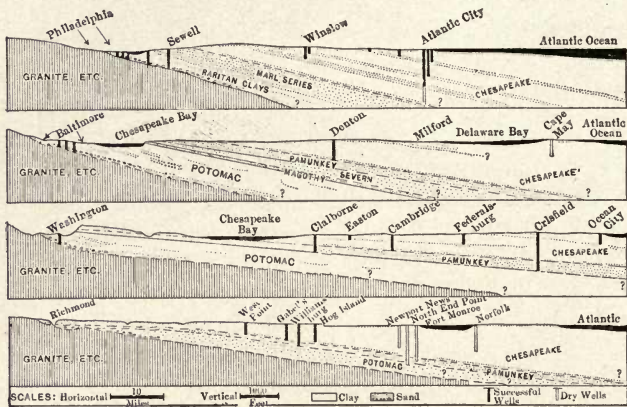


FIG. 133. — Geologic section of Atlantic Coastal Plain, showing water-bearing horizons. (*After Darton, Amer. Inst. Min. Engrs., Trans. XXIV.*)

*Crystalline Rocks.* — Recent investigations have shown that a considerable amount of water may seep downward along the vertical joint planes of crystalline rocks (Pl. XXXVII, Fig. 2), such as granite, crystalline limestone, gneiss, and schist, and become stored in the horizontal joint fissures, but owing to the density of these rocks, very little water can accumulate in the pores. If now a well
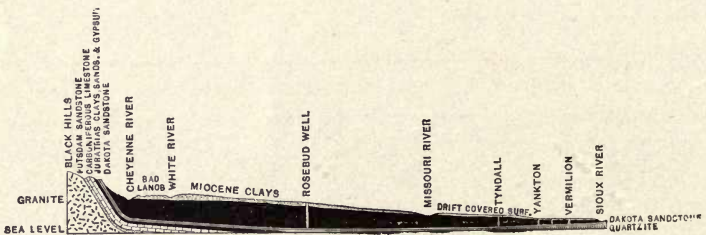


FIG. 134. — Section from Black Hills across South Dakota, showing artesian well conditions. (*After Darton.*)

is drilled so as to strike these water-bearing joints, a more or less steady supply may be obtained. In most cases the volume is not more than 10 gallons per minute, but occasionally as much as 90 gallons has been obtained by pumping.

While the finding of a supply of water in crystalline rocks is more

or less a matter of chance, still the proportion of successful wells is large, although the possibility of success decreases greatly below 200 feet, and is less even below 50 feet than above it.

A number of wells have been bored in the crystalline rocks of New England and even other eastern states (3, 21, 31).

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## MINERAL WATERS

This term is commonly applied to those spring waters containing a variable amount of dissolved solid matter of such character as to make them of medicinal value. Their origin, although often regarded as curious, is simple, the dissolved substances having been derived from the rocks through which the spring waters have circulated. Many mineral waters contain carbonic and even other acids, and alkalies, which further increase their powers of solution. There is apparently some connection between hot mineral springs and geological structure, as they are more abundant in regions of faulting or recent volcanic activity. Waters flowing from shallow sources usually show the lowest mineralization, and those derived from sedimentary rocks often show a greater quantity of dissolved material than those occurring in igneous rocks.

Springs whose temperature is above 70° F. are termed thermal, those between 70° F. and 98° F. being classed as tepid, and those

hotter than this as hot springs. The following will serve as examples to show the temperature of different thermal springs: Sweet Springs, West Virginia, 74° F.; Warm Springs, French Broad River, Tennessee, 95°; Washita, Arkansas, 140° to 156°; San Bernardino Hot Springs, California, 108° to 172°; Las Vegas, New Mexico, 110° to 140°.

The volume of discharge shown by mineral springs is quite variable. The famous Orange Spring of Florida discharges 5,055,000 gallons per hour, while others are as follows: Champion Springs, Saratoga, New York, 2500 gallons; Roanoke Red Sulphur Springs, Virginia, 1278 gallons; Warm Sulphur Springs, Bath, Virginia, 360,000 gallons; Glen Springs, Waukesha, Wisconsin, 45,000 gallons.

While a classification of mineral waters may be geographic, geologic, therapeutic, or chemical, that prepared by A. C. Peale is perhaps as satisfactory as any. He subdivides mineral waters into the following classes: —

| | | | |
|---|---|---|---|
| Alkaline | | | |
| Alkaline-saline | { Sulphated<br>{ Muriated | { Sodic<br>{ Lithic | |
| Saline . . . . | { Sulphated<br>{ Muriated | Potassic<br>Calcic<br>Magnesic<br>Chalybeate<br>Aluminous | |
| Acid . . . . . | Sulphated<br>Muriated<br>Siliceous | { Sulphated<br>{ Muriated | |

The springs falling in the above groups may be either thermal or nonthermal, and may be either free from gas or contain $CO_2$, $H_2S$, N, or $CH_4$.

Other classifications will be found in references.

Most mineral water classifications are unsatisfactory, partly for the reason that, although they give the important salt present in each class, they do not give the amount, a matter of some importance. Thus it has been pointed out for example that two mineral waters might contain, respectively, 250 and 2000 parts per million of mineral matter of the same relative composition, and would therefore fall in the same class. Both might be *carbonated*, *sodic*, *calcic*, *muriated*, *alkaline-saline*. Now the former would be satisfactory, but the latter would not only be too *hard* for household uses, but would contain so much salt as to give it a decided taste.

Again, it is important in some cases to know the probable combinations present. To a physician it is immaterial to know whether sulphates present

are those of sodium or magnesium, since they have similar medicinal effects. The engineer must know which, as the former is harmless, while the latter forms boiler scale.

**Distribution of Mineral Waters in the United States.** — There are, according to Peale, between eight and ten thousand mineral springs in the United States, and of this number 695 reported production, 1908. The majority of the commercially valuable mineral springs are located in the eastern United States and Mississippi Valley. West of the 101st meridian they are confined chiefly to the Pacific coast. No thermal springs are known in the New England states. Among the American springs, those at Saratoga, New York, have an international reputation, and compare well with many of the foreign ones. Others of importance are the Hot Springs of Virginia and the Hot Springs of Arkansas.

The following table contains the analyses of several types of mineral waters from the United States: —

ANALYSES OF AMERICAN MINERAL WATERS

| CHEMICAL CONSTITUENTS | CONGRESS SPRING, SARATOGA, N. Y. SALINE CARBONATED | EXCELSIOR SPRING, SARATOGA, N. Y. SALINE, CARBONATED | WARM SULPHUR SPRINGS, VIRGINIA CALCIC | HOT SPRINGS, ARK. THERMAL, CARBONATED | RED SULPHUR SPRING, SHARON, N. Y. ALKALINE SALINE, SULPHURETED | LAS VEGAS HOT SPRINGS, NEW MEXICO ALKALINE SALINE | BETHSEDA SPRING WAUKESHA, WIS. ALKALINE CALCIC |
|---|---|---|---|---|---|---|---|
| | gr. per gal. | gr. per gal. | gr. per gal. | gr. per gal. | gr. per gal. | gr. per gal. | gr. per gal. |
| Sodium carbonate . . | — | — | — | — | — | 5.00 | — |
| Sodium bicarbonate . | 10.77 | 8.75 | — | — | .49 | — | 1.26 |
| Sodium sulphate . . | — | — | — | — | — | 16.27 | .54 |
| Calcium carbonate . . | — | — | 5.22 | } 3.17 | — | 11.41 | — |
| Magnesium carbonate . | — | — | — | | — | | — |
| Calcium bicarbonate . | 143.40 | 41.32 | — | 12.66 | 12.93 | — | 17.02 |
| Magnesium bicarbonate | 121.76 | 29.34 | — | — | .69 | — | 12.39 |
| Lithium bicarbonate . | 4.76 | — | — | — | — | Trace | — |
| Iron bicarbonate . . | .34 | 3.00 | — | 2.17 | — | — | .04 |
| Magnesium sulphate . | — | 2.15 | — | — | 18.96 | — | — |
| Potassium sulphate . | .89 | — | 1.38 | — | — | — | — |
| Sodium chloride . . . | 400.44 | 166.81 | — | — | .33 | 27.34 | .46 |
| Potassium chloride . . | 8.05 | — | — | — | — | — | 1.16 |
| Potassium bromide . . | — | 1.57 | — | — | — | — | — |
| Sodium bromide . . . | 8.56 | — | — | — | — | — | — |
| Sodium iodide . . . | .14 | 4.67 | — | — | — | — | — |
| Silica . . . . . . | .84 | .53 | 1.72 | .38 | .45 | 2.51 | .74 |
| Calcium sulphate . . | — | — | 14.53 | 2.54 | 96.64 | — | — |

**Production of Mineral Waters.** — The production of mineral waters in the United States for the last five years was as follows: —

Production of Mineral Water in the United States, 1910–1914

| Year | Commercial Springs | Gallons Sold | Value |
|------|------|------|------|
| 1910 . . . . . . . . | 709 | 62,030,125 | $6,357,590 |
| 1911 . . . . . . . . | 732 | 63,788,552 | 6,837,888 |
| 1912 . . . . . . . . | 746 | 62,281,201 | 6,615,671 |
| 1913 . . . . . . . . | 838 | 57,867,399 | 5,631,391 |
| 1914 . . . . . . . . | 829 | 54,358,466 | 4,892,328 |

Rank of States Based on Springs Reporting, on Quantity Sold, and on Value of Output, 1914

| Rank | Number of Springs Reporting | Quantity Sold | Value of Medicinal Waters | Value of Table Waters | Total Value |
|------|------|------|------|------|------|
| 1 | New York | New York | California | New York | New York |
| 2 | Massachusetts | Minnesota | Indiana | Wisconsin | Wisconsin |
| 3 | Virginia | Wisconsin | Virginia | California | California |
| 4 | California | Ohio | Texas | Maine | Maine |
| 5 | Pennsylvania | Massachusetts | Maine | Pennsylvania | Virginia |
| 6 | Connecticut | Virginia | Wisconsin | Minnesota | Pennsylvania |
| 7 | Missouri | Pennsylvania | Arkansas | Virginia | Minneosta |
| 8 { | Ohio / Wisconsin | Connecticut | New York | Massachusetts | Massachusetts |
| 9 | Texas | California | Missouri | New Jersey | New Jersey |
| 10 | Maine | Illinois | Kansas | Connecticut | Ohio |

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# PART II

## ORE DEPOSITS

# CHAPTER XIV

## ORE DEPOSITS

**Definition.** — The term *ore deposits* is applied to concentrations of economically valuable metalliferous minerals found in the earth's crust, while under the term *ore* are included those portions of the ore deposit of which the metallic minerals form a sufficiently large proportion and are in the proper combination to make their extraction possible and profitable. The term *ore mineral* can be applied to those minerals carrying the desired metallic elements which occur within the deposit. These ore minerals may in some cases make up the entire mass of the ore.

A metalliferous mineral or rock might therefore not be an ore at the present day, but become so at a later date, because improved methods of treatment or other conditions rendered the extraction of its metallic contents profitable.

A few metallic minerals serving as ore minerals, such as gold, copper, platinum, and mercury, sometimes occur in a native condition; but in most cases the metal is combined with other elements, forming sulphides, oxides, carbonates, sulphates, silicates, chlorides, phosphates, or rarer compounds, the first five of these being the most numerous. A deposit may contain the ore minerals of one or several metals, and there may also be several compounds of the same metal present.

**Gangue Minerals.** — Associated with the economically valuable metallic minerals there are usually certain common ones, of metallic or non-metallic character, which carry no values worth extracting. These are termed the *gangue minerals*. They often form masses in the ore deposit which can be avoided or thrown out in mining, but at other times they are so intermixed with the valuable metalliferous minerals that the ore is crushed and the two separated by special methods.

Quartz is the most abundant gangue mineral, but calcite, barite, fluorite, and siderite are also common, while dolomite, hornblende, pyroxene, feldspar, rhodochrosite, etc., are found in some ore bodies.

x                              429

**Origin of Ore Bodies.** — The fact that ores form masses of greater or less concentration is explainable in two ways : either they have been formed at the same time as the inclosing rock (*contemporaneous* or *syngenetic*) ; or else they have been formed by a process of concentration at a later date (*subsequent* or *epigenetic*).   The first theory is found to be applicable to some ores in igneous rocks, and to some sedimentary ones, while the second applies to most cre deposits, regardless of the character of the inclosing rock.

It must not be inferred from this, however, that the origin of all known ore bodies has been definitely settled, for a strong difference of opinion sometimes exists among geologists regarding the same deposit, and some have been placed first in one class and then in another; but with all this shifting the number of occurrences falling in the syngenetic class has increased considerably and now includes some large and important ore deposits.

**Syngenetic Deposits.** — These may be divided into two groups, viz. those of magmatic origin, and those of sedimentary origin.

**Magmatic Segregations** (2, 4, 13, 21, 52–60). — Under this heading is included a small class of deposits, whose intimate association with igneous rocks proves beyond doubt that they have been derived from the igneous magma by a process of segregation during their crystallization from it.

These separations generally take place during the early stages of cooling, and form the first of a series of minerals, usually crystalizing out in a somewhat definite order.

The order of crystallization stated by Rosenbusch, and which applies especially to granitic and dioritic rocks, there being some exceptions for more basic ones, is as follows:

1. Iron ores and accessory constituents (magnetite, hematite, ilmenite, apatite, zircon, spinel, titanite, etc.).

2. Ferromagnesian silicates (olivine, pyroxene, amphibole, mica, etc.).

3. Feldspathic constituents (feldspars and feldspathoids, including leucite, nephelite, sodalite, etc.).

4. Free silica (quartz).

We see then that the crystallizations show an order of decreasing basicity. Moreover, if the magma contains water, this is retained in part in the still fluid or molten part, so that finally we may have a mixture of silica, possibly some alkalies, water and other mineralizers (fluorine, boron, etc.).

Separations of the heavy metals appear to be characteristic of igneous magmas deficient in acid-forming constituents, but this is not surprising, for a consideration of the composition of igneous

rocks shows us that since the basicity of an eruptive rock depends partly on the percentage of the oxides of heavy metals, the basic ones are more apt to yield magmatic separations than the acid ones. In some cases, however, metallic concentrations occur in acid rocks.

In these segregations it is seen that the metallic minerals which have gathered together to form the ore deposits are simply common accessory, and not important, constituents of the igneous rocks. That is, the ore body and the country rock contain the same minerals, but the relative abundance of the silicates and metallic



FIG. 135. — Chromite in olivine (in part altered to serpentine), from Kraubath, Austria.  ×15.

minerals is reversed.   As an example: the average percentage of chromium in the rocks of the earth's crust is about .01 per cent. In a peridotite magma it forms about .2 per cent, but in segregations within the magma we find 40 to 60 per cent $Cr_2O_3$.

Where the metallic minerals crystallize out and segregate, the ore body forms a portion of the igneous mass, and usually grades off into it, but in some cases the ore minerals have not only become differentiated from the parent magma, but this separated portion has been forced up from below, independent of the rest of the igneous mass, thus forming a true dike.

The end products in the cooling of a magma, which crystallize out as pegmatite dikes or quartz veins, may sometimes carry metals, such as tin (North Carolina) or gold (Silver Peak, Nev.)

and these are likewise regarded by some as magmatic syngenetic deposits.

Ores formed by magmatic segregation show a crystalline texture (Fig. 164), usually of coarse, but sometimes fine, grain. Porphyritic texture is sometimes developed in these deposits, the phenocrysts being ore minerals. Graphic inter-growths may occur, and while some believe it indicates that the magma contained a eutectic mixture of two minerals which crystallized at the same time, this view is not held by all geologists.

*Form of Magmatic Ore Bodies.* — Ore deposits formed by magmatic segregation not only show a varying degree of concentration, but vary greatly in their size and form. Some exhibit vast dimensions, as the Scandinavian iron ore deposits of Kirunavara and Luossavara (Fig. 162); indeed, these are much larger than any of this type known in North America, the nearest approach to them being the nickel deposits of Sudbury-Ontario.

Magmatically segregated ore bodies may occur: (1) as irregularly distributed deposits, which show a transition into the surrounding igneous rock; (2) as deposits on the border of the igneous rock, but lying mainly within the former and sending tongues out into either; or (3) as dikes in the igneous rock. In the latter case they might be regarded as very basic segregations, which have been forced up from below, subsequent to the intrusion of the basic rock itself. (See Iron ore, Wyoming.)

As stated above, the number of ore deposits formed by magmatic segregation is small in number, but the following types can probably be referred to this class:

1. Titaniferous iron ores in basic and intermediate eruptives (Adirondacks, New York, Iron Mountain, Wyoming, etc.), and perhaps some iron ores in acid eruptives (Mineville, New York).

2. Chromite in peridotites and the secondary serpentines.

3. Some sulphide ores (Sudbury, Ontario, and Lancaster, Pennsylvania) (?).

4. Nickel-iron ores in eruptive rocks (no value).

5. Platinum in basic eruptives (no value).

6. Tin ores in some pegmatites (South Carolina).

7. Some gold ores in quartz veins (Silver Peak, Nevada).[1]

**Syngenetic Deposits of Sedimentary Origin.** — If ores in sedimentary rocks are of contemporaneous origin they must have been

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[1] These would be referred to the deeper vein zone by some.

formed at the same time as the rock in which they occur, the process being either a chemical or mechanical one, similar to that by which the different kinds of stratified rocks have been formed. Two classes might be recognized, viz. (1) interstratified deposits, and (2) surficial deposits or placers.

*Interstratified sedimentary deposits.* — These may have originated by processes analogous to those which have formed the inclosing rocks. Some may have accumulated by precipitation from sea water or fresh water, a process which is going on even at the present day, as shown by the deposition of limonite in ponds, or the formation of nodules of limonite, pyrite, or manganese on the ocean bottom.

Others may be of mechanical origin, the grains of metallic minerals having been set free by disintegration of rocks on the land, and the particles later becoming segregated, as in the case of magnetite sands, formed along the beaches by wave action. Both types may be subsequently covered up by other sediments, or in rarer cases by igneous flows.

Sedimentary deposits of the two types just mentioned are of tabular form, and thin out horizontally in all directions, but many of them are of great extent and even of curiously uniform character, as for example the Clinton ores of the eastern United States (p. 538), the bedded limonites of France and Germany (p. 556) or the hematite of Newfoundland (p. 546). They are sometimes sharply separated from the inclosing rocks, or at others grade into them. Further characteristics to be noted are the absence of fragments of the overlying country rock in the ore and of veinlets branching off from the bed. If folding of the rocks has occurred, the beds follow the folds. Sedimentary deposits are occasionally enriched by water circulating through the beds and causing a concentration of the contents, either by removal of soluble elements, addition of metallic compounds or rearrangement of those present. Syngenetic bedded deposits often show a fine-grained texture. In cases they are oolitic or even fossiliferous, the metallic minerals in part replacing the fossils. Some may show finely crystalline quartz and also finely crystalline secondary minerals.

*Placer deposits.* — This term is applied to deposits of gravel, sand, or even clay, containing heavy metallic minerals like gold, cassiterite, platinum, etc., concentrated usually by mechanical agents such as streams, waves or wind.

When the products of rock decay are washed down the slopes

and into the streams, the lighter material is carried off to sea, while the heavier particles such as pebbles and metallic mineral grains remain behind in the stream channels. The metallic fragments by reason of their higher specific gravity settle to the bottom of the channel, and all become more or less rounded by the rubbing action they are subjected to while being moved along by the stream current.

Placer deposits may also be formed along beaches by wave action, while a rare type are those which originate in dry climates by the disintegration of rock, little of the material being removed, except sandy particles which are blown away by the wind. A somewhat special type, called *eluvial* placers, originates by the weathering of gold-bearing rocks, the residual products remaining at the point of origin, or migrating a short distance down grade. The gold in these is rough and angular. Eluvial placers are known in the southern Appalachians.

From what has been said above, one must not get the idea that placer deposits did not form in the past, for they did, and are known to exist in sedimentary formations as far back as the Cambrian. (See Gold, South Dakota.)

**Epigenetic Ore Deposits.** — These, as previously stated, are of later age than the inclosing rock. In other words, they have been concentrated in the rocks by natural processes.

In order to demonstrate this it is necessary to show: (1) the source of the metals found in the rocks; (2) the existence of a carrier which could transport the metals, in solution probably; and (3) the existence of conditions favorable to the precipitation of the ore.

**Occurrence of Metals in the Rocks.** — It is well known that metallic minerals in small quantities are widely distributed, in both igneous and sedimentary rocks. Sandberger (18), for example, has shown by analyses the presence of nickel, copper, lead, tin, and cobalt in such minerals as hornblende, olivine, and mica; and Curtis has found traces of silver, gold, and lead in the quartz-porphyries at Eureka, Nevada,[1] and silver, arsenic, lead, copper, and gold in the granite at Steamboat Springs, Nevada.[2] Grout[3] found .029 per cent copper in Keweenawan traps of Minnesota, while Lewis[4] recorded .025 per cent CuO in the New Jersey dia-

[1] U. S. Geol. Surv., Mon. VII: 80.
[2] *Ibid.*, Mon. XIII: 350.
[3] Econ. Geol., V: 471, 1910.
[4] *Ibid.*, II: 242, 1907.

base. Winslow has pointed out the presence of small quantities of lead and zinc in the limestones of Missouri and Wisconsin (see lead and zinc references), and Wagoner has made similar tests on California sediments (172). Since, however, the sediments were originally derived from the igneous rocks, it follows that the latter must be the original source of the minerals.[1] It is interesting to note that even in the igneous rocks the metals are not impartially distributed, but that certain metals seem to favor certain rocks.[2] Thus iron, manganese, nickel, cobalt, chromium, and platinum, seem to favor basic rocks; while tin, tungsten, and some rarer metals favor the acid ones. Titanium has been found in both acid and basic.

While the occurrence of metallic minerals in the rocks of the earth's crust is widely recognized, few, perhaps, realize the small percentage existing outside of those concentrated portions, the ore deposits; and the following table, showing the average composition of rocks of the earth's crust,[3] will serve to emphasize this point:

| | | | |
|---|---|---|---|
| Oxygen | 47.29 | Manganese | .078 |
| Silicon | 28.02 | Sulphur | .103 |
| Aluminum | 7.96 | Barium | .092 |
| Iron | 4.56 | Chromium | .033 |
| Calcium | 3.47 | Nickel | .020 |
| Magnesium | 2.29 | Lithium | .004 |
| Potassium | 2.47 | Chlorine | .063 |
| Sodium | 2.50 | Fluorine | .10 |
| Titanium | .46 | Zirconium | .017 |
| Hydrogen | .16 | Vanadium | .017 |
| Carbon | .13 | Strontium | .033 |
| Phosphorus | .13 | | |

An examination of the above figures shows that, of some twenty metals that are of importance to us for daily use, only five, viz. aluminum, iron, manganese, chromium, and nickel, are included in the above list, and that the others must be present in amounts of less than .01 per cent.

Professor Vogt [4] has endeavored to estimate the approximate average amount present of other important (economically) metals,

[1] For a most interesting discussion of this see Siebenthal, U. S. Geol. Surv., Bull. 606: 67, 1915.

[2] De Launay, Ann. d. Min., Aug., 1897.

[3] Clarke, U. S. Geol. Surv., Bull. 616: 27, 1916.

[4] Zeitschr. prak. Geol., July and Sept., 1898.

not included in the table on page 435. According to him, the percentage amount of tin, zinc, and lead is expressed by a digit in the third or fourth decimal place, copper in fourth or fifth, silver in sixth or seventh, gold and platinum in seventh or eighth. Mercury would show a slightly larger percentage than silver, and arsenic, antimony, molybdenum, and tungsten, between copper and silver. Bismuth, selenium, and tellurium would be placed between silver and gold in the list.

Lindgren (13) differs somewhat from Vogt, and would place the percentage of copper at .01 to .005, zinc at .004 per cent and lead at .002 per cent. He suggests that silver may constitute .00001 per cent of the earth's crust, and gold .0000005 per cent.

As actual examples of the amounts present, we may quote the following determinations made on eruptive rocks from several localities:—

| Metal | Per cent | Locality |
|---|---|---|
| Copper . . . . . . . | .009 | Missouri |
| Copper . . . . . . . | .029 | Minnesota |
| Lead . . . . . . . | .0011 | Colorado |
| Lead . . . . . . . | .004 | Missouri |
| Zinc . . . . . . . | .009 | Missouri |
| Silver . . . . . . . | .00007 | Leadville, Colo. |
| Silver . . . . . . . | .00016 | Eureka, Nev. |
| Gold . . . . . . . | .00002 | Eureka, Nev. |
| Gold . . . . . . . | .00004 | Owyhee Co., Ido. |

It is quite evident that the percentage of metal normally distributed in the rocks of the earth's crust, as indicated above, is far too low to be regarded as workable ore, for, in order to be classed as such, the rock must contain at least a certain percentage of the metal, which varies not only with the metal, but even with the same one under different conditions, such as location and nature of ore.

Iron ores, for example, especially low-grade ones, cannot be successfully worked, unless favorably located; whereas gold ores, being of higher unit value, are much less affected by this factor. Again, the nature of the ore has to be considered, some being quite easily treated, but others less so, and here the manner of association comes into consideration. Thus the presence of copper or

lead may facilitate the extraction of gold and silver, while zinc hinders it. Lastly, with changed conditions, a rock which was formerly of no economic value may become a profitable ore to work, partly because improved methods of treatment have lowered the cost of production. The quantity of metal necessary in an ore for profitable working is referred to under " Value of Ores " in this chapter.

**Source of Water in the Earth's Crust** (142, 143, 145, 147, 152). — Water is known to be widely but not uniformly distributed in the rocks of the earth's crust, and much of it is in slow but constant circulation. Geologists admit that this *ground water* has been an important ore carrier, but there has existed a strong difference of opinion, regarding its source, or at least the source of that portion which has been active as an ore carrier.

Three types of ground water are recognized, viz. (1) *Meteoric*, (2) *Connate* and (3) *Juvenile*.

*Meteoric Water.* — A variable portion of the rain falling on the earth's surface penetrates the pores and other cavities of the regolith and bed rock, forming a more or less saturated zone, whose upper limit is known as the *water-table*. While the latter follows in a general way the surface contours, it may approach close to the surface under the valleys, and lie at a greater depth below the hills. In moist regions the average depth of the water table is shallow, but in arid regions it may lie deep, sometimes 2000 feet or more.

Between the surface and the water table is a zone of descending oxidizing waters, as well as one containing altered rocks and minerals. This zone has been variously called the *vadose region* (Posepny), *belt of weathering* (Van Hise) and *gathering zone* (Finch).

Below the water table, the meteoric water penetrates to variable but probably not great depths. Some, like Van Hise, believed that it might go as deep as cavities existed, in other words to the bottom of the zone of fracture or cavities. Hoskins figured that this might be as deep as 10,000 meters, but the experiments of Adams and King [1] indicated that it may be even deeper.

The last named, in their experiments, subjected granite cylinders with a .05-inch hole bored through them to a pressure of 96,000 pounds per square inch, and a temperature of 550° C. for 70 hours, without producing any change

[1] Jour. Geol., XX: 119, 1912.

in the opening.  The pressure corresponded to that which would exist at a
depth of 15 miles, and the temperature to that estimated to prevail at 11 miles
below the surface.  In granitic rocks therefore cavities might exist at the
above mentioned depth.

There seems strong doubt, however, as to whether surface
waters penetrate to any such depth, for observations in mines not
only indicate frequently a decrease in water with depth, but the
bottoms of some deep ones are dry and dusty.

Finch suggests dividing the water below the water table into
two zones.  The upper one he calls the discharge zone, and in this
the water is in lateral motion toward some lower discharge level.
The lower is called the *static* zone, and in this the water is sta-
tionary or nearly so.

Attempts have been made to estimate the quantity of water in the outer
part of the earth's crust, the amount being expressed in terms of thickness of
a sheet of water covering the earth's surface.[1]

These estimates by different authors are:

Delesse, 1861, 7500 feet.
Slichter, 1902, 3000–3500 feet.
Chamberlin and Salisbury, 1903, 800 feet.  .
Chamberlin and Salisbury, 1903, 1600 feet (on another assumption).
Van Hise, 1904, 226 feet.
Fuller, 1906, 96 feet.

The later estimates, which are probably more exact, indicate a rather
shallow depth, and indicate the impossibility of assuming meteoric waters
to be genetic factors in the formation of deep veins.

That meteoric waters were the most important, if not the only
collecting agents of ores, was advocated by many of the earlier
geologists, including J. Le Conte,[2] F. Posepny,[3] and L. De Launay,[4]
while in recent years this theory of ore formations has been strongly
urged by Van Hise (12).

There is no doubt that the circulation of meteoric waters is
quite extensive, and it plays an important role in the secondary
concentration of ores, by downward-moving solutions, but its
effects as a factor in the primary concentration of ore deposits
are probably unimportant except in a few regions.

*Connate Water* (147).—This is water which is indigenous to the
rocks containing it, such as original sea-water in a sedimentary

[1] Fuller, Water Supply Paper, 160: 59, 1906.
[2] Amer. Jour. Sci., July, 1883, p. 1.
[3] Trans. Amer. Inst. Min. Engrs., XXIII, p. 213.
[4] La Recherche, Captage, et Aménagement des Sources Thermo-Minerales.

PLATE XXXIX
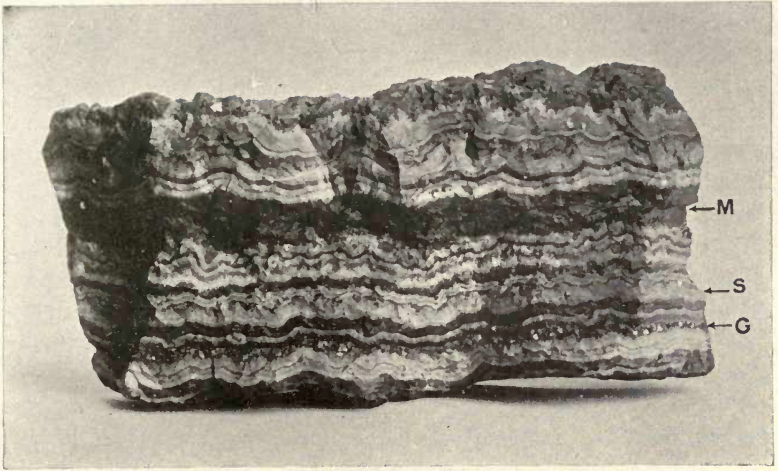


FIG. 1. — Specimen from Moresnet, Belgium, showing crustified structure. Light bands, sphalerite (*S*); Dark bands, pyrite (*M*); Light grains, galena (*G*). (*From specimen in Cornell collection.*)



FIG. 2. — Steamboat Springs, Nev. The white deposit is siliceous sinter carrying mercury and antimony. Steam rises from numerous fissures whose sides are coated with sulphur crystals. (*H. Ries, photo.*)

(439)

rock or magmatic water in an igneous rock. In the former it is found chiefly in sandstones and sands, the brines of the Lower Carboniferous and some other formations being examples of it.

Igneous rocks may retain some of their magmatic waters on consolidation, and it is possible that some of the changes which go on in them after solidification depend on this residual liquid (13).

Submarine lava flows may absorb ocean water, and that found in some deeply-buried lava flows, as those of the Keweenaw peninsula of Michigan, may be of this nature. Lane (1 8), in his Lake Superior work, has called attention to the relatively large calcium chloride content of the copper-mine waters at depths of 600 to 1600 feet, and believes that it must be of marine origin. In fact, both sodium and calcium chlorides are in evidence with depth, the former preponderating at first, but deeper down yielding to the latter.

*Magmatic Water* (40, 75, 80, 83, 130, 145, 147, 152). — The majority of geologists now believe that the primary concentration of ores has in most cases been performed by magmatic waters.

This theory, although it has grown greatly in recent years, is not a new one, for it was suggested by Elie de Beaumont as early as 1850;[1] but its full significance was not grasped until some years later, when the writings of Vogt[2] (in 1894), Spurr,[3] Lindgren, and especially Kemp (80) did much to emphasize its importance.

The general theory is that deep-seated masses of igneous rock have dissociated water as well as other gaseous elements, the water- and gas-filled cavities in quartz indicating this. In addition, there may also be chemically combined water. As the magma solidified, the water (probably in gaseous form) was expelled, carrying along dissolved substances.

Some have claimed, of course, that the water contained within the magma may have come from external sources in at least two ways as follows: 1. By infiltration of sea-water to the igneous mass, a somewhat unlikely process, as the heat would drive it out. 2. By the absorption of hydrated rocks, which became engulfed in the rising magma as it forced its way upward, a phenomenon regarding which field evidence is lacking.

[1] Geol. Soc. France, Bull. IV: 1249.
[2] Zeitschr. für prak. Geol. II.
[3] U. S. Geol. Surv., 16th Ann. Rept., II.

One thing seems certain, and that is, that the igneous rocks give off water in vaporous form during cooling. Evidence of its presence is found in volcanic emanations, as most convincingly shown by Day and Shepherd (39), by the analyses published by F. C. Lincoln (40), and the work of R. T. Chamberlin.[1]  As against this evidence there is the statement of P. Brun (37), based on possibly insufficient field data, that water is not given off by magmas.

Many of the points brought out by the advocates of magmatic waters as ore-concentrating agents have been used as arguments against the possible efficiency of meteoric ones.  These include the following: Meteoric waters do not reach great depths, in fact probably not more than 2000 feet or sometimes less from the surface, and when they do penetrate to a greater distance, it is because they have followed some fissure.  The lower levels of many deep mines are so dry as to be dusty.  Ores have been concentrated at a much greater depth than that reached by surface waters.  It is perfectly reasonable to regard igneous rocks as an important source of water, and the experiments of Daubree have shown that a molten granite contains a large amount of vapor which it retains while at great depths, but gives off on approaching the surface and cooling.

It is an undeniable fact that most metalliferous veins are found in areas of igneous rocks, and Lindgren (see Metallogenetic Epochs on a later page) has shown that in the case of the gold deposits of North America the periods of vein formation agreed closely with those of igneous activity.  It is also a noteworthy fact that, with the exception of some deposits of commoner metals, such as some iron, copper, lead, and zinc, ores are found in close association with igneous intrusions, which seems to postulate a close connection between igneous rocks and ore deposits, as advocated by such authorities as Weed, Kemp, Lindgren, and Emmons. While the importance of magmatic waters as agents of primary deposition is quite generally admitted, it is true that the metalliferous minerals as originally deposited have not always been sufficiently concentrated to serve as ores, but they have become concentrated at a later date by meteoric waters, as at Bisbee, Arizona. (See Ransome, under copper references.) Posepny (84), in his work on the Genesis of Ore Deposits, distinguishes between descending surface waters, or *vadose* circulations, and

[1] Carnegie Institution, 1908.

ascending waters from great depths.  It is the former that have
been active in the secondary concentration of ores.

**Composition of Ground Waters** (5, 13, 140, 142, 147).—The ground
waters show a variable temperature and always a variable quan-
tity of dissolved matter.

The waters of sedimentary rocks, beyond the influence of igne-
ous intrusions, are mainly of carbonate character.  In chloride
waters, sodium and calcium are prevalent, and even calcium
and sulphate ones are not uncommon, but sodium carbonate
waters are rare in mining regions.  The waters are chiefly cold,
although many tepid ones, and even some hot ones occur.  Both
hydrogen sulphide and carbon dioxide may be present in either
hot or cold waters.

In the older igneous rocks, where the effects of vulcanism have
subsided, there is less variation.  The surface waters in these,
where free from disturbing influences, are of the calcium car-
bonate type, but may often show sodium chloride, ferrous and
magnesium carbonates, and even much silica.  If the rocks
contain pyrite, sulphuric acid may be present locally, together
with sulphate of lime, alumina and iron.

Ascending waters in igneous rocks of recent or Tertiary volcanic
activity are often tepid or hot.  They may carry sodium chloride,
or sodium carbonate with carbon dioxide.

*Mine Waters* (110, 140, 146, 148). — These are usually surface
waters, whose composition is modified by the presence of soluble
salts derived from the decomposing minerals of the ore body, or
igneous sources.  They may therefore contain both metallic and
non-metallic elements, and show the power of water to transport
different elements in solution.  The analyses on page 443 will
serve for purposes of illustration.

**Metalliferous Deposits from Springs** (141, 149, 150, 153). —
The composition of many spring waters also affords further
testimony of the ability of underground waters to serve as ore
carriers.  Moreover, occasional examples of metalliferous deposits
now being formed by springs are sometimes found as shown
below.

Weed has described a hot spring near Boulder, Montana (153),
which is depositing auriferous quartz, and the deposit is pointed
out by him to be identical with silver- and gold-bearing quartz
veins of the region between Butte and Helena, Montana.  Of
still more interest is the collection, by evaporation, of copper

ANALYSES OF MINE WATERS

(Parts per million)

|  | I | II | III | IV |
|---|---|---|---|---|
| $SO_4$ . . . . . . . | 406.5 | 2672 | 43.2 | 2039.51 |
| Cl . . . . . . . . | 6.8 | 13 | 7.9 | 8.16 |
| $CO_3$ . . . . . . . | 13.2 | —— | 110.5 | —— |
| $NO_3$ . . . . . . . | —— | —— | —— | —— |
| $PO_4$ . . . . . . . | tr. | tr. | tr. | —— |
| $B_4O_7$ . . . . . . | —— | tr. | —— | —— |
| Br . . . . . . . . | —— | tr. | —— | —— |
| F . . . . . . . . | —— | tr. | —— | —— |
| $SiO_2$ . . . . . . . | 23.2 | 47.7 | 25.9 | 43.80 |
| K . . . . . . . . | 7.1 | 13.1 | 10.6 | 70.0 |
| Na . . . . . . . | 16.2 | 39.6 | 36.4 | 106.27 |
| Li . . . . . . . . | tr. | —— | tr. | —— |
| Ca . . . . . . . | 151.2 | 132.5 | 37.4 | 187.15 |
| Mg . . . . . . . | 28.2 | 61.6 | 12.25 | 93.50 |
| Al . . . . . . . . | —— | 83.5 | 0.4 | 3.12 |
| Mn . . . . . . . | 0.5 | 12.0 | 0.8 | 155.58 |
| Ni . . . . . . . } | —— | 0.5 | —— | —— |
| Co . . . . . . . } |  |  |  |  |
| Cu . . . . . . . | tr. | 59.1 | tr. | 77.05 |
| Zn . . . . . . . | 0.3 | 852 | 0.2 | 49.66 |
| $Fe'''$ . . . . . . . } | 1.8 | 159.8 | 0.7 | 164.82 |
| $Fe''$ . . . . . . . } |  |  |  |  |
| Cd . . . . . . . | —— | 41.1 | —— | —— |
| Pb . . . . . . . | —— | —— | tr. | 3.44 |
| $CO_2$ . . . . . . . | —— | —— | 37.2 | —— |

I. Green Mountain Mine, Butte, Mont., 220-foot level fissure in granite, remote from known veins; II. St. Lawrence Mine, Butte, Mont.; III. Geyser Mine, Custer Co., Col.; IV. Stanley Mine, Idaho Springs, Col. All quoted by Emmons, U. S. Geol. Surv., Bull. 529, pp. 60, 62 and 63, 1913.

from certain Javan hot springs, in which the metal occurs as iodide of copper.[1]

Lindgren has also recently called attention to the occurrence of certain mineral springs near Ojo Caliente, New Mexico (150), whose strongly alkaline water contains much sodium carbonate as well as fluorine, boron, and barium, the last being present in considerable amount.

The pre-Cambrian gneiss near by contains veinlets of colorless

[1] Stevens, Copper Handbook, IV: 156, 1904.

fluorite, probably deposited when the spring waters issued at a higher level.   Higher up the slope is a narrow vein, carrying small amounts of gold and silver in a gangue of colorless fluorite and some barite, and capped by a calcareous tufa.   The latter is supposed to have been deposited at the surface while the fluorite was precipitated farther down in the vein fissure.

At Steamboat Springs, Nev., the hot chloride waters are depositing siliceous sinter (Plate XXXIX, Fig. 2), which contains mercury and antimony in small amounts, while stibnite crystals have been found in some of the spring basins.

**Mode of Concentration.** — From what has been said above we see that water is not only widely distributed in the rocks, but also serves as a carrier of mineral matter.   It is, therefore, an important concentrating agent, whatever its source.   While cold water, free from impurities, has comparatively little solvent power, the presence of acids or alkalies materially increases its solvent capacity, while heat and pressure have also a great influence.

Before considering the causes governing the precipitation of ore minerals in cavities or solid rocks, we may turn to a discussion of the deposits formed by waters of magmatic origin.

**Deposits from Magmatic Emanations.** — Under magmatic emanations are included gases, vapors, or liquids, given off by molten magmas during cooling.

These emanations (37–40), may be determined from those actually in process of emission from cooling igneous magmas, or from those which remain imprisoned in the rocks.

As evidence of the variety of the former we may list the following emanations identified at two well-known volcanoes:

Vulcano, S, Te, As S , $B_2O_3$, NaCl, $NH_4Cl$, $FeCl_3$, $Na_2SO_4 \cdot CaSO_4$, $Li_2(SO_4)_3$, $Al_2(SO_4)_3$, Tl, Rb, Ce, Co, Zn, Sn, Bi, Pb, Cu, I, P.

Vesuvius, 1895.   HCl, $SO_2$, $H_2S$, $CO_2$, S, $CaSO_4$, iron and copper chlorides, NaCl, KCl, $Na_2SO_4$, $K_2SO_4$, $NH_4Cl$, CuO, $Fe_2O_3$, Se, HF, HBr, $NaHCO_2$.

The springs of Carlsbad, Bohemia, which are supposed to be of magmatic derivation show $CO_2$ and salts of the elements Cl, F, B, P, S, Se, Tl, Rb, Cs, As, Sb, Zn, Na, K, Li, Ca, Mg, Sr, Ba, Fe, Mn, Al and Si.

In order to point out more clearly the several processes by which ores may be deposited from magmatic emanations it may be well to turn for a moment to the molten magma and consider certain changes which take place during the period referred to.

A study of large intrusive masses has shown us that the molten mass after coming to rest sometimes tends to separate into two

parts, the one basic, the other acid, with a gradational zone between. The acid portion may be either the outer or central part of the mass.

A segregation of metallic minerals may occur, even if the magma as a whole does not split up. But whether or not such a differentiation occurs, the molten magma, after coming to rest, will cool first in its outer and upper portion, the contraction incident to solidification causing numerous fractures. Into these there may be forced molten rock from the still uncooled lower portions of the mass, or water and gases forced out of the solidifying parts of the magma. This water, however, must be in a vaporous form, because the heat is undoubtedly sufficiently great to raise its temperature above the critical point, and the pressure is likewise heavy. In many cases no doubt the fissure may become filled by a mixture of water and magma, the former in such excess that it may be difficult to say whether this should be called an igneous fusion, or a watery solution, for under pressure water can mix with a magma in all proportions, giving us a series of mixtures, with a fused mass at one end and a hot solution at the other.

Many magmas in cooling give off mixtures of watery vapors and gases (such as fluorine, boron, etc.); and these before leaving the igneous mass no doubt extract metallic or other elements and carry them along, only to deposit them later, either in the outer parts of the cracks in the border of the intrusion or in the surrounding rocks.

As these emanations from the magma get farther away from it, where temperature and pressure are less, the watery vapors condense, and these hot solutions (magmatic or juvenile waters) gradually work their way towards the surface, sometimes reaching it, and flowing out as hot springs.

It is possible and indeed probable that as they reach shallower depths they may become more or less mixed with meteoric waters.

These magmatic emanations with their burden of mineral matter may not only deposit this at a varying distance from the intrusive, but they in many cases often attack the rocks through which they pass, altering them to a marked degree, and in addition dissolve materials from the rocks they permeate.

The kind of materials deposited and the character of the alteration depend to a large degree upon physical conditions, primarily temperature and pressure.

If the deposition and alteration occur while the magmatic emana-

tions are still in a vaporous form (due to high temperature and pressure), the process is termed *pneumatolysis* (gaseous). If it occurs when the water is in liquid form, it is termed *hydatogenesis* (aqueous). In some instances both gases and liquids may be present, the work then being *gas-aqueous* or *pneumato-hydato-genetic*.

It is naturally difficult to prove in many cases whether the phenomena observed were produced by pneumatolytic or hydatogenetic processes.

Certain important types of deposits, formed under these varying physical conditions, may now be referred to.

**Pegmatite Dikes**[1] (2, 13, 20, 21). — The last unconsolidated portions of an intrusive magma may be forced out from the parent mass to form dikes. These dikes, which may be of either basic or acid character, will in general contain the same constituents that are present in the parent magma, but in different proportions, certain residual products being in excess. When coarse grained these dikes are termed pegmatites. Basic rocks like gabbros may be accompanied by pegmatites containing chiefly plagioclase feldspar and pyroxene, while granites are accompanied by those consisting chiefly of feldspar, quartz and muscovite, as well as cassiterite, tourmaline, topaz, monazite, or even other rare minerals.

An important feature is the presence of volatile substances, *mineralizers* (including *watery vapor*), which tend to lower the solidification point of the mass. Indeed, the temperature according to Lindgren may be lower than 500° C., and this combined with the fluidity of the mass, due evidently to a high water content, undoubtedly permits the pegmatite to force its way into many rocks along the separation planes.

Of the mineralizers, fluorine and boron seem to favor acid pegmatites, while chlorine, phosphorus and sulphur are present in the basic ones.

Pegmatite dikes form an interesting and important link in the chain of magmatic products, and while rich in minerals, are not important as sources of the ores. They have been worked for cassiterite as in South Carolina (Ref. 10, Tin) and South Dakota (Ref. 14, Tin). For gold, as at Silver Peak, Nev. (Ref. 92, Gold); for bismuth in the New England district of New South Wales; and for molybdenite in Norway. New South Wales and Queensland.

[1] See Harker, Natural History of Igneous Rocks, p. 293.

**High-Temperature Veins.** — These form a series related in a way to the pegmatite dikes. The latter were intrusions, containing so much water as to be classed properly as aqueo-igneous fusions, and having naturally rather sharply defined boundaries.

The high-temperature veins represent magmatic products forced out from a cooling magma, consisting probably of a mixture of water and gases, with other substances in solution, the whole being under high pressure and temperature. The latter is probably not in excess of 575° C., the inversion point of crystalline quartz,[1] nor is it supposed to have been below 300° C., and the water being heated above its critical temperature was undoubtedly in a vaporous form.

A characteristic feature of these veins is the frequently intense metasomatic alteration of the wall rock, which may result in the conversion of the latter into a coarse-grained mineral aggregate.

The evidence of these conditions is shown by the presence of essentially high-temperature minerals (p. 458), some of which crystallize only in the presence of mineralizers. These include pyroxenes, amphiboles, garnets, apatite, ilmenite, tourmaline, topaz, brown and green micas, spinel, soda-lime feldspars, cassiterite, arsenopyrite, pyrrhotite and some others.

The veins have been formed at great depth, and while in some cases they are close to the intrusive, or even within it, at others they may be some distance from it, but still initially at such depth as to maintain the conditions of temperature and pressure.

Several classes of veins seem to belong to this group, as follows:[2]

1. Veins of cassiterite, wolframite and molybdenum, the first named being specially important.

2. Gold-bearing veins in crystalline schists as those of the southern Appalachians, southern Brazil, southeastern Alaska, Ontario, Lead City, S. Dak., and Kalgoorlie, W. Australia.

3. Copper-gold-tourmaline deposits, represented by those of Cornwall, Eng.;[3] Cactus Mine, Utah; Rossland, British Columbia; and Meadow Lake, Calif.[4]

[1] F. C. Wright and E. S. Larsen, Quartz as a Geologic Thermometer, Amer. Jour. Sci., XXVII: 147, 1909.

[2] Those not referred to in the following footnote are discussed in subsequent chapters on those metals.

[3] Vogt, Krusch and Beyschlag, Ore Deposits, Translation, I: 431.

[4] Lindgren, Amer. Jour. Sci., XLVI: 201, 1893.

4. Lead-silver tourmaline veins associated with the Helena batholith, Montana.[1]

5. Cobalt-tourmaline veins of San Juan, Chile.[2]

**Contact-Metamorphic Deposits** (24–36). — These include masses of metallic minerals and silicates which are found in some sedimentary rocks, chiefly calcareous ones, near their contact with igneous intrusions, specially those of a more or less acidic character (Fig. 136).

It has long been known that an igneous mass may often exert considerable effect on the rocks which it has penetrated, sandstone,
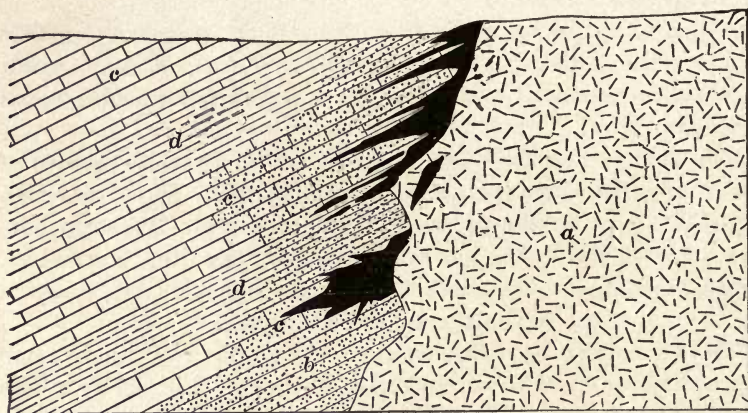


Fig. 136. — Section through a contact-metamorphic zone; showing (a) intrusive rock; (b) quartzite; (c) limestone; (d) shale. Contact-metamorphic zone shown in stippled area, including ore in black. (From *Ries and Watson, Engineering Geology*.)

for example, being altered to quartzite, clay or shale to hornstone, and limestone to marble. Moreover, the contact-metamorphism is accompanied by the development of new minerals in the wall rock.

Thus in limestone there may be formed garnet, wollastonite, epidote, diopside, amphibole, wernerite, vesuvianite, etc.; while in aluminous rock such as shale and slate we find andalusite, sillimanite, biotite, etc.

It was formerly believed by many that these silicates, as in the limestones, must be segregated and recrystallized impuri-

[1] Knopf, Econ. Geol., VIII: 105, 1913.
[2] Stutzer, Zeitschr. prak. Geol., XIV: 294, 1906.

ties, and hence could form only in impure rocks, the pure lime-stones yielding simply a marble.

Investigation of these contact zones has shown us, however, that they contained many elements which were not found in the limestone outside of this belt of metamorphism, and we are therefore driven to the conclusion that they represent substances which have been given off by the magma and lodged in the lime rock.

The theory usually advanced to explain the origin of these contact-metamorphic deposits, is that the original magma contained various volatile substances in solution, such as water, carbon dioxide, sulphur, boron, chlorine, and fluorine, which on the cooling and solidification of the magma are forced out into the surrounding rocks. The watery vapor was evidently heated above its critical temperature (365° C.).

The metals and many of the other elements found in contact metamorphic deposits are supposed to have been carried out by these vapors, but their exact form of combination during emission is not known, although it has been suggested that some were combined with fluorine or boron.

These were forced out into the fissures or pores of the limestone, and replaced the latter wholly or in part, the silica, alumina and iron combining with some of the lime to form different silicates.

While contact-metamorphic effects may extend to a distance of 1 to 2 miles from the eruptive, ore deposits rarely extend more than a few hundred feet, and often terminate suddenly.

Normal granites or other highly acid intrusives may produce contact metamorphism, but do not as a rule form ore deposits. Intrusives like monzonite, quartz monzonites or granodiorites are important associates of contact-metamorphic ores, as can be seen by the numerous occurrences in the Cordilleran region of the United States. The more basic rocks are of less importance, although they sometimes yield contact-metamorphic ores in limestones as in the case of gabbro at Hedley, British Columbia, and diabase at Cornwall, Pennsylvania.

Contact-metamorphic deposits were probably formed at depths of several thousand feet, and possibly in most cases within the zone of fracture. The temperature according to Lindgren was probably high, from 300° C. to 600° C.

Contact-metamorphic deposits are usually of irregular shape

and somewhat bunchy in character, but very little can be said regarding the depth to which they may extend. Where the development has followed certain beds a tabular structure often results.

The common ore minerals found are magnetite and specularite, together with such sulphides as bornite, chalcopyrite, pyrite, pyrrhotite, and more rarely galena and zinc blende. Some gold and silver may be present, but tellurides are probably very rare. Molybdenite and tetrahedrite are known.

The gangue minerals are in general lime-alumina silicates, and include garnet [1] (Fig. 137), wollastonite, epidote, tremolite,
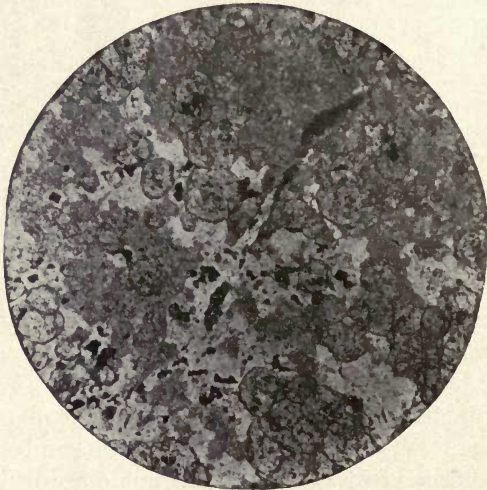


FIG. 137. — Section of garnetiferous limestone from Silver Bell, Ariz. Dark gray, garnet; black, sulphides.

diopside, hedenbergite, zoisite, vesuvianite, ilvaite, quartz and calcite. The first of these is especially abundant and may form nearly the entire mass of the rock. There may also be present minerals containing boron, fluorine, and chlorine, such as axinite, tourmaline, fluorite, scapolite and danburite.

Some difference of opinion exists regarding the details of the contact-metamorphic process.

Thus, while most geologists are agreed that most of the constituents of the ore body are derived from the magma, others like

[1] Mainly andradite, the iron-lime garnet, and less often grossularite, the lime-alumina garnet.

Leith, while admitting some magmatic emanations, hold that the silicate gangue minerals are mainly the result of the recrystallization of original constituents of the limestones. This means the removal of an excess of certain constituents and a consequent reduction of volume, a fact which is said not to be proven by the field evidence.

In strong contrast to the usually accepted theory of the formation of contact-metamorphic deposits, is that advanced and energetically defended by A. C. Lawson (30), who contends that they originate by the action of meteoric waters. According to him any circulation of groundwater will be profoundly disturbed by igneous injections into sedimentary terranes. As a result of this there would be developed an upward circulation following along the periphery of the heated mass, and competent, he considers, to form the characteristic lime-silicate zones. Fractures in the country rock caused by the igneous intrusion, or shrinkage cracks in the latter due to crystallization or cooling, would afford channelways for the rising waters, and these by bringing in material leached from the surrounding region, or by additional leaching of the intrusive, could deposit these in the area referred to usually as the contact-metamorphic zone.

W. O. Crosby has also suggested that contact-metamorphic deposits are the work of meteoric waters (26), while Klockman believes that they represent pre-existing ore bodies altered by intrusives (29).

Other divergent views refer to the question of whether or not the magma was consolidated before mineralization began. Some writers consider that the metamorphism of the limestone occurred first, followed by mineralization.

The order of succession of the minerals is certainly not always the same, and according to different observers the sulphides sometimes follow the silicates, or at other times are contemporaneous with them.

Contact-metamorphic deposits, though sometimes rich enough to mine where not secondarily enriched, need this process in many cases to make the ore workable. This was well illustrated in the case of the Morenci, Arizona, copper ores.

Although this class of deposits was recognized by von Groddeck, as early as 1879, he failed to appreciate the true importance of the associated intrusive. In more recent years the writings of Vogt, Kemp, Weed, Lindgren, and Barrell have greatly increased

our knowledge of the true nature of these interesting deposits, and we now know, moreover, that they form a very important and somewhat common type, which in the United States is restricted mainly, however, to the Pacific Cordilleras. They are also known in Canada, the Yukon, Alaska, and many other countries.

Contact metamorphic deposits may be classified as follows (13):—

1. Magnetite deposits.
   Examples: Iron Springs, Utah, [1] Fierro, N. Mex.,[2] and Cornwall, Pa.[3]
2. Chalcopyrite deposits. Chief ore minerals, chalcopyrite, pyrite, pyrrhotite, sphalerite, molybdenite and specularite.
   Examples: Clifton, Aiiz.,[4] San Pedro, N. Mex.,[5] and Cananea, Mex.[6]
3. Galena-blende deposits.
   Examples: Magdalena Mines, N. Mex.[7]
4. Arsenopyrite-gold deposits. Chief minerals, arsenopyrite and pyrrhotite.
   Examples: Hedley, Brit. Col.[8]
5. Gold deposits.
   Examples: Cable Mine, Mont.[9]
6. Cassiterite deposits.
   Examples: Pitkaranta, Finland,[10] Seward Peninsula, Alas.[11]

**Ore Deposits Formed at Intermediate Depths.**—Following the succession of deposits formed under conditions of gradually decreasing temperature and pressure, there has been recognized another group formed presumably at intermediate depths, deposited by ascending hot waters, and evidently genetically connected with intrusive rocks.

It is, of course, difficult to tell the exact depth of their formation, which Lindgren has estimated within a somewhat wide range of 4000 to 12,000 feet; but it can sometimes be approximately judged by determining the thickness of overlying rock removed by erosion. An important character of these deposits is the absence of high-temperature minerals.

[1] Leith and Harder, U. S. Geol. Surv., Bull. 338, 1908.
[2] Graton, *Ibid.*, Prof. Pap. 68: 313.
[3] Spencer, *Ibid.*, Bull. 430.
[4] Lindgren, *Ibid.*, Prof. Pap. 43, 1905.
[5] Lindgren and Graton, *Ibid.*, Prof. Pap. 68.
[6] Emmons, S. F., Econ. Geol., IV: 312, 1910.
[7] Lindgren, U. S. Geol. Surv., Prof. Pap. 68: 241.
[8] Camsell, Can. Geol. Surv., Mem. 2, 1910.
[9] Emmons, W. H., U. S. Geol. Surv., Bull. 315: 45, 1907.
[10] Vogt, Krusch and Beyschlag. Lagerstätten.
[11] Knopf, U. S. Geol. Surv., Bull. 358, 1908.

The deposits are often fissure veins or a related type, and while the minerals frequently fill open fissures, replacement deposits are not uncommon, and where limestone is the country rock, may be of considerable extent.

The most important metals in these deposits are gold, silver, copper, lead and zinc, but the deeper-formed members of the series may carry molybdenum, bismuth, tungsten and arsenic. Sulphides, arsenides, sulpharsenides and sulphantimonides are the prominent compounds, while oxides are rare. Quartz is the chief gangue mineral, but carbonates are common.

The country rock usually shows intense alteration next to the ore, feldspathic and ferromagnesian rocks yielding sericite, carbonates and pyrite, and calcareous rocks often showing silicification. The last-named process may also be accompanied by dolomitization.

The following types, with examples added, may be enumerated as belonging to this class:—

1. Gold quartz veins of California and Victoria type. Sierra Nevada,[1] Interior Cordilleran region;[1] Victoria, Australia,[1] and Nova Scotia.[1]

2. Gold-bearing replacements in limestone. Mercur, Utah;[1] siliceous gold ores of Black Hills, S. Dak.[1]

3. Gold-bearing replacements in quartzite. Delamar Mine, Nevada.[2]

4. Gold-bearing replacements in porphyry. Cripple Creek, Colo. (in part). Little Rocky Mountains, Montana.[3]

5. Silver-lead veins, including
      *a.* Quartz-tetrahedrite-galena veins. Organ, N. Mex.[4]
      *b.* Tetrahedrite-galena-siderite veins. Wood River, Idaho.[5]
      *c.* Galena-siderite veins. Cœur d'Alene, Idaho.[6]

6. Lead-silver veins with calcite, siderite and barite. Clausthal, Germany and Przibram, Bohemia.[6]

7. Pyritic-galena-quartz veins. Freiberg,[7] Saxony; Cerbat range, Arizona.[8]

8. Silver-lead replacements in limestones. Aspen[6] and Leadville, Colo.;[7] Eureka, Nev.;[6] Lake Valley, N. M.;[6] Park City and Tintic, Utah;[6] Sierra Mojada, N. Mex.[6]

9. Tungsten veins. Boulder County, Colo.[9]

[1] See references under Gold.

[2] Emmons, S. F., Amer. Inst. Min. Engrs., Trans., XXXI: 658, 1901.

[3] Emmons, W. H., U. S. Geol. Surv., Bull. 340: 98, 1908.

[4] Lindgren and Graton, U. S. Geol. Surv., Prof. Pap. 68: 209.

[5] Lindgren, *Ibid.*, 20th Ann. Rept., Pt. 3: 190, 1900.

[6] See under Lead-Silver ores.

[7] See under Lead-Silver ores.

[8] Schrader, U. S. Geol. Surv., Bull. 397, 1909.

[9] See under Tungsten.

10. Native silver veins. With cobalt and nickel as at Cobalt, Ont.,[1] and Annaberg, Saxony;[1] with zeolites, as at Kongsberg, Sweden.

11. Copper veins. Butte, Mont.,[2] and Virgilina, Va.[2]

12. Pyritic replacement deposits. Rammelsberg, Harz;[2] Mt. Lyell, Tasmania;[2] Rio Tinto, Spain;[2] Shasta County, Calif.;[2] Tyee, Vancouver Island.[2]

**Ore Deposits Formed at Shallow Depths** (13, 21). — These include a number of fissure-vein deposits, found in the Cordilleran region, and carrying gold with much silver, as well as subordinate amounts of lead, zinc, and copper. The fact that they are found in flows of volcanic origin indicates their formation at comparatively shallow depths, that is, from a few hundred to four or five thousand feet. They include most of the veins of western Nevada, the San Juan region of Colorado, Cripple Creek, Colorado district, etc.

Gold and silver are prominent, although the former is more abundant and the native gold usually more finely divided.

Like the deeper veins, they may carry pyrite, galena, and sphalerite, but in addition chalcopyrite, arsenopyrite, argentite, and stibnite are characteristic ore minerals. Quartz is a common gangue mineral, and calcite, dolomite, siderite, barite, and fluorite are also found. Adularia is also widespread as a gangue mineral.

Metasomatism varies somewhat with the different rocks. In moderately acid rocks sericitization and even pyritization seem to be common near the vein, and propylitization[3] farther away. In basic igneous rocks, propylitization may extend close to the vein, but sericitization occasionally takes its place. Silicification of the wall rock may occur, especially in rhyolites and sometimes in calcareous rocks.

A change in the character of the vein mineralization is sometimes shown, as when earlier calcite gangue is replaced by quartz and adularia.

Since these ores are of shallow origin, they are formed in the zone of fracture, and are therefore found filling cavities of varied origin and wide distribution.

Deposits formed at shallow depths may be separated into different types as follows:·

[1] See under Nickel-Cobalt.

[2] See under Copper.

[3] This consists in the development of chlorite and epidote as well as pyrite, from dark silicates, and the breaking down of feldspar to quartz, chlorite, and epidote, the rock assuming a dull green color.

1. Quicksilver deposits.[1]
2. Stibnite deposits.[2]
3. Gold-quartz veins.[3]
    *a.* In andesite, Brad, Transylvania; Hauraki Peninsula, N. Z.
    *b.* In rhyolite. De Lamar, Ido.
4. Argentite-gold-quartz veins.[3] Tonopah and Comstock Lode, Nev.
5. Argentite veins.[3] Pachuca and Guanajuato, Mexico.
6. Gold-telluride veins.[3] Cripple Creek, Colorado.
7. Gold-selenide veins.[3] Republic, Washington.
8. Base-metal veins.[3] San Juan region, Colorado.
9. Gold-alunite veins.[3] Goldfield, Nevada.

**Deposits Formed at the Surface by Hot Waters** (83). — At or near the surface mineral deposits may be formed by hot springs, but they are not usually of economic importance.

Such springs may deposit earthy carbonates as sinter, and silica as opal or chalcedony. Ore minerals developed under these conditions in crystallized form are stibnite, marcasite, and cinnabar, but other sulphides have been detected by chemical means. Calcite, fluorite, barite, and celestite may also develop.

According to what has been said above there is a somewhat continuous series of deposits from the deepest to the higher and cooler zones, the mineral combinations gradually changing from those of magmatic and contact-metamorphic conditions, to those known to exist in surface hot springs.

**Formation of Cavities.** — The deposition of ores in the rocks is greatly facilitated by the presence of cavities along which the ore-bearing solutions freely pass, and consequently a great many ore deposits occur in such spaces. There are a number of different ways in which cavities may be formed in rocks. The percolation of surface water through certain ones, such as limestones, often results in the formation of solution cavities, these in many instances attaining the size of veritable caverns; a soluble rock may contain more or less insoluble material, such as clay or chert, which collapses when the surrounding rock is dissolved, and partly fills the cave thus formed. At times the more resistant parts are so bound together that they remain in their original position, forming a porous mass, in the cavities of which mineral matter is later deposited.

Dynamic disturbances produce cavities of variable extent in

[1] See under Mercury.
[2] See under Antimony.
[3] See under Gold-silver.

many different rocks. These range from microscopic cracks, like the rift planes of granite, to enormous faults of great depth and linear extent, and include the joint planes so common in the rocks of almost all regions. Fault fissures form one of the most important types of passageways for ore-bearing solutions. They are often irregular, branching, and partly filled by fault breccia, caused by the breaking of the rock during the movement along the fault plane. A third important group of cavities in the rocks are those resulting from shrinkage of the mass, which may be due to (1) shrinkage during cooling, as in igneous rocks; (2) shrinkage during certain forms of replacement. For example, the change of calcite to dolomite may be accompanied by a shrinkage of the mass, which renders the dolomite more porous than the original rock; and in the alteration of siderite to limonite there is a shrinkage of fully 20 per cent (139). A fourth type of channelway for the passage of underground water is the contact plane between two quite different kinds of rock, one of them fairly dense and impervious. Gas cavities of lavas and the pore spaces of pyroclastic rocks may also serve as openings for ore deposition.

**Deposition of Ore in Open Cavities.** — Open cavities may, according to general belief, exist to a depth of many thousands of feet below the surface. If rock pressure alone were active, they could not theoretically exist below the zone of fracture, but it seems probable that hydrostatic pressure due to gravity may to some extent counteract rock pressure.

There is evidence to show that some large cavities must have existed at great depths, and here it is supposed that the force of crystallization has been sufficient to spread the walls apart. Becker and Day have demonstrated the actual existence of such a force,[1] but Lindgren points out that it seems scarcely possible to attribute such power to it as would be necessary to open deep-seated crevices sufficiently to form room for the crystals, and moreover that it would " seem impossible that under these conditions comb structure and coarsely, even-grained quartz could be produced." Graton [2] suggests the crevices formed below the zone of fracture have been opened by the pressure of solutions forced out of the cooling magma.

**Precipitation of Metals from Solution.**—In some cases the metalliferous and other minerals found in ore deposits have no

[1] Proc. Wash. Acad. Sci., VII: 283.
[2] U. S. Geol. Surv., Bulletin 293.

doubt been taken into solution by surface waters, and precipitated at no great depths; but in the majority of instances the metals were taken into solution at some point considerably below the point of precipitation, where heat and pressure were evidently high. The ascent then of these solutions toward the surface where temperature and pressure were low, would reduce the solvent capacity of the liquid and cause deposition.

As has been pointed out by Lindgren (83) the physical conditions during deposition, especially temperature and pressure, are of great importance in determining the mineral association in ores formed by deposition from solution.

Certain minerals, for example, are very stable under high pressure and temperature, and could not therefore exist under conditions prevailing near the surface. That is to say, that the different minerals have their " critical level," above or below which they cannot form or exist. Other minerals are termed " persistent minerals," because they have a large interval of existence.[1]

The conditions under which different ore minerals, as well as some others, may exist are given in the following table (pp. 458–461) compiled by Emmons.[2]

The deposition of the metals may have been due, however, to other causes, such as the mingling of waters, resulting in chemical reactions, contact of the solution with reducing agents such as carbon, ferrous sulphate, or hydrogen sulphide; or where the precipitation occurs near the surface, by oxidation.

Other conditions may, however, operate to cause precipitation, for, as shown by Sullivan (86), the natural silicates have the power of precipitating metals from solution of salts, " while at the same time the bases of the silicates are dissolved in quantities nearly equivalent to the precipitated metals." The bases which most commonly replace metals in such a process are potassium, sodium, magnesium, and calcium, and the metals are precipitated as hydroxides or basic salts. Cupric sulphide, for example, is precipitated as a basic cupric sulphate similar to brochantite or langite.

The same investigator (87) has also found that when a solution of ferric sulphate is passed through a Pasteur filter, 18 per cent of the iron is held in the tube. Repeated passage of the same solu-

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[1] A. Grubenmann, Die Kristallinen Schiefer, Berlin, 1904, p. 55.
[2] Econ. Geol., III: 611, 1908.

| MINERALS. | IGNEOUS ROCKS. | PEGMATITE VEINS | CONTACT-METAMORPHIC DEPOSITS | DEPOSITS OF DEEP VEIN ZONE | DEPOSITS OF MODERATE AND SHALLOW DEPTH. IGNEOUS ROCKS NEAR BY | DEPOSITS OF MODERATE AND SHALLOW DEPTH. No IGNEOUS ROCKS NEAR BY | SEC'Y MINERALS IN ZONES OF OXIDE AND SULPHIDE ENRICHMENT | PRODUCTS OF DYNAMO REGIONAL METAMORPHISM |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Acmite | + | + | | | | | | +? |
| Actinolite | +? | | + | | | | | +? |
| Adularia | | | | ? | + | | + | |
| Aegerite | + | | | | | | | |
| Alum | | | | | | +? | | |
| Alunite | | | | | + | +? | + | |
| Albite | + | + | + | + | | | | + |
| Allanite | + | + | + | | | | | + |
| Amalgam | | | | | | | + | |
| Amphiboles | + | + | + | + | | | | + |
| Analcite | + | | | | | | + | |
| Andalusite | +? | +? | | | | | | +? |
| Andradite | +? | +? | + | +? | | | | + |
| Anglesite | | | | | | + | + | |
| Anhydrite | | | | + | | | | + |
| Ankerite | | | + | | + | + | + | + |
| Anorthite | + | + | + | | | | | + |
| Anthophyllite | | | | | | | | + |
| Antimony | | | | | | | | |
| Apatite | + | + | + | + | + | + | + | + |
| Aquamarine | | + | | | | | | |
| Apophyllite | | | | | | | + | |
| Arfvedsonite | + | | | | | | | |
| Argentite | | | | | + | +? | + | |
| Aragonite | | | | | | | + | |
| Arsenic | | | | | | | + | |
| Arsenopyrite | | + | + | + | + | | | |
| Atacamite | | | | | | ? | + | |
| Augite | + | +? | + | | | | | + |
| Aurichalcite | | | | | | + | + | |
| Azurite | | | | | | + | + | |
| Barite | | | | | + | + | +? | |
| Bauxite | | | | | | + | + | |
| Beryl | | + | + | | | | | |
| Bismuth | | + | | | | | + | |
| Bismuthinite | | +? | + | +? | + | | | |
| Biotite | + | + | + | + | | | | + |
| Bornite | +? | + | ? | + | + | + | + | |
| Bort | + | | | | | | | |
| Bromyrite | | | | | | | + | |
| Brookite | | | | +? | +? | | | |
| Calamine | | | | | | + | + | |
| Calaverite | | | | | + | | | |
| Calcite | +? | +? | + | + | + | +? | + | + |
| Caledonite | | | | | | +? | + | |
| Calomel | | | | | | | | |
| Cancrinite | + | | | | | | | |
| Cassiterite | + | + | + | + | | | | |
| Celestite | | | | | + | + | + | |
| Cerussite | | | | | | + | + | |
| Cerargyrite | | | | | | + | + | |
| Chalcanthite | | | | | | + | + | |
| Chalcedony | | | | | + | + | + | |
| Chalcocite | | | | | ? | + | + | |
| Chalcopyrite | + | + | + | + | +? | + | + | + |
| Chert | | | | | +? | | | |
| Chlorite | | | +? | +? | | | + | + |
| Chromite | + | +? | + | | | | | + |
| Chrysocolla | | | | | | + | +? | |
| Cinnabar | | | | + | + | | | |
| Cobaltite | | | | | + | | | |

| Minerals. | Igneous Rocks. | Pegmatite Veins | Contact-Metamorphic Deposits | Deposits of Deep Vein Zone | Deposits of Moderate and Shallow Depth. Igneous Rocks Near By | Deposits of Moderate and Shallow Depth. No Igneous Rocks Near By | Sec'y Minerals in Zones of Oxide and Sulphide Enrichment | Products of Dynamo Regional Metamorphism |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Copper | | | | | +? | +? | + | |
| Corundum | + | + | + | | | | | + |
| Cordierite | + | | | | | | | + |
| Covellite | | | | | | + | + | |
| Cryolite | ? | ? | ? | + | | | | |
| Cuprite | | | | | | + | + | |
| Cyanite | | + | + | | | | | +? |
| Diallage | + | | | | | | | |
| Diamond | + | | ? | | | | | |
| Diopside | + | + | + | | | | | +? |
| Dolomite | | | +? | | + | + | + | |
| Eleolite | + | | | | | | | |
| Emerald | | | + | | | | | |
| Emery | + | + | + | | | | | + |
| Enargite | | | | | + | | +? | |
| Epidote | +? | | + | + | | | | + |
| Fayalite | + | | | | | | | |
| Fluorite | + | + | + | + | + | +? | | +? |
| Forsterite | + | | + | | | | | + |
| Franklinite | | | + | | | | | + |
| Gahnite | | | + | + | | | | ? |
| Galena | | +? | + | + | + | + | + | + |
| Garnet | + | + | + | + | | | | |
| Gibbsite | Weat | hering | produc | t. | | | | |
| Glauconite | Forme | d with | sedime | nts | | | | |
| Glaucophane | | | +? | | | | | + |
| Gold (native) | + | + | + | + | + | + | + | +? |
| Goslarite | | | | | | ? | + | |
| Greenockite | | | | | ? | | + | |
| Graphite | + | + | + | + | | ? | | + |
| Gypsum | | | | | ? | + | + | |
| Haüynite | + | | | | | | | |
| Hematite | + | + | + | + | | +? | +? | + |
| Hornblende | + | + | + | + | | | | + |
| Humite group | | | + | | | | | |
| Hydrozincite | | | | | | + | + | |
| Ilmenite | + | + | + | + | | | | +? |
| Iron (native) | + | | | | | | | |
| Jadeite | +? | +? | +? | | | | | +? |
| Kalgoorlite | | | | + | +? | | | |
| Kaolinite | | | | | ? | + | + | |
| Lead (native) | | | | | | | + | |
| Leadhillite | | | | | | + | + | |
| Lepidolite | +? | + | | + | | | | + |
| Leucite | + | | | | | | | |
| Limonite | | | | | | + | + | |
| Magnesite | | | | | + | +? | + | |
| Magnetite | + | + | + | + | | +? | +? | + |
| Malachite | | | | | | + | + | |
| Manganite | | | | | | + | + | |
| Marcasite | | | | | +? | +? | ? | |
| Melaconite | | | | | | | + | |
| Melilite | + | | | | | | | |
| Mercury | | | | | | | + | |
| Microcline | + | + | + | | | | | + |
| Millerite | | + | + | + | +? | +? | + | |
| Molybdenite | | + | + | + | | | + | |
| Molybdite | | | | | | | + | |
| Monazite | + | + | +? | + | + | | | +? |
| Muscovite | + | + | + | + | + | | | + |
| Nepheline | + | | | | | | | |

| Minerals. | Igneous Rocks | Pegmatite Veins | Contact-Metamorphic Deposits | Deposits of Deep Vein Zone | Deposits of Moderate and Shallow Depth. Igneous Rocks Near By | Deposits of Moderate and Shallow Depth. No Igneous Rocks Near By | Sec'y Minerals in Zones of Oxide and Sulphide Enrichment | Products of Dynamo Regional Metamorphism |
|---|---|---|---|---|---|---|---|---|
|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Niccolite | ? |  |  |  | + | + | ? |  |
| Noselite | + |  |  |  |  |  |  |  |
| Octahedrite |  |  |  | + |  |  |  | + |
| Olivine | + |  | ? |  |  |  |  | + |
| Opal |  |  |  |  | +? | + | + |  |
| Orpiment |  |  |  |  | + |  | + |  |
| Orthoclase | + | + | + |  |  |  |  | + |
| Ottrelite |  |  |  |  |  |  |  | + |
| Pentlandite | + |  |  |  | ? |  |  | + |
| Perofskite | + |  |  |  |  |  |  |  |
| Petzite |  |  |  |  |  | + |  |  |
| Picotite | + |  | + |  |  |  |  |  |
| Platinum | + |  | +? | ? | +? |  |  |  |
| Polybasite |  |  |  |  | +? |  | + |  |
| Proustite |  |  |  |  | + |  | + |  |
| Psilomelane |  | · |  |  |  | + | + |  |
| Pyrargyrite |  |  |  |  |  |  | + |  |
| Pyrite | + | + |  | + | + |  | + | + |
| Pyrolusite |  |  |  |  |  | + | + |  |
| Pyromorphite |  |  |  |  |  | + | + |  |
| Pyrophyllite | Weat | hering. |  |  |  |  |  |  |
| Pyroxenes | + | + | + |  |  |  |  | + |
| Pyrrhotite | + | + | + | + | + |  |  | + |
| Quartz | + | + | + | + |  | + | + |  |
| Realgar |  |  |  |  | + |  | ? |  |
| Rhodochrosite |  | + |  |  | + |  | + |  |
| Rhodonite | + | + | + |  | + | + |  |  |
| Riebeckite | + |  |  |  |  |  |  | +? |
| Ruby | ? | + |  |  |  |  |  |  |
| Rutile | + | + | + | + |  |  |  | + |
| Sapphire | + | + | +? |  |  |  |  | + |
| Scapolite | ? | + | +? | + |  |  |  |  |
| Scheelite |  | + | +? | + | + |  |  |  |
| Selenite |  |  | + | + |  |  |  |  |
| Sericite |  |  | + | + |  |  |  | + |
| Serpentine |  |  |  | + |  |  |  | + |
| Siderite |  |  |  | + | + | + | + | + |
| Sillimanite | +? | + | + |  |  |  |  |  |
| Silver (native) |  |  |  |  | ? | + | + |  |
| Smithsonite |  |  |  |  |  | + | + |  |
| Sodalite | + |  |  |  |  |  |  |  |
| Specularite | + | + | + | + |  |  |  | + |
| Spinel | + | + | + |  |  |  |  |  |
| Spodumene | + | + |  |  |  |  |  | + |
| Staurolite |  |  | + |  |  |  |  |  |
| Steatite, talc | Surfa | ce | alte | ration |  |  |  |  |
| Stephanite |  |  |  |  | + |  | + |  |
| Stibnite |  |  |  | ? | + |  |  |  |
| Stilbite |  |  |  | +? |  |  | + | + |
| Stromeyerite |  |  |  |  |  |  | + |  |
| Sulphur |  |  |  |  | ? | + |  |  |
| Sylvanite |  |  | +? | ? | + |  |  |  |
| Talc | Surfa | ce | wea | thering |  |  |  |  |
| Tellurides |  |  | ? | + | + |  |  |  |
| Tennantite |  |  |  |  | + |  |  |  |
| Tenorite |  |  |  |  |  |  | +? |  |
| Tetradymite |  |  |  |  | + | ? | + |  |
| Tetrahedrite |  |  |  |  | + |  | + |  |
| Tin (native) |  |  |  |  |  |  |  |  |
| Titanite | + | + | + |  |  |  |  | + |
| Topaz | + | + | + | + |  |  |  | + |

| Minerals. | Igneous Rocks | Pegmatite Veins | Contact-Metamorphic Deposits | Deposits of Deep Vein Zone | Deposits of Moderate and Shallow Depth. Igneous Rocks Nearby | Deposits of Moderate and Shallow Depth. No Igneous Rocks Near by | Sec'y Minerals in Zones of Oxide and Sulphide Enrichment | Products of Dynamo Regional Metamorphism |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Tourmaline | + | + | + | + | | | | + |
| Tremolite | | | + | + | | | | + |
| Tridymite | + | | | | | | | +? |
| Turgite & amorphous hematite | | | | | | + | + | +? |
| Turquoise | | | | +? | +? | | | + |
| Uralite | | | | ? | + | | | + |
| Valencianite | | | | ? | | | | |
| Vesuvianite | | | +? | +? | | | | + |
| Willemite | | | +? | +? | ? | ? | + | |
| Witherite | | | | | ? | ? | + | |
| Wolframite | | + | | + | | | | + |
| Wollastonite | | | + | | + | | +? | + |
| Wurtzite | | | | | + | | | |
| Xenotime | + | + | | | | | | |
| Yttrialite | + | + | | | | | | |
| Zeolites | +? | | | | | | | |
| Zincblende | ? | + | +? | +? | + | + | +? | ? |
| Zincite | | | +? | ? | | | | + |
| Zircon | + | | | | | | | + |
| Zoisite | | | + | + | | | | + |

tion caused the retention of additional quantities of the same metal. The explanation advanced is that hydrolysis has produced a colloid form of the iron oxide, which is caught in the pores of the porcelain. The experiment is highly suggestive and indicates that metalliferous solutions in passing through porous rocks may be robbed of some of their metallic contents by a similar process.

And this brings up the question of whether the minerals are precipitated in ore deposits as crystals or colloids. In the case of deposits formed below the surface and above surface temperatures, crystalline precipitates probably prevail; but at the surface many metallic and non-metallic compounds are no doubt thrown down in colloidal form, even though they may later change to the crystalline condition (79, 82).

Some fifty years ago not a few geologists, prominent among them De la Beche, advocated the theory of ore precipitation by galvanic action (72, 77, 91), and a number of experiments were made attempting to prove the existence of such action; now little weight is attached to this theory.

**Replacement, or Metasomatism** (99–105).—It is a well-known fact that under favorable conditions mineral-bearing solutions may attack the minerals of the rocks which they penetrate, dissolving
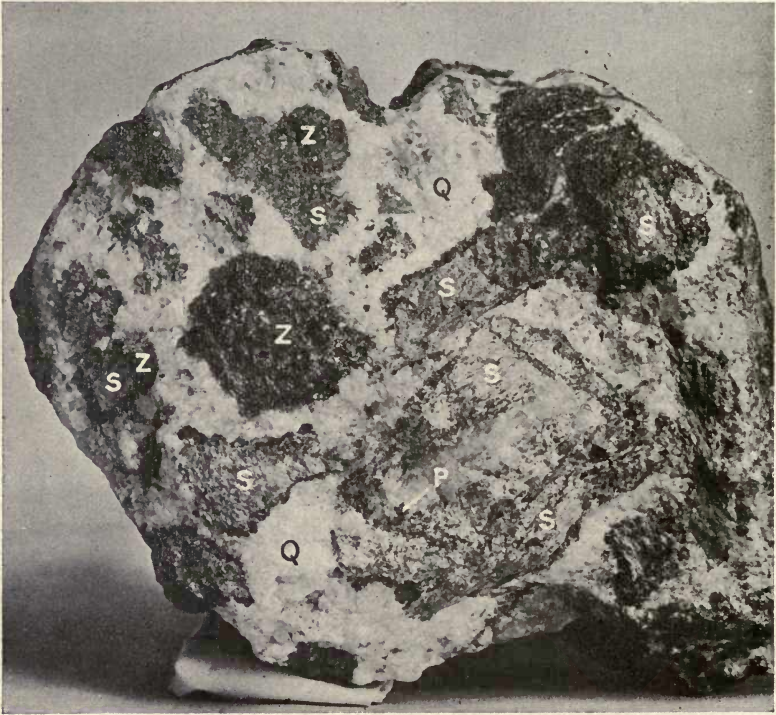


FIG. 138. — Vein breccia from Freiberg, Germany.

The specimen shows fragments of altered schist (S), which are in some cases surrounded, and in others more or less completely replaced by sphalerite (Z), and cemented by quartz (Q). Scattered grains of pyrite (P) are also present. (*Specimen in Cornell collection.*)

them wholly or in part, and depositing some of the original burden in place of the material removed. This replacement, termed "metasomatism," is an important factor in the formation of many ore deposits, and may involve a total or partial loss of certain constituents of the rock attacked and a gain of others, even to the extent of introduction of entirely new compounds and elements.

While some (100) believe that replacement may be accompanied by a volume change, others (102) assert that it proceeds independent of molecular weight, molecular volume, and specific gravity.

The replacing solutions gain entrance to the rock mass, along fractures of different sorts, and penetrate the rock first along the smallest cracks, and then work their way into the individual mineral grains along their cleavage planes until they finally permeate the entire mass (Figs. 139, 140, and 142). The reactions between the dissolved mineral, and the original rock probably take place in films of the solution coating the grains.
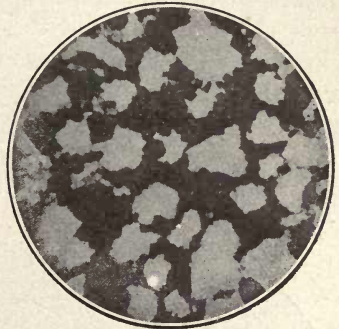


Fig. 139.—Photo-micrograph of a section of quartz conglomerate, showing replacement of quartz (white), by pyrite (black), ×25 diam. (*After Smyth, Amer. Jour. Sci., XIX*, 1905.)

Metasomatic processes show great variety, and are not confined
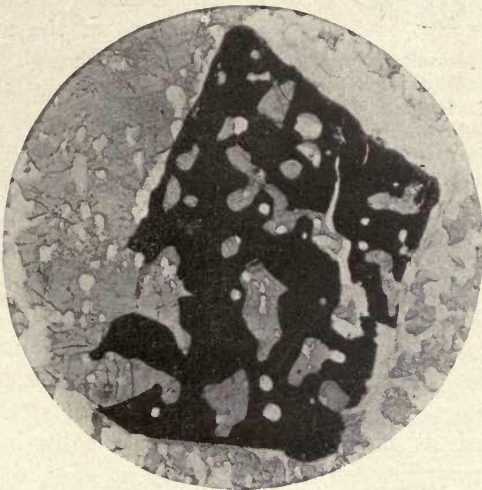


Fig. 140. — Pyrite replacing hornblende, Mineral, Louisa County, Va. ×35. Black, pyrite; gray, hornblende; white, quartz.

to one kind of rock or mineral. In its simplest form the result of metasomatism may often be seen in fossiliferous rocks, where

organic remains have been replaced by common mineral compounds, as in the replacement of the lime carbonate of corals by quartz, or the replacement of molluscan shells by pyrite. From such simple conditions there is every gradation to the complete replacement of extensive areas of rock by ore, or to the extensive operation of metasomatism along the walls of fissure veins.

The complexity of metasomatic processes referred to above may be due to variations in temperature, character of rock, and nature of solution. Metasomatism may take place through a wide range of temperature, but heat greatly aids the process, and the replacing solutions while usually liquid, may also be gaseous. Of the many different rocks affected, limestones are most favorable to replacements, while those high in alumina are least easily attacked.



Fig. 141. — Replacement vein in syenite rock, War Eagle Mine, Rossland, B.C. (a) granular orthoclase with a little sericite; (b) secondary biotite; (q) secondary quartz; (c) chlorite; *black*, secondary pyrrhotite. (*After Lindgren, Amer. Inst. Min. Engrs., Trans. XXX.*)

The original structure and even the texture of the rock may be preserved, although its mineral composition is completely altered, illustrations of the former being sometimes seen in silicified limestones, or of the latter in replaced porphyritic rocks, in which the outlines of the phenocrysts are still preserved.

The replacing mineral is referred to as the *metasome*, while if it shows crystal outlines it is called a *metacryst*, and some minerals in replacement show a greater tendency to develop crystals than others.

Replacement at high temperatures is usually indicated by complete recrystallization, the development of silicate minerals with little or no water, and coarse texture. That performed at lower temperatures commonly results in a much finer-textured mass.

To definitely decide whether replacement has occurred, both field and laboratory study is often necessary. In hand specimens

it is not always possible, without examination of a thin section under the microscope, to decide whether the minerals present are due to replacement or to simple interstitial filling.

Certain criteria representing both field and laboratory features have been suggested (100), although all are rarely applicable to a single deposit. These are: (1) Presence of complete crystals in foreign rock masses; (2) Preservation of rock structures; (3) Intersection of rock structures by replacing mass; (4) Absence of crustification; (5) Presence of unsupported nuclei; (6) Rela-
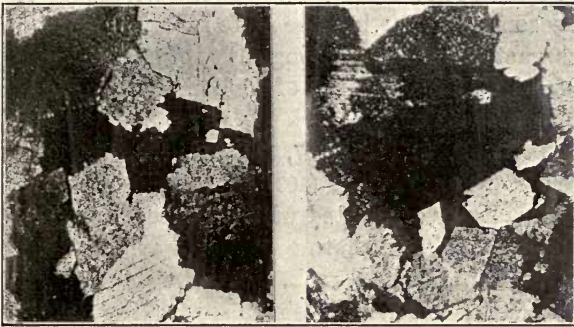


FIG. 142.      FIG. 143.

FIGS. 142 and 143. — Photo-micrographs of thin sections of ore from Austinville, Va., mines.×20 diam. crossed nicols. Shows crystalline granular dolomitic limestone, and the filling of fine cracks accompanied by replacement of limestone grains along crystallographic directions by the sulphides. Very dark irregular areas in center represent sulphides. Reëntrant angles along margins of the sulphides and the spider-like arrangement of the sulphide areas as a whole are well shown. (*After Watson, Va. Geol. Surv., Bull. I.*)

tion of replacement to fissures and other cavities; and (7) Form of deposit.

As mentioned before, metasomatic processes show endless variety. Non-metallic minerals may replace each other as quartz replacing calcite, or metallics may replace nonmetallics, as galena in limestone or pyrite in hornblende (Fig. 140); and lastly one sulphide may be replaced by another, as pyrite by chalcocite (Plate XLII), or sphalerite by chalcocite.

Although the process of metasomatism was recognized by Charpentier as early as 1778, it was generally disregarded, and not widely accepted or recognized until many years later, and geologists continued to assume that ores precipitated from solution were deposited in cavities. Replacement was, however,

finally recognized in the United States, being applied by Pumpelly to the Lake Superior copper deposits in 1873; by Emmons to Leadville in 1886, and by Irving and Van Hise to the Gogebic Range in 1887 to 1888.

Ore deposits of great size, as those of Leadville, Colorado, or Bisbee, Arizona, may be formed by replacement, and a frequent expression of it is seen in the alteration of the wall rocks of many fissure veins. (See Hydrothermal alteration, p. 486.)

**Forms of Ore Bodies** (163). — Ore bodies vary greatly in their form, and this character has at times been used as a basis of classification by some writers; but the more modern tendency is to use genetic characters instead, making shape of secondary importance in the grouping. Certain forms of ore bodies are so numerous as to deserve special mention.

*Fissure Veins* (2, 21, 125, 127, 128, 131, 133, 135, 138, 163). — A fissure vein may be defined (103) as a tabular mineral mass occupying or closely associated with a fracture or set of fractures in the inclosing rock, and formed either by filling of the fissures as well as pores in the wall rock, or by replacement of the latter (metasomatism). When the vein is simply the result of fissure filling, the ore and gangue minerals are often deposited in successive layers on the walls of the fissure (Rico, Colorado), the width of the vein depending on the width of the fissure and the boundaries of the ore mass being sharp. In most cases, however, the ore-bearing solutions have entered the wall rock and either filled its pores or replaced it to some extent, thus giving the vein an indefinite boundary. Therefore the width of the fissures does not necessarily stand in any direct relation to the width of the vein (138) (Butte, Montana). The term *vein material* is best used to apply to the aggregate of materials which make up the ore body. *Vein stone*, though sometimes used, is less desirable (Emmons).

Veins formed by the simple filling of a fissure often show a banded structure of varying regularity termed *crustification* [1] by Posepny (Plate XXXIX, Fig. 1 and Fig. 144), which may sometimes be brecciated by later movements along the fissure. Secondary bands may be formed after reopening of the fissures (Fig. 144), and such a movement may cause brecciation of the vein material. There are many filled fissure veins in which banding is

[1] The replacement of certain layers only in a bed of stratified rock may also produce a banded structure.

PLATE XL
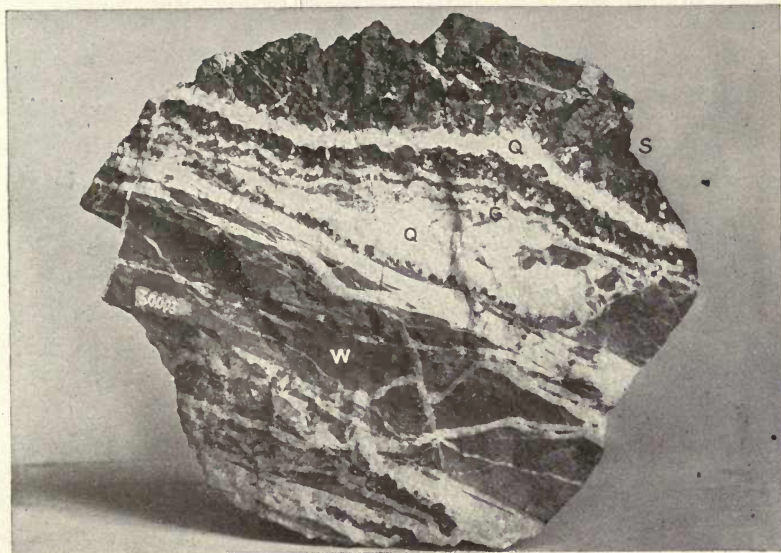


FIG. 1.—Banded vein from Clausthal, Germany. Sphalerite, *S*; Quartz, *Q*; Argillite wall rock, *W*, fragments of which have been separated by quartz crystallizing in the cracks.



FIG. 2.—Banded vein, same locality. Sphalerite, *S*; Galena, *G*; Chalcopyrite, *C* (black); Calcite, *C* (white); streak of later quartz, *Q*.

absent, the ore minerals and gangue being intermixed, but so related as to indicate probably simultaneous deposition of the two. Later movement along the vein wall may sometimes form a layer of soft, clayey material, known as *gouge* or *selvage*, between the vein and the country rock, but where the vein filling adheres closely to the country rock it is said to be *frozen to the walls*. Where the fissure has not been completely filled, thus leaving a central space into which the crystals of gangue project, a *comb structure* is formed. The bands in a filled fissure may consist of gangue and ore alternating, or of



Fig. 144. — Section of vein in Enterprise mine, Rico, Colo.   The right side shows later banding due to reopening of the fissure.   (*After Ransome, U. S. Geol. Surv., 22d Ann. Rept., II.*)

different ores.   Among the commonest ore minerals seen in these fissure veins are pyrite, chalcopyrite, galena, blende, and sulphides of silver.   Some regions afford especially fine examples of banded veins, notably those of Grass Valley, California, and Rico, Colorado. Abroad the mines of Freiberg, Saxony, and Clausthal, Prussia, also often yield magnificent specimens.   Even in a single vein the ore may follow certain streaks which are termed *shoots* (*q.v.*) or again it may be restricted to pockets of great richness, which are known as *bonanzas*.

In some veins the friction breccia or dragged in fragments of the country rock form a considerable portion of the vein filling, and the ore has been deposited in layers around these fragments.

Fissure veins in which metasomatic action has predominated show great irregularity of width and an absence of well-defined boundaries; they also lack as a rule the symmetrical banding and the breccias cemented by vein material.   There are all gradations

PLATE XLI
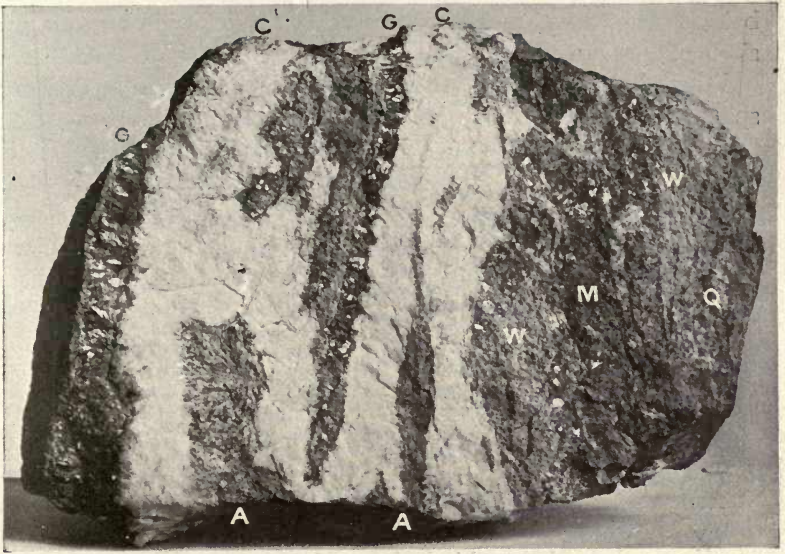


FIG. 1.—Vein specimen from Przibram, Bohemia; Galena, *G*; Stibnite and quartz, *A*; Galena and quartz, *M*; Dolomite, *C*; Quartz, *Q*; Fragments of graywacke wall rock, *W*.
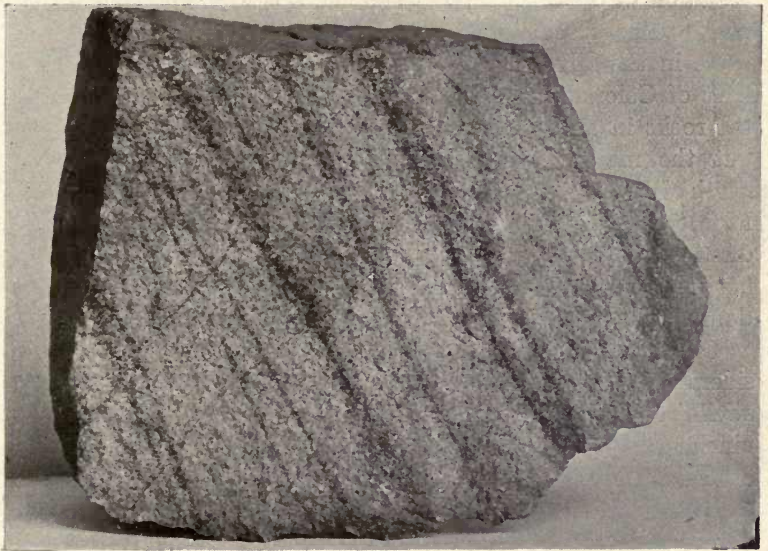


FIG. 2.—Veinlets of tin ore in granite, Altenberg, Saxony.

(469)

between these two types of fissure veins; and even in a single vein simple filling may occur in one part and replacement in another.

Veins often split or intersect, and at the point of intersection or splitting the ore is apt to be richer. There are other reasons for variations in richness, among the most important being the character of the wall rocks, some kinds being more easily replaceable or more porous than others. Their physical character will moreover exercise considerable influence on the shape and size of the fissure. Tough rocks like gneiss, for example, give a clean-cut fissure, but in brittle rock the fissure is apt to split frequently, and therefore a vein may be workable in one kind of rock, but becomes worthless when passing to another, since the profuse branching interferes with economical mining (Fig. 145). A dike may also cause local irregularities, and in a given region the fissures not uncommonly show great variation in their direction. Thus at Butte, Montana (q.v.), east-west veins predominate, while in the Silverton district of Colorado they cut the rocks in all directions, but the majority show a north of east trend. In the Monte Cristo, Washington, district the veins with northeast trend are predominant (Fig. 146).



FIG. 145.— Section showing change in character of vein passing from gneiss (g) to quartz porphyry (p). (After Beck, Lehre von der Erzlagerstätten: 135.)

Fissure veins vary considerably in their width, swelling at some points and pinching or narrowing at others. They also at times show lateral enrichment (Ouray, Colorado); for instance, where the ore cuts through stratified beds, into which the ore-bearing solutions



FIG. 146.— Tabulation of strikes of principal veins in Monte Cristo, Wash., district. (After Spurr, U. S. Geol. Surv., 22d Ann. Rept., II.)

have spread out laterally along the planes of stratification or other planes. It has been noticed in some veins, especially those formed by replacement, that the filling varies with the wall rock, at times changing suddenly; but where the vein is formed wholly by the filling of an open fissure, the rock exerts no influence on the character of the ore (138). If the vein is inclined, the lower wall is spoken of as the *foot wall* and the upper one as the *hanging wall*.

A *horse* is a mass of rock broken off from the vein wall, and held between the walls of the fissure. It is often surrounded by ore, and may itself sometimes be mineralized to a varying degree.

Parallel fissures are not uncommon, but the several veins do not necessarily show an equal degree of richness. Where the vein is of
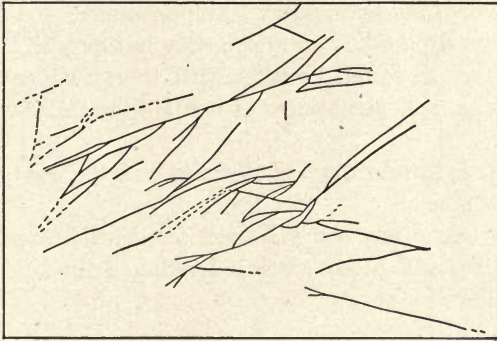


Fig. 147. — Linked veins.   (*After Ordonez.*)

composite character,—that is, consisting of closely spaced parallel fissures accompanied sometimes by a mineralization of the intervening rock, — it is termed a *lode*.

The term *vein systems* is suggested for a larger assemblage of vein fissures, which may include several lodes.

Subordinate fractures, such as little veins, that cross the material included within the vein walls, are called *veinlets* or *stringers*.

The top of the vein is called the *apex*, and is occasionally traceable for a long distance. It does not necessarily outcrop at the surface.

*Linked veins* represent a type in which the parallel fissures are connected by diagonal ones (Fig. 147), giving a series resembling the links of a chain.

*Gash veins* are a special type of fissure vein of limited extent. Some are formed by the enlargement of joint planes and sometimes bedding planes.—They are characteristic of the upper
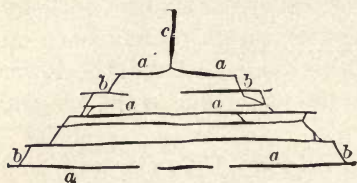


FIG. 148. — Gash vein with associated "flats" (a) and "pitches" (b). Wisconsin zinc region. (*After Grant, Wis. Geol. and Nat. Hist. Surv., Bull. IX.*)

Mississippi Valley lead and zinc region, but are usually of limited extent and local importance. In the simplest form they are a vertical fissure, but develop into types shown in Fig. 148. Other gash veins may be the result of torsional strain, as those accompanying the Catoctin type of copper ores.

*Bedded Vein.*— This term is sometimes applied to a deposit conforming with the bedding. It is also called *bedded deposit*. Among miners the term *blanket vein* is commonly applied to any nearly flat deposit.

*Bedded deposits*, found parallel with the stratification of sedimentary rocks, and sometimes of contemporaneous origin (Clinton iron ore).

*Cross veins* is a term applied to those which cross the stratification.

*Lenticular veins* are short lenses, frequently found in metamorphic rocks, and often scattered along a line, or lying more or less parallel in a zone.

*Filling of Fissure Veins* (131). — The manner in which fissure veins have been filled, and the source of the metals which they contain, formed a most fruitful subject of discussion among the earlier geologists. The several theories advanced and the arguments for and against them are well set forth in Kemp's paper (131), and it may simply be said here that most geologists now believe that the primary deposition of ores in fissure-vein deposits was accomplished by solutions ascending along the fissures, which sometimes spread out into the wall rocks, to a variable distance.

*Other Forms of Ore Deposits.*—*Chimney* is a term applied to ore bodies which are rudely circular or elliptical in horizontal cross-section, but may have great vertical extent. A *stock* is a somewhat similarly shaped ore body, but of greater irregularity of outline. *Fahlband* is a term originally used by German miners to indicate certain bands of schistose rocks impregnated with finely divided sulphides, but not always rich enough to work. It is occasionally used in this country. *Stockwork* is the term applied to a rock

mass broken in different directions by short fissures, which may be mineralized. *Impregnation* is a term indicating the occurrence of minerals in a finely disseminated condition in rocks, either
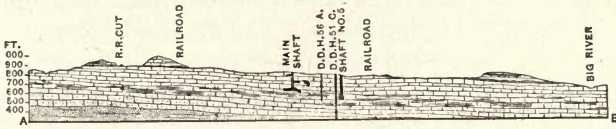


FIG. 149. — Section at Bonne Terre, Mo.. showing ore disseminated through limestone.

as a filling of open spaces or as a replacement of certain minerals. *Disseminated deposits* (Fig. 149) is regarded as a better term by some. *Contact-metamorphic deposits*, as now understood, represent ore bodies formed along the contact of a mass of igneous and
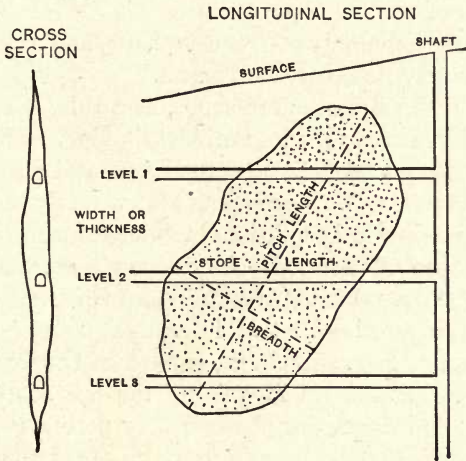


FIG. 150.    FIG. 151.

FIGS. 150 and 151. — Sketch showing dimensions of an ore shoot.    (*After Lindgren and Ransome.*)

country or invaded rock (usually calcareous), the ore having been derived wholly or in part from the intrusive mass (Clifton, Arizona, in part). If the term *contact-metamorphic deposit* is used for this type, it would not necessarily conflict with the term *contact deposit*, applied to any ore body occurring along the boundary between two formations or two kinds of rock. *Ore channels* include those ore bodies formed along some path which the mineral

solutions could easily follow, as the boundary between two different kinds of rock (Mercur, Utah).

*Shear zones* or *sheeted zones* represent a zone of rock broken by numerous parallel and often closely spaced fractures, which may be mineralized as at Cripple Creek, Colorado (Fig. 262).

*Ore shoots* (92–96). — Few ore deposits are of uniform character throughout, indeed the occurrence of pay ore is apt to be more or less irregular, the richer material being often somewhat restricted in its occurrence. These richer portions, if small, may be called *nests*, or *pockets*, but if large, the term *ore shoot* is commonly applied to them. According to some authors the ore shoot includes only the richer portion of the workable ore. (Van Hise.)

Other writers, among them Emmons, Lindgren and Ransome, employ the term ore shoot or pay shoot to signify the workable part of a lode or similar deposit.

Ore shoots are commonly of irregular shape, and usually steep dip, although they may be nearly horizontal.

According to Emmons the ore shoot, as a rule, has a longer axis that forms a large angle with a horizontal plane. This longer axis may be called the *pitch length*,[1] and the horizontal dimensions along the level the *stope length*. Ore shoots are evidently caused by varying chemical and physical conditions in different parts of the deposit, at the time the ore was formed, thus causing a more abundant precipitation of the ore minerals in certain parts of the deposit. More abundant fissuring, or brecciation, in certain parts of the rock may operate to promote deposition in those parts of the mass; clay walls may be influencing factors in guiding the ore solutions towards certain spots; or intersecting fissures may permit the mingling of reacting solutions, thereby bringing about more abundant precipitation of ore at these crossing points. The existence of fissures in certain parts of the ore body might produce additional deposition in those parts, by serving as a guiding channel to either ascending or descending enriching solutions.

The examples cited above apply especially to epigenetic deposits; but if the term *ore shoot* is used in its broadest sense, one might reasonably include ore masses formed by magmatic segregation.

Several attempts have been made to classify ore shoots, all of them being on a genetic basis. Thus Van Hise [2] divides them into three

---

[1] Lindgren and Ransome.
[2] Amer. Inst. Min. Engrs., Trans. XXX: 27.

groups as follows : (A) those explained largely by structural features ; (B) those formed by the influence of wall rocks ; and (C) those formed by secondary concentration by descending waters.

Irving (92) has classified them as (1) shoots of variation, or those which vary from the inclosing material only in relative richness of the ore ; and (2) shoots of occurrence, or those which occur in isolated positions with no other ore of any kind about them.

Winchell [1] makes a division into (1) paragenetic shoots, or those developed mostly at the time of the original formation of the ore deposit inclosing them ; and (2) postgenetic shoots, or shoots developed mostly after the original formation of the inclosing ore deposit.

**Secondary Changes in Ore Deposits** (106–122, 155–158). — Ore deposits are often changed in their upper parts, and sometimes to a considerable depth, by weathering agents, while the lower-lying portions, below the ground-water level, are often enriched by secondary processes.

The two zones each show a somewhat characteristic set of compounds. Thus in the weathered zones we find sulphates, carbonates, silicates, oxides, chlorides, arsenates and native metals ; while in the lower zone the compounds are sulphides, tellurides, arsenides, and antimonides.
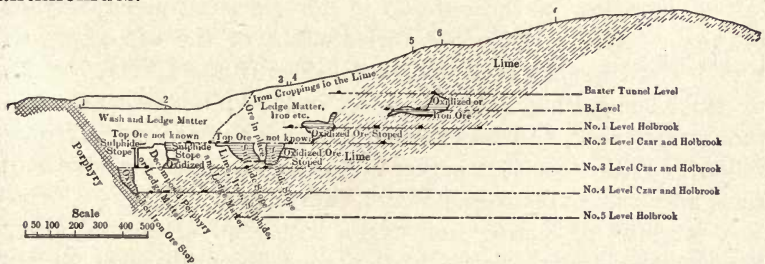


FIG. 152. — Section through Copper Queen Mine, Bisbee, Ariz., showing variable depth of weathering. (*After Douglas, Amer. Inst. Min. Engrs., Trans. XXIX.*)

Weathering may disguise the true character of an ore body most effectually. For example, the ore found in the outcrop may be a gold ore, and mills are sometimes erected and operated for a period on such ore, without any suspicion that beneath there may be great bodies of copper or lead sulphides. Such a change has been found at Bingham, Utah; Butte, Montana; or Mount Morgan, Australia. The last has been one of the world's greatest gold mines, but is now producing copper from its lowest levels.

[1] Econ. Geol., III: 425, 1908.

In other cases, the base metals may all have been leached out of the upper part of the ore body, and too little gold remains in the gossan to make it profitable.   Butte, Montana, is a well-known example of this, for the nearly barren outcrops gave little clew to the great sulphide ore bodies lying below, and which might never have been discovered but for the presence of another system of closely associated veins carrying silver.

**Weathering or Superficial Alteration** (155-158). — Nearly all minerals are attacked by the weathering agents, but the metallic minerals are more easily and more profoundly affected than the non-metallic ones.

This weathering process involves both chemical and physical changes similar to the decay and disintegration of common rocks, but in ore bodies the great number of minerals involved, including many with a metallic base, give rise to a large number of intricate chemical reactions.

As a result of weathering worthless minerals may be removed, leaving the weathered part more porous, and this may increase the richness, because we have a greater quantity of metals per ton of rock.

The character of the outcrop in non-glaciated areas depends on the relative resistance to weathering of the ore and wall rock.   Hard quartz veins, silicified ledges (Plate LVIII, Fig. 2), or dense fine-grained garnet rock are usually more resistant than the country rock, and may remain standing in more or less strong relief.   Pyritic deposits weather more easily usually than the wall rock, and hence a depression may be developed.

A mixture of quartz and pyrite will yield a mass of rusty honeycombed quartz, or a hard porous limonite, such a mass being known as *gossan* or iron hat (French, *Chapeau de fer;* German, *Eisener Hut*).   Solid sulphide ore bodies also are often capped by a gossan.

The weathering of an ore body is a comparatively slow process, so that in glaciated areas, unweathered ore may extend close to or actually up to the surface, because since the retreat of the ice the time has been too short to permit much weathering.

Oxidation in general extends to the water level, although there may be a number of exceptions to this rule.   It may hence show great variation in depth due to this cause alone, but aside from this other factors exert an influence, such as topographic conditions, rainfall, nature of the rock, whether fissured, porous

or dense, kind of ore minerals, climate, etc. Even in the same deposit oxidation may extend to greater depths in one place than another (Fig. 152), because of the presence of fissures which permitted local penetration of the surface waters.

As examples of the maximum depth to which weathering may extend in some parts of an ore body the following can be mentioned:

| | |
|---|---|
| Bisbee, Ariz. . . . . . . . . . . | 1600 feet in places. |
| Tintic, Utah . . . . . . . . . . | 2000 |
| Bingham, Utah . . . . . . . . . | 1300 |
| Tonopah, Nev. . . . . . . . . . | 1200 |
| Ducktown, Tenn. . . . . . . . . | 100 |
| Butte, Mont. . . . . . . . . . . | 400 |

As a result of oxygen-bearing surface waters entering the ore body, chemical changes begin, oxidation and hydration being important; and these together with other changes, produce many soluble compounds.

The oxidation of pyrite, for example, gives sulphuric acid, and the latter is active in the formation of ferrous and ferric sulphates, of which the last-named is important as an oxidizing agent.

Not all of the sulphides appear to be attacked with equal readiness, and the same mineral may show different degrees of resistance under different conditions. That the order of resistance does not seem to be the same in all cases, is indicated by the first table on page 478. The second table by Emmons (110), shows in an interesting manner the changes that have taken place in the weathering of the copper ores at Ducktown, Tenn.

Whatever the order in which the sulphides succumb to the attacks of the weathering agents, they all yield, forming new compounds stable under surface conditions, and sometimes of soluble character, which permits their removal.

Among the compounds found in the oxidized zone are the hydrous oxides of iron, hematite, manganese oxides, free gold under favorable conditions, silver chloride, silicates, carbonate and sulphate of lead, and oxidized compounds of zinc and copper.

Tolman (120) claims that the zone of weathering can be divided into three subzones, which beginning at the surface are: (1) Zone of complete oxidation; (2) zone of complete leaching; and (3) zone of oxide enrichment which is of variable thickness and lying immediately above the sulphides.

The first represents complete oxidation and includes the iron cap. It shows limonite, hematite, residual silica, and some-

ORDER OF OXIDATION OF SULPHIDES, ACCORDING TO SEVERAL AUTHORITIES

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| Iron | Arsenopy-rite | —— | —— | —— | —— | Pyrrhotite | Marcasite |
| Copper | Pyrite | —— | —— | —— | Sphalerite | Sphalerite | Pyrite |
| —— | Chalcopy-rite | —— | —— | —— | Chalcocite | —— | Pyrrhotite |
| Zinc | Sphalerite | Chalcocite | Chalcocite | Chalcocite | Galena | Galena | Chalcopy-rite |
| Lead | Galena | —— | —— | Bornite | —— | —— | Bornite |
| Silver | Chalcocite | —— | Pyrrhotite | Pyrrhotite | Pyrite | —— | Millerite |
| —— | —— | —— | —— | Chalcopy-rite | Chalcopy-rite | Chalcopy-rite and pyrite | Chalcocite |
| —— | —— | Pyrite | Pyrite | Pyrite | Argentite | —— | Galena Sphalerite |

1. Van Hise, Amer. Inst. Min. Engrs., Trans., XXX: 101, 1901; 2. Weed, *Ibid.*, XXX: 429, 1901; 3. Lindgren, U. S. Geol. Surv., Prof. Pap., 43: 180, 1905; 4. Emmons and Laney, U. S. Geol. Surv., Bull. 470: 151, 1911; 5. Vogt, Amer. Inst. Min. Engrs., Trans., XXXI: 125, 1902; 6. Gottschalk and Buehler, Econ. Geol., IV: 28, 1910; 7. Wells, U. S. Geol. Surv., Bull. 529: 76, 1913; 8. Beck (Weed), Nature of Ore Deposits, p. 337.

CHEMICAL CHANGES BY OXIDATION PROCESSES AT DUCKTOWN, TENN.

| | 1a | 1b | 2a | 2b | 3 |
|---|---|---|---|---|---|
| SiO$_2$ | 22.44 | 90.88 | 9.95 | 21.89 | −69 |
| Al$_2$O$_3$ | 2.93 | 11.87 | 1.57 | 3.45 | − 8.4 |
| Fe | 33.43 | 135.39 | 49.9 | 109.78 | −25.6 |
| MgO | 3.15 | 12.76 | (?) | (?) | −12.7 |
| CaO | 8.28 | 33.534 | .35 | .77 | −32.7 |
| CO$_2$ | 2.85 | 11.54 | ...... | ...... | −11.5 |
| S | 21.23 | 85.98 | .65 | 1.43 | −84.5 |
| MnO | .44 | 1.78 | | | |
| Cu | 2.45 | 9.92 | .86 | 1.89 | − 8 |
| Zn | 2.79 | 11.30 | ...... | ...... | −11.3 |
| H$_2$O | ..... | ...... | [1] 15.40 | 22.88 | +33.88 |
| O | ..... | ...... | [1] 21.38 | 47.04 | +47.04 |
| Total | 99.99 | 404.954 | 100.06 | 220.13 | −182.8 |

[1] H$_2$O and O are estimated, on the assumption that the Fe is in limonite.

1a, Percentage weight of constituents of primary sulphide ore, Mary mine; 1b, percentage weight times specific gravity (4.05), and expresses number of grams in 100 cubic centimeters of the primary ore; 2a, chemical composition of gossan, 2b, percentage weight, times its specific gravity (2.2, corresponding to 39 per cent porosity); 3, gain and loss of the several constituents.

times residual gold, as well as silver chloride. Lead, zinc, and copper oxidation products may be present. The second is usually somewhat thoroughly leached of its metallic contents, but the gold and less often silver may extend down into it. The third may contain partly oxidized minerals, and include native elements, oxides, carbonates and silicates brought from above. Some authors do not agree to this constant zonal division of the weathered zone.

**Reactions of Oxidized Zone.** — The reactions that take place in the oxidized zone are primarily those taking place between the sulphides, oxygen, water, carbon dioxide and sulphuric acid. These may be followed by reactions between the products so formed or between these and other minerals, the result in some cases being the formation of minerals of stable and slightly soluble character, which are evidence of weathering reactions. Some of the possible reactions follow:

$$FeS_2 + 4O \qquad = FeSO_4 + S,$$
$$FeS_2 + 7O + H_2O = FeSO_4 + H_2SO_4.$$
$$FeS_2 + 6O \qquad = FeSO_4 + SO_2.$$
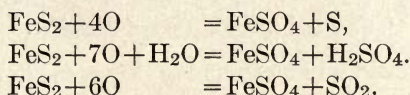
Ferrous sulphate, however, oxidizes to ferric sulphate,

$$2FeSO_4 + H_2SO_4 + O = Fe_2(SO_4)_3 + H_2O.$$
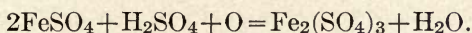
But the ferric sulphate is not very stable near the surface, although deeper down this salt together with ferric chloride and even other ferric salts may remain in solution, and serve as oxidizing agents.

Both ferric and ferrous sulphates may yield limonite as follows:

$$6FeSO_4 + 3O + 3H_2O = 2Fe_2(SO_4)_3 + Fe_2(OH)_6,$$
$$Fe_2(SO_4)_3 + 6H_2O = 2Fe(OH)_3 + 3H_2SO_4,$$
$$4Fe(OH)_3 = 2Fe_2O_3 + 6H_2O = 2Fe_2O_3 \cdot 3H_2O + 3H_2O,$$
$$2Fe_2(SO_4)_3 + 9H_2O = 2Fe_2O_3 \cdot 3H_2O + 6H_2SO_4.$$
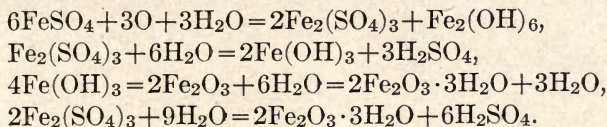
As evidence of the oxidizing effect of ferric sulphate we have

$$FeS_2 + Fe_2(SO_4)_3 = 3FeSO_4 + 2S \text{ and}$$
$$2S + 6Fe_2(SO_4)_3 + 8H_2O = 12FeSO_4 + 8H_2SO_4.$$
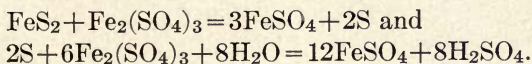
Again the ferric sulphate may break up in the presence of water as follows:

$$Fe_2(SO_4)_3 + H_2O = 2FeSO_4 + H_2SO_4 + O.$$
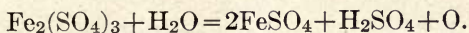
the atom of oxygen liberated being free to attack oxidizable substances.

Another important role played by ferrous and ferric salts is as solvents and precipitants of gold (Emmons).

Gold forms no insoluble compound in the oxidized zone, and it is not soluble in sulphuric acid; nor is it soluble in ferric sulphate as has been sometimes stated.

If gold is in solution as the chloride, it is precipitated by ferrous sulphate, formed in manner indicated above, but if much manganese oxide is present, the ferrous sulphate is oxidized to ferric sulphate, which does not precipitate the gold. The presence of manganese oxides therefore favors the dissolving of gold in acid solutions, and it may be carried downward. On meeting a reducing environment, however, both the gold and manganese are precipitated.

Copper sulphides also are subject to oxidizing action, thus:

$$CuFeS_2 + 8O = CuSO_4 + FeSO_4.$$
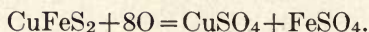
At times, however, a reduction may occur, as shown by the next equation:

$$CuSO_4 + 2FeSO_4 = Cu + Fe_2(SO_4)_3.$$
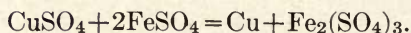
The copper sulphate may be held in the oxidized zone as a result of the following reactions:

$$2CuSO_4 + 2H_2Ca(CO_3)_2$$
$$= CuCO_3(CuOH)_2 + 3CO_2 + 2CaSO_4 + H_2O,$$
$$3CuSO_4 + 3H_2Ca(CO_3)_2$$
$$= 2CuCO_3(CuOH)_2 + 3CaSO_4 + 4CO_2 + 2H_2O,$$
$$2CuSO_4 + 2FeSO_4 + H_2O = Cu_2O + Fe_2(SO_4)_3 + H_2SO_4,$$
$$Cu_2O + H_2SO_4 = Cu + CuSO_4 + H_2O,$$
$$CuSO_4 + H_2Ca(CO_3)_2 + H_4SiO_4$$
$$= CuO \cdot H_4SiO_4 + CaSO_4 + H_2O + CO_2.$$
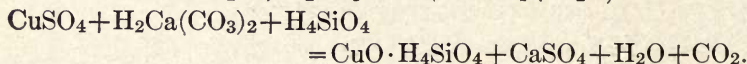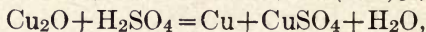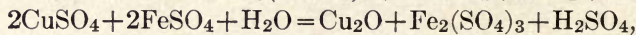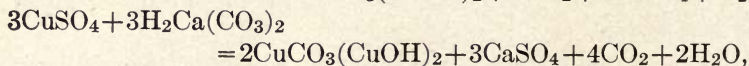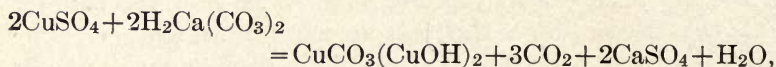
If zinc sulphide is present unaccompanied by pyrite the reaction will be:

$$ZnS + 4O = ZnSO_4.$$
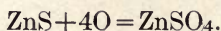
If, however, pyrite or some other source of $Fe_2(SO_4)_3$ is present, then the reactions may be more complicated, as shown by the following:[1]

[1] Wang, Y. T., Amer. Inst. Min. Engrs., Bull. Sept., 1915, 1959.

$$ZnS + Fe_2(SO_4)_3 = 2FeSO_4 + ZnSO_4 + S,$$
$$3ZnSO_4 + 3Na_2CO_3 + 4H_2O =$$
$$= ZnCO_3 \cdot 2Zn(OH)_2 + 3Na_2SO_4 + 2H_2CO_3.$$
$$ZnSO_4 + Ca(HCO_3)_2 = CaCO_3 + ZnCO_3 + H_2SO_4,$$
$$ZnSO_4 + 2NaHCO_3 = ZnCO_3 + Na_2SO_4 + H_2CO_3.$$
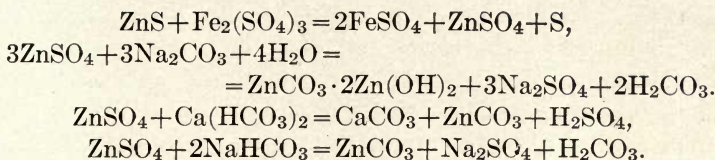
**Downward Secondary Sulphide Enrichment** (106–122). — In many ore bodies there is found below the oxidized zone a second one in which the ore may be richer than that above or below it. This zone, known as the *secondary sulphide zone*, has been enriched by the deposition of secondary sulphides, is of variable thickness and richness, and represents the results of important processes which have often converted a non-workable ore deposit into a workable one.[1]

The process of downward sulphide enrichment briefly stated is as follows: Ore minerals in the zone of weathering become converted into soluble compounds (sulphates chiefly), as explained above, and these, on being carried down below the water level, come in contact with unaltered sulphides or other reducing agents

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[1] There is likely to be some confusion if, in the future different investigators do not adhere to uniformity in usage of the terms primary and secondary. In this book, the term secondary sulphide enrichment is applied to the precipitation of sulphides below the oxidized zone, from meteoric waters, penetrating the ore body from above, and taking metallic salts from the oxidized to the unoxidized zone. Emmons (110) applies the term *primary* to all ore bodies whose chemical and mineral composition have remained essentially unchanged by superficial agencies since the ores were deposited. A *secondary* ore he classes as one that has been altered by superficial agencies.

Tolman (120) classifies the minerals of an ore deposit into *original* minerals of the rock; *primary* minerals introduced by vapors and waters of deep-seated or igneous origin, and *secondary* minerals contributed by descending surface waters.

Rogers (117) would apply the name secondary to a mineral formed at the expense, or by the replacement of, an earlier formed mineral. He then uses the term *upward secondary enrichment* to sulphides deposited from rising solutions, and *downward secondary enrichment* to those deposited from descending solutions. These two terms correspond respectively to Ransome's *hypogene* and *supergene*.*

In the case of copper ores which Rogers has studied he states that the criteria of downward chalcocite enrichment may be summarized as: (1) comparatively regular replacement along anastomosing channels; (2) the presence of quartz veinlets related to chalcocite deposition; (3) the association of melaconite with chalcocite along veinlets. Criteria of upward chalcocite enrichment may be summarized as follows: (1) Irregular intricate replacements; (2) the presence of so-called graphic intergrowths of bornite and chalcocite; and (3) presence of sericite related to chalcocite deposition. Further study will be required to see whether these criteria hold.

which reduce them again to insoluble sulphides. Thus they bring about a secondary enrichment of the ore body.

Important as this process is, it was not clearly recognized until a comparatively late date, when the writings of De Launay [1] in France, and of S. F. Emmons (108), Weed (122), and Van Hise (88), in the United States did much to increase our knowledge of the subject.

All ore minerals are not subject to the process of secondary enrichment as outlined above, it being most often seen in ores of copper, gold, and silver, and to lesser extent in lead and zinc.

Secondary-sulphide enrichment like weathering may be affected by a number of, and sometimes the same factors. These include climate, altitude, relief, permeability, geologic history of the locality, chemical and mineral composition.

Warm climates favor chemical reactions, and cold climates not only retard them, but freezing temperatures prevent solution. Secondary-enrichment zones are rare in north latitudes as compared with southern ones. If formed in the past under different climatic conditions they may have been removed by glaciation.

Rainfall in abundance may be favorable, because of its stimulating effect on groundwater circulation, but scarcity of rainfall does not preclude the possibility of finding secondary ores, as a moderate supply of water acting through a long period of time may have yielded favorable results.

High altitude may act unfavorably because of rapid erosion and low temperatures, but under favorable conditions enrichment may occur.

Strong relief favors deep and rapid underground circulation and hence may cause relatively deep enrichment, while in a base leveled area the circulation will be sluggish, and the waters will not descend far before losing the metals dissolved higher up.

Slow erosion means a longer exposure of outcrop, hence long weathering and thorough leaching, but if the process continues there may be a downward migration of both the oxidized and secondary enrichment zone; the products of secondary enrichment may therefore be derived from portions of the ore body long since removed.

. Permeability is an essential factor, because unless the solutions can penetrate the unweathered part of the ore body, secondary enrichment can not occur. The permeability may be due to original porosity of the ore, or to fractures caused by post-mineral movements. Comparatively small openings sometimes appear sufficient for permeation.

An important point to consider is the past topography, for the enrichment may have taken place when physiographic conditions were quite different from what they are now, and hence the zone of secondary sulphides shows no rational relationship to the present land surface.

[1] Les variations des filons métallifères en profundeur, Revue générale des Sciences, etc., Apr. 30, 1900, No. 8.
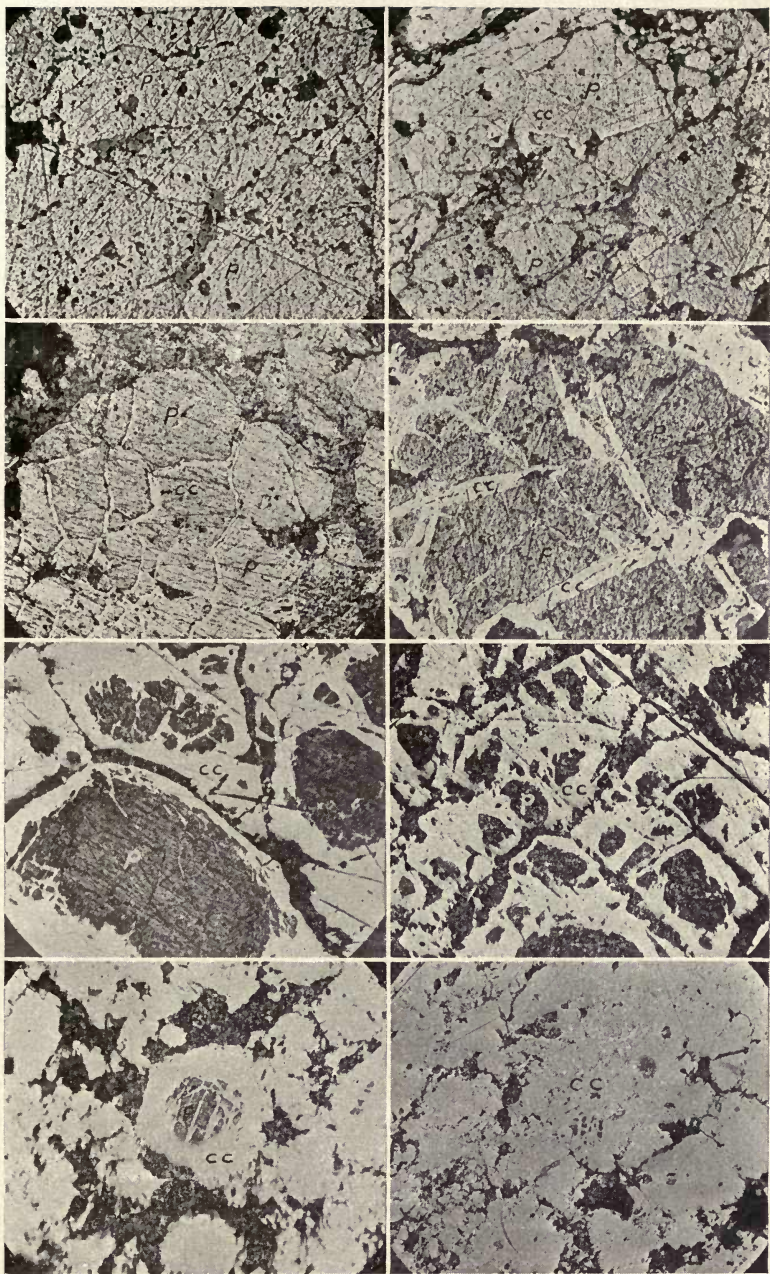
PLATE XLII.—Photomicographs of polished specimens of ore from Burro Mountains, N. Mex., showing progressive replacement of pyrite (*p*) by chalcocite (*cc.*). ×40. (*R. E. Somers, photo.*)

Under normal conditions the secondary sulphides would be deposited below water level, but subsequent changes in the latter, too rapid for the chemical changes to keep pace with, may result in secondary sulphides extending above the water level.

*Criteria of Downward Secondary Sulphide Enrichment* (111, 116, 117). — These may be geologic, mineralogic and textural. Any one alone will not necessarily afford conclusive evidence. The geologic criteria include suggestive surface conditions such as a leached ferruginous gossan, underlain by chalcocite and this in turn by cupriferous pyrite. Or the weathered zone may show argentiferous galena, more or less altered to cerussite, with deeper down the appearance in increasing quantities of sphalerite and pyrite. Assay maps of an ore body showing a lean zone above, passing downward into one of relatively greater richness, and this in turn into a much poorer zone, are also suggestive.

It is difficult to name any mineral as distinctively characteristic of secondary enrichment. Even chalcocite which at one time was regarded as typical of this process is now known to be formed by primary deposition.

Textural criteria may be of value. Thus we find veinlets of rich ore in leaner material; the irregular replacement of one mineral by another (Plate XLII); evidence of solution followed by deposition of fresh material; or grains of primary sulphide surrounded by secondary ones, as chalcocite surrounding pyrite. No one of these, however, should be used alone.

*Chemistry of Secondary Sulphide Enrichment* (110, 119, 120). — The exact equations of secondary sulphide enrichment are not always known. Reference has already been made to some of those that may occur in the zone of weathering, resulting in the formation of soluble sulphates, chlorides or bicarbonates.

Precipitation below the water level may be due to: (1) Reduction of sulphates to metallic sulphides by carbonaceous matter; (2) Reduction by hydrogen sulphide; and (3) Reaction of salts with sulphides.

With regard to the precipitation of sulphates by sulphides, it has been found that this agrees somewhat closely with Schurmann's law which arranges the metallic sulphides in a series, any member of which will be precipitated at the expense of any sulphide lower in the series.[1] His series was Hg, Ag, Cu, Bi, Cd, Pb, Zn, Ni, Co, Fe, Mn. According to this pyrite for example

[1] Liebig's Ann. der Chemie, CCXLIX: 326, 1888.

would precipitate, copper, lead, zinc or others in the series above it. Again if we had descending solutions carrying copper, lead and silver, the order of precipitation of the sulphides of these would be silver, copper and lead sulphides.

The order of precipitation mentioned above may not hold under all conditions, for as mentioned by Tolman (120), on account of mass action, a strong solution of a metallic salt, may cause a precipitate at the expense of a member of the series higher up.

*Reactions of Secondary Sulphide Deposition* (110, 120).—Various reactions have been written to explain the precipitation of metallic sulphides in the zone of secondary enrichment. It is probable that some of them do not always state the case exactly, and that the change instead of being a simple and direct one may involve several intermediate steps. Thus, for example, chalcocite is found as a secondary mineral, precipitated by pyrite, but careful work by Graton and Murdock (111), corroborated by experimental work performed in the Carnegie Geophysical Laboratory at Washington [1] has shown that the change from pyrite to chalcocite is not a direct one, but that there may be intermediate stages so that the order of formation in some cases at least is: Pyrite$\rightarrow$Chalcopyrite$\rightarrow$Bornite$\rightarrow$Covellite$\rightarrow$Chalcocite. These changes result from the action of copper sulphate solutions on sulphides, and at low temperatures are probably exceedingly slow.

For copper some of the enrichment zone reactions published are:

$$2CuSO_4 + 2FeS_2 = Cu_2S + 2FeSO_4 + 3S, \text{ or}$$
$$14CuSO_4 + 5FeS_2 + 12H_2O = 7Cu_2S + 5FeSO_4 + 12H_2SO_4,$$
$$4CuSO_4 + FeS_2 + 3SO_2 + 6H_2O = 2Cu_2S + FeSO_4 + 6H_2SO_4,$$
$$CuSO_4 + CuFeS_2 = 2CuS + FeSO_4, \text{ or}$$
$$2CuSO_4 + CuFeS_2 + SO_2 + 2H_2O = Cu_2S + CuS + FeSO_4 + 2H_2SO_4,$$
$$CuSO_4 + 2FeS_2 + 2O = CuFeS_2 + FeSO_4 + SO_2,$$
$$CuSO_4 + ZnS = CuS + ZnSO_4,$$
$$CuSO_4 + H_2S = CuS + H_2SO_4.$$
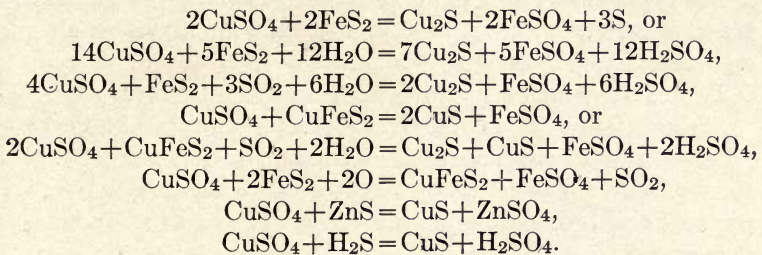
For zinc the equations may be:[2]

$$ZnSO_4 + FeS_2 = ZnS + FeSO_4 + S, \text{ or}$$
$$2ZnSO_4 + FeS_2 + H_2O = 2ZnS + FeSO_4 + H_2SO_4 + O, \text{ or}$$
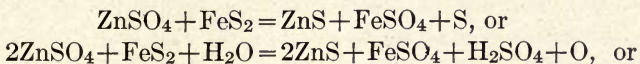
[1] Day, Min. and Sci. Pr., CX: 841, 1915.
[2] For cases of secondary sphalerite see Blow, Amer. Inst. Min. Engrs., Trans., XVIII: 172, 1890; Graton, U. S. G. S., Bull. 430, 71: 1910; Ransome, *Ibid.*, Prof. Pap. 75: 169, 1911; Finlayson, Econ. Geol., V: 417, 1910.

$$7ZnSO_4 + 4FeS_2 + 4H_2O = 7ZnS + 4FeSO_4 + 4H_2SO_4.$$

For lead we have

$$PbSO_4 + FeS_2 + O_2 = 9PbS + FeSO_4 + SO_2,$$
$$PbSO_4 + ZnS = PbS + ZnSO_4.$$
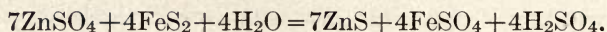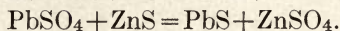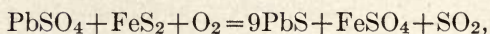
It is difficult to distinguish secondary lead and zinc minerals from primary ones, because they are the same in each case, and while they no doubt occur, few well-defined cases have been described.[1]

Secondary silver sulphides undoubtedly occur. The compounds said by Ransome to be more often secondary than primary are stephanite, polybasite, argentite, pyrargyrite and proustite.

**Hydrothermal Alteration** (13, 21, 103). — The hot ascending solutions of varying composition often bring about a most profound alteration of the rocks which they traverse, extracting it may be, certain elements and adding others. Indeed in some cases the alteration is so extensive that the rock affected bears no resemblance to its former self.

Alteration is usually most intensive along the fissures which guided the solution, but if the rock is extensively fractured it may be affected over a large area.

The changes produced will not only vary with the composition of the solution, but also with the temperature and pressure, and in some cases similar changes may be wrought by cold solutions of non-magmatic character.

The types of hydrothermal alteration which are well recognized are *propylitiaztion, sericitization, silicification, alunitization* and *greisenization.*

Two of these may sometimes occur in the same rock.

*Propylitization* (21, 103). — This is a common type of alteration, which affects chiefly andesites and basalts, but rarely rhyolites. It results in a change of the silicates to abundant chlorite, and pyrite, as well as epidote in some cases. Carbonates are likewise formed, and in some cases there may also be sericite. The rocks so changed are usually of a greenish-gray color, but may preserve their original texture. The process may involve extraction of soda and potash, as well as silica, and even lime, and magnesia unless carbonates are formed, while the additions consist chiefly of sulphur and water.

[1] See Finlayson, Econ. Geol., V: 421, 1910; Weed, Amer. Inst. Min. Engrs., XXX: 424, 1901; Irving and Bancroft, U. S. G. S., Bull. 478: 97, 1911.

Propylitization is probably a somewhat shallow process, and is a common accompaniment of some western gold and silver veins. It is found in the rocks bordering the veins at Virginia City and Tonopah, Nev., Cripple Creek, Colo., and other places.

*Sericitization.* — This is a common type of hydrothermal alteration, which is often seen near veins, but may pass outward into propylitic alteration. The rocks so altered are white or light yellow in color, and the mass often appears clay-like. Indeed sericite masses are sometimes mistaken for kaolin, and it is difficult to distinguish sericite from kaolinite, under the microscope.

Sericitization involves a loss of soda and a gain of potash. Silica may be reduced or increased in amount, and carbonates may be formed, while pyrite is usually added. The resultant product is a fine-grained mixture of sericite, adularia and pyrite, with sometimes calcite and quartz, the first-named of these being developed from both quartz and feldspar. Close to the vein, silicification sometimes overshadows sericitization. The latter process may take place in veins of both shallow and intermediate depth; moreover although chlorite may be developed first, sericite may crowd it out later (Butte, Mont.).

*Silicification.* — This is also a common form of alteration associated with the deposition of ores, being more often noticed in acid than in basic rocks. Rhyolites may often show it, both the groundmass and phenocrysts being affected. At Goldfield, Nev., the silicified ledges so prominently associated with the ore bodies are formed by the alteration of andesite (Plate LXVIII, Fig. 2). The quartz thus formed is of cherty character, but the original structure of the rock may be clearly preserved. Limestones and other calcareous rocks may also be silicified, as in some contact metamorphic deposits. (See Bisbee and Miami, Arizona.)

In some cases silicification may be brought about by meteoric waters (southwest Missouri zinc district).

*Alunitization.* — This type of alteration, which is not a very common one, was first noticed at Goldfield, Nev., where the feldspars have been somewhat extensively altered to alunite. It is a change that takes place at shallow depths, and is thought to be due to the action of descending sulphuric waters, meeting ascending alkaline ones.

The alunite at Goldfield occurs not only as a massive crystalline constituent of the altered rocks, but also intergrown with pyrite, gold, tellurides, and other minerals of the ore.

Alunitization has since been noticed at a number of other western localities. (See references under Potash.)

*Greisenization.* — The granite walls of many tin veins show a strong and characteristic alteration, the feldspar and muscovite being attacked by water vapors carrying fluorine and boric acid, resulting in the development of a mass of quartz, topaz, tourmaline and lepidolite, to which the name *greisen* is applied. Cassiterite may also be present in the altered wall rock.

**Value of Ores.** — The terms *rich* and *poor*, as applied to ores, are used with great frequency, although most indefinite and often meaningless. Under very favorable conditions it is possible to profitably work an ore of given value at one locality, while if found under other less favorable conditions at another point it might be almost worthless.

Those who have not given special study to ore deposits often fail to realize that in the majority of ores the percentage of metal contained in the ore falls considerably below the theoretic percentage of the metallic contents in the ore-bearing minerals, due of course to the presence of a greater or less quantity of gangue minerals which tend to dilute the metallic values of the vein. Many low-grade lead ores are profitably mined because their gold and silver contents more than pay the cost of metallurgical treatment. In many cases the metallic contents of the ore is increased by mechanical concentration or by roasting (in the case of sulphides), or both, before the ore is smelted.

*Allowable Minimum of Metal in an Ore* (52). — Iron ores are of little value, wherever they may be located, unless they contain at least 30 per cent of iron when charged into the furnace.

*Copper* has an average minimum of about 2 per cent, but the Lake Superior ores, because of their peculiar characteristics, can be operated on a lower percentage. Many of the western disseminated copper sulphides, which are worked on such an extensive scale, do not average much over 2 per cent. In the case of these low-grade ores the metallic contents are raised by mechanical concentration or roasting, or both, before entering the furnace.

*Lead.* — In southeastern Missouri lead ores are profitably mined when carrying as little as 5 to 10 per cent metal, but the concentration raises the percentage up to 65 or 70 per cent.

*Zinc* ores on entering the furnace should have a minimum of 25 to 30 per cent zinc, but the contents are sometimes raised to 60 or more per cent by concentration, the concentrates being sold on a percentage basis. Some of the Missouri zinc ores as mined run as low as 3 per cent zinc.

*Gold and Silver.*—The metallic contents of these ores are expressed, not

in percentages, but in troy ounces per ton, a troy ounce in a ton being $\frac{1}{300}$ per cent. The market value of silver is, in round numbers, 50–60 cents per ounce, while gold in round numbers is figured at $20 per ounce.

Silver rarely occurs alone, and the ore may be treated primarily for its associated lead and copper.

In the base ores there should be enough silver to yield a minimum of $5 or 10 ounces in the resulting ton of copper, to make its extraction profitable. If now in a 5 per cent copper ore 20 tons of ore are concentrated to 1 ton of pig copper (or 21 tons, allowing for losses), it follows that we need 10 ounces of silver, in 21 tons of ore, or a minimum of $\frac{1}{2}$ ounce silver per ton, or $\frac{1}{600}$ per cent.

Under favorable conditions gold can be extracted down to $\frac{1}{20}$ ounce per ton or $\frac{1}{6000}$ per cent. It usually runs from $\frac{1}{2}$ to 1 ounce.

In some copper or lead ores the saving of even $\frac{1}{20}$ ounce gold may be an object. In gravels, a gold content of as low as 7 to 10 cents per cubic yard ($\frac{1}{200}$ to $\frac{1}{300}$ ounce) may be saved.

*Tin.* — For this metal the crude ore commonly ranges from 1.5 to 3 per cent, but by concentration it can be raised to 70 per cent.

*Nickel* should reach 2 to 5 per cent in the crude ore.

*Platinum.* — Owing to the scarcity of this metal, few figures are available, but in Russia placers are worked which carry $\frac{1}{40}$ ounce per cubic yard, which is the equivalent of $\frac{1}{60}$ ounce per ton or 5.5 hundred-thousandth per cent.

*Manganese* to be considered of commercial grade must contain at least 35 per cent manganese and otherwise conform to the specifications of the trade in which they are used.

*Chromium* ore should carry 40 per cent of the metal.

**Classification of Ore Deposits.** — Many attempts have been made to develop a suitable classification of ore deposits, and many schemes have been suggested (46). These are usually based either on form, mineral contents, or mode of origin. The first is perhaps the most practical from the miner's standpoint, the second is undesirable because several kinds of ore may often be found in the same ore body, while the third is the most scientific, and is of value to the mining geologist and engineer.

Those desiring to look into this phase of the subject in more detail are referred to the bibliography at the end of this chapter, especially the papers by Kemp (46), Posepny (68), Van Hise (2), and Vogt (13).

Two classifications are given here, viz., those of W. H. Weed and W. Lindgren. Both are based in part at least on genetic characters, but the second goes a little farther, and attempts to indicate more definitely the physical conditions of deposition.

### CLASSIFICATION OF ORE DEPOSITS (AFTER WEED)

A. Igneous, magmatic segregation.
    (a) Siliceous.
        1. Masses, Aplitic masses.　Ehrenberg, Shartash.
        2. Dikes, Beresite or Aplite.　Berezovsk.
        3. Quartz veins.　Alaska, Randsburg, Black Hills.
    (b) Basic.
        1. Peripheral masses.　Copper, iron, nickel.　(Sudbury, Ont.)
        2. Dikes, titaniferous iron.　Adirondacks, Wyoming.
B. Igneous emanations.　Deposits formed by gases above or near
        the critical point, *e.g.* 365° C. and 200 atmospheres for $H_2O$.
    (a) Contact-metamorphic deposits.
        1. Deposits confined to contact.　Magnetite deposits (Hanover,
           N. Mex.), chalcopyrite deposits, Kristiania type, gold ores,
           Bannock, Ido., type.
        2. Deposits impregnating and replacing beds of contact zone.
           Chalcopyrite deposits, pyrrhotite ores, magnetite ores, Can-
           anea type, gold tellurium ores, Elkhorn type, arsenopyrite
           ores, Similkameen type.
    (b) Veins closely allied to magmatic veins and to Division D.
        1. Cassiterite.　Cornwall.
        2. Tourmaline copper.　Sonora.
        3. Tourmaline gold.　Helena, Mont., Minas Geraes, etc.
        4. Augite copper, etc.　Tuscany.
C. Fumarolic deposits.
    (a) Metallic oxides, etc., in clefts in lava.　No commercial impor-
        tance.　Copper, iron, etc.
D. Gas-aqueous or pneumato-hydato-genetic deposits, igneous emana-
        tions, or primitive water mingled with ground water.
    (a) Filling deposits.
        1. Fissure veins.
        2. Impregnation of porous rock.
        3. Cementation deposits of breccia.
    (b) Replacement deposits.
        1. Propylitic.　Comstock.
        2. Sericitic kaolinic, calcitic, Copper silver, Silver lead.　Claus-
           thal.　De Lamar, Ido.
        3. Silicic dolomitic, silver lead, Aspen.
        4. Silicic calcitic.　Cinnabar, California.
        5. Sideritic silver lead.　Cœur d'Alene, Slocan, Wood River.
        6. Biotitic gold copper.　Rossland, Brit. Col.
        7. Fluoric gold tellurium.　Cripple Creek, Colo.
        8. Zeolitic.　Michigan copper ores.

*Structure Types of Above*

    Fissure veins.　(San Juan, Colo.)
    Volcanic stocks, Nagyag.　Cripple Creek.
    Contact chimneys.　Judith.

Dike replacements and impregnations.

Bedding or contact planes. Mercur.

Axes of folds, synclinal basins, anticlinal saddles. Bendigo, Elkhorn.

**E.** Meteoric waters. (Surface derived.)

    (*a*) Underground.

        1. Veins. (Wisconsin lead and zinc.)

        2. Replacements. Iron ores, Michigan; lead, zinc.

        3. Residual. Gossan iron ores, manganese deposits. (Virginia.)

    (*b*) Surficial.

        1. Chemical. Bog iron ores, sinters. Some bedded iron ores, etc. (Clinton ore.)

        2. Mechanical. Gold and tin placers.

**F.** Metamorphic deposits. Ores concentrated from older rocks by metamorphism, dynamo or regional.

### Classification of Ore Deposits (after Lindgren)

I. Deposits produced by mechanical processes of concentration. (Temperature and pressure moderate.)

    Ex. Placers of gold, platinum, etc.

II. Deposits produced by chemical processes of concentration. (Temperature and pressure vary between wide limits.)

    **A.** In bodies of surface water.

        1. By interaction of solutions:

            *a.* Anorganic reactions. Clinton iron ore.

            *b.* Organic reactions. Ex. Bog iron ore.

        2. By evaporation of solvents. (No metallic examples).

        { Temp., $0°–70°\pm$. Pressure moderate.

    **B.** In bodies of rocks.

        1. By concentration of substances contained in the geological body itself.

            *a.* Concentration by rock decay and residual weathering near surface. Ex. Residual iron and manganese ores.
    { Temp., $0°–100°\pm$. Pressure moderate.

            *b.* Concentration by ground water of deeper circulation. Ex. Lake Superior iron ores
    { Temp., $0°–100°\pm$. Pressure moderate.

            *c.* Concentration by dynamic and regional metamorphism. Ex. Fahlbands in some schists?
    { Temp. up to 400°. Pressure high.

            *d.* Zeolitization of surface lavas. Ex. L. Superior copper ores.
    { Temp., $50°–300°$. Pressure moderate.

2. Concentration effected by introduction of substances foreign to the rock.

    *a.* Origin independent of igneous activity.

| | |
|---|---|
| By circulating atmospheric waters at moderate or slight depth.  Ex. Miss. valley lead and zinc ores. | Temp., to 100°. Pressure moderate. |

    *b.* Origin dependent upon the eruption of igneous rocks.

        **a**. By hot ascending waters of uncertain origin, but charged with igneous emanations.

| | |
|---|---|
| 1. Deposition and concentration at slight depth.  Ex. Goldfield, Nev. | Temp., 50° ± − 150° ±. Pressure moderate. |
| 2. Deposition and concentration at intermediate depth.  Ex. Leadville, Colo.;  Cobalt, Ont. | Temp., 150° ± − 300° ±. Pressure high. |
| 3. Deposition and concentration at great depth or at high temperature and pressure. Ex. Tin veins; Ontario quartz veins. | Temp., 300° ± − 500° ±. Pressure very high. |

        **b**. By direct igneous emanations.

| | |
|---|---|
| 1. From intrusive bodies.  Contact metamorphic deposits and allied veins. | Temp., probably 300° ± − 800°. Pressure very high. |
| 2. From effusive bodies.  Sublimates, fumaroles.  No ore deposits. | Temp., 400° ±. Pressure atmospheric to moderate. |

**C**. In magmas, by processes of differentiation.

    *a.* Magmatic deposits proper.  Temp., 700°–1500°.  Pressure high.

        Ex. Titaniferous iron ore.  Chromite.

    *b.* Pegmatites.  Temp. about 575°.  Pressure very high.

        Ex. Molybdenum ore.

**Metallogenetic Epochs.**—The term metallogenetic epoch refers to a period of time during which a deposition of metals was taking place, and usually accompanied or immediately followed periods

of igneous activity. This process has been active, during a number of periods in the past, as shown by the geologic records, and the available data for North America have been summarized by Lindgren as follows (62).

*Pre-Cambrian Period.* — The pre-Cambrian rocks, which underlie a number of extensive areas in the United States, include not only metamorphosed schists and gneisses, but also various types of intrusives, the characteristic metals being iron, copper, nickel, gold, and silver. Lead and zinc are less abundant than they are in the later periods, while quicksilver and antimony are rare.

The ilmenites and magnetites of the eastern states are chiefly of igneous origin, while the hematites of Lake Superior are partly igneous and partly sedimentary, but subsequently oxidized and concentrated by surface waters, a process which is believed to have gone on in pre-Cambrian times. The copper and nickel ores are associated with basic igneous rocks, some of these, as in Michigan, being of effusive nature. This copper concentration Lindgren suggests must have gone on in pre-Cambrian times, following the close of Keeweenawan (Algonkian) volcanic activity. Of similar age are the cobalt-silver veins of Ontario. The auriferous-quartz veins of the southern states, whose deposition followed that of granitic intrusions in schists, are also to be placed here, although some writers would date them later.

In the Cordilleran region the pre-Cambrian was productive of gold and copper deposits, which are found at many points from South Dakota and Wyoming to Arizona. These gold ores are usually lenticular quartz veins in schists, associated with such gangue minerals as tourmaline, garnet, etc. The copper ores often contain chalcopyrite, and form veins or irregular masses, which are probably of magmatic origin, and have been modified by dynamo-metamorphism. Sphalerite may accompany the chalcopyrite, but lead is almost entirely wanting.

In Ontario a careful study of the pre-Cambrian rocks by Miller and Knight [1] (66) has shown the possibility of recognizing at least five metallogenetic epochs as follows:

1. Grenville. — Epoch of extensive deposition of " iron formation," as a chemical precipitate among other sediments.

2. Timiskanian. — Epoch of minor deposition of " iron formation " as a chemical precipitate.

3. Algoman. — Epoch following granite intrusions, of gold at

[1] For classification used here, see Geol. Soc. Amer., Bull. XXVI: 87, 1915.

Porcupine and other localities, and of auriferous mispickel.    Preceding granite intrusions, basic intrusions of probable post-Timiskanian age, gave rise to nickel, titaniferous and non-titaniferous magnetites and chromite.

4. Animikean. — Epoch of deposition of "iron formation" as a chemical precipitate.

5. Keweenawan. — Epoch following basic intrusions of: *a*. Silver, cobalt, nickel and arsenic at Cobalt and elsewhere; *b*. Nickel and copper at Sudbury and copper elsehwere.

*Paleozoic*. — During this time a number of granitic intrusions occurred from New York and New England northward to Quebec and Nova Scotia, and these were accompanied by the formation of some gold-quartz veins; but little metallization occurred in the West during this period.

Two periods of iron-ore formation occurred during Paleozoic time in the East.   One of these was in the Silurian, when the persistent beds of low-grade Clinton hematite were formed; the other was during the Carboniferous, when the layers of carbonate blackband ores were deposited.

*Mesozoic*. — During the Triassic, small deposits of copper and iron ores were formed in the eastern states, along the contact of the trap sheets and sedimentary rocks.   The deposits were in part veins and in part of contact-metamorphic character.

In the West important accumulations of ores were beginning, for during the Triassic there began a series of eruptions which continued through the Jurassic, the products of these being basic lavas which were extruded from California to Alaska.   The metallization accompanying or following these yielded copper deposits, which include some of those found in California, British Columbia, and those of the Copper River region in Alaska.

Another important metallization epoch followed the intrusion of the great early Cretaceous quartz-monzonite or grano-diorite batholiths of the Pacific coast.

These injections were of vast extent, one batholith extending through California, and another from Washington up through British Columbia to Alaska, while other smaller masses occur in several of the western states.   These intrusions were followed by intense metallization, mineral deposits being formed in abundance around the margin of the batholiths, as in the gold belt of California.   Gold was the chief metal formed, with copper next.   Along the Pacific coast, where there is little limestone in the intruded

sediments, lead is rarely found, but in the interior (Nevada and Idaho) where limestones were present, lead and zinc both occur. Silver is everywhere present, but is rarely important unless associated with lead; arsenic and antimony are rare; and mercury is wanting in commercial quantities.

*Early Tertiary.* — About this time, perhaps a little earlier, or a little later, important concentrations of lead and zinc took place in the Mississippi Valley, but they appear to have been independent of igneous intrusions, and are thought by most geologists to represent the work of surface waters, the ultimate source of the metals being the pre-Cambrian rocks.

At the close of the Cretaceous violent outbursts began along the eastern margin of the Cordilleran region, the magmas being of intermediate character and laccolithic form. They occur from British Columbia through Montana, Colorado, New Mexico, and eastern Arizona down into Mexico.

There ensued then another or third epoch of Cordilleran metallization, during which many contact-metamorphic deposits and veins were formed around the margins of the laccoliths. Gold and silver are the characteristic metals, with abundant lead and zinc, especially where the intrusions cut limestones. The latter may also show copper and iron along the contact. Arsenic and antimony are more common than they were in the earlier epochs, but mercury is still rare.

*Late Tertiary.* — After a period of mountain-making disturbances, uplift, warping, and dislocations, there were extruded a series of lava flows which spread over a large area in the far West, and are prominent in California, Washington, Oregon, Idaho, Colorado, Utah, Nevada, New Mexico, and Arizona. Andesites and rhyolites predominate. This was accompanied by a fifth metallization, whose characteristic metals are gold and silver, forming deposits often of great richness; lead and zinc are not abundant, except in limestone, and neither is copper. Tellurium and antimony are; not that they are absent in older metallizations, but the tellurium seems to be especially characteristic of this epoch. The metallic deposits seem to be somewhat restricted, occurring mainly near the foci of igneous activity.

*Post-Pliocene.* — There came finally an epoch of metallization at a late date, restricted, however, to the Pacific coast line, and characterized by the mercury deposits of the Pacific coast belt.

*Cretaceous or Later Copper Epochs.* — These, being of wide time

range, cannot be included in the previous classes. They represent disseminations of copper in sandstones, shales or conglomerates, and carry in most cases primary chalcocite with a little silver.

*Summary.* — The following table of Lindgren summarizes the conditions for the western states:—

| | PRINCIPAL METALS | PRINCIPAL ROCKS ASSOCIATED WITH DEPOSITS |
|---|---|---|
| 1. Deposits of the pre-Cambrian period . . . . | Gold and copper . . | Granites, diorites, gabbro |
| 2. Deposits of the early Mesozoic epoch . . . | Copper . . . . | Basalt, diabase, gabbro |
| 3. Deposits of the late Mesozoic epoch . . . . | Gold . . . . . | Granodiorite, quartz-monzonite |
| 4. Deposits of the early Tertiary epoch . . . . | Gold, silver . . . Copper, lead, zinc . | Granodiorite, quartz-monzonite, monzonite |
| 5. Deposits of the late Tertiary epoch . . . . | Gold, silver . . . | Andesite Rhyolite, |
| 6. Deposits of the Post-Pliocene epoch . . . | Quicksilver . . . | Basalt |
| 7. Cretaceous or later concentrations in sedimentary rocks . . . . . | Copper . . . . . | Sandstone, shale, conglomerate |

**Metallographic Study of Ores** (14).—Owing to the opaque character of most ore minerals these cannot be examined in thin sections by transmitted light, as is done with non-metallic minerals.

Another method of study has therefore been developed in recent years, and consists in examining polished surfaces of the ore under the microscope by reflected light. By this means the relationships of the different metallic minerals in the ore can be quite satisfactorily studied, and differentiated by means of their color, microchemical tests, etc. Plate XLII, shows a series of ore specimens examined and photographed in the manner described above. This method of study has been most helpful in studying genetic problems, secondary enrichment processes, etc.

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# CHAPTER XV

## IRON ORES

Iron is an abundant constituent of the earth's crust, and yet few minerals are capable of serving as ores of this metal, because they do not contain it in the right combination or in sufficient quantity to make its extraction possible or profitable.

The iron ores having the greatest commercial value at the present day are usually those which are favorably located, of high quality, in considerable quantity, and possessing a structure such as to render their extraction easy. These four requirements have been met to such an eminent degree by the deposits located in the Lake Superior district that they now form the main source of supply for furnaces in the eastern and central states, and many of the iron mines in the eastern part of the United States have found it difficult to compete with them, although it is true that a number of deposits are worked to supply local demand, owing to their proximity to furnace, flux, and coal, or because they possess certain desirable characteristics.

**Iron-ore Minerals.** — The ore minerals of iron, together with their composition and theoretic percentage of metallic iron, are: —

| | | |
|---|---|---|
| MAGNETITE. | Magnetic iron ore, $Fe_3O_4$ . . . . . . | 72.4% |
| HEMATITE. | Specular iron ore, red hematite, fossil ore, Clinton ore, $Fe_2O_3$ . . . . . . . . , | 70% |
| LIMONITE.[1] | Brown hematite, bog iron ore, ochre, brown ore $2Fe_2O_3, 3H_2O$ . . . . . . . | 59.89% |
| SIDERITE. | Spathic ore, blackband, clay-iron stone, kidney ore, $FeCO_3$ . . . . . . . | 48.27% |

Of subordinate value: —

| | | |
|---|---|---|
| PYRITE. | $FeS_2$ . . . . . . . . . | 46.6% |
| FRANKLINITE. | (Fe, Zn, Mn)O, (Fe, Mn)$_2$O$_3$ . . . . | ± 44.1% |
| PYRRHOTITE. | Chiefly FeS . . . . . . . | ± 61.6% |

Magnetite is black, often granular with a metallic luster. It has a black streak, hardness of 5.5–6.5, specific gravity of 5.5–6.5, and is strongly magnetic.

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[1] The group name "*brown ore*" is sometimes used to include several hydrous oxides, such as limonite, turgite, and göthite.

Some occurrences may run high in titanium, especially those found in basic igneous rocks. Hematite is red to brownish red, steel-gray, or even black. It is commonly fine-grained, but the specular varieties may be quite coarse. It ranges from massive to powdery, and has a specific gravity of 5.2. Limonite is never crystalline, and varies widely in appearance; some forms are powdery, others massive, and these may be porous, vesicular, stalactitic, or even, though rarely, solid. The specific gravity is 3.8. The color is brown to brownish yellow on the fracture, but may be black and shiny on the natural surface. Göthite ($Fe_2O_3$, $H_2O$) and other hydrous oxides with less water than limonite are sometimes associated with it. Indeed much of the commercial limonite or brown ore is an intimate mixture of several of the hydrous oxides of iron. Siderite, when occurring in commercial quantities, is rarely in cleavable form, but occurs as a fine-grained mass, with impurities. Hematite is by far the most valuable of the iron-ore minerals, chiefly on account of its easier reduction, but also because of the greater richness of the known important deposits.

The deficiency in iron content shown by many ores is due to the presence of common rock-forming minerals in the gangue, the impurities which they supply being alumina, lime, magnesia, silica, and also metallic minerals which have titanium, arsenic, copper, phosphorus, and sulphur. The effect of the last four is in general to weaken the iron.

Silica is objectionable because it displaces iron, and because just so much lime is required to flux it, but some furnaces turn out iron for foundry purposes containing 10 or more per cent. Ores carrying as high as 40 per cent $SiO_2$ are used in small quantities. Lime in small amounts does no harm, but in large quantities needs to be fluxed off. It is not present in any quantity in limonite, but may run high in the Clinton red ores. Alumina may run somewhat high in limonites, because of admixed clay. Pyrite is the common source of the sulphur, but in some limonites it may come from gypsum or barite. Titanium, a common ingredient, is found in some quantity in many magnetite deposits (see Titaniferous magnetites, also refs. 28, 30, 33a) and up to the present time has rendered them practically useless, not because it interferes with the quality of the iron, but because it makes the ore highly refractory, and drives much of the iron into the slag. Experiments have been made looking towards the utilization of these titaniferous magnetites for the manufacture of ferrotitanium; indeed these have been used for several years in the manufacture of this alloy, for although rutile is preferred it is too expensive. Manganese, when present, is found mostly in the limonite ores and for certain purposes is desirable. It is also prominent in some of the Lake Superior ores. Apatite yields the phosphorus. As this cannot be eliminated in either the blast furnace or the acid converter used in making Bessemer steel, and as the allowable limit of phosphorus in pig iron used for this purpose is $\frac{1}{10}$ per cent, a distinction is usually made between Bessemer and non-Bessemer ores, the maximum amount of phosphorus permissible in iron ore to be used for this purpose being $\frac{1}{1000}$ of the percentage of metallic

iron contents of the ore. The phosphorus contents of many high-grade ores falls considerably below the allowable limit.

**Classification.**—Iron-ore deposits have originated in a number of different ways, including: 1. Magmatic segregation deposits (Lake Sanford, New York, etc.) 2. Contact-metamorphic deposits (Iron Springs, Utah; etc.). 3. Sedimentary ores (bedded hematite and limonite, bog ores, etc.). 4. Ores concentrated by meteoric waters, and deposited as replacements (some Lake Superior hematites, Oriskany limonites), or in residual materials (Virginia Cambro-Silurian limonites). 5. Lenticular masses in metamorphic rocks, of variable origin (some magnetite and pyrite deposits). 6. Gossan ores (limonite capping of many sulphide ore bodies). 7. Replacements by ascending waters; and 8. Placer deposits (magnetite sands).

Iron-ore bodies may show a variety of form, but many of the important deposits known in this country are lens- or basin-shaped in outline. Irregular masses and beds are not uncommon.

Iron ores show a wide geologic distribution, those found in the United States for example ranging from pre-Cambrian to Recent. The occurrences of the different kinds of ore are best discussed separately, and for practical as well as for other purposes a mineralogic and geographic grouping seems better in this case than a genetic one.

### MAGNETITE

**United States.**—Magnetite occurs (Fig. 153) (1) as lenticular masses commonly in metamorphic rocks; (2) as more or less lens-shaped and tabular bodies in igneous rocks; (3) as sands on the shores of lakes and seas; (4) as contact-metamorphic deposits; (5) as replacements in limestone, not of contact-metamorphic character; (6) as veins, and (7) in residual clays.

The first class includes the most important deposits now worked in this country. The second [1] and third groups run too high in titanium to have any commercial value at the present time, but the second may become of importance in the future, and moreover some of its representatives are of large size. Examples of the fourth class are known at a number of points in the West, and while few of them are worked, they may some day become of great importance. They carry hematite in addition to magnetite. The fifth, sixth, and seventh groups are unimportant.

[1] This is not true of all the European deposits, see p. 517.

**Distribution of Magnetites in the United States** [1] (Fig. 153).
**Non-Titaniferous Magnetites.** — These are usually found in the
form of lenticular deposits in metamorphic rocks. The most
important series of occurrences lies in the crystalline belt of rocks
extending from New York into Alabama, deposits being known in
New York, New Jersey, Pennsylvania, Virginia, and North Caro-
lina.



FIG. 153. — Map showing distribution of hematite and magnetite deposits in the
United States. (*After Harder, U. S. Geol. Surv., Min. Res.*, 1907.)

The lenses, which are interbedded with gneisses of either acid or
basic character and often conform with the latter in dip and strike,
are of variable size, and may occur either singly or in series, the ore
body commonly showing pinching and swelling, or even faulting.
Well-defined boundaries are sometimes wanting. Feldspar, horn-
blende, and quartz are common gangue minerals, while apatite is
prominent in some. Although the ore as mined is frequently of
sufficient purity to be shipped direct to the blast furnace, in some
instances it is so lean as to require concentration by magnetic
methods. A description of one or two occurrences will serve as types :

*Adirondack Region, New York* (27, 30) — The rocks of the Adiron-
dack region (Fig. 154) are almost exclusively of pre-Cambrian age,
with occasional inliers of the bordering Paleozoic strata, whose basal

[1] Magnetites in general fall into two classes on basis of titanium content, viz.
the non-titaniferous and titaniferous.

FIG. 154. — Geologic map of Adirondack Region, New York, showing location of iron-ore deposits. (*After Newland, Econ. Geol., II.*)

member, the Potsdam sandstone, rests unconformably on the older crystallines. The latter have in most cases been subjected to powerful compression, and sometimes greatly changed by metamorphism, in fact so much so that their original character is determinable with difficulty.

The following members are recognized, beginning with the oldest:

I. *Metamorphic rocks.* — 1. *Sedimentary or Grenville Series.* These consist of limestones and dolomites, often impregnated with pyrite, graphite, and silicates, and by an increase in the latter may pass into schists. Both rock types occur in long narrow belts, bounded by sedimentary gneisses. 2. *Gneisses of acid to basic character,* often showing garnet, sillimanite, graphite, cyanite, pyrite, etc. 3. *Amphibolites,* composed mainly of hornblende and feldspar, and which may be metamorphosed dikes or magnesian shale. 4. *Quartzites* of infrequent occurrence. 5. *Gneisses* of doubtful relationships.

II. *Igneous Rocks.*—These include: (1) anorthosite (the earliest), gabbro, syenite, and granite, all connected by intermediate rock types and probably representing derivations from the same magma. (2) Dikes, mostly diabases.

*Ores.*—The non-titaniferous magnetites are the most widespread of the Adirondack ores, and occur on both the eastern and western sides of the mountains.
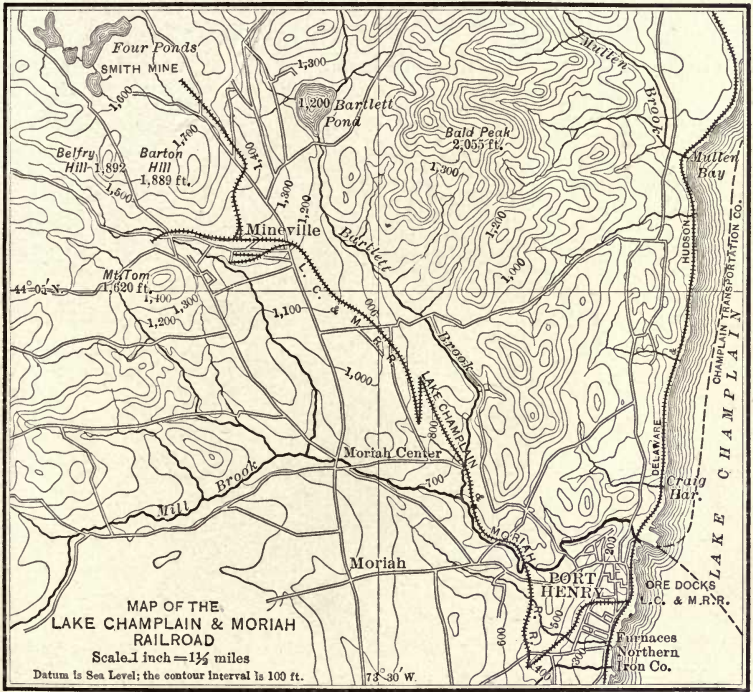


FIG. 155.— Map of Mineville, N. Y., iron-ore district. (*After Granbery, Eng. and Min. Jour., LXXXI.*)

The ores vary from impure lean varieties, consisting of magnetite mixed with the country-rock minerals (*i. e.* quartz, feldspar, pyroxene, hornblende, etc.), to pure magnetite. The richest ore averages 60 to 70 per cent iron, and comes chiefly from Mineville, while those ores carrying under 50 per cent have to be concentrated. The phosphorus content is variable, but seems to be lower in the leaner ones, while in the non-Bessemer ores it may exceed 2 per cent. The amount of sulphur is also changeable, but is highest in those ore bodies found in the Grenville gneiss.

While the ore bodies are variable in shape they show in general a somewhat lenticular cross-section, with the tabulation extending parallel with the strike; but regularity is more common on the north and west sides of the province, for in the eastern districts there is the greatest irregularity due to a complexity of pinches, swells, and compressed folds. The wall rocks include gneisses of granitic, syenitic, and dioritic composition, as well as schists and occasionally limestones.

*Mineville, New York* (30).—The ore bodies at this locality are the largest and most productive in New York State at the present time.

They are of lenticular character, but in some cases the lenses
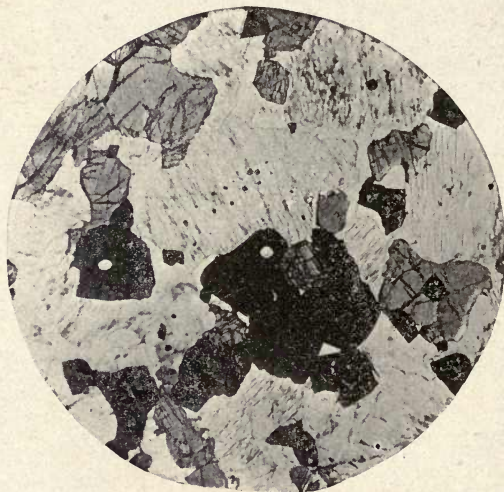


Fig. 156. — Thin section of magnetite gneiss, Lyon Mountain, N. Y. Magnetite (black); feldspar (gray); pyroxene (crossed cleavage). ×30.

are so flat and of such extent as to be commonly spoken of as beds; moreover, some of them have been bent over into a southwesterly pitching fold, whose crest has been stretched and pinched, while faulting at the northern end of this has complicated the structure.

The ores occur as integral members of the syenite series, and are in the form of layers conformable to the banding or foliation of the inclosing rocks.

There are at least three large ore bodies (Fig. 157), viz.:—

1. The Barton Hill ore body, forming a practically continuous bed, whose outcrop is approximately 3500 feet long in a direction

PLATE XLIII



FIG. 1. — View of open cut in magnetite deposit, Mineville, N. Y. The pillars are left to support the gneiss hanging wall. (*After Witherbee, Iron Age, Dec.* 17, 1903.)
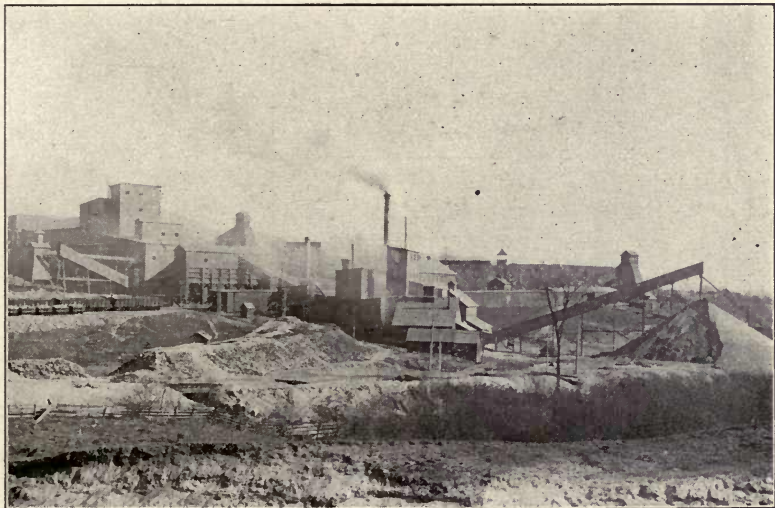


FIG. 2. — General view of magnetic separating plants and shaft houses, Mineville, N. Y. (*After Witherbee, Iron Age,* 1903.)

a little east of north. Iron content, 30-35 per cent; concentrates, 65 per cent; Fe, .025 per cent P.
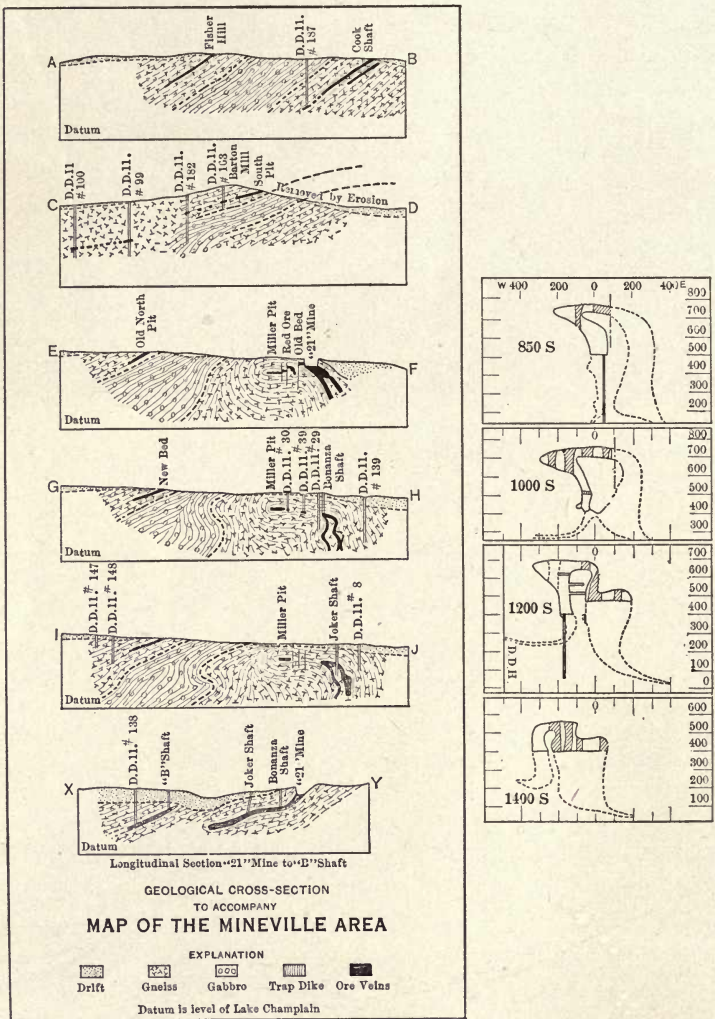


Fig. 157. — Sections of the old, " 21 "-Bonanza-Joker ore beds, Mineville, N. Y. (*After Granbery, Eng. and Min. Jour., LXXXI.*)

2. The Harmony bed, ying to the southwestward of Barton Hill, and striking northwest, with a rather flat southwest dip.

It is 10 to 20 feet thick and cut by several narrow trap dikes which occupy fault planes of 10 to 50 feet displacement.

3. A large ore body which appears to be made up of three principal and separated parts, known as the Miller, the Old Bed or Mine 23, and the " 21"-Bonanza-Joker. This is the chief source of the ore. There is some doubt whether there is any connection between the Joker and the Harmony. This Old Bed group extends in a practically unbroken stretch for about a half mile, exhibiting at the same time a most complex fold, referred to above.

The ores are granular masses of magnetite which in the Barton Hill group were prevailingly of Bessemer grade, but which in the Old Bed series are high in phosphorus.

The lean ores are mixed with the minerals of the wall rocks, and among these the basic syenite is the chief one.

At Lyon Mountain (30) the ore is a lean magnetite traceable for 6 miles and from 20 to 200 feet wide, and occurs in a rock intermediate between granite and syenite. Most of the ore is low in phosphorus, the concentrates carrying about .008 per cent P and 65 per cent Fe.

*New Jersey.* — In northern New Jersey, the magnetite deposits form layers or bands in the Franklin (pre-Cambrian) limestone, or as flat lenses in the associated gneisses.

The ore according to Bayley (24a) consists mainly of magnetite, hornblende, pyroxene, and apatite, sometimes intimately mixed. Pyrite and quartz are not uncommon, and all the associated minerals occur in the country gneiss.

The ore bodies, which are lens-shaped, lie with their longer axes conforming to the foliation of the gneisses, and the ore usually grades into the gneiss, although sharp boundaries are in some cases known. Several lenses may overlie each other, and then the intervening rock may be either gneiss, pegmatite full of magnetite, or coarse-grained hornblendic rock, with ore veinlets paralleling the foliation of the gneiss. This series of magnetites extends northeastward into the Highland region of New York.

*Origin of Magnetites.*—The origin of the magnetites found in the gneisses has formed a puzzling problem to geologists, whose correct solution depends in part at least on the correct interpretation of the origin of the inclosing rocks.

If the gneisses are of sedimentary origin, then it is possible that the ores may represent metamorphosed deposits of magnetite sands, limonite, or siderite, and the parallelism of the ore bodies with the foliation of the gneisses might be regarded by some as evidence in favor of such a view.

But even if the gneisses were of sedimentary origin, it might still be possible that the ores were of later introduction, as has been suggested by some.  Thus Keith held the view that the North Carolina magnetites were replacement deposits (26), while Kemp formerly advanced the theory that the ore bodies at Mineville (27) have been formed by iron-bearing magmatic waters, which were given off from the neighboring gabbros and penetrated the gneisses while the latter were probably still at great depths, and before their metamorphism was complete.  The presence of apatite and fluorite was thought to show that mineralizing vapors also played a part. A similar origin was suggested by Spencer for the New Jersey magnetites (34).

Later studies by Kemp and Newland in the Adirondacks (30) seem, however, to indicate that the acid gneisses are probably of igneous origin. and that the magnetites themselves are products of magmatic differentiation.  That there is no obstacle to this theory is shown by Newland, who points out that the acid igneous rocks of the region contain a large excess of iron over the amounts combined with the lime and magnesia to form silicates.  The peculiar form of some of the ore bodies is likewise perhaps only explainable by this theory.  A fact not to be overlooked, however, is the occurrence of fluorite, apatite, hornblende, etc., intercrystallized with magnetite, or the frequent association of the latter with pegmatite or vein quartz, a group of conditions which are suggestive of mineralizing agents, and their deposition by pneumatolytic or aqueous action.

*Cornwall, Pennsylvania* (35). — A somewhat unique deposit occurs at Cornwall, Lebanon County, Pennsylvania, and at several other localities in southern Pennsylvania.  The ore is found along the contact of Triassic diabase, with Cambro-Ordovician limestones or more rarely Triassic shales, and consists mainly of magnetite, but carries sufficient pyrite to require roasting, and occasionally a little specular hematite.  The ore forms large and small masses of irregular shape, lying either within the sediments or along the contact, and while it appears to be a true contact metamorphic deposit, the contact silicates are not prominent.  The ore averages about 45 per cent iron, is low in phosphorus, but high in sulphur, silica, lime, and magnesia.  It also carries some copper.

*Iron Springs, Utah* (29). — Iron deposits are widely scattered over the western states, but few have been worked, owing to the limited demand in that region.  They can be regarded, however, as reserves which may become of importance in the future. Among the best known of these are those of the Iron Springs

district of southwestern Utah, which belongs to the contact-metamorphic type.

At this locality the series of sedimentary rocks ranges from Carboniferous to Pleistocene (Fig. 158), and is intruded by three laccoliths of biotite andesite, which have especially affected the Home-
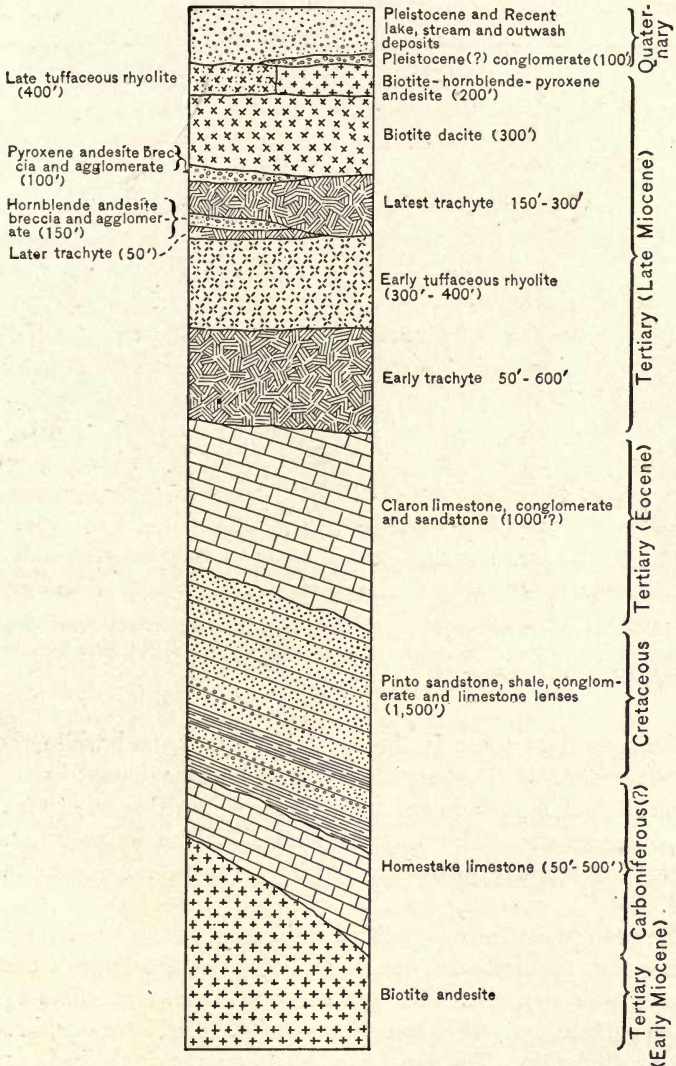


Fig. 158. — Geologic column of the Iron Springs, Utah district. (*After Leith and Harder, U. S. Geol. Surv., Bull. 338.*)

stake (Carboniferous) limestone, and to a lesser extent the Claron (Tertiary) limestone.

The ore bodies are of three types, viz.: (1) fissure veins in andesite; (2) fissure and replacement deposits on the contact of the andesite and Carboniferous limestone; and (3) as breccia cement in Cretaceous quartzite.
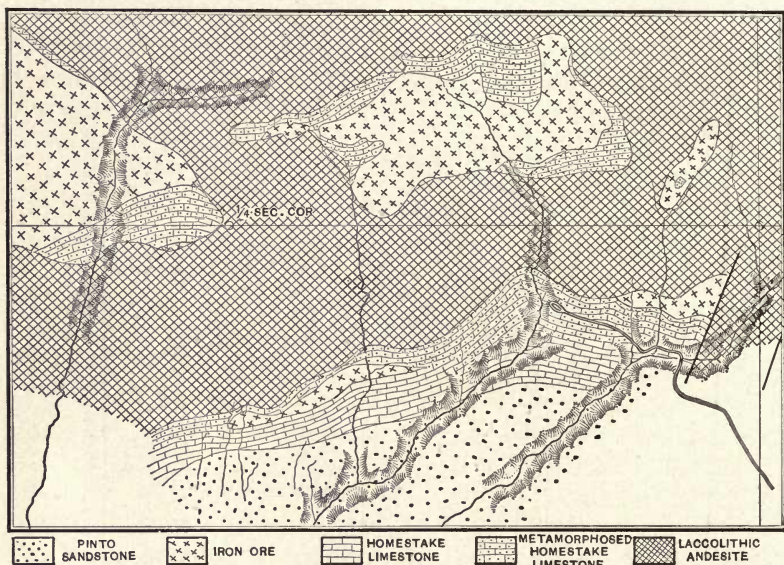


FIG. 159. — Map of a portion of the Iron Springs, Utah district, showing occurrence of iron ore in limestone near andesite contact, and also in the igneous rock. (*After Leith and Harder, U. S. Geol. Surv., Bull.* 338.)

The second of these is the most important, and while the ore bodies are roughly lens-shaped, with their longer diameters parallel to the contact, still there are numerous irregularities, due to faulting and other causes. The vertical dimensions are unknown, as the deepest test shaft is down only 130 feet, and has not reached water level.

The ore consists of magnetite and hematite with a small amount of limonite, the first two, of course, being characteristic of contact-metamorphic deposits. The ore shows a hard, crystalline texture at the surface, but, as is sometimes found in arid regions, becomes softer with depth. The gangue is chiefly quartz or chalcedony near the surface, but calcite increases with depth. The contact minerals,

garnet, diopside, apatite, mica, hornblende, and other silicates, are minor constituents.
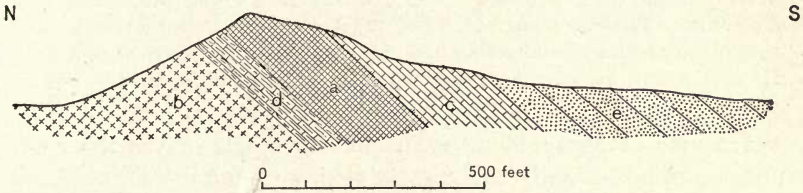


FIG. 160. — Cross section of Desert Mound contact deposit, Iron Springs, Utah district. *a*, iron ore ; *b*, laccolithic andesite ; *c*, Homestake limestone ; *d*, altered Homestake limestone ; *e*, Pinto sandstone. (*After Leith and Harder, U. S. Geol. Surv., Bull.* 338.)

While much of the ore runs above 60 per cent in iron, the average is about 56. Phosphorus is uniformly high, but sulphur, copper, and titanium are not in prohibitive amounts.

Leith and Harder believe that the ores are closely related in origin to the andesite laccolith intrusions, and suggest the following:

The contact metamorphism first produced a zone of about 60 feet width, containing varying amounts of albite, kaolinite, actinolite, diopside, quartz, orthoclase, serpentine, phlogopite, andradite, iron ores, osteolite (earthy apatite), andalusite, wollastonite, calcite, etc. There is also glassy material which appears to represent fused wall rock. Solutions given off by the andesite dissolved out the lime and magnesia carbonates, while the residue recrystallized to form silicates. Later the iron was brought in from the eruptive, probably as ferrous chloride, which reacted with water (above 500° C.), yielding magnetite and hydrochloric acid, thus:—

$$3 \ FeCl_2 + 4 \ H_2O = Fe_3O_4 + 6 \ HCl + H_2 + 77 \text{ calories.}$$

The HCl attacked the limestone, which was replaced by the magnetite.

This view that the eruptive contributed but little material to the contact zone is disputed by Kemp, who, by taking the author's analyses and recasting them, shows that the reverse may be true. Moreover, if Leith's conclusions are correct, then a contact zone 60 feet thick must represent a shrunken residue of a limestone belt 300 feet thick which, as pointed out by Kemp, seems hardly possible.

*Other Occurrences* (16).—Small deposits of magnetite are found in the limestones of the Shenandoah Group and their residual clays in southwestern Virginia (16, 23*a*). The magnetite, which is associated with hematite and

siderite, is of high grade and low in phosphorus (23a). Magnetite occurs sparingly in the Marquette Range of Michigan, where it is found in the schists. Contact-metamorphic deposits are found at a number of localities in the West, but the chief occurrences are in Colorado, New Mexico, Utah, and California. That at Fierro, N. Mex. (25a) occurs in Paleozoic limestone, near its contact with a Tertiary monzonite porphyry. Another found at Heroult, Calif., lies chiefly at the contact of diorite and Triassic limestone (32).

**Analyses of Magnetites.** — The following table gives the composition of non-titaniferous magnetites from a number of localities. It is not possible in all cases to obtain analyses of recent date.

ANALYSES OF MAGNETITES

|  | I | II | III | IV | V | VI | VII | VIII | IX |
|---|---|---|---|---|---|---|---|---|---|
| Fe . . | 60.03 | 60.91 | 61.69 | 59.93 | 56.05 | 64.9 | 56.00 | 61.85 | 89.4[1] 7.5[2] |
| $SiO_2$ . | 4.48 | 4.49 | 18.90 | 7.72 | 7.76 | 3.98 | 7. | 4.74 | 2.4 |
| P . . | 1.635 | 1.548 | 1.30[5] | .08 | .036 | .021 | .2 | .112 | .011 |
| S . . | .021 | .027 | 1.23 | .19 | .06 | .071 | .057 | .015 | .099 |
| Ti . . | .12 | .03 | 1.30 | — | — | — | — | — | — |
| Cu . . | — | .007 | — | — | — | .005 | .027 | — | — |
| Moist . | .28 | .25 | — | — | — | — | 3. | 2.62 | — |
| Mn . | — | — | .55[4] | .17 | none | .158 | .196 | 2.42[3] | .18[4] |
| $Al_2O_3$ . | — | — | 12.48 | — | — | .324 | 1. | .74 | — |
| CaO . | — | — | 4.45 | — | — | 1.010 | 4. | .16 | — |
| MgO . | — | — | .86 | — | — | 1.131 | | .95 | .3 |

I. Sample 60 carloads. II. Sample 35 carloads, 21 pit, both Mineville, N. Y., N. Y. State Museum, Bull. 119 : 82. III. Warren County, N. J., N. J. Geol. Surv., Ann. Rept. 1873 : 80. IV. Philpot, Patrick County, Va.. U. S. Geol. Surv., Bull. 380 : 219. V. Limestone magnetite. Abingdon, Va., *Ibid.* VI. Cornwall, Pa., Amer. Inst. Min. Engrs., Trans. XIV : 892. VII. Iron Springs, Utah, U. S. Geol. Surv., Bull. 338. VIII. Hanover, N. Mexico, U. S. Geol. Surv., Bull. 380 : 212. IX. Shasta County Calif., Econ. Geol., III : 472.

[1] $Fe_3O_4$. [2] $Fe_2O_3$. [3] $MnO_2$. [4] $MnO$. [5] $P_2O_5$.

**Canada.** — Two important magnetite occurrences in eastern Canada are those at Bathurst, N. B., and Moose Mountain, Ont. Some magnetite is obtained at Torbrook, N. S., and north of Lake Superior, but both of these are better discussed under Hematite.

*Bathurst, N. B.* (83, 86, 96). — The magnetite here forms three bodies or groups of bodies striking approximately north and south, with walls of quartz-porphyry and quartz-free porphyry. Diabase is also present, but its exact relation to the ore is not known. Both the igneous rocks and ore are more or less schistose or banded. The ore, which consists largely of magnetite with a variable amount of hematite, is fine grained, fine to coarse banded, and with sharply-defined walls. Considerable pyrite is at times present, and veins and stringers of quartz are relatively abundant. The iron content ranges from 39.6–58.7 per cent; sulphur .009– .27 per cent; and phosphorus, .385–1.222 per cent.

The ore is believed to be a replacement of the schistose quartz porphyry along sharply defined zones, and the banded structure may be an original one.

*Moose Mountain, Ont.* (97). — This deposit, which is situated north of the Sudbury nickel basin (page 796) is one of the largest in Canada. The magnetite shows a more or less strongly banded structure, due to alternations of iron ore and silica, while epidote sometimes fills fissures in the ore, which are often bordered by hornblende that passes outwards into magnetite. The iron formation which lies in Keewatin schists is steeply tilted. Ordinary banded ore runs about 36 per cent iron and is concentrated to 55 per cent, but much of the good ore exceeds the first figure.

*Texada Island, B. C.* (89).—Contact-metamorphic deposits of magnetite with some copper, occurring in limestone near granite and diorite contacts are found on Texada Island, northwest of Vancouver, but they have not been steadily worked.
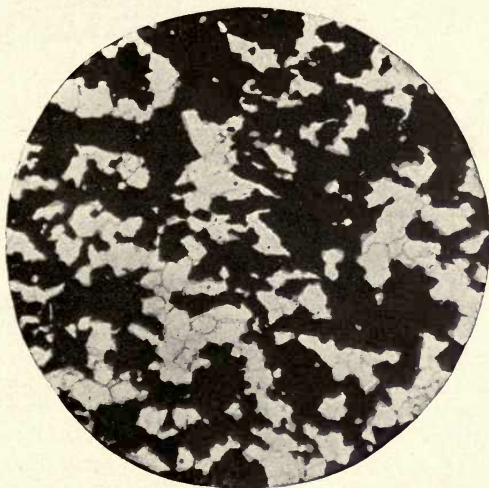


FIG. 161. — Photomicrograph of thin section of ore from Kiruna, Sweden. Black magnetite; white, apatite.

**Other Foreign Deposits** (1). — Two of the most remarkable deposits of, magnetite known in the World are those of Kiruna and Gellivare in northern Sweden.[1] That at Kiruna occurs as a great steeply dipping tabular or dike-like mass, traceable for about 8 kilometers in the hills of Kirunavaara and Luossavaara (Plate XLIV, Fig. 1 and Fig. 161), and has a width of

[1] Sjögren, Amer. Inst. Min. Engrs., Trans. **XXXVIII**: 766, 1907. Stutzer, Zeitschr. prak. Geol., **XIV**: 65 and 137, 1906.

32 to 152 meters.   The total tonnage as determined from outcrops and bor-
ings is estimated at 480,000,000 tons.   The footwall is an orthoclase porphyry
or syenite, while the hanging wall is quartz porphyry, which in turn is overlain
by quartzites, clay slates and conglomerates, supposedly of pre-Cambrian age.

The ore is a fine-grained mixture consisting chiefly of magnetite and apa-
tite (Fig. 161).

Much discussion has been aroused over the origin of these ores.   Högbom
in 1898 thought them to be due to magmatic segregation, while de Launay
argued for a sedimentary origin, assuming that the footwall was a submarine
flow, from which iron chlorides and sulphides emanated in gaseous form
and were then oxidized to ferric oxide, which later was changed to magnetite
by a covering flow of quartz porphyry.   Stutzer, with probably more reason,
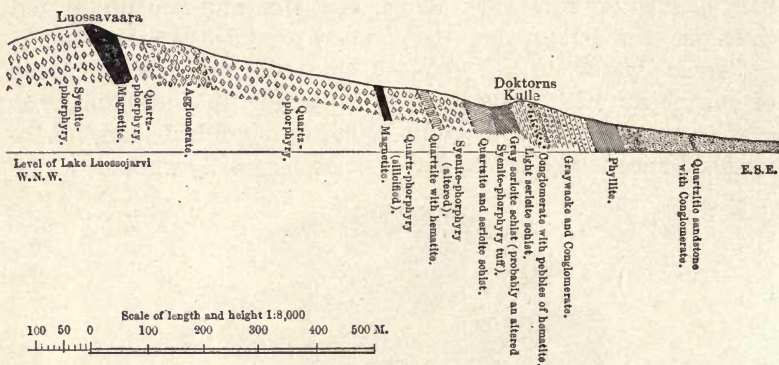


FIG. 162. — Section across Luossavaara near Kiruna, Sweden.   (*After Lundbohm.*)

has regarded the ore as a dike, whose intrusion was preceded by the footwall
syenite, and followed by the hanging wall quartz porphyry.

At Gellivare (Plate XLIV, Fig. 2), the ore is similar to Kiruna mineralogic-
ally, but coarser grained.   It occurs as steeply dipping irregular lenses, in a
gray or red gneiss, often surrounded by a curious hornblendic zone (*skarn*).
The ore is probably similar in origin to that at Kiruna, but has been strongly
altered by metamorphism.[1]

Other large magnetite deposits are known in the Ural Mountains at Wys-
sokaia Gora and Goroblagodat.[2]   Of historic and scientific interest are the
contact metamorphic deposits of magnetite with some sulphides found in the
province of Banat, Hungary, and first described by von Cotta.[3]

Most interesting are the Cuban [4] deposits lying in a belt stretching eastward
from Santiago, and supplying ore which is chiefly magnetite, but carries some
hematite and pyrite, especially in its upper parts.   Prominent among the
sedimentary and igneous rocks of the district is a large area of intrusive

[1] Sjögren, loc. cit., and Lundbohm, Internat. Geol. Cong., Sweden, Guidebook,
1910.

[2] Beck, Erzlagerstttäten, 3rd ed., I: 29.

[3] Beck, loc. cit.

[4] Kemp, Amer. Inst. Min. Engrs., Bull. 105: 1801, 1915;  Lindgren, *Ibid.*, Bull.
106: 2171, 1915.   These contain additional references.

PLATE XLIV
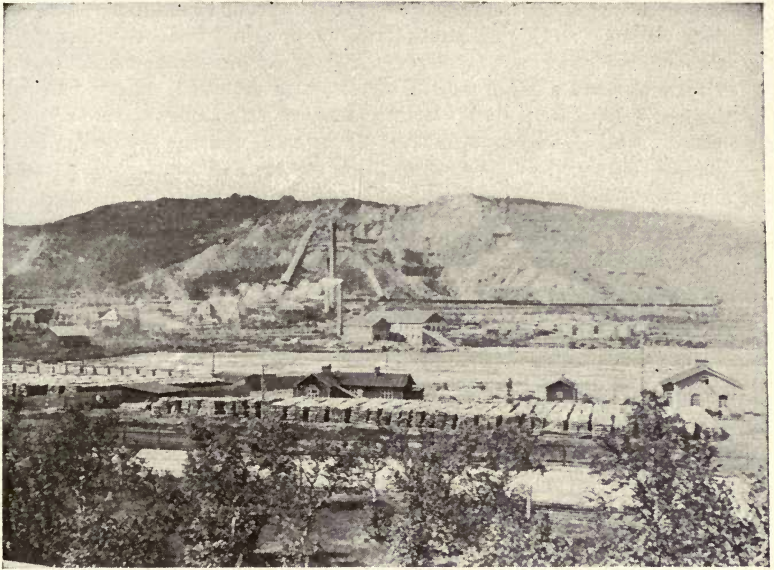


FIG. 1. — View of iron ore mines in Kirunavaara, Sweden. Open cuts near top in iron ore. Lower slopes chiefly hanging wall. (*H. Ries, photo.*)
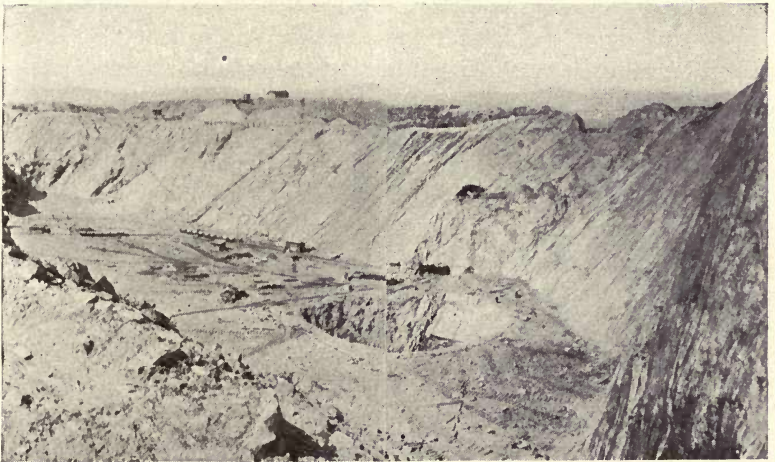


FIG. 2. — Iron deposit at Gellivare, Sweden. Note pit in floor connecting with lower workings. Walls of cut are country gneiss and in part " skarn." (*H. Ries, photo.*)

diorite, which encloses fragments of an older, bedded limestone. The ore deposits consist of: (1) small streaks to larger ones in limestone, with quartz, garnet and epidote, gangue, and evidently of contact-metamorphic origin; (2) Great tabular masses in diorite, but showing the same gangue minerals as the first. Kemp regards the latter as replacements along fracture zones in the diorite, while Lindgren is inclined to the view that the ore bodies are a product of contact metamorphism exerted by the diorite on included masses of limestone.

**Titaniferous Magnetites** (24, 28, 30, 33$a$). — These form a peculiar class by themselves, and with one or two exceptions are found always associated with rocks of the gabbro family. The ore bodies usually represent products of magmatic segregation, and may occur: (1) within the eruptive mass but grading off into it; (2) as irregular bands (schlieren); or (3) as dikes which have separated from the magma at greater depth, and then forced their way upward.

An exception to any of the above is the deposit at Cebolla Creek, Colo., which is in part of the contact metamorphic type (33$b$).

Many titaniferous magnetites are granular aggregates of magnetite and ilmenite, the relation between the two minerals being usually those of a granular igneous rock. The ilmenite is highly lustrous with a rougher surface, while the magnetite shows duller, black, cleavage surfaces. The grains of the latter sometimes have minute intergrowths of ilmenite, which show most commonly as lines and dots, the former representing sections of very small ilmenite lamellæ oriented parallel to the octahedral faces of the magnetite.

The gangue minerals may be pyroxene, brown hornblende, hypersthene, enstatite, olivine, spinel, garnet, and plagioclase. The ores are usually low in phosphorus and sulphur, but V, Cr, Ni, and Co are almost always present.

Titaniferous magnetites are found in many parts of the world, the deposits being often of large size, but their possibilities have been greatly overestimated. This is due to the fact that it is often impossible to separate the ilmenite (non-magnetic) from the magnetite (magnetic) to a sufficient degree, owing to the fine intergrowths of the two.

**United States** (28, 33$a$). — In this country titaniferous magnetites are found in New York, New Jersey, Wyoming, Minnesota, Virginia, Colorado, etc., but are not worked. The two localities of greatest importance are Sanford Hill, in the Adirondack region of New York, and Iron Mountain, Wyo.

The following analyses illustrate their composition : —

<div align="center">ANALYSES OF TITANIFEROUS MAGNETITES</div>

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| FeO . | 70.50 | 80.78 | 27.95 | 79.78 | 70.80 | 28.84 | 24.55 | 51.44[2] |
| $Fe_2O_3$ . | — | | 15.85 | | | 14.05 | 48.97 | — |
| $TiO_2$ . | 14.00 | 12.09 | 15.66 | 12.08 | 19.52 | 10.11 | 23.18 | 16.76 |
| $SiO_2$ . | 8.60 | 2.02 | 17.90 | .75 | 1.39 | 22.35 | 2.15 | — |
| $Al_2O_3$ . | 4.00 | 2.58 | 10.23 | 4.62 | 4.00 | 5.26 | — | — |
| $Cr_2O_3$ . | — | 2.40 | .51 | .32 | — | Tr. | — | — |
| $V_2O_5$ . | — | — | .55 | Tr. | — | .18 | — | — |
| MnO . | — | — | Tr. | .28 | — | .43 | — | — |
| CaO . | 1.60 | — | 2.86 | .13 | — | 1.17 | — | — |
| MgO . | 2.30 | — | 6.04 | 2.04 | | 16.10 | — | — |
| $H_2O$ . | — | — | .04 | — | — | .42 | — | — |
| $P_2O_5$ . | — | .03 | .14 | — | .022[1] | .02 | — | .97[1] |
| S . | — | — | — | — | .028 | .38 | .03 | — |
| $Na_2O$ . | — | — | — | — | — | .44 | — | — |
| $K_2O$ . | — | — | — | — | — | .10 | — | — |
| Zn . | — | — | — | — | — | .71 | — | — |
| Cu . | — | — | — | — | — | .08 | — | — |
| Co, Ni. | — | — | — | — | — | 7.08 | — | — |
| Pb . | — | — | — | — | — | — Tr. | — | — |

1. Grape Creek, Col.  2. Mayhew Range, Minn.  3. Split Rock, N. Y.
4. Greensboro, N. Ca.; Nos. 1–4, U. S. Geol. Surv., 19th Ann.
Rept., III : 377, 1899.  5. Lake Sanford, N. Y., N. Y. State Mus.,
Bull. 119 : 163.  6. Cumberland Hill, R. I., Amer. Jour. Sci., Jan.,
1908.  7. Iron Mountain, Wyo., U. S. Geol. Surv., Bull. 315 : 209.
8. Marksville, Va., Min. Res. Va., 1907 : 419.

Descriptions of two localities will serve to illustrate the mode of
occurrence of these titaniferous ores.

*New York* (28, 30). — Titaniferous magnetite deposits of large
size occur in the Adirondack region, and while they carry $TiO_2$ as an
essential ingredient, the percentage of this element may vary con-
siderably.  Thus in the Adirondack ores it is at least 8 to 9 per
cent ($TiO_2$), and averages 15 per cent.

The ores are closely associated with gabbro-anorthosite intrusions,
and are found chiefly in Essex and southern Franklin counties.
At Lake Sanford, where the most important ore bodies occur, the
small deposits are found in gabbro dikes cutting the anorthosite and
having a tabular form conformable with the strike of the dikes, but

<div align="center">[1] P.    [2] Fe.</div>

large ones occur in the anorthosite and may be segregations during cooling, or actual intrusions forced into the anorthosite after partial consolidation.

The ores are essentially magnetite and ilmenite, the richest showing little else and running about 60 per cent Fe. The magnetite grains are recognizable by parting planes parallel to the octahedron and smooth breaks, while the ilmenite grains show a rough fracture, brighter luster, and but slight magnetism.

Other minerals present are plagioclase, pyroxene, hornblende, biotite, olivine, garnet, pyrite, apatite, spinel, and quartz. The usual order of crystallization is reversed, being silicates, pyrite, ilmenite, magnetite. Analyses of the Sanford deposits show 70.73–87.60 $Fe_3O_4$, .87–2.46 $SiO_2$; 9.45–20.03 $TiO_2$; .53–4.00 $Al_2O_3$; .007–.022 P; .027–.028 S.

The following results were obtained by magnetic separation after crushing to 40 mesh. Finer crushing would probably improve the product.

|  | 1 | 2 | 3 |
|---|---|---|---|
|  | MAGNETITE | CONCENTRATE | ILMENITE AND OTHER MINERALS |
| $Fe_2O_3$ . . . . . . . | 55.9 | 54.39. | 14.28 |
| FeO . . . . . . . . | 27.5 | 28.66 | 30.93 |
| $TiO_2$ . . . . . . . | 14.0 | 8.93 | 45.23 |

*Wyoming* (24). — An occurrence of titaniferous magnetite of some importance is found at Iron Mountain in southeastern Wyoming. Iron Mountain is a ridge 300 to 600 feet wide, and $1\frac{1}{4}$ miles long, which rises sharply from the anorthosite hills to the east and pre-Cambrian uplands to the west. The pre-Cambrian complex near the iron ore dike consists of three granular igneous rocks, viz. anorthosite, iron ore, and granite, the anorthosite, or oldest, being cut by dikes and lenticular masses of iron ore and granite.

The ore, which forms a dike $1\frac{1}{4}$ miles long, 40 to 300 feet wide, and has a northerly strike, is sharply bounded on both sides by anorthosite, and paralleled by several smaller dikes. It is a black, granular, holocrystalline rock, which carries as impurities biotite, olivine, and feldspar. The iron content averages about 50 per cent.

It is suggested (Ball) that the ore and anorthosite are differentiation products from a common magma, the iron having been intruded after the complete solidification of the anorthosite; but the relationship of the two is shown by the presence in each of similar minerals, although their proportions are different.

The granite is probably the youngest of the pre-Cambrian rocks, and grades into, as well as being cut by, a biotite-pegmatite which carries some magnetite.

Fig. 164 shows a thin section of a low grade titaniferous ore found in gabbro at Cumberland, Rhode Island.

*Magnetite Sands.* — These are found in those regions where the beach sands are composed of weathering products of metamorphic and igneous rocks. The sorting action of the waves serves to carry the heavy mineral grains high up on the beaches, where they form black streaks, composed mostly of magnetite (usually titaniferous), mixed with monazite, apatite, and other heavy minerals.

Deposits are known in this country on the shores of Lake Champlain, Long Island, etc., but they are of small extent as well as lacking in quality.

New Zealand and Brazil are said to possess magnetite sands of commercial value.

Sandstones of Upper Cretaceous age, and carrying titaniferous magnetite are known in Montana, but are of no commercial value (36a).
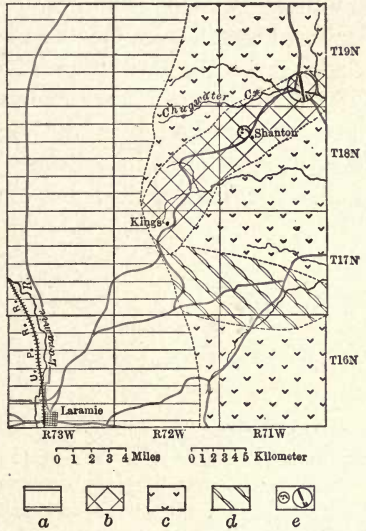


FIG. 163. — Map of Iron Mountain, Wyo., titaniferous magnetite deposit. *a*, post-Devonian; *b*, anorthosite; *c*, granite; *d*, gneiss; *e*, ore. (*After Kemp, Zeitschr. prak. Geol.,* 1905.)
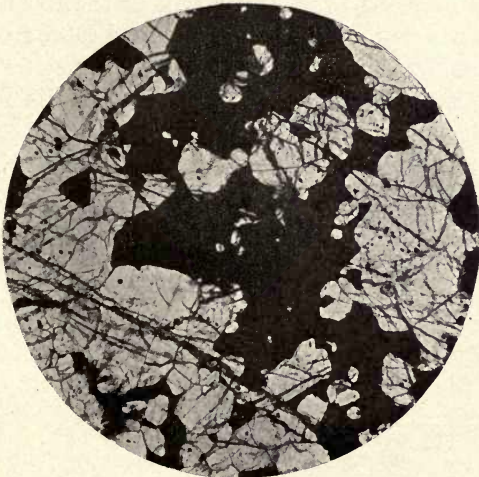


FIG. 164. — Section of Cumberlandite (Rhodose) from Cumberland, R. I. Black ilmenite and magnetite; white, olivine. ×30.

**Canada** (85, 88). — Titaniferous magnetites have been found at a number of localities in Ontario, those of the Chaffey and Matthews mines being well known. Another large deposit occurs at St. Urbain, Quebec .

Along the St. Lawrence River, in Saguenay County, Quebec (88), magnetite sands are somewhat abundant. Where the sands have been worked over by the waves, the magnetite grains have been concentrated into lenses distributed through the ordinary sand. Analyses of the sand, etc., are given below:

|  | Fe[1] | TiO$_2$[1] | INSOLU- BLE RES- IDUE | P | S |
|---|---|---|---|---|---|
| Crude sand . . . . . | 14.7 | 4.43 | 76.00 | .006 | .006 |
| First concentrate . . . | 67.2 | 3.51 | 7.45 | .043 | .012 |
| First tailings . . . . . | 8.3 | 4.7 | —— | —— | —— |

[1] Soluble iron only.

**Other Foreign Deposits.**—A number of titaniferous magnetite deposits are found in Scandinavia. The best known is that of the Ekersund-Soggendal [1] on the south coast of Norway, where the labradorite rock contains some large ore bodies. Routivare in northern Sweden has a large mass of spinel-bearing titaniferous magnetite in altered gabbro, while at Taberg in southern Sweden is still another large deposit, which occurs in olivine-gabbro and was recorded as early as 1806.

### HEMATITE

This is by far the most important ore of iron in the United States, having in 1914 formed over 90 per cent of the total production, and about 85 per cent of the hematite mined came from the Lake Superior region. It is also an important ore in some other countries. Hematite may occur mixed with magnetite in magmatic segregations (Kiruna, Sweden, page 517) and contact-metamorphic deposits (29), as beds in sedimentary rocks (51–59), as replacements in limestone (page 548); as irregular deposits formed by circulating surface waters (page 525); and as specular hematites in metamorphic rocks (page 525).

**Distribution of Hematite Ores in the United States** (Fig. 153).— At the present day there are but two very important hematite-producing regions, in the United States, viz. the Lake Superior region and the Birmingham, Alabama, district. Other areas which are worked will also be referred to, but they are less important.

[1] Vogt, Krusch u. Beyschlag, Ore Deposits, Translation, I: 250, 1914.

**Lake Superior Region** (45, 47).— Under this head are included a great series of deposits lying in the region surrounding the south and west sides of Lake Superior (47). The rocks are of remote geologic age, and the age and names of the iron-bearing formations are as follows:

Algonkian system.
    Keweenawan series: Carries titaniferous gabbros in Minnesota but no hematite.
    Huronian series:
        Upper Huronian (Animikie group).
            Biwabik formation of Mesabi.
            Animikie group of Animikie district, Ontario.
            Ironwood formation, Penokee—Gogebic district, Michigan and Wisconsin.
            Vulcan formation, Menominee and Calumet districts, Michigan.
            Vulcan iron-bearing member of Crystal Falls, Iron River, and Florence districts, Michigan and Wisconsin.
            Gunflint formation, Gunflint Lake district, Canada, and Vermilion district, Minnesota.
            Bijiki schist, Marquette district, Michigan.
            Deerwood iron-bearing member, Cuyuna district, Minnesota.
        Middle Huronian.[1]
            Negaunee formation, Marquette district, Michigan.
Archæan system.[1]
    Keewatin series:
        Soudan formation, Vermilion district, Minnesota.
        Helen formation, Michipicoten district, Ontario.
        Unnamed formation of Atikokan district, Ontario.
        Several non-productive formations in Ontario.

The ore-bearing districts have been studied in considerable detail, but the intervening parts are less well known, and it is therefore difficult to correlate the major geological units of the several districts.

*Character of formations.* — The Archæan includes a complex series of acid and basic igneous rocks, and two or more sedimentary formations, including the iron formations and slate of the Keewatin. The Algonkian includes four unconformable sedimentary series, all associated with igneous rocks, the entire succession being separated by an unconformity from the Archæan below and the Potsdam above.

The iron ores occur as concentrations in the so-called iron forma-

---

[1] The Lower Huronian and Laurentian, although present in the series of formations found in this region, do not carry any ore bodies.

tions, which range in thickness from a few hundred to a thousand feet.

In their present form these iron formations represent alterations of chemically deposited sediments, such as cherty iron carbonates, which are usually interbedded with normal clastic sediments such as slate and quartzite.

In general terms the iron formations may be described as consisting mainly of chert or quartz and ferric oxide, usually segregated into bands, but sometimes irregularly mixed. Jasper is a banded rock of highly crystalline character with the quartz layers colored red. Ferruginous chert differs from it in being less crystalline, and with the quartz either banded or irregularly mingled. This latter type is known as *taconite* in the Mesabi district. Other phases of the iron formation are clay slates, paint rocks (alterations of preceding), amphibole-magnetite schists, cherty iron carbonate, hydrous ferrous silicate (greenalite), and iron ores.

The original iron rocks were cherty iron carbonate, ferrous silicate, and pyritic iron carbonate, and unaltered remnants of these are still found.

The average iron content of all the original phases of the iron-bearing formations for the region, excluding interbedded slates, is 24.8 per cent, and the iron ores, though of great commercial importance, form but a small percentage of the rocks of the iron-bearing formations. This percentage varies from .062 to 2.00 per cent.

The iron ores are the result of subsurface alterations of richer layers of the iron-bearing rocks, and are localized both where these alterations have been most effective, and structural features have served to collect the underground waters.

The existence of ore then, depends largely on secondary concentration. Of great importance in determining the distribution of the ores are impervious basements and fractures, the former often shaped like pitching troughs.

The ore bodies vary widely in their form, although steeply dipping deposits are the rule, with the horizontally tabular ones of the Mesabi range forming a marked exception.

The ores of the Lake Superior region vary from hard blue ores to soft earthy ones. They are mostly hematite with small quantities of limonite, but some magnetite is known in the Marquette district.

The following tables, taken from Van Hise and Leith, show the average composition and range of Lake Superior ores. Many

additional ones can be found in the reports on Mineral Resources issued annually by the United States Geological Survey.

AVERAGE COMPOSITION OF TOTAL YEARLY PRODUCTION OF LAKE SUPERIOR IRON ORE FOR 1906 AND 1909

|  | 1906 | 1909 |
|---|---|---|
| Moisture . . . . . . . . . . . . . . | —— | 11.28 |
| Analysis of ore dried at 212° F.: | | |
|    Iron . . . . . . . . . . . . . . | 59.80 | 58.45 |
|    Phosphorus . . . . . . . . . . . . | .081 | .091 |
|    Silica . . . . . . . . . . . . . . | 6.83 | 7.67 |
|    Alumina . . . . . . . . . . . . . | 1.60 | 2.23 |
|    Manganese . . . . . . . . . . . . | | .71 |
|    Lime . . . . . . . . . . . . . . | 2.70 | .54 |
|    Magnesia . . . . . . . . . . . . . | | .55 |
|    Sulphur . . . . . . . . . . . . . | | .06 |
|    Loss by ignition . . . . . . . . . | 3.92 | 4.12 |

The range in percentages shown by the analyses from which the foregoing averages are derived is as follows:

RANGE OF EACH CONSTITUENT OF ORES YIELDING THE ABOVE AVERAGES

|  | 1906 | 1909 |
|---|---|---|
| Moisture at 212° F. . . . . . . | —— | .50 to 17.40 |
| Range of ore dried at 212° F. | | |
|    Iron . . . . . . . . . . . | 38.15 to 66.07 | 35.74 to 65.34 |
|    Phosphorus . . . . . . . . | .008 to .85 | .008 to 1.28 |
|    Silica . . . . . . . . . . | 3.21 to 40.97 | 2.50 to 40.77 |
|    Manganese . . . . . . . . . | —— | .00 to 7.20 |
|    Alumina . . . . . . . . . . | .20 to 3.59 | .16 to 5.67 |
|    Lime . . . . . . . . . . . | —— | .00 to 4.96 |
|    Magnesia . . . . . . . . . . | —— | .00 to 3.98 |
|    Sulphur . . . . . . . . . . | —— | .003 to 1.87 |
|    Loss on ignition . . . . . . | .00 to 10.0 | .40 to 11.40 |

In addition there is given below two other tables compiled by Birkenbine.

TYPICAL ANALYSES OF LAKE SUPERIOR IRON ORES

| CONTENT | MARQUETTE RANGE | MENOMINEE RANGE | GOGEBIC RANGE | VERMILION RANGE | MESABI RANGE |
|---|---|---|---|---|---|
| Iron . . . . . | 56.5 | 55.2423 | 56.308 | 61.36 | 56.0996 |
| Phosphorus . . | .0353 | .0594 | .0338 | .0373 | .0365 |
| Silica . . . . | 4.584 | 6.7693 | 3.3961 | 4.2545 | 3.4867 |
| Sulphur . . . | .0089 | --- | — | — | — |
| Moisture . . . | 11.85 | 6.525 | 10.828 | 4.5649 | 12.3158 |

ANALYSES OF SILICEOUS ORES

| CONTENT | MARQUETTE RANGE | MENOMINEE RANGE | VERMILION RANGE |
|---|---|---|---|
| Iron . . . . . . . | 42.27 | 42.129 | 51.1938 |
| Phosphorus . . . . | .0316 | .0244 | .0498 |
| Silica . . . . . . | 35.834 | 34.141 | 22.3642 |
| Sulphur . . . . . | .0099 | — | — |
| Moisture . . . . . | 1.23 | 2.2 | 3.21 |

The Lake Superior region includes the following districts:

| DISTRICTS | STATE | AREA SQ.MI. |
|---|---|---|
| Marquette . . . . . . . . . . | Mich. | 330 |
| Menominee . . . . . . . . . . | Mich. | 112 |
| Crystal Falls . . . . . . . . | Mich. | 540 |
| Iron River . . . . . . . . . | Mich. | 210 |
| Florence . . . . . . . . . . | Wis. | 75 |
| Calumet and Felch Mtn. . . . . | Mich. | 200 |
| Penokee-Gogebic . . . . . . . | Mich.–Wis. | 450 |
| Vermilion }  . . . . . . . . . Mesabi }  . . . . . . . . . | Minn. | 1400 |
| Cuyuna . . . . . . . . . . . | Minn. | 300 |
| Michipicoten . . . . . . . . | Can. | 140 |

The general mode of occurrence of the ore in several of these is shown in Figs. 166 to 168, and the more important ones are referred to individually below.

**Marquette Range** (48). — This occupies a rather large area west and southwest of Marquette, Michigan, and carries iron formations in both the

Upper and Middle Huronian, the latter being the more important. That of the Upper Huronian is underlain by quartzite and covered by slate, while the Middle Huronian iron formation is underlain by slate which in turn rests on quartzites. Igneous intrusions of Keweenawan age are common. The structure of the range is that of a great east-west synclinal basin containing
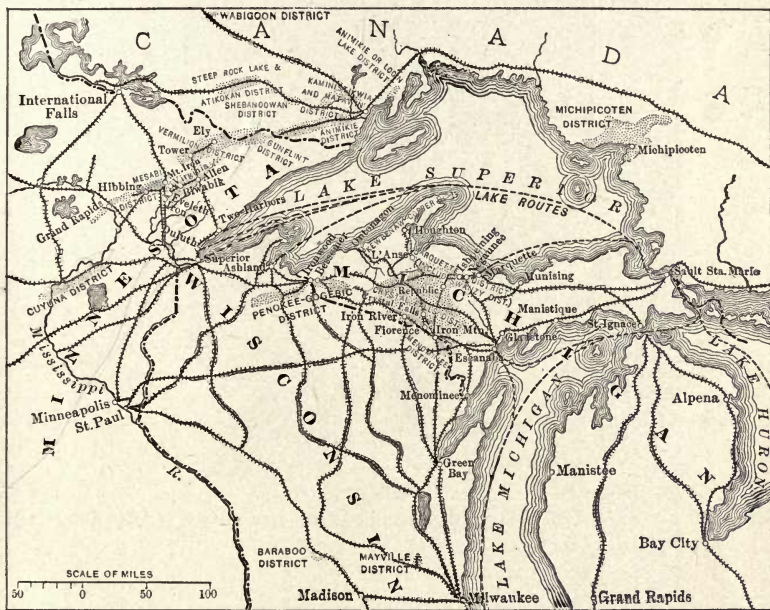


Fig. 165. — Map of Lake Superior iron regions, shipping ports, and transportation lines. (*After Van Hise and Leith, U. S. Geol. Surv., Mon. LII.*)

a number of minor folds, and while the ores occur on both limbs of the basin, they are most abundant on the northern one.

The ores may be divided into three classes, namely, (1) ores at the base of the iron-bearing Negaunee (Middle Huronian) formation, (2) the ores within the Negaunee formation, (3) detrital ores at the base of the Goodrich (Upper Huronian) quartzite. Ores of the first and second class are mostly soft hydrated hematite, while those of the third class are hard specular ores with some magnetite from metamorphism due to greater movements along the contact of the Middle and Upper Huronian during the faulting within these rocks themselves.

**Menominee Range** (39). — While this carries iron formations in both the Middle and Upper Huronian, only the former are commercially important and are confined to the southern part of the district. The iron ores are mainly gray, finely banded hematite with lesser amounts of a flinty hematite which shows local banding.
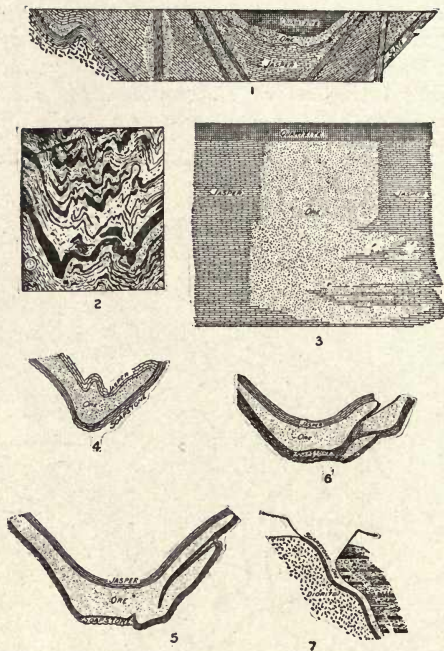
FIG. 166. — Sections of iron-ore deposits in Marquette range. (*After Van Hise*).
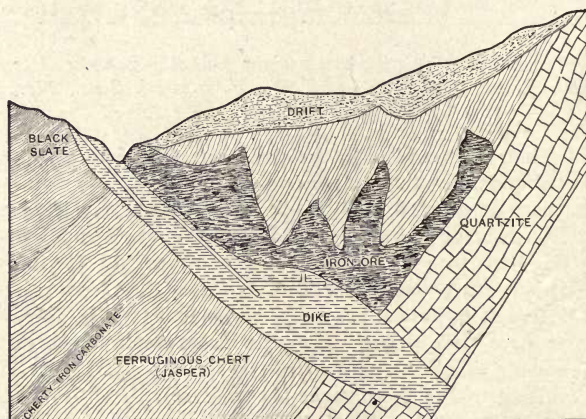


FIG. 167. — Generalized vertical section through Penokee-Gogebic ore deposit and adjacent rocks ; Colby mine, Bessemer, Mich. (*After Leith.*)

**Penokee-Gogebic Range** (42). — The ores occur in Upper Huronian, the iron formation being overlain by slate and underlain by quartzite and

*a*
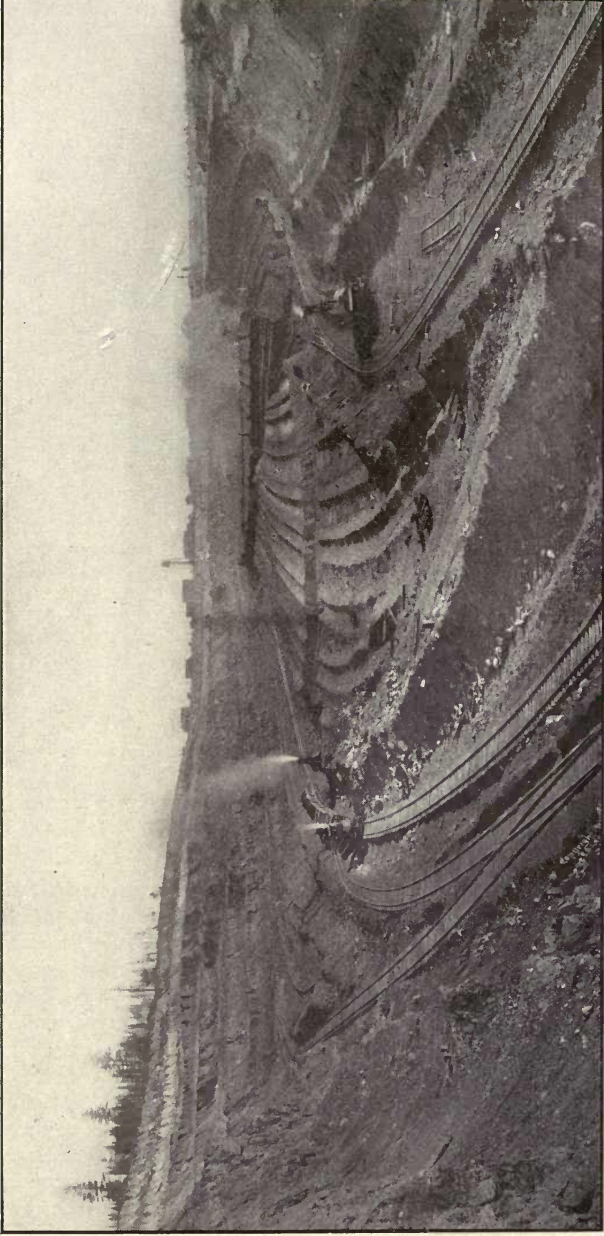
PLATE XLV. — General view of Mountain Iron mine, Mesabi Range, Minn., shows mining of ore with steam shovels, and covering of (*a*) glacial drift. (*Crandall and Maher, photo.*)

(531)

black slate. The latter is covered by a gabbro of Keweenawan age, which is found in contact with the iron formation in places and has altered it to jasper and amphibole-magnetite rock. Most of the iron formation, however, is ferruginous chert. The steeply dipping sedimentary rocks are cut by dikes of basic igneous rocks, thus forming troughs in which the ores are concentrated. Most of the deposits reached depths of 1000 feet and upwards, but the horizontal extent is small. While soft hydrated hematite is the normal type of ore, still the hard slaty ore is not uncommon. Manganese is found in a few deposits.

**Mesabi Range** (44). — The rocks of this region are less folded and metamorphosed, and dip slightly to the southeast. The iron formation, which is mainly ferruginous chert, is overlain by a thick slate and underlain by a thin quartzite, which in turn rests on granite, or graywacke and slate of lower Middle Huronian. At the eastern end of the range the iron formation has been metamorphosed to amphibole-magnetite rock by a gabbro intrusion. The iron-ore deposits are very irregular in shape, but their horizontal extent is great as compared with their depth (Fig. 168), most of them being less than 200 feet. The mining is done mainly by open pits (Pl. XLV), and the ore is a rather soft hematite of high grade. It preserves the stratification of the original iron formation and in places is found grading into the latter.
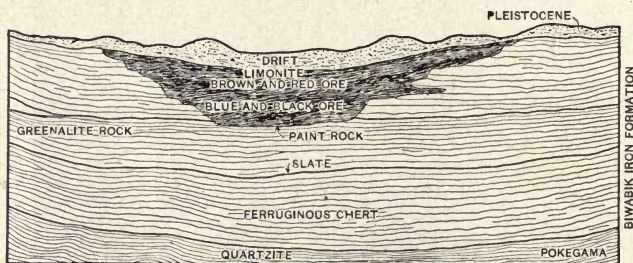


FIG. 168. — Generalized vertical section through Mesabi ore deposit and adjacent rocks. (*After Leith.*)

**Vermilion Range** (40). — The chief ore deposits occur in the highly folded and metamorphosed Keewatin rocks, and the iron formation is largely altered to jasper. The country rock is mostly greenstones in which the jasper occurs in basins or troughs. The ores associated with the jasper in these troughs usually have a greenstone footwall and consist of dense hard red or blue hematite, which is sometimes brecciated but rarely specular.

**Cuyuna Range** (48). — This range lies to the southwest of the Mesabi range and shows a series of small northeast-southwest anticlines in a broad synclinal basin on whose northern limb the Mesabi range is situated, while on the southern limb we find the Penokee. Owing to the limited number of outcrops and lack of development at the present time, the geology is not yet perfectly known, but the formations seem to include quartzite and its altered equivalents, iron formations, slate, and intrusive granite and diorite. The ores form the altered and concentrated upper

PLATE XLVI
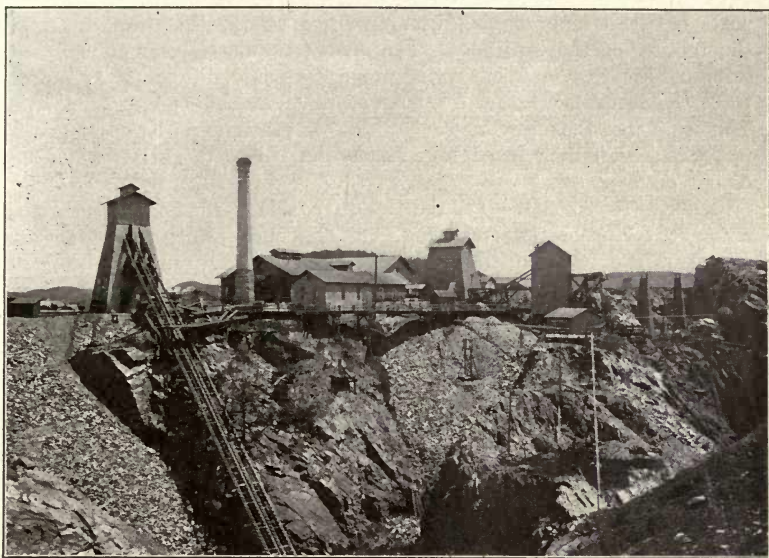


FIG. 1.— Iron mine, Soudan, Minn. Shows old open pit with jasper horse in middle.
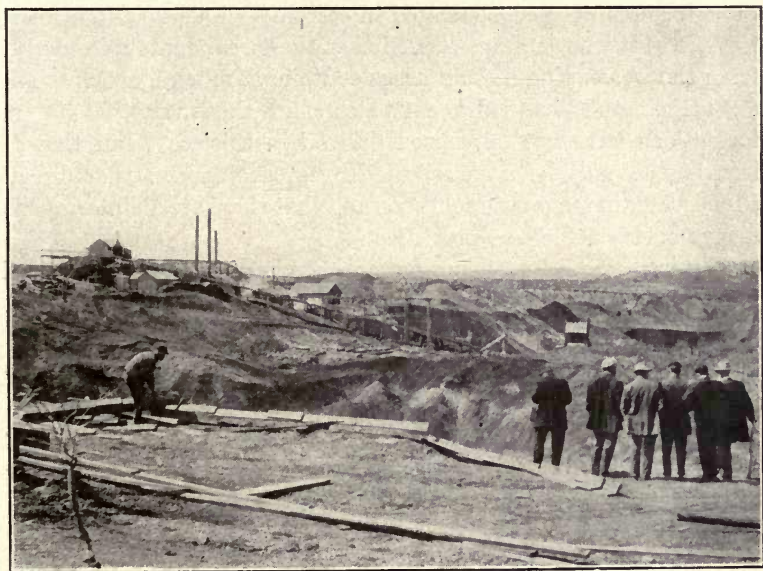


FIG. 2.— View of limonite pit near Ironton, Pa. (*H. Ries, photo.*)

(533)

parts of the steeply dipping iron-formation strata, which are exposed by the erosion of the anticlines. The hanging wall is commonly chloritic slate and iron carbonate in varying proportions and degrees of alterations, while the footwall is either a quartz schist or amphibole-magnetite schist. The ore bodies thus far found seem to be in the form of lenses 100 to 250 feet thick, with their longer dimensions parallel to the highly tilted bedding of the series.

Canada (79, 80, 81). — On the Canadian side of the boundary there are a number of iron-bearing areas (Fig. 165), only one of which is of importance, viz. the Michipicoten district. Here the iron-bearing formation lies in the Keewatin, the geology and structure being similar to the Vermilion district of Minnesota. The iron formation includes sideritic and pyritic cherts, jaspers, siderite, schists and iron ore, and the Helen ore body lies in an amphitheatre with iron carbonate on the east, ferruginous chert on the north, and tuffs on the south, while a diabase dike crosses the basin.

The ore, which chemically resembles the hydrous Mesabi ores, dips eastward, apparently under the carbonate, but exploration below the latter has developed a very large body of pyrite.

*Origin.* — The origin of these ores has for years been a puzzling problem to geologists. Foster and Whitney considered them eruptive, while Brooks and Pumpelly looked upon them as altered limonite beds.

The work of Van Hise and Leith has shown us that the Lake Superior ores were concentrated in certain sedimentary iron formations, and it was at first believed that these sediments were derived from the weathering of land areas containing much igneous rock.

Further study has led them to conclude, however, that the iron formations have not only been derived in this way, but that the iron has actually been contributed by greenstone magmas directly to the water in magmatic solutions and that there are all intermediate stages between the two processes (41).

The iron ore as first deposited consisted essentially of chemically precipitated iron carbonate or ferrous silicate (greenalite) with some ferric oxide, all finely interlayered with chert.

Later on, when these sediments were uplifted to form the land surface and exposed to weathering, the ferrous compounds, the siderite and greenalite, were oxidized to hematite and limonite. While this occurred mainly in place, some of the iron was carried off and redeposited elsewhere. This resulted in a ferruginous chert carrying less than 30 per cent of iron.

Further concentration of the iron to 50 per cent or over was accomcomplished mainly by the silica being leached from the bands of ferruginous chert.

Where the concentration of the ore has occurred in troughs, the chemistry of the process is thought to be as follows : —

Part of the ferric oxide was deposited as an original sediment containing silica and other impurities, or in some cases as sulphides or carbonates. This was later enriched by the addition of iron carbonate. These were originally contained in the rocks near the surface, and became oxidized by percolating waters, which took up the carbon dioxide liberated, and were thus able to dissolve iron carbonates or silicates, which they came in contact with in their downward course toward the troughs in which the ore is found.

The precipitation of the ore was then caused by these solutions meeting with others which had filtered in by a more open and direct path from the surface, and hence contained some free oxygen, which converted the dissolved iron compounds into oxides.

The same solutions, carrying carbon dioxide, dissolved the alkalies out of the basic igneous rocks, and these waters were then able to dissolve silica. In some cases the solution of silica proceeded faster than the deposition of the iron ore, and made the rock quite porous. The general result was therefore a concentration of the iron and removal of silica.

The weathering processes have yielded mainly soft ores and ferruginous cherts, while metamorphism has formed hard red and blue specular ores and brilliant jaspers, as well as changed the iron formation into amphibole-magnetite schists.

Most of the rich ores are found above the 1000-foot level, except in the Mesabi district, where the deposits are shallow, as compared with their horizontal extent, some, however, being over 400 feet deep.

In the early period of mining many of the Lake Superior bodies were worked as open cuts, but with depth underground working has been resorted to. There are many deposits in the Mesabi district which are worked as open pits from which the granular ore is dug with a steam shovel and loaded directly on to the ore cars, which are run along the working face (Pl. XLV).

The market value of the ores is based on the iron contents, percentage of water, and amount of phosphorus, and at times the manganese contents is taken into consideration. Some objection was at first raised to the fine character of the Mesabi ore and its tendency to clog the blast furnace, therefore requiring the admixture of lump ore from the other ranges; but this objection has disappeared, and some furnaces now use over 75 per cent of Mesabi ore in their charge.

The Lake Superior iron ore region is not only the most important in the world, but the production of some of the individual mines is startling. (See production of individual mines at end of this chapter.) The Marquette range was developed as early as 1849, the Mesabi as late as 1892, and the Cuyuna some years after this. The total yield of the Lake Superior region from 1854 to the end of 1914 has been 666,268,797 long tons. While the output has been phenomenal, and the supply large,

high-grade ore is no longer abundant, and much ore running high in silica is now shipped.

*Wyoming* (60). — Important deposits of hematite are found in the pre-Cambrian schists at several localities in Wyoming, viz. in the Hartville District, Laramie County, and near Rawlins, in Carbon County.

The Hartville deposits form a portion of the Hartville uplift, which is a broad, low dome similar to that formed by the Black Hills, and while the iron range extends from Guernsey to Frederick, a distance of 8 miles, the productive area extends only from a point 2 miles northeast and 1 mile southeast of Sunrise.

The pre-Cambrian sediments have been folded into a complex synclinorium, and faulting has been a common phenomenon, while the brecciation which accompanied both the folding and faulting was an important structural factor in the ore formation.

The most important ore bodies are lenses occurring in the schist along a limestone footwall, the ore either replacing the schist or to a lesser extent filling the joint, fault, and breccia cavities.   These lenses range up to 1000 feet in length, and conform to the foliation of the schists.   Detrital ores derived from the foregoing are also found.

The following geological section is involved : —

| | |
|---|---|
| Pleistocene | Terrace gravels, alluvium, and wash. |
| Tertiary (Arikaree) | Sandstone. |
| Jura-Trias and Cretaceous | |
| Carboniferous nearly flat | Hartville 650′ thick.   White or gray limestone.   Red sandstone. Unconformity. Guernsey 150′ thick.   Conglomeratic quartzite or sandy limestone. |
| Pre-Cambrian rocks, the stratified ones with steep dip. | Quartzose beds, partly conglomerate and associated jaspers. Unconformity. Interbedded siliceous limestones and muscovite and biotite schists with beds and lenses of quartz and jasper rock. Intrusives, diabase, aplites and pegmatites, biotite granite, gabbros, diorites, and porphyrites, derivative hornblende and chlorite schists. |

The ores are high-grade hematites (chiefly hydrated), averaging over 60 per cent iron.   Sulphur is absent, silica may be high, and much of the ore is non-Bessemer.   Two grades of ore are recognized,

viz. a hard gray hematite, and a soft greasy one of brown-red color.

Siderite and limonite are of subordinate importance, while the associated minerals are calcite, quartz, gypsum, chalcedony, barite, chrysocolla, etc. The copper minerals occur in the fractures in the hematite. Both types of hematite grade into the schist, but much of the soft ore has been derived from the hard by percolating waters.

Ball assigns an epigenetic origin to the ore, believing that it was deposited by descending water, because (1) the ore is along zones of maximum downward circulation, (2) lenses and veins are found along joints at a distance from the main body, and (3) the associated minerals, quartz, calcite, and limonite, are all water-formed ones. The magnetite and iron pyrite of the schist lying above the limestone footwall are regarded as the source of the iron. During pre-Cambrian times there was extensive erosion of this schist, and a downward transferal of this iron by carbonated surface waters flowing along the impervious limestone footwall, where it was precipitated by oxygen-bearing waters coming by a more direct path.

**Clinton Ore** (51–59). — This ore, which is also called fossil, pea, or dyestone ore, was given the first name on account of the ore bed having been originally discovered at Clinton, N. Y. It is one of the most persistent iron-ore deposits that is known (Fig. 169), for it occurs at most points where rocks belonging to the Clinton stage of the Silurian are found.

The following districts may be enumerated as showing the location of the more important deposits: (1) west central New York; (2) several narrow belts in central Pennsylvania; (3) Alleghany County, Virginia; (4) a belt through Lee and Wise counties, Virginia, extending southwestward into the La Follette district of Tennessee; (5) narrow belts in the region of Chattanooga, Tennessee; (6) Birmingham, Alabama; (7) Bath County, Kentucky; and (8) Dodge County, Wisconsin.[1] Other known occurrences of minor importance are indicated on the map, Fig. 169, and in addition the ore has been recently discovered by drilling in Missouri.

Of all these districts, the Birmingham, Alabama, one is the most important, with Chattanooga, Tennessee, and central New York ranking respectively second and third.

[1] It has been recently shown that this area is not of Clinton age, but is older and represents deposition in local, but connected basins of Maquoketa (Richmond) time (58a).
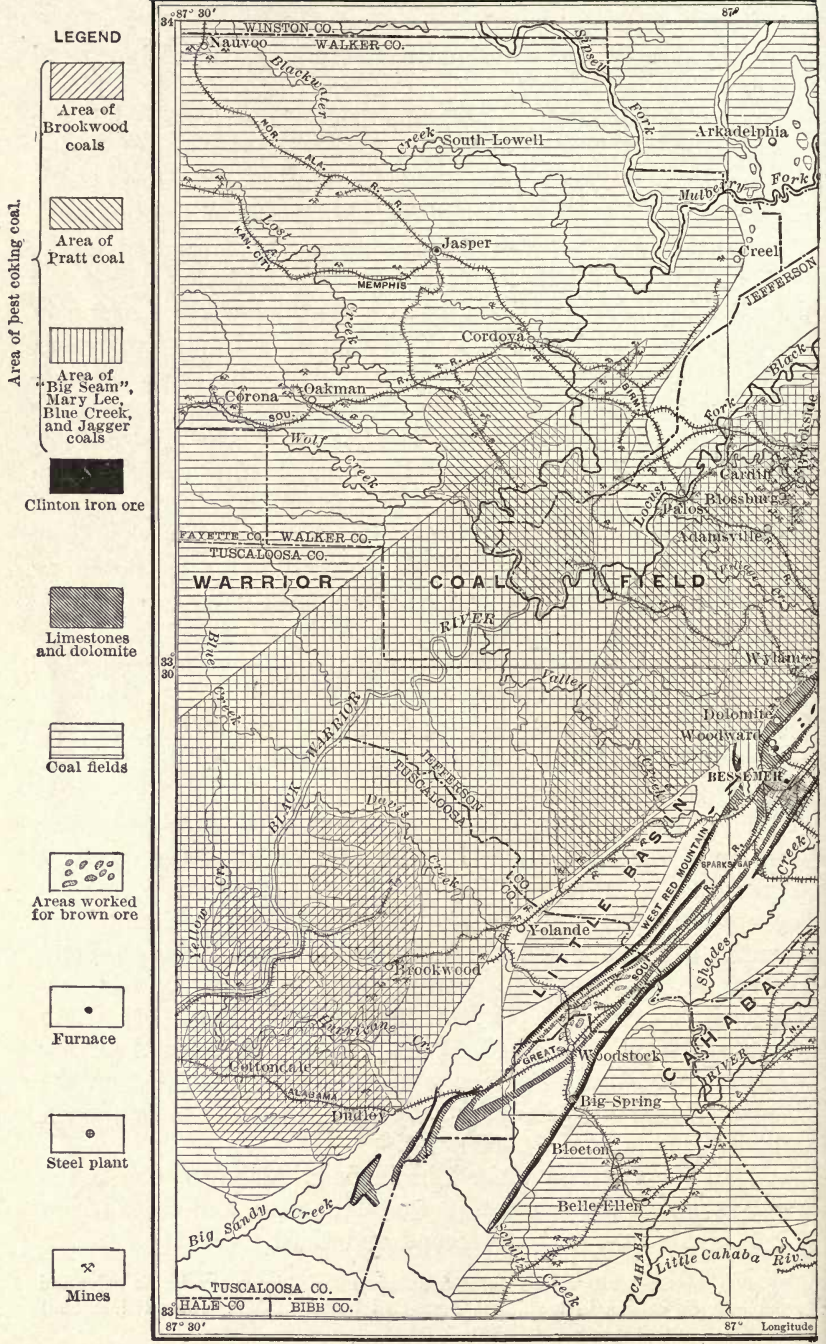
PLATE XLVII. — Geologic map of western half of Birmingham, Ala., district. (*After Burchard, Amer. Inst. Min. Engrs., Bull.* 24, 1908.)
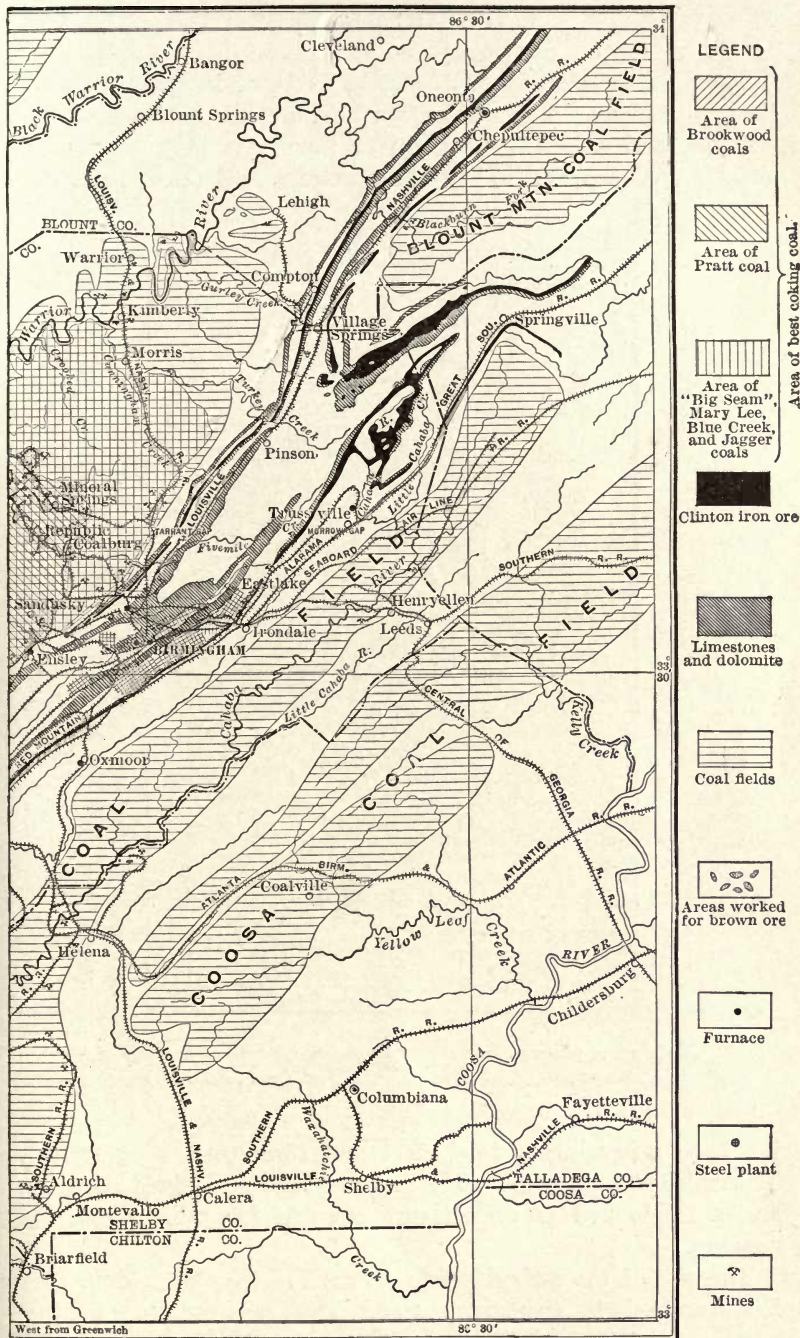
PLATE XLVIII. — Geologic map of eastern half of Birmingham, Ala., district. (*After Burchard, Amer. Inst. Min. Engrs., Bull.* 24, 1908.)

(539)

The Clinton ore deposits occur as beds, or lenses, interstratified with shales and sandstones at different horizons in the Clinton, and as many as three or four beds may be present at any one locality.  They show extremes of thickness, rang-



Fig. 169. — Map of eastern United States, showing areas of outcrop of Clinton iron ore.[1]   (*After McCallie, Ga. Geol. Surv., Bull.* 17.)

ing from a few inches to 40 feet, but rarely exceeding 10 feet. The thicker beds often contain sandstone and shale partings, and a single bed is sometimes traceable for miles along the outcrop.

The dip of the beds depends on the intensity of folding that has occurred in any given area.  Thus the ore beds in New

[1] See footnote, page 537.

Areas containing
workable iron-ore

Areas containing possibly
workable iron-ore

Areas probably containing
little or no workable iron-ore

Scale

0   5   10   15   20   25   30 miles

FIG. 170. — Map showing outcrop of Clinton ore in Alabama. (*After Burchard, Amer. Inst. Min. Engrs., Bull.* 24, 1908.)

York State are nearly horizontal, and can at times be mined for some distance from the outcrop by stripping; while those found in the Appalachian region show a variable and sometimes

steep dip, and hence require to be worked by underground methods.

Two textural varieties of Clinton ore are recognized, viz. (1) fossil ore, and (2) oölitic ore.

The former is made up almost entirely of a mass of fossil fragments, while the latter consists of small, rounded grains of concretionary character. These two varieties may occur in the same or separate beds.



FIG. 171. — Outcrop of Clinton iron ore, Red Mountain, near Birmingham, Ala.
(*Photo. from Tennessee Coal and Iron Company.*)

A second classification, based on grade, includes (1) soft ore, and (2) hard ore. The former is found in the outcropping portion of the seam and may extend to variable depths, sometimes as much as 400 feet, while the latter, which is usually sharply separated from the former, occurs lower down. The soft ore runs high in iron and silica, but low in lime, because this has been removed by weathering. The hard ore runs high in lime, but low in silica and iron. Both varieties are high in phosphorus and hence of non-Bessemer grade.

*Birmingham, Alabama* (51). — The great development of the Birmingham district is due to peculiar local conditions, for we find the iron ores, flux, and fuel all in close proximity to each other (Fls. XLVII, XLVIII).

The Clinton ore beds are found in Red Mountain (Figs. 170, 171) on the east side of the valley in which the city of Birmingham lies. There the Clinton formation, which is 200 to 500 feet thick and dips southeastward from 20° to 50°, is composed of beds of shale and sandstone and includes four well-marked iron-ore horizons, generally in the middle third of the formation.

These beds are known as the Hickory, Ida, Big, and Irondale seams, but there is difficulty in correlating them in different parts of the field.

Of these four beds the Big and Irondale are the most important. The thickness of the former is estimated at from 16 to 30 feet, but the good ore is rarely more than 10–12 feet thick, and at most places only 7 to 10 feet are mined. In the middle of the district, the bed is separated into two benches by a parting along the bedding plane, or by a shale bed. Either bench, though producing in one part of the district, may grade into shaly low-grade ore in another part.

The following analyses are given by Harder (Min. Res. 1908), to show the gradation from hard ore to soft ore.

ANALYSES OF CLINTON IRON ORE FROM ALABAMA

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Fe . . . . . . . . . . . . . | 37.00 | 45.70 | 50.44 | 54.70 |
| $SiO_2$ . . . . . . . . . . . . | 7.14 | 12.76 | 12.10 | 13.70 |
| $Al_2O_3$ . . . . . . . . . . . | 3.81 | 4.74 | 6.06 | 5.66 |
| CaO . . . . . . . . . . . . | 19.20 | 8.70 | 4.65 | .50 |
| Mn . . . . . . . . . . . . | .23 | .19 | .21 | .23 |
| S . . . . . . . . . . . . . | .08 | .08 | .07 | .08 |
| P . . . . . . . . . . . . . | .30 | .49 | .46 | .10 |

The unweathered ore is said by Burchard to range from a richly ferruginous sandstone to a ferruginous-siliceous limestone.

*New York* (55). — In this state the outcrop of the ore extends across the central and western part of the state (Fig. 172). The whole formation dips gently southward, with a gentle north-south synclinal trough in Cayuga and Wayne counties. Both oölitic and fossiliferous ore are found, and at least two beds, and sometimes four, may be present at any given locality. The ore varies in its richness, and while the deposits are very extensive, they have been but little developed.
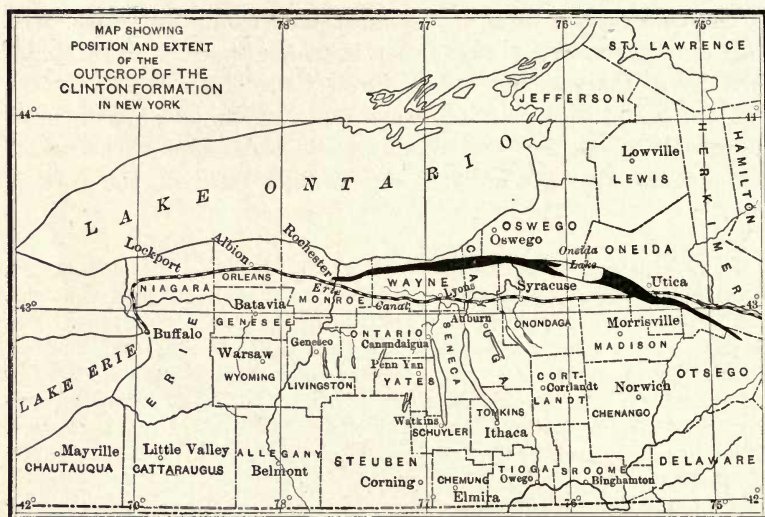
FIG. 172. — Map showing outcrop of Clinton ore formation in New York State.
(*After Newland.*)

*Analyses of Clinton Ore.* — The following are analyses of the Clinton ore from several localities, which serve more to show its variation in character, than as types. Others are given above under Alabama.

|  | I | II | III | IV | V |
|---|---|---|---|---|---|
| Fe . . . . . . | 31.3 | 31.07 | 54.3 | 33.341 | 57.00 |
| P . . . . . . | .24 | .69 | .462 | 1.202[3] | .678 |
| SiO$_2$ . . . . . | 23.98 | 8.56 | 15.64 | 1.143 | 7.12 |
| TiO$_2$ . . . . . | .225 | — | — | — | — |
| Al$_2$O$_3$ . . . . . | 7.26 | 5.04 | .89 | 5.468 | — |
| MnO . . . . . | — | Tr. | .28 | — | .15[4] |
| CaO . . . . . | 9.15 | 13.71 | 1.09 | 16.56[1] | 1.46 |
| MgO . . . . . | 2.92 | 7.37 | .13 | 9.974[2] | — |
| SO$_3$ . . . . . | .987 | .072 | — | — | — |
| CO$_2$ . . . . . | 9.6 | 18.8 | None | — | — |
| H$_2$O . . . . . | .26 | Undet. | 3.07 | 10.865 | — |
| S . . . . . . | — | — | .03 | — | — |

I, II, N. Y. State Mus., Bull. 123 : 33, 1908. III. Ga. Geol. Surv., Bull. 17 : 130. IV. U. S. Geol. Surv., Bull. 385. V. U. S. Geol. Surv., Bull. 285 : 188, Alleghany Co., Va.

[1] CaCO$_3$.     [2] MgCO$_3$.     [3] P$_2$O$_5$.     [4] Mn.

*Origin of Clinton Ore.* — The origin of this ore has created considerable discussion, and whatever theory is advanced, it must explain the following features: (1) the fossiliferous character of some beds, (2) the oölitic character of others, (3) the bedded structure, (4) the soft non-calcareous ore at the surface, and the hard or more calcareous ore at lower levels.

The three theories which have been advanced are the following: (1) original deposition, (2) residual enrichment, (3) replacement. As can be easily seen, the correct solution of the problem is of practical value, since it indicates the possible extent of the ore body.

**Residual Enrichment.** — This theory supposes that the ore beds represent the weathered outcrops of ferruginous limestones. That is to say, the lime carbonate was leached out by surface waters down to the water level, leaving the insoluble portion carrying the iron, in a more concentrated form. If this theory is correct, then the ore should pass into limestone below the water level.

Russell (57), who was an earnest advocate of this theory, noted that at Attalla, Alabama, the Clinton limestone at a depth of 250 feet from the surface carried only 7.75 per cent of iron, while at the outcrop it had 57 per cent of iron. These figures would seem to bear out this theory, but Eckel (51) has recently claimed that they must be incorrect, as the hard ore at the depth mentioned carries 38 to 42 per cent of iron.
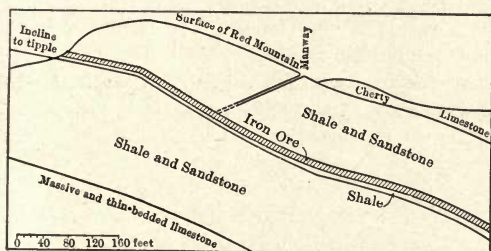


Fig. 173. — Typical profile of slope on Red Mountain, starting on the iron-ore out-crop. Shows bedded character of ore. (*After Burchard, Amer. Inst. Min. Engrs., Bull.* 24, 1908.)

Moreover, in none of the many fairly deep mines in Clinton ore has any change to limestone been noted.

**Sedimentary Origin.** — This supposes that the ores are of contemporaneous origin with the inclosing rocks, having been deposited on the sea bottom as chemical precipitates.

This view was advocated at an early date by James Hall, who believed that the iron came from the old crystalline rocks, which were leached of their iron content, the oölitic ore being a chemical precipitate on the ocean floor.

Smyth (59) in amplifying this theory agrees with Hall as to the source of the ore. He points out that during Clinton times the drainage from the crystalline area was carried into a shallow sea or basin. When the iron was carried into these inclosed basins, it was slowly oxidized and precipitated, gathering layer upon layer about the sand grains, thus forming oölitic ore.

Where the ferruginous waters came in contact with shell fragments the iron was precipitated around these, either due to a reaction with the carbonate of lime in the shells, or more often by oxidation. Later both types of deposit became covered by ordinary sediments such as shales, sandstones, or even limestones.

Additional evidence favoring a sedimentary origin is the continuation of the ore with depth, some mines in Alabama being 2000 feet from the outcrop. Moreover some borings in Alabama have struck the ore $\frac{1}{2}$ to 1 mile from the outcrop and 400 to 800 feet below the surface. The occurrence of fragments of ore in the overlying limestone also points to the ore being laid down before the lime rock.

McCallie (54), after studying the Georgia ores, while admitting their sedimentary origin, believes that the original iron mineral was greenalite or glauconite.

**Replacement Theory.** — This theory assumes that the ores were of much later origin than the inclosing rock, and were formed by the replacement of the lime carbonate by iron, brought in by percolating waters, which had leached the ferruginous constituents from the overlying strata.

The structure of the formations, the comparative absence of iron in the limestone overlying the ore, and restricted vertical range of the ores have been advanced as arguments against this theory.

Rutledge (58), however, as a result of his studies of the Clinton ores of Stone Valley, Pennsylvania, concludes that they represent replacement deposits, and that the only part of the iron content which is of sedimentary character is that contained in the siliceous concretions, most of the iron having come from the shale overlying the ore beds; the hematite deposits have thus been formed by replacement of limestone and concentration of the ore. The evidence presented in favor of this view is: (1) the invariable association of the soft, rich ore with the leached decolorized shales, and of the hard, lean ores with unweathered bright shales; (2) the relations of the ores to the shattered sandstones and to the topographic situation of the ores; (3) the fact that analogous replacements are now taking place in the Medina; (4) the observed progressive steps in the transformation of the limestone to an ore, which may be followed in the field, in thin sections, and in chemical analyses, and (5) the absence of conditions, such as a local crumpling, including a shrinking of the strata, pointing to a relative rather than an absolute enrichment of the ores.

In view of the fact that the advocates of the several theories often bring apparently good evidence to support their case, one may perhaps question whether several different methods of concentration have not been operative. To the author, it seems that the sedimentary mode of accumulation has probably been the dominant one in most cases.

**Canada.** — *Wabana, Newofundland* (84). — The ores found here are of a distinctly bedded character, being part of a series of northwesterly dipping Ordovician sediments exposed for about three miles along the north shore of Bell Island in Conception Bay. The whole series extending from Lower Cambrian to Lower

Ordovician is several thousand feet thick, and consists of un-metamorphosed sandstones and shales, but in the upper thousand feet there has been a concentration of ferruginous minerals.

Within the Lower Ordovician series, considered as equivalent to the British beds of Arenig to Llandeilo age, there are six zones, containing beds of shale and sandstone alternating with oolitic iron ore, and in one zone oolitic pyrite. The iron ore is red brown, massive, and breaks up readily into parallelopiped-shaped blocks, the breaks being marked by minute veinlets of calcite and quartz. Texturally the ore shows a number of concretions from $\frac{1}{10}$ to $\frac{1}{2}$ inch diameter. These spherules are composed of alternating concentric layers of hematite and chamosite, which were pierced by living boring algæ. Siderite is locally abundant and may replace hematite, chamosite or even quartz.

The ore, which is of shallow-water orgin, and shows ripple-marked surfaces, is thought to represent a chemical precipitate.

Iron brought into the sea from crystalline rocks on the land, was precipitated by the oxidizing action of the algæ, as ferric oxide, some of which may have reacted with aluminous sediment to form chamosite. The siderite was possibly formed by ammonium carbonate given off as a decomposition product, below the sediment surface.

The oolitic pyrite represents a deeper water formation, formed presumably in the same way as the pyrite nodules now originating in the Black Sea, viz. due to the action of hydrogen sulphide liberated by bacterial action, reacting with iron salts. The

ANALYSES OF CANADIAN IRON ORES

| | I | II | III | IV | V | VI | VII | VIII |
|---|---|---|---|---|---|---|---|---|
| Fe | 52.58 | 47.5 | 36.70 | 55.77 | 31.35 | 53.89 | 40.36 | 59.57 |
| $SiO_2$ | 12.59 | [2] 22.7 | 45.20 | 12.78 | [2] 46.70 | 12.52 | 12.12 | 8.33 |
| $Al_2O_3$ | 5.71 | ——— | .25 | 1.58 | .92 | 3.17 | 4.33 | 1.71 |
| P | [1] 1.63 | .65 | .057 | .107 | .81 | 1.032 | 1.19 | .057 |
| S | ——— | .05 | .019 | .074 | .006 | .091 | ——— | .137 |
| CaO | 1.49 | ——— | 1.06 | 3.77 | 2.11 | 2.07 | 15.26 | 3.82 |
| MgO | .42 | ——— | 1.59 | 3.52 | .31 | .41 | ——— | 1.05 |
| MnO | .06 | [3] 1.2 | [3] .04 | [3] .09 | ——— | 1.9 | ——— | ——— |
| $TiO_2$ | .27 | ——— | ——— | ——— | ——— | ——— | ——— | ——— |
| Cu | ——— | ——— | ——— | ——— | ——— | ——— | ——— | .08 |
| Ignition loss | 2.17 | ——— | ——— | ——— | ——— | ——— | ——— | ——— |

[1] As $P_2O_5$.  [2] Insoluble.  [3] Mn.

I. Hematite, Dominion Bed, Wabana, N. F.; II. Bathurst, N. B., Magnetite; III. Crude magnetite, Moose Mountain, Ont.; IV. Concentrates, same place; V. Magnetite Nictaux-Torbrook basin, N. S.; VI. Hematite, Leckie vein, same district; VII. Hematite, shell vein, same district; VIII. Magnetite, Texada Island, B. C.

Wabana deposits are of great economic importance, the underground workings extending out under the sea.

*Nictaux-Torbrook Basin, Nova Scotia* (94). — An interesting series of bedded Silurian ores is found in this belt lying between the Devonian granites, and the Triassic area, of southwestern Nova Scotia. The ore, which is interbedded with shales and sandstones, dips steeply, and while it is chiefly hematite, it may be locally changed to magnetite. Other bedded hematites of similar age occur at Arisaig on the north shore.

**Other Foreign Deposits.** — The hematite deposits of the Minas Geraes district of Brazil,[1] located some 300 miles from the coast, are among the largest known iron deposits of the world. The iron series includes clay slates, subordinate limestone beds, and most important, quartzites (itabirite), the last ranging from a nearly pure quartz rock with scattered flakes of hematite, to massive quartz-free hematite. The ore forms lenses, often of tremendous size, interbedded with the quartzite. The following analyses show the composition of: (I), hard blue massive ore, and (II) thin-bedded ore.

|  | Fe | P | Si | Mn | Al | CaO | MgO | S | Ign |
|---|---|---|---|---|---|---|---|---|---|
| I | 69.35 | .010 | .13 | .15 | .33 | tr | .03 | .01 | .31 |
| II | 63.01 | .184 | 1.79 | .16 | 1.53 | .08 | .01 | .03 | 6.00 |

The iron-bearing formation is supposed to represent a sedimentary series, the iron having been deposited originally as ferric hydrate, or possibly ferrous carbonate. Subsequent metamorphism changed the iron to crystalline hematite, while later surface weathering gave some detrital deposits.

Other interesting and to some extent important hematite deposits are, the replacements of hematite in limestone of Bilbao, Spain,[2] the contact metamorphic deposits on the island of Elba,[3] the replacement deposits of Erzberg in Styria,[4] and similarly formed hematites in Carboniferous and Silurian limestones of Cumberland and Lancashire, Eng.[5]

## LIMONITE [6]

Limonite (23, 23*a*, 62–73), or brown hematite, is, like magnetite, of little importance in the United States as compared with hematite, having yielded but 3.7 per cent of the total domestic iron-ore production in 1914, but in other countries of the world it may sometimes be of great commercial importance.

[1] Leith and Harder, Econ. Geol., VI: 670, 1911; Derby, Iron Ore Resources of World, Stockholm, 1910: 817; Harder, Econ. Geol., IX: 101, 1914.

[2] Vogt, Krusch u. Beyschlag, Lagerstätten II: 319, 1912.

[3] Vogt, Krusch u. Beyschlag, Ore Deposits, Translation I: 369, 1914.

[4] Vogt, Krusch u. Beyschlag, II: 311, 1912.

[5] *Ibid.* p. 317.

[6] The name limonite is used here in a broad sense to include the different hydrous iron oxides.

Limonites are rarely of high purity, mainly because of the fact that they are frequently associated with clayey or siliceous matter, but this can sometimes be separated to a large extent by washing.

**Types of Deposits** (23*a*, 62*b*, 63*a*). — Limonite ores may occur under a variety of conditions, and associated with different kinds of rocks, the more important types being as follows:

1. Residual deposits, consisting of residual clay derived from different kinds of rocks by weathering processes, through which the limonite is scattered in pieces ranging from small grains to large masses. The deposits are usually siliceous, except in those of a lateritic character (Cuba).

2. Gossan deposits, derived usually from the weathering of sulphide ore bodies. These may cap pyrite masses, or sulphides of other metals (many western ones).

3. Replacement deposits.

4. Bedded deposits, usually of oolitic character, and marine origin (Luxembourg). Here the limonite may have been precipitated as such on the ocean bottom, or it was possibly precipitated as siderite or glauconite and later changed to the ferric hydroxide.

5. Bog-iron ores, representing deposits of ferric hydroxide precipitated in bogs or ponds, the iron having been brought to the pond in solution. Ferrous compounds are more easily soluble than ferric ones, and the iron may go into solution as sulphate, as bicarbonate in presence of an excess of $CO_2$, or as soluble salts of organic acids.

The precipitation may be due to: 1. Certain bacteria, which deposit ferric hydroxide in their cells; 2. By oxidation of ferrous carbonate; 3. By precipitation of ferrous carbonate first as such due to loss of $CO_2$, and presence of organic matter, the carbonate sometimes changing over later to the hydroxide. 4. By change of ferrous sulphate to ferric hydroxide in presence of oxygen, but the former might react with calcium carbonate, and yield siderite with gypsum; or the sulphide may be derived from sulphate in presence of decaying vegetable matter.

The ferric hydroxide is possibly precipitated first in colloidal form, and changes later to a crystalline condition. Its precipitation in some localities has been sufficiently rapid to permit gathering a supply from the pond bottom every few years.

**Distribution of Limonite in the United States** (13, 22*a*, 62–73). — Although deposits of limonite are widely scattered over the United States (Fig. 174), about nine-tenths of the quantity produced cones from five states, viz., Alabama, Virginia, Tennessee, Georgia, and Pennsylvania; indeed, the first supplied over 60 per cent of the total output in 1914.

**Residual Limonites.**—The residual limonites supply a large percentage of the domestic production, and have been formed (1) by the weathering of pyritiferous sulphide bodies (see gossan), or (2) more often by the weathering of ferruginous rocks.

FIG. 174. — Map showing distribution of limonite and siderite in the United States.
(*After Harder.*)

*Gossan deposits* (16, 23*a*). — Limonite gossan ores derived from
the oxidation of pyrite, chalcopyrite, and pyrrhotite deposits
are found at a number of localities in the crystalline belt of
New England and the southern Atlantic states, but they are of
limited importance at the present time. One belt of historic
and former commercial importance is the "Great Gossan
Lead" found mainly in southwestern Virginia (23*a*), and trace-
able for over 20 miles, its contents averaging 40 to 41 per cent
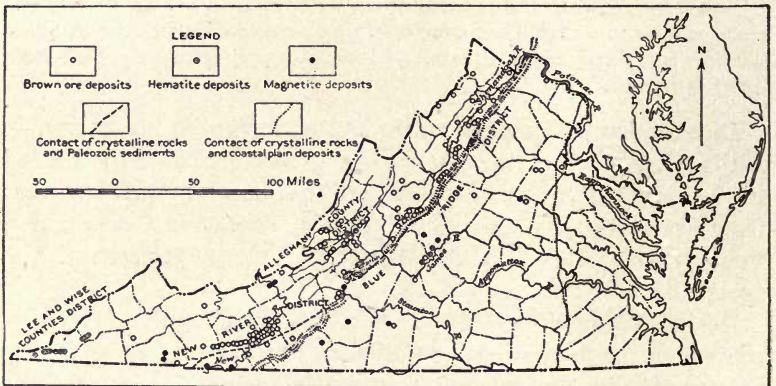


FIG. 175. — Map showing location of iron-ore deposits in Virginia. (*After Harder,
U. S. Geol. Surv., Bull.* 380.)

PLATE XLIX
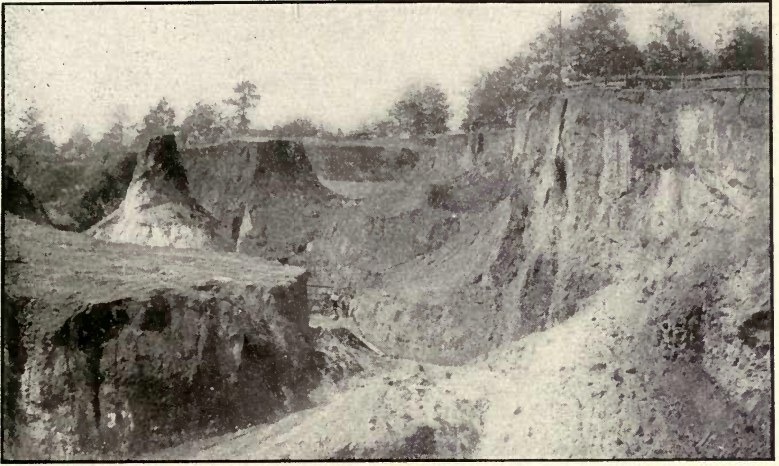


FIG. 1. — Pit of residual limonite, Shelby, Ala. *(After McCalley, Ala. Geol. Surv., Rept. on Valley Regions, Pt. II.)*
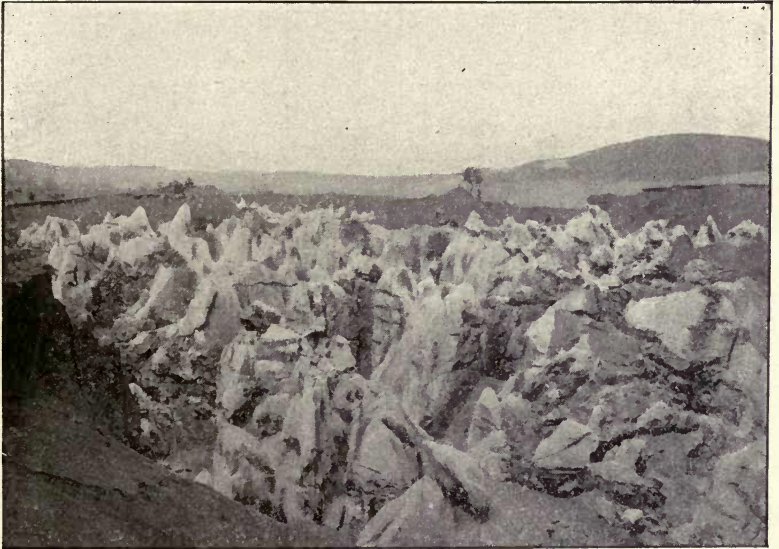


FIG 2. — Old limonite pit, Ivanhoe, Va., showing pinnacled surface of limestone which underlies the ore-bearing clay. The level of surface before mining began is seen on either side of excavation. *(H. Ries, photo.)*

(551)

metallic iron. (See also Ducktown, Tennessee, and Copper in Virginia.)

Limonite gossan ores are not uncommon in many of the western sulphide deposits, and many of them carry more or less manganese
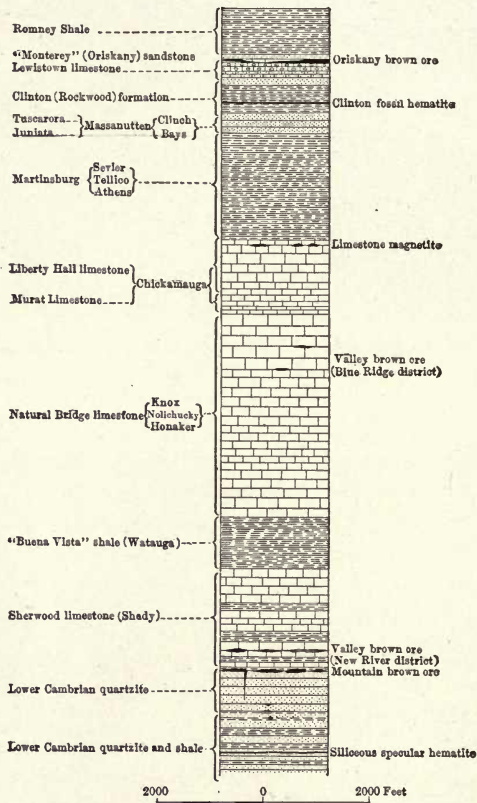


FIG. 176. — Geologic section showing position of iron-ore deposits in Virginia.
(*After Watson, Min. Res. Va.*, 1907.)

oxide, some, as those at Leadville, having sufficient to be used in the manufacture of spiegeleisen. Their main use, however, is as a flux in copper and silver smelting in the western states. The most important ones are in the Black Hills, South Dakota; Leadville, Colorado; Neihart, Monarch, and Elkhorn, Montana; the Tintic district, Utah; Tombstone, Arizona; and Pioche and Eureka, Nevada.

*Limonites in Residual Clays.* — The other class of residual

limonites has many scattered representatives, but the most important ones form a belt extending from Vermont to Alabama (51, 71) and divisible into two groups, viz., the mountain and the valley ores. In these the iron occurs as grains, lumps, or masses scattered through residual clays, associated with Cambro-Silurian limestones, shales, and quartzites.
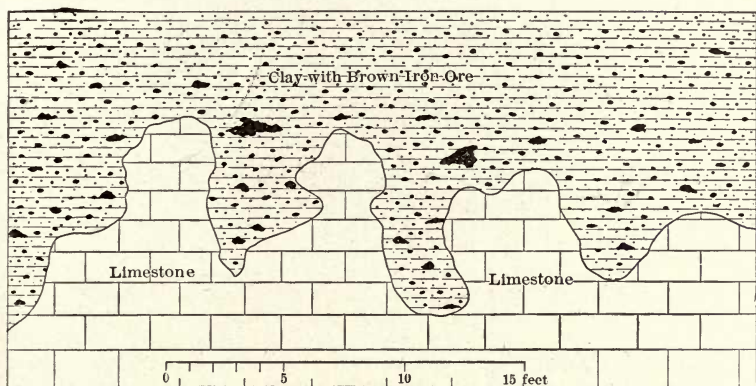


Fig. 177. — Vertical section showing the structure of the valley brown ore deposits at the Rich Hill mine, near Reed Island, Va. (*After Harder, U. S. Geol. Surv., Bull.* 380.)

The mountain ores are located in the eastern part of the Appalachian limonite belt, generally in the Blue Ridge or Appalachian Mountains, or at least near their western edge.

The valley ores are closely associated with them on the west, and there is no sharp line of separation between the two. The two types, however, present certain important differences.

Thus the mountain ores usually form relatively small, disconnected pockets in the residual material over the Lower Cambrian quartzite, at or near its contact with the overlying formation, usually a limestone, while other types of less common occurrence are known. The valley ores, on the other hand, form more extensive though shallower deposits in residual clay overlying limestones (Fig. 177) above the quartzite.

In either case, however, the ore is not uniformly distributed through the clay, so that individual pockets soon become worked out, necessitating the finding of a new one.

Mountain ores may extend to a depth of several hundred feet, but the valley ores rarely exceed fifty feet in depth, and in neither case do the deposits as a rule exceed 500,000 tons, the average being
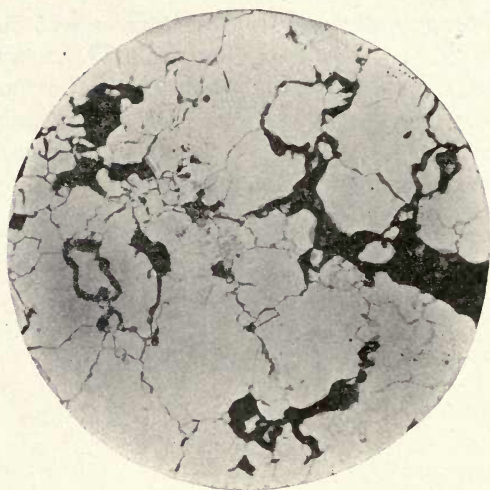
FIG. 178. — Section of fractured quartzite from residual limonite deposit, Pittsville, Va. Iron oxide deposited in part between grains and in part by replacement?

100,000 to 200,000. The ore may form from 5 to 20 per cent of the clay and sand in different deposits or different parts of the same deposit. Limonite and göthite are the two iron-ore minerals, the higher grades carrying as much as 55 per cent metallic iron, but the average shipments run about 45 per cent. The mountain ores are usually poorer than the valley ones, and phosphorus is generally high enough to make the ore non-Bessemer.

The following tables show the percentage range of the chief constituents (Harder) of I, mountain ore, and II, valley ore: —

|  | I PER CENT | II PER CENT |
|---|---|---|
| Fe | 35.00–50.00 | 40.00–56.00 |
| SiO₂ | 10.00–30.00 | 5.00–20.00 |
| P | .10–2.20 | .05– .50 |
| Mn | .50–10.00 | .30– 2.00 |

While Virginia (23a) is the main producer of residual limonites, still Alabama's output is of importance, and some is also obtained from Georgia (67, 72) and Pennsylvania (69).

*Origin of the Cambro-Silurian Limonites.* — Both the valley and mountain ores are believed to have been formed by the action of weathering.
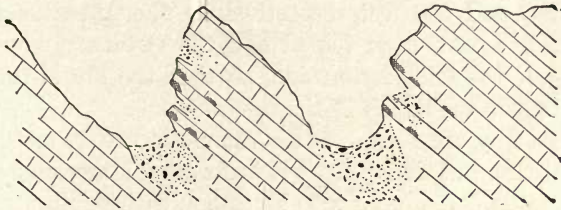
Fig. 179.—Section illustrating formation of residual limonite in limestone. (*After Hopkins, Geol. Soc. Amer., Bull. XI.*)

As the shale and limestones overlying the Cambrian quartzite weathered, the iron oxide was set free, either by the decomposition of ferruginous silicates, or of pyrite or siderite in the limestones. This was then carried downward and concentrated first in the residual clays of the limestone, forming the valley ores. If weathering continued still deeper, the downward percolating iron solutions reached the impervious quartzite, the ores (mountain type) becoming concentrated in the clay overlying this, although some was deposited in crevices in the quartzite.

*Oriskany Limonites* (23a). — These are so called because of their association with the Oriskany sandstone. To be more exact, they are found in the Lewistown (Silurian) limestone, under the Monterey (Oriskany) sandstone, or the Romney (Devonian) shale. The main producing districts are in Alleghany County, Virginia, and central Pennsylvania, but local deposits are found at the same horizon in West Virginia, Kentucky, and Ohio.

The deposits (Fig. 180) form replacements in the upper portion of the Lewistown limestone, and may extend along the strike for a distance of several miles. The thickness and depth are variable, but in some cases may
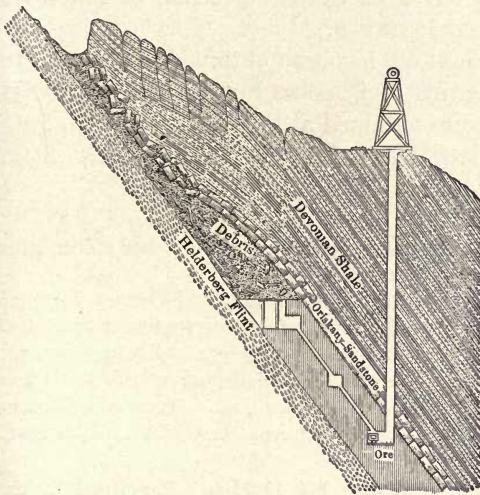


Fig. 180. — Section of Oriskany limonite deposit. (*After Holden, Min. Res. Va.*, 1907.)

reach 75 feet and 600 feet respectively. The formations in which the ore occurs have been folded and the Oriskany removed from the crests of the folds by erosion, so that the ore is found along the outcrops on the flanks of the ridges.

The Oriskany ore resembles the mountain ore in texture, grade, and impurities, but differs from it in forming larger and more continous deposits. It grades into limestone with depth.

**Other Limonite Deposits.** — In northwestern Alabama, western Kentucky, and Tennessee, limonite occurs in residual and sedimentary clays overlying the Mississippian limestone.[1] Brown ore also occurs in the Claiborne (Tertiary) formation of northeastern Texas (62b, 65, 70), and adjoining parts of Louisiana (62a) and Arkansas. The ore forms horizontal beds of slight thickness but some extent. It is of little value.

In the Ozark region of Missouri and Arkansas (73), limonites are found in residual clays over Cambrian limestone, but are of little economic value.

Small deposits are known in Iowa (63), Wisconsin (62), Minnesota, and Oregon (16).

The brown ores of the Appalachian belt are much used by pig iron manufacturers because, owing to their siliceous character, they can be mixed with high-grade Lake Superior ores which are deficient in silica. They are also cheaper, and their mixture with other ores seems to facilitate the reduction of the iron in the furnace.

The analyses on page 557 give the composition of limonites from a number of different localities.

**Canada** (4, 92). — Bog iron ore has been obtained from deposits in the Three Rivers District of Quebec, but its importance is decreasing. Some of the ore obtained at the Helen Mine (p. 534) is quite strongly hydrated, but otherwise comparatively little limonite is mined in Canada.

**Other Foreign Deposits.** — Limonite is obtained at a number of localities in other countries (1), but only a few need mentioning.

The so-called *minettes*[2] of Lorraine, Luxembourg, and Germany are of great importance to the European iron industry. They represent great flat lenses associated with shales, sandstones and marls of middle Jurassic age. The ore, which is chiefly limonite, with some admixture of calcite, is low grade, its iron content ranging from 30 to 40 per cent. Other constituents include: P, 1.3–1.8 per cent; $SiO_2$, 7.5–33.6 per cent; CaO, 5.3–12.3 per cent.

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[1] Burchard, U. S. Geol. Surv., Bull. 315: 154, 1907; and Hayes and Ulrich, Geol. Atlas Folio, 95, 1903.

[2] Cayeux, Minerais de fer oolitique de France, Paris, 1909; Iron Ore Resources of the World, Stockholm, 1910.

ANALYSES OF LIMONITE

| | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | XIII | XIV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $Fe_2O_3$ | — | — | 62.11 | — | — | — | 52.86 | — | — | — | — | — | — | — |
| Fe | 57.088 | 29.323 | — | 49.18 | 32.59 | 53.75 | — | 53.75 | 36.15 | 47.00 | 48.54 | 47.19 | 44.68 | 43.6 |
| $MnO_2$ | — | — | 2.85 | — | — | — | .61 | — | — | — | — | — | — | — |
| Mn | .504 | .33 | — | .32 | .12 | .57 | — | .57 | 1.40 | 2.70 | — | .72 | — | .80 |
| $SiO_2$ | 5.145 | 41.575 | 18.97 | 13.73 | 45.24 | 10.31 | 33.26 | 10.31 | 16.36 | 12.25 | 11.22 | 12.50 | 18.90 | 24.00 |
| $P_2O_5$ | — | — | 1.10 | — | — | — | 1.325 | — | — | — | — | — | — | — |
| P | .122 | .055 | — | .376 | .068 | .191 | — | .191 | .12 | .85 | .38 | — | .09 | .14 |
| S | .023 | .105 | .06 | — | — | — | .014 | — | — | — | .09 | — | .20 | .018 |
| $Al_2O_3$ | 1.471 | 3.995 | 2.39 | — | 6.30 | — | 5.26 | — | — | — | 3.61 | 2.44 | 5.76 | 2.3 |
| CaO | .137 | 1.85 | .48 | — | — | — | .28 | — | — | — | .84 | — | .18 | .58 |
| MgO | tr. | .776 | .42 | — | — | — | — | — | — | — | — | .26 | tr. | .30 |
| P | | | | | | | | | | | & moist. | | | |
| $H_2O$ | 11.01 | 9.67 | 11.62 | 10.33 | — | 10.48 | 1.90 | 10.48 | — | — | 13.00 | 7.10 | 11.03 | — |

I. Best ore, Old Hill mine, Salisbury district, Conn., Econ. Geol., II : 171, 1907. II. Poor ore, same mine. *Ibid.* III. Average of 29 commercial analyses of Pennsylvania limonite, Bull. Geol. Soc. Amer., XI : 481. IV. Earthy mountain brown ore, Greenville, Augusta County, Va., U. S. Geol. Surv., Bull. 380 : 222. V. Red shaly mountain brown ore, Buena Vista, Rockbridge County, Va., *Ibid.* VI. Oriskany brown ore, near Low Moor, Alleghany County, Va., *Ibid.* VII. Oriskany brown ore, Covington, Va., U. S. Geol. Surv., Bull. 285 : 187. VIII. Valley brown ore, U.S. Geol. Surv., Min. Res. 1908. IX. Gossan ore, Betty Baker, Carroll County, Va., Min. Res. Va., 1907: 265. X. Limonite ore, Pittsville, Pittsylvania County, Va., *Ibid.* XI. Average composition, Alabama limonites. XII. Average of Champion area, Birmingham district, Ala., U. S. Geol. Surv., Bull. 400 : 169. XIII. Rusk, Cherokee County, Tex. XIV. Average composition of rock and wash ore, Spring Valley, Wis., Mich. Acad. Sci., 11th Ann. Rept.

The theory of their origin is that the ore has been precipitated in sea water directly as limonite, or first as siderite or glauconite and then oxidized.

Other oolitic bedded deposits may carry chamosite and thuringite, as those of Thuringia and Bohemia, or hematite as some European ones found in Paleozoic rocks.



FIG. 181. — Section of oolitic iron ore (*minette*) from Luxembourg.   ×33.

Eastern Cuba [1] contains three important districts of residual iron ore, two of these—Moa and Mayari in Oriente province, and a third, San Felipe in Camaguey province.   The ore is in residual clay derived from serpentine, and shows a dark red, earthy, surface zone occasionally containing shots and lumps of solid brown ore and hematite, below which is yellowish or yellowish brown ore changing rather suddenly to serpentine.   The average depth at Mayari is 15 feet.   The analyses indicate appreciable hematite and bauxite in the upper zone, while farther down hydrous iron oxides predominate. We have here then a case of lateritic alteration.

Analyses of the surface ore I, and bottom layer II indicate the high grade of these ores.

|  | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | $Cr_2O_3$ | FeO | NiO | MgO | $H_2O$ comb. |
|---|---|---|---|---|---|---|---|---|
| I . . . . . . . . . | 2.26 | 14.90 | 68.75 | 1.89 | .77 | .74 | —— | 11.15 |
| II . . . . . . . . | 7.54 | 4.97 | 64.81 | 3.66 | 1.49 | 2.75 | 1.50 | 12.75 |

## SIDERITE

**United States.** — Siderite (74-78) is of little importance in the United States, both on account of the small extent of the deposits (Fig. 174) and its low iron content.   When of concretionary structure with clayey impurities, it is termed *clay ironstone*, and these concretions are common in many shales and clays.   In some districts siderite forms beds, often several feet in thick-

[1] Kemp, Amer. Inst. Min. Engrs., Bull. 98: 129, 1915.   (Has bibliography.) Leith and Mead, *Ibid.*, Bull. 103: 1377, 1915; and *Ibid.*, Trans., XLII: 90, 1911.

ness, but containing much carbonaceous and argillaceous matter, and is known as *black band ore*. This is found in many Carboniferous shales.

Iron carbonate in bedded deposits is found in the Carboniferous rocks of western Pennsylvania, northern West Virginia, eastern Ohio, and northeastern Kentucky. These ores were formerly the bases of an important iron-mining industry, but little is obtained now except in southeastern Ohio (16).

Concretions and layers of iron carbonate occur in the Cretaceous clays of Maryland (13) and were formerly mined somewhat extensively in the vicinity of Baltimore and Washington. Small deposits are also known in the Chickamauga (Ordovician) limestone of southwestern Virginia (23a). In the western states iron carbonate nodules are found associated with the Laramie (Cretaceous) formation in Colorado and northern New Mexico, but they possess no commercial value (16).

**Foreign Deposits.**[1] — Earthy carbonates, occurring as beds, form the great bulk of the British iron ore deposits. The most important ones are those found in Mesozoic rocks, especially of the Yorkshire district. Others of less importance occur in the Carboniferous. Considerable siderite has been obtained from the Cretaceous limestones at Bilbao, Spain.

### PYRITE

Pyrite is primarily used for sulphuric acid, but after driving off the sulphur, the residue is sometimes sold under the name of " blue billy " and used for iron manufacture, being mixed with a natural ore in the desired proportions.

**Production of Iron Ores.** — The iron-ore mining industry in the United States has progressed with phenomenal strides, and this country now leads the world in the production of iron ore. Indeed so great has the production become that in 1903 it was equal to the combined output of Germany and Luxemburg and the British Empire for 1902. Moreover, the average iron content of the ore mined in the United States is higher than that mined in foreign countries, thereby resulting in the production of a greater amount of pig iron from a given quantity of ore.

The phenomenal growth of the iron-mining industry is shown in the following table: —

| DECADE | QUANTITY | PERCENTAGE OF INCREASE |
|---|---|---|
| | Long tons | |
| 1870–1879 . . . . . . . . | 43,770,527 | — |
| 1880–1889 . . . . . . . . | 91,043,854 | 108.0 |
| 1890–1899 . . . . . . . . | 163,989,193 | 80.1 |
| 1900–1909 [1] . . . . . . . . | [2] 392,000,000 | 138.0 |

[1] Iron Ore Resources of the World, Stockholm, 1910.    [2] Approximate.
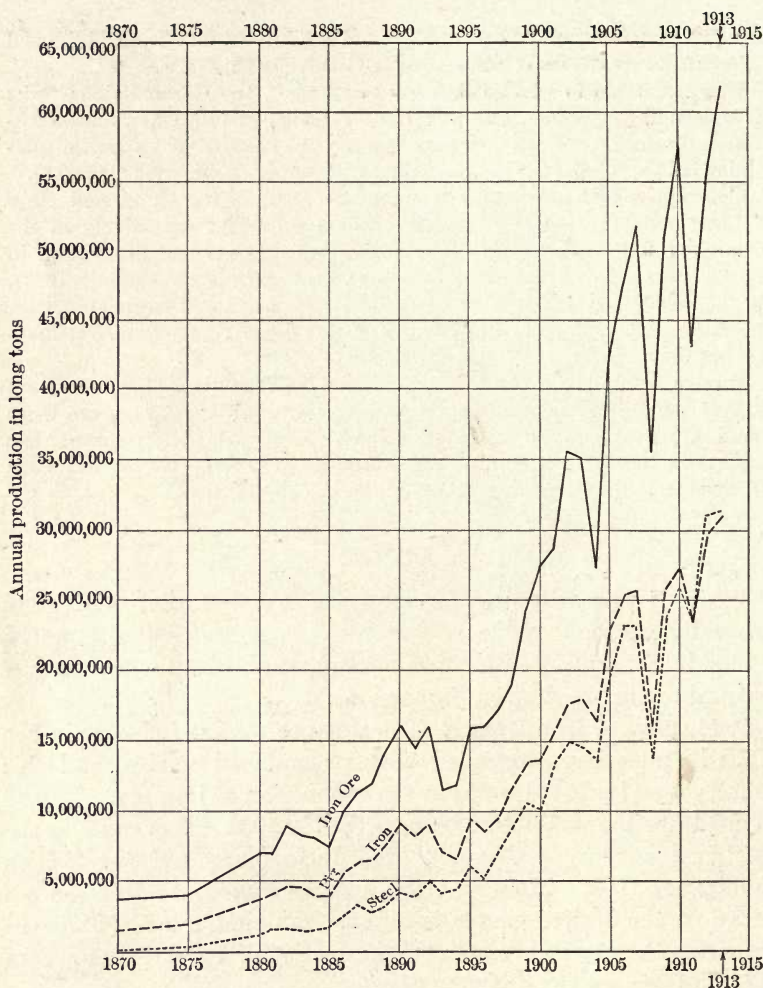
FIG. 182. — Diagram showing the production of iron ore, pig iron, and steel in the United States, 1870 to 1913. (*U. S. Geol. Surv. Min. Res.*, 1913.)

The Lake Superior region is now producing at least three quarters of the iron ore used in the United States, and it has large reserves of ore, although the high-grade ones are becoming rapidly exhausted. The low-grade ores of this region and others will, however, be available for a much longer time.

While there is not danger of the present supply of ore soon becoming exhausted, still, with the present consumption, it is well to consider possible sources of the future.

In the United States the Utah and some other western deposits will no doubt be drawn upon, and many ores now looked upon as too low grade to work will also be considered. Aside from domestic sources of supply there are foreign ones which may perhaps be eventually turned to, such as those from Canada, Newfoundland, and Brazil on this side of the Atlantic, or even those of Scandinavia on the European side. Cuba, even now is sending considerable ore to the United States.

PRODUCTION OF IRON ORES IN THE UNITED STATES FROM 1909–1914, BY VARIETIES, IN LONG TONS

|  | 1909 | 1910 | 1911 | 1912 | 1913 | 1914 |
|---|---|---|---|---|---|---|
| Hematite . . | 46,208,640 | 51,367,007 | 39,626,224 | 51,345,782 | 57,933,251 | 38,286,670 |
| Brown ore . . | [1] 2,839,265 | [1] 2,993,744 | 2,032,094 | 1,614,486 | 1,682,063 | 1,537,750 |
| Magnetite . . | [1] 2,229,839 | [1] 3,631,835 | 2,202,527 | 2,179,533 | 2,357,274 | 1,610,203 |
| Carbonate . . | 16,257 | 22,320 | 15,707 | 10,346 | 7,849 | 5,138 |
| Total . . | 51,294,271 | 57,014,906 | 43,876,552 | 55,150,147 | 61,980,437 | 41,439,761 |

[1] Some brown ores are included in magnetite.

PRODUCTION OF IRON ORE IN THE MORE IMPORTANT STATES, 1910–1911

| STATE | 1910 | | 1911 | |
|---|---|---|---|---|
|  | LONG TONS | VALUE | LONG TONS | VALUE |
| Minnesota . . . . . . . . | 31,966,769 | $78,462,560 | 23,398,406 | $48,447,760 |
| Michigan . . . . . . . | 13,303,906 | 41,393,585 | 8,945,103 | 23,810,710 |
| Alabama . . . . . . . . | 4,801,275 | 6,083,722 | 3,995,582 | 4,876,106 |
| New York . . . . . . . | 1,287,209 | 3,848,683 | 1,057,984 | 2,959,009 |
| Wisconsin . . . . . . . | 1,149,551 | 3,610,349 | 610,871 | 1,146,188 |
| Virginia . . . . . . . . | 903,377 | 1,845,144 | 559,763 | 1,386,616 |
| California, Colorado, New Mexico, Washington and Wyoming | 861,850 | 877,223 | [1] | [1] |
| Pennsylvania . . . . . . | 739,799 | 911,847 | 514,929 | 539,553 |
| Tennessee . . . . . . . | 732,247 | 1,048,328 | 469,728 | 632,339 |
| New Jersey . . . . . . . | 521,832 | 1,582,213 | 359,721 | 1,158,271 |
| Georgia . . . . . . . . | 313,878 | 482,659 | 207,279 | 315,704 |

[1] 1911 production given only with a large group of states.

PRODUCTION OF IRON ORE IN THE MORE IMPORTANT STATES, 1912–1914 [1]

|  | 1912 | | 1913 | | 1914 | |
|---|---|---|---|---|---|---|
|  | LONG TONS | VALUE | LONG TONS | VALUE | LONG TONS | VALUE |
| Minnesota . . | 34,249,813 | $61,805,017 | 36,603,331 | $80,789,025 | 23,298,547 | $40,628,771 |
| Michigan . . | 12,797,468 | 29,003,163 | 12,668,560 | 33,479,954 | 8,533,280 | 18,722,358 |
| New York . . | 1,167,405 | 2,933,024 | 1,420,889 | 3,100,235 | 640,252 | 1,992,892 |
| Alabama . . | 4,776,545 | 5,734,371 | 5,333,218 | 6,648,569 | 4,514,926 | 5,727,619 |
| Wisconsin . . | 1,152,250 | 2,731,574 | 896,243 | 2,149,397 | 591,595 | 1,178,610 |
| Virginia . . . | 412,520 | 903,130 | 492,649 | 983,279 | 346,382 | 719,415 |
| Pennsylvania . | 522,172 | 481,353 | 478,693 | 589,038 | 400,062 | 399,639 |
| Tennessee . . | 416,885 | 564,443 | 364,092 | 493,556 | 330,214 | 466,523 |
| New Jersey . . | 366,823 | 1,192,816 | 291,653 | 980,303 | 346,820 | 1,076,208 |
| Georgia . . . | 135,337 | 227,282 | 153,336 | 237,876 | 66,222 | 119,363 |

[1] Figures for 1913 and 1914 refer to quantity marketed.

PRODUCTION OF LAKE SUPERIOR IRON ORE BY RANGES, 1904–1914, IN LONG TONS

| YEAR | MAR-QUETTE | ME-NOMINEE | GO-GEBIC | VER-MILION | MESABI | CUYUNA | TOTAL |
|------|-----------|-----------|----------|-----------|--------|--------|-------|
| 1904 | 2,465,448 | 2,871,130 | 2,132,898 | 1,056,430 | 11,672,405 | —— | 20,198,311 |
| 1905 | 3,772,645 | 4,472,630 | 3,344,551 | 1,578,6z6 | 20,156,566 | —— | 33,325,018 |
| 1906 | 4,070,914 | 4,962,357 | 3,484,023 | 1,794,186 | 23,564,891 | —— | 37,876,371 |
| 1907 | 4,167,810 | 4,779,592 | 3,609,519 | 1,724,217 | 27,245,441 | —— | 41,526,579 |
| 1908 | 3,309,917 | 2,904,011 | 3,241,931 | 927,206 | 17,725,014 | —— | 28,108,079 |
| 1909 | 4,291,967 | 4,789,362 | 3,807,157 | 1,097,444 | 27,877,705 | —— | 41,863,635 |
| 1910 | 4,631,427 | 4,983,729 | 4,746,818 | 1,390,360 | 30,576,409 | —— | 46,328,743 |
| 1911 | 3,743,145 | 4,062,778 | 3,099,197 | 1,336,938 | 23,126,943 | 181,224 | 35,550,225 |
| 1912 | 3,545,012 | 4,465,466 | 3,926,632 | 1,457,273 | 32,604,756 | 369,739 | 46,368,878 |
| 1913 | 3,977,808 | 4,997,246 | 4,743,515 | 1,536,115 | 36,378,671 | 744,007 | 52,377,362 |
| 1914 | 3,320,763 | 3,671,499 | 4,601,240 | 1,362,416 | 19,808,434 | 776,051 | 33,540,403 |

TWELVE IRON MINES OF THE UNITED STATES WHICH PRODUCED THE LARGEST TONNAGE IN 1914 [1]

| NAME OF MINE | STATE | NEAREST TOWN | VARIETY OF ORE | QUANTITY MINED IN 1914 |
|--------------|-------|-------------|----------------|------------------------|
| Red Mountain group (3) | Alabama | Bessemer | Hematite | 2,008,465 |
| Mahoning (7) | Minnesota | Hibbing | " | 1,212,287 |
| Sauntry–Alpena (4) | " | Virginia | " | 1,156,150 |
| Canisteo (12) | " | Coleraine | " | 1,051,895 |
| Leonard (2) | " | Chisholm | " | 1,022,490 |
| Norrie group (10) | Michigan | Ironwood | " | 991,291 |
| Newport (11) | " | " | " | 950,243 |
| Uno (5) | Minnesota | Hibbing | " | 947,502 |
| Susquehanna (14) | " | " | " | 906,913 |
| Woodward, 1, 2 and 3 (24) | Alabama | Lipscomb | " | 650,507 |
| Shenango (16) | Minnesota | Chisholm | " | 619,569 |
| Leetonia (26) | " | Hibbing | " | 592,940 |

[1] The numbers in parentheses after the names give the rank of these same mines in 1913.

IMPORTS AND EXPORTS OF IRON ORE INTO AND FROM THE UNITED STATES, 1912–1914

| | IMPORTS | | EXPORTS | |
|------|-----------|-------|-----------|-------|
| | LONG TONS | VALUE | LONG TONS | VALUE |
| 1912 | 2,104,576 | $6,499,690 | 1,195,742 | $3,537,289 |
| 1913 | 2,594,770 | 8,336,819 | 1,042,151 | 3,513,419 |
| 1914 | 1,350,588 | 4,483,832 | 551,618 | 1,794,193 |

PRODUCTION OF IRON ORE IN CANADA BY PROVINCES, 1912–1914

| PROVINCE | 1912 | | 1913 | | 1914 | |
|----------|------|-------|------|-------|------|-------|
| | TONS | VALUE | TONS | VALUE | TONS | VALUE |
| New Brunswick | 71,520 | $127,716 | 86,416 | $153,820 | 4,725 | $10,841 |
| Nova Scotia | 30,857 | 168,877 | 20,436 | 21,049 | —— | —— |
| Quebec | 1,185 | 4,232 | 5,102 | 26,999 | —— | |
| Ontario | 112,321 | 222,490 | 195,680 | 427,975 | 240,029 | 531,200 |
| Total | 215,883 | $523,315 | 307,634 | $629,843 | 244,754 | $542,041 |

Shipments of iron ore from Wabana mines, Newfoundland, were: 1913, 1,605,220 short tons; 1914, 639,430 short tons.

EXPORTS AND IMPORTS OF IRON ORE IN CANADA

| | | | |
|---|---|---|---|
| Exports . . . . . . . . . . . . | 1914 | 135,451 tons | $   360,974 |
| Imports . . . . . . . . . . . . | 1914 | 1,147,108 short tons | 2,387,358 |

PRODUCTION OF IRON ORE IN PRINCIPAL COUNTRIES, IN LONG TONS

| COUNTRY | LONG TONS | COUNTRY | LONG TONS |
|---|---|---|---|
| Canada (1914) . . . . | 218,620 | Norway (1913) . . . . | 77,693 |
| Cuba (1913) . . . . . | 1,582,431 | Spain (1913) . . . . . | 9,706,366 |
| Newfoundland (1912) . . | 1,251,968 | Sweden (1913) . . . . | 7,357,845 |
| United States (1914) . . | 41,439,761 | United Kingdom (1913) . | 15,997,328 |
| Austria-Hungary (1913) . | 5,018,109 | China (1913) . . . . . | 269,748 |
| Belgium (1912) . . . . | 164,734 | India (1912) . . . . . | 580,029 |
| France (1913) . . . . . | 21,572,835 | Chosen (Korea) (1912) . | 121,224 |
| German Empire and Lux- | | | |
| embourg (1913) . . . | 26,771,598 | Algeria (1912) . . . . | 1,171,252 |
| Greece (1913) . . . . | 305,195 | Tunis (1912) . . . . . | 470,866 |
| Italy (1913) . . . . . | 593,618 | Australia (1912) . . . . | 113,989 |
| | | [1] Russia . . . . . . . | |

[1] Russia produced 4,131,890 long tons of pig iron in 1912

**Iron-ore Reserves** (3). — As a result of the recent agitation over the conservation of our mineral resources, attempts have been made by the United States Geological Survey to estimate the quantity of both at present available and non-available ore still remaining in the ground.    That such estimates can only be very approximate is self-evident, partly because the irregularity of most iron-ore deposits makes it difficult to estimate their contents.    Bedded ores like those of the Clinton can be most closely figured on, while in the case of the Adirondack ores there may be an error of 15 to 20 per cent.

The estimate of availability is influenced by the cost of ore delivered at furnace, cost of reduction, and accessibility; and any of these factors might change at no distant future.

The metallic iron content of ores now used ranges from about 30 to 65 per cent, this wide variation being due in part to character of other elements in the ore, and in part to favorable location.    Thus the Clinton ores, running as low as 30 per cent iron, can be used, because their high lime content makes them practically self-fluxing, but they must be used near the point of production.

Siliceous ores running under 40 per cent iron are not at present available unless located near fuel supplies, because they will not bear the cost of transportation and are expensive to reduce.

So, too, the amount of other constituents present, such as phosphorus, sulphur, copper, chromium, manganese, and alumina, exert a determining influence on the cost of production and quality of the iron.

Two tendencies are noticeable in the iron industry of the present day, viz., the use of ores with a lower average iron content, and the decentralization of the iron industry.

This involves a corresponding increase in the cost of transportation per unit of iron, and an increase in the proportion of fuel which goes to the ore-

producing region. An accompaniment of this will be the general adoption of by-product coking, and Hayes points out that in certain furnaces now operating in the Lake Superior district the profit corresponds approximately to the value of the by-products from the coke ovens.

The following table gives in condensed form the figures compiled by a committee of the International Geological Congress (1). They are, because of the difficulties involved in making estimates, to be regarded as only approximate, but they show enormous reserves nevertheless.

| COUNTRY | VARIETY OF ORE | ACTUAL ORE SUPPLIES. MILLION TONS | EQUIVALENT METALLIC IRON. MILLION TONS | POTENTIAL ORE SUPPLIES, MILLION TONS | EQUIVALENT METALLIC IRON. MILLION TONS |
|---|---|---|---|---|---|
| United States | | | | | |
| *Eastern region* | | | | | |
| Clinton | R . . . . . | 505.3 | 187 | 1,368.0 | 481 |
| Ohio and other states | C . . . . . | —— | —— | 308.0 | 90 |
| Other deposits | R. L. M. . . | 204.5 | 95.4 | 265.5 | 119 |
| *Lake Sup. reg.* . | R. L . . . . | 3,500.0 | 2,000.0 | 72,000.0 | 36,000 |
| *Mississippi Valley* | R. L. . . . . | 45.0 | 21.0 | 830.0 | 382 |
| *Cordilleran* . . | M. H. . . . . | 3.0 | 1.2 | 115.8 | 50 |
| *Adirondack, etc.* . | T . . . . . . | —— | —— | 218.0 | 100 |
| | | 4,257.8 | 2,304.6 | 75,105.3 | 37,222 |
| Canada . . . . | M. H. C. . . | Consi | derable | Very | great |
| Newfoundland . . | R. T. C. S. . . | 3,635.0 | 1,961.0 | " | " |
| Mexico . . . . | M. . . . . . | 55.0 | 30.0 | " | " |
| Central America . | M. . . . . . | —— | —— | ? | ? |
| Cuba . . . . . | H. M. L. . . | 1,903.0 | 856.8 | 1,007.0 | 454 |
| South America . . | M. H. L. C. S.. | 4.2 | 2.0 | 5,710.0 + | 3,055 + |
| Europe . . . . | H. M. T. L. C. . | 12,031.9 | 4,732.8 | 41,028.7 + | 12,084.6 + |
| Asia . . . . . | M. H. L. S. . . | 260.4 | 155.5 | 457.0 + | 282.8 + |
| Africa . . . . | H. L. M. C. T. . | 125.0 | 75.0 | Very | high |
| Australia . . . | H. M. B. L. C. T. | 135.9 | 73.8 | 68.6 + | 37.1 + |
| | | 22,408.2 | 10,189.5 | Enormous | |

R, red hematite; H, hematite; L, brown ore; C, carbonate and clay iron stone; M, magnetite; T, titaniferous magnetite; S, titaniferous iron sand; B, bog ore.

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## CHAPTER XVI

### COPPER

**Ore Minerals of Copper.** — Copper-bearing minerals are not only numerous, but widely though irregularly distributed. More than this, copper is found associated with many different metals and under varied conditions.

Nevertheless but few copper-bearing minerals are important in the ores of this metal, and the number of important producing districts is comparatively small.

The ore minerals of copper together with their theoretic composition and percentage of copper are as follows: —

| Ore Mineral | Composition | Per Cent Cu |
|---|---|---|
| Chalcopyrite | $CuFeS_2$ | 34.5 |
| Chalcocite | $Cu_2S$ | 79.8 |
| Bornite | $Cu_5FeS_4$ | 63.3 |
| Enargite | $3 Cu_2S, 2 As_2S_3$ | 48 |
| Covellite | $CuS$ | 66.5 |
| Tetrahedrite | $Cu_8Sb_2S_7$ | 52.06 |
| Tennantite | $Cu_8As_2S_7$ | 57 |
| Native copper | $Cu$ | 100 |
| Azurite | $2 CuCO_3, Cu(OH)_2$ | 55.10 |
| Malachite | $CuCO_3, Cu(OH)_2$ | 57.27 |
| Chrysocolla | $CuSiO_3, 2 H_2O$ | 36.06 |
| Cuprite | $Cu_2O$ | 88.8 |
| Melaconite | $CuO$ | 79.84 |
| Brochantite | $CuSO_4, 3 Cu(OH_2)$ | 62.42 |
| Atacamite | $Cu(OH)Cl, Cu(OH)_2$ | 59.45 |
| Chalcanthite | $CuSO_4, 5 H_2O$ | 25.4 |

Very few ores approach the theoretic percentages given above. Thus, in Michigan, where native copper is the ore mineral, this as now mined rarely averages above 1 per cent metallic copper, and may fall as low as .6 per cent. At Butte, Montana, the important copper-bearing minerals are chalcocite, enargite, and bornite, but much of the concentrating ore in 1914 averaged about 2 per cent metallic copper, and smelting ore 5 per cent.

Most of the copper ores now worked are of low grade, but can be profitably treated because of the extent of the operations and pos-

sibility of concentration.  Occasionally low-grade ores are found
which are self-fluxing, as those of the Boundary District of western
Canada.   The introduction of pyritic smelting has permitted
the profitable treatment of low-grade pyritic-copper ores, even if
they carry no gold or silver.  Complex ores of copper, lead, and
zinc sulphides are more costly to treat, but this expense may be
more than made up for by their gold and silver contents.

In the unaltered portion of the ore body the copper compounds
are mainly sulphides, but arsenides and antimonides are also
known.   In the gossan the copper occurs as carbonates, sulphates,
silicates, oxides, native, and more rarely as phosphates, arsenates,
antimonates and vanadates.

**Gangue Minerals.**—Quartz is the commonest gangue mineral,
but calcite and siderite are abundant in a few; barite, rhodo-
chrosite, and fluorite are also known.  Sericite is found in some
veins, and so is tourmaline in certain tin-copper and gold-copper
ones.

Metallic impurities may be present which cause trouble in the reduc-
tion of the ores.  Of these zinc is the most objectionable, but bismuth,
though rare, is also very undesirable, but can be eliminated by electrolytic
refining.   Arsenic, antimony, tellurium, and selenium are partially elim-
inated in smelting, but must be completely removed by electrolytic
methods to make the copper pure enough for electrical work.

Tellurium is not uncommon in some districts, and renders the metal
red-short even in small amounts.  Silver, even if present in as small
amounts as .5 per cent, lowers the electric conductivity, and above 3 per
cent affects the toughness and malleability of the copper.  Sulphur up to
.25 per cent lowers the malleability and .5 per cent renders the metal
cold-short, while .4 or more per cent phosphorus makes it red-short.

A high percentage of silica is detrimental, as it requires too much basic
flux.

**Occurrence and Origin.**— Copper ores are found in many
formations ranging from the pre-Cambrian to the Tertiary, and
the deposits have been formed in many different ways.   Indeed
in some cases more than one mode of origin may be represented
by the deposits of one locality (Clifton, Ariz.; Bingham, Utah),
which makes it a little difficult to separate the different occur-
rences sharply on genetic grounds.   Then too, a difference of opin-
ion sometimes exists regarding the origin of some one deposit
(Rio Tinto, Spain).

A rough grouping might therefore be made as follows:

1. Magmatic segregations.

2. Contact-metamorphic deposits, in crystalline, usually gar-

netiferous limestone, along igneous rock contacts. (Clifton-Morenci, Ariz., Bingham, Utah, etc.)

3. Deposits formed by circulating waters, and deposited in fissures, pores, or other cavities, or by replacement.

    *A*. By ascending thermal waters.
    *B*. By waters, probably of meteoric character, and unassociated with igneous rocks.

4. Lens-shaped deposits of variable origin in crystalline schists.

All of these except the first have important representatives in the United States, but in many cases their commercial value depends on secondary enrichment and not the mode of primary deposition.

**Superficial Alteration** (2, 4, 11, 12, 14, 17, 18, 19). — This may produce results of great economic importance, and excellent examples of it are seen in some of the Arizona ores, where the upper portions of the copper deposits are brown or black ferruginous porous masses, brightly colored with oxidized copper minerals such as cuprite, malachite, azurite, and chrysocolla, while below this at a variable depth they pass into sulphides.

In weathering, the copper minerals, such as chalcopyrite or other sulphides, are usually oxidized first to sulphates, and subsequently changed to oxides, carbonates, or silicates, and occasionally even to chlorides. A concentration of the ore deposit may take place partly by segregation and partly by leaching, and pockets of the ore form, which are surrounded by oxidized iron minerals forming part of the gangue.

While the oxidation will not increase the total copper content of the ore body, still it may change it into a more concentrated form, for the carbonates and other oxidized copper minerals contain more copper than the original sulphide. The ore in the gossan may therefore run from 8 to 30 per cent or more, while below it may show only 5 per cent of copper (see Penrose under ore deposit refs.). These altered ores cannot, however, be more cheaply treated. If leaching follows oxidation, the gossan may be freed of its ore, as at Butte, Montana, where the upper part of the ore-bearing fissures is poor siliceous gangue.

Below the zone of oxidation, there often lies a zone of secondary sulphide enrichment (p. 481), of variable depth, followed still lower down by the primary ore.

But even with secondary enrichment, the deposit may not

PLATE L.—Map showing distribution of Copper Deposits in the United States. (*U. S. Geol. Survey.*)

(571)

carry more than 2 to 3 per cent of copper, and yet because of its concentrating possibilities and size be worth working.

The processes of secondary enrichment have been referred to on p. 481, and it was shown there that the work of Graton and Murdock has demonstrated that the change is not as simple or direct as was formerly thought.

**Importance of United States as a Copper Producer.** — The map, Plate L, sets forth clearly the distribution of copper ores in the United States, and statistics show the leading position of this country as a world's producer. The following table compiled by Butler shows in an interesting way the production of copper according to the geologic age of the deposits.

|  | PERCENTAGE IN 1913 |
|---|---|
| Pre-Cambrian. Michigan; Jerome, Ariz.; Encampment, Wyo. | 15.60 |
| Paleozoic. Ducktown, Tenn., and other Appalachian deposits . | 1.60 |
| Mesozoic. Shasta County, Calif.; Foothills belt, Calif.; Ely, Nev.; Yerington, Nev.; Alaska; Bisbee, Globe, and Ray, Ariz.; Others . . . . . . . . . . . . . . . . . . . . . . | 36.71 |
| Tertiary. Butte, Mont.; Morenci, Ariz.; Santa Rita, N. Mex.; Bingham, Frisco and Tintic, Utah; Others . . . . . . . | 45.98 |

About 82 per cent of the copper produced in the United States in 1914 was obtained from four states, viz. Arizona, Montana, Utah and Michigan, named in the order of their output, nearly all of the rest coming from the Appalachians and Cordilleran region; the ores of the latter are often worked chiefly for their gold contents, with copper as a secondary product.

### Magmatic Segregations

While it is known that copper sulphides may crystallize from a magma, chalcopyrite being the best known example, still few cases of copper ores formed by magmatic segregation are known. Moreover, it is sometimes difficult to prove definitely that the deposit has originated in this manner, in other words whether the copper sulphide has crystallized from fusion, or has been deposited from solution. The criteria that may be used include: (1) primary intergrowths of sulphides and silicates, (2) inclusions of sulphides in silicates, (3) corrosion of silicates by sulphides, if the latter crystallized later, and (4) absence of hydrothermal effects. Metamorphism may sometimes obscure the original characters of the ore body.

The deposits of this class fall into two groups, viz. 1, those representing crystallizations from the magma, with the sulphides and silicates intergrown, and 2, bodies of comparatively pure sulphides, which are believed by some to represent injections.

Those of the first group usually show pyrrhotite associated with the chalcopyrite, the best known example being the Sudbury, Ontario, deposits (described under Nickel). In the United States a small one has been described from Elkhorn, Mont., and another from Knox County, Me.[1] Of greater interest, however, is an occurrence found in Plumas County, California (48), where a norite-diorite carries bornite, chalcopyrite and magnetite associated with the silicates in such a way as to leave little doubt of their magmatic origin.

Another interesting deposit is found near Apex, Colo. (50), and consists of primary bornite and chalcopyrite, intergrown with silicates in monzonitic dikes.

Of the injected pyritic deposits, the best known cases perhaps are those of Röros and Sulitjelma, Norway, where great flat lenses, carrying pyrite, chalcopyrite and pyrrhotite are found in metamorphic schists, closely associated with metamorphosed gabbro, and sometimes in it. Their intrusive nature may be doubted by some.

Others are known at Bodenmais, Bavaria[2] and Falun, Sweden.[3]

### Contact—Metamorphic Deposits

Some of the most important copper deposits of the world belong not only to this type, but are located in the United States. It should be pointed out, however, that the ores of some of these districts are not exclusively of this type, but include several others which are closely associated genetically. Moreover, while in some cases it was the true contact-metamorphic ores that were first worked at some of these localities, the other types are now the important sources of production. There are included under this heading also certain deposits, which have the proper mineralogic characters, but show no closely associated intrusive.

**United States.** *Bisbee or Warren District* (32, 34, 37). — This district, which contains the famous Copper Queen Mine, lies on the eastern slope of the Mule Pass Mountains (Fig. 183),

[1] Journ. Geol., XVI: 124, 1908.
[2] Weinschenk, Zeitschr. prak. Geol., 1900: 65.
[3] Sjögren, Internat. Geol. Cong., Stockholm, 1910, Guidebook.

but a short distance from the Mexican boundary. The section
at that locality involves strata from pre-Cambrian to Creta-
ceous age, with an important unconformity between the Carbon-
iferous and Cretaceous (Fig. 185). Prior to the deposition of



Fig. 183. — Map of Arizona, showing location of more important mining districts.
(*After Lindgren.*)

the latter the rocks had been broken by numerous faults (Fig. 184),
one of these, the Dividend fault, being specially prominent in
forming one boundary of the ore-bearing area. This was followed
by intrusions of a granite magma forming dikes, sills, or irregular
stocks, which have metamorphosed the Carboniferous limestones,
with the production of characteristic contact minerals.

The Carboniferous limestone forms a shallow basin, which is cut through by the Dividend fault. The principal ore bodies lie around the porphyry stock, and along faults and fissures where replacement of the limestone has occurred. Most of the
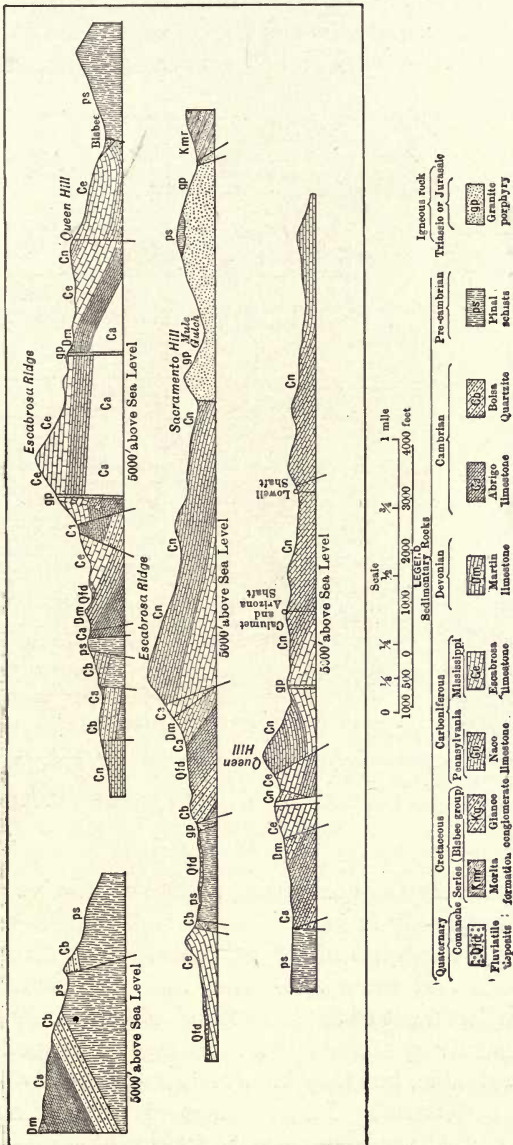


Fig. 184.— Geologic sections of Bisbee, Ariz., district. (*After Ransome, U. S. Geol. Surv., Prof. Pap. 21.*)

ore has been developed in the Carboniferous and Devonian lime-stones, though in recent years important bodies have been dis-covered in the Cambrian, and some even in the granite porphyry. The ore bodies form large, irregularly distributed, but rudely tabular masses. The ore consists of malachite, azurite, cuprite, and other oxidized copper minerals above, which pass at variable depths into unaltered sulphides; but between the two, or at least

| Description | Formation | Series | System |
|---|---|---|---|
| Red nodular shales with cross-bedded, buff, tawny, and red sandstones. A few beds of impure limestone near base. Unconformably overlain by fluviatile Quaternary deposits. | Cintura formation, 1,800 feet plus unknown thickness, removed by erosion. | Bisbee group (Comanche series) | Cretaceous |
| Thick-bedded, hard, gray, fossiliferous limestone. / Thin-bedded arenaceous fossiliferous limestones. | Mural limestone, 650 feet. | | |
| Buff, tawny and red sandstones and dark-red shales, with an occasional thin bed of impure limestone near top. | Morita formation 1,800 feet. | | |
| Bedded conglomerate with rather angular pebbles chiefly schist and limestone. Rests on irregular surface produced by erosion. | Glance conglomerate, 25 to 500 feet. Great unconformity, | | |
| Chiefly light-gray, compact limestone in beds of moderate thickness. Contains abundant fossils. Cut by granite-porphyry | Naco limestone, 3,000 feet plus unknown thickness, removed by pre-Cretaceous erosion. | Pennsylvania series | Carboniferous. |
| Thick-bedded, white & light-gray, limestone. Contains abundant crinoid stems. Cut by granite-porphyry. | Escabrosa limestone. 700 feet. | Mississippian series. | |
| Dark-gray fossiliferous limestone in beds of moderate thickness. Cut by granite-porphyry. | Martin limestone, 340 feet Unconformity. | | Devonian. |
| Thin-bedded, impure cherty limestones Cut by granite-porphyry. | Abrigo limestone, 770 feet. | | Cambrian |
| Moderately thick, cross-bedded quartzites, with basal conglomerate. Cut by granite-porphyry. | Bolsa quartzite, 430 feet Great unconformity. | | |
| Sericite-schists. Cut by granite and granite-porphyry. | Pinal schist. | | Pre-Cambrian |

0    500 1000    2000 Feet

FIG. 185. — Geological section at Bisbee, Ariz. (*After Ransome, U. S. Geol. Surv., Prof. Pap.* 21.)

never far from the effects of oxidation, masses of massive or sooty chalcocite are frequently found.

The primary ore consists of pyrite, chalcopyrite, with smaller bodies of galena and some sphalerite, and was deposited by metasomatic replacement of the limestone. As originally formed, the deposits usually contained too little copper to make them commercially valuable, but they have been subsequently enriched by secondary enrichment. Large bodies of primary sulphides of commercial grade have been recently developed.

The general relations of these ores to the intrusive porphyry and the contact silicates indicate that they are of contact-metamorphic origin.

In some cases an iron gossan has indicated an underlying ore body, but many others do not outcrop.



LEGEND

SEDIMENTARY ROCKS

Alluvial sands and gravels

Pinkard formation
(Shales and sandstones,
partly metamorphosed)

Modoc formation
(Heavy-bedded limestones
and dolomites)
(Coralliferous limestone,
lowest member)

Morenci formation
(upper shales)
(lower argillaceous limestone)

Longfellow formation
(cherty limestones
and lime shales)

METAMORPHIC ROCKS

Contact metamorphic limestone
and shale of Paleozoic age

Contact metamorphic lime-
stone now garnet, epidote
and magnetite
(mainly Modoc formation)

Metamorphic quartzite

IGNEOUS ROCKS

Quartz-monzonite-porphyry

Faults ▨ Shafts
Drainage

GEOLOGIC MAP OF THE VICINITY OF MORENCI,
ARIZONA

1000    0    1000    2000 feet

Fig. 186. — Geologic map of vicinity of Morenci, Ariz.   (*From Weed.*)

In 1914 the average copper recovery of the Bisbee ores was about 5.4 per cent and the average precious metals value about $1.35 per ton of ore.

*Clifton-Morenci District* (33). — The copper deposits of this district are located at Morenci (Fig. 183) and Metcalf in eastern Graham County.   The ores were discovered in 1872, but remained undeveloped for a long time because of the fact that they were of too low grade, and too far from the railroads.

At the present time, however, these large bodies of low-grade ore
are utilized, most of the work being done by three large companies.

The geologic section involves the following :
Quaternary (Gila) conglomerate.
Tertiary flows of basalt, rhyolites, and some andesites.
Cretaceous shales and sandstones.    Several hundred feet thick.
Lower Carboniferous heavy-bedded pure limestones, 180 feet.
Devonian (?) shale and argillaceous limestone, 100 feet.
Ordovician limestone, 200 to 400 feet.
Cambrian (?) quartzitic sandstone, 200 feet.
Pre-Cambrian granite and quartzitic schists.
 Intrusions of granitic and dioritic porphyries of post-Cretaceous age
pierce all the older rocks, forming stocks, dikes, laccoliths, and sheets.

All of these rocks have been bowed up and subsequently
faulted by late Cretaceous or early Tertiary movements.
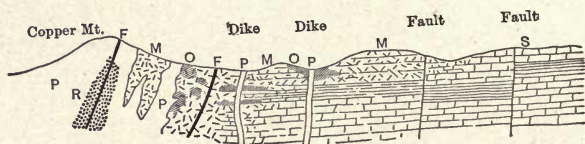


Fig. 187. — Section in Morenci, Ariz., district.   P, porphyry;   S, unaltered sedi-
    ments;  F, fissure veins;  M, metamorphosed limestone and shale;  O, contact-
    metamorphic ores; R, disseminated chalcocite.  (After Lindgren, Eng. and Min.
    Jour., LXXVIII.)
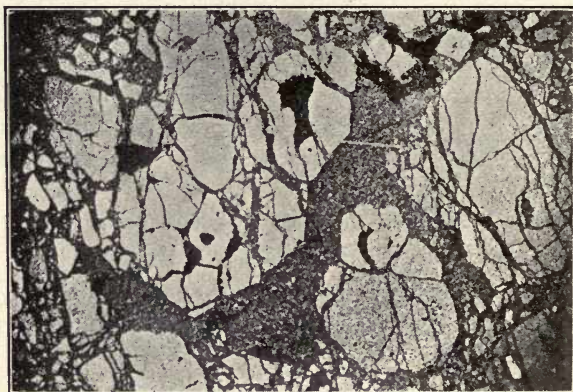


Fig. 188. — Photo-micrograph showing replacement in Clifton-Morenci ores.   Dark
    gray chalcocite, developing by replacement of pyrite (light gray).   The chalco-
    cite is accompanied by small amounts of microcrystalline quartz, sericite shreds,
    and kaolin.   Black areas represent open field.  (After Lindgren, U. S. Geol. Surv.,
    Prof. Pap. 43.)

Briefly stated, the distribution of the deposits of copper (Fig. 187) ore is practically coextensive with a great porphyry stock and its dike systems, the deposits occurring either in the porphyry or close to its contact, as well as along dikes of porphyry in some other rock.

The original ores were pyrite and chalcopyrite, of too low grade to be workable, but they have since become so by a process of secondary enrichment. No ores were formed before the porphyry intrusion.

Where the latter is in contact with the granite and quartzite,
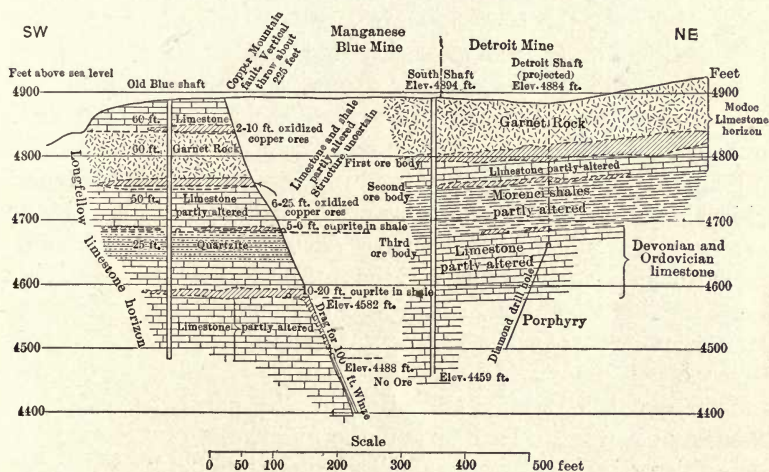


FIG. 189. — Vertical section of ore body in Clifton-Morenci district, showing contact metamorphosed limestone. (*After Lindgren, U. S. Geol. Surv., Prof. Pap.* 43.)

but little change is produced, but where the porphyry is found adjoining the limestones or shales, extensive contact metamorphism developed, resulting in the formation of large masses of garnet and epidote, especially in the Lower Carboniferous limestones.

Where alteration has not masked the phenomena, magnetite, pyrite, chalcopyrite, and zinc blende accompany the contact minerals.

The ore bodies in the limestone are often irregular, but more frequently roughly tabular, because of the accumulation of the minerals along the stratification planes, or walls of dikes.

In many parts of the district the copper occurs in fissure veins which cut porphyry, granite, and sedimentary rocks, and were

probably formed shortly after the consolidation of the porphyry. These in the lower levels carry pyrite, chalcopyrite, and sphalerite, but no magnetite. Surface leaching of these veins has often left limonite-stained, silicified porphyry outcrops.

Accompanying these veins, and of more importance commercially, are often extensive impregnations of the country rock. These disseminated deposits in the highly altered porphyry are leached out above, but lower down show a zone of pyrite and chalcocite, which does not usually extend below 400 feet.

Most of the copper in the district is obtained from concentrating ores containing chalcocite in altered porphyry. In 1914 the yield of copper from the concentrating ores was 1.65 per cent, while the smelting ores gave an average yield of 4.7 per cent.

The precious metal content is so low that much of the output of this district is not refined electrolytically unless the copper is not pure enough to put on the market.

The intrusions of porphyry produced strong contact metamorphism in the shales and limestones of Paleozoic age, resulting in the contemporaneous and metasomatic development of various contact silicates and sulphides,[1] the contact zone thus receiving large additions of iron, silica, sulphur, copper, and zinc, substances unknown in the sedimentary series away from the porphyry.

Subsequent to the solidification of the porphyry, extensive fissuring occurred in both it and the sediments, resulting in the deposition of quartz, pyrite, chalcopyrite, and zinc blende in the fissures and by replacement of the wall rock. These are low in copper, but there is a close relation between the veins and contact deposits because of the similarity of their metallic contents, and of the similar development of tremolite and diopside where limestone forms the wall. The extensive impregnation of the porphyry also occurred at this time. Subsequent exposure of the deposits by erosion permitted the entrance of surface waters which was followed by weathering and secondary enrichment.

*Bingham Cañon, Utah* (101, 102). — This camp, which is the leading copper-producing locality of Utah, is situated in the north-central part of the state, on the eastern slope of the Oquirrh Mountains, 20 miles southwest of Salt Lake City.

The rocks of this area include a great thickness of Carbonif-

[1] Garnet, epidote, diopside, etc., pyrite, magnetite, chalcopyrite and sphalerite.
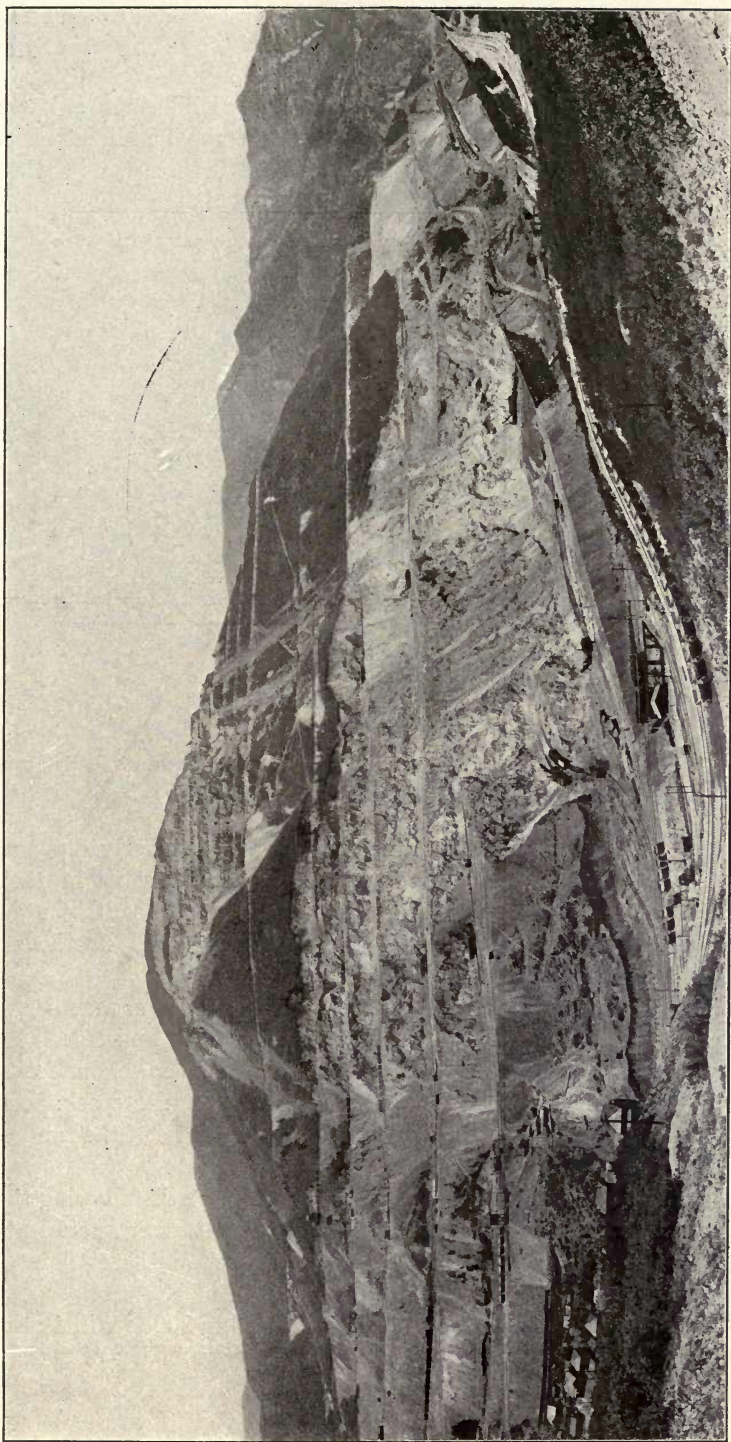
PLATE LI. — Utah copper mine, Bingham, Utah. Showing great body of monzonite porphyry which is being worked for its copper contents. (Cut loaned by Amer. Inst. Min. Engrs.)

(581)

erous sedimentary formations, which are divisible into a lower member of massive quartzite with several interbedded limestones, and an upper member of quartzite with black calcareous shales, sandstones, and limestones.
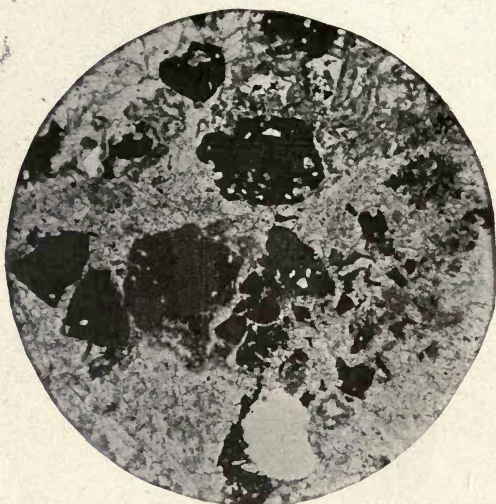


FIG. 190.—Thin section of altered porphyry, from Clifton-Morenci district, containing grains of pyrite surrounded by chalcocite (both black). ×18.

The sediments, though showing in general a northerly dip, and northeast-southwest strike throughout the region, vary in their strike from east-west on the western slope to north-south on the eastern, so that they form a synclinal basin, with northward pitch.

The whole series of sediments, but especially the lower member, is pierced by an igneous intrusion, forming dikes, sills, and laccoliths. Prominent among these are two large areas of monzonite, one forming an irregular laccolith, the other a broad irregular stock. An extensive latite flow, outcropping on the eastern slope of the ranges, covered some of the sediments and older intrusives.

There has been fissuring at several different periods following the igneous intrusion, but in most cases displacement along these fractures does not exceed 150 feet. The northwest-southeast fissures carry the most important lead-silver ores.

The limestones of the lower member, averaging 200 feet in thickness, have been highly marbleized, and carry large bodies of copper

PLATE LII



FIG. 1. — Smelter of Arizona Copper Company, Clifton, Ariz. (*After Church, Min. Mag., X.*)



FIG, 2. — View of Bingham Cañon, Utah. (*After Keith, U. S. Geol. Surv., Prof. Pap. 38.*)

(583)

ore, and the calcareous carbonaceous shales of the upper member sometimes carry it as well.

In many cases the ore is closely associated with the intrusives.

Two types of copper deposits are recognized, viz.: (1) great tabular replacement masses in limestone, lying roughly parallel with the bedding, and showing sometimes an extent of several hundred feet along the strike, as well as a thickness of even 200 feet; (2) disseminations in a large monzonite laccolith, especially in the fractured, fissured, and altered portions of the same.

The contact replacement deposits have been important ones in the past, but the enormous bodies of low-grade disseminated ore in the monzonite are now the most important (Pl. LI).

The limestone ores consist of primary pyrite and chalcopyrite, enriched in some cases by chalcocite and tetrahedrite. Quartz is the chief gangue mineral, but as might be expected in a contact deposit, garnet, epidote, tremolite, specularite, pyrrhotite, sphalerite, galena, etc., are also present.

The primary ore of the disseminated type consists of grains and veinlets of pyrite and chalcopyrite, distributed through both
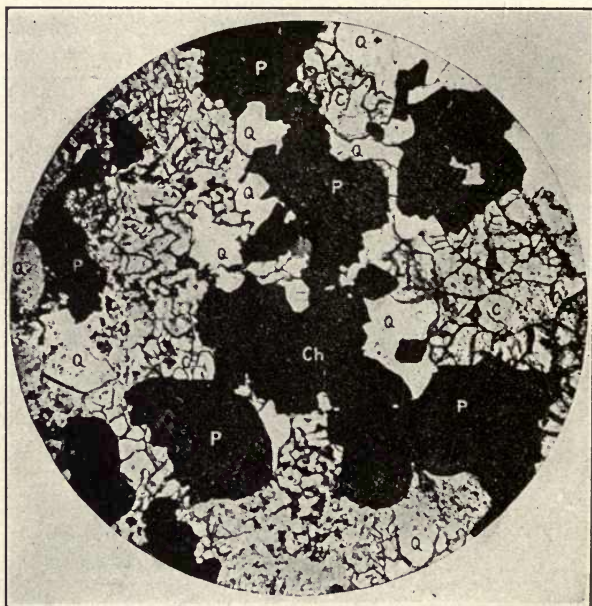


Fig. 191. Section showing replacement of limestone by pyrite (*P*) and chalcocite (*Ch*). Quartz (*Q*). (*After Boutwell, U. S. Geol. Surv., Prof. Pap.* 38.)

shattered and altered monzonite porphyry and quartzite. The commercial ore is due to secondary enrichment, and the zone containing it underlies the leached or partly leached capping, and overlies the primary ore. In this ore zone, whose average thickness is about 165 feet,[1] the secondary sulphides are covellite and chalcocite. The average thickness of the capping was 115 feet.

The theory of origin advanced by Boutwell is that the quartzites and limestones were intruded by the monzonite in Mesozoic or early Tertiary times, producing contact metamorphism of the limestone and replacing it with sulphides.

After the upper portion of the monzonite intrusion was partly cooled, the inclosing rocks were fractured by northwest-southeast fissures, along which there ascended heated aqueous solutions from the deeper, uncooled portions of the magma. These solutions not only altered the fissure walls, but deposited additional metallic sulphides, thus enriching the limestones as well as altering the monzonite by the addition of copper, gold, silver, pyrite, and molybdenite.

In 1914 the ore treated at the mills of the Utah Copper Company had an average copper content of 1.425 per cent, with an average recovery of 66.04 per cent.

*Ely, Nevada* (79, 81). — This district, although of recent development, promises to become of great importance. The copper belt, which lies 6 miles west of Ely, in White Pine County (Fig. 232), is about one mile wide and six miles long extending in an east-west direction.

It lies in a pass through the Egan Range, along what used to be a route to Eureka, Nevada.

The section there involves the following formations: —

| | |
|---|---|
| Ruth limestone | |
| Arcturus limestone | 1000 feet |
| Ely limestone, Carboniferous | 1500 feet |
| White Pine shale ⎫ Devonian | 1000 feet |
| Nevada limestone ⎭ | 1000 feet |

The sediments which have a gentle dip are cut by a coarse-grained quartz monzonite, which has effected only a limited amount of alteration in the adjacent limestone, producing some garnet rock and chalcopyrite.

There are present also dikes of porphyry and rhyolite lavas, the

[1] On property of Utah Copper Company.

latter resting on the uneven limestone surface (Fig. 192), but these eruptives bear no genetic relation to the ore.

Of importance in this connection are the monzonite intrusions, which carry ore. The ore, consisting of pyrite and chalcocite, is disseminated through the much altered and shattered monzonite porphyry and there is a sharp line of separation between the gossan and unoxidized bluish white rock containing the grains of pyrite and chalcocite. The oxidized zone on the average extends to a
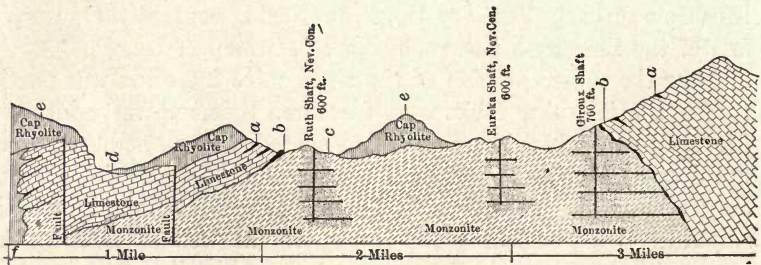


Fig. 192. — Section of Ely, Nev., district. (*From Weed.*)

depth of 100 to 150 feet, while a thickness of ore ranging from 190 to 280 feet has been determined.

Some of the ore bodies are of great size, that at the Ruth mine having a width of 50 to not less than 250 feet, and being developed for a length of not less than 900 feet.

Lawson believes that the ore bodies have resulted from a leaching of secondary ores in the oxidized zones and that the only primary ore now known is the chalcopyrite in the garnet rock occurring beneath the quartz " blouts." These latter are masses of quartz occurring mainly along the contact, and formed by the replacement of both limestone and porphyry with silica which was leached out of the porphyry by carbonated waters.

The ores are worked in part as open cuts (Pl. LIII, Fig. 2), and the average copper content of those mined in 1914 was 1.483 per cent.

**Other Deposits.** — Among the other deposits, yielding copper ores in part or wholly of the contact metamorphic type may be mentioned those of the following districts; Santa Rita, N. M. (85); Yerington, Nev. (78, 80); Silver Bell, Ariz. (40). The first named of these is becoming important chiefly on account of its great disseminated deposits in highly altered and shattered sedimentary and intrusive rocks, in which the copper occurs largely native or as the oxide, although chalcocite is by no means uncommon.

PLATE LIII



FIG. 1. — View looking northeast from the Eureka ore pit of the Nevada Consolidated Copper Company, Ruth, Ely district, Nev. (*D. Steel, photo.*)
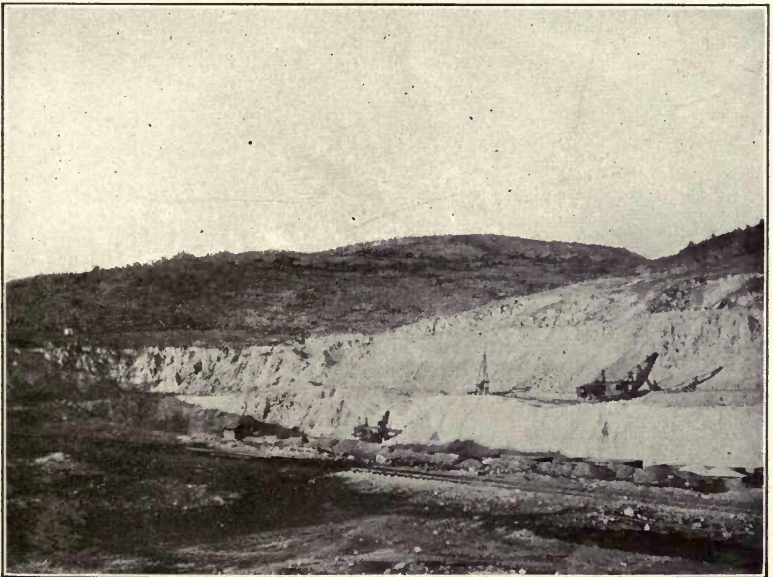


FIG. 2. — South end of the Eureka ore pit, Ruth, Nev. The hills in the background are limestone at the top and porphyry at the base. (*D. Steel, photo.*)

**Alaska.** *Ketchikan District* (26, 28). — The most important ore bodies are contact-metamorphic ones occurring in irregular masses from 10 to 250 feet in dimensions, along the contacts of the intrusive rocks, usually with limestones, the ore composed mainly of chalcopyrite, magnetite, pyrrhotite, and pyrite in a gangue of amphibole, orthoclase, epidote, garnet, and calcite.
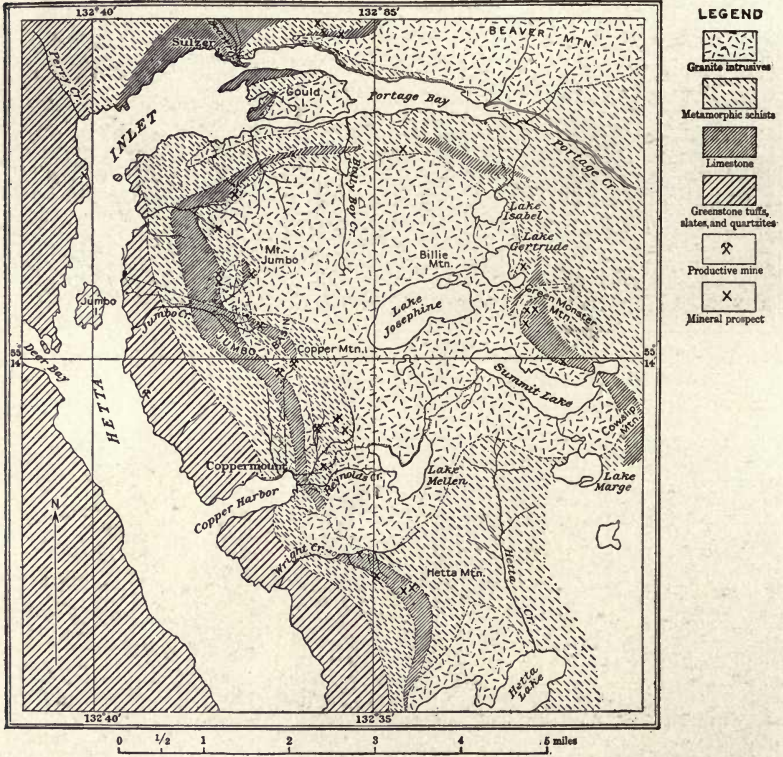


FIG. 193. — Geologic map of Copper Mountain Region, Prince of Wales Island, Alas. (*After Wright, U. S. Geol. Surv., Bull.* 379.)

In addition to these there are lode deposits in shear zones, vein deposits in fissures, and disseminated ores.

The ores mined are somewhat low in grade, with a little gold and silver, but high in iron and lime, and form a desirable flux for smelters of Tacoma and British Columbia.

At Copper Mountain in the Hetta Inlet district (Fig. 193) the ores are (1) contact deposits occurring between granite and lime-

PLATE LIV
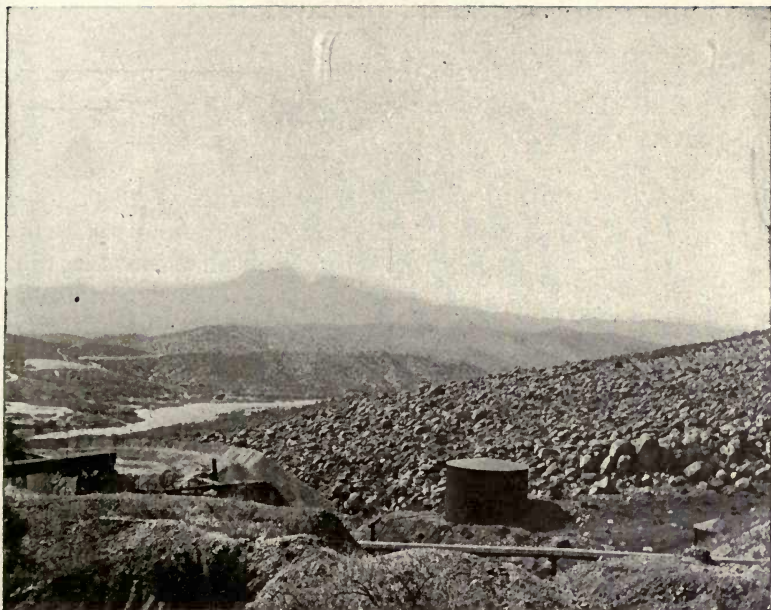


FIG. 1. — View from open cut of Old Dominion mine, Globe, Ariz., looking towards Miami. Rocky surface beyond tank, weathered dacite; low ridges beyond creek, Gila conglomerate. (*H. Ries, photo.*)



FIG. 2. — Open cut, Mother Lode mine, near Greenwood, Brit. Col. Right wall, limestone; left wall, contact metamorphosed rock. (*H. Ries, photo.*)

stone or schist, and (2) vein or shear zone deposits, occurring along the bedding planes of the greenstone schist and quartzites. The contact zone is of variable width and is broadest in the limestone.

**Canada** (117, 118).  *Boundary District, British Columbia.* — Copper ores, which in many respects possess the characteristics of
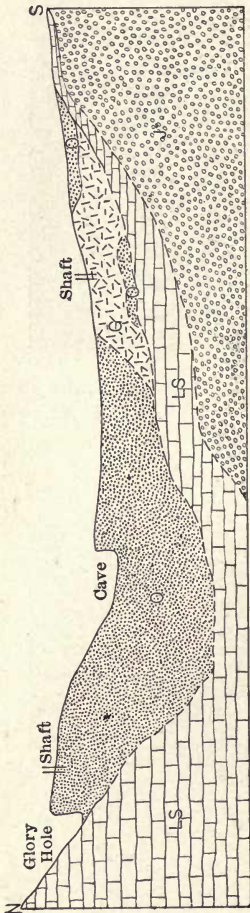


FIG. 194. — Section through ore deposit at Phoenix, Brit. Col. O, ore; LS, limestone; J, jasperoid; G, lightly mineralized or barren gangue. (After Le Roy, Can. Geol. Surv., Mem. 21, 1912.)

contact-metamorphic deposits, are found in the Boundary District of southern British Columbia.   In the Phoenix area the geologic section involves the following formations:

Tertiary.   Pulaskite porphyry, augite porphyrite and trachyte flows; conglomerate, sandstone and shale.

Jurassic.   Granodiorite; a batholith, probably underlying Phoenix.

Carboniferous.   Rawhide formation.   Argillites.

Brooklyn formation, with: (1) Mineralized zone of garnet, epidote and ore;   (2) zone of jasperoids, tuffs, argillites and altered basic intrusives; and (3) crystalline limestone.

Knob Hill group.   Massive breccias, tuffs, and cherts, with argillites and limestone. Crustal disturbances have obscured the relationships of the different formations.

The lenticular ore bodies lie in basin-shaped troughs in the jasperoid zone and crystalline limestone (Fig. 194).   The average ore, which is self-fluxing, ranges from 1.2 to 1.6 per cent copper, and the metallic minerals, which are disseminated through the gangue, along fracture and cleavage planes (Fig. 195), consist of chalcopyrite, pyrite, specular hematite and magnetite.   The gangue minerals are epidote, garnet, actinolite, quartz, calcite and chlorite.

At Deadwood (117) the geological formations and ores are similar to those occurring at Phoenix.  Fig. 196 shows a section



Fig. 195. — Thin section of crystalline limestone containing branched veinlet of sulphides, from Phoenix, B. C.    ×33.

across the Mother Lode ore body at Deadwood.  The ore here consists of a massive mixture of chalcopyrite, pyrite and mag-
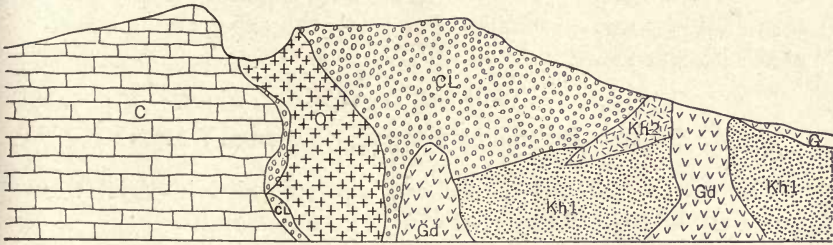


Fig. 196. — Section through Mother Lode ore body at Deadwood, B. C. O, ore; C, crystalline limestone, Brooklyn formation; Cl, mineralized contact metamorphic zone of C; Gd, granodiorite; Kh1, Knob Hill group, chert tuff zone; Kh2, Knob Hill group, jasperoid tuff zone; G, clay, sand, gravel.  (*After Le Roy, Can. Geol. Surv., Mem. 19.*)

netite, finely and uniformly distributed along fracture and cleavage planes in the gangue minerals, which consist chiefly of contact silicates.   The ore carries 1.1–1.3 per cent copper, and $1.00 gold and silver per ton.

*Whitehorse, Yukon Territory.* — These deposits are located
in southern Yukon Territory. They consist of contact metamor-
phic deposits in Carboniferous limestone near its contact with a
Mesozoic granite. The chief ore minerals are bornite and chal-
copyrite, with occasional tetrahedrite and chalcocite. Iron
sulphides are not abundant, but iron oxides are common and may
form separate masses. The non-metallic gangue is chiefly andra-
dite, augite, tremolite and calcite. The general average of
copper contents is 4 per cent, and gold and silver are present, but
not in large amounts (119).

**Mexico.** — The copper deposits of Cananea,[1] which are in part of the con-
tact metamorphic type, are well known. They have been developed in Pale-
ozoic limestones, by the intrusion of diorite porphyry and granodiorite, and
carry chalcopyrite, sphalerite, bornite, magnetite, hematite and galena, in a
gangue of contact silicates. Of greater importance, however, are the lodes
and disseminations in sericitized and silicified diorite porphyry. Other
interesting deposits occur at San Jose,[2] Matehuala [3] and Velardena.[4]

### Deposits Formed by Circulating Waters

This grouping includes deposits of the fissure vein or related
types which have been formed by cavity filling or replacement,
and is further subdivided into: (*A*) those deposited by ascending
thermal solutions, evidently of magmatic origin, and (*B*) those
deposited by waters, probably of meteoric character, and unassoci-
ated with igneous rocks.

### A. Deposits Formed by Ascending Thermal Waters

This group includes copper ore bodies formed in the lower
vein zone, and those deposited at intermediate depths.

**Lower Vein Zone.** — Copper veins or lodes carrying tourmaline
as a high temperature index mineral have been described from a
number of localities. In the United States the most important
deposit is that found in the Cactus mine of southern Utah. This
is a low-grade chalcopyrite-pyrite ore containing tourmaline and
occurring in a brecciated area of sericitized and tourmalinized

[1] Emmons, S. F., Econ. Geol., V: 312, 1910.

[2] Kemp, Amer. Inst. Min. Engrs., Trans. XXXVI: 178, 1905.

[3] Spurr, Garrey and Fenner, Econ. Geol., VII: 444, 1912.

[4] Spurr and Garrey, *Ibid.*, III: 688, 1908.

post-Paleozoic monzonite. Other deposits are known at Copperopolis, Ore.,[1] and Meadow Lake,[2] Calif.

In Canada, a somewhat important example of this type occurs at Rossland, Brit. Col. (115). Here the Carboniferous sediments have been cut by a series of extrusives and intrusives ranging from Triassic to Tertiary in age, with several periods of deformation and two of mineralization. The ores occur as replacements along fissures and sheeted zones, chiefly in the augite-porphyrite and monzonite, with pyrrhotite and chalcopyrite as the ore minerals in a gangue of altered country rock. Hydrothermal alteration of the wall rock is marked, the high temperature conditions being indicated by the development of biotite, and also some tourmaline, garnet, wollastonite and epidote.

The values run about .7–3.6% Cu; .4–1.2 oz. Au; and .3–2.3 oz. Ag.

**Deposits of the Intermediate Vein Zone.** — These consist usually of deposits of the fissure vein type, but sometimes form disseminations, etc. They include a large number of very important deposits.

**United States.** *Montana* (70–77). — The mining camp of Butte is of importance and interest both on account of the size and extraordinary richness of its deposits, all of which have combined to make it the greatest copper-producing camp of the world.

Up to August, 1913, it had yielded in round numbers, 6,000,000,000 pounds copper; 260,000,000 ounces gold; 1,250,000 ounces silver; and a large but not definitely known tonnage of zinc (74).

Butte lies on the western border of the Boulder batholith, the latter having a width of 75 miles and a length of over 100 miles.

Lying between the main range of the Rocky Mountains on the east, and the Bitterroot Mountains on the west, the batholith seems to have been intruded in the Eocene (?) after a period of folding and thrust faulting, and without causing any doming.

Associated with the batholith are a number of fissure veins, one type of which is found only in the Butte district, and therefore concerns us here. The rocks of the Butte district include: (1) Granite or quartz monzonite, the Butte granite, much jointed, and hence permeable to solutions; (2) Aplite, in irregular bodies

[1] Lindgren, U. S. G. S., 22d Ann. Rept., Pt. 2, p. 551.
[2] Lindgren, A. J. S., XLVI: 201, 1893.
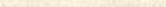
FIG. 197. — Map of eastern part of Butte, Mont., district, showing distribution of veins, and geology. (*U. S. Geol. Surv.*)

and dikes, especially in the northwestern portion of the district; (3) Quartz porphyry dikes, roughly parallel in an east-west direction, and following the earliest vein system; (4) Rhyolite, of intrusive and extrusive character, especially in west and northwest part of district, its offshoots cutting both the copper and silver veins; (5) Andesite, of pre-Tertiary age and bearing no relation to the ores.

The granite is cut by many faults, which are hard to detect, and which are often mineralized. Fissures are common in the batholith, and there are two main series, striking east-west, and northwest-southeast, corresponding broadly to the two most important fracture zones of the district.

There have been identified six distinct fissure systems, which cut the granite, aplite and quartz-porphyry, but not always the rhyolite, and displacement is found along some. These systems are: (1) Anaconda or oldest, striking east-west and carrying important ore bodies. (2) Blue, earliest fault fissure, striking in general N. 55° W., and carrying ores of great value; (3) Mountain view breccia fault, striking N. 75° E. and carrying ore; (4) Steward, striking northeast-southwest, and not usually ore bearing; (5) Rarus fault, a complex fissure of variable northeast strike, and dipping about 45° northwest, with fragmental ore dragged in from other veins (Fig. 198, 200); (6) Middle faults, non-orebearing; (7) Continental fault, striking north-south on eastern edge of district, of recent age, with 1500 feet vertical displacement, and Butte on down-throw side (Fig. 198).



Fig. 198.— Generalized cross section of Butte district, Montana. (After Sales, Amer. Inst. Min. Engrs., XLVI.)

The granite is much altered by hydrothermal metamorphism, especially in the Anaconda Hill area, so that it is now a mass of pyrite, sericite and quartz near the veins.

The ore deposits are fissure veins, formed by the filling of fissures and replacement of the country rock, the oldest fissures having been continuously mineralized.

Within the Butte district there is: (1) A main or central copper zone, free from zinc and manganese; (2) An indeterminate intermediate zone, with copper predominant, and with some sphalerite, rhodochrosite and rhodonite; (3) An outer peripheral zone, without copper, but filled chiefly with quartz, rhodonite, rhodochrosite, sphalerite, and pyrite and which is silver bearing.

In the central or copper zone, the order of relative abundance of the copper sulphides is (74); chalcocite, enargite, bornite, chalcopyrite, tetrahedrite, tennantite and covellite. Quartz and pyrite form the gangue.

Sales (74) gives the following details regarding the sulphides: Chalcocite has supplied 60% of the Butte copper to date, occurring
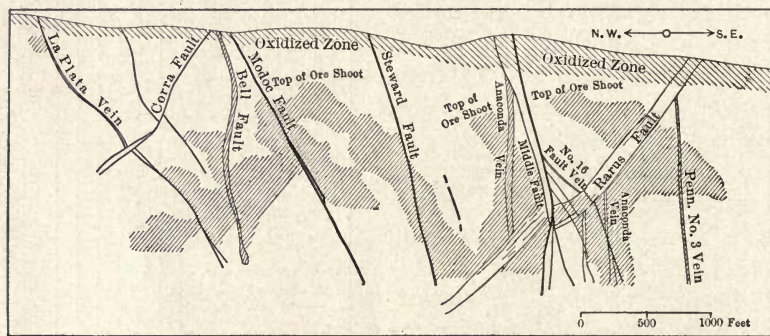


Fig. 199. — Longitudinal vertical projection of the High Ore Vein, a member of the Blue Vein system, showing distribution of the ore shoots. (*After Sales, Amer. Inst. Min. Engrs., XLVI.*)

in veins of all ages, and at all levels down to below 3000 feet. Once regarded entirely as a downward secondary enrichment product, it is now divisible into, (*a*) sooty secondary chalcocite, forming a dull black coating on pyrite and other sulphides or replacing pyrite, sphalerite, enargite and chalcopyrite; (*b*) massive chalcocite, considered as primary because: (1) it is abundant in the depest levels (over 3000 feet); (2) its intimate association with bornite, enargite and pyrite show it to be contemporaneous; (3) it occurs at all depths without relation to topography; (4) it is found in dry veins, at deep levels, cut by the older faults; (5) it replaces granite at deep levels; and (6) there is no evidence of present replacement except in the sooty material.

Enargite is of wide vertical and lateral distribution, of comparatively old mineralization, and usually primary but sometimes secondary.
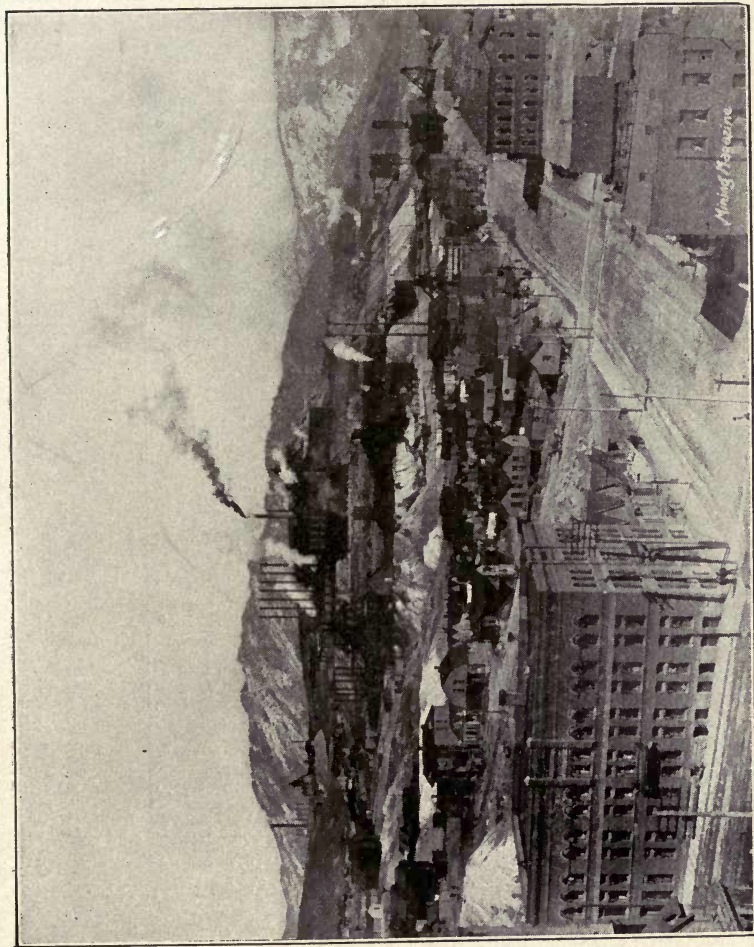
PLATE LV. — View of Anaconda group of mines, Butte, Mont.   (*After Weed, Min. Mag., X.*)

(597)

Bornite is primary, of all ages, and at all levels.    Chalcopyrite is unimportant and chiefly primary, so also is covellite.

The vein outcrops are usually barren of copper, and while the oxidation depth is variable, it averages 250 feet.

In the silver zone, quartz and manganese are the common gangue materials, the veins showing on the surface as ledges of manganese-stained quartz.
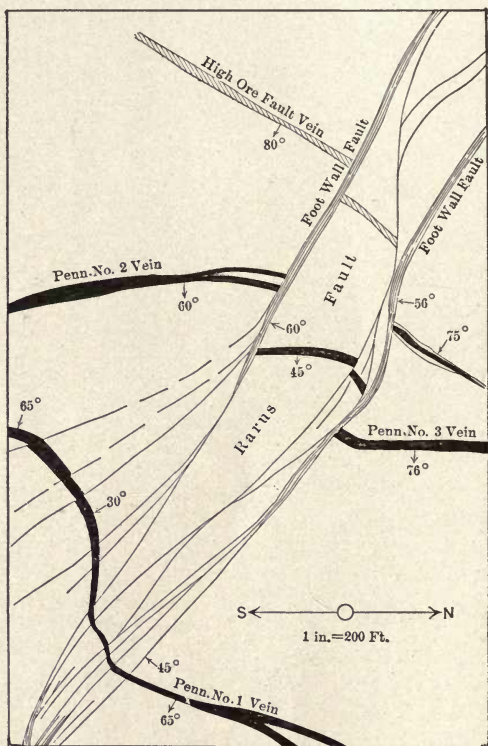


FIG. 200. — Plan of 500-ft. Level of Pennsylvania Mine, showing effect of Rarus fault on different veins.    (*After Sales, Amer. Inst. Min. Engrs., XLVI.*)

The Butte ores have been derived primarily from igneous rocks, the quartz porphyry having perhaps opened up the way for the ore-bearing solutions, the elements carried by the latter having included $SiO_2$, S, Fe, Cu, Zn, Mn, As, Pb, Ca, W, Sb, Ag, Au, Te, Bi, and K.

In the central part of the area, the more highly heated and acid solutions deposited the copper ores, while the zinc, manganese

and lead were precipitated toward the periphery where the temperature was lower, and the solutions more alkaline from reactions with the granite.

In 1914 the smelting ores averaged 4.97 per cent copper, and yielded about 28 per cent of the output, while the concentrating



BUTTE GRANITE    BLUEBIRD GRANITE    QUARTZ PORPHYRY    RHYOLITE

FIG. 201. — Geologic map of western half of Butte district. (*U. S. Geol. Surv.*)

ores averaged 2.04 per cent. Silver averaged 1.83 ounces, and gold .059 ounce.

The history of this mining camp is full of interest. Butte in 1864 was a gold camp, but difficulties in working the gravels directed attention to the mineral-vein outcrops, and unsuccessful attempts were made to work their copper and silver contents, so that it was not until 1875, following a period of quiescence, that the discovery of rich silver ore in the Travona lode revived the mining industry of Butte. In 1877 several silver mines were opened, followed by others; but this did not last many years, for with the drop in the price of silver many mines closed, although one, the Bluebird, had produced 2,000,000 ounces of silver from 1885 to 1892.

The copper mines were worked to only a limited extent at first, and the industry did not assume permanance until 1879–1880, when matte smelting was introduced. In 1881 the Anaconda mine, which was first worked for silver, began to show rich bodies of copper ore, and since then the output of copper has steadily increased, there being a number of large smelting plants located at Anaconda and Great Falls.

*Globe-Miami, Arizona District* (35, 36, 41). — This district became well known through the Old Dominion mine at Globe, long before the now more important ores at Miami were developed.

The formations include a pre-Cambrian crystalline complex, the Final schist cut by granitic intrusives. Overlying these unconformably is a thick series of Paleozoic sediments including conglomerates, quartzites, shales and limestones. In Mesozoic times probably there followed an intrusion of diabase and granitic rocks, and then after an erosion interval Tertiary volcanics and sediments, the Gila conglomerate being prominent among the latter. Faulting of both pre- and post-Tertiary age is known.

Around Miami the great disseminations of chalcocite, in the Pinal schist near the Schultze (Mesozoic) granite are of importance. The original ore was a sulphide of iron and copper, which in its upper part has undergone leaching and oxidation, accompanied by secondary enrichment of the ore below. The section therefore shows a leached capping, followed by an irregular zone of oxidized ore, and this in turn by a secondary enrichment zone, showing grains and stringers of pyrite and chalcopyrite replaced by chalcocite. The ore-bearing solutions are believed to have come from the Schultze granite, and resulted not only in deposition of ore, but also a more or less complete silicification of the schist.

These disseminated ores represent such an important type in the West to-day that a few figures showing their low grade, extent, etc., as explanatory of their working at a profit, may be given.

The estimated ore reserves of the Miami Copper Company at Miami [1] on January 1, 1915, were 19,500,000 tons of sulphide averaging 2.4 per cent copper, and 17,000,000 developed tons, averaging 1.21 per cent copper, also 6,000,000 tons oxidized or partly oxidized ore averaging 2 per cent copper. The copper per cent in ore milled averaged 2.28 per cent. The mill extraction was 69.93 per cent, and the concentrates contained 39.31 per cent copper.

[1] The Inspiration Company near by has similar deposits.

In the Globe section of the district the ore bodies occur as lenticular replacements in limestone, and as fault lodes, or fissure zones in diabase.

Much of the limestone ore thus far extracted has been oxidized, but that in the diabase is enriched material. Some bodies of primary ore of commercial value have also been developed. In 1914 the average copper contents of the smelting ore was 8.28 per cent; concentrating ore 4.69 per cent; and silica lining, 3.12 per cent. The gold and silver run low, but are saved.

*Mineral Creek or Ray district, Ariz.* (42). — The geology here is similar to that at Miami. The deposits (Figs. 202 and 203)
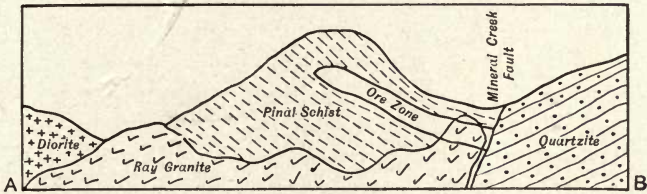


Fig. 202. — Vertical section (A B, Fig. 203) showing ore body in schist, Mineral Creek district, Arizona. (*After Tolman, Min. and Sci. Press, XCIV.*)

are found in sedimentary rocks associated with faults and fissures, or as disseminations in the Pinal schist and granite, this second type being the more important. In 1914 the ore concentrated averaged 1.76 per cent copper. At the beginning of 1915 the ore reserves were estimated at 74,765,789 tons, averaging 2.214 per cent copper.

Another interesting district of the disseminated type is that of the Burro Mountains in New Mexico (86).

*Virgilina, Va.* — This region is of interest especially because of the



Fig. 203. — Geologic map of a portion of the Mineral Creek, Ariz., copper district. (*After Tolman, XCIX.*)

relationships of the primary sulphides found within the ore body.

The rocks are greenstone and sericitic schists, intruded in places by granite and gabbro. The schists have been derived from a

series of andesites and quartz porphyries with a preponderating amount of tuffs. The fissure veins, which occur in the chloritized and epidotized andesite, contain primary bornite and chalcocite, in a gangue of quartz, and subordinate calcite or epidote. The ore-bearing solutions are thought to have come from the granite,
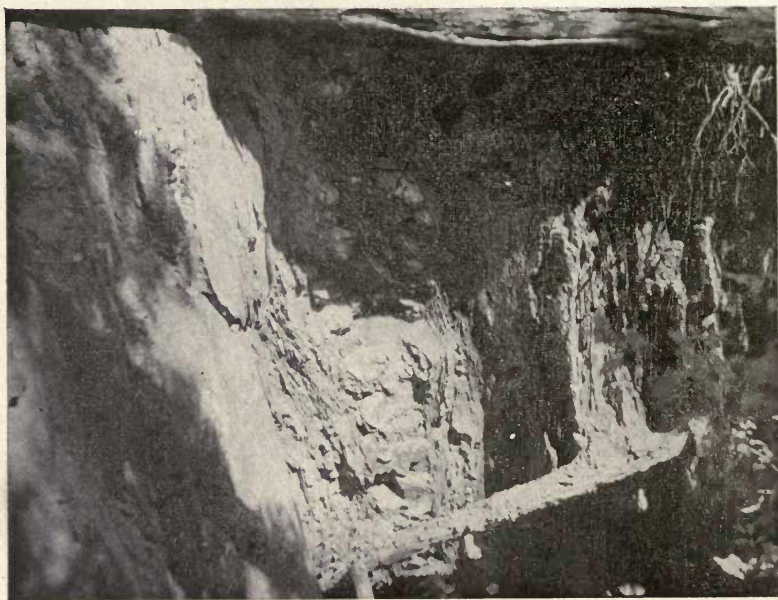


Fig. 204. — Quartz vein carrying copper sulphides, between walls of chloritized and schistose andesite, Virgilina, Va. (*H. Ries, photo.*)

whose intrusion postdates the development of schistosity in the volcanics.

**Alaska.** *Copper River District* (23, 24). — This region, which is situated some distance from the coast, and hence difficult of access, has been but little developed, although transportation facilities have now been provided.

The primary ore is chiefly chalcocite with some bornite replacing Triassic limestone near a greenstone. The ore is chiefly chalcocite, but other sulphides as well as oxidized ores occur. In the Bonanza mine on the Chitina River, the ore consists of a solid mass of chalcocite in limestone, averaging about 60 per cent copper, with about 22 ounces of silver to the ton.

**Foreign Deposits.**— Among those which deserve mention here is the Rammelsberg deposit of the northern Hartz district of Germany, interesting not only historically, but also because of its disputed origin. The ore body lies more or less conformably in strongly folded Devonian slates, and has a variable thickness. The ore minerals are chalcopyrite, pyrite, arsenopyrite and sphalerite in a gangue chiefly of barite. Banding is present, and the ore minerals excepting pyrite are drawn out into streaks. Bergeat [1] and Klockmann [2] thought it a sedimentary deposit, while Vogt [3] and others believed it to have been deposited from solutions of magmatic origin. Lindgren and Irving [4] called it a bedded vein, in part conformable to the surrounding slates, and exhibiting the structure of a dynamo-metamorphic rock. They agreed with Vogt as to the source.

At the Braden mines in the Chilean Andes, the ore minerals are chalcopyrite, bornite, magnetite and sphalerite, with tourmaline, quartz, sericite, epidote, etc., occurring as lodes in andesite, at its contact with a tuff. The volcanics surround an ancient crater.

Chuquicamata, Bolivia, remarkable for its great masses of brochantite underlain by sulphides should also be mentioned. [5]

**Native Copper Deposits.**— Deposits of native copper occurring in basic volcanic rocks, especially those of basaltic character, form a widespread type. They are not strictly speaking the work of circulating waters, although the minerals are precipitated from solution. A noteworthy fact is the constant association of the copper with zeolites, calcite, quartz, epidote, etc., the ore and gangue minerals either filling the gas cavities or replacing the rock.

The igneous rocks are regarded by many as the source of the copper, analysis often showing a small percentage of this metal, and its concentration seems to be associated with the development of the zeolites, so that a theory proving the origin of one must include the other. It is therefore believed by some that the magmas erupted either on the ocean floor, or in bodies of fresh water, absorbed the water of these on cooling, and that this on mixing with magmatic exhalations broke up the copper silicate present, changing it to copper chloride. Iron silicates were similarly affected. These chlorides were then decomposed by silicates or even carbonates of lime, yielding native copper, ferric oxide and calcium chloride as shown by the following reactions:

$$2FeCl_2 + 2CuCl + 3CaSiO_3 = 2Cu + Fe_2O_3 + 3SiO_2 + 3CaCl_2.$$
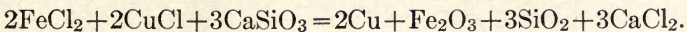
Widespread as native copper deposits of this type are, they are not all of economic importance. In North America, the Michigan

[1] Erzlagerstätten, p. 329, 1904.
[2] Berg und Hüttenwesen des Oberharzes, 1895, p. 57.
[3] Zeitschr. prak. Geol., 1894: 173.
[4] Econ. Geol., VI: 303, 1911.       [5] Min. Mag., IX: 36, 1913.

FIG. 205. — Generalized northwest-southeast section including Isle Royal and Keweenaw Point. (After Lane, Mich. Geol. Surv., Pub. 6, V. I. I, 1911.)
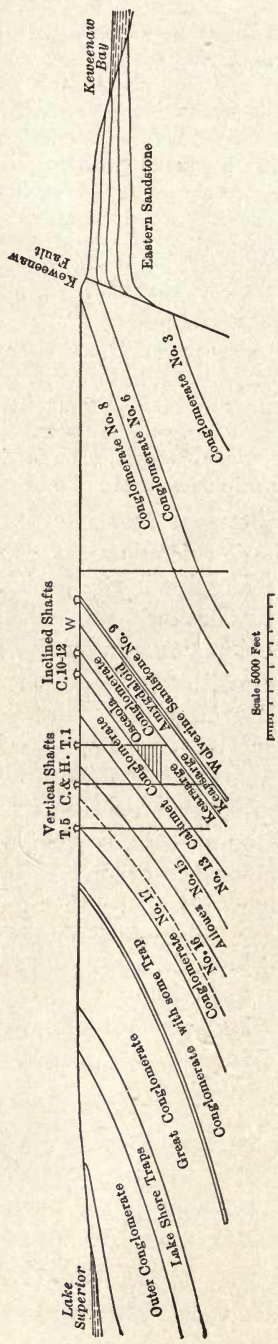


FIG. 206. — Section across the Michigan copper belt. (After Lane, same as Fig. 205.)

ones outrank all others. Some production has also been obtained
from the Triassic traps of New Jersey (82), and from those on the
Bay of Fundy, in Nova Scotia (115a). Other occurrences are
known in Oregon (92a), the White River region of Alaska (22),
and in Arctic Canada (114). In other countries they are known
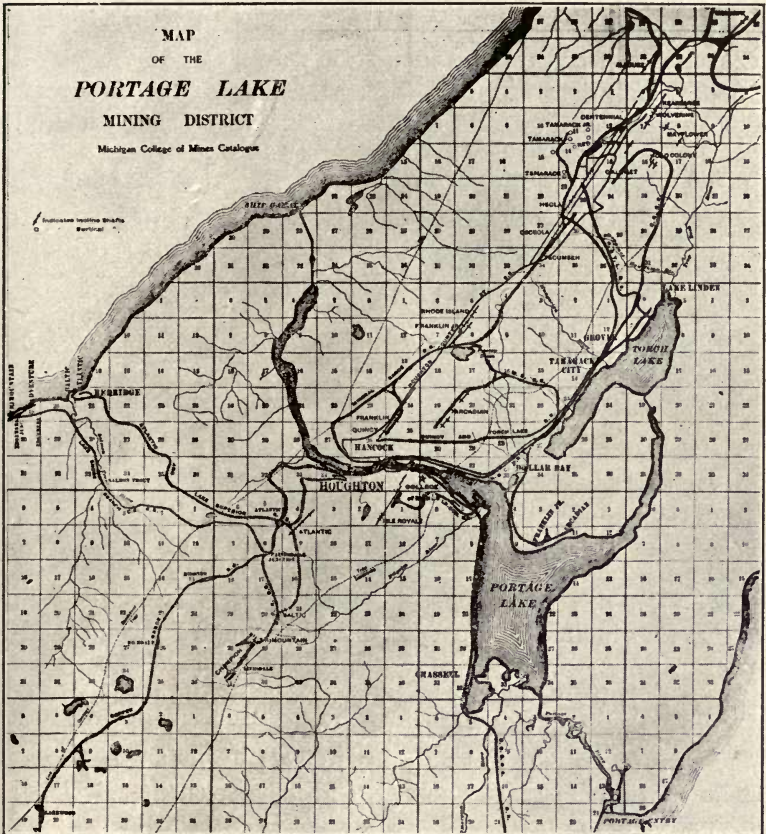


FIG. 207. — Map of a portion of the Michigan copper district, showing strike of
lodes.

in New Guinea,[1] Brazil,[2] the Transbaikal,[3] Norway,[4] Germany,
etc., but are not all productive.

[1] Beck, Lehre v. d. Erzlagerstätten, I: 345, 1909.
[2] Hussak, Centrbl. f. Min., 1906: 333.
[3] Beck, Zeitschr. prak. Geol., 1901: 391.
[4] *Ibid.*, VII: 12, 1899.

*Michigan* (63–68). — This region, which was discovered in 1830 by Douglas Houghton, has become one of the most famous, as well as one of the leading, copper-producing districts of the world.

The rocks of the region, known as the Keweenaw series, consist of interbedded lava flows, sandstones, and conglomerates, the latter being rounded fragments of igneous rocks, mainly reddish-quartz porphyry.

This series of beds, whose entire thickness may be from 25,000 to 30,000 feet, dips westward (Fig. 206) from 35 to 70 degrees, being overlain conformably on the west by sediments, while on



▨ Copper  ▨ Amygdaloid  ⊞ Trap
AMYGDALOID COPPER LODE IN QUINCY MINE
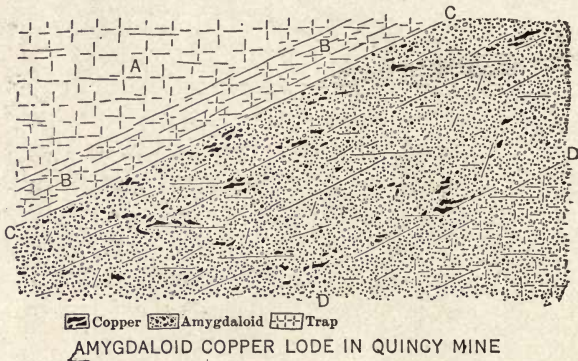
Fig. 208. — Section showing occurrence of amygdaloidal copper, Quincy Mine, Mich.   (*After Rickard, Eng. and Min. Jour., LXXVII.*)

the east they are faulted up against the horizontal Potsdam sandstones.

These beds form a belt 2 to 6 miles wide, which extends from Houghton to the end of the Keweenaw peninsula, and rises as a ridge from 400 to 800 feet above the lake (Pl. LVI).

The ore, which is native copper, and is occasionally associated with native silver, occurs (1) as a cement in the conglomerate of porphyry pebbles, or replacing the latter, (2) as a filling in the amygdules of the lava beds (Fig. 208), (3) as masses of irregular and often large size, in veins with calcite and zeolitic gangue.

The tilting of the beds has been accompanied by some slipping and cross faulting, and the presence of copper in cross joints and slip planes indicates later deposition.

The veins, which cut both the igneous and sedimentary rocks, have yielded much copper in former years, and the large masses obtained from them have made the region famous; but at the pres-
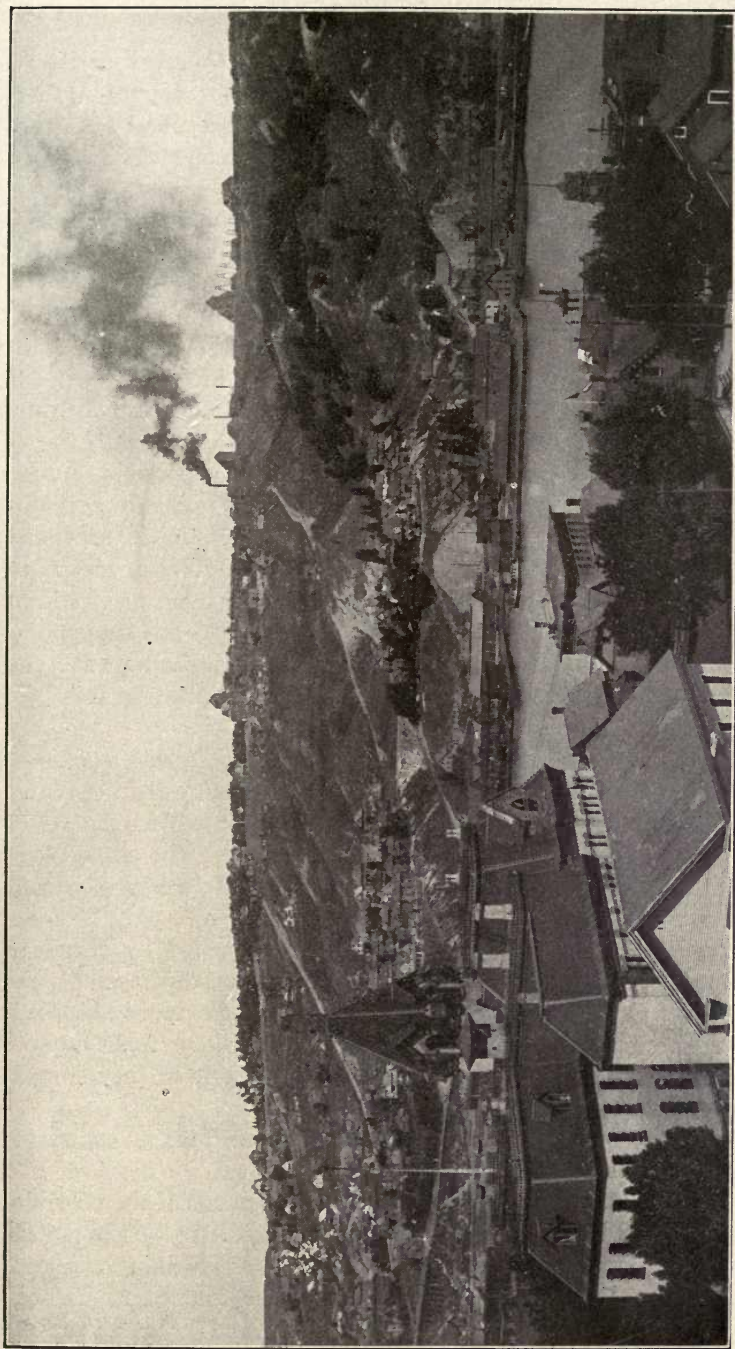
PLATE LVI. — View from Houghton, Mich., looking towards Hancock, and showing a portion of the ridge under which the copper deposits lie. (607)

ent time most of the production comes from the Calumet conglomerate, while the balance comes from two other copper-bearing conglomerates known as the Albany and the Allouez, and from the ashbeds and amygdaloids, whose gas cavities are filled with a mixture of native copper, calcite, and zeolites.

A curious and hitherto unexplained feature is the irregular distribution of the copper in the different beds, which may be due to the copper solutions being directed by certain joints or slip planes. Thus the Calumet conglomerate carries practically no ore outside of the Calumet and Hecla ore shoot, which is three miles long, 12–15 feet thick, and has been mined to a depth of 5000 feet.

Various theories have been brought forward to account for the origin of the copper ores in this region.

The diabase was looked upon by Pumpelly as a possible source of the ore, and since its extensive alteration was no doubt accompanied by the oxidation of protoxides of iron, this might account for the reduction of the copper mineral to the native or metallic condition, it being known that ferrous salts may precipitate metallic copper (1). More recently Lane (65, 66) has suggested that originally buried water has also been an important factor in concentration, but agrees that the final precipitation was by water working downward.

Lane has pointed out that the mine waters show a striking increase in chlorine with depth, in fact there is more than enough to satisfy the sodium present, and it is contained in relatively large amounts of calcium chloride. Moreover, the molecules of sodium chloride decrease steadily with depth, while those of calcium chloride increase.

He therefore suggests, and his views are backed by chemical experiments, that the basalt flows originally contained small percentages of copper; that while still heated they no doubt absorbed sea water charged with sodium chloride, and in later times atmospheric waters not containing any, but obtaining it as they seeped through the rocks.

These waters, rich in NaCl, migrated downward, taking copper in solution as copper chloride.

Reactions with the glassy base or original minerals of the volcanic rocks gave rise to the formation of sodium silicates, accompanied by precipitation of copper and formation of calcium chloride. Descending solutions from wide areas became concentrated along lines favorable to underground circulations, and hence shoots of

relative richness resulted. It is supposed that certain faults and slips guided these waters.

The theory, although reasonable and backed by laboratory experiments (5), may not be universally accepted, and some observers believe that these deep-seated waters with their peculiar composition are very likely of magmatic origin.

Although these deposits were worked in prehistoric times, as evidenced by copper implements and ornaments found in the mines, the famous Calumet and Hecla Mine was not opened up until 1846. In 1847 Michigan produced 213 long tons of the total United States production of 300 tons of copper. Since 1863 the annual output has exceeded 1000 tons and gradually and steadily increased up to 1905, when it reached 230,287,992 pounds. Since that year it has only exceeded it once, and has usually been less.

The ores from this district, which are known as Lake ores,[1] are all of low grade, but the deposits are of great extent and rather uniform mineralization, and this fact, together with the possibility of high concentration and low cost of refining, makes it possible to work these low-grade deposits at a profit.

The richest ore now mined contains under 1.5 per cent of copper, while the poorest runs but little over .5 per cent.

The crushed and concentrated material carries about 65 per cent copper, and this passes through a combined smelting and refining process.

That portion of the copper which contains enough silver to make its recovery profitable, and some which runs too high in impurities for certain uses, is refined electrolytically. The amount so treated has been lessened, owing to a recent demand for copper carrying arsenic. The average recovery of silver per ton of rock mined was .2 fine ounce.

## B. Deposits from Meteoric Waters

In many parts of the world there are low-grade disseminated ores of copper (chiefly chalcocite) in sandstones and shales, ranging from Carboniferous to Triassic in age. They are not as a rule sufficiently rich to work, although the carbonates on the surface may make them attractive propositions to some. That they seem to have been concentrated from the surrounding rock by meteoric waters is a commonly accepted view.

This type of copper occurrence is widespread in the Red Beds (Permian) of the southwest, but is of no economic importance. Similar deposits have been worked in the well-known Corocoro [2] district of Bolivia, and in the Triassic of England. They are also known in the Permian of Russia and Bohemia, and the Triassic of western Prussia.

Reference may be made in this connection to the famous Mansfeld copper deposits of Germany, which are probably of syngenetic nature. These occur as minutely disseminated sulphides in Permian shale.[3]

[1] The term has now lost its original meaning, since copper from western states is brought to Michigan for refining and sold as Lake ore.

[2] Vogt, Krusch u. Beyschlag, Lagerstätten, II: 428, 1912.

[3] Bergeat, Erzlagerstätten.

## Deposits, Usually Lens-Shaped, in Crystalline Schists.

Scattered over the world are a number of copper sulphide deposits, often more or less lenticular in character, and occurring in schistose rocks, which may be either igneous or sedimentary metamorphics. Some criticism may be urged against grouping them together, because their mode of origin is admittedly somewhat variable, but otherwise they show more or less mineralogical and structural resemblances.

In general it may be said that they represent deposits formed at deep or intermediate levels, by replacement or in cavities. Zones of shearing have often afforded channel ways for the solutions. While the host rock is often a schist, in other cases it may have been a limestone, of which little or nothing now remains, so complete has been the replacement.

**United States.** — Copper deposits in schist are most prominent in the Appalachian belt of the east, and in California. The more important ones are reviewed below.

*Appalachian States* (29, 30, 104). — The Appalachian states contain a number of copper deposits in schist distributed from Maine to Alabama, but few of them are of commercial importance.

*Ducktown, Tenn.* (97–99). — Here we have steeply dipping lenses replacing calcareous beds in folded and faulted schists. These lenses, whose exact origin was not clear until sufficient mining had been done to furnish the necessary evidence, range from a few feet to over 250 feet in thickness, have the shapes and character of closely folded sedimentary beds. The ores are somewhat metamorphosed and the gangue minerals bent. Primary ore consists of pyrrhotite, pyrite, chalcopyrite, sphalerite, bornite, hematite and magnetite in a gangue of calcite, actinolite, tremolite, garnet, zoisite and other silicates, a combination representing deep-seated conditions and limestone replacement. The gossan of the different bodies, now worked out, had a maximum thickness of 100 feet, and showed 40–50 per cent Fe, under 12 per cent $SiO_2$ and $Al_2O_3$, and .3–.7 per cent Cu. Between the gossan and dense sulphides there were found shallow zones of rich chalcocite.

In 1914 the ores yielded 28.7 pounds of blister copper per ton, or 1.435 per cent, with an average value of 9 cents in gold and silver per ton of ore. Some of the copper is marketed without electrolytic refining. The massive ore requiring little timber in

mining, together with cheap fuel and labor costs, have made it possible to work these low-grade ores at a profit. Pyritic smelting is employed, and large sulphuric acid plants have been erected to utilize the sulphur driven off from the ores in roasting.
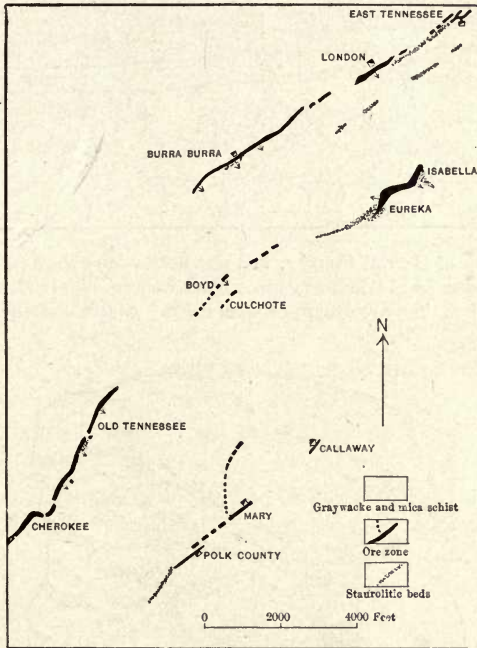


FIG. 209. — Plan of ore bodies at Ducktown, Tenn. (*After W. H. Emmons, U. S. Geol. Surv., Bull.* 470.)

*Virginia-North Carolina.* — The Gossan Lead of southwestern Virginia (104) (Fig. 210) and the copper deposits of Ore Knob, North Carolina, also belong to this type. At the former the ore is a mixture of pyrrhotite with subordinate chalcopyrite, and admixed quartz and schists. The vein fills a fault fracture between sericite schists, which contains mica, calcite, quartz, and actinolite, replaced by the later pyrrhotite and chalcopyrite (Fig. 211). The copper content is low, viz., .75 per cent, and hence the ore is used for acid making, but the residue is available for copper.

*Arizona, Jerome District* (31). — The ores occur in a pre-Cambrian schist, and consist of pyrite, chalcopyrite, some sphalerite, and varying amounts of quartz, replacing the schist.
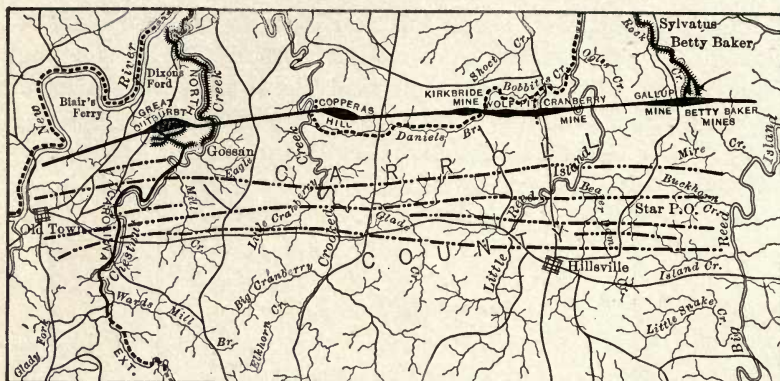
Fig. 210. — Map of Carroll County, Va., pyrrhotite area, showing position of the " Great Gossan Lead " in heavy black band, and principal copper mines located on it. Broken lines are other probable leads. (*After Watson and Weed, Min. Res. Va.*)



Fig. 211. — Section of ore from Chestnut Yard, Va., showing pyrrhotite (white) and chalcopyrite (black) replacements in hornblende (parallel lines). (*After Weed and Watson, Econ. Geol., I.*)

The ore body is really composed of a series of irregular lenses. Unlike most of the other Arizona copper deposits, this ore carries rather high gold and silver values.

*California* (44, 45, 46). — In the Klamath Mountains of Shasta County, there are important replacement deposits of pyritic ore occurring mainly along fissures and shear zones of an intrusive

Mesozoic alaskite porphyry. Two areas separated by the Sacramento River are recognized.

An eastern one, containing the Bully Hill and Afterthought districts, with deposits more vein-like, the ore siliceous, relatively high in chalcopyrite, and sphalerite important. A western one, with more or less flat, tabular ore bodies, carrying pyrite, some chalcopyrite and variable sphalerite, the last being sometimes rich enough to form zinc ore.

The gangue is gypsum, calcite and barite, and while chalcocite and bornite are sometimes found intergrown with chalcopyrite, they may at times be secondary. Good gossans are found.

Magmatic waters are supposed to have deposited the ore in the highly sericitized alaskite porphyry.

In 1914 the average copper content was 3.56 per cent, with $1.70 per ton of precious metals.

The so-called *Foot Hills belt* (46), occupying a somewhat extensive area in Calaveras County, carries pyrite and chalcopyrite lenses in schistose rocks. The ores at times carry considerable lead, zinc and precious metals.

**Alaska.** *Prince William Sound District* (21). — In this district the ore is chalcopyrite disseminated through metamorphic schists. The most important mine is on Latouche Island, and here the ore, which is a mixture of chalcopyrite, pyrrhotite, and pyrite, has been deposited mainly as a cavity filling, less often as a replacement or impregnation, in a shear zone in interbedded slates and graywackes.

**Canada** (112). — A number of interesting pyritic deposits occur in the eastern townships of Quebec. There are three belts of crystalline rocks separated by apparently Paleozoic sediments cut by intrusives, but some of the former prove to be altered schistose volcanics.

Most of the copper deposits are associated with more or less highly altered schistose volcanic rocks, and while a few were formed by the impregnation and partial replacement of limestone, most of them have originated by the irregular impregnation of the more schistose bands along shear zones in metamorphosed igneous rocks. In other cases the replacement of the schists has given rise to lenticular bodies of ore, which include some of the most important mines. The sulphides are chiefly chalcopyrite and pyrite, but zinc and lead may occur in small amounts.

**Other Foreign Deposits.** — Of the many foreign occurrences, the two best known perhaps are those of Rio Tinto, Spain, and Mount Lyell, Tasmania. The former occur as lenses, often of large size, in sheared and schistose porphyries and slates. The massive pyritic ore carries pyrite, chalcopyrite, sphalerite and galena. The hematite gossan, caps sulphides which, due to enrichment, carry from 3 to 12 per cent copper. The wall rocks, according to Finlayson, show hydrothermal alteration. Klockman argued for a sedimentary origin [1]; DeLaunay regarded them as veins or lodes formed by cavity filling; [2] Vogt assigned a pneumatolytic origin, following the porphyry intrusion; [3] while Finlayson believes them to have been the result of metasomatism by magmatic solutions along shear zones. [4]

At Mount Lyell we have great lenses of pyrite, with quartz and barite gangue, occurring chiefly in sericite schists, which have been intruded by porphyrites. The ore carries from 2 to 3 per cent copper, due to a chalcopyrite content. Large deposits are also worked in Russia. [5]

**Uses of Copper.** — Since prehistoric times copper alloyed with tin has been used in various parts of the world for the manufacture of bronze. Thus it was used for this purpose in Homeric times, and it is found in the lake dwellings of Switzerland. The bronze found in Troy contains a very little tin, and since this metal is not found in the excavations in the West, it seems probable that the bronze was made in Asia, perhaps in China or India, by some secret process, and imported to the western countries.

By an alloy of copper and tin, although both metals are soft, a comparatively hard metal is produced. The properties of this alloy, bronze, vary greatly according to the proportions of the two metallic constituents, and these vary with the use for which the alloy is intended. United States ordnance is 90 per cent copper and 10 per cent tin, while ordinary bell metal is about 80 per cent copper, though the percentage varies with the tone required. Statuary bronze is generally an alloy of copper, tin, and zinc; and, in these various bronzes, the color varies from copper-red to tin-white, passing through an orange-yellow.

An alloy of copper and zinc produces brass, which is found of so much value for small articles used in building and for ornamental purposes in machinery. Copper is also used in roofing and plumbing.

A large supply of this metal is made into copper wire, and the most important present use of copper is in electricity, for which its

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[1] Zeitschr. prak. Geol., 1897: 113.  
[2] Ann. des Mines., ser. 7, XVI: 407.  
[3] Zeitschr. prak. Geol., 1894: 241.  
[4] Econ. Geol., V: 357, 1910.  
[5] Stickney, Kyshtim deposits, Min. Mag., XIV: 77, 1916; also Econ. Geol., XI, 1915.

high conductivity especially fits it for the transmission of electric currents.

**Production of Copper.** — The production of copper in the United States has increased steadily and rapidly in the last fifty years, placing the United States in the lead of the world's copper producers. This increase can be seen from the following tables:

PRODUCTION OF COPPER IN THE UNITED STATES, 1910-1914, BY STATES, IN POUNDS

| | 1910 | 1911 | 1912 | 1913 | 1914 |
|---|---|---|---|---|---|
| Alaska | 4,311,026 | 22,314,889 | 31,926,209 | 23,423,070 | 24,985,847 |
| Arizona | 297,250,538 | 303,202,532 | 359,322,096 | 404,278,809 | 382,449,922 |
| California | 45,760,200 | 35,835,651 | 31,516,471 | 32,492,265 | 29,784,173 |
| Colorado | 9,307,497 | ,9791,861 | 7,963,520 | 9,052,104 | 7,316,066 |
| Idaho | 6,877,515 | 4,514,116 | 7,182,185 | 8,711,490 | 5,875,205 |
| Maryland | | | | | 12,248 |
| Michigan | 221,462,984 | 218,185,236 | 231,112,228 | 155,517,286 | 158,009,748 |
| Missouri | | | | 576,204 | 53,519 |
| Montana | 283,078,473 | 271,814,491 | 308,770,826 | 285,719,918 | 236,805,845 |
| New Mexico | 3,784,609 | 2,860,400 | 29,170,400 | 50,196,881 | 64,204,703 |
| Nevada | 64,494,640 | 65,561,015 | 83,413,900 | 85,209,536 | 60,122,904 |
| North Carolina | | | | 180 | 19,712 |
| Oklahoma | | | | 11 | |
| Oregon | 22,022 | 125,943 | 311,860 | 77,812 | 5,599 |
| Pennsylvania | | | | 245,337 | 422,741 |
| South Dakota | 43 | 1,607 | 23,657 | 4,549 | |
| Tennessee | | | | 19,489,654 | 18,661,112 |
| Texas | | | | 39,008 | 34,272 |
| Utah | 125,185,455 | 142,340,215 | 132,150,052 | 148,057,450 | 160,589,660 |
| Vermont | | | | 5,771 | |
| Virginia | | | | 46,961 | 17,753 |
| Washington | 65,021 | 195,503 | 1,069,938 | 732,742 | 683,602 |
| Wisconsin | | | | | 10,098 |
| Wyoming | 217,127 | 130,499 | 25,080 | 362,235 | 17,082 |
| Other States and unapportioned | 18,342,359 | 20,358,791 | 19,310,298 | 46,803 | 55,381 |
| Total | 1,080,159,509 | 1,097,232,749 | 1,243,268,720 | 1,224,484,098 | 1,150,137,192 |

WORLD'S PRODUCTION (SMELTER OUTPUT) OF COPPER IN 1913, IN POUNDS

| COUNTRY | PRODUCTION IN POUNDS | COUNTRY | PRODUCTION IN POUNDS |
|---|---|---|---|
| Germany | 55,776,380 | United States | 1,224,484,098 |
| England | 661,380 | Argentina | 220,460 |
| Italy | 3,527,360 | Bolivia | 8,157,020 |
| Norway | 19,400,480 | Chile | 88,184,000 |
| Austria | 8,377,480 | Peru | 56,658,220 |
| Russia | 74,735,940 | Venezuela | 2,865,980 |
| Sweden | 2,204,600 | Cuba | 7,495,640 |
| Spain and Portugal | 120,591,620 | Cape Colony | 7,275,180 |
| Turkey | 1,102,300 | Namaqualand | 5,511,500 |
| Servia | 14,109,440 | Japan | 161,376,720 |
| Canada | 76,975,832 | Australia | 104,277,580 |
| Mexico | 116,402,880 | | |
| Hungary | 661,380 | World's Total | 2,198,732,130 |

### COPPER PRODUCED IN 1914 FROM ORES IN WHICH COPPER CONSTITUTES THE PRINCIPAL VALUE, BY STATES

| State | Copper ore | Copper in ore | Percentage | Gold in ore | Silver in ore | Value in gold and silver per ton |
|---|---|---|---|---|---|---|
| | Short tons. | Pounds. | | Fine ounces. | Fine ounces. | |
| Alaska | 153,605 | 21,450,628 | 6.64 | 8,283.30 | 283,355 | $ 2.17 |
| Arizona | 7,508,020 | 391,020,335 | 2.60 | 50,842.80 | 2,604,371 | .33 |
| California | 397,868 | 30,507,692 | 3.84 | 16,630.16 | 703,042 | 1.84 |
| Colorado | 12,196 | 1,330,056 | 5.45 | 3,243.88 | 173,845 | 13.38 |
| Idaho | 93,040 | 4,986,206 | 2.68 | 1,076.54 | 239,355 | 1.66 |
| Michigan | 9,269,413 | 164,344,058 | .89 | ........ | 413,500 | .02 |
| Missouri | 18 | 2,463 | 6.85 | ........ | 14 | .43 |
| Montana | 4,346,034 | 231,019,109 | 2.66 | 25,422.61 | 8,015,694 | 1.14 |
| Nevada | 2,882,121 | 60,398,084 | 1.05 | 49,476.61 | 181,733 | .39 |
| New Mexico | 2,005,024 | 58,878,888 | 1.47 | 11,352.45 | 292,266 | .20 |
| Oregon | ........ | ........ | .... | ........ | ........ | .... |
| Pennsylvania and Maryland | 252,823 | 658,264 | .13 | ........ | ........ | .... |
| Tennessee | 653,621 | 18,737,656 | 1.44 | 299.63 | 97,402 | .09 |
| Texas | 231 | 23,760 | 5.13 | ........ | 6,826 | 16.32 |
| Utah | 7,578,220 | 142,988,221 | 1.94 | 97,955.32 | 1,726,230 | .39 |
| Virginia | 1,440 | 139,008 | 2.05 | 20.76 | 1,458 | .86 |
| Washington | 21,752 | 746,297 | 1.71 | 220.93 | 90,574 | 2.51 |
| Wisconsin | 37 | 10,300 | 13.51 | ........ | 16 | .47 |
| Wyoming | 78 | 17,421 | 11.54 | ........ | 79 | .56 |
| Total and Aver. | 35,175,541 | 1,127,258,546 | 1.60 | 264,824.99 | 14,829,760 | .39 |

### COPPER ORES CONCENTRATED AND SMELTED, CONCENTRATES PRODUCED, AND COPPER PRODUCED FROM EACH CLASS OF ORE IN 1914, BY STATES

| STATE | ORE CONCENTRATED | | | | ORE SMELTED | | |
|---|---|---|---|---|---|---|---|
| | Quantity | Concentrates produced | Copper in concentrates | Percentage of copper from ore | Quantity | Copper produced | Percentage of copper from ore |
| | Short tons. | Short tons. | Pounds. | | Short tons. | Pounds. | |
| Alaska | 58,968 | 8,144 | 8,515,713 | 7.22 | 94,637 | 12,934,915 | 6.83 |
| Arizona [1] | 5,329,245 | 440,161 | 158,932,432 | 1.49 | 2,135,614 | 231,103,784 | 5.41 |
| California | (²) | ...... | ........ | ... | 397,868 | 30,507,692 | 3.84 |
| Colorado | ........ | ...... | ........ | ... | 12,196 | 1,330,056 | 5.45 |
| Idaho | 68,484 | 5,031 | 2,228,382 | 1.63 | 24,546 | 2,757,824 | 5.62 |
| Michigan | 9,269,413 | 132,070 | 164,344,058 | .89 | ........ | ........ | ... |
| Missouri | | | | | 18 | 2,463 | 6.85 |
| Montana [3] | 3,716,347 | 1,305,976 | 166,352,667 | 2.24 | 573,032 | 58,168,286 | 5.08 |
| Nevada | 2,735,415 | 445,223 | 50,366,650 | .92 | 136,005 | 10,016,559 | 3.68 |
| New Mexico | 1,917,104 | 148,919 | 53,390,820 | 1.39 | 87,920 | 5,488,168 | 3.12 |
| Pennsylvania and Maryland | 252,768 | 7,659 | 646,016 | .13 | 55 | 12,248 | 1.10 |
| Tennessee | ...... | ...... | ........ | ... | 653,621 | 18,737,656 | 1.44 |
| Texas | | | | | 231 | 23,760 | 5.13 |
| Utah | 7,106,594 | 360,569 | 125,778,515 | .88 | 471,626 | 17,209,706 | 1.82 |
| Virginia | ...... | ...... | ........ | ... | 1,440 | 139,008 | 2.05 |
| Washington | 13,278 | 1,486 | 215,865 | .81 | 8,474 | 530,432 | 3.13 |
| Wisconsin | ...... | ...... | ........ | ... | 37 | 10,300 | 13.51 |
| Wyoming | ...... | ...... | ........ | ... | 78 | 17,421 | 11.54 |
| Total and Aver. | 30,467,626 | 2,855,238 | 730,771,118 | 1.20 | 4,597,398 | 389,090,278 | 4.23 |

[1] Slag smelted and ore leached amounted to 43,161 tons, containing 984,119 pounds of copper.

[2] Small quantity of copper ore concentrated included under ore smelted.

[3] Ore leached, 56,655 tons; copper from ore leached, 1,281,374 pounds; copper from precipitates, 5,216,782 pounds.

TOTAL UNITED STATES IMPORTS AND EXPORTS OF COPPER, INCLUDING ORE,
MATTE, AND REGULUS, PIGS, BARS, INGOTS, PLATES, RODS AND WIRE

| YEAR | IMPORTS IN POUNDS | EXPORTS IN POUNDS |
|---|---|---|
| 1912 . . . . . . . . . . . | 410,241,295 | 775,000,658 |
| 1913 . . . . . . . . . . . | 408,778,954 | 926,241,092 |
| 1914 . . . . . . . . . . . | 306,350,827 | 840,080,922 |

PRODUCTION OF COPPER IN CANADA BY PROVINCES, 1912 TO 1914

| PROVINCE | 1912 | | 1913 | | 1914 | |
|---|---|---|---|---|---|---|
| | POUNDS | VALUE | POUNDS | VALUE | POUNDS | VALUE |
| Quebec . . . . . . | 3,282,210 | $ 536,346 | 3,455,887 | $ 527,679 | 4,201,497 | $ 571,488 |
| Ontario . . . . . . | 22,250,601 | 3,635,971 | 25,885,929 | 3,952,522 | 28,948,211 | 3,937,536 |
| British Columbia . . . | 50,526,656 | 8,256,561 | 45,791,579 | 6,991,916 | 41,219,202 | 5,606,636 |
| Other districts [1] . . . | 1,772,660 | 289,670 | 1,843,530 | 281,489 | [2] 1,367,050 | 185,946 |
| Total . . . . . | 77,832,127 | $12,718,546 | 76,976,925 | $11,753,606 | 75,735,960 | $10,301,606 |

[1] Includes Nova Scotia and Yukon.    [2] Yukon only.

EXPORTS AND IMPORTS OF COPPER IN CANADA, 1912–1914

| YEAR | [1] EXPORTS | | [2] IMPORTS |
|---|---|---|---|
| | Pounds | Value | Value |
| 1912 . . . . . . . . . . . . | 78,488,564 | $9,036,479 | $7,047,356 |
| 1913 . . . . . . . . . . . . | 85,147,560 | 9,927,814 | 7,414,610 |
| 1914 . . . . . . . . . . . . | 77,398,723 | 8,270,689 | 4,256,901 |

[1] Copper in ore, matte, etc.    [2] Pigs, ingots, manufactured, etc.

**Copper Reserves.** — Lindgren (5 a) points out that the visible copper
reserves of the United States are much larger than those of lead ore, and,
moreover, they are much larger, now, at the maximum of production, than
they have ever been before, and yet they are in most cases not nearly so
great as those blocked out for some other materials like coal.    This, how-
ever, is owing to the different mode of occurrence of the two substances.
The amount of available reserves to be estimated depends on the market
price of copper. With the latter at, say, 20 cents per pound one can estimate
a much larger reserve than if the price were only 13 cents.    Lindgren believes
that the copper resources of the United States are large enough to respond
for a number of years to a demand increasing at the rate of 30,000,000
pounds per annum.

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See also Annual Reports, Minister of Mines, British Columbia, especially Rept. for 1914: 143 for Granby Bay.

## LEAD AND ZINC

I⊤ is usually customary to treat these two ores together for the reason that they are so frequently associated with each other, but it must not be understood from this that they are found free from association with other metals, as in the Rocky Mountain region for example, gold, silver, or copper may often occur with them, forming ores of somewhat complex character.

The silver-lead ores form a somewhat distinct class and are treated separately.

**Ore Minerals of Zinc.** — The zinc-ore minerals, together with the percentage of zinc which they contain, are : —

| | | |
|---|---|---|
| Sphalerite (Isometric) . | $ZnS$ | 67 |
| Wurtzite (Hexagonal) . | $ZnS$ | 67 |
| Smithsonite . . . . . | $ZnCO_3$ | 51.96 |
| Calamine . . . . . . | $2\,ZnO,SiO_2,H_2O$ | 54.2 |
| Hydrozincite . . . . | $ZnCO_3,2Zn(OH)_2$ | 60 |
| Zincite . . . . . . . | $ZnO$ | 80.3 |
| Willemite . . . . . . | $2ZnO,SiO_2$ | 58.5 |
| Franklinite . . . . . | $(FeMnZn)O,(FeMn)_2O_3$ | variable |

Of these ores, sphalerite (also known as blende, jack, rosin jack, or black jack) is by far the most important, except in northern New Jersey, where it is practically lacking and franklinite and willemite abound.

Sphalerite may be either a primary or secondary ore mineral. Wurzite has been noted in some of the Missouri ores and also foreign ones, indeed, many massive blendes may be a mixture of sphalerite and wurtzite.[1]

Blende is often associated with other sulphides, especially galena, pyrite, and marcasite, but more rarely chalcopyrite.

Smithsonite, found in the oxidized zone, is a comparatively rare ore mineral in the United States, although it is an important one in Europe. Calamine, also an oxidized ore mineral, is far more abundant, and found in many deposits. Both smithsonite and calamine may occur in a pure and crystalline form, but more often they are quite impure, of crusted or earthy character and are usually intimately associated. Hydrozincite is not uncommon in some districts.

[1] J. Noelting, Zeit. Kryst. u. Min., XVII: 220, 1890.

**Ore Minerals of Lead.** — The lead-ore minerals, together with their composition and the percentage of lead which they contain, are: —

| | | |
|---|---|---|
| Galena . . . . . . | PbS | 86.4 |
| Cerussite . . . . . | $PbCO_3$ | 77.5 |
| Anglesite . . . . . | $PbSO_4$ | 68.3 |
| Pyromorphite . . . . | $Pb_3P_2O_8 + \frac{1}{3} PbCl_2$ | 76.36 |

There are a vast number of lead minerals in addition to the above, but they have little or no commercial value on account of their rarity.

Of the above-named ore minerals galena is the commonest, and may be of either primary or secondary character. It frequently, especially in the complex ores, carries variable amounts of silver. The other three lead-ore minerals are usually found in the oxidized zone, and the cerussite is not uncommon, but the sulphate when formed usually changes to the carbonate.

The lead and zinc ores may be divided into three groups as follows: (1) lead and zinc ores, practically free from copper and the precious metals; (2) lead and zinc ores, carrying more or less gold and silver, as well as some iron and copper; and (3) lead-silver ores.

In the first group iron and manganese are not uncommon impurities, and those of southwestern Missouri contain small amounts of cadmium; but this is not injurious, as it is more volatile than the zinc and easily driven off. Calcite, dolomite and pyrite or marcasite are common gangue minerals, and barite or fluorite may occur at certain localities.

In the United States the ores of the second group are found chiefly in the Rocky Mountain region,[1] and are not only of complex character, but differ in their form and origin from most of the eastern ones. Quartz is probably the commonest gangue mineral, but there may be other less important ones. Antimony, arsenic, and iron may be among the impurities.

The silver-lead ores, found in many of the western states, carry silver and lead as their chief metals, but may contain smaller amounts of zinc, gold, or iron. They show a preference for limestone.

**Mode of Occurrence.** — Zinc and lead ores may occur under a variety of conditions, viz.: (1) as true metalliferous veins; (2) as irregular masses in metamorphic rocks; (3) as irregular

[1] Exceptions are some Louisa and Spottsylvania County deposits of Virginia, and the Cid district of North Carolina.

masses or disseminations, formed by replacement or impregnation in limestones or quartzites; (4) in contact-metamorphic deposits; (5) in cavities not of the fissure-vein type; and (6) in residual clays.

**Mode of Origin.** —While both lead and zinc may form under a variety of conditions, they are not found in commercial quantities in igneous rocks including pegmatites. Occurrences of workable character of one or the other are found in: (1) contact metamorphic deposits; (2) deeper zone veins; (3) intermediate depth veins; and (4) in sedimentary rocks, unassociated genetically with igneous ones, and concentrated by meteoric circulation. The third and fourth are the most important, and veins of the third often contain gold, silver, and copper, but these are treated in the next two chapters.

Neither lead nor zinc ores are restricted to any one formation, but the majority of economically valuable deposits of these metals, without silver, gold, or copper, are found in the Paleozoic formations, although a few are known in pre-Cambrian and Triassic (Silesia) rocks.

While the metallic content of the ore as mined is often low, still, owing to the great difference in gravity between ore and gangue minerals (excepting pyrite or marcasite and blende), it is often possible to separate them by mechanical concentration; and for the zinc ores magnetic separation has been successfully tried.

**Superficial Alteration of Lead and Zinc Ores.** — Galena is often altered near the surface to anglesite or cerussite. The former, however, is unstable in the presence of carbonated waters and changes readily to the carbonate. Phosphates are developed in rare instances.

Sphalerite, the common ore of zinc, is often changed superficially to smithsonite, hydrozincite, or calamine. Such oxidized ores are of greater value than unoxidized ones, because, although carrying a lower percentage of zinc, they occur in a more concentrated form and yield more easily to metallurgical treatment.

The chemical changes involved in the weathering of lead ores are probably simple, but those of zinc are more complex than was formerly thought (3). They are given on p. 480.

Galena is more resistant to weathering and solution than sphalerite, hence when associated in the same deposit, galena is often found in the oxidized zone while sphalerite is removed.

The soluble compounds produced by weathering may be carried down below the water level and reprecipitated as sulphides (see reactions, p. 485), but authentic cases of secondary zinc and lead sulphides are rare.

**Distribution of Lead and Zinc Ores in the United States.** — The general distribution of lead and zinc ores is shown on the map, Fig. 212. Deposits of lead alone are found in the Appalachian belt, and southeastern Missouri. With the former there are also a number of small veins in metamorphic rocks from Maine to Georgia, but with the exception of some of the Virginia occur-



FIG. 212. — Map showing distribution of lead and zinc ores in the United States.
(*Adapted from Ransome, Min. Mag., X.*)

rences, they are of little importance. Zinc ores, almost free from lead, occur in New Jersey, the Virginia Tennessee belt, the Saucon Valley, Pennsylvania and southwestern Missouri. Lead and zinc together, free from gold, silver, or copper are prominent in the Upper Mississippi Valley. The mixed ores are prominent in the Cordilleran region.

*Desilverized Lead.*[1] — The important localities supplying this type of lead are described under lead-silver ores, but brief reference may be made to them here. Idaho is the most important prducer, most of the ore coming from the Cœur d'Alene district. In Utah much is obtained from the Park City district of Summit

---

[1] This term is applied to those occurrences of lead associated with silver. In the smelting of the ore, the two metals are separated.

SECTION A-A

SECTION B-B

SECTION C-C

SECTION D-D

SECTION E-E

SCALE OF FEET

⅜ 0 ⅜ ¾ ½ 1 MI.

1200 0 1000 2000 3000 4000 ft.

Franklin Furnace

Parker Shaft

Trotter Mine
Mine Hill

Buckwheat Mine

Hill Mine (Magnetite)

Gooseberry
Mine

Hardystone
Sparta

74° 35'

GEOLOGIC CROSS SECTIONS

SCALE OF FEET

0 600 1200 1800

Township
Line

41° 05'

Shade Unknown

SECTION F-F

N. J. Zinc Co. Mine
Sterling Hill
Passaic Mine
Noble Mine

SECTION G-G

LEGEND

| Cambrian Limestone and Quartzite (blue limestone) | Franklin Limestone (white crystalline limestone) | Gneiss | Outcrop of Zinc Ore Bodies | Magnetite Outcrop |

GEOLOGIC MAP OF FRANKLIN FURNACE AND VICINITY
WITH SECTIONS OF THE ZINC ORE BODIES

PLATE LVII. — Geologic map of Franklin Furnace and vicinity, with sections of the zinc-ore bodies. (*After Spencer, N. J. Geol. Surv.*)

(625)

County, the Bingham Cañon and Cottonwood districts of Salt
Lake County, and the Tintic district of Juab County. Colorado's
main supply is yielded by the Leadville mines in Lake County
and the Aspen mines of Pitkin County, while smaller amounts are
obtained from Creede, Lake City, Ouray, and Rico. (See Lead-
Silver references.)

Comparatively little lead is produced in the western states,
except in the three mentioned above. The important lead ores
of this region being closely associated with both igneous and
sedimentary rocks.

Most of the zinc obtained in the Rocky Mountain states is
from complex ores. Leadville is the most important producer,
and is described below together with some others of minor im-
portance.

### Contact-Metamorphic Deposits

**United States.** — Few undoubted deposits of this type are
known. *Magdalena, N. Mex.* (42). — At this locality faulted
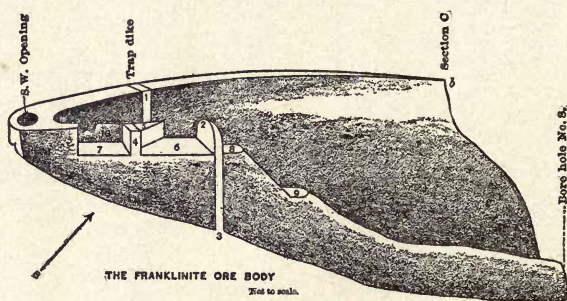


FIG. 213. — Model of Franklin zinc-ore body. (*After Nason, Amer. Inst. Min.
Engrs., Trans. XXIV.*)

blocks of Paleozoic limestone have been cut by granite-porphyry
dikes, the former containing roughly lenticular ore bodies, which
in their oxidized zone yield lead, silver and zinc, while in the
sulphide zone the ore carries much sphalerite with a little galena
and chalcopyrite. Magnetite and specularite are present, while
the gangue has abundant epidote, pyroxene and tremolite, but
little garnet.

*Sussex County, New Jersey* (39–41).—The output of these mines
is second in importance to those of Mississippi Valley region.

The district (Pl. LVII) includes two general areas situated close together, the one called Mine Hill, at Franklin, and the other called Sterling Hill, at Ogdensburg, two miles farther south.

The ore deposits are in white crystalline limestone, which is bounded on the northwest by gneiss, and on the southeast by blue Cambrian limestone along a fault line.

At Mine Hill (Fig. 213) the northerly pitching ore body lies in the white limestone adjacent to its contact with the gneiss, and has the shape of a trough, whose southern end appears to be doubled over into an anticline. Magnetite deposits outcrop locally along the limestone-gneiss contact, both adjacent to the zinc deposit, and for a distance of more than one-half mile to the southwest.

The Sterling Hill (Fig. 214) deposit at Ogdensburg lies away from the limestone-gneiss contact. The ore body is also a trough, which
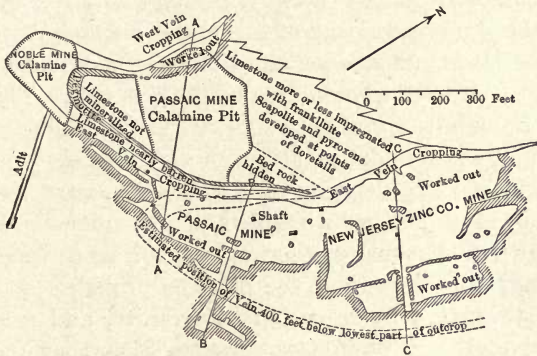


FIG. 214. — Plan of outcrop and workings of the Sterling Hill ore body. (*After Spencer, N. J. Geol. Surv., Ann. Rept.*, 1908.)

pitches towards the east, and has a hook-like outcrop. Both sides of the trough dip southeast; the exact extent of this ore body is not known.

The ore minerals are principally franklinite, willemite (often somewhat manganiferous), and zincite. These, together with tephroite, are practically the only metallic minerals at Sterling Hill; but in the Mine Hill deposits, several other zinc- and manganese-bearing minerals, mainly silicates, are not uncommon. Sphalerite occurs sparingly.

The gangue minerals are calcite, rhodonite, garnet, pyroxene, and hornblende. The ore is granular, and some of it shows strong foli-

ation.    There is usually a gradation from ore into country rock,
and while the ore appears to show a lamination corresponding with
that of the gneisses, the three dominant ore minerals mentioned are
not evenly mixed in all parts of the ore body.

At Mine Hill the run of mine ore has been estimated to contain from
19 to 22.5 per cent iron, 6 to 12 per cent manganese, 27 per cent zinc.

The franklinite has been found to contain from 39 to 47 per cent iron,
10 to 19 per cent manganese, and 6 to 18 per cent zinc; the willemite from
1.5 to 3 per cent each of iron and manganese; and the zincite about 5 per
cent manganese and iron.

At Sterling Hill the limestone lying between the outcropping ends
of the sides of the trough is mineralized, while inside the trough of
ore there is a curved dike of hornblendic pegmatite, and on the con-
vex side of the dike, towards the ore, there are occasional develop-
ments of garnet, zinciferous pyroxene, and biotite.

We have in this district two zinc deposits, which are quite different
from all other known deposits of this metal, not only because of the
association of iron, manganese, and zinc in such ore bodies, but also
because of the form of combination of the zinc ores.   Thus we have
the oxides franklinite and zincite, together with the silicate willemite,
occurring in great abundance, although very rare elsewhere.

The origin of these deposits is of unusual interest, for they not
only contain in abundance a number of zinc minerals, rare or un-
known elsewhere, but many other mineral species as well.

Kemp (39) considers that the ore was probably deposited by
solutions stimulated by intrusions of granite, and subsequently
metamorphosed, but Wolff (41) suggests that they are contem-
poraneous in form and structure with the inclosing limestones and
hence older than the granites.

Spencer (40) argues that the present characters of the ore masses
and wall rocks originated contemporaneously because the two are
not sharply separated; so that the deposits must have been intro-
duced either before or during the metamorphism of the containing
rocks and the igneous rocks which are now gneisses.   He favors
the view that the lean ore of Sterling Hill was probably deposited
by magmatic waters which permeated and replaced the limestone,
and while the richer ore may have been formed in the same way,
there is also the possibility that the main ore layer at Sterling Hill
and the mass of ore at Mine Hill were injected bodily into the lime-
stones, like igneous intrusions.

The pegmatites are evidently the source of many of the rarer

minerals found in these deposits, because they are closely associated with them.

While the origin of these deposits has undoubtedly been a puzzling problem, one is forced to admit that it is perhaps as well to class them as contact-metamorphic deposits, a view held by both Vogt and Lindgren.

These ore bodies are of some historic interest, having been prospected as early as 1640 and mined in 1774. The Mine Hill deposits were worked for iron ore as early as the beginning of the last century, the zinc mining having begun about 1840.

The Sussex County ores, while chiefly valuable as a source of zinc, are likewise of importance because of their iron and manganese contents.

Three products, viz. spelter, zinc oxide, and spiegeleisen, are made from them.

The Mine Hill ores are now treated by magnetic separators, which yield three products, as follows: 1. Mainly franklinite, used in preparation of zinc white, the residuum from this going to blast furnace to make spiegeleisen. 2. Half and half, containing franklinite, rhodonite, garnet, and other silicates with attached particles of the richer zinc minerals. This contains a little more zinc than the franklinite, and while it can be used for zinc white, the residuum is too high in silica for the spiegeleisen furnaces. 3. Willemite product, which consists of willemite and zincite, with calcite and silicates as impurities. The calcite is removed in jigs and on concentrating tables, leaving material adapted to manufacture of high-grade spelter free from lead or cadmium.

The dust from the crushing and concentrating plant is also saved for making zinc oxide. The following gives the approximate percentage of each product and its zinc contents.

PRODUCTS OF MILL AT FRANKLIN FURNACE

|  | PER CENT OF EACH | PER CENT OF ZINC |
|---|---|---|
| Franklinite . . . . . . . . . | 49 | 22 |
| Half and Half . . . . . . . | 12 | 24 |
| Dust . . . . . . . . . . . | 4 | 27 |
| Willemite . . . . . . . . . . | 25 | 48 |
| Calcite . . . . . . . . . . . | 10 | 5 |
|  | 100 |  |

## High-Temperature Veins

The only representative of this class described from the United States is found as veins in the Boulder batholith southwest of Helena. The ore is chiefly galena, associated with sphalerite and pyrite. Tourmaline is a characteristic feature.

## Deposits Formed at Intermediate Depths

**United States.** — Most of the deposits of this type found in the United States carrying lead or zinc, contain sufficient gold or silver to be classed with the silver-lead (p. 658) or gold-silver ores (p. 675). The most prominent example deserving notice in this chapter is that of Leadville, Colo., but in recent years large quantities of blende have been obtained from Butte, Mont. (See under Copper), and considerable zinc also comes from the Cœur d'Alene, Idaho,.district. (See under Silver-Lead.)

*Leadville District, Colorado* (6–12). — This region lies on the western side of the Mosquito Range at the headwaters of the Arkansas River in south-central Colorado, while the town of Leadville is situated on the western spurs of the range overlooking the Arkansas Valley. The latter is bounded by the Sawatch Range on the west.

The mines which have made Leadville famous for its production of silver, gold, lead, zinc, iron, and manganese are mostly high up on the ridge and from 2 to 3 miles east of the town, but in later years developments have been spreading westward towards the valley. The district was formerly placed among the lead-silver camps, but since the rich bodies of silver-bearing lead carbonate have become exhausted a large tonnage is obtained from the lead-zinc sulphide ore bodies deeper down, and for that reason it is placed here, although it is not to be understood from this that other metals are not produced there in quantity.

The Sawatch Range is an oval mass of gneisses, granites, and schists on whose flanks rest the Cambrian and later sediments, dipping away from the range on all sides.

The Mosquito Range (elevation 13,000 to 14,000 feet) is composed mainly of Paleozoic rocks, with some Mesozoic deposits on its eastern flanks, while between these beds are
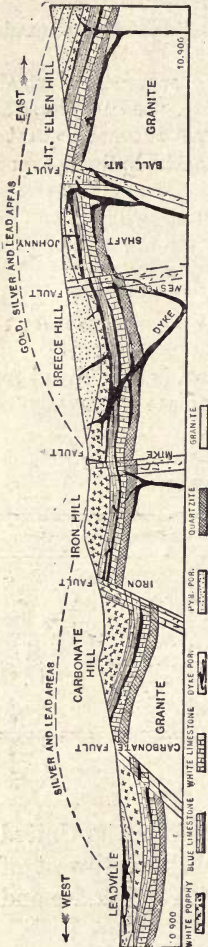


FIG. 215. — Ideal section of Leadville, Colo., district. (After Warwick, Min. Mag., XI.)

PLATE LVIII
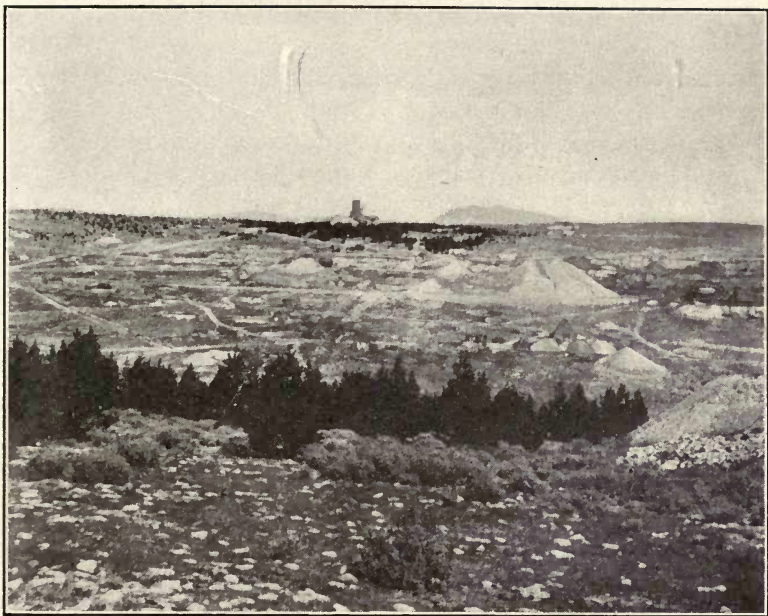


FIG. 1. — View from top of Carbonate Hill, Leadville, Col., looking towards Iron Hill. The valley in center ground marks position of the Iron fault. Shaft house is that of Tucson shaft, and ridge in distance fault scarp of Mosquito Range. (*H. Ries, photo.*)



FIG. 2. — View from south end of Carbonate Hill, Leadville, Colo., overlooking California Gulch in foreground, and town of Leadville in the valley. Sawatch Range in distance. (*H. Ries, photo.*)

(631)

sills and laccoliths of igneous rocks, whose intrusions occurred before the uplift of the region.

This uplift was formed by an east-to-west thrust which pushed the beds up into folds against the Sawatch Range and later faulted them (Fig. 215).

In consequence, therefore, of folding, faulting, igneous intrusions, and detrital material, the structural geology of Leadville affords a somewhat complex problem.

The geological section best shown in Carbonate Hill perhaps is as follows : —

| Local Name | Age | Rocks | Thickness, Feet |
|---|---|---|---|
| White porphyry . | Pre-Cretaceous | White rhyolite porphyry | 800 |
| Blue limestone . | Lower Carboniferous | Blue-gray dolomite | 200 |
| Gray porphyry . | Pre-Cretaceous | Gray monzonite porphyry | 50 |
| Parting quartzite | Devonian | Coarse quartzite | 30 |
| White limestone | Silurian | Drab siliceous dolomite limestone | 160 |
| Lower quartzite | Cambrian | Mostly white quartzite | 160 |
| Granite . . . . | Basement complex of pre-Cambrian age | Granite and gneiss | —— |

The fracturing and displacement of these rocks has resulted in the formation of a number of great fault blocks, which in their eroded form stand out as prominent hills, known as Breece, Iron, Carbonate, Fryer, etc. (Fig. 215).

The ore bodies occur mainly as great replacement masses in the blue and white limestones, and in the Devonian quartzite; but in addition there have been discovered fissures and cavities in the Cambrian quartzite (6) which carry ore that has evidently been deposited from solution and not by replacement (Fig. 216). While these fissures are known to be connected with the Silurian limestone ores, they have not yet been traced to the granite. Later, however, other fissures were discovered leading into the granite porphyry (9).

Gold ores are found on Breece Hill to the eastward, but these belong to a different type.

The original ore of the district consisted of lead, zinc, iron, and

copper sulphides carrying silver and gold, the proportions of the several metals varying in different parts of the district.

For some years the oxidized ore bodies of cerussite and cerargyrite in a matrix of iron and manganese oxide formed the mainstay of the camp, but the practical exhaustion of these led to deeper mining and the discovery of the large sulphide bodies at lower levels.
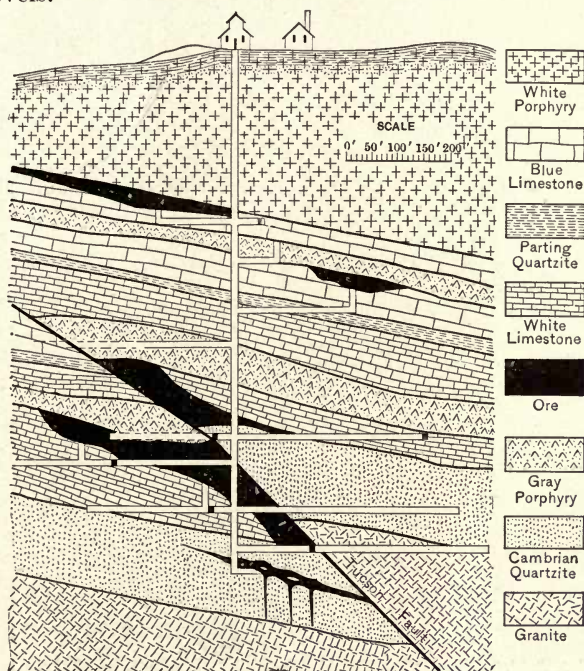


Fig. 216. — Vertical section along line *AB*, Fig. 186. Tucson shaft, Leadville, Col. (*After Argall, Eng. and Min. Jour., LXXXIX.*)

While the sulphide ores became an important source of supply, still, as late as 1911 (7, 9) there were discovered in the blue and also white limestone great quantities of zinc carbonate of replacement origin. P. Argall has also noted the presence of great masses of manganiferous siderite in the limestone associated with intrusive gray porphyries (8).

The camp now is turning out a large tonnage of lead and zinc sulphides which may carry gold and silver, zinc carbonate, manganese ores from oxidized deposits on Carbonate Hill, some copper sulphides, and some bismuth ores.

The origin of these ores has been discussed by several geologists, Emmons and Blow being among the earlier ones.

Emmons, in his classic monograph on this district (4) expressed



GEOLOGICAL PLAN

ON PLANE OF

5TH LEVEL

DECEMBER 1909

LEGEND

WHITE LIMESTONE    GRAY PORPHYRY    CAMBRIAN QUARTZITE

ORE

SCALE OF FEET
0   50   100
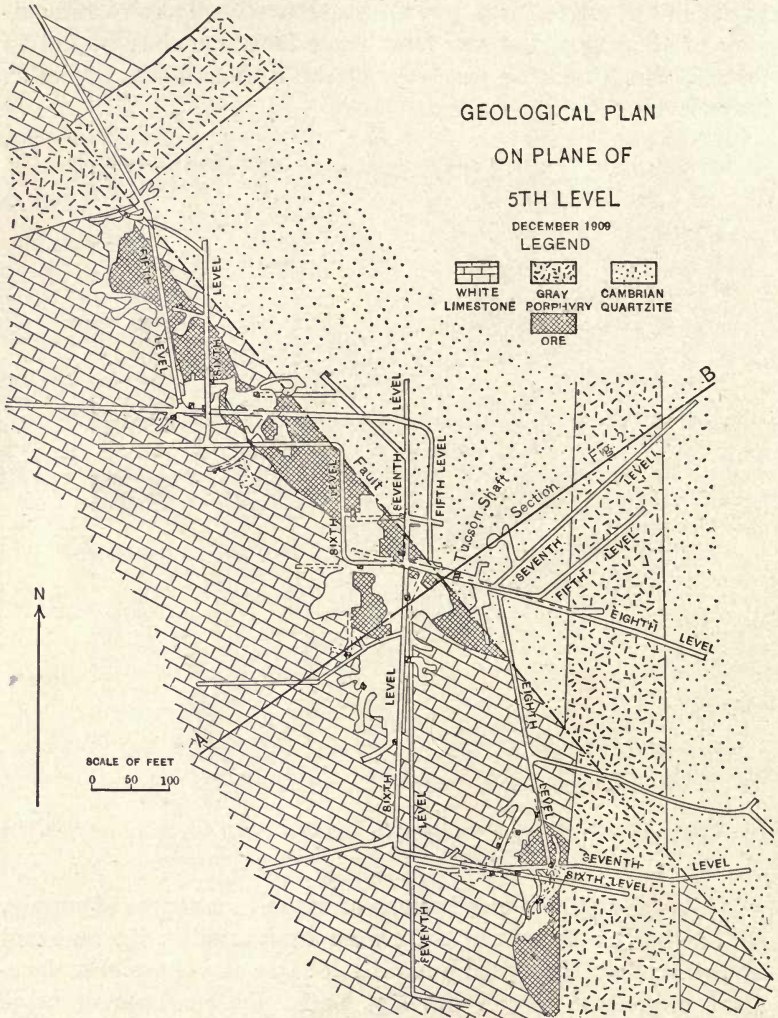
Fig. 217. — Geologic plan of fifth level and workings, Tucson shaft, Leadville, Col.
(*After Argall, Eng. and Min. Jour., LXXXIX.*)

the following views regarding the origin of the ore deposits: (1) that they have been derived from aqueous solution; (2) that this solution came from above; (3) that the ores derived their metallic contents from the neighboring eruptive rock.   He further adds that

these statements are not intended to deny the possibility that the
metals may have originally come from depth, nor to maintain that
they were necessarily derived entirely from eruptive rocks at present
in immediate contact with the deposit.    (4)  The ores were deposited
by replacement of the country rock.    (5)  They are of later age than
the porphyry sheets, but were introduced before the faulting of the
region occurred.

These views are not agreed to entirely by all persons familiar
with the district, and there is a tendency among many engineers
who have a more or less
intimate knowledge of the
region to feel that the ores
may have been brought in
by solutions ascending di-
rectly from the granite, a
theory which they regard as
being strengthened by the
finding of fissure ores in the
Cambrian quartzite (Figs.
216, 218).



A, pyrite and blende; B, galena; C, mud deposit;
D, open cavity; E, Quartzites.

FIG. 218. — Cavities in Cambrian quartzite,
Tucson shaft, Leadville, Col.  (*After Argall.*)

We must remember, of
course, that since Emmons'
work was done the district
has been greatly and more
deeply developed, thus affording apportunity for more extended
investigation.

The plan [1] (shown at the top of page 636) shows graphically
the course of treatment of Leadville ores from mine to market.

The quantity of the several classes of ore produced in 1914 was:
Siliceous  gold-silver  ores,  33,000  short  tons;  sulphide  ores,
307,559 short tons;  oxide ores, 192,143 short tons, of which
113,881 were zinc carbonate.

Even in former years Leadville was a mining camp of great importance,
having indeed given Colorado its first serious start as a mining state.  From
an area of about a square mile the output of silver was for a number of years
greater than that of any foreign country except Mexico, and during the
same period the production of lead was nearly equal to that of England and
greater than that of any European country excepting Spain and Germany.
Although regarded originally as a silver camp, it really ceased being such
nearly fifteen years ago, and is now an important producer of at least eight
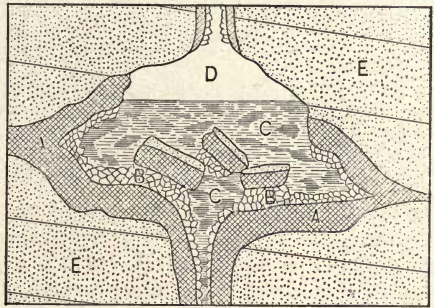
[1] From U. S. Geol. Surv., Min. Res., 1911.

Mine Mouth | Mine Mouth | Mine Mouth | Mine Mouth | Mine Mouth | Mine Mouth

Old Wet Mill Dump

- Zinc Carbonate
- Zinc Sulphide (Zinc, iron, copper, lead)
- Denver Sulphuric acid plant
- Iron Sulphide (Iron, copper, lead sulphides)
- Lead Oxide
- Copper Oxide
- Iron Manganese Silver
- Gold Silver (Siliceous)
- Kans. City Sulphuric acid plant
- Zinc concentrations
- Magnetic Mills Leadville Canon City Pueblo Denver
- Lead Zinc Sulphides
- Wet Mill
- Lead concentrates
- Assay furnace
- Lead furnace Copper matte
- Lead and iron sulphides concentrates
- Zinc concentrates
- Matte Enriching Furnace
- Load Smelters Leadville, Pueblo, Durango, Salida, Denver, El Paso
- Bullion
- Mint
- Zinc Smelters and Oxide Plants Kans, Okla., Ill., Colo.
- Zinc residues
- Spelter and zinc oxide markets
- Enriched lead furnace matte (40-45% copper)
- Base bullion
- Copper refineries
- Eastern refineries

metals, of which five or six are sometimes all obtained from the same group of properties. It will thus be seen that the successful marketing of one may affect all the others. Leadville began as a gold camp in 1860, when a placer deposit of gold was found in a gulch near there and several million dollars' worth of metal were extracted, resulting in the establishment of a flourishing town called Oro, which, however, soon lost its importance when the gold began to be exhausted. Not until 1875 was the carbonate of lead, which has since been so important, actually recognized.

## Deposits Formed Near Surface [1]

**United States.** — Several ore districts of the west may be referred to under this head. Thus certain veins of the Lake City district carry considerable galena and zinc in a quartz gangue (11a), and cut volcanic rocks. Again in the Creede district of Colorado there are found fissure veins in rhyolite, also showing lead and zinc with a gangue of quartz, barite and fluorite (10a). Others carrying a stronger content of the noble metals are referred to under Lead-Silver and Gold-Silver.

## Deposits in Sedimentary Rocks, Unrelated to Igneous Ones

Deposits of lead and zinc in sedimentary rocks, and showing no relationship to igneous rocks form a widely distributed type, whose association with calcareous rocks, as limestones, dolomites and calcareous shales is most pronounced.

[1] These localities are not strictly lead-zinc producers.

PLATE LIX



FIG. 1. — View of valley at Austinville, Va. Zinc ores in hill at left, white heap of mill tailings on right. (*H. Ries, photo.*)



FIG. 2. — Old oxidized ore workings at Austinville, Va. The ore was in residual clay which formerly covered these limestone pinnacles. Sulphides underlie these. (*H. Ries, photo.*)

The primary ore minerals are galena and blende, while above them in the weathered zone are the usual oxidation products. Iron sulphide may often be present, and is undesirable, but gold and antimony are rare, and the deposits are with few exceptions non-argentiferous. The blende may contain small quantities of cadmium, or the latter as the sulphide, greenockite may be present as a secondary mineral. Nickel and cobalt are found in small amounts in the southeastern Missouri ores. Dolomite is a common gangue mineral, and chert is often present.

The deposits, which are not of great depth, may fill solution cavities, fault fissures, or form disseminations.

Most geologists believe that the ore bodies of this type have been formed by meteoric circulation.

**United States.** — In the United States this type of ore deposits is especially important in the Mississippi Valley region, and also in southwestern Virginia and east Tennessee.

*Virginia-Tennessee Belt* (50–53, 59). — Zinc and some lead occur in a belt extending from southwest Virginia into Tennessee.
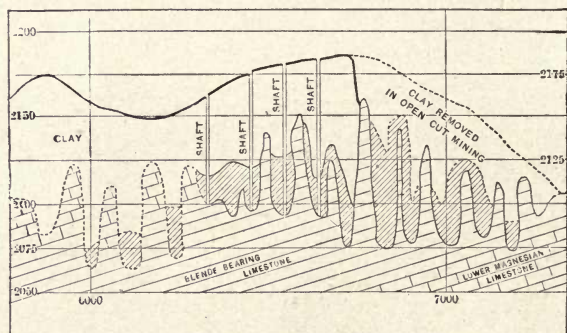


Fig. 219. — Section of Bertha zinc mines, Wythe Co., Va., showing irregular surface of limestone covered by residual clay-bearing ore. (*After Case, Amer. Inst. Min. Engrs., Trans. XXII.*) Compared with Plate LIX, Fig. 2.

The ores are intimately associated with Cambro-Ordovician limestone, and show two types, viz.: (1) secondary or weathered ores, including calamine, smithsonite, and cerussite, which are concentrated in the residual clays next to the irregular weathered surface of the limestone (Fig. 219 and LIX, Fig. 2); and (2) primary ores, including sphalerite, galena, and some pyrite, belonging to the disseminated replacement breccia

type (Fig. 220), and which have been localized by ground waters along the crushed and faulted axes of the folds. The gangue miner-
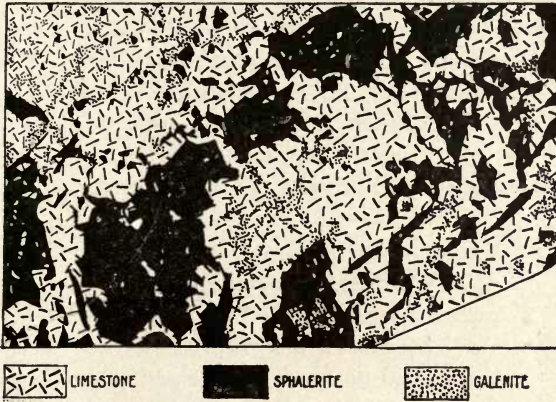


FIG. 220. — Section showing replacement of limestone by sphalerite and galena, Austinville, Va. (*After Watson, Va. Geol. Surv., Bull. I,* 1905.)

als are chiefly calcite, dolomite, and some barite. Fluorite is known, and quartz may occur in the form of chert. One deposit only, in Albemarle County, is found in schist, and is closely associated with igneous rocks.

*Pennsylvania* (48, 49). — The Saucon Valley deposits promised at one time to become prominent producers, but have not, owing more to geological conditions than actual scarcity of ore.



FIG. 221. — Map of Ozark region. (*After Branner, Eng. and Min. Jour., LXXIII.*)

**Mississippi Valley Lead and Zinc Region.** — This region contains several somewhat separated groups of deposits, viz.: (1) the Ozark Region, (2) upper Mississippi Valley area, (3) outlying districts, chiefly in northern Arkansas, Kentucky and Illinois. Of these the first is the most important.

*Ozark Region* (5, 23, 27-36). — This region, which lies mostly in
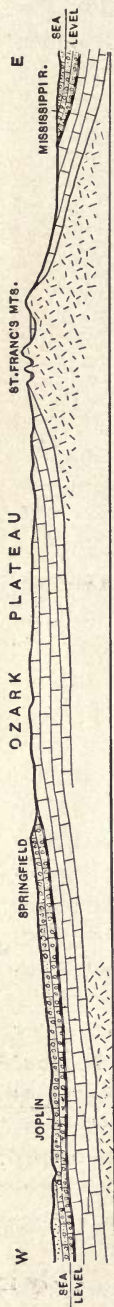
FIG. 222. — General west-east section through Joplin and the St. Francis Mountains. Shows the flat-topped dome of Cambrian and Ordovician limestones and pre-Cambrian rocks overlain by thin Devonian shale and Carboniferous sediments. (*U. S. Geol. Surv., Atl. Fol.* 148.)

Missouri (Fig. 221), but also includes portions of Arkansas, has four districts, viz.: (1) the southwestern Missouri, which is essentially lead-producing, and has been described on an earlier page; (2) the Central Missouri, containing small ore bodies with both lead and zinc (28); (3) the Missouri-Kansas, or southwestern Missouri, mainly a zinc-producing area; (4) northern Arkansas (1, 2), producing chiefly zinc, with some lead.

The third, or most important one, will be specially referred to.

The Ozark uplift or plateau is a low, rudely elliptical dome (Figs. 222, 223), lying mostly in southern Missouri and northern Arkansas. The Boston Mountains form the southern boundary, while it merges into prairie on the west and north, and the Gulf Plains on the east and southeast.

The rocks are mostly of sedimentary origin, but pre-Cambrian granites and porphyry form some of the peaks of the St. Francis Mountains. The Cambrian and Cambro-Ordovician dolomites, and limestone and sandstones underlying the central Ozark area, surround these mountains concentrically, and are in turn flanked successively by Devonian to Pennsylvanian rocks.

*Joplin Area* (27, 31-34). — This is the most important area in the Missouri-Kansas district, and the generalized geological succession is shown in the accompanying diagram (Fig. 224).



FIG. 223. — General south-north section through Springfield and Sedalia. Shows the flat-topped dome of Cambrian and Ordovician limestones overlain by thin Devonian and Carboniferous sediments. (*U. S. Geol. Surv., Atl. Fol.*, 148.)

The ore deposits of the Joplin district occur in large but very irregular masses of chert and limestone, which are unusually brecciated and cemented by, or impreganted with, dolomite, jasperoid,

| SYSTEM | SERIES | FORMATION | COLUMNAR SECTION | THICKNESS IN FEET | CHARACTER OF ROCKS |
|---|---|---|---|---|---|
| CARBONIFEROUS | PENNSYLVANIAN | Cherokee | | 150+ | Drab to black shale and gray to buff sandstone with occasional beds of coal. |
| | | UNCONFORMITY | | | |
| | | Carterville | | | Light to dark shales and shaly and oolitic limestone with some massive soft to hard sandstones, |
| | | UNCONFORMITY | | 0·50 | |
| | MISSISSIPPIAN | ( Short Creek oolite member.) | | (2–8) | Massive homogeneous bed of oolitic limestone. |
| | | Boone | | 140–485 | Limestone, in large part crystalline, with interbedded chert. |
| | | (Grand Falls chert member.) | | (15–120) | Heavy-bedded, solid chert. |

Fig. 224.—Generalized geologic section of the Joplin district. (*U. S. Geol. Surv., Atl. Fol.* 148.)

clacite or sphalerite, and carry considerable amounts of sphalerite, galena, and iron sulphide. Of subordinate importance are chalcopyrite, greenockite, barite and other minerals. Weathering develops oxides, carbonates, sulphates, and silicates of many of the above. They are found in the Boone formation and show a close association with certain forms of fracturing and brecciation.

Jasperoid, which is the commonest gangue material, forms a cement of chert breccias or intercalations in practically undis-

turbed beds in sheet ground; it is usually of a dark gray to
nearly black color when fresh, and the microscope shows it to be a
fine-grained allotriomorphic aggregate of quartz (Fig. 225). Some
have thought it to be a mud-like deposit that was later silicified,
but it is more probably a siliceous replacement of limestone.



Fig. 225. — Photo-micrograph of jasperoid, showing fine granular aggregate of
quartz, with sphalerite (shaded) and dolomite, the latter including minute quartz
crystals.   × 53.   (*After Smith and Siebenthal.*)

The two important forms of ore body are *runs* and *sheet ground*.

The runs are irregular, usually elongated, and in places tabular
and inclined bodies of ore, associated with breccias produced, ac-
cording to Smith, by minor faulting. They may be 10–50 ft. wide.
and are comparatively shallow. It is thought they represent ore
deposition in sink holes formed in the upper part of the Boone
formation (Fig. 224), during a period of pre-Pennsylvanian erosion.

Sheet ground deposits, which occur in the Grand Falls chert
member of the Boone formation are tabular ore bodies, often
of great lateral extent, and 6 to 15 feet thick.   The sulphides occur
in part along bedding planes of cherts and in part in breccias
resulting from slight folding and faulting of the bedded rocks.
In the breccias the ore occurs as a cement or in jasperoid, while
in the bedding planes it is in solution cavities or in jasperoid.

The sheet ground averages lower in ore content than the runs, but
is more uniform in character and being all at one level is more easily mined

PLATE LX
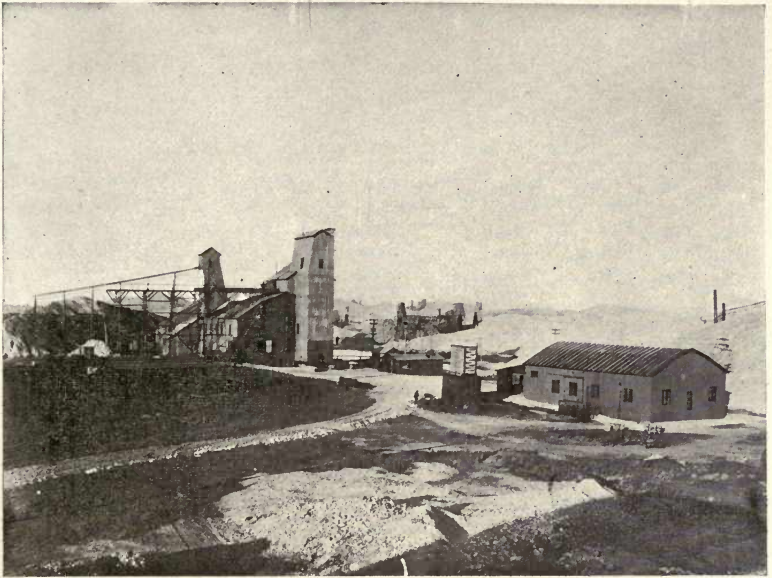


FIG. 1. — View in Joplin district near Webb City, Mo.  (*Photo from F, C. Wallower.*)



FIG. 2. — Chambers in Disbrow Mine, near Webb City, Mo.   These include both sheet ground and the " broken ground " above.  (*Photo from F. C. Wallower.*)

(643)

Ore running 6 per cent is regarded as good, but when it falls to $2\frac{1}{2}$ per cent it hardly pays to work it.

In the runs the galena is most abundant above, while the sphalerite occurs in the middle or lower portion, but in the sheet ground there is no such vertical separation.

The Joplin district is a most important producer of zinc, and while the content of this metal is low in the ore as it comes from the mines, still concentration raises it to about 58 per cent. The average tenor of lead is .5 to 1 per cent and of iron from 1 to 2 per cent. It assays about 30 per cent sulphur, and the remainder, besides a little cadmium, is silica.

An analysis representing the average of 3800 carloads of blende shipped from the Joplin district in the first part of 1904 is given by Ingalls as: Zn, 58.26; Cd, .304; Pb, .70; Fe, 2.23; Mn, .01; Cu, .049; $CaCO_3$, 1.88; $MgCO_3$, .85; $SiO_2$, 3.95; $BaSO_4$, .82; S, 30.72; total 99.773.

*Origin of the Ores.* — Most of the theories of the origin of these ores agree in considering that their concentration has been caused by circulating meteoric waters which have collected the ore particles from the limestones, although in one instance at least they were thought to be associated with igneous intrusions (35).

Analyses of the limestones (36) show amounts of from .001 to .015 per cent of lead and zinc in the Cambro-Silurian magnesian limestones and Archæan rocks in the southeastern part of the Ozark region, and from .002 to .003 per cent in the Lower Carboniferous limestones.

These averages, expressed in different form, give 87 pounds of galena per acre in a one-foot layer, and 261 pounds of blende in the same volume of rock.

The most detailed study of the genesis of these ores has been made by Siebenthal (33). He points out that the erosion of the Pennsylvanian shale from the central portion of the uplift exposed the Cambro-Ordovician and Mississippian rocks, down the dip of which the surface waters flowed, and ascended again on the inner margin of the Pennsylvania shale which still covered the flanks of the uplift. This water charged with carbon dioxide took the sulphides into solution as bicarbonates. As the solutions rose in the broken, cavernous ground in the Mississippian limestones, the $CO^2$ escaped and the metals were precipitated as sulphides by the hydrogen sulphide still remaining in solution.

There has been some difference of opinion among geologists who have studied these ores in the past, and therefore a brief résumé of these views is of interest partly because they indicate what varied conceptions may be based on the same evidence.

A. Schmidt [1] believed that dolomitization of the cherty limestones caused

[1] Mo. Geol. Surv., I, 1873–1874.

a shrinkage of the rock, and was accompanied by a deposition of the ore. Subsequent solution of the limestone caused a collapse of the residual chert, followed by further deposition of ore.

Haworth [1] suggested that after the chert and limestone were greatly fractured and dislocated, the sulphides were deposited, but that the deposition of secondary chert had begun before sulphide deposition ceased.

Winslow (36) thought that the breccia-filled caverns in the country rocks were formed by the percolation of surface waters, and that the metalliferous minerals were leached out of the overlying rocks by surface solutions and deposited in the breccias.

Jenney (31), however, believes the ores to have been deposited by ascending solutions.

Bain and Van Hise (27) after studying the district concluded that both ascending and descending waters were active. They also expressed the view that while the more important circulations have occurred in the Cambro-Silurian limestones and those of the Mississippian or Lower Carboniferous series, still the concentration process has been often repeated in many different horizons and at different depths.

According to their theory, then, the chemical changes which took place in the primary concentration of the ores were the oxidation of sulphides (in the limestones) to sulphates, the transportation of these in solution, and their reprecipitation as sulphides in favorable localities. The localization of the ore bodies has been due to the presence of fissures which permitted the mixing of the ore-bearing solutions, but the circulation of the latter has been limited in many instances by impervious beds of shale, and organic matter has served as a reducing agent.

In the section presented in the Ozark region, the Devono-Carboniferous shales and the undifferentiated Carboniferous shales afforded impermeable barriers to circulation. The former, where not faulted, held down the ascending solutions; but where absent or fissured, the solutions from the underlying Cambro-Silurian formation were able to pass upward into the Mississippian and impregnate them.

The Cambro-Silurian ores were first concentrated by deep circulation, and formed the disseminated ores. Later, when erosion cut away the Devono-Carboniferous capping, further concentration took place by descending solutions, giving rise to the ore bodies in crevices, breccias, and synclines.

Two concentrations have occurred in the Mississippian limestones.

Smith (34) agreed with Van Hise and Bain that the immediate sources of the ores were the various limestone formations below the Pennsylvanian. He assumed that the surface waters entered the Mississippian and Cambro-Silurian exposures to the south and east. Flowing westward along these beds, they then pass upward through fractures into the Mississippian limestones, mingling with the waters from these. Both flows are believed to have leached the smaller quantities of lead and zinc ores from the limestones through which they passed.

Precipitation of the ore occurred in the brecciated portions of the Boone formation (Fig. 224), and was caused by hydrocarbons which reduced the

[1] Contribution to Geology of Lead and Zinc Mining Districts of Cherokee Co., Kansas.

sulphates to sulphides. These hydrocarbons were set free by the dolomitization of the limestone, while $CO_2$ was set free by reaction between the hydrocarbons and the dissolved metallic compounds. The $CO_2$ thus liberated attacked some of the adjacent limestone, a part of which became replaced by silica.

The repetition of this cycle gave a continuous formation of dolomite, jasperoid, and disseminated blende. Secondary concentration of the ore may have occurred.

There are certain points of similarity in the two preceding views.

Quite different, however, is the theory worked out by Buckley and Buehler (29). According to them there was an elevation of the region after the deposition of the Burlington limestone, followed by its extensive erosion and dissection. As a result of this process, great surface breccias of residual chert were probably produced on the hillsides and along the edges of the stream valleys. Subsidence during the Coal Measures period caused their burial under Pennsylvanian (Middle Carboniferous) sediments, where they now lie and have been identified by some (Bain) as fault breccias, but in reality are due to weathering.

They also of necessity lie along the horizon of what is now a marked unconformity, giving the semblance of faults. The metals and their ores are believed by these authors to have been derived from the overlying Pennsylvanian rocks, through the agency of descending surface waters.

*Central Missouri district*, containing small deposits of both lead and zinc. In this area the ore as far as exploited occurs rather in vertical crevices or chimneys than in breccias.

*The northern Arkansas district*, but partly developed, has many rich ores, occurring as bedded deposits (disseminations), veins (in faults or filling breccias), or as replacements (4, 5).

*Southeastern Missouri* [1] (30, 36). — The disseminated lead ores of southeastern Missouri lie mainly within St. Francis, Washington, and Madison counties, the geologic section involving the following formations: —

| | | |
|---|---|---|
| | Potosi dolomite. | 300 ft. $+$ |
| | Doerun argillaceous dolomite. | 60–100 ft. |
| | Derby dolomite, thickly bedded. | 40 ft. |
| Upper and Middle Cambrian. | Davis formation, chiefly shale with thin beds of limestone, dolomite and limestone conglomerate. | 170 ft. |
| | Bonneterre, mainly magnesian limestone with sandy dolomite and shale. | 365 ft. $\pm$ |
| | Lamotte sandstone. | 200 ft. or less. |
| | Unconformity. | |
| Pre-Cambrian. | Granite and rhyolite with intrusive diabase dikes. | |

[1] The abstract of this district was kindly furnished by Dr. E. R. Buckley.

While the sedimentary series as a whole has retained its originally approximately horizontal position, there are numerous local dips, some of which may be as much as 45°. The numerous small faults of the district are roughly groupable into a northeast-southwest and a northwest-southeast system. Most of the faults are of normal type and usually have a throw of less than 100 feet; but those of the major zones show aggregate displacements of 700, 600, and 400 feet respectively.

The ore bodies of the district usually lie in pitching troughs, and while some galena of massive crystallized type has been mined with profit from the Potosi, and upper part of the Bonneterre, the disseminated deposits, which are the main source of the lead ore in the district at the present day, occur mainly in the lower half of the Bonneterre.

In the so-called disseminated lead-ore bodies, seven types of occurrence are noted, of which the first is the most important: (1) disseminations in dolomite, shale, and chloritic rock; (2) horizontal sheets along bedding planes; (3) filling or lining the walls of joints; (4) in cavities, vugs, and similar openings, sometimes embedded in soft blue clay or mixed with calcite and pyrite; (5) in shale along fault planes; (6) in cubes and aggregates of cubes in red clay, filling channels and large openings along fault zones; (7) as cerussite in decomposed dolomite.

The disseminated lead-ore bodies are in part the result of the abstraction of lead from waters circulating along channels and bedding planes in their journey from the surface to the Lamotte sandstone, and in part from solutions, under hydrostatic pressure, which rise along channels extending upward into the dolomite, from the underlying sandstone.

In the Bonneterre formation the conditions were favorable for



LEGEND

LIMESTONE

CHLORITIC LIMESTONE

SHALE

CHLORITIC SHALE

GALENA
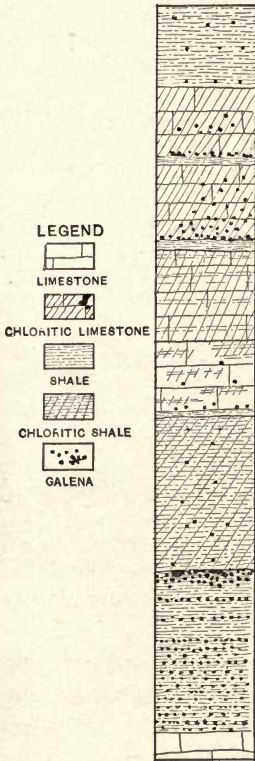
FIG. 226. — Four and one half foot section showing occurrence of ore in Bonneterre limestone, Doe Run, Mo. (*After Buckley, Mo. Bur. Geol. Min., IX.*)

the reduction of the metallic salts, resulting in their precipitation as ore bodies.

The details of the deposition are considered to be about as follows: At the surface there is an oxidized zone containing galena, which is being abstracted by surface water percolating down towards the Lamotte sandstone, which on account of its high porosity serves as a storage reservoir of water containing lead in solution. Between these two zones is the Bonneterre formation, with its carbonaceous and chloritic reducing agents, and in which formation the lead has been deposited.

Channels furnish connecting ways between the oxidized zone and the sandstone, and the rocks along these have been and are being oxidized, permitting the direct transference of oxidizing solutions, carrying lead.

Some water may have also entered the sandstone by other channels.

The dolomite, which is now oxidized along the channels traversing it, was at one time of a reducing nature, and the deposition of the galena found in the rock adjacent to these passageways must have occurred before the dolomite was oxidized. At such time any oxidizing solutions carrying lead which penetrated the lower horizon of the Bonneterre formation must have been brought in from other areas, chiefly through the rock outcropping near the area of igneous rocks. The galena in the crevices may have been introduced in part by ground water from the surface, and in part from water rising from the Lamotte sandstone. It is thought that the ore bodies in the Bonneterre are mainly subsequent to the establishment of zones of communication along the oxidized channels. The original source of the lead was the igneous rocks, its transference to the sedimentary formation having taken place during successive periods of decomposition by the surface and ground water circulations, the waters carrying the metallic compounds down into the sea where they became incorporated in the sediments then forming.

*Upper Mississippi Valley.* — This area embraces southwestern Wisconsin (63), eastern Iowa (20, 21), and northwestern Illinois (11), but the first-named state contains the most productive territory. The section in the Wisconsin area (63), which may be taken as typical, involves the following formations, beginning at the top: —

|  |  | FEET |
|---|---|---|
| Pleistocene | Loess, alluvium, and soil | 7 |
| Silurian | Niagara limestone | 50 |
|  | Maquoketa shale | 160 |
|  | Galena limestone | 230 |
| Ordovician | Platteville limestone (Trenton) | 55 |
|  | St. Peter sandstone | 70 |
|  | Lower Magnesian limestone | 200 |
| Cambrian | Potsdam sandstone | 700 |
| Pre-Cambrian | Crystalline rocks |  |

A bituminous shaly layer, known as the *oil rock*, occurs at the base of the Galena, and below it, or at the top of the Platteville, is a fine-grained limestone called the *glass rock*. While the series as a whole shows a very gentle southwest dip, there are a few low folds.

The ores occur in crevices (Fig. 227) in the dolomite or as disseminations in certain beds. In the former the order of deposition or arrangement is (1) marcasite, (2) sphalerite with some galena, and (3) galena.

The crevice deposits (Fig. 227) form the most important source of the ore, and consist commonly of a vertical fissure, which at its lower end splits into two horizontal branches called flats, while these in turn pass into steeply dipping fissures termed pitches. Galena commonly predominates in the crevices, while sphalerite occurs



TRENTON LIMESTONE    GLASS ROCK    OIL ROCK    GALENA LIMESTONE
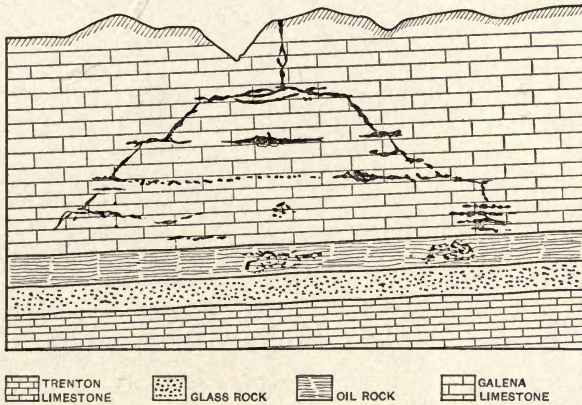
FIG. 227. — Section showing occurrence of lead and zinc ore in Wisconsin ; fissure ore in flats and pitches, and disseminated ore in wall rock. (*After Chamberlin.*)

in great abundance lower down. The main crevices extend approximately east and west, but there are other less important intersecting fissures.

The chief ore bodies lie in the lower part of the Galena limestone. Flats unconnected with pitches are found just above the oil rock at base of Galena, and in the lower part of the *glass rock*, while disseminated deposits may occur in the same position as these flats, or even in the oil rock.

The ores below the ground-water level are galena, sphalerite, and iron sulphide (usually marcasite), while above this they are galena, smithsonite, and limonite. Calcite is a common gangue mineral.

In explaining the origin of the ore bodies some have claimed (63) that the metallic minerals were gathered by circulating meteoric waters from the Galena limestone; these waters entered the limestone probably from the northeast, where the overlying shales had been eroded, and moved to the southwest. The ore was precipi-

tated in crevices as sulphides, either because of a reducing action exerted by bituminous matter present in the rocks or by hydrogen sulphide.

Surface waters descending crevices have produced a secondary concentration, which has resulted in a separation of the zinc and galena, accompanied by a transferal of much of the former to lower levels.

More recently Cox (18) has expressed the opinion that the Maquoketa shale was the probable source of the lead and zinc.



Fig. 228.—Map of a portion of Wisconsin lead and zinc district, showing strike of crevices, underground contours of Galena limestone, and underground workings. (*After Bain, U. S. Geol. Surv., Bull.* 294.)

Lead was discovered in the Upper Mississippi area as early as 1692, and the first mining was done in Dubuque in 1788. The early work was restricted to lead mining entirely, the zinc ores being disregarded. The increased price of zinc in later years led to the opening of deposits below water level, and a continued production of zinc. Mechanical concentration methods have been introduced, and while the galena can be separated quite thoroughly from the sphalerite and marcasite, the last two are parted with difficulty. On account of the presence of marcasite in most of the mines, the zinc ores of this district command a lower price than those from other areas.

Both electrostatic and electro-magnetic separation have been used on these ores with good results. Thus working on a material that assays 30 per cent zinc and 20 per cent iron, the zinc product assays 56 per cent zinc and 4 per cent iron, while the iron product gave 39 per cent iron and 5 per cent zinc.

The crude ore yields from 5 to over 20 per cent concentrates, and these in 1914 averaged 35.05 per cent zinc.

**Foreign Deposits.**[1]— Europe contains two important lead-zinc districts, somewhat analogous to the Mississippi Valley type. The first of these is the Moresnet district in Belgium and Prussia, where the ores, which carry sphalerite, galena, iron sulphide and calcite are associated with faults in the Devonian and Carboniferous limestones, and have been deposited in cavities or by

[1] Vogt, Krusch und Beyschlag, Lagerstätten.

replacement. Considerable oxidized ore was obtained from the upper part of the ore bodies.

The second of these, located in Silesia, Prussia, is among the world's leading producers. The ore here appears to form replacements in dolomitized Triassic limestone at two horizons, the lower one yielding sphalerite, galena and marcasite, and the upper one smithsonite.

Other European occurrences in limestone are those of Raible and Bleiberg in Austria; Santander, Spain, Sardinia, etc.

**Uses of Lead and Zinc.** — Both of these are important base metals; although in value of production they rank below gold, silver, copper, and iron, neither do they come into competition with these, for they lack the high tenacity of iron and steel, the conductivity of copper, and the value resulting from scarcity possessed by gold and silver. They are of value, however, on account of their high malleability and the application of their compounds for pigments.

*Uses of Lead.* — Lead finds numerous uses in the arts, the most important being for white lead. Litharge, the oxide of lead, is used not only for paint, but also somewhat in the manufacture of glass, although red lead is more frequently employed instead.

A further use of lead is for making pipe for water supply, sheet lead for acid chambers, and shot.

Among the alloys formed by lead are type metal (lead, antimony, and bismuth, with copper, or iron), white metal, organ-pipe composition, and fusible alloys used in electric lighting.

In addition to these, the acetate, carbonate, and other compounds are used in medicine. In smelting, lead is used to collect the gold and silver, and the bulk of the lead of commerce is obtained as a by-product in the smelting of the precious metals.

*Uses of Zinc.* — Metallic zinc is used for a variety of purposes, partly owing to its slight alteration in air, and secondly, because it can be rolled into thin sheets. In this condition it is used extensively for roofing and also for plumbing, and as a coating to iron this metal is extensively called for in galvanizing. It is also used for cyaniding gold.

One of the most important applications is for making brass, which is ordinarily composed of from 66 to 83 parts of copper and 27 to 34 parts of zinc. The composition varies, entirely depending on the use to which it is to be put, and, with the variation in proportion, the color becomes more golden, or whiter, according as the percentage of copper is increased or decreased. With an increase in the

amount of zinc, the alloy becomes more fusible, harder, and more brittle.

White metal is an alloy of zinc and copper in which zinc predominates, and which is often employed for making buttons. Imitation gold is also made by alloying zinc with a predominance of copper, varying from 77 to 85 per cent of the mass, and this is in common use as "gold foil" for gilding. Zinc is also made use of in the construction of electric batteries.

German silver has 60 parts copper, 20 zinc, and 20 nickel. Its use is for mathematical and scientific instruments.

Zinc is used wholly or in part as the base of four pigments, viz. zinc oxide, leaded zinc oxide, zinc-lead oxide, and lithophone. All of these can be made directly from the ore, and the first three usually are. Zinc oxide is the most important of the four. Lithophone is an intimate mixture by chemical precipitation of zinc sulphide and barium sulphate.

**Production of Lead and Zinc.** — The production of refined lead and spelter in the United States from 1875 to 1914 are given below. Other statistics of production are given in the tables on pages 653 to 655.

The imports of manufactured, block, and pig zinc amounted to $1,363,884 worth in 1912; $632,036 in 1913, and $84,120 in 1914. The total amount of zinc ore imported in the year 1914 was valued at $149,503. The total value of the exports of ore and manufactured zinc in 1914 were valued at $9,381,050. The imports of zinc oxide in 1914 amounted to 2,629 short tons, while the exports in that same year amounted to 15,592 short tons, valued at $1,408,525.

The total value of lead imported in 1914 was $504,978, while the exports were valued at $4,501,674 for the same period.

PRODUCTION OF REFINED LEAD AND SPELTER IN THE UNITED STATES, 1875 TO 1914, IN SHORT TONS

| YEAR | REFINED LEAD | SPELTER |
|------|-------------|---------|
| 1875 . . . . . . . . . . . . . . . . . | $6,913,620 | 15,823 |
| 1880 . . . . . . . . . . . . . . . . . | 9,572,500 | 23,239 |
| 1885 . . . . . . . . . . . . . . . . . | 10,095,360 | 40,688 |
| 1890 . . . . . . . . . . . . . . . . . | 14,205,960 | 63,683 |
| 1895 . . . . . . . . . . . . . . . . . | 15,092,608 | 89,686 |
| 1900 . . . . . . . . . . . . . . . . . | 32,364,024 | 123,886 |
| 1905 . . . . . . . . . . . . . . . . . | 36,500,858 | 203,849 |
| 1910 . . . . . . . . . . . . . . . . . | 41,383,936 | 269,184 |
| 1914 . . . . . . . . . . . . . . . . . | 42,285,516 | 353,049 |

PRODUCTION OF PRIMARY SPELTER IN THE UNITED STATES IN 1912-1914,
APPORTIONED ACCORDING TO SOURCE OF ORE, IN SHORT TONS

| SOURCE | QUANTITY | | |
|---|---|---|---|
| | 1912 | 1913 | 1914 |
| Arizona | 4,092 | 4,675 | 3,905 |
| Arkansas | 604 | 478 | 670 |
| California | 1,672 | 1,012 | 159 |
| Colorado | 60,841 | 58,113 | 41,746 |
| Idaho | 6,800 | 10,190 | 22,720 |
| Illinois | 3,952 | 1,345 | 1,833 |
| Kansas | 5,668 | 9,956 | 10,634 |
| Kentucky | 394 | 172 | 147 |
| Missouri | 149,557 | 129,018 | 114,019 |
| Montana | 14,196 | 35,604 | 55,986 |
| Nevada | 6,132 | 5,828 | 6,041 |
| New Jersey | 16,941 | 24,247 | 27,734 |
| New Mexico | 6,882 | 3,765 | 4,345 |
| North Carolina | —— | 152 | —— |
| Oklahoma | 2,041 | 6,397 | 9,449 |
| Tennessee | 1,935 | 2,635 | 6,122 |
| Texas | 245 | 303 | 156 |
| Utah | 7,756 | 9,503 | 6,818 |
| Virginia | 62 | 116 | 20 |
| Wisconsin | 34,137 | 33,743 | 30,914 |
| Total from domestic ores | 323,907 | 337,252 | 343,418 |
| Foreign | | | |
| Canada | 4,199 | 1,424 | 4,538 |
| Mexico | 10,700 | 6,205 | 5,093 |
| Europe | —— | 1,175 | —— |
| Siberia | —— | 620 | —— |
| Total from foreign ores | 14,899 | 9,424 | 9,631 |
| Grand Total | 338,806 | 346,676 | 353,049 |

PRODUCTION OF SPELTER IN THE UNITED STATES, 1910–1914, APPORTIONED
ACCORDING TO THE LOCALITY IN WHICH SMELTED, IN SHORT TONS

| | 1910 | 1911 | 1912 | 1913 | 1914 |
|---|---|---|---|---|---|
| Illinois | 73,038 | 83,130 | 88,397 | 106,654 | 127,946 |
| Kansas | 105,697 | 98,413 | 101,104 | 74,106 | 44,510 |
| Missouri | 5,571 | 4,116 | 7,805 | 5,085 | 3,550 |
| Oklahoma | 34,760 | 46,315 | 76,925 | 83,214 | 91,367 |
| Eastern and Southern | 43,606 | 47,155 | 56,252 | 69,063 | 77,593 |
| Colorado | 6,512 | 7,397 | 9,043 | 8,554 | 8,083 |
| Total | 269,184 | 286,526 | 338,806 | 346,676 | 353,049 |

PRODUCTION OF ZINC IN CANADA, 1912—1914

| YEAR | ZINC ORE SHIPPED | | METALLIC ZINC IN ORE SHIPPED | |
|---|---|---|---|---|
| | Tons | Spot Value | Pounds | Final Value |
| 1912 | 6,415 | $215,149 | 5,354,700 | $371,777 |
| 1913 | 7,889 | 186,827 | 7,069,800 | 399,302 |
| 1914 | 10,893 | 262,563 | 9,101,460 | 474,459 |

The Canadian imports of zinc blocks, pigs, and sheets in 1914 were valued at \$189,785, and spelter at \$551,031.

SOURCES OF PRIMARY LEAD SMELTED OR REFINED IN THE UNITED STATES, 1912–1914, IN SHORT TONS

| SOURCE OF ORE | 1912 | 1913 | 1914 |
|---|---|---|---|
| *Domestic ore:* | | | |
| Alaska | 45 | 6 | —— |
| Arizona | 3,891 | 4,901 | 5,602 |
| Arkansas | —— | | 52 |
| California | 811 | 3,294 | 3,698 |
| Colorado | 37,039 | 42,840 | 41,198 |
| Idaho | 127,780 | 137,802 | 177,827 |
| Illinois | 513 | 619 | 427 |
| Iowa | —— | | 34 |
| Kansas | 1,937 | 1,504 | 1,043 |
| Kentucky | 91 | 16 | 16 |
| Missouri | 162,610 | 152,430 | 194,275 |
| Montana | 2,517 | 3,256 | 4,386 |
| Nevada | 5,699 | 6,142 | 5,996 |
| New Mexico | 2,511 | 1,821 | 741 |
| North Carolina | 34 | 10 | —— |
| Oklahoma | 2,500 | 3,214 | 3,916 |
| Oregon | 21 | 37 | 17 |
| South Dakota | 12 | 7 | 2 |
| Texas | 30 | 108 | 89 |
| Utah | 60,664 | 71,069 | 88,976 |
| Virginia | 85 | 878 | 143 |
| Washington | 53 | 9 | 2 |
| Wisconsin | 3,301 | 2,639 | 1,818 |
| Undistributed | 120 | 63 | 99 |
| Zinc residues | 3,131 | 3,765 | 4,125 |
| Total from domestic ores | 415,395 | 436,430 | 534,482 |
| *Foreign ore:* | | | |
| Africa | 1,774 | 5,976 | 2,942 |
| Canada | 29 | 16 | 2 |
| Mexico | 7,407 | 4,512 | 2,386 |
| South America | 2,332 | 2,617 | 1,821 |
| Other foreign | 30 | 102 | 488 |
| *Foreign base bullion:* | | | |
| Mexico | 76,805 | 37,359 | 21,689 |
| Total from foreign ore and base bullion | 88,377 | 50,582 | 29,328 |
| Grand total derived from all sources | 503,772 | 487,012 | 563,810 |

PRODUCTION OF LEAD IN CANADA, 1912–1914

| YEAR | [1] POUNDS | VALUE | LEAD ORES SHIPPED, TONS | [1] LEAD CONTENTS, POUNDS | SILVER CONTENTS, OUNCES |
|---|---|---|---|---|---|
| 1912 | 35,763,476 | \$1,597,554 | 59,814 | 45,896,537 | 2,366,294 |
| 1913 | 37,662,703 | 1,754,705 | 85,978 | 53,807,570 | 2,564,155 |
| 1914 | 36,337,765 | 1,627,568 | 70,207 | 50,537,130 | 2,501,820 |

[1] Difference between production of lead, and that in ore shipped due in part to ore accumulations at smelters.

The Canadian imports of lead in all shapes in 1914 were valued at \$928,532, while the exports of pig and lead in ores and concentrates had a total value of \$22,188.

THE WORLD'S PRODUCTION OF SPELTER, 1912–1913, IN SHORT TONS

|  | 1912 | 1913 |
|---|---|---|
| Australia | 2,531 | 4,105 |
| Austria and Italy | 21,609 | 23,928 |
| Belgium | 220,678 | 217,928 |
| France and Spain | 79,543 | 78,289 |
| Germany | 298,794 | 312,075 |
| Great Britain | 63,086 | 65,197 |
| Holland | 26,380 | 26,811 |
| Norway | 8,959 | 10,237 |
| Poland | 9,659 | 8,389 |
| United States | 338,806 | 346,676 |
| Total | 1,070,045 | 1,093,635 |
| United States percentage of world's production | 31.7 | 31.7 |

THE WORLD'S PRODUCTION OF LEAD, 1912–1913, IN SHORT TONS

| Country | 1912 | 1913 |
|---|---|---|
| Australia | 118,387 | 127,867 |
| Austria-Hungary | 23,589 | 26,565 |
| Belgium | 56,438 | 55,997 |
| Canada | 17,968 | 18,849 |
| France | 34,282 | 30,864 |
| Germany | 194,666 | 199,627 |
| Great Britain | 32,187 | 33,620 |
| Greece | 15,983 | 20,282 |
| Italy | 23,699 | 23,920 |
| Japan | 4,960 | 3,968 |
| Mexico | 132,276 | 68,343 |
| Russia | 1,102 | 1,102 |
| Spain | 205,799 | 223,767 |
| Sweden | 1,433 | 1,653 |
| Turkey in Asia | 13,779 | 15,322 |
| Other countries | 13,448 | 6,834 |
| United States (domestic, refined) | 392,517 | 411,878 |
| Total | 1,282,513 | 1,270,458 |
| United States percentage of world's production | 30.6 | 32.4 |

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# CHAPTER XVIII

## SILVER-LEAD ORES

THE silver-lead ores form a large class, of rather wide distribution, and while the two metals characterizing the group are prominent, there may also be, and often is, present a variable quantity of other metals such as gold, zinc, and copper. Indeed, some that are included in this chapter might possibly be placed in the following one. The silver contents, though sometimes high, are not necessarily visible, and may be contained within the galena as $Ag_2S$.[1]

The ore bodies as a whole present a variety of forms, the ore having been deposited either by cavity filling or replacement, or both. Most of the important occurrences seem to have been formed at intermediate depths. Oxidation zones frequently cap the ore body, and downward secondary enrichment has probably occurred in some cases.

Silver-lead ores form a widely distributed class in the Cordilleran region of the United States and supply most of the lead mined in this country. Deposits are prominent in Colorado, Idaho, and Utah, but are also known in New Mexico, Montana, Wyoming, Nevada, Arizona, California, and South Dakota.

Canada supplies a small but steady production from British Columbia, while in other foreign countries districts worth noting for either commercial or historic importance are Broken Hill, New South Wales; Clausthal and Freiberg, Germany; Przibram, Bohemia; Sala, Sweden; Laurium, Greece; Mexico, etc.

## Deep-vein Zone Deposits

**United States.** — Silver-lead mines of this class are unimportant in the United States, but some carrying tourmaline occur in the Boulder batholith (15) of Montana (p. 593).

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[1] Nissen, A. E., and Hoyt, S. L., Econ. Geol., X: 172, 1915.

**Canada.** — In Canada there are certainly two occurrences in British Columbia that should be mentioned. One of these, the Sullivan mine (30), northwest of Cranbrook, represents a conformable replacement of argillaceous quartzites by galena, blende, iron sulphides, and jamesonite ($Pb_2Sb_2S_5$), with garnet, diopside, actinolite, and biotite. This has been a good producer.

The other deposit, no longer worked, is the St. Eugene at Moyie (29), which is a replacement in a fractured quartzite, and shows somewhat similar mineral composition to the preceding.

**Other foreign deposits.** — The best-known example perhaps of this group is the Broken Hill Lode in western New South Wales.[1]

This great lode, discovered in 1883, was first worked for silver, then silver lead, and in recent years, also zinc. The rocks of the region include: (1) pre-Cambrian sediments, chiefly arkoses and sandstones near the lode, all altered to gneisses and schists; (2) amphibolites derived from eruptives; and (3) granite gneisses and pegmatites. Regional metamorphism was accompanied by shearing along the line of the lode, and later injection of pegmatite along the ore zone. There was also developed in the country rock, garnet, gahnite ($ZnAl_2O_4$), sillimanite, and rhodonite.

The ore bodies, which are associated with the shear zone, often form peculiar saddle-shaped masses. A gossan rich in manganese and iron, passes downwards into oxidized ores of lead, silver, and some copper, while below this is a coarse-grained mixture of sphalerite and galena, carrying silver, and intergrown with quartz, garnet, feldspar, and rhodonite. Oxidation extends to depths of 500 to 600 feet, and secondary enrichment is well marked. The primary ores average 3 to 14 oz. silver, 14 to 16 per cent lead, and 8 to 18 per cent zinc.

The theories advanced to explain these saddle deposits include, lateral secretion (Pittman and Jacquet); bedded deposits (Krusch, Stelzner and Bergeat); epigenetic origin (Beck), and contact metamorphism (Vogt). Moore [2] suggests replacement in the hanging wall of the tabular shear zone, the beds being replaced in such a way as to give the saddle form.

In this same group may also be mentioned the lead-silver-zinc ores of Sala, Sweden, which occur in dolomitized limestone. One series of steeply-dipping ore bodies carries silver and lead, with some blende, pyrite, arseno-pyrite, and stibnite; the other series of lesser dip predominates in zinc. The ore minerals are intergrown with salite, tremolite, actinolite, epidote, biotite, and a little tourmaline. They are regarded as replacements, but show no direct connection with any instrusive.[3]

[1] Vogt, Krusch, and Beyschlag, Ore Deposits, Translation, I: 399, 1914. Jacquet, Mem. Geol. Surv., N. S. W., No. 5 Geology, 1894; Mawson, Mem. Roy. Soc. S. Austral., 1912; Austral. Inst. Min. Engrs., VI, No. 2, 17, 1910.

[2] Manuscript notes, kindly loaned to author

[3] Vogt, Krusch, and Beyschlag, Lagerstätten, II: 264, 1912; also Sjögren, Internat. Geol. Cong., Stockholm, 1910, Guidebook, No. 28.

## Deposits Formed at Intermediate Depths

**United States.** — Most of the occurrences of silver-lead ores found in the United States are placed in this group.

*Cœur d'Alene, Idaho* (13). — The Cœur d'Alene district (which is really made up of several local mining districts)
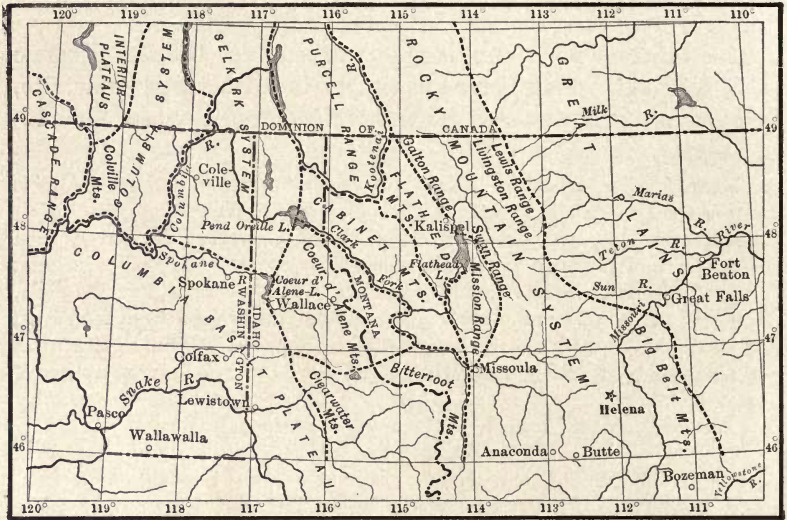


Fig. 229. — Map showing location of Cœur d'Alene, Ido., district. (*After Ransome, U. S. Geol. Surv., Prof. Pap.* 62.)

lies in Shoshone County, mostly on the western slope of the Cœur d'Alene Mountains. Wallace is the principal town, but there are several smaller ones, as Wardner, Mullan, Burke, Mace, Gem, and Murray.

The prevailing rocks here are a thick (10,000 feet), apparently conformable series of shales, sandstones, and some limestones of Algonkian age, which on the west are faulted down against granitic and gneissic rocks, but extend some distance to the eastward.

The condensed section is as follows: —

|  | FEET |
|---|---|
| Striped Peak shales and sandstones . . . . . . . . | 1,000+ |
| Wallace sandstones, shales and limestones . . . . | 4,000 |
| St. Regis shales, and sandstones . . . . . . . . . | 1,000+ |
| Revett white quartzite . . . . . . . . . . . . | 1,200 |
| Burke shales and sandstones . . . . . . . . . . | 2,000 |
| Prichard shales and sandstones . . . . . . . . . | 8,000 |
|  | 17,200+ |

Plate LXI
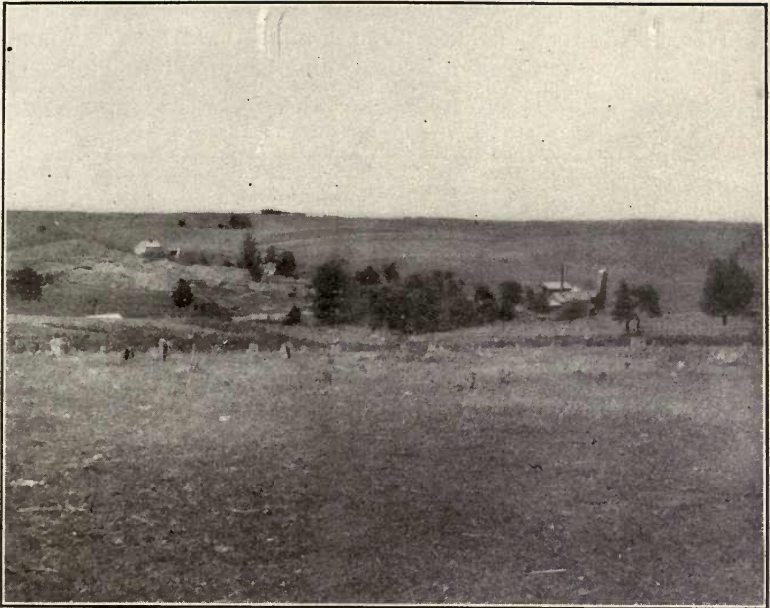


Fig. 1. — View near Linden in Wisconsin lead and zinc district. (*H. Ries, photo.*)



Fig. 2. — View looking north over the Cœur d'Alene Mountains from the Stemwinder tunnel above Wardner. Shows mature dissection of plateau-like uplift. Town of Wardner in foreground. (*After Ransome, U. S. Geol. Surv., Prof. Pap. 62.*)

The igneous rocks includes some small intrusive stocks of monzonite, and a few dikes of diabase and lamprophyre-like rocks, but the age of all is uncertain.
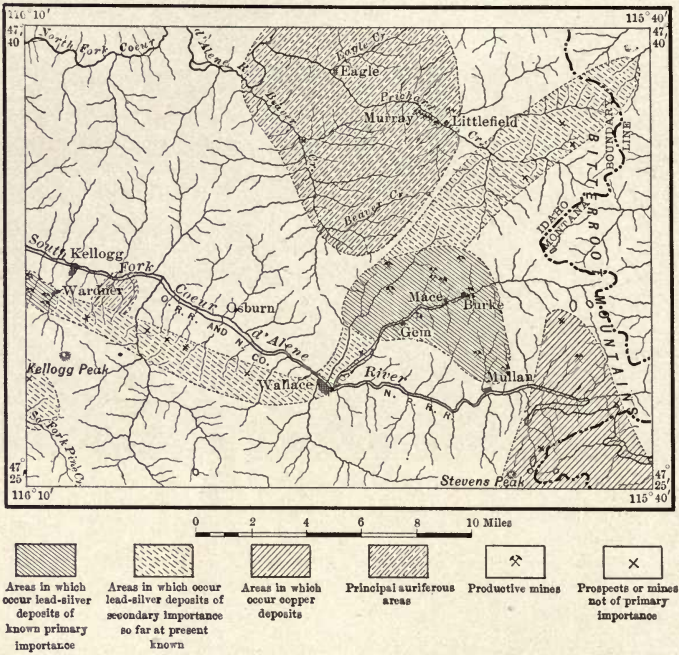


FIG. 230.—Geologic map of Cœur d'Alene, Ido., district.   (*After Ransome, U. S. Geol. Surv., Prof. Pap.* 62.)

The rocks show a series of complex, sometimes overturned, folds as well as extensive faults, and slaty cleavage has been developed in all except the quartzite.

The largest ore bodies, although wonderfully persistent, are likely to become poor at depths ranging from 1000 to 2000 feet.   Three types of ore bodies are recognized, and of these, which are described below, the first is the most important.

1. Lead-silver deposits, consisting essentially of metasomatic fissure veins, formed in greater part by replacement of siliceous sedimentary rocks, along zones of fissuring, and carrying mainly galena and siderite.   The galena may first replace the quartzite, or siderite may replace quartzite first and then be replaced by galena.

Pyrite and sphalerite are always present, and tetrahedrite, if

found, indicates high silver values, but chalcopyrite is rare.  Oxidized ores occur above.

The lead-silver veins, which lie mainly in that portion drained by the south forks of the Cœur d'Alene River and its tributaries, occur mostly in the Burke formation, while a few are found in the Revett, Wallace, St. Regis, and Prichard.
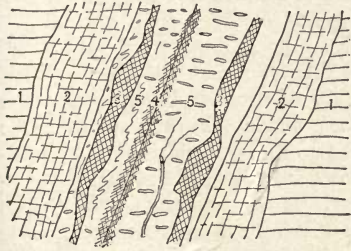


FIG. 231.— Section of lead-silver vein, Cœur d'Alene, Ido.  (1) Country rock.  (2) Sheared rock.  (3) Galena and siderite.  (4) Fissure with fine-grained galena.     (5) Barren, silicified country rock.  (*After Finlay Amer. Inst. Min. Engrs., XXXIII.*)

The average contents of ore in silver is a little over half an ounce to each per cent of lead per ton.   In 1914 the Bunker Hill and Sullivan milling ore assayed 10.35 per cent of lead and 3.796 ounces silver, while concentrates from the same mine averaged 62.91 per cent lead and 20.68 ounces silver.   The tailings assayed 2.675 per cent lead and 1.331 ounces of silver.  The bulk of the ore ranges from 3 to 14 per cent lead and 2.5 to 6 ounces silver per ton.   Most of the ore in the district is concentrated to 50 or 60 per cent lead.

The rich ores and concentrates may be sent to Tacoma ; San Francisco ; Salida, Colorado ; Helena, Montana; etc.

In the mines, the galena is shown to have a vertical range of at least 2600 feet.

2. Gold deposits, including bed veins, fissure veins, and placers formed in at least two periods.

The productive gold-quartz veins occur near Murray and are bed veins, following stratification planes of the Prichard formation.   They are usually a foot or two in width and carry quartz, gold, pyrite, galena, sphalerite, and chalcopyrite, with occasional bunches of scheelite.   The average value of the ore probably does not exceed over $7 per ton.

3. Copper deposits, consisting either of impregnations along certain quartzitic beds or metasomatic fissure veins.   Only the former type is of commercial importance, and at the Snowstorm mine it forms an impregnated zone with a maximum width of 40 feet.   The ore is chalcopyrite, bornite, chalcocite, etc., and the greater part runs 3 to 4 per cent copper, and 4.5 to 5.5 ounces silver.

*Origin of lead-silver ores.* — It is believed that the association of the ore with fissures and the absence of irregular deposits indicate that it has been deposited by ascending solutions, moreover the mineralogical composition of the ore suggests its precipitation from hot solutions.

These solutions are thought to have been given off by the monzonite in vaporous form, producing contact metamorphism and

depositing ores rich in sphalerite and pyrrhotite associated with garnet and biotite, found in some parts of the district.

Farther away from the intrusive the lead-silver ores were deposited. It is probable that the solutions entered the stratified rocks carrying ferrous carbonate and lead sulphide, and not only filled the open spaces but replaced the quartzite.

The first prospecting occurred in this district about 1878, and subsequent discoveries in 1879 started a rush to this region, but this centered round the placers, which commanded the most attention even up to 1885; but in the following year the miners awoke to an appreciation of the lead-silver deposits, and the building of a railroad into the district in 1887 gave a great impetus to the lode-mining industry. Since then the Cœur d'Alene has been an important producer, in spite of severe though temporary setbacks due to labor troubles in 1892 and 1899.

*Park City, Utah* (22), which is located on the eastern slope of the Wasatch Range, about 25 miles southeast of Salt Lake City (Fig. 246), has made Summit County famous as one of the important mining centers of this country, as there are here large bodies of rich silver-lead ores carrying minor values of gold and copper. The success of this camp, therefore, depends more or less on the condition of the silver and copper industry.

The geological section involves a series of limestones, quartzites, and shales, of Carboniferous to Triassic age, the series being folded into an anticline, which has been intruded by diorite rocks of post-Cretaceous age. Numerous fault fractures cross the district. The ores, which in the oxidized zone are cerussite, anglesite, azurite, malachite, etc., and in the sulphide zone are galena, sphalerite, tetrahedrite, and chalcopyrite, occur either as lodes or fissures, or as bedded deposits in limestones. The latter, which supply most of the ore, form replacements in certain strata of both the Upper Carboniferous and Permocarboniferous, and lie between siliceous members as walls. Both types of ore deposit are frequently associated with porphyry.

The fissures carry either silver or lead with or without zinc, and copper or gold with some silver. The replacement ores of the limestones hold silver and lead chiefly. The contact ores contain copper and gold with or without silver, and form irregular bodies in metamorphic limestone adjacent to the igneous rock.

Fig. 232. — Map of Nevada, showing location of more important mining districts.

The ordinary crude ore carries 50 to 55 ounces silver, 20 per cent lead, .04 to .05 ounce gold, 1.5 per cent copper, 10 to 18 per cent zinc. Silver is obtained in the proportion of 3 ounces silver to each per cent iron, 1 ounce

silver to each per cent lead, and .5 ounce silver to each per cent zinc. Bonanzas are known. The low-grade ores are treated at the concentrating mill, while the rich ores are shipped to the smelter.

*Tintic District, Utah* (23 and 26). — This district lies in the Tintic Mountains, about 65 miles southwest of Salt Lake City (Fig. 246). The rocks of the district include over 12,000 feet of Paleozoic sediments, folded into an overturned syncline, and broken by faulting, fissuring and sheeting. Following a period of erosion there was a period of igneous activity in the
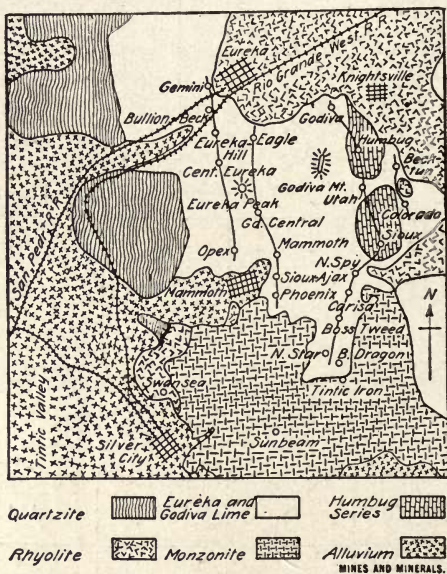


FIG. 233.—Geologic map of Tintic district, Utah. (*Adapted from Tower and Smith.*)

Tertiary, yielding rhyolites, tuffs and breccias, as well as monzonitic intrusions. The ore deposits include: (1) Thin iron-manganese deposits on the limestone-igneous rock contacts; (2) veins of silver-lead ores in monzonite, mostly abandoned; and (3) limestone replacement deposits. The last, or most important, occur in four parallel zones, the lead-silver ores predominating at the north end of the belts, and gold-copper ores at the south end, while zinc is found in both. The ores are mainly oxidized ones, weathering having reached a depth of from 1500 to 2300 feet. Crane suggests that the ore-bearing solutions came from the monzonite.

The Tintic is one of the oldest camps in the state, the ore

PLATE LXII



FIG. 1. — General view of Rico, Col., and Enterprise group of mines.



FIG. 2. — View of a portion of Mercur, Utah, and the Mercur mine.

(667)

having been discovered in 1869, and it was at first shipped as far as Baltimore and Wales. Since then mills have been erected at the mines. The chief towns are Eureka, Mammoth, Robinson, Silver City, and Diamond.

The same type of ore occurs in Big and Little Cottonwood cañons and Bingham Cañon (Fig. 246), the latter having been worked longer than those of the Tintic district. The camps lie southeast and southwest of Salt Lake City, and the ores are oxidized silver-lead ones, parallel to the bedding of Carboniferous limestones and the underlying quartzite. Galena and pyrite occur in the lower workings below water level.

*San Francisco district, Utah* (23). — This is an area producing essentially silver-lead ores, as well as copper and zinc, and lies in Beaver County, Utah. There is a sedimentary series of Paleozoic limestones, shales, and quartzites, covered by a thick flow of lava, and intruded by quartz monzonite and related rocks. The ore deposits consist of: (1) Replacements along fissures in quartz monzonite, as in the Cactus ore zone, referred to under Copper; (2) replacements in limestone, consisting chiefly of lead-silver with smaller amounts of gold and copper, and also some contact deposits; (3) replacement fissure deposits in the lava, the primary ore containing chiefly pyrite, galena, and sphalerite in a gangue of quartz, sericite and altered lava. Interesting replacements of one sulphide by another occur.

*Aspen, Colorado* (11). — The ores are oxidized and occur in highly folded and faulted Carboniferous limestone, although the section involves rocks ranging in age from Archæan to Mesozoic. Two quartz porphyries, one at the base of the Devonian, the other in the Carboniferous, are present, but bear no special relation to the ore.

At the close of the Cretaceous the rocks were folded into a great anticline, with a syncline on its eastern limit, which passed into a great fault along Castle Creek west of the mines. Contemporaneous with the folding there were also produced two faults parallel to the bedding of the Carboniferous dolomite, while at the same time much cross faulting occurred. The ore is found chiefly at the intersection of these two sets of fault planes, and Spurr believes that the ores were deposited by magmatic waters ascending vertically along faults, and were precipitated by a reaction between the solutions and certain wall rocks, chiefly shale. Mingling of solutions at

the intersection of fissures also played an important rôle in the formation of the ore. This stronger deposition of the ore at the intersection of fault planes was thought by Weed to be due to secondary enrichment, but Spurr finds little evidence of secondary sulphide formation.

On account of the intimate association of the dolomite, quartz, and barite with the ore their origin is considered as similar.

The ores are peculiarly free from other metals except lead, and the rich polybasite ($Ag_9SbS_6$) ores of Smuggler Mountain do not contain even this.

The mining camp of Aspen started in 1879, but its development for a time was much retarded by lawsuits. The richer ore bodies were not discovered until 1884, and then by underground exploration, for owing to the heavy mantle of glacial gravels their outcrops were hidden. Since also the ore carries no iron or manganese, as do the Leadville ores, its outcrop may be inconspicuous.



GLACIAL DRIFT    PARTING QUARTZITE

WEBER FORMATION    YULE FORMATION

ORE    SAWATCH FORMATION

LEADVILLE DOLOMITE    GRANITE

QUARTZ PORPHYRY

FIG. 234.— Section of ore body at Aspen, Col. (*After Spurr, U. S. Geol. Surv., Mon. XXXI.*)

The railroads did not reach the camp until 1887, so that during the first few years of its history the ore had to be carried out on burros.

In both Aspen and Smuggler Mountains long tunnels have been run for drainage and hauling purposes. The Cowenhoven tunnel, which is the largest of these, is over 8300 feet long, and taps a number of mines. Aspen was one of the first mining camps in the West to install electric machinery for hoisting, haulage, etc., and the current was cheaply supplied by the neighboring water power. One shaft 1000 feet deep is operated electrically.

At the present day the larger ore bodies are worked out, but the camp

is still an active producer. From 1881 to 1895 it produced $63,653,989 worth of silver.

*Rico, Dolores County, Colorado* (3, 9, 10). — In this region the mountains, which are the remains of the structural dome rising above the Dolores plateau lying in the San Juan region, contain a series of sedimentary beds ranging from Algonkian to Jurassic in age, which have been uplifted partly by the intrusion of igneous rocks, as stocks, sills, and dikes, and partly by upthrows due to faulting.

The ore occurs as lodes, replacements in limestones, stocks, and blankets, the last consisting usually of deposits lying parallel to the planes of bedding or to the sheets of igneous rock, and known locally as "contacts," although not such in the true sense.

The four types of deposit mentioned may pass into each other. Most of the ore in the district has, however, come from the blankets, and the bulk of this has been found in the Carboniferous, especially in the Her-



FIG. 235. — Diagrammatic section across a northeasterly lode at Rico, Col., showing "blanket" of ore. (*After Ransome, U. S. Geol. Surv., 22d Ann. Rept.*)

mosa formation, a striking feature of the deposits being their limited vertical range.

The ores are primarily galena, often highly argentiferous and associated with rich silver-bearing minerals. In many deposits the more or less complete oxidation of the silver ores has resulted in powdery masses, often very rich in silver. Below the zone of oxidation, the veins have not been successfully worked.

The bulk of the ores can be roughly divided into pyritic ores, usually low grade, and silver-bearing galena ores, sometimes containing rich silver minerals. Quartz is the commonest gangue mineral, but the beautiful pink rhodochrosite is also conspicuous.

The ore deposition is believed to be closely associated with the igneous intrusions of the district, especially with the later ones.

Most of the ore produced in the Rico district has been shipped crude or smelted in Rico without mechanical concentration.

*Other Occurrences.*— Argentiferous lead ores also occur in the Ten Mile district (4), in Chaffee County, and along the Eagle River (8), both in Colorado.

The Eureka district (17, 18) of eastern Nevada (Fig. 232), discovered in 1868, is chiefly of historic importance. The ores are oxidized lead-silver ores, carrying some gold. They occur in Cambrian limestone which is much faulted and crushed, and is part of a Paleozoic section 30,000 feet thick.

The ore is associated with a great fault, and is oxidized to a depth of 1000 feet. There are two mining districts, Prospect Hill and Ruby Hill. Near the mines are great prophyry masses which are supposed to have afforded the ores. Up to 1882 the output was not far from $60,000,000 of precious metals and 225,000 tons of lead, but the production now is insignificant.

Montana contains several lead-silver ore localities. Those of Neihart (16) occur as veins in gneiss and igneous rocks. the ores being galena, silver sulphides, and some blende. The veins are best defined in the gneiss, and are mostly replacement deposits, which have been subsequently fractured and



Fig. 236. — Vein filling a fault fissure, enterprise mine, Rico, Col. (*After Rickard, Amer. Inst. Min. Engrs., Trans. XXVI.*)

secondarily enriched. Lead-silver ores also occur at Glendale and in Jefferson County. Some are also known in South Dakota, and at Lake Valley, New Mexico (20, 21).

**Canada. British Columbia.**— The Slocan (28) district, which lies between the Kootenay and Arrow Lakes of the Selkirk province of southern British Columbia, contains a number of silver-lead and zinc deposits. The country rock includes a series of interbedded argillaceous quartzites, limestones and slates of the Slocan series (Carboniferous ?), which have been invaded by the granitic rocks of the Nelson (Jurassic ?) batholith. Folding, faulting, and lithologic similarity of the sedi-

ments have interfered with an accurate determination of the structural details. There is also an extensive system of quartz porphyry and lamprophyre dikes which seem to antedate the vein fissures. The ores occur in veins, in part breccia filled, whose length varies from a few hundred to over 4000 feet, and a thickness of from a few inches to over 50 feet. Ore shoots of varying size and sometimes following cross-fractures are common. The chief ore minerals are galena, sphalerite and freibergite, as well as ruby silver, native silver, and argentite. Chalcopyrite and pyrite are common but unimportant. Siderite, calcite, and quartz form the gangue. Weathering effects are shallow, and the ore seems to be primary, derived probably from the Nelson batholith.

The tenor of the ores ranges from 7 per cent Pb and 20 ounces per ton Ag to 50–75 per cent Pb and 80–175 ounces per ton Ag. A little gold is found in some.

**Other foreign deposits.** — Przibram, Bohemia, is a classic locality, yielding argentiferous lead ores.[1] The steeply dipping veins occur in graywackes and clay slates, which have been folded, faulted, and intruded by a diorite stock. There are also a number of diabase dikes, which follow the veins more or less closely. The veins, some of which have been followed to a depth of over 3500 feet, show a variable thickness, some being 25 feet. The common ore minerals are galena and blende, with some pyrite and chalcopyrite, in a gangue chiefly of calcite, siderite, and quartz. Silver sulphides are found especially in the oxidized zone. Where the veins pass from the graywacke into the diorite, they may lose their galena and silver, and take up stibnite (Plate XLI, Fig. 1). The origin is not perfectly clear, but was possibly connected with the associated intrusives.

The Freiberg, Saxony, district, now practically closed, possesses an historic interest, because it was here that Werner in 1791 developed his theories regarding fissure veins. The veins, of which over 1100 are known, occur in an arch of biotite gneiss, and are separable into an older and a younger group. The former contains the argentiferous quartz, pyritic lead, and argentiferous ("noble") lead formation. The latter, the barytic-lead formation.[2]

Clausthal, Germany,[3] is also well known on account of its series of veins carrying argentiferous galena, blende, and subordinate chalcopyrite, pyrite, or marcasite, in a gangue of calcite-quartz (Plate XL), or barite-siderite. The enclosing formations consists of Devonian and Carboniferous clay slates and graywackes. The ores are found filling fissures or breccia zones, and while unassociated with igneous rocks, may be genetically connected with the granite of the Brocken Mountains of the Harz.

[1] Vogt, Krusch, und Beyschlag, Lagerstätten, II: 197, 1912.
[2] *Ibid.*, II: 163, 1912.
[3] *Ibid.*, II: 177, 1912.

Laurium, Greece,[1] is another locality deserving mention, its replacement deposits of ores carrying argentiferous galena and sphalerite in crystalline limestone. In Burma, the Bawdwin mines are looked upon by some as a coming great producer. They represent replacements of ancient volcanic rocks.[2]

Among the Mexican silver-lead deposits those of the Sierra Mojada[3] forming replacement deposits in Cretaceous limestone and similar ones of the Santa Eulalia district[4] are of importance.

## Deposits Formed at Shallow Depths

**United States.** — In the Creede district of Colorado (5), lead-silver zinc veins occur in rhyolite, and rhyolite breccias, the ore carrying sphalerite, galena, pyrite, etc., in a gangue of manganiferous quartz, barite, chlorite, and adularia.

At Lake City, Colo. (6), the ores fill fissures in Tertiary flows and tuffs of the Silverton volcanic series. The primary minerals at lower levels are chiefly quartz, galena, blende, and pyrite, while at shallower depths there are also tetrahedrite, rhodochrosite, barite, and jasperoid. Secondary minerals are chiefly pyrargyrite and galena, as well as some chalcocite and possibly proustite. Native gold occurs in the upper part of the sulphide enrichment zone. The mineralizing solutions came probably from a quartz-monzonite intrusion.

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[1] Vogt, Krush und Beyschlag, Lagerstätten, II: 163, 1912.

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[4] Weed, Amer. Inst. Min. Engrs., Trans. XXXII: 396, 1902.

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## GOLD AND SILVER

GOLD and silver are obtained from a variety of ores, in some of which the gold predominates, in others silver, while in still a third class these two metals may be mixed with the baser metals, lead, copper, zinc, and iron. Few gold ores are absolutely free from silver, and *vice versa*, so that a separate treatment of the two is more or less difficult; however, some lead-silver ores, although they may carry some gold, are sufficiently prominent to be discussed as a separate type, and have been referred to in the preceding chapter.

**Ore Minerals of Gold.** — Gold occurs in nature chiefly as native gold, mechanically mixed with pyrite, or as telluride such as calaverite ($AuTe_2$; Au, 39.5 per cent; Ag, 3.1 per cent; Te, 57.4 per cent).[1]

Gold is also found at times in chalcopyrite, arsenopyrite, and stibnite, but not as a rule in such large amounts as may be shown by pyrite. Sphalerite and pyrrhotite sometimes carry it.

The gold-bearing sulphides, as well as the tellurides, are of primary character, although auriferous chalcopyrite might be formed by secondary enrichment.

Native gold may occur in the primary, secondary enrichment, or oxidized zones. The tellurides, which are usually associated with pyrite, are widely distributed, though not so abundant, but not always recognized; indeed by some they are mistaken for sulphides.

**Ore Minerals of Silver.** — The minerals which may serve as ores of silver, together with the percentage of silver they contain, are shown in the table on the following page.

Galena, sphalerite, pyrite, chalcopyrite, and chalcocite may all be and frequently are argentiferous, but in most ore deposits is usually favors the first named.

Of the ore minerals above mentioned, the most common primary ones are argentiferous galena, sphalerite, and pyrite, while native silver and the sulphides and arsenides are less common.

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[1] Other tellurides are sylvanite and krennerite.

| MINERAL [1] | COMPOSITION | Ag |
|---|---|---|
| Native silver . . . . . . . | Ag | 100. |
| Argentite, silver glance . . | $Ag_2S$ | 87.1 |
| Pyrargyrite, ruby silver . . | $3Ag_2S, Sb_2S_3$ | 59.9 |
| Proustite, light ruby silver . | $3Ag_2S, As_2S_3$ | 65.5 |
| Stephanite, brittle silver, black silver . . . . . . . . . | $5Ag_2S, Sb_2S_3$ | 68.5 |
| Polybasite . . . . . . . . | $Ag_9SbS_6$ | 75.6 |
| Cerargyrite, horn silver . . | AgCl | 75.3 |
| Bromyrite . . . . . . . | AgBr | 57.4 |
| Embolite . . . . . . . | Ag(ClBr) | 64.5 |
| Iodyrite . . . . . . . | AgI | 46.0 |
| Tetrahedrite (Freibergite). . | $4(Cu_2Ag_2FeZn)S, Sb_2S_3$ | Variable; usually present; may be high. |

In the oxidized zone, silver chloride is the most abundant, and native silver less so, while the iodides and bromides are quite rare and formed only under certain conditions.

The secondary enrichment ores include native silver, argentite, stephanite, tetrahedrite, pyrargyrite, and proustite.

**Mode of Occurrence.** — Most of the gold and silver mined in the United States is obtained from fissure veins, or closely related deposits of irregular shape (113), in which the gold and silver ores have been deposited from solution, either in fissures or other cavities, or by replacement. Considerable gold and a little silver are obtained from gravel deposits, and some true contact-metamorphic deposits are known. Gold has been found to occur in rare instances as an original constituent of igneous rocks (1, 15, 18) and also metamorphic ones (19), but there are no known deposits of commercial value belonging to this type.

The gold- and silver-bearing fissure veins include two prominent types (113), viz.: (1) the quartz veins, and (2) the propylitic type, in which the metasomatic alteration of the wall rock is often propylitic. In the quartz-vein type silver is present usually in but small quantities, while in the propylitic type the silver often is an important constituent. Veins of intermediate character may also occur.

While the mode of occurrence of gold and silver is quite variable, the character of the wall rock is equally so, gold and silver ores being found in either sedimentary or igneous rocks, and along the contact between the two, showing that the kind of rock exerts little influence, except perhaps where replace-

[1] Other less common ones are polyargyrite, pearcite, miargyrite, etc.

ment has been active. On the other hand the influence of locality is much stronger, for it has been found that many gold- and silver-bearing deposits are closely associated with masses of igneous rock, the most common of these being diorite, monzonite, quartz-monzonite, granodiorite, while true granites are rare as associates. A second large class of vein systems shows a close association with lavas of recent age, and the telluride ores rather favor these (8).

**Weathering and Secondary Enrichment.** — The superficial alteration of gold ores differs somewhat from that of deposits containing ores of the other metals. In quartz veins with auriferous pyrite, the change of the latter to limonite leaves a rusty quartz with nuggets or threads of free gold, and leaching may remove most of the iron.

The conditions under which gold is removed by the influence of manganese are discussed on p. 480.

Telluride ores weather in a somewhat characteristic manner, the product being free gold. This may be of earthy appearance and faint brownish color, or consists of aggregates of extremely small crystals of gold which form a spongy mass, or a thin film on the surface of the rock.

Silver sulphides are changed to chlorides, and native silver may also be formed. In the weathered portion of some silver-bearing deposits, silver bromides and iodides are also found.

Penrose has suggested [1] that such ore bodies were in the vicinity of saline deposits, where haloid compounds were dissolved by the soil waters that penetrate the ores. Keyes, however, believes that the prevailing source of saline materials is the wind-blown dust produced by disintegrative processes so predominant in arid regions (9).

Downward secondary enrichment has evidently occurred in a number of silver and silver-gold deposits. According to W. H. Emmons (7), all deposits in which gold appears to have migrated include manganiferous ores. In deposits carrying both metals, especially where chlorides form, secondary silver minerals are likely to be precipitated as bonanzas near the surface, while gold is carried deeper, but if chlorides are not formed in manganiferous deposits, silver may be carried deeper than gold. Abundant pyrrhotite is said to rapidly halt the downward migration of both gold and silver. In copper deposits where silver

[1] Jour. Geol. II: 1894.

and gold migrate downward, these are deposited chiefly in the upper part of the secondary sulphide zone. Many deposits of rich silver ore and some of rich gold ore terminate downward in low-grade sphalerite ores.

**Geological Distribution.** — Gold and silver ores have been deposited at a number of different periods in the geological history of the continent, notably, in the pre-Cambrian, Cambrian, Cretaceous, and Tertiary ages.

Some of the Appalachian veins are probably early Paleozoic, and those of Nova Scotia are post-Cambrian. Silver ores show much the same geological range.

The geological distribution is referred to in more detail under Metallogenetic Epochs in Chapter XIV.

**Classification.** — A classification of gold and silver ores is in any event attended with more or less difficulty. Divisions based on geological and structural characters would for many purposes be more satisfactory, while for commercial or metallurgical work a grouping according to metallic contents is perhaps more desirable.

The following classification according to the associations of the ores is sometimes used in the United States.

1. *Placers or Gravel Deposits.* — These serve chiefly as a source of native gold, but may, and often do, contain a little silver, much of which is never separated from the ore in which it occurs. These gravels are derived chiefly from quartz veins of Mesozoic age in the Pacific coast region, and to a less extent from pre-Cambrian veins of the Appalachian region and Black Hills of South Dakota. Some are also derived from veins in Tertiary lavas, but these usually contain the metals in such a finely divided condition, or in such combination, that they do not readily accumulate in stream channels.

Large quantities of placer gold are obtained from Alaska and California.

Taking all sources, we see that placer gold is obtained by dredging, drift-mining,[1] hydraulicking, and sluicing, as well as in small amounts from dry placers in the southwest and beach gravels of California and Oregon.

Dredging, which was started in New Zealand about 1882, and first profitably tried in the Bannock district of Montana in 1893, is now of great importance, the modern bucket elevator dredge (often electrically driven)

[1] In decreasing quantity from frozen ground in Alaska, but still in considerable amounts from buried channels in California.

being capable of excavating as much as 10,000 cubic yards daily, and the buckets each having a capacity of 16 cubic feet. The total value of gold in millions of dollars produced in this manner by several states up to date is: Montana, $6\frac{1}{2}$; Idaho, 3; Colorado, $2\frac{3}{4}$; Alaska, 10; California, over 71.

2. *Dry or Siliceous Ores.* — These include: (*a*) The gold and silver ores proper; (*b*) fluxing ores carrying considerable quantities of iron and manganese oxides with small gold and silver contents; and (*c*) precious-metal bearing ores with copper, lead and zinc in small amounts. Colorado, California, Nevada, South Dakota, and Alaska have been the largest gold producers of this type.

The siliceous gold ores are in part free milling (amalgamating) as Alaska, California, and Oregon; in part both amalgamating and concentrating; in part simply concentrating, as parts of Colorado and Arizona; in increasing part all-sliming and cyaniding; and in part smelting.

A great deal of the silver from the gold-silver siliceous ores is obtained with the gold by amalgamation and cyanidation, the silver being recovered by refining the mill bullion. The remainder is obtained by smelting rich ores and refining copper or lead bullion produced.

Nevada yields now over one-half the silver production, but much also comes from Colorado.

The siliceous ores are of varying age. Those of California, Oregon, and Alaska are Mesozoic and associated chiefly with quartz—monzonite, granodiorite, and diorite. Another great class of post-Miocene age, found chiefly in Colorado, Nevada, and Montana, is associated with Tertiary lavas and characterized by Bonanzas. The most productive ones carry fluorite and normally also tellurides. In some, gold may predominate; in others, silver. A third class, of pre-Cambrian age, is found in the Atlantic states, Wyoming, and South Dakota, the last mentioned including the famous Homestake mine.

3. *Copper ores*, usually with over $2\frac{1}{2}$ per cent copper, but with less in the case of the western disseminated ores and those of Lake Superior.

The largest gold producers are those of Utah, Arizona, Nevada, and Montana. The silver production comes from the electrolytic refining of Michigan copper, and blister copper produced by smelting. The great disseminated deposits of Utah, Arizona, Nevada, and New Mexico are yielding increasing quantities, while the vein deposits of Butte, Mont., are also important.

The gold- and silver-bearing copper ores exhibit great differences in form and age; neither do all the occurrences yield much gold or silver, and, moreover, they are of more importance as gold producers, silver being less often associated with the copper.

4. *Gold- and Silver-bearing lead ores*, containing $4\frac{1}{2}$ per cent or more of lead. The gold is obtained chiefly from Utah and Colorado. The silver comes mainly from the lead-silver ores of Cœur d'Alene, Idaho, Utah (chiefly Park City and Tintic), Colorado (Leadville and Aspen). Most of the output is obtained by the de-silverization of lead bullion.

5. *Copper-lead or Copper-lead-zinc Ores.* — These are unimportant as compared with the others. The gold supply is small, and the main silver supply is from Colorado and Nevada.

6. *Zinc ores*, containing at least 25 per cent zinc. These yield little gold, and the silver which is obtained mainly as a by-product from the smelting of zinc concentrates is obtained chiefly from Nevada, Montana, and Arizona.

**Extraction.** — Since gold and silver ores vary so in their mineralogical associations and richness, the metallurgical processes involved in their extraction are varied and often complex.

Those ores whose precious metal contents can be readily extracted after crushing, by amalgamation with quicksilver, are termed *free-milling ores.* This includes the ores which carry native gold or silver, and often represent the oxidized portions of ore bodies. Others containing the gold as telluride or containing sulphides of the metals, are known as *refractory ores* and require more complex treatment. These, after mining, are sent direct to the smelter if sufficiently rich, but if not they are often crushed and mechanically concentrated. The smelting process is also used for mixed ores, the latter being often smelted primarily for their lead or copper contents, from which the gold or silver is then separated. While in some cases there are smelters at the mines, still there is a growing tendency towards the centralization of the industry, and large smelters are now located at Denver, Salt Lake City, etc., which draw their ore supply from many mining districts.

Low-grade ores may first be roasted, and the gold then extracted by leaching with cyanide or chlorine solutions. The introduction of the cyanide and chlorination processes, which are applied chiefly to gold ores, has permitted the working of many deposits formerly looked upon as worthless, and in some regions even the mine dumps are now being worked over for their gold contents. It is estimated that in 1914 $28,629,147 worth of gold bullion was recover by cyanidation. The chief fields are in the Cripple Creek region of Colorado; the De Lamar district, Idaho; Marysville, Montana; Bodie, California; and in Arizona.

The most important gold-milling centers of the United States are the Mother Lode district of California; the Black Hills, South Dakota, and Douglas Island, Alaska.

The value of ore and bullion is determined from a sample assay, and the smelter, in paying the miner for his ore, allows for gold in excess of $1 per ton of ore at the coining rate of $20.67 per ounce, and for silver at New York market price, deducting 5 per cent in each case for smelter losses. Lead and copper are paid for in the same manner, as are also iron and manganese, if there is a sufficient quantity present. No allowance is, however, made for zinc, and, in fact, a deduction is made if it exceeds a certain per cent.

**Distribution of Gold and Silver Ores in the United States** (Fig. 237). — Gold ores are widely distributed in the Cordilleran and Appalachian regions, while the silver ores are found



Fig. 237. — Map showing distribution of gold and silver ores in the United States. (*Adapted from Ransome, Min. Mag., X.*)

chiefly between the Great Plains and Pacific coast ranges, exclusive of the Colorado plateau region. This occurrence in two widely separated areas is brought out in an interesting manner in Fig. 237.

More than one-half of the United States production of gold comes from three states—California, Colorado, and Nevada. In these, however, the ores vary widely in their mineralogical associations, the gold occurring mostly in combination with silver, lead, copper, and zinc ores, but also at times free, or, in the most productive district, as a telluride.

The Pacific belt, excluding Alaska, supplies about 25 per cent of the total amount of gold produced, the famous Mother Lode region, mentioned later, being the most important producer. Alaska yields about 17 per cent, and the Basin Range province nearly 22 per cent, collected from widely separated deposits in Utah, Nevada, Arizona, and New Mexico, and in which the gold is associated with copper, silver, or lead.

About 49 per cent of the silver obtained in the United States comes from the Rocky Mountain region, Idaho alone yielding nearly one-fifth, while Montana supplies a little less. The Basin Range province furnishes something under two-fifths, nearly one-half of this coming from Utah, especially from the Park City mines near Salt Lake City[1] (114).

The gold and silver occurrences of the United States can be grouped under five regions as follows:

1. *Cordilleran Region.* — This includes several types geologically arranged as follows: (*a*) belt of Pacific coast Cretaceous gold quartz ores, characterized by ores with free gold, and auriferous sulphides, extending along the Pacific coast from Lower California up to the British Columbia boundary. The deposits belonging to this are especially important in California, but farther north, in Oregon and Idaho, the veins in many cases have been covered up by the lava flows of the Cascade Range, and those known in that region differ somewhat from the California deposits in containing many mixed silver-gold ores and also veins carrying auriferous sulphides without free gold. The ores of this belt are all of undoubted Mesozoic age, and are accompanied by many extensive placer deposits, which have been derived by the weathering down of the upper parts of the quartz veins, the portions now remaining in the ground representing probably but the stumps of originally extensive fissure veins (113).

Among the deposits of this belt two groups stand out in some prominence, namely, those of the so-called Mother Lode district and of Nevada County.

*b.* Late Cretaceous or Early Tertiary deposits, occupying a broad zone in the central and eastern part of the Cordilleran region, and yielding gold ores of varying character. While they differ in ʻ ʻ and characters from the Pacific coast ores,

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[1] These estimates are, of course, only approximate.

and those of the belt next to be mentioned, nevertheless they are not absolutely separated from them geographically.

The Mercur, Utah (Fig. 246), and Leadville, Colorado (Fig.



FIG. 238. — Map of California, showing location of more important mining districts

249), deposits, the latter referred to under lead and zinc, are included under this type.

The northward continuation of this belt of gold-bearing veins

in Idaho and Montana presents somewhat different types of deposits, for there the veins are causally connected with great batholiths of Mesozoic granite; and while the veins resemble those of the Pacific coast in the quartz filling and free gold contents, they differ from the latter in containing more silver, and often large quantities of sulphides with little free gold. In fact, in their geologic relations they are intermediate between the quartz vein and propylitic type. Of special prominence are those of Marysville, Montana (80), and Idaho Basin, Florence, etc., in Idaho. This difference is more marked in the Montana occurrences, in which the gold becomes subordinate and is obtained as a by-product in silver mining.

(c) Eastern belt of Tertiary gold-silver veins, of greater importance than the preceding class and characteristic of regions of intense volcanic acticity. The veins cut across andesite flows, or more rarely rhyolite and basalt. They may be entirely within the volcanic rocks, or the fissures may continue downward into the underlying rocks, which have been covered by the extrusive masses. Many of these Tertiary deposits belong to the propylitic class, showing characteristic alterations of the wall rock. The ores are commonly quartzose, and though either gold or silver may predominate, the quantities of the two metals are apt to be equal. Bonanzas are of common occurrence, and on this account the mines may be very rich but short-lived; still, the workable ore in many extends to great depths; but is less rich than nearer the surface. Extensive and rich placers are rarely found in the Tertiary belt of veins, for the reason that the fine distribution of the gold is not favorable to its concentration and retention in stream channels. Deposits of this type are worked in a number of states, including Colorado, Nevada, Arizona, New Mexico, and Idaho. Colorado leads in the production of gold ores, for in no state are the Tertiary deposits of the propylitic type developed on such a scale.

2. *Black Hills Region*, the ores which are found chiefly in the northern Black Hills, including: (a) Auriferous schists in pre-Cambrian rocks; (b) Cambrian conglomerates; (c) refractory siliceous ores; (d) high-grade siliceous ores; and (e) placers. Of these, the first and third are the most important.

The surface placers, being the most easily discovered, were developed first, followed by the conglomerates at the base of

the Cambrian.[1] These are found near Lead, occupying depressions in the old schist surface, and the material is thought to have been derived from the reef formed by the Homestake ledge in the Cambrian sea. These deposits are of interest as being probably the oldest gold placers known in the United States. The fact, however, that the matrix of the gold-bearing portion of the conglomerate is pyrite rather than quartz, and the occurrence of the gold along fractures stained by iron, has led some to believe that the gold has been precipitated chemically by the action of iron sulphide and is not a detrital product.

3. *Eastern Crystalline Belt* (114). — Gold, with some silver, has been found in the rocks of this belt from Vermont to Alabama, but the deposits are of little importance except in North Carolina (96–97), South Carolina (106, 107), Georgia (69–71), and Alabama (22, 23), in other words, in the southern Appalachian and Piedmont region; but even in this part of the area the deposits are not found everywhere, but are restricted to three belts (Becker), viz.: (1) the Georgia belt, extending from Montgomery, Alabama, across northern Georgia to North Carolina; (2) the South Mountains region of North Carolina; (3) the Carolina belt, lying to the eastward of the others, and extending from South Carolina northeastward through Charlotte, North Carolina, and continued in Virginia; at least the Virginia deposits lie in part in the line of strike of this zone.

**Geologic Comparisons** (13a). — It will be seen from the preceding pages that the ores of South Dakota and the Appalachians belong to an older group whose age ranges from pre-Cambrian to Paleozoic, and to which belong also the gold ores of Nova Scotia, Ontario, and Quebec. Here too belong many of the deposits of Brazil and other eastern and northern South American countries. Representatives of this group are known also in other countries, notably Australia.

The other North American occurrences belong to a younger group of late Mesozoic to Quaternary age. Few representatives of this class are found in Canada, but they yield the enormous silver supply of Mexico, and many are known and worked in the Andean region of South America.

Other important occurrences are worked in Hungary, New Zealand, etc.

[1] These are referred to as cement mines, owing to their partly cemented character.

### Contact-metamorphic Deposits

Gold and silver may be present in small amounts in copper deposits of this class, but ore bodies of this type containing the noble metals as important constituents are rare.

Such a case has, however, been recorded in the Cable mine in the Philipsburg quadrangle of Montana (78a), where the ore body occurs in limestone surrounded by quartz-monzonite. The chief non-metallic minerals are calcite, quartz, barite, and dolomite, with pyrite, chalcopyrite, pyrrhotite, arsenopyrite, magnetite, specularite, and gold as the primary metallic ones. Contact silicates also occur.

Of considerably greater importance is the ore deposit of the Nickel Plate Mine at Hedley, British Columbia (135), which is of a rare type. The ore deposits occur at the contact of dikes and sheets of gabbro in Carboniferous limestones (Fig. 239) which are interbedded with quartzite, shale and volcanic tuffs. The ore bodies, which are of irregular outline, contain arsenopyrite, with chalcopyrite, pyrrhotite, blende, pyrite, native gold and tetradymite ($Bi_2Te_3$). The gangue includes garnet, epidote, diopside, amphibole, quartz, calcite, and axinite. The gold averages $11.00 per ton.

Other deposits of this group are auriferous tellurides at Elkhorn, Montana, and deposits of argentiferous and auriferous bornite at Chiapas, Mexico.[1]

### Deposits of the Deep-vein Zone

These include deposits, chiefly in the form of fissure veins, precipitated under high-temperature conditions, either in cavities or by replacement. In most of the deposits belonging to this class, gold is more abundant than silver.

**United States.** — Gold and silver ores of this class are not very abundant in the United States, but include some well-known deposits.

*Silver Peak, Nev.* (92). — The deposits at this locality are so closely associated with igneous rocks that Spurr classed them as magmatic segregations (p. 92), but some may feel that they might be better put in the deep-vein zone class. The ore occurs in lenticular masses and fissure veins of quartz, which

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[1] McCarty, Inst. Min. and Met., London, Trans. IV: 169, 1895.

PLATE LXIII
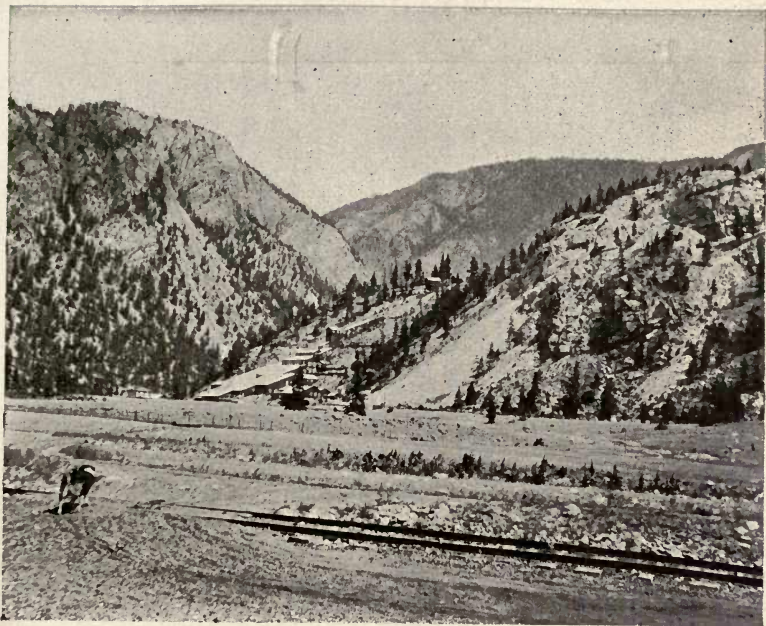


FIG. 1. — Mill of Nickel Plate mine, Hedley, B. C. Mines on ridge in background. (*H. Ries, photo.*)



FIG. 2. — Virginia City, Nev., Mt. Davidson in rear, on whose lower slope the Comstock Lode outcrops. (*H. Ries, photo.*)

(687)
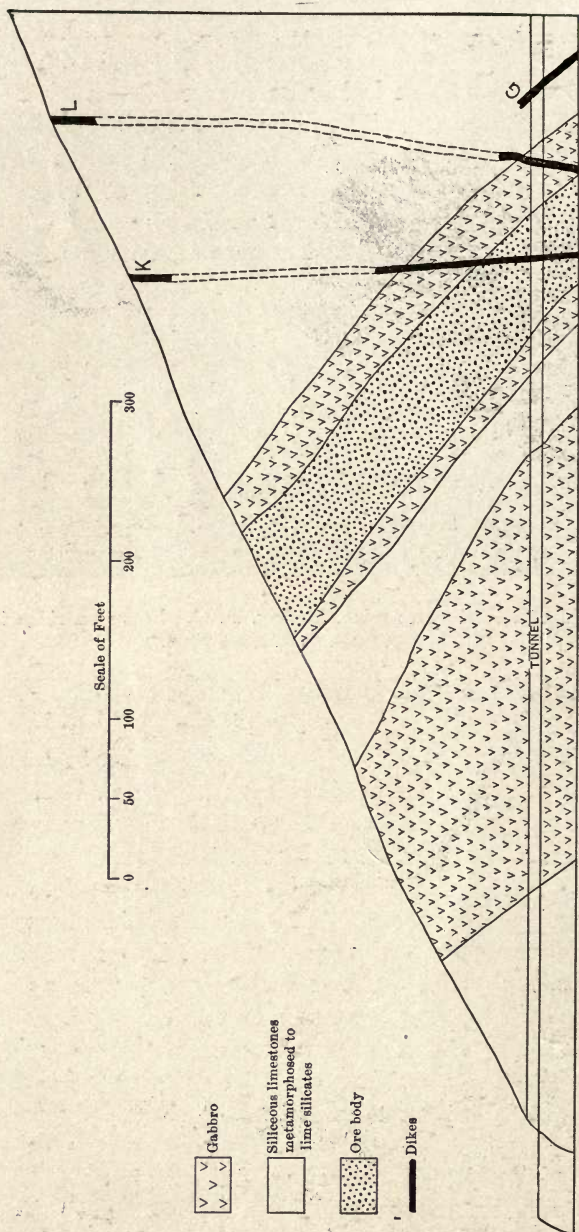
Fig. 239. — Vertical section through ore body at Hedley, Brit. Col. (After Camsell.)

grade into alaskite and this in turn into granite, so that the quartz represents the end-phase of the intrusion. The gold
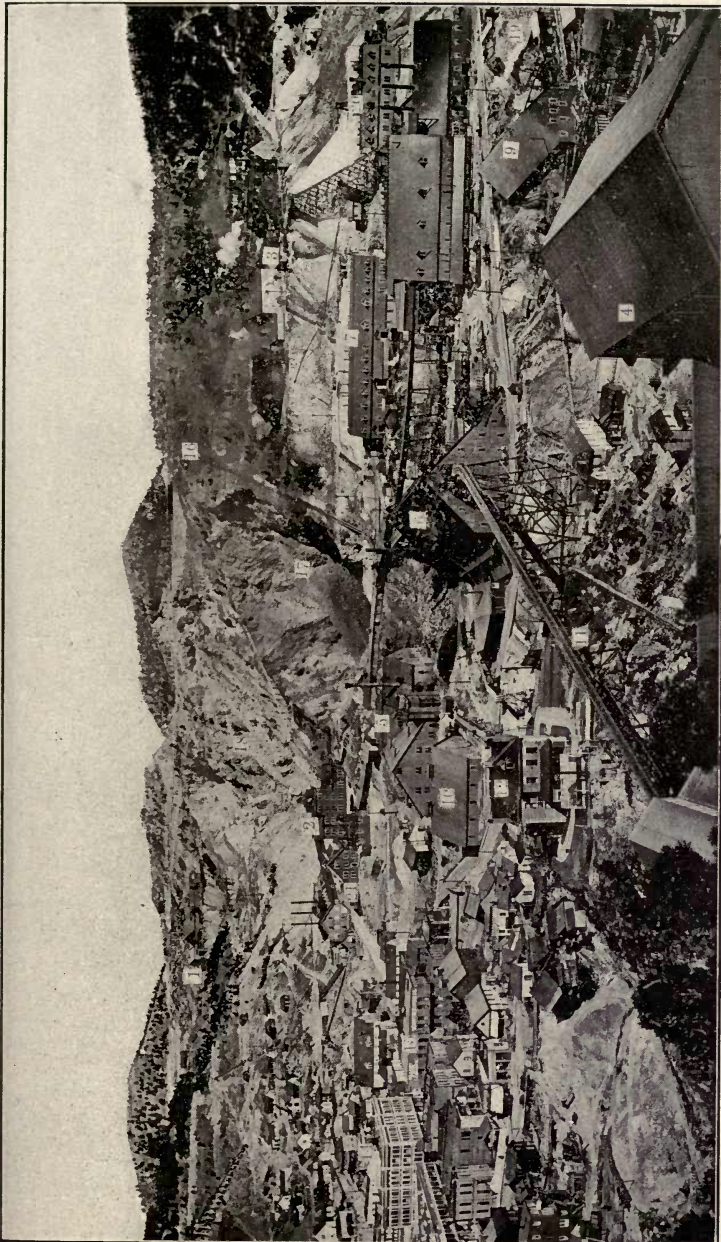
PLATE LXIV. — Homestake mills, hoists, and open cuts at Lead, S. Dak.  (*After O'Harra, S. Dak. Sch. of Mines, Bull. 6.*)

1. Highland hoist and sawmill.
2. Golden Star hoist.
3. Old Abe hoist.
4. Ellison hoist.
5. Homestake mill.
6. Golden Star mill.
7. Amicus mill.
8, 9, 10. Plate houses.
11. Steel bridge.
12. Superintendent's residence.
13. Coal chute.
14. Hotel Smead.
15. Office, Hearst free library, and company store.
16. Old experimental cyanide plant.
17, 18. Open cuts.
19. Wood chute.
20. Shop.
21. Miners' bath and dressing rooms.

(722)

occurs chiefly in the quartz. Paleozoic limestone is the main country rock.

*South Dakota.* — The gold ores of the Homestake belt (109, 110), which are the most important in the Black Hills, occur in a broad zone of impregnated schists, containing many quartz lenses, alternating with dikes of fine-grained rhyolite, which also formed sheets in the Cambrian sediments overlying the schists, and now remain as a resistant cap on many of the surrounding ridges (Fig. 240). The ore, which is all low-grade, averaging about $4 per ton, is usually a mixture of quartz,
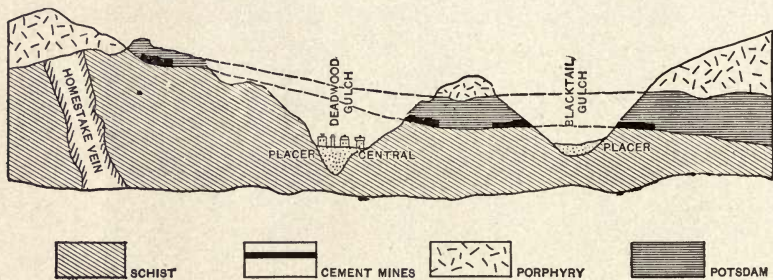


FIG. 240. — Section of Homestake belt at Lead, S. Dak., showing realtion of ancient and modern placers to Homestake lode. (*From Min. Mag., XI.*)

pyrite, and occasionally other minerals having no definite connection with it, occupying a zone in the Algonkian rocks which shows greater hardness, irregularity of structure, and mineralization than the surrounding schists. The boundaries are poorly defined, and superficial examination may fail to distinguish between ore and barren rock. In the upper levels the ore seems to be with the dikes, but diverges from them in depth, and there is apparently no genetic relation between the two. In the earlier days the ore encountered was oxidized and freemilling, but the appearance of sulphides with depth has necessitated the introduction of the cyanide method of extraction. The ore was originally worked as an open cut (Pl. LXIV), but later by underground methods.

In 1914 the output of this mine was 1,587,774 short tons of ore milled, with $6,160,161 of bullion recovered, the ore value per ton being $3.87.

*Appalachian Belt* (114). — The crystalline belt of the southern Appalachians contains numerous quartz veins, some of which

are of lenticular character. There may also be replacement deposits in silicified schist. The placers derived from these quartzose ores have yielded considerable gold in the past, notably in Georgia, Virginia, and North Carolina, but the vein mining has been less productive. It is doubtful whether all the veins belong to the deeper-vein zone, some probably having been formed at intermediate depths.

In the Carolina belt Graton (106) states that the quartz veins with more or less pyrite occur in dense metamorphic rocks, and most commonly in amphibole or gabbro closely related to it, and formed by the filling of fracture spaces. The veins, which are irregular and have a steep dip, conform usually somewhat closely to the strike and dip of the inclosing rocks.

Similar occurrences are found in the other belts of the southern Appalachians, and some, as those at Gold Hill, North Carolina, have shown copper with depth, so that they were worked for both metals.

The replacement type, which is important in the Carolina belt, is less common but more productive than the preceding, and with one or two exceptions is found in volcanic rocks, mostly tuffs. The porous nature and easily alterable character of these, especially the tuffs, has allowed widespread penetration and replacement by the ore solutions, which deposited chiefly silica and pyrite.

The ore bodies are usually large, and range from 40 or 50 to hundreds of feet in length, and 20 to several hundred feet in width; but their outline is rudely lenticular.

At the Haile Mine in South Carolina, which belongs to this type, the country rock is a quartz-sericite schist, which has been derived by foliation from a porphyry tuff which had an original well-bedded structure that is still preserved in some cases. The silicification appears to correspond in intensity with the amount of foliation, although in cases of extreme silicification all traces of former structure have been quite destroyed, and the rock is simply a massive siliceous hornstone. Several dikes of diabase cut the schist.

The ore consists of large lenses of altered tuff, which have been silicified and pyritized, the two processes having gone on at the same time, so that the rock now consists of a fine-grained aggregate of quartz and pyrite with scattered fibers of sericite. The replacement is not uniform. The gold occurs (1) mainly as native gold

originally deposited, (2) free gold derived from oxidation of the inclosing pyrite, and (3) gold in pyrite.

This mine, which has been worked more or less continuously since about 1830, has been one of the most important producers in the southern Appalachian region.

*Other occurrences.* — The copper deposits of the Cactus Mine, Utah; Copperopolis Calif; and Meadow Lake, Calif, yield not a little gold, but copper as well, and are mentioned under the latter.

**Alaska** (24). — Although gold has been known to occur in Alaska since the early part of the century, and was even worked in 1860, its production is not definitely stated until 1880, when



Fig. 241. — Map showing mineral deposits of Alaska.   (*After Brooks, U. S. Geol. Surv., Bull.* 250.)

it was added to the list of gold-producing regions, with an output of $20,000, which since that time has increased many times over, but not steadily, until it reached a maximum of $22,036,794 in 1906, and had dropped to $15,764,259 in 1914.

The first gold was discovered on the islands of the Alexander Archipelago and along the adjoining coast, but subsequently prospectors found their way into the interior, the first strikes there being

made in British Columbia near the head of the Stikine River. These were followed by discoveries in the Yukon Valley, especially along some of the tributaries known as Birch Creek, Mission Creek, and Forty Mile Creek. In 1896 still richer discoveries were made along the Klondike River, and within one year the yield of this region had exceeded the purchase price of Alaska. Other discoveries have since followed rapidly.

At the present time approximately 68 per cent of the value of the gold produced in Alaska is obtained from placers, 31 per cent from quartz ores, and the balance from copper ores.

*Auriferous Lodes* (32). — The gold quartz lodes, which are most prominent along the coast (Fig. 241), were first discovered near Sitka in 1897, but the first important production came from the Treadwell mine on Douglas Island southeast of Juneau (32) in 1882.

The geology of this region bears in many ways a strong resemblance to the California gold belt, but the ores differ in
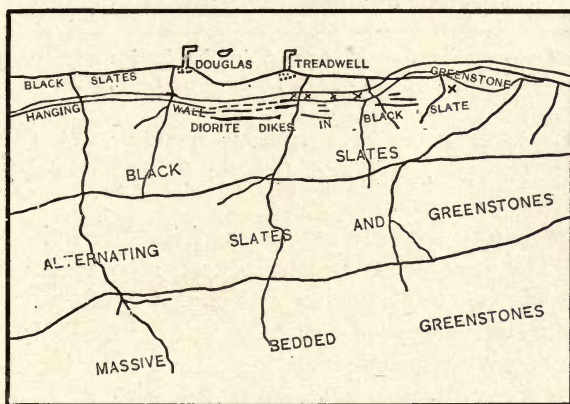


FIG. 242. — Sketch map of Douglas Island, Alaska. (*After Spencer, U. S. Geol. Surv., Bull.* 259.)

origin. The section involves a series of steeply dipping slates and greenstone and diorite dikes. The ore bodies (Figs. 242, 243) are dikes of albite-diorite, permeated with metallic sulphides and carrying small amounts of gold, with a hanging wall of greenstone and a foot wall of black slate. The veinlets, which are thought to have been formed by shearing stresses incident to epeirogenic movements, occur in two sets of fractures at right

angles to each other. Spencer believes that the mineralization has been caused by hot ascending solutions of magmatic origin. Secondary concentration is not in evidence, and it is thought that the depth to which the ores can be worked will depend more on the increased cost of mining at great depths than on exhaustion of the ore.

The workings on Douglas Island extend for a distance of 7000 feet. Gold also occurs in quartz veins along the cost.

The southeastern Alaska gold ores are placed in this group because of the character of the gangue minerals and alteration of the wall rocks.



Fig. 243. — Cross section through Alaska Treadwell mine on northern side of Douglas Island. (*After Spencer, U. S. Geol. Surv., Bull.* 259.)

**Canada.** — A number of auriferous quartz veins are known in Ontario (126, 127, 137) and Quebec (138), but few of them are of much importance.

The best known deposits are those of the Porcupine district, Ontario. The ore bodies which occur in the metamorphosed sediments of the Temiskaming series, and schistose volcanics of the Keewatin, consist of lenticular veins, irregular veins and domelike masses of quartz, carrying native gold together with pyrite and some other metallic sulphides, with which are associated calcite, dolomite, sericite, chlorite, tourmaline, and quartz. The gold and pyrite appear to have been deposited about the same time, and especially in the crushed portions of the quartz or the schist bordering these. The annual production of this district now exceeds $4,000,000.

Other gold quartz veins are known in the Lake of the Woods (145) and Rainy Lake districts (137), also at Lakes Abitibi (145) and Larder Lake (147).

The deposits at Rossland, B. C., referred to under copper, also yield an appreciable quantity of gold.

**Other Foreign Deposits.** — *West Australia* [1] contains several gold mining districts, that of Kalgoorlie being the most important, the others including Pilbarra, Murchison, and Mount Margaret. The rocks are chiefly crystalline schists derived from igneous rocks and granites together with altered sedimentaries, but the gold deposits are found chiefly in the schists. Two types are recognized, viz.: (1) Quartz veins in amphibolite, or at its contact with granite, and (2) lodes, formed by ore deposition along shear zones. The first class carries native gold, galena, blende, pyrrhotite, chalcopyrite, arsenopyrite, stibnite, bismuthinite, pyrite, scheelite, chlorite, calcite, sericite, and sometimes tourmaline; the latter has native gold, tellurides, pyrite, chalcopyrite, blende, galena, pyrargyrite, magnetite, siderite, ankerite, sericite, tourmaline, albite, etc. The wall rock bordering the lodes has been noticeably altered.

*Brazil* contains several deep gold mines in the province of Minas Geraes, of which the Morro Velho is not only the most important, but also the deepest in the world, having reached a vertical depth of 5800 feet.[2] The ore deposits are quartz veins in Archaean schists, gneisses and granites, or in sedimentary schists and quartzites.

*India.* — The pre-Cambrian veins in crystalline schists of the Kolar gold fields in Mysore, India, also belong in this group.[3]

## Deposits Formed at Intermediate Depths

This group includes a number of auriferous quartz veins, carrying free gold, pyrite, and even other sulphides, but lacking the silicates characteristic of the deep-vein zone. The quartz veins do not, as a rule, show a high silver content. Alteration of the wall rocks sometimes occurs, resulting in the development of sericite, carbonates, and pyrite.

**United States.** — *California. Mother Lode Belt* (45, 52). — This includes a great series of quartz veins, beginning in Mariposa County and extending northward for a distance of 112 miles. The veins of this system break through black, steeply dipping slates and altered volcanic rocks of Carboniferous and Jurassic age (Fig. 244), and since they are often found at a considerable distance from the granitic rocks of the Sierra Nevada, they have apparently no genetic relation with them. The veins, which occur either in the slate itself or at its contact with diabase dikes, show a remarkable extent and uniformity, due to the

[1] Bulletins of West Austral. Geol. Surv., especially Nos. 6, 14, 15, 20, 22, 23, 45, 46, 51, 56; also Lindgren, Econ. Geol., I: 530, 1905; Maclaren and Thomson, Min. and Sci. Pr., CVII: 45, 1913; Larcombe, *Ibid.*, CXI: 238, 1915.

[2] Harder and Leith, Jour. Geol., XXIII: 341 and 385, 1915; also Lindgren Amer. Inst. Min. Engrs., Bull. 112: 721, 1916.

[3] Hatch, Geol. Surv., Ind., Mem. 33, 1901.

fact that in the tilted layers of the slates there were planes of
weakness for the mineral-bearing solution to follow. The ore
is native gold or auriferous pyrite in a gangue of quartz, and
the average value may be said to vary from $3 to $4 up to $50
or $60 per ton. The veins often split and some of the mines
have reached a depth of several thousand feet.
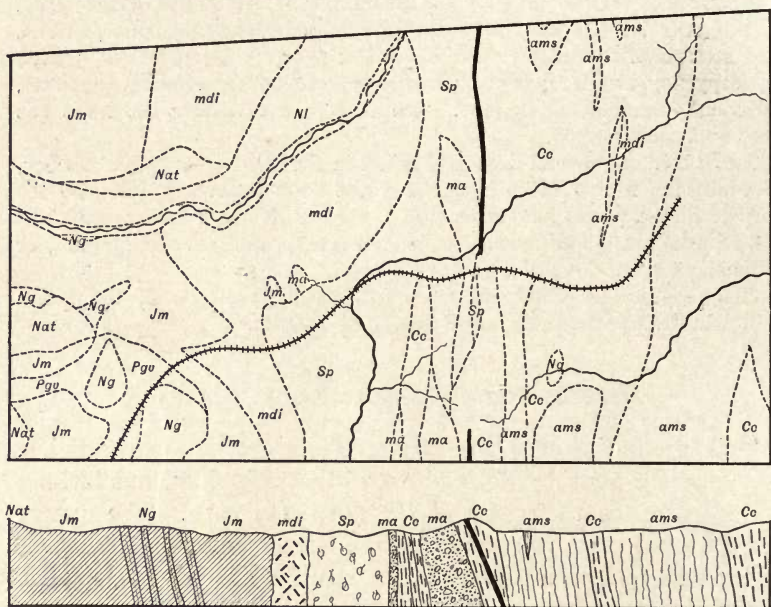


Fig. 244.— Map and section of portion of Mother Lode district, Calif. *Pgv*, river
gravels, usually auriferous; *Ng*, auriferous river gravels. Sedimentary rocks:
*Jm*, mariposa formation (clay, slate, sandstone, and conglomerate); *Cc*, cala-
veras formation (slaty mica schists). Igneous rocks: *Nl*, latite; *Nat*, andesite
tuffs, breccia, and conglomerate; *mdi*, meta-diorite; *Sp*, serpentine; *ma*,
meta-andesite; *ams*, amphibole schist. (*From U. S. Geol. Surv., Atlas Folio,
Mother Lode sheet.*)

*Nevada County* (48). — In Nevada County the mines of Grass
Valley and Nevada City are likewise quartz veins (Pl. LXV, Fig. 2)
but they occur along the contact between a granodiorite and dia-
base porphyry, as well as cutting across the igneous rock (Fig. 245).
Two systems of fault fissures occur, and in these the ore is found
either in native form or associated with metallic sulphides. The
width of the vein averages from 2 to 3 feet, and the lode ore
generally occurs in well-defined bodies or pay shoots. The vein
filling was deposited by hot solutions, and while the wall rocks

PLATE LXV
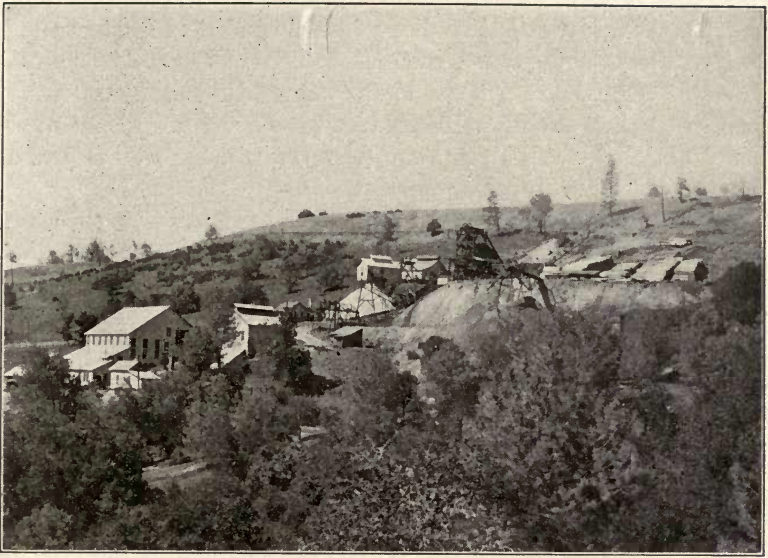


FIG. 1. — Kennedy mine on the Mother Lode, near Jackson, Calif.



FIG. 2. — Auriferous quartz veins in Maryland mine, Nevada City, Calif. (*After Lindgren, U. S. Geol. Surv., 17th Ann. Rept., III.*)

(697)

contain the rare metals in a disseminated condition, Lindgren (48) believes that the ores have been leached out of the rocks at a considerable depth. The mines at Nevada City and Grass Valley have been large producers of gold and some silver. Placer mines have furnished a small portion of the product, but at the present day these latter are of little importance.

In Oregon, the quartz veins are worked in Baker County, which is the most important gold-producing region of the state (104, 105). Gold ores with sulphides in quartz gangue are worked in the Monte Cristo district of Washington (122)



GRANODIORITE          METAMORPHIC SCHIST AND DIABASE

*a.* MERRIFIELD VEIN *b.* URAL VEIN *c.* SLATE VEIN
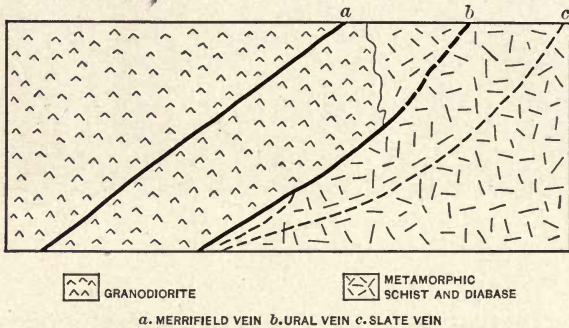
FIG. 245. — Section illustrating relations of auriferous quartz veins at Nevada City, Calif. (*After Lindgren, U. S. Geol. Surv., 17th Ann. Rept., II.*)

*South Dakota. Siliceous Cambrian Ores* (109, 111). — The refractory siliceous Cambrian ore is found in the region between Yellow Creek and Squaw Creek, and yielding about two-thirds as much gold as the Homestake. The deposits, which occur as replacements in a siliceous dolomite (Fig. 247), are found at two horizons, one immediately overlying the basal Cambrian quartzite, and the other near the top of the Cambrian series. The ore forms flat banded masses known as shoots, and varying in width from a few inches to 300 feet. It is overlain by shale or eruptive rock, and associated with a series of vertical fractures, made prominent by a slight silicification of the wall rock. These fractures, which are termed *verticals*, are supposed to have conducted the ore-bearing solutions.

The ore is a hard, brittle rock, composed of secondary silica, with pyrite and fluorite, and at times barite, wolframite, stibnite, and jarosite. Its contents range from $3 or $4 per ton to in rare cases $100 per ton, with an average of $17. Other,
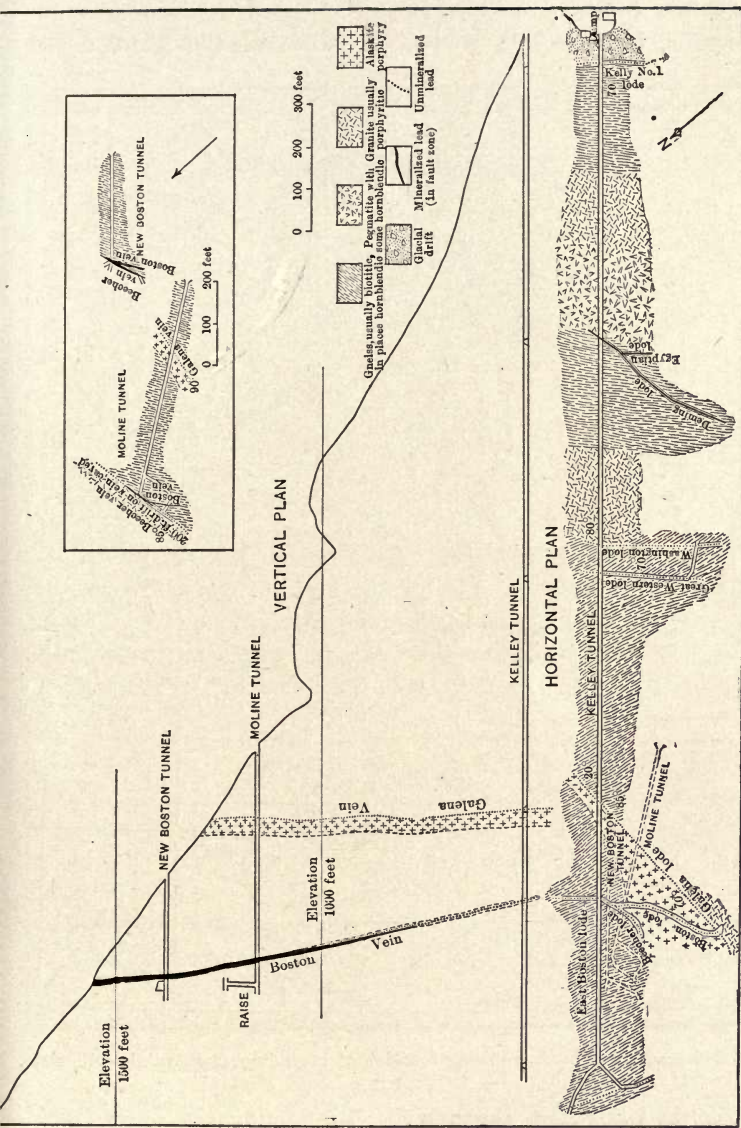
PLATE LXVI. — Vertical and horizontal plan of Kelly tunnel and associated mine workings, Georgetown, Col., district.
(*After Spurr, U. S. Geol. Surv., Prof. Pap.* 63.)

(699)

but less important, siliceous ores occur in the Carboniferous rocks.

*Mercur, Utah.* — The gold-silver mines of the Mercur (117)



Fig. 246. — Map of Utah, showing location of more important mining districts.

district in Utah form perhaps the most important occurrence in this central zone. Here the Carboniferous limestones, shales, and sandstones, representing about 12,000 feet of sediment, are folded into a low anticline (Fig. 248). Near the center of the section is the great blue limestone, carrying an upper and a lower shale bed.

Quartz porphyry has intruded the limestone, and, at two places especially, spread out laterally in the form of sheets, on whose under side the ore is found, the silver ores under the lower sheet, the gold



CONGLOMERATE    ORE    COMPARATIVELY IMPERVIOUS SLATE    DOLOMITE    HARD QUARTZITE    ALGONKIAN. SCHIST    PORPHYRY
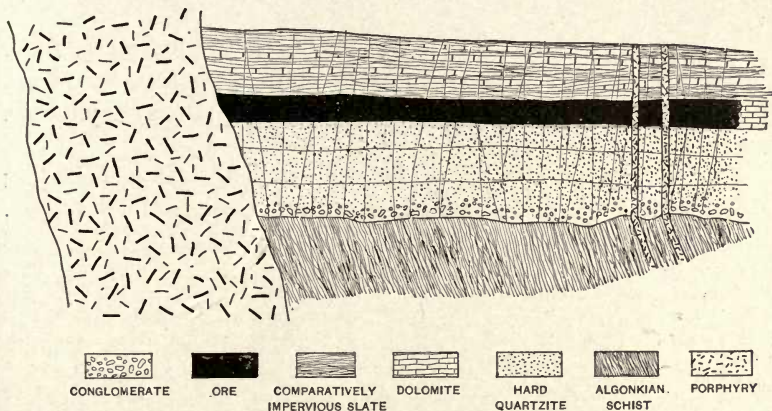
FIG. 247. — Typical section of siliceous gold ores, Black Hills, S. Dak. (*After Irving, U. S. Geol. Surv., Prof. Pap. 26.*)

ores under the upper one, about 100 feet above the first. The silver ore is cerargyrite and argentiferous stibnite in a silicified belt of the limestone. The gold is native and occurs in a belt of residual contact clay, near northeast fissures cutting the limestone, being oxidized in places and accompanied by sulphides in others.
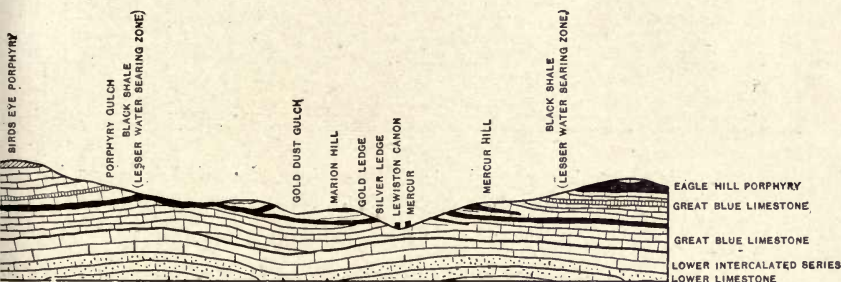


FIG. 248. — Section at Mercur, Utah. (*After Spurr, U. S. Geol. Surv., 16th Ann. Rept., II.*)

The ore runs 1–19 ounces of silver per ton, and 2–3 ounces of gold, with a gangue of quartz, barite, limonite, and arsenical sulphides. The silver minerals are thought to have been deposited by heated solutions which came up along the igneous sheet some time after its intrusion, and the deposition of the gold ore is believed to have taken place some time after the silver was deposited. Some doubt

exists as to the exact source of the ascending waters, but in all probability they were derived from some deep-seated cooling mass of igneous rock. The ores are especially suited to the cyanide treatment.

*Georgetown, Colorado* (68). — Clear Creek County (Fig. 249), in which Georgetown lies, is, next to Gilpin County, the oldest mining district in Colorado, if not the entire Rocky Mountain region.

There are a number of mining camps in this area, including Georgetown, Idaho Springs, Silver Plume, Central City, etc.,



FIG. 249. — Map showing approximate distribution of the principal silver, lead and gold regions of Colorado. (*After Spurr.*)

but the only area which has been described in detail is that included in the Georgetown quadrangle. The conditions here, however, are in a general way similar to those existing in other parts of the district.

The earliest rocks of the district consist of a series of pre-Cambrian schists, the oldest ones (Idaho Springs formation) being probably of sedimentary origin, but the later ones metamorphosed igneous rocks.

This series has been successively injected by about eight types of plutonic rocks ranging from granites to diorites.
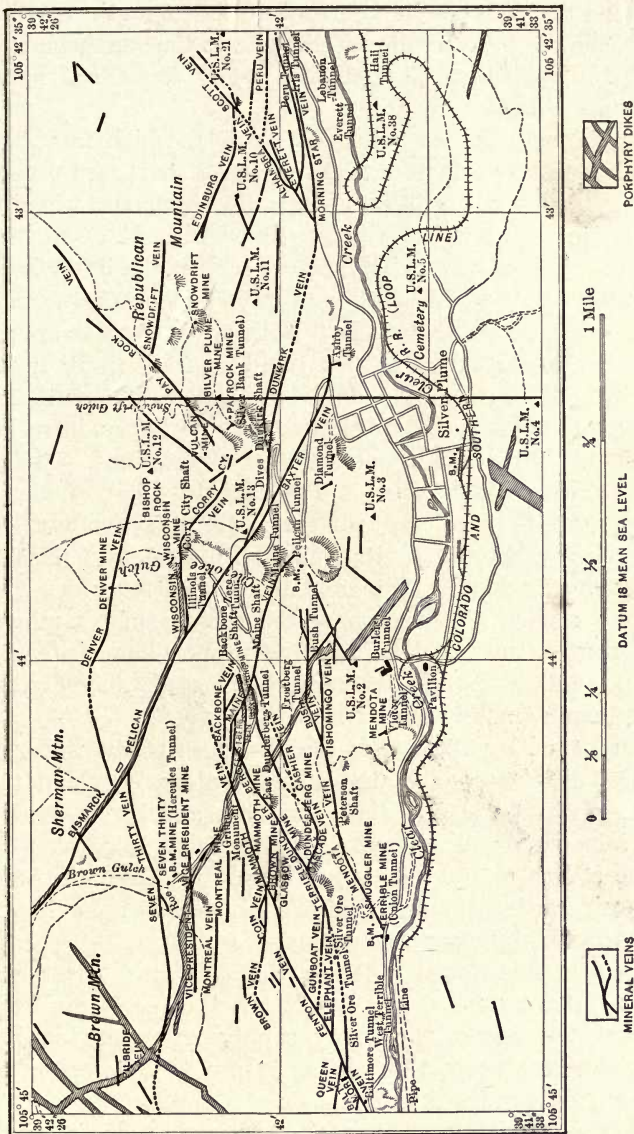
Fig. 250. — Map showing veins and porphyry dikes in the Silver Plume, Col., region. (*After Spurr, U. S. Geol. Surv., Prof. Pap. 63.*)

Following these, in late Cretaceous or early Tertiary, came the intrusion of a series of porphyry dikes which are as varied in their composition as the plutonics. These porphyries are of more than local interest because they form part of a wide ir-

regular zone that extends in a general northeast-southwest direction from Boulder to Leadville and then on to the San Juan region (Fig. 249). It will thus be seen that many important mining districts lie within it.

The ore-bearing fissure veins (Pl. LXVI), which may occur in any of the older schistose rocks of the district, are divisible into two groups, viz., argentiferous blende-galena ones with little gold, and auriferous pyrite veins with or without silver. The former predominate in the Georgetown region, the latter southwest of Idaho Springs, but the two types of ore are occasionally known to occur in the same vein. Both types of veins are seen to show a general agreement in trend and distribution with the porphyry dikes (Fig. 250), and the vein formation is thought by Spurr not only to have followed the porphyry intrusions, but to show characteristic petrographic associations. That is, the silver-galena-blende veins are related to dikes of alaskite porphyry, granite porphyry, quartz-monzonite porphyry, and dacite; the auriferous pyrite veins with bostonite, alaskite, quartz monzonite, biotite latite, and alkali syenite.

The two classes of veins show the same primary minerals (galena, blende, and pyrite), but the proportions of them in each differ, and they have the same bonanzas, wall rocks, and gangue minerals (mainly quartz).

It is suggested by Spurr that the alteration of the wall rocks was caused by descending atmospheric waters, changing them to mixtures of quartz, sericite, carbonates, and kaolin, and the gangue minerals have, moreover, come from the walls; but while the source of the metals in the silver veins is in doubt, Spurr considers that the metalliferous minerals of the gold veins were contributed by magmatic waters.

Crosby has questioned whether the gold and silver veins represent distinct classes, and points out that since the former outcrop at low levels, they may simply represent the basal portions of silver veins, these being known to outcrop only at the higher points in the district.

*Gilpin County* (54). — The rock formations are somewhat similar to those of the Georgetown quadrangle, as are also the gold-silver ore veins, which are grouped by Bastin and Hill as: (1) Pyritic ores; (2) galena-sphalerite ores; and (3) composite ores, carrying the minerals of both the other classes, and being the result of dual mineralization. Most of the veins

occupy zones of minor faulting the ore deposition having been partly by filling and partly by replacement.



FIG. 251. — Map of Colorado, showing location of mining regions.    (*After Rickard, Amer. Inst. Min. Engrs. Trans.*, 1904.)

**Canada.** *Nova Scotia* (140, 146). — The gold veins of this province, which form a belt along the south coast, occur in folded Cambrian (?) slates and quartzites which have been intruded by Silurian (?) granites. The veins, which are often saddle-shaped, are usually found along the axes of plunging anticlines, and most of them are parallel to the stratification. Some show a strong crenulation supposed to be of post-mineral character, and small veins often pass outward from the main ones. The ore mineral is native gold, in quartz gangue, and associated with pyrite, chalcopyrite, galena, blende, and arseno-pyrite. While the ore is supposed to be due to cavity filling, Faribault believes that the veins are younger than the granite, but Rickard holds that they are later.

**Other Foreign Deposits.** — *Victoria.*[1] This colony contains two well-known gold districts, viz., those of Bendigo and Ballarat. In both we find

[1] Rickard, Amer. Inst. Min. Engrs., Trans. XX: 463, 1891; Lindgren, Eng. and Min. Jour., Mar. 9, 1905; Vogt, Krusch und Beyschlag, Lagerstätten, II: 107, 1912.
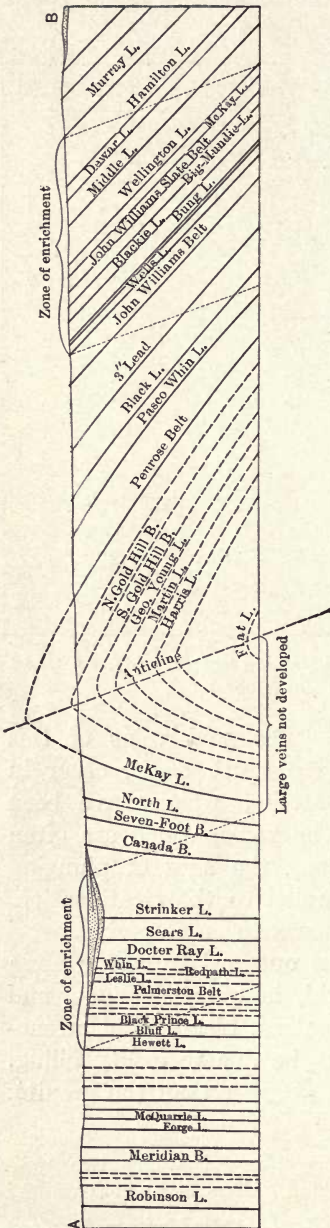
Fig. 252. — Section across the Goldenville district, Nova Scotia. (After Malcolm, Can. Geol. Surv., Mem. 20-E.)

strongly folded Ordovician slates and sandstones cut by a batholith of granite or quartz monzonite. At Bendigo especially the ore bodies show saddles along the axes of anticlines, there being not only several lines of these saddles, but in each line a number, one below the other. Other irregular veins occur. The ore is gold-bearing quartz, with associated pyrite and arsenopyrite, and some albite. These reefs, as they are called, have been worked to a depth of 4500 feet, but are much richer in the first 2500 feet.

At Ballarat, the gold-quartz veins show more irregularity of form, and the rich ore often appears to be at the contact of flat bodies of quartz with thin veins of pyrite, or carbonaceous seams in the slate, both known as "indicators."

Other important Australian districts are those of Charter Towers, Queensland, and Hill End, New South Wales.

*Queensland.* — The ore body at Mount Morgan, Queensland [1] is to be classed as one of the interesting occurrences of the world. Worked for many years as a gold deposit, it now shows signs of changing to copper. Below a rich gossan of limonite and manganese carrying free gold, there is a mass of porous, crumbly, siliceous rock, carrying gold and some silver, which is in the oxidized zone. This at depths of 200 to 300 feet grades into a mixture of pyrite and chalcopyrite, carrying gold. While several theories of origin have been advanced, it can probably be regarded as a replacement, and is provisionally placed in the intermediate group.

[1] Rickard, Amer. Inst. Min. Engrs., XX: 133, 1891; Vogt, Krusch and Beyschlag, Lagerstätten, II: 134, 1912.

DETAIL SECTION
Showing the structure of quartz crumple and "feeders" at east face of drift
on Borden lead, from actual measurements and photographs, 10th Sept. 1903,
by E.R. Faribault

North

South

Borden lead very thin

Belt of slate with thin layers of whin bordering lead bholcon

Axis of Crumple

Quartz stringers or feeders generally barren connecting the crumples

Rich ore

Rich quartz

Rich ore

Rich quartz

Very rich roll of quartz

INDEX

Whin

Slate

Quartz

Scale of Feet

10    5    0    10    20    30    40

FIG. 253. — Transverse section of a part of West Lake Mine, Mount Uniake,
N. S.   (*After Malcolm, Can. Geol. Surv., Mem.* 20-E.)

Siebert tuffs

Olivine basalt

Andesite

Black Butte

Dacite

Rhyolite

Andesite

Alaskite

Vindicator Mtn.

Andesite

Rhyolite

Dacite

Andesite Paleozoic sediments

Dacite

Siebert tuffs

Goldfield.

Quartz latite

Siebert basalt

Rhyolite formation

Olivine basalt

1 Mile

Scale

0    ½    1

Feet
6000
5000
4500

Fig. 254. — Geologic section across the Goldfield district. (After Ransome.)

## Deposits Formed at Shallow Depths

These include a great number of gold and silver deposits, in which the two metals mentioned are present in varying proportions, and always associated with Tertiary volcanics. The group corresponds to the young gold-silver group of Vogt, Krusch, and Beyschlag.[1]

The wall rocks may show propylitization, silicification, or in rarer cases, alunitization. Sericitization is also noted. Quartz is the commonest gangue mineral, but carbonates of lime, iron, or manganese, as well as adularia are noticed. The gold may be native, or combined with tellurium, while the silver is usually present as sulphides, sulpharsenides, or sulphantimonides.

**United States.** — As stated on p. 684, the ores of this group are of great importance in the western United States.

*Goldfield, Nevada* (88, 89). — Goldfield lies near the eastern border of Esmeralda County (Fig. 232), on the southern rim of one of the typical desert basins of the region which connects, through a low pass on the north, with a still larger basin west of Tonopah.

The geologic structure (Fig. 254) of the district is quite simple, consisting essentially of a low dome-like uplift of Tertiary lavas and lake sediments, resting on a foundation of ancient granitic and metamorphic rocks.

The kind of rocks in this district, their age, and relationships are shown in the map and section given by Ransome (Figs. 255, 256). The oldest or Cambrian beds were intruded by alaskite

[1] Lagerstätten, II: 12, 1912.

at about the close of Jurassic time, and there then followed a long interval of erosion before the eruption of the Tertiary lavas. It will be seen from the section that the same type of rock was in some cases erupted more than once.
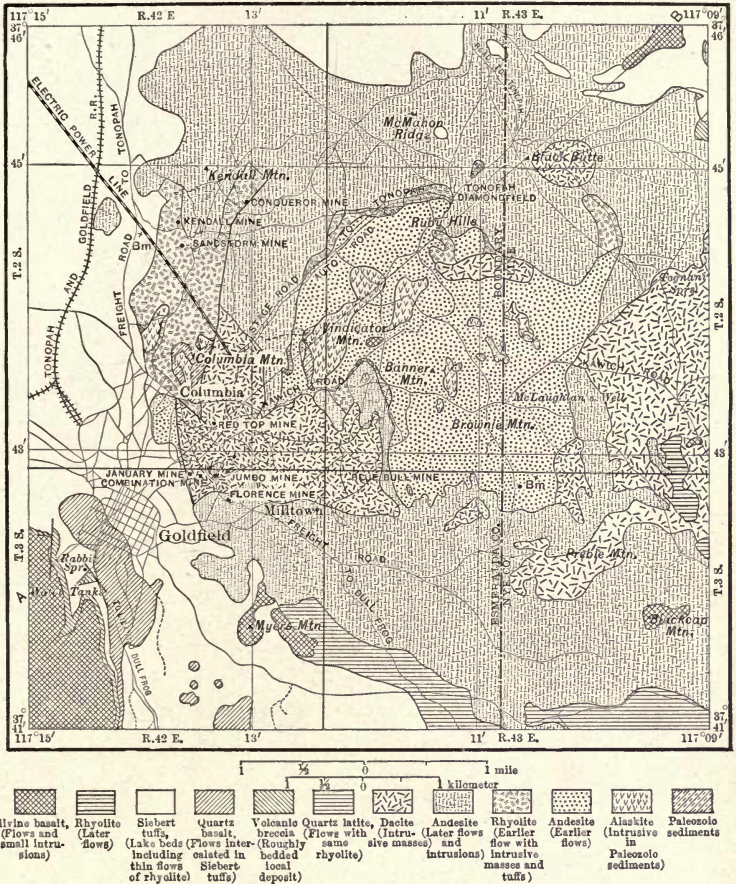


FIG. 255.—Geologic, Map of Goldfield, Nev., district. (*After Ransome, Econ. Geol.*)

The ores of this district, which are of somewhat complex character, consist of native gold and pyrite accompanied by minerals containing copper, silver, antimony, arsenic, bismuth, tellurium, and other elements.

The free gold occurs in some of the ores, in fine particles closely crowded together and forming bands or blotches in the

flinty gangue, and is not likely to be recognized as such until examined with a lens. The common associated minerals are pyrite, marcasite, bismuthinite, and famatinite (?). At times the rich ore shows a curious concentric crustification, consisting of
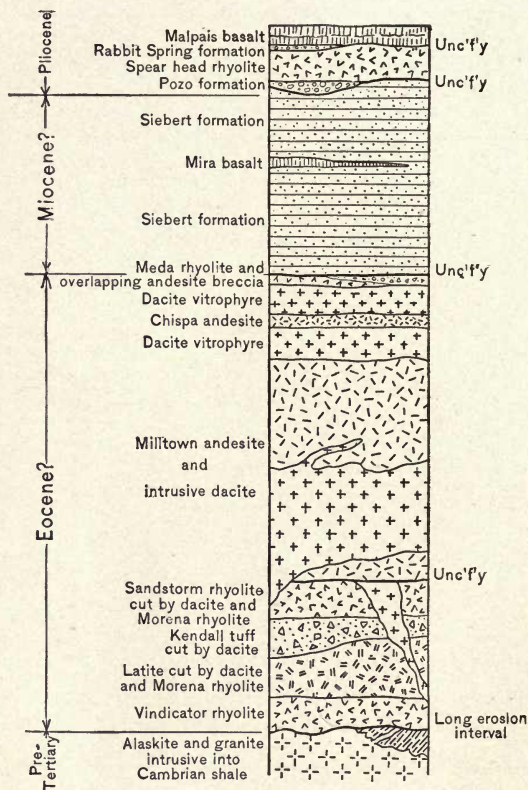


Fig. 256. — Generalized columnar section of geological formations at Goldfield, Nev. (*After Ransome, U. S. Geol. Surv., Prof. Pap.* 66.)

fragments of silicified, alunitized, and pyritized rock, covered with shells of gold and sulphides.

The ore bodies, which are noted for their remarkable richness and irregularity (Pl. LXVII) are closely related to fissures, usually of irregular trend, but not representing fault planes.

The deposits (Pl. LXVII) are defined as irregular masses of altered and mineralized rock, traversed by multitudes of small irregular, intersecting fractures, such fracturing passing in many places into brecciation.
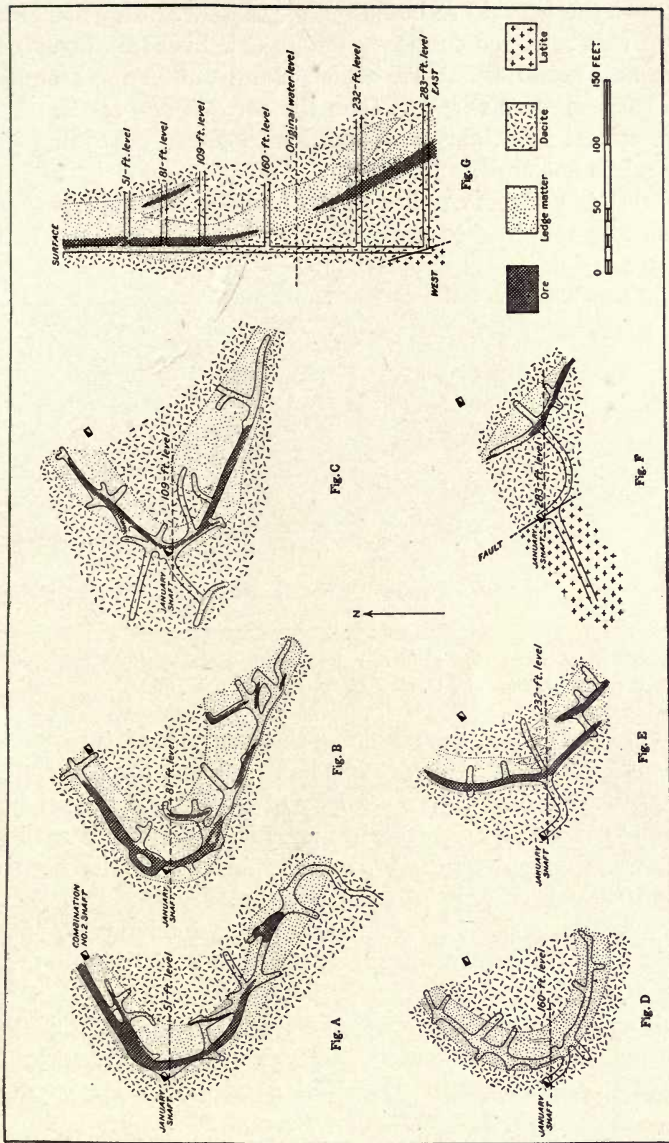
PLATE. LXVII. — Plans of the principal levels of the January mine, Goldfield, Nev., with a diagrammatic section, showing relation of ore, ledge, matter, and country rock. (After Ransome, U. S. Geol., Prof. Pap., 66.)

(711)

These irregular masses are termed ledges (Fig. 257), and within them occur the actual ore bodies or pay shoots. Capping these ledges of soft rock are craggy outcrops (Pl. LXVIII, Fig. 2) of silicified and alunitic material which stand out in relief on the surface because more resistant than the surrounding rocks. The ores are almost invariably associated with these, but every siliceous knob is not underlain by ore.

The most important ore bodies are found in dacite, but some small although rich ones are known in the Milltown andesite (Fig. 256).
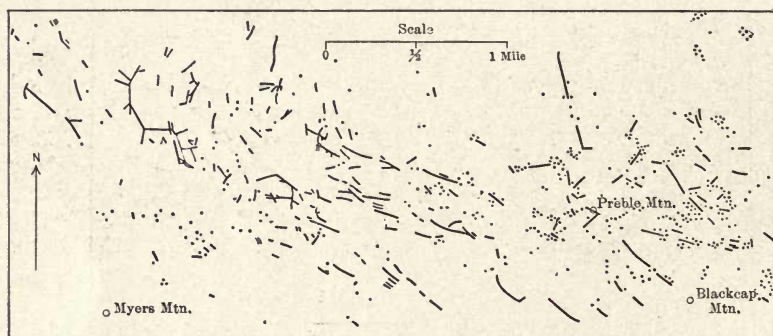


FIG. 257. — Map showing outcrops of siliceous ledges east of Goldfield, Nev.
(*After Ransome, U. S. Geol. Surv., Prof. Pap.* 66.)

The alteration of the rock adjoining the fissures is of three types. Where it is most intense the rock has been changed to porous, fine-grained aggregates consisting essentially of quartz. A second type is the change to a soft, light-colored mass of quartz; while a third, which is of propylitic character, consists in the development of calcite, quartz, chlorite, epidote, and gypsum.

Most of the ore produced during the first two or three years of the camp was oxidized in character, but now some of the mines are working in sulphides.

*Origin.* — Ransome's theory is that after the dacite had solidified, but not perhaps entirely cooled, the subjection of the rocks to stresses of unknown origin developed a complicated system of fractures.

Hot waters carrying hydrogen sulphide with some carbon dioxide and the metallic constituents of the ores rose along these fissures; oxidation of a part of the hydrogen sulphide to sulphuric acid occurred in the upper parts of the fissure zones or at the surface.

PLATE LXVIII
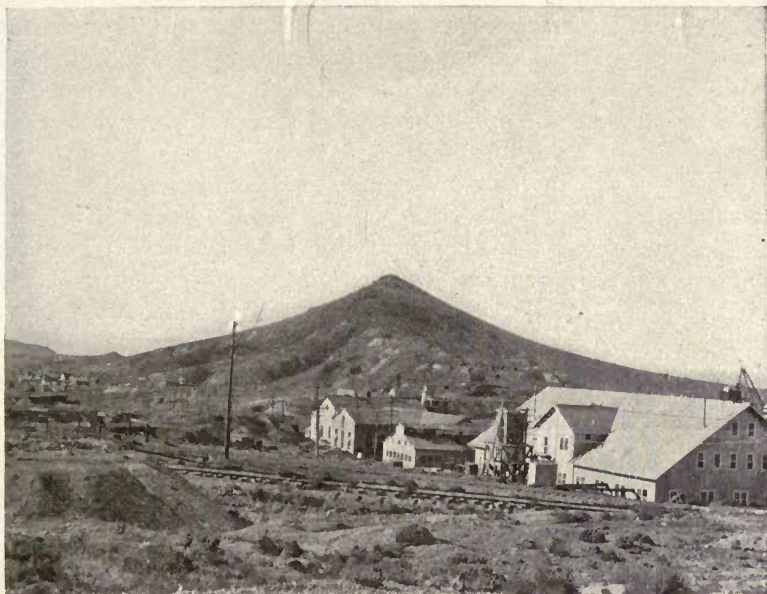


FIG. 1. — Columbia Mountain, Goldfield, Nev., from the south.    (*H. Ries, photo.*)



FIG. 2. — Ledge outcrop in dacite between the Blue Bell and Commonwealth mines, Goldfield, Nev.  The conspicuous white dump is alunitic material. The rough knob on sky line near right side of view is Barner Mountain. (*After Ransome, U. S. Geol. Surv., Prof. Pap.* 66.)

These acid solutions then percolated downward through the shattered rocks, changing their feldspars to alunite, mingled with the rising solutions, and precipitated most of their metallic load as ore, but the original solutions were not everywhere rich in metals.

Following this the ledges were fractured, and a second stage of mineralization occurred, during which further deposition of ore and in some cases repeated precipitation followed more fracturing.

The ledges are thought to have been formed during the first stage of deposition, and the softening and alunitization of the rock, as well as the propylitization, are believed to have occurred at the same time. Some good ore was also deposited then.

The Goldfield mining district may be classed as one of the newer ones of Nevada. For some years the total production of the state had been small but the discovery of Tonopah in 1900 gave a new impetus to the search for precious metals in this region, and the finding of the Goldfield deposits may be rightly reckoned as one of the results.

From the year 1904 to the end of 1914 the Goldfield district has produced $71,311,552 in gold, 833,442 ounces of silver, and 3,139,780 pounds of copper. The maximum total production of about $11,000,000 was reached in 1910, since which time it has dropped off to about $5,000,000. The bulk of the ore is cyanided.

*Tonopah, Nevada* (83a–c, 90a, 91). — This district, which was opened up in 1900, has grown somewhat steadily in production, so that its maximum yield in 1913 was about $9,500,000.[1] Tonopah (Pl. LXX, Fig. 2) lies in the arid desert region of Nevada, and the rocks consist according to Spurr of a somewhat complex series of flows and intrusives as follows:

8. Basalts and rhyolites.

7. Siebert tuffs.

6. Rhyolitic flows.

5. Midway andesite flow.

4. West end rhyolite, intrusive just above 3.

3. Montana breccia, a trachy-alaskite intrusion, just above 2.

2. Andesite intrusion between 1a and 1b.

1. Trachyte consisting of: a, an upper part, and b, a lower flowbanded glassy part.

Burgess (83c), differs with Spurr in considering that the rocks are all surface flows.

---

[1] The 1914 production was slightly lower.

The veins belong to three sets or periods as follows: (1) The chief set, formed after the lower trachyte, and before the andesite intrusion, carrying quartz gold and silver; (2) formed after the West end rhyolite and before the Midway andesite, and including four subgroups, viz. *a*, large typically barren quartz veins; *b*, tungsten bearing veins; *c*, barren, mixed quartz and adularia
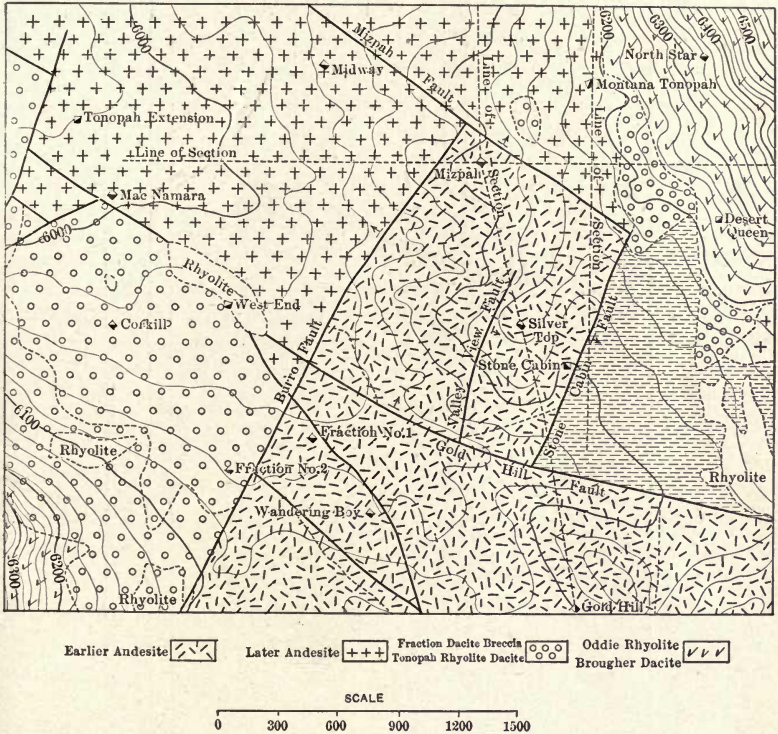


Fig. 258. — Geologic surface map of the producing area of Tonopah. (*After Burgess, Econ. Geol.*, IV: 683, 1909.)

veins; *d*, productive veins like those of set 1; (3) formed after the Tonopah rhyolite, and carrying quartz with occasional lead, zinc and copper sulphides.

The rocks are complexly faulted, and the movement has occurred at different periods. The primary ore consists of finely divided native gold, argentite, and polybasite in a gangue of quartz and adularia. In the oxidized ore, which may extend to over 700 ft., cerargyrite, embolite and iodyrite are found.
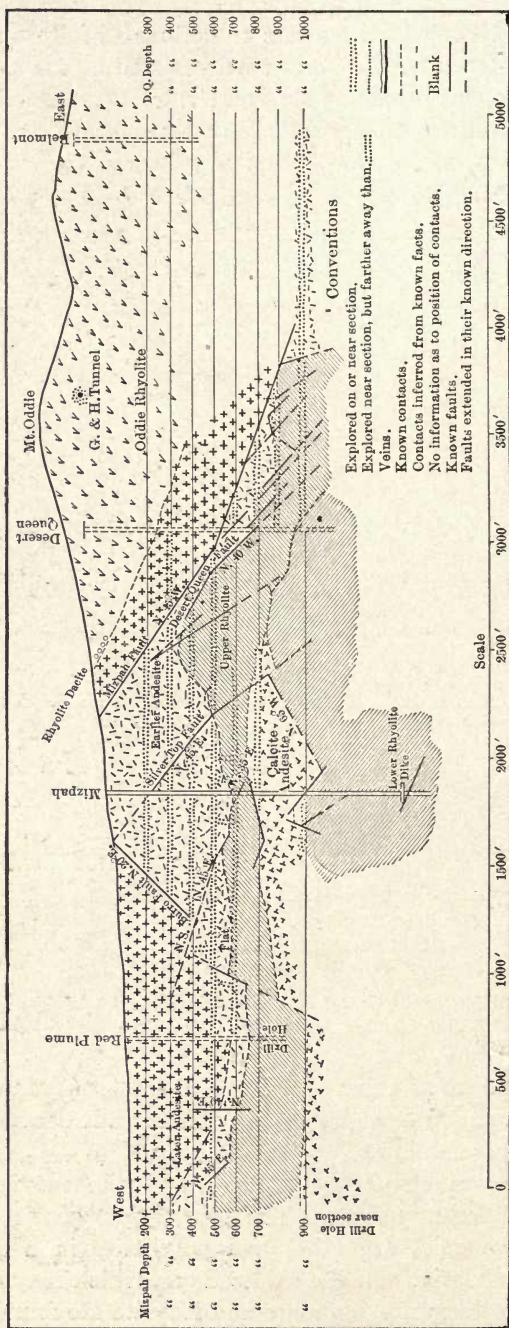
Fig. 259. — East-west section through Mizpah shaft, Tonopah. (*After Burgess, Econ. Geol. IV: 684, 1909.*)
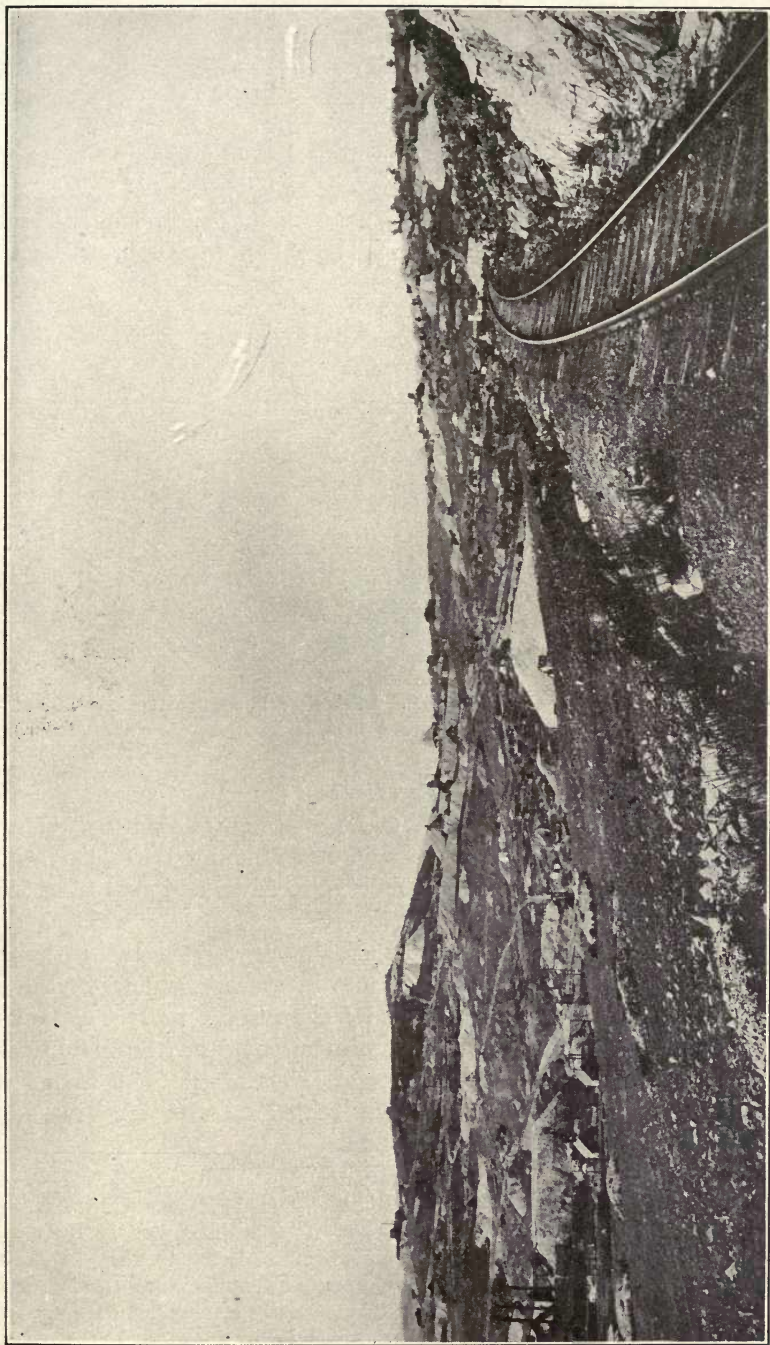
PLATE LXIX. — General view in Cripple Creek district. The outcrop on right is phonolite. (*H. Ries, photo.*)

(717)

In 1914 the total average recovery value per ton of ore produced was $16.84, most of the ore being treated by cyanidation with and without concentration.

*Comstock Lode, Nevada* (83). — This lode, of historic interest, occurs near Virginia City, in southwestern Nevada (LXIII, Fig. 2), and is a great fissure vein (Fig. 260), about 4 miles long, several hundred feet broad, and branching above, following approximately
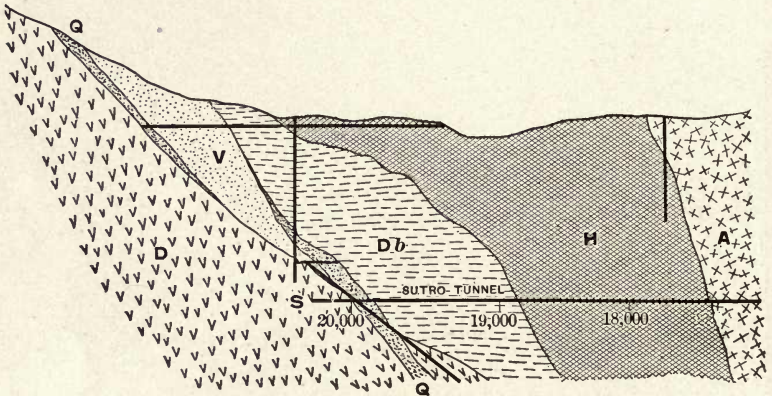


FIG. 260. — Section of Comstock lode. *D*, diorite; *V*, vein matter in earlier diabase (*Db*); *H*, earlier hornblende andesite; *A*, augite andesite. (*After Becker.*)

the contact between eruptive rocks, and dipping at an angle of 35 to 45 degrees. There is abundant evidence of faulting, which in the middle portion of the vein has amounted to 3000 feet. The lode is of Tertiary age, and contains silver and gold minerals in a quartzose gangue.

One of the peculiar features of the deposit is the extreme irregularity of the ore, which occurs in great " bonanzas," some of which carried several thousand dollars to the ton. The faulting is considered to have been quite recent, and the high temperatures encountered in the lower levels of the mine indicate that there is probably a partially cooled mass of igneous rock at no great depth.

In former years the enormous output of this mine caused Nevada to be one of the foremost silver producers. It was discovered as early as 1858, and increased until 1877, after which it declined. Many serious obstacles were met with in the development of the mine, such that it has never become a source of much profit in spite of its enormous output. In 1863, at a depth of 3000 feet, the mine was flooded by water of a temperature

of 170° F., due to a break in the clay wall; and to drain it $2,900,000 were spent in the construction of the Sutro tunnel, which was nearly four miles long, but by the time it was finished the workings were below its depth. A second difficulty was the encountering of high temperatures in lower workings, those in the drainage tunnel mentioned being 110° to 114° F. The lode is credited with a total production of over $378,000,000. In recent years its output has been slowly increasing again.

*Cripple Creek* (63). — This district, which is a most important one of this type, is a producer of ores containing gold almost exclusively. The region lies about ten miles west of Pike's Peak proper, but in the foothills of this mountain mass.
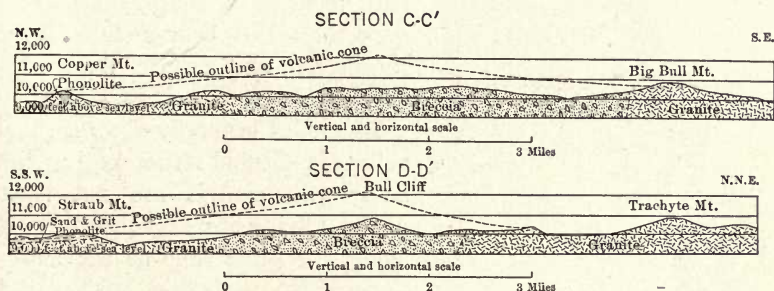


FIG. 261. — Sections showing possible outline of the Cripple Creek volcanic cone at the close of the volcanic epoch. (*After Lindgren and Ransome, U. S. Geol. Surv., Prof. Pap.* 54.)

The rocks of the district include (1) a series of pre-Cambrian metamorphic rocks and igneous basement complex, and (2) the products of the Tertiary Cripple Creek volcano (Fig. 261).

The metamorphic rocks include a quartz-muscovite-fibrolite schist, and a biotite gneiss; the old igneous rocks include (1) three varieties of granite, viz. the Pikes Peak (quartz-biotite-microcline), Cripple Creek (finer-grained but similar), Spring Creek (quartz-orthoclase mainly, and of medium grain); and (2) differentiation products of an olivine-syenite magma.

The Tertiary volcanic rocks represent a series of chemically related products, from a single eruptive center. Commonest of these are tuffs and breccias, which are cut by a series of dikes of phonolite, next a latite-phonolite, followed by a syenite, trachy-dolerite, and several dark basic dike rocks.

The ore bodies, which in nearly all cases are associated with fissures, are of two types, viz. (1) lodes or veins (Figs. 262, 263),

and (2) irregular replacement bodies, occurring usually in granite. The two are not sharply separated.

All the veins are characterized by the narrowness of the fissure and incomplete filling. The lode fissures occur mainly within the volcanic neck, have a roughly radial plan, and are usually nearly vertical, the individual fissures rarely exceeding a half mile in length. But even the productive ones may be quite short, not exceeding a few hundred feet; and while productive lodes may occur in all rocks, except perhaps the schist, they seem to favor the breccia and granite, many following phonolitic or basic dikes.

The lodes generally show a characteristic sheeted structure, but the fissures in general are not fault planes, having probably been formed about the same time as the intrusions of the basic dikes and caused by compressive stresses set up by a slight sinking of the solidified breccia and associated intrusives.
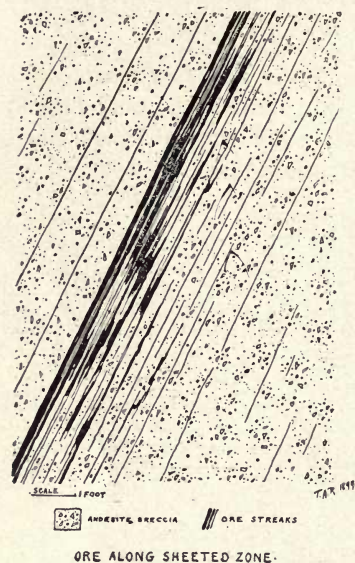


Fig. 262.—Section of vein at Cripple Creek, Col. (*After Rickard.*)

The ore occurs filling narrow fissures, and within the veins it occurs in shoots of variable size, which may develop in any rock.

The ore minerals are mainly tellurides of gold, deposited chiefly by fissure filling and less often by replacement, with pyrite as a common associate; but native gold is rare in the unoxidized ore. Quartz, fluorite, and dolomite are the most important gangue minerals, and galena, sphalerite, tetrahedrite, stibnite, and molybdenite are found sparingly.

Oxidation changes the vein to a soft brown, homogeneous mass, and the tellurides into brown, spongy gold and tellurites, but there is no evidence of secondary enrichment. The ore does not appear to decrease in its value per ton with depth, though the actual quantity of it is less.

The rocks bordering the veins have undergone some alteration, which is more pronounced in the breccia, and involves a change of the dark silicates to carbonates, pyrite, and fluorite,

and of the feldspars and feldspathoids to sericite and adularia.
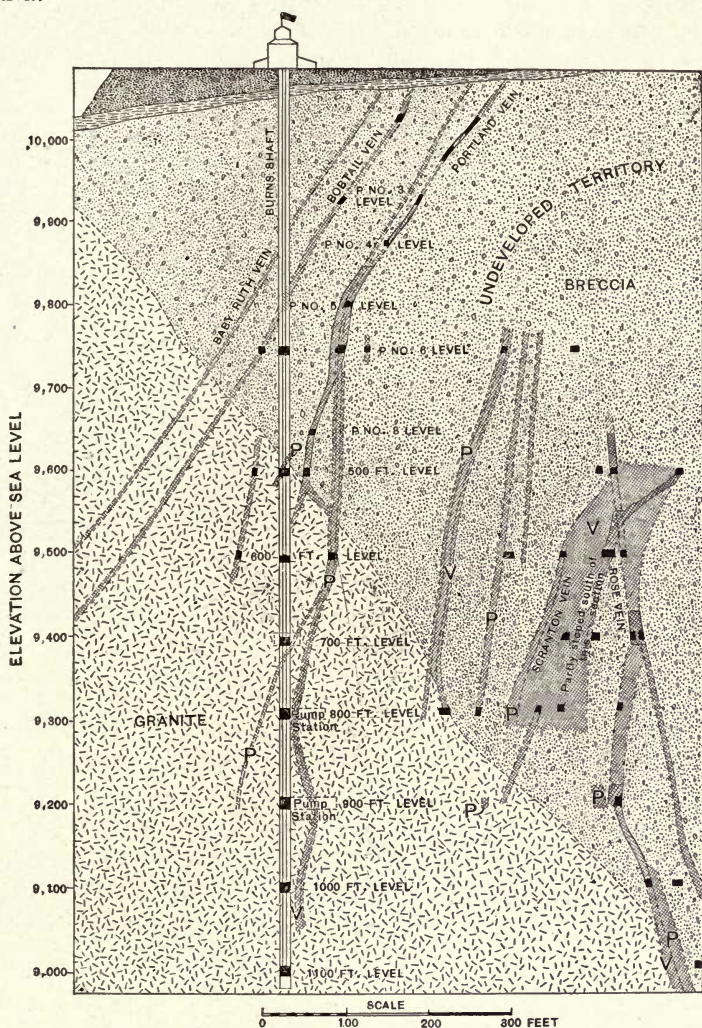


FIG. 263. — Vertical section through the Burns shaft, Portland Mine, Cripple Creek, Col. Shows breccia, contact veins, and dikes. *V*, veins; *P*, phonolite. (*After Lindgren and Ransome, U. S. Geol. Surv., Prof. Pap. 54.*)

The ores are believed to have been deposited by hot alkaline solutions, which contained the following compounds and ions either free or in combination: $SiO_2$, $CO_2$, $H_2S$, $CO_3$, $SO_4$, S, Cl, F, Fe, Sb, Mo, V, W, Te, Au, Ag, Cu, Zn, Pb, Ba, Sr, Ca,

Mg, Na, K. Some of these may have been leached out of the volcanics.

The ore is in part smelting ore, which is sent to Pueblo and Denver for treatment, but the balance, which is considerable, is treated by the cyanide or the chlorination process.

The Cripple Creek ores as a rule run low in silver as compared with gold, the average value of the two combined being about $12.00 per ton. Over 95 per cent of the crude ore is treated by the chlorination or cyanide process at mills in the district or at custom mills near Colorado City, the rest going to smelters.

The rapid rise of this district is well shown by the following figures of production. A maximum was reached in 1900, since which the output has gradually declined.

PRODUCTION IN CRIPPLE CREEK DISTRICT IN 1893–1908 AND 1914

| YEAR | VALUE | YEAR | VALUE |
|------|-------|------|-------|
| 1893 | $2,010,367 | 1902 | $16,912,783 |
| 1894 | 2,908,702 | 1903 | 12,967,338 |
| 1895 | 6,879,137 | 1904 | 14,504,350 |
| 1896 | 7,512,911 | 1905 | 15,441,591 |
| 1897 | 10,139,708 | 1906 | 14,286,675 |
| 1898 | 13,507,244 | 1907 | 10,953,549 |
| 1899 | 15,658,254 | 1908 | 12,772,477 |
| 1900 | 18,073,539 | 1914 | 12,045,364 |
| 1901 | 17,261,579 | | |
| | | Total | $203,835,568 |

*San Juan Region, Colorado* (59, 62, 65, 66, 67). — This region covers a large tract of mountainous country, in southwestern Colorado, and includes the counties of San Juan, Dolores, La Plata, Hinsdale, and Ouray. The continental divide crosses it, but the main portion consists of a deeply cut volcanic plateau. The area is an important one noted for its veins carrying gold, silver, and lead ores in varying proportions, but owing to the precipitous slopes, high ridges, and great altitude at which the veins outcrop, mining is sometimes attended with difficulty. Important towns in the area are Telluride, Silverton, Ouray, Creede, etc.

The geological history of the San Juan region is exceedingly complex, the pre-Tertiary surface being deeply buried under volcanic beds which still cover the main area, but the older rocks have been exposed by erosion in the surrounding districts. The most complete section is seen in the Animas Valley, between Silverton and Durango, but the two generalized columnar sections of the Telluride and Ouray quadrangles (Pl. LXXI) will serve to give a somewhat clear idea of the age and succession of the formations.

PLATE LXX



FIG. 1. — View of Independence Mine and Battle Mountain, Cripple Creek, Col.
(*A. J. Harlan, photo.*)
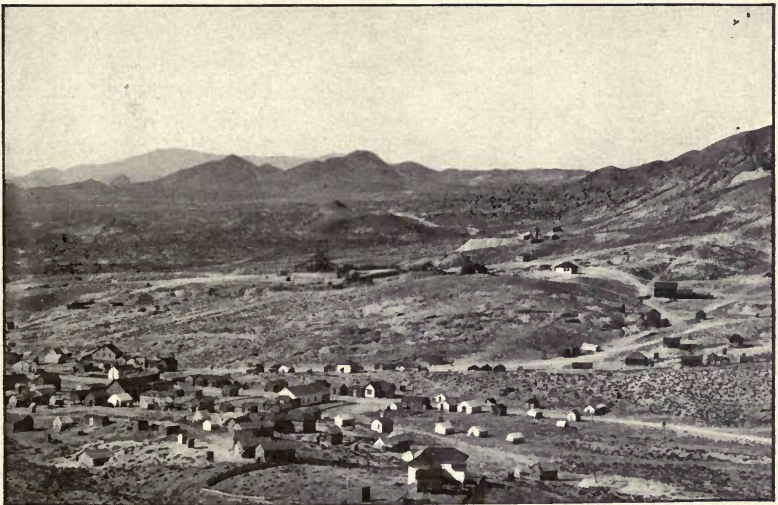


FIG. 2. — General view of region around Tonopah, Nev.   (*J. E. Spurr, photo.*)
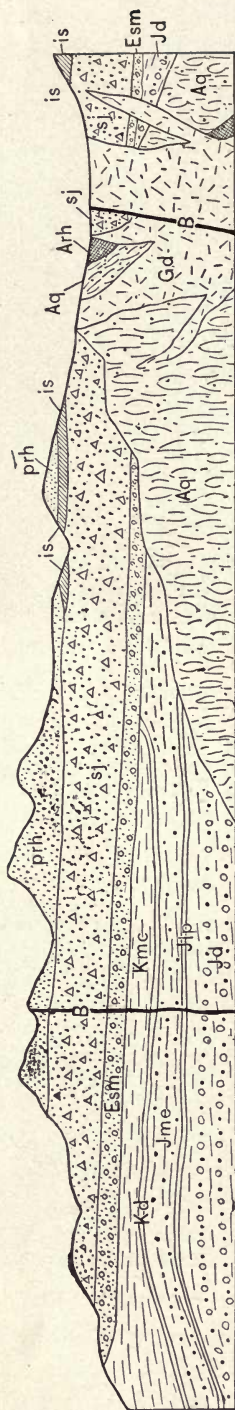
Fig. 264. — Geologic section across the northwest portion of the Telluride quadrangle. (U. S. Geol. Surv.) Arh, older rhyolite; Si, San Juan series; is, Intermediate series; prh, Potosi rhyolite; B, basic dikes; Gd, gabbro diorite, Aq, quartzite; Jd, Dolores formation; Jlp, La Plata sandstone; Jmc, McElmo formation; Kd, Dakota formation; Kmc, Mancos formation; Esm, San Miguel formation.

The entire region has not been studied in detail geologically, but several quadrangles are known with some intimacy and may be referred to.

*Telluride Quadrangle* (65). — In this quadrangle, whose geologic section is shown (Pl. LXXI and Fig. 264) the ores occur in veins which are filled fissures that penetrate all rocks exposed in the area, and were later even than the rhyolite or the intrusions of the diorite stocks. Four general directions of fissuring are noted.

The lodes are narrow zones of closely spaced fissures filled with ore, little of which is found outside of the zone. The veins vary in width, averaging about 3 feet, but the ore usually forms a narrow strip following one side or the other, and rarely filling the entire zone.

The veins also vary somewhat in their regularity, according to the kind of rock through which they pass, being best developed in the andesite. Faulting is rare.

The ore minerals are galena, freibergite (argentiferous gray copper), polybasite, proustite, stephanite, and perhaps other silver sulphides, with more or less gold, which may be in pyrite and chalcopyrite. There are also a number of metallic and nonmetallic gangue minerals, including sphalerite, zinc blende, mispickel, magnetite, native copper, quartz, calcite, siderite, rhodochrosite, dolomite, fluorite, barite sericite, biotite, chlorite, amphibole, apatite, garnet, orthoclase, picotite, and kaolinite.
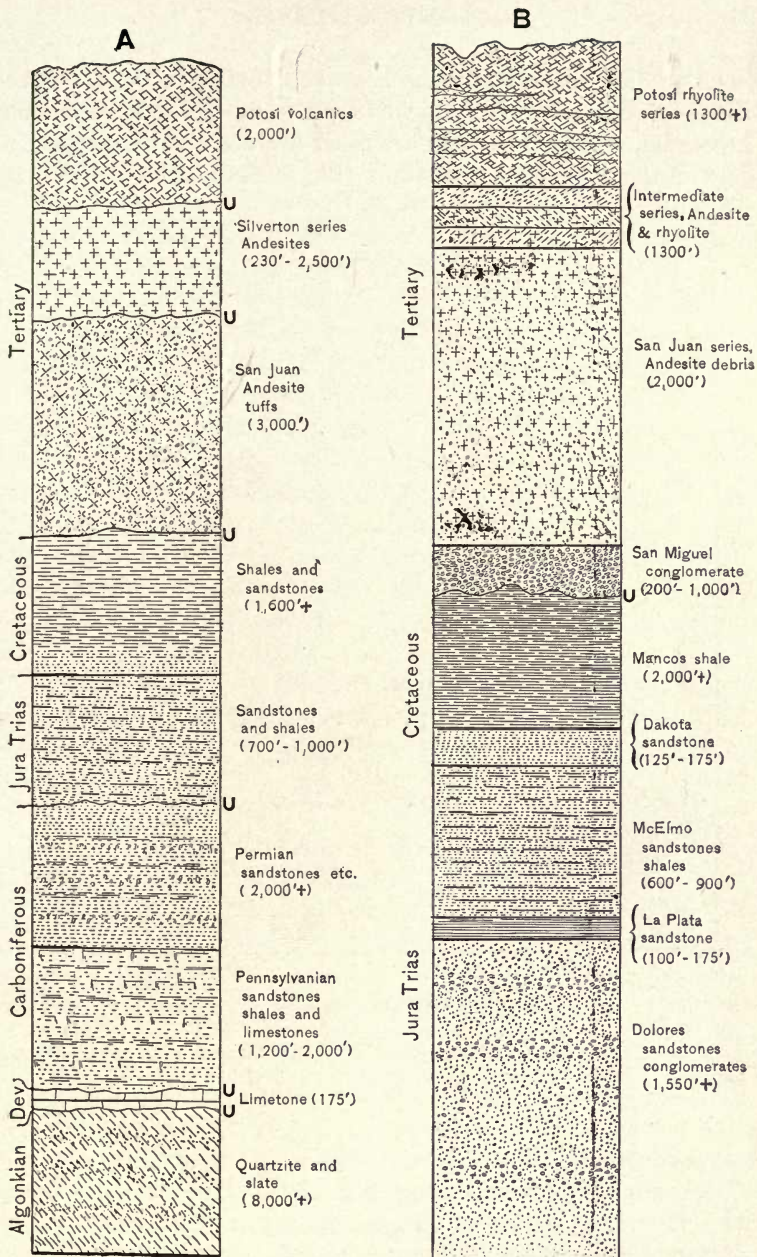
**PLATE LXXI** — General columnar section of *A*, Ouray quadrangle; *B*, Telluride quadrangle. U = unconformity. (*U. S. Geol. Surv.*)

(725)

The greater number of veins have been found in the granular
rocks of the stocks along the central, east, and west portions
of the area, and in the heavy andesitic breccia, tuff, and agglom-
erate of the San Juan formation (Pl. LXXI), best  developed
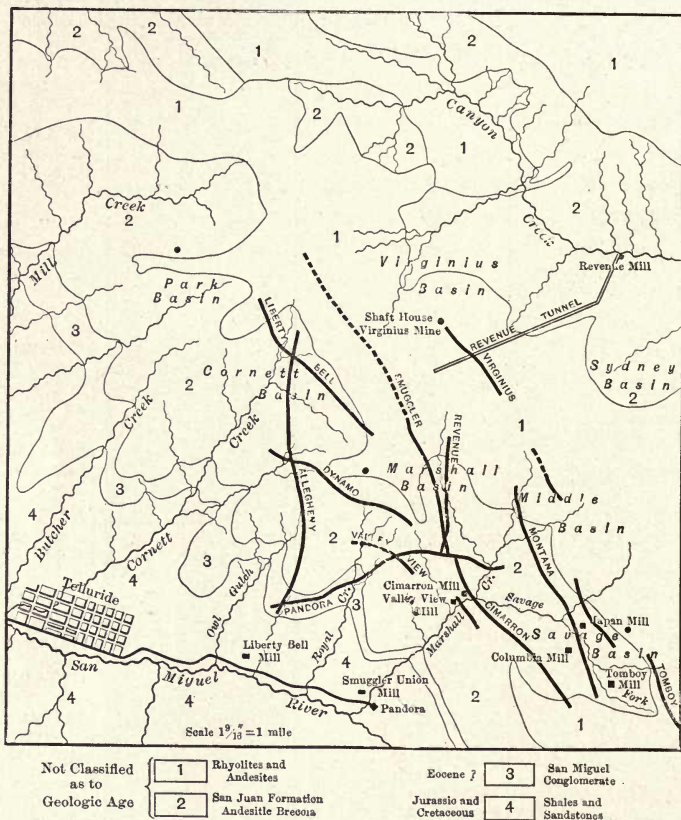


FIG. 265. — Geologic map of Telluride district, Col., showing outcrop of more
important veins.   (*After Winslow, Amer. Inst. Min. Engrs, Trans. XXIX.*)

in the northern half of the area.   This last horizon has been the
most productive.

The ore appears to have been deposited from ascending hot-water
solutions which penetrated all open spaces in the fissured zones.

Ransome explains it as follows : Surface waters percolating down-
ward dissolve alkalies from the igneous rocks as sulphides.   These
alkalies as they become hotter on approaching the magma become
charged with sulphidic and carbonic acids derived from volcanic

sources, thus becoming solvents for the metals, and silica, lime, etc., which they gathered from the more basic portions of the magma. These solutions then brought metals and silicates and deposited them higher up.

The metals were deposited in the fissures, while the penetration of the wall rocks by the alkaline solutions containing sulphuric acid changed the iron in the ferromagnesian silicates, and the potash went toward the formation of sericite. Carbonates were deposited on the walls, due to the action of water on lime feldspars. Silica was set free and removed mostly from the walls. Gold was carried into the walls to some extent.

*Silverton Quadrangle* (67). — This quadrangle lies east of the Telluride. The oldest formations are the Archæan schists and gneisses, overlain by Algonkian quartzites, and these in turn by Cambrian, Devonian, and Carboniferous sediments, the whole being capped by a thick series of Tertiary volcanics similar to those of the Telluride quadrangle, but separated from the top of the Carboniferous by a conglomerate. A number of unconformities are present in different parts of the series.

The ore deposits are of three types, viz.: (1) lodes, which include most of the now productive deposits; (2) stocks or masses, which include most of the ore bodies formerly worked on Red Mountain; (3) metasomatic replacements, including a few deposits found in limestones or rhyolite.

The lodes, which are widely distributed and vary in size and degree of mineralization, may occur in all the rocks from the pre-Cambrian schists to the latest monzonitic intrusions, cutting the Tertiary volcanics, but the greater number are found in the San Juan tuff and Silverton volcanic series. Moreover, the gold and silver are not uniformly distributed in the quadrangle.

The most conspicuous fissuring is northeast-southwest, with dips usually of about 75°, and faulting noticeable in but a few lodes. The fissures were formed substantially at the same time, and probably in late Tertiary.

Most of the lodes are simple fissure veins, showing bands of gangue and ore confined between definite walls, while the width of the workable vein varies from a few inches up to 10 or 12 feet. The wall rock is not usually much altered except in the rhyolite replacement deposits.

The ore minerals are tetrahedrite, very common, may carry both As and Sb; enargite, common in Red Mountain range; chalco-

pyrite, common and sometimes auriferous; galena, very important and widespread; sphalerite, common and accompanies galena, and several silver sulphides, not very abundant. Both native gold and silver also occur.

The gangue minerals are quartz, barite, calcite, dolomite, rhodochrosite, kaolinite, pyrite, etc.

The ores were probably deposited by ascending waters, but their exact source or depth of origin is not known.

Metasomatism of wall rocks differs in different parts of the quadrangle. Thus, for example, in the Silver Lake Basin, feldspar is altered to sericite, calcite, and quartz; augite, to calcite and chlorite; and biotite, to sericite and rutile. Sericite and quartz are common close to the vein. This shows a propylitic type of alteration.

*Ouray Quadrangle* (62). — The ore deposits, which may be regarded as an extension of those of the Silverton quadrangle area, are all located near the town of Ouray, and while the district contains but few productive mines, they are of great scientific interest. A few are found in disturbed rocks near dikes or sheets of porphyry, but most of them occur in but slightly disturbed formations. All owe their existence to the presence of fissures, the form of the ore body depending, however, on the openness of the fissure and kind of wall rock. The three following types are recognized: (1) fissure veins of great vertical extent; (2) replacements in quartzite; (3) replacements in limestone. Where the fissures followed by the ore-bearing solutions were open, a simple, banded, filled vein was formed; but where narrow, the solutions spread out laterally in the wall rock, replacing the same, and the process reached a maximum in the more soluble beds.

The fissures show great vertical extent, and the characters of the several types are as follows: —

*Fissure Veins.* — (a) This type, which is the most important, includes silver-bearing veins in fissures of slight displacement, distributed from the Mancos shale, to the sandstones underlying the McElmo (Pl. LXXI). Ore more abundant and of higher grade in quartzite walls, but may be absent or of low grade in shales. Tetrahedrite and argentiferous galena, with quartz and barite gangue as common vein minerals. (b) Gold-bearing veins representing a group of mineralized, highly inclined, sheeted zones in dikes of quartz-bearing monzonite porphyry. The chief minerals are auriferous pyrite, and chalcopyrite in a gangue of country rock and clay.

*Quartzite Replacements.* — Irregular bodies in the Dakota sandstones, with gold and subordinate silver.

*Limestone Replacements.* — Broad flat ore bodies, adjoining fissure veins, or associated with numerous small vertical fissures. Silver predominates in some, with a barite, silica gangue, and gold with a magnetite gangue in others. The former are associated with the fissure veins which penetrate limestone.

All the deposits of the Ouray district appear to belong to a single period of mineralization, and are of recent formation, being later than the latest igneous intrusions.

*Other Occurrences.* — Among the other occurrences of this group may be mentioned the gold-quartz veins in rhyolite of the De Lamar mine in Idaho (72); the Bullfrog district of Nevada (87), and the National mining district in the same state (85c). At the last named, the fissures in Tertiary lavas carry gold and some silver in a quartz gangue, together with pyrite, blende, and always more or less stibnite, while one contains cinnabar. One vein had a remarkable shoot of pale gold which in four years yielded nearly $4,000,000.

Another interesting occurrence is in the Republic district of Washington whose beautifully crustified quartz veins carry both gold and selenium (119a), the only other deposit of this type being the Redjang Lebong of Sumatra.[1]

**Foreign Deposits.** — *Hungary.* In eastern Hungary[2] including Transsulvania, there are a number of gold and silver deposits, associated with Tertiary eruptives chiefly andesites and dacites. Those in Hungary include Nagybanya, Felsöbanya, and Kapnik, and in Transylvania, Brad (the most important), Nagyag, etc. At Nagyag the gold occurs as tellurides, while in the other Transylvanian districts, it is native. Accompanying it are silver-ore minerals, as well as some pyrite, galena, blende, antimony, and tetrahedrite, in a gangue chiefly of quartz, but often containing as well manganese carbonate and silicate. The veins, which may be a meter thick, are usually fissure fillings, and the lodes may be 30 to 60 feet across. Propylitic alteration of the wall rocks is common.

*New Zealand.* — The veins of the Hauraki region known in later years for the output of the famous Waihi mine, contain small veins of massive or comby quartz with rich pockets of gold in propylitized Tertiary andesites and dacites in the northern part of the district, while the southern part the veins are of great width, with the ore shoots uniform and continuous.[3]

[1] Beck, Erzlagerstätten, I: 488; Truscott, Min. Mag., VI: 355, 1912.
[2] Vogt, Krusch und Beyschlag, Lagerstätten, II: 31, 1912.
[3] Finlayson, Min. Mag., II: 281, 1910; also Econ. Geol., IV: 632, 1909.

*Mexico* [1] contains a number of well-known representatives of this group, located especially in the eastern Sierra Madre, which, though usually occurring in Tertiary eruptives, sometimes cut sediments. Among these localities should be mentioned Parral, Guanajuato, Real del Monte, Zacatecas, and Pachuca. Silver predominates, the ore minerals, including pyrargyrite, argentite, stephanite, and polybasite, accompanied by tetrahedrite, galena, and blende in a gangue chiefly of quartz. The greater part of the Mexican gold production comes from the mines of El Oro.

## Gold Placers

These form an important source of supply of gold, together with a little silver, and, although widely distributed, become prominent chiefly in those areas in which auriferous quartz veins are abundant. So, while in North America they are found in many parts of the Cordilleran region, the Black Hills, and southern Appalachian region of the United States, their greatest development is in the Pacific Coast belt from California to Alaska, and in the Yukon district of Canada. Others of importance are found in South America and Australia.

Most of the gold placers are of Tertiary or Quaternary age, but older ones are also known (p. 685).

**Types of Placers.** — Placer deposits may be formed in different ways, as follows:

*Eluvial placers.* — These originate in those regions where gold-bearing rocks are subjected to deep weathering, during which the gold may undergo more or less concentration, and also migrate down slope to some extent. The gold grains are usually angular, as they have not been exposed to the wearing action of streams. In the United States, this type is known in the southern Appalachians, but it has also been found in Brazil, the Guianas, etc.

*Dry cr Eolian placers* (36, 36a). — In regions of aridity, where the rocks are disintegrated, the lighter particles may be blown away while the heavier ones, including gold, remain behind.

*Stream placers* (42, 47). — These represent the most important and widespread type. As the products of rock decay are washed down the slopes into streams, the fine clayey material is carried a long distance, but the heavier particles, including gold, settle rapidly, the gold, on account of its higher gravity, usually col-

[1] Vogt, Krusch und Beyschlag, Lagerstätten, II: 66, 1912. Aguilera, Amer. Inst. Min. Engrs., Trans. XXXII: 497, 1902; Ordoñez, *Ibid.*, p. 224, 1902. (Pachuca); Blake, *Ibid.*, p. 216, 1902. (Guanajuato); Bordeaux, A. F. J., *Ibid.*, XXXIX: 357, 1909. (Silver Mines.)

lecting in the lower part of the deposit, or even in crevices of the bed rock. Even if it does not do so at once, agitation of the sediment may cause it to settle deeper, or even slowly migrate down stream as the sediment shifts. Coarse gold carried down by streams from higher levels, will settle with coarse sediment in the upper part of a stream's course, but very fine flake gold may be transported some distance farther down stream.

In some regions thick gold-bearing gravel deposits have by downward cutting of the streams due to elevation of the land, been deeply trenched, leaving the uneroded remnants as benches along the valley slopes. Cases of this sort are found on the western slope of the Sierra Nevada in California, on Anvil Creek in the Nome district of Alaska, and in the Klondike district of the Yukon.

In some instances stream placers may have become buried under other barren gravels, or lava flows. (Victoria and some California deposits.) The gold in such instances has to be recovered by underground methods.

*Marine placers.* — These are formed by the sorting action of the waves along coasts where auriferous gravels or sands are exposed. They are known in California and Oregon, but the best examples are those of Cape Nome, Alaska.

**Size of the Placer Gold.** — Gold occurs in placers in the form of nuggets, flakes or dust-like grains. The nuggets represent the largest pieces, and the finding of some very large ones has been recorded from time to time in different parts of the world. Two large nuggets are recorded from Victoria: one the " Welcome Stranger," weighing 2280 ounces; and the other the " Welcome Nugget," weighing 2166 ounces. Most of the placer gold obtained is in small grains, and some may be very fine. Lindgren states that a piece of gold worth one cent is without trouble divisible into 2000 parts, each of which can be readily recognized in a pan.

**Associated Minerals.** — Placer deposits may contain a number of heavy minerals, which settle out with the gold in the sluice boxes. These include magnetite, ilmenite, (black sand), garnet, zircon (white sand), monazite (yellow sand), cassiterite, and platinum. Pyrite or marcasite may form in the gravels.

**California** (42, 47). — These have been derived from the wearing down of the Sierras, and are found in those valleys leading off the drainage from the mountains. Many were formed during the Tertiary period, when the Sierras were subjected to a

long-continued denudation, while violent volcanic outbursts at
the close of the Tertiary have often covered the gravels and pro-
tected them from subsequent erosion. These lava cappings are
at times 150 to 200 feet thick, as in Table Mountain, Tuolumne
County.

Many of the gravel deposits are on lines of former drainage, while
others lie in channels still occupied by streams. Some show but one
streak of gold, while in others
there may be several, some of
which are on rock benches of
the valley bottom (Fig. 266).
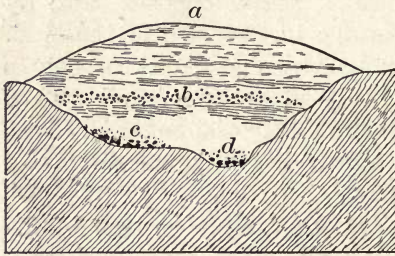


FIG. 266. — Generalized section of old
placer, with technical terms. *a*, vol-
canic cap ; *b*, upper lead ; *c*, bench
gravel ; *d*, channel gravel. (*After R. E.
Browne.*)

During the early days of gold
mining in California the gravels
at lower levels and in the valley
bottoms were worked, but as
these became exhausted, those
farther up the slopes or hills
were sought.

In the earlier operations the
gravels were washed entirely by
hand, either with a pan or rocker, and this plan is even now followed
by small miners and prospectors ; but mining on a larger scale is
carried on by one of three methods, viz. drift mining, hydraulic
mining, and dredging.

Drift mining is employed in the case of gravel deposits covered
by a lava cap, a tunnel being run in to the paying portion of the
bed and the auriferous gravel carried out and washed.

In hydraulic mining (Pl. LXXII, Fig. 1), a stream is directed
against the bank of gravel and the whole washed down into a
rock ditch lined with tree sections, or into a wooden trough with
crosspieces or riffles on the bottom. The gold, being heavy,
settles quickly and is caught in the troughs or ditches, while the
other materials are carried off and discharged into some neigh-
boring stream. Mercury is sometimes put behind the riffles to
aid in catching the gold.

The water which is used to wash down the gravel deposits is
often brought a long distance, sometimes many miles, and at
great expense, bridging valleys, passing through tunnels, and
even crossing divides, this being done to obtain a large enough
supply as well as a sufficient head of water.

Owing to the great amount of débris which was swept down into

Plate LXXII



Fig. 1. — Hydraulic mining of auriferous gravel. The sluice box in foreground is for catching the gold.



Fig. 2. — An Alaskan placer deposit.

(733)

the lowlands, a protest was raised by the farmers dwelling there, who claimed that their farms were being ruined; and it soon became a question which should survive, the farmer or the miner, for in places the gravels and sand from the washings choked up streams and accumulated to a depth of 70 or 80 feet. The question was settled in 1884 in favor of the farmer by an injunction, issued by the United States Circuit Court, which caused many of the hydraulic mines to suspend operations; and at a later date this was extended by state legislation, adverse to the hydraulic mining industry. Owing to this setback, hydraulic mining fell to a comparatively unimportant place in the gold-producing industry of California, while at the same time quartz mining increased.

The passage of the Caminetti law now permits hydraulic mining, but requires that a dam shall be constructed across the stream to catch the tailings. This resulted in a revival of the industry, but even so, the placer mining industry is seriously hindered by the present laws governing it.

Dredging consists in taking the gravel from the river with some form of dredge. The method, which was first practiced in New Zealand, has been introduced with great success into California, especially on the Feather River, near Oroville, and its use has spread to other parts of the Cordilleran region and Alaska. The gravel when taken from the river is discharged onto a screen, which separates the coarse stones, and the finer particles pass over amalgamated plates, tables with riffles, and then over felt.

Placer gold is also worked in Idaho, Montana, Oregon, New Mexico, and Colorado, all of the deposits except those of the last two states having been derived mostly from Mesozoic veins.

Gold also occurs in beach sand of certain portions of the Pacific coast of Washington (119), and placer mining has been carried on since 1894; but the supply of gold, which is obtained from Pleistocene sands and gravels, is small.

In arid regions, where the gold-bearing sands are largely the product of disintegration, and water for washing out the metal is wanting, a system known as dry blowing is sometimes resorted to.

**Alaska.** — The placer deposits have been found in many parts of Alaska, but the two regions which have yielded the largest amount are the Yukon region (24, 33) and the Seward Peninsula (24, 30), the latter being now the first.

Gold was discovered in the Forty Mile district of the Yukon in 1886, and caused a stampede for this region; but the deposits

of the Klondike did not become known until 1896, and their discovery was followed by a rush of gold seekers that eclipsed all previous ones. Indeed, it is said that by 1898 over 40,000 people were camped out in the vicinity of the present site of Dawson.

The Klondike region proper is situated on the eastern side of the Yukon River, and the richest deposits found have been on the Canadian side of the boundary. The gold has collected either at the bottom of the gravel in the smaller streams tributary to the Yukon, or else in gravels on the valley sides, this latter occurrence being known as bench gravel. The metal is supposed to have been derived from the quartz veins found in the Birch Creek, Forty Mile, and Rampart series of metamorphic rocks lying to the east. Up to the end of 1902 the total production of the Klondike is stated to have been $80,000,000. The annual output has, however, decreased, and mining in that region has settled down to a more permanent basis. Gravels running under 50 cents per cubic yard cannot be worked at a profit, even by dredging, because the difficulties and expenses of mining in such a region are great, and form an interesting comparison with conditions in California, where gravel carrying 25 cents per yard is considered good, while that running as low as 5 cents per yard can be worked as a dredge proposition (26).[1]

Since the discovery of the rich gold gravels on the Yukon, auriferous gravels have been developed in many other parts of Alaska, where they are being more or less actively worked (Fig. 241), but of these various finds those in the Seward Peninsula, which is now the largest producer, have been the most important.

The first of the localities discovered in the last-mentioned region was Cape Nome (30, 31), which for a time proved to be a second Klondike. The gold was discovered here on Anvil Creek, and the following year in the beach sands where Nome now stands. These discoveries caused another northward stampede, which resulted in the rapid exhaustion of the beach sands; but other deposits were found farther inland near Nome, as well as the other localities on the Seward Peninsula. Some quartz veins are also worked. Up to the end of 1914 the Seward Peninsula had produced $68,642,700 in gold, and in 1906 its production is given as $7,500,000, but by 1914 it had dropped to $2,733,000. In the Fairbanks district (29), which is another important placer area, and lies in central Alaska (Fig. 241), there is a remarkable accu-

[1] See also U. S. Geol. Surv., Bull. 263.

mulation of unconsolidated material overlying the bed rock, which seems to have been deposited in an area where glaciation was absent, but fluviatile conditions predominated.

An interesting feature of these deposits is their remarkable thickness, and their depth of consolidation by ice, over 300 feet, as revealed by mining operations. The unconsolidated material includes slide rock, muck, sand, silt, clay, barren gravels, and the gravels in which the gold is found. These productive gravels, so far as discovered, are a thin layer next to bed rock, and the value of the gold recovered has ranged from less than $1 to $8 or more per square foot of bed rock surface. The present activities are supported by low-grade deposits of $1 or less per square foot, and in 1914 deep placers yielding as little as 40 cents per square foot were worked by drifting.

The Iditarod district, which produced about $2,000,000 worth of gold in 1914, obtained mostly by dredging, is the third large producer.

A number of smaller districts add to the total supply of the territory.

**Yukon Territory** (133). — The Klondike gold fields are situated on the east side of the Yukon River at its confluence with the Klondike, and cover an area of about 200 square miles. The district is a part of a dissected upland, and a second uplift in recent times has caused the streams to deepen their valleys, but portions of the old valley bottoms, covered with heavy accumulations of gravel, still remain as benches on the valley sides at many points. Owing to the unglaciated character of the region, the rocks are deeply weathered. The surface materials are permanently frozen.

The auriferous gravels occur under the following conditions: (1) Low-level creek gravels, 4 to 10 feet deep, resting on bed rock, and covered by 2 to 30 feet more of black frozen muck. These are the most important; (2) gulch gravels, found in the upper portions of the main creek valleys, and small tributary valleys; (3) gravels on rock terraces, formed during the deepening of the valleys, and representing portions of an old valley bottom; (4) high-level gravels, representing ancient creek deposits, accumulated when the river flowed several hundred feet higher than it does now. Of these the " White Channel " gravels, so called because of their white or light-gray color, are important, and represent the oldest stream deposits of the district.

They range in thickness from a few to 150 feet, and are second in commercial importance to the present creek gravels.

The Klondike gold varies in fineness, due to its being in all cases alloyed with silver. The lowest grade has a value of about $12.50 an ounce, but some has exceeded $17.50 an ounce.

**Victoria.**[1] This colony contains a remarkable series of buried channels, called "deep leads." The gold occurs in gravels of Tertiary streams, which, following a depression, became covered by thick beds of sand and clay, and these in turn by basalt flows of several hundred feet thickness. The gold was first discovered in the upper part of the former stream courses and then followed down under the basalt.

**Russia.** — Gold gravels, which Purington claims belong to one of the greatest placer fields of the world, are being developed on the Lena River, in Siberia.[2]

**South Africa.**[3] The auriferous conglomerates of the Johannesburg district of the Transvaal, S. Afr., are among the most remarkable known. They are of apparently simple structure, yet very puzzling as to origin. The section involves a basal series of crystalline schists intruded by granites, on whose eroded surface rests the Upper and Lower Witwatersrand system of slates, quartzites, and conglomerates, aggregating 19,000 feet in thickness, and overlain in turn by the Ventersdorp system of volcanics.

The Witwatersrand, which is probably of Cambrian or pre-Cambrian age, forms a syncline with Johannesburg on its north side. The series has been faulted and also cut by diabase dikes, and while auriferous conglomerates are found at several different horizons, the most productive ones are in the upper part.

The ore consists of pebbles mostly of quartz, in a sandy matrix, with abundant pyrite in the cement. The gold, which occurs in the cement but not in the pebbles, is closely connected with the pyrite. Some of the gold has migrated and recrystallized. It is not yet definitely settled whether the auriferous conglomerate represents an ancient placer, or whether the gold and pyrite are epigenetic and introduced after the dikes, and for the detailed arguments reference should be made to the articles referred to. It is provisionally placed with the placer deposits.

**Uses of Gold.** — Gold is chiefly used for coinage, ornaments, and ornamental utensils. It is employed to a considerable extent in dentistry and in an alloy for the better class of gilding.

Its value for use in the arts depends on its brightness, freedom from tarnish, and its ductility and malleability, which permit it

[1] Lindgren, Min. Mag. XI: 33, 1905, and Eng. and Min. Jour., Feb. 16, 1905.
[2] Min. Mag. XII: 341, 1915.
[3] Hatch, Types of Ore Deposits, San Francisco, 1911; Gregory, Econ. Geol., IV: 118, 1909; Hatch, Min. and Sci. Pr., CIII: 98 and 132, 1911; Horwood, Min. and Sci. Pr., CVII: 563, etc., 1913; Schwarz, Min. Mag., XIII: 223, 1915.

to be easily worked. As pure 24-carat gold is too soft for use, it is alloyed with a small amount of some other metal, such as copper, to gain hardness.

**Uses of Silver.** — This metal was formerly of much importance for coinage, but is much less so now. It is, however, widely employed in the arts for making jewelry and utensils such as tableware. Its salts are of more or less value in medicine and in photography. Its brightness and white color are valuable properties when the metal is used, but, unlike gold, it tarnishes somewhat readily when exposed to sulphurous gases. There are a number of alloys of silver, those with gold and copper, respectively, being of importance.

**Production of Gold and Silver.** — The total production of gold and silver for the United States and other countries is given on the following pages.

PRODUCTION OF GOLD AND SILVER IN THE UNITED STATES, 1860 TO 1914

| YEAR | GOLD | | SILVER | |
|---|---|---|---|---|
| | Ounces | Value | Ounces | Commercial Value |
| 1880 | 1,741,500 | $36,000,000 | 30,318,700 | $34,717,000 |
| 1881 | 1,678,612 | 34,700,000 | 33,257,800 | 37,657,500 |
| 1882 | 1,572,187 | 32,500,000 | 36,196,900 | 41,105,900 |
| 1883 | 1,451,250 | 30,000,000 | 35,732,800 | 39,618,400 |
| 1884 | 1,489,950 | 30,800,000 | 37,743,800 | 41,921,300 |
| 1885 | 1,538,373 | 31,801,000 | 39,909,400 | 42,503,500 |
| 1886 | 1,686,788 | 34,869,000 | 39,694,000 | 39,482,400 |
| 1887 | 1,603,049 | 33,136,000 | 41,721,600 | 40,887,200 |
| 1888 | 1,604,478 | 33,167,500 | 45,792,700 | 43,045,100 |
| 1889 | 1,594,775 | 32,967,000 | 50,094,500 | 46,838,400 |
| 1890 | 1,588,877 | 32,845,000 | 54,516,300 | 57,242,100 |
| 1891 | 1,604,840 | 33,175,000 | 58,330,000 | 57,630,000 |
| 1892 | 1,597,098 | 33,015,000 | 63,500,000 | 55,662,500 |
| 1893 | 1,739,323 | 35,955,000 | 60,000,000 | 46,800,000 |
| 1894 | 1,910,813 | 39,500,000 | 49,500,000 | 31,422,100 |
| 1895 | 2,254,760 | 46,610,000 | 55,727,000 | 36,445,500 |
| 1896 | 2,568,132 | 53,088,000 | 58,834,800 | 39,654,600 |
| 1897 | 2,774,935 | 57,363,000 | 53,860,000 | 32,316,000 |
| 1898 | 3,118,398 | 64,463,000 | 54,438,000 | 32,118,400 |
| 1899 | 3,437,210 | 71,053,400 | 54,764,500 | 32,858,700 |
| 1900 | 3,829,897 | 79,171,000 | 57,647,000 | 35,741,100 |
| 1901 | 3,805,500 | 78,666,700 | 55,214,000 | 33,128,400 |
| 1902 | 3,870,000 | 80,000,000 | 55,500,000 | 29,415,000 |
| 1903 | 3,560,000 | 73,591,700 | 54,300,000 | 29,322,000 |
| 1904 | 3,892,480 | 80,464,700 | 57,682,800 | 33,456,000 |
| 1905 | 4,265,742 | 88,180,700 | 56,101,600 | 34,222,000 |
| 1906 | 4,565,333 | 94,373,800 | 56,517,900 | 38,256,400 |
| 1907 | 4,374,827 | 90,435,700 | 56,514,700 | 37,299,700 |
| 1908 | 4,574,340 | 94,560,000 | 52,440,800 | 28,050,600 |
| 1909 | 4,821,701 | 99,673,400 | 54,721,500 | 28,455,200 |
| 1910 | 4,657,018 | 96,269,100 | 57,137,900 | 30,854,500 |
| 1911 | 4,687,053 | 96,890,000 | 60,399,400 | 32,615,700 |
| 1912 | 4,520,717 | 93,451,500 | 63,766,800 | 39,197,500 |
| 1913 | 4,299,783 | 88,884,400 | 66,801,500 | 40,348,100 |
| 1914 | 4,572,976 | 94,531,800 | 72,455,100 | 40,067,700 |
| Total | 102,852,715 | 2,126,152,400 | 1,831,133,800 | 1,340,356,500 |

The recovered output of gold and silver in the United States from domestic ores and gravels in 1914 is given below.

APPROXIMATE DISTRIBUTION, BY PRODUCING STATES AND TERRITORIES, OF THE PRODUCTION OF GOLD AND SILVER IN THE UNITED STATES FOR THE CALENDAR YEAR 1914, IN FINE OUNCES [1]

| STATE OR TERRITORY. | GOLD | | SILVER | |
| --- | --- | --- | --- | --- |
| | Quantity | Value | Quantity | Commercial Value |
| Alabama . . . . . . . . . . | 495 | $    12,300 | 300 | $      200 |
| Alaska . . . . . . . . . . | 800,471 | 16,547,200 | 865,900 | 478,800 |
| Arizona . . . . . . . . . . | 221,020 | 4,568,900 | 4,439,500 | 2,455,000 |
| California . . . . . . . . . | 1,028,061 | 21,251,900 | 2,020,800 | 1,117,500 |
| Colorado . . . . . . . . . . | 962,779 | 19,902,400 | 8,804,400 | 4,868,800 |
| Georgia . . . . . . . . . . | 813 | 16,800 | 100 | 100 |
| Idaho . . . . . . . . . . | 57,431 | 1,187,200 | 12,573,800 | 6,953,300 |
| Illinois . . . . . . . . . . | —— | | 1,900 | 1,200 |
| Maryland . . . . . . . . . | 10 | 200 | 100 | 100 |
| Michigan . . . . . . . . . | —— | —— | 415,500 | 229,800 |
| Missouri . . . . . . . . . . | —— | | 60,000 | 33,200 |
| Montana . . . . . . . . . . | 200,446 | 4,143,600 | 12,536,700 | 6,932,800 |
| Nevada . . . . . . . . . . | 558,064 | 11,536,200 | 15,877,200 | 8,780,100 |
| New Mexico . . . . . . . . | 58,974 | 1,219,100 | 1,771,300 | 979,500 |
| North Carolina . . . . . . | 6,303 | 130,300 | 1,500 | 800 |
| Oklahoma . . . . . . . . . | —— | | 6,200 | 3,400 |
| Oregon . . . . . . . . . . | 76,887 | 1,589,400 | 147,400 | 81,500 |
| Philippine Islands . . . . . | 53,179 | 1,099,300 | 10,300 | 5,700 |
| Porto Rico . . . . . . . . | 135 | 2,800 | —— | —— |
| South Carolina . . . . . . | 155 | 3,200 | | |
| South Dakota . . . . . . . | 354,782 | 7,334,000 | 179,800 | 99,400 |
| Tennessee . . . . . . . . . | 309 | 6,400 | 102,800 | 56,800 |
| Texas . . . . . . . . . . | 426 | 8,800 | 574,700 | 317,800 |
| Utah . . . . . . . . . . | 163,362 | 3,377,000 | 11,722,000 | 6,482,300 |
| Virginia . . . . . . . . . . | 15 | 300 | 1,500 | 800 |
| Washington . . . . . . . . | 28,435 | 587,800 | 341,300 | 188,700 |
| Wyoming . . . . . . . . . | 324 | 6,700 | 100 | 100 |
| Total . . . . . . . | 4,572,976 | 94,531,800 | 72,455,100 | 40,067,700 |

[1] Gold value, $20.67 + per fine ounce. Average commercial price of silver in 1914, 55.3 cents per fine ounce.

The totals for this table are based on bullion deposits in the United States mints and assay offices and statements from the smelting and refining establishments. The table is derived from three sources: (1) the unrefined domestic gold and silver deposited in the United States mints and assay offices; (2) the domestic gold and silver in fine bars reported by the private refineries; (3) the unrefined gold and silver contained in ores and matte exported for reduction. The last is an item of small relative importance. In addition, the domestic smelters and refineries produced as refined bullion from foreign ore, matte, and unrefined bullion, 875,250 fine ounces of gold, and 39,789,129 fine ounces of silver. Of the foreign gold there is credited to Mexico, 199,652 ounces; to Canada (including British Columbia, the Yukon, and the Klondike), 532,572 ounces; to Central America, 61,123 ounces; to South America, 45,161 ounces; to Cuba, 320 ounces; and to all other foreign sources, 36,420 ounces. Of foreign silver there is credited to Mexico, 19,643,774 fine ounces; to Canada, 7,084,354 ounces; to Central America, 2,458,094 ounces; to South America, 5,432,676 ounces; to Cuba, 51,542 ounces; and to all other foreign sources, 5,118,689 ounces.

SOURCE OF MINE PRODUCTION OF GOLD IN 1914 IN STATES AND TERRITORIES, AS REPORTED FROM THE MINES TO THE UNITED STATES GEOLOGICAL SURVEY, BY KINDS OF ORE AND BY STATES, IN FINE OUNCES [1]

| STATE OR TERRITORY | PLACER. | DRY OR SILICEOUS ORES. | COPPER ORES. | LEAD ORES. | ZINC ORES. | COPPER-LEAD AND COPPER-LEAD-ZINC ORES. | LEAD-ZINC ORES. | TOTAL. |
|---|---|---|---|---|---|---|---|---|
| Alabama | 24.19 | 554.86 | | | | | | 579.05 |
| Alaska | 519,063.75 | 235,248.98 | 8,283.30 | | | | | 762,596.03 |
| Arizona | 1,458.02 | 145,255.71 | 50,842.80 | 2,188.48 | 1,570.45 | 108.75 | 742.41 | 202,166.62 |
| California | 439,286.07 | 541,815.62 | 16,630.16 | 1,381.02 | 2.24 | | | 999,112.87 |
| Colorado | 31,074.16 | 893,819.64 | 3,243.88 | 30,525.24 | 6.77 | 288.91 | 2,891.13 | 961,845.20 |
| Georgia | 534.20 | 252.86 | | | | | | 787.06 |
| Idaho | 33,884.46 | 17,582.57 | 1,076.54 | 2,467.13 | | | 725.77 | 55,743.24 |
| Maryland | | 10.64 | .24 | | | | | 10.88 |
| Montana | 45,579.75 | 121,599.07 | 25,422.61 | 1,972.44 | 41.99 | 6.63 | 4,581.45 | 199,203.94 |
| Nevada | 18,250.05 | 484,796.50 | 49,476.59 | 2,541.09 | 291.70 | 46.54 | | 555,402.47 |
| New Mexico | 1,410.22 | 43,630.49 | 11,352.45 | 268.86 | | 18.77 | | 56,680.79 |
| North Carolina | 324.45 | 6,012.91 | 6.58 | | | | | 6,343.94 |
| Oregon | 26,524.83 | 50,388.32 | | 73.77 | | | | 76,986.92 |
| South Carolina | 21.72 | 334.32 | | | | | | 356.04 |
| South Dakota | 67.97 | 354,688.88 | | | | | | 354,758.45 |
| Tennessee | | | 299.63 | | | | | 299.63 |
| Texas | | | | 1.60 | | | 11.32 | 11.32 |
| Utah | 59.55 | 18,274.43 | 97,955.32 | 33,094.69 | | 78.17 | 8,499.00 | 157,961.16 |
| Virginia | | | 20.76 | | | | | 20.76 |
| Washington | 278.45 | 26,453.86 | 220.93 | | | | | 26,953.24 |
| Wyoming | 89.06 | 153.11 | | | | | | 242.17 |
| Total, 1914 | 1,117,930.90 | 2,940,872.77 | 264,831.79 | 74,514.32 | 1,913.15 | 547.77 | 17,451.08 | 4,418,061.78 |
| Value . . . | $23,109,683 | $60,793,236 | $5,474,559 | $1,540,348 | $39,548 | $11,323 | $360,746 | $91,329,443 |
| Percentage of total | 25.30 | 66.56 | 6.00 | 1.69 | 0.04 | 0.01 | 0.40 | |
| Total, 1913 | 1,075,783.74 | 2,864,900.58 | 275,633.75 | 73,880.52 | 896.30 | 4,696.89 | 15,311.28 | 4,311,103.06 |
| Value . . . | $22,238,424 | $59,222,751 | $5,697,855 | $1,527,246 | $18,528 | $97,094 | $316,512 | $89,118,410 |
| Percentage of total | 24.96 | 66.45 | 6.39 | 1.69 | 0.02 | 0.11 | 0.36 | |

[1] Philippines and Porto Rico not included.

SOURCE OF MINE PRODUCTION OF SILVER IN 1914 IN STATES AND TERRITORIES, AS REPORTED FROM THE MINES TO THE UNITED STATES GEOLOGICAL SURVEY, BY KINDS OF ORE AND BY STATES, IN FINE OUNCES [1]

| State or Territory | Placer | Dry or Siliceous Ores | Copper Ores | Lead Ores | Zinc Ores | Copper-Lead and Copper-Lead-Zinc Ores | Lead-Zinc Ores | Total |
|---|---|---|---|---|---|---|---|---|
| Alabama | | 199 | | | | | | 199 |
| Alaska | 83,196 | 28,254 | 283,355 | | | | | 394,805 |
| Arizona | 241 | 1,133,976 | 2,604,371 | 493,226 | 34,691 | 31,991 | 79,498 | 4,337,994 |
| California | 34,877 | 268,828 | 703,042 | 465,112 | | | | 1,471,859 |
| Colorado | 7,321 | 6,584,493 | 173,845 | 1,532,943 | 1,046 | 82,119 | 414,298 | 8,796,065 |
| Georgia | 29 | 38 | | | | | | 67 |
| Idaho | 7,071 | 39,002 | 239,355 | 8,697,580 | 5,039 | | 3,491,469 | 12,479,516 |
| Illinois | | | | 2,112 | | | | 2,112 |
| Maryland and Virginia | | | 1,502 | | | | | 1,502 |
| Michigan | | | 413,500 | | | | | 413,500 |
| Missouri | | | 14 | 61,514 | | | | 61,168 |
| Montana | 7,041 | 1,249,555 | 8,015,694 | 388,194 | 48,373 | 5,271 | 2,302,332 | 12,016,460 |
| Nevada | 6,367 | 14,724,094 | 181,733 | 286,935 | 56,115 | 85,109 | 115,138 | 15,455,491 |
| New Mexico | 330 | 1,459,814 | 292,266 | 17,875 | | 7,160 | | 1,777,445 |
| North Carolina | 33 | 1,467 | 24 | | | | | 1,524 |
| Oklahoma | | 6,187 | | | | | | 6,187 |
| Oregon | 5,512 | 136,398 | | 642 | | | | 142,552 |
| South Carolina | | 33 | | | | | | 33 |
| South Dakota | 11 | 176,241 | | 390 | | | | 176,642 |
| Tennessee | | | 97,402 | | | | | 97,402 |
| Texas | | 517,863 | 6,826 | | | | | 530,817 |
| Utah | 9 | 1,317,364 | 1,726,230 | 7,350,213 | | 37,216 | 6,128 | 11,154,916 |
| Washington | 83 | 168,499 | 90,574 | 5,705 | | | 723,884 | 264,861 |
| Wisconsin | | | 16 | | | | | 16 |
| Wyoming | 7 | 30 | 79 | | | | | 116 |
| **Total** | 152,128 | 27,812,335 | 14,829,828 | 19,302,081 | 145,264 | 248,866 | 7,132,747 | 69,623,249 |
| Value Percentage of total | $84,126 0.22 | $15,380,221 39.95 | $8,200,895 21.30 | $10,674,051 27.72 | $80,331 0.21 | $137,623 0.36 | $3,944,409 10.24 | $38,501,656 |
| Total, 1913 | 123,739 | 28,010,875 | 18,250,253 | 18,629,246 | 86,432 | 752,563 | 5,334,120 | 71,187,228 |
| Value Percentage of total | $74,738 .17 | $16,918,569 39.35 | $11,023,153 25.63 | $11,252,065 26.17 | $52,205 0.12 | $454,548 1.06 | $3,221,808 7.50 | $42,997,086 |

[1] Philippines and Porto Rico not included in this table.

PERCENTAGE OF OUTPUT OF GOLD AND SILVER BY PROCESSES IN THE UNITED
STATES IN 1912, 1913, AND 1914

| PRODUCTION BY | PERCENTAGE OF TOTAL OUTPUT | | | | | |
| | Gold | | | Silver | | |
| | 1912 | 1913 | 1914 | 1912 | 1913 | 1914 |
| --- | --- | --- | --- | --- | --- | --- |
| Placers . . . . . . . . | 24.8 | 24.9 | 25.3 | 0.2 | 0.2 | 0.2 |
| Gold and silver mills: | | | | | | |
| By amalgamation . . | 22.3 | 21.5 | 20.9 | 1.2 | .6 | .4 |
| By cyanidation . . . | 30.9 | 31.2 | 31.4 | 17.8 | 19.7 | 22.1 |
| By chlorination . . . | .4 | .3 | .2 | — | — | — |
| Total milling . . | 53.6 | 53.0 | 52.5 | 19.0 | 20.3 | 22.5 |
| Smelting [1] . . . . . . | 21.6 | 22.1 | 22.2 | 80.8 | 79.5 | 77.3 |
| Total [2] . . . . | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |

[1] Both crude ore and concentrates.

[2] Philippine Islands and Porto Rico excluded.

AVERAGE EXTRACTION VALUE OF GOLD AND SILVER PER TON IN 1914, BY
STATES AND TERRITORIES

| STATE OR TERRITORY. | DRY OR SILICEOUS ORES | COPPER ORES | LEAD ORES | ZINC ORES | COPPER-LEAD AND COPPER-LEAD-ZINC ORES | LEAD-ZINC ORES |
| --- | --- | --- | --- | --- | --- | --- |
| Alabama and Georgia | $2.46 | — | — | — | — | — |
| Alaska . . . . . . | 2.80 | $2.14 | — | — | — | — |
| Arizona . . . . . | 8.46 | .33 | 11.92 | $2.86 | $4.08 | $2.53 |
| California . . . . . | 5.53 | 1.84 | 16.99 | — | — | — |
| Colorado . . . . . | 10.25 | 13.38 | 7.66 | .004 | 43.11 | 1.72 |
| Idaho . . . . . . | 8.85 | 1.66 | 3.42 | .34 | — | 2.91 |
| Maryland and Virginia [1] | 20.00 | .84 | — | — | — | — |
| Michigan [1] . . . . | — | .20 | — | — | — | — |
| Montana . . . . . | 9.37 | 1.14 | 8.62 | 3.05 | 18.17 | 3.40 |
| Nevada . . . . . | 11.39 | .39 | 13.13 | 3.90 | 12.77 | 3.96 |
| New Mexico . . . . | 10.11 | .20 | 6.20 | — | 11.45 | — |
| North Carolina [2] . . | 7.17 | 14.90 | — | — | — | — |
| Oklahoma . . . . | 18.00 | — | — | — | — | — |
| Oregon . . . . . | 8.99 | — | 32.98 | — | — | — |
| South Carolina . . . | .92 | — | — | — | — | — |
| South Dakota . . . | 3.68 | — | 35.57 | — | — | — |
| Tennessee [2] . . . . | — | .09 | — | — | — | — |
| Texas . . . . . . | 7.09 | 16.34 | — | — | — | 2.21 |
| Utah . . . . . . | 7.38 | .39 | 7.91 | — | 18.76 | 2.75 |
| Washington . . . . | 8.66 | 2.51 | 10.41 | — | — | — |
| Wisconsin [1] . . . . | — | .27 | — | — | — | — |
| Wyoming . . . . . | 9.22 | .56 | — | — | — | — |
| Total average . | 6.95 | .49 | 5.29 | .19 | 12.87 | 2.90 |
| Per cent of tonnage . | 25.46 | 64.26 | 5.36 | 1.44 | .02 | 3.46 |

[1] Includes only copper ore yielding precious metals.

[2] Lead and zinc ores yielded no precious metals.

**Gold and Silver Reserves.** — Lindgren has pointed out (13) that the
gold reserves of the United States are large, but that it is difficult to
estimate them with any degree of exactness, a rough estimate even being

possible only in the case of placers, which are found chiefly in California and Alaska. These are estimated to contain perhaps $1,000,000,000 of gold in reserve, and the output from this source will probably not decrease for some time. The gold derived from copper ores is not large ($4,800,000 in 1908), but is a stable and increasing quantity, likely to last for 25 years at least. That derived from lead ores is much less, and a slow decrease may be expected.

The quartzose ores form an important source, likely to continue active and strong producers. The United States gold production is not likely to rise above $110,000,000, nor is it likely to sink below $60,000,000 for a long time. Owing to the low price of silver, a number of mines producing ore of this metal have shut down, but the increasing amount supplied as a by-product from lead and copper ores has kept the output steady. The present supply is regarded as assured as long as the mining of lead and copper ores, as well as quartzose gold ores, continues on the present scale.

PRODUCTION OF GOLD AND SILVER IN CANADA BY PROVINCES IN 1914

| PROVINCE | GOLD | | SILVER | |
|---|---|---|---|---|
| | Ounces. (fine) | Value | Ounces | Value |
| British Columbia . . | 252,730 | $5,224,393 | 3,159,897 | $1,731,971 |
| Yukon . . . . . | 247,940 | 5,125,374 | 92,973 | 50,959 |
| Nova Scotia . . . | 2,904 | 60,031 | — | — |
| Ontario . . . . . | 268,264 | 5,545,509 | 25,139,214 | 13,779,055 |
| Quebec . . . . . | 1,292 | 26,708 | 57,737 | 31,646 |
| Alberta . . . . . | 48 | 992 | — | — |
| Total . . . | 773,178 | 15,983,007 | 28,449,821 | 15,593,631 |

PRODUCTION OF GOLD AND SILVER IN CANADA

| YEAR | GOLD | | SILVER | |
|---|---|---|---|---|
| | Ounces | Value | Ounces | Value |
| 1858 . . . . . . | 34,104 | $ 705,000 | — | — |
| 1860 . . . . . . | 107,806 | 2,228,543 | — | — |
| 1865 . . . . . . | 192,898 | 3,987,562 | — | — |
| 1870 . . . . . . | 83,415 | 1,724,348 | — | — |
| 1876 . . . . . . | 97,729 | 2,020,233 | — | — |
| 1880 . . . . . . | 63,121 | 1,304,824 | — | — |
| 1885 . . . . . . | 55,575 | 1,148,829 | — | — |
| 1890 . . . . . . | 55,620 | 1,149,776 | 400,687 | $ 419,118 |
| 1895 . . . . . . | [1] 100,798 | 2,083,674 | 1,578,275 | 1,030,299 |
| 1900 . . . . . . | [2] 1,350,057 | 27,908,153 | 4,468,225 | 2,740,362 |
| 1905 . . . . . . | 684,951 | 14,159,195 | 6,000,023 | 3,621,133 |
| 1910 . . . . . . | 493,707 | 10,205,835 | [3] 32,869,264 | 17,580,455 |
| 1914 . . . . . . | 773,178 | 15,983,007 | 28,449,821 | 15,593,630 |

[1] Yukon output began about this time.

[2] Decreased from here until 1907, then remained stationary, until Porcupine discovery increased it again.

[3] The maximum production was 19,440,165 ounces in 1912.

PRODUCTION OF GOLD IN THE WORLD, 1860–1914

[The annual production from 1860 to 1872 is obtained from 5-year periods compiled by Dr. Adolph Soetbeer. From 1872 to 1912, inclusive, the estimates are those of the Bureau of the Mint. The figures for 1913 and 1914 are in part final and in part estimates of the Survey from best available information, and are subject to revision.]

| YEAR | VALUE | YEAR | VALUE | YEAR | VALUE | YEAR | VALUE |
|---|---|---|---|---|---|---|---|
| 1860 | $134,083,000 | 1875 | $ 97,500,000 | 1890 | $118,848,700 | 1905 | $380,288,700 |
| 1861 | 122,989,000 | 1876 | 103,700,000 | 1891 | 130,650,000 | 1906 | 402,503,000 |
| 1862 | 122,989,000 | 1877 | 113,947,200 | 1892 | 146,651,500 | 1907 | 412,966,600 |
| 1863 | 122,989,000 | 1878 | 119,092,800 | 1893 | 157,494,800 | 1908 | 442,476,900 |
| 1864 | 122,989,000 | 1879 | 108,778,800 | 1894 | 181,175,600 | 1909 | 454,059,100 |
| 1865 | 122,989,000 | 1880 | 106,436,800 | 1895 | 198,763,600 | 1910 | 455,239,100 |
| 1866 | 129,614,000 | 1881 | 103,023,100 | 1896 | 202,251,600 | 1911 | 461,939,700 |
| 1867 | 129,614,000 | 1882 | 101,996,600 | 1897 | 236,083,700 | 1912 | 466,136,100 |
| 1868 | 129,614,000 | 1883 | 95,392,000 | 1898 | 286,879,700 | 1913 | 454,942,211 |
| 1869 | 129,614,000 | 1884 | 101,729,600 | 1899 | 306,724,100 | 1914 | 453,000,000 |
| 1870 | 129,614,000 | 1885 | 108,435,600 | 1900 | 254,576,300 | | |
| 1871 | 115,577,000 | 1886 | 106,163,900 | 1901 | 260,992,900 | Total | $11,257,320,811 |
| 1872 | 115,577,000 | 1887 | 105,774,900 | 1902 | 296,737,600 | | |
| 1873 | 96,200,000 | 1888 | 110,196,900 | 1903 | 327,702,700 | | |
| 1874 | 90,750,000 | 1889 | 123,489,200 | 1904 | 347,377,200 | | |

GOLD PRODUCTION IN THE WORLD IN 1913 AND 1914 BY COUNTRIES

| COUNTRY | 1913 | 1914 |
|---|---|---|
| North America: | | |
| United States . . . . . . . . . . . | [1] $88,884,400 | [1] $94,531,800 |
| Canada . . . . . . . . . . . . | [1] 16,216,131 | [1] 15,925,044 |
| Mexico . . . . . . . . . . . . | [2] 18,250,000 | [3] 18,000,000 |
| Cuba . . . . . . . . . . . . . | [3] 24,600 | |
| Africa . . . . . . . . . . . . . | [4] 205,875,000 | [3] 201,000,000 |
| Australasia . . . . . . . . . . . | [1] 53,038,090 | [5] 49,386,180 |
| Europe: | | |
| Russia and Finland . . . . . . . | [6] 24,578,575 | [3] 26,750,000 |
| Austria-Hungary . . . . . . . . | [4] 2,180,414 | [3] 1,500,000 |
| Germany . . . . . . . . . . | [3] 60,000 | |
| Norway . . . . . . . . . . . | | |
| Sweden . . . . . . . . . . . | [4] 36,630 | |
| Italy . . . . . . . . . . . . | [4] 30,572 | |
| Spain and Portugal . . . . . . . | [6] 2,500 | |
| Turkey . . . . . . . . . . . | [6] 500 | |
| France . . . . . . . . . . . | [6] 1,946,600 | [3] 1,000,000 |
| Great Britain . . . . . . . . . | [1] 17,860 | |
| Servia . . . . . . . . . . . | [3] 250,000 | 100,000 |
| South America: | | |
| Argentina . . . . . . . . . . | [3] 100,000 | |
| Bolivia and Chile . . . . . . . | [3] 800,000 | [3] 500,000 |
| Colombia . . . . . . . . . . | [3] 3,000,000 | [3] 3,000,000 |
| Ecuador . . . . . . . . . . . | [7] 289,133 | |
| Brazil . . . . . . . . . . . | [4] 3,009,786 | [3] 3,000,000 |
| Venezuela . . . . . . . . . . | [4] 444,800 | |
| Guiana: | | |
| British . . . . . . . . . . | [4] 1,353,368 | [3] 1,250,000 |
| Dutch . . . . . . . . . . . | [4] 470,433 | [3] 500,000 |
| French . . . . . . . . . . | [8] 3,050,600 | [3] 3,000,000 |
| Peru . . . . . . . . . . . . | [8] 492,200 | [3] 500,000 |
| Uruguay . . . . . . . . . . | [8] 111,000 | |
| Central America . . . . . . . . . | [3] 3,000,000 | [3] 3,500,000 |
| Asia: | | |
| Japan . . . . . . . . . . . | [1] 4,470,723 | [9] 4,476,500 |
| China . . . . . . . . . . . | [8] 3,658,900 | [3] 3,800,000 |
| Indo-China . . . . . . . . . . | [3] 70,000 | |
| Chosen (Korea) . . . . . . . . | [4] 3,281,333 | [3] 3,750,000 |
| Siam . . . . . . . . . . . | [8] 56,500 | |
| India, British . . . . . . . . . | [1] [8] 11,152,463 | [5] 11,388,870 |
| East Indies, British . . . . . . . | [8] 1,352,000 | } 4,750,000 |
| East Indies, Dutch . . . . . . . | [8] 3,387,100 | |
| Total . . . . . . . . . | 454,942,211 | [4] [10] 453,000,000 |

[1] Official; [2] Min. World, Feb. 6, 1915; [3] estimated; [4] Director Mint. Ann. Rep., 1914; [5] Min. Mag., Apr., 1915; [6] Min. Mag., 1914; [7] Min. Jour., Dec. 5, 1914; [8] Min. Indus., 1914; [9] Min. and Sci. Pr., May, 8, 1915; [10] includes estimates for countries not specified.

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## MINOR METALS

### ALUMINUM — MANGANESE — MERCURY

#### ALUMINUM

**Ores.** — This is one of the few metals whose ores do not present a metallic appearance. Many different minerals contain aluminum, but it can be profitably extracted from only a few. Common clay, for example, presents an inexhaustible supply, but the chemical combination of the aluminum in it is such that its extraction up to the present time has not been found commercially practicable, although a number of processes with this end in view have been patented.

The minerals which might serve as sources of aluminum, together with the percentage of metal they contain are: *Corundum*, $Al_2O_3$ (53.3 per cent); *cryolite*, $3NaF \cdot AlF_3$ (12.8 per cent); *diaspore*, $Al_2O_3$, $H_2O$ (45.1 per cent); *bauxite*, $Al_2O_32H_2O$ (39.13 per cent); *gibbsite*, $Al_2O_33H_2O$ (34.6 per cent).

Of these, corundum is too valuable as an abrasive, and is not found in sufficient quantity to permit its use as an ore of aluminum. Until the discovery of bauxite, cryolite, (see p. 332) was the chief source of the metal, all of it being obtained from Greenland.

While aluminum ore is usually referred to as bauxite, it seems doubtful whether this is the only one of the aluminum hydrates present, and there is no doubt that gibbsite may also occur. It is known in the Arkansas deposits, and Watson (16) believes it also to be present in the Georgia ones.

Bauxite derives its name from Baux in southern France, where it was first discovered, but in recent years large deposits have been found in the United States. It is usually pisolitic in structure, and may sometimes resemble clay in appearance. The com-

mon impurities are silica, iron oxide, and titanic acid; and the variation in the amount of these ingredients can be seen from the following analyses of both domestic and foreign occurrences.

ANALYSES OF BAUXITE

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Alumina ($Al_2O_3$) . | 57.60 | 61.89 | 63.16 | 59.22 | 61.00 | 62.05 | 62.46 | 39.92 |
| Ferric oxide ($Fe_2O_3$) | 25.30 | 1.96 | 23.55 | 3.16 | 2.20 | 1.66 | .81 | 16.84 |
| Silica ($SiO_2$) . . . | 2.80 | 6.01 | 4.15 | 3.30 | 2.10 | 2.00 | 4.72 | 20.00 |
| Lime carbonate ($CaCO_3$) . . . | .40 | — | — | — | — | — | — | — |
| Titanic acid ($TiO_2$) | 3.10 | — | — | 3.62 | — | — | .23 | 1.47 |
| Water ($H_2O$) . . | 10.80 | 27.82 | 8.34 | 28.80 | 31.58 | 30.31 | 31.03 | 19.52 |
| Moisture . . . . | — | — | — | 1.90 | 3.12 | 3.50 | — | 1.25 |
| Alkalies ($Na_2O$, $K_2O$) . . | — | — | .79 | — | — | — | — | — |

1. Baux, France.   2. Glenravel, Ireland.   3. Wochein, Germany.   4. Georgia.   5. Rock Run, Alabama.   6. Arkansas.   7 and 8. Wilkinson County, Georgia.

It should be stated that all of these, except Nos. 3 and 8, represent good grades of ore, but that within any one district, or even in the same deposit, there may be considerable variation in composition.

It is indeed probable that some highly aluminous fire clays and kaolins may contain aluminum hydroxides, and Galpin (5), has identified gibbsite (hydrargillite) in those from Olive Hill, Kentucky, etc. Aluminum hydroxides also occur abundantly in laterites, (9, 10, 17) but these are too impure to be used as ores of aluminum.

**Distribution of Bauxite in the United States.** — Bauxite in commercial quantity is known to occur in but six districts in the United States. These are the Georgia-Alabama district, the Arkansas district, Wilkinson County, Georgia, near Chattanooga, and Keenburg, Tennessee, and a small area in southwestern New Mexico.

*Georgia-Alabama* (8, 15, 16). — The bauxite deposits of these two states, except those of Wilkinson County, Georgia, noted below, form a belt about 60 miles long, extending from Jacksonville, Alabama, to Cartersville, Georgia (Fig. 267). The ore, which is either pisolitic or claylike in its character, forms pockets or lenses of variable diameter and depth, in the residual clay

derived from the Knox dolomite (Fig. 268 and Pl. LXXIV).
A pronounced feature is their occurrence close to 900 feet above
sea level, few being found above 950 feet or below 850 (8).

The bauxite is believed by Hayes (8) to be a hot-spring deposit.
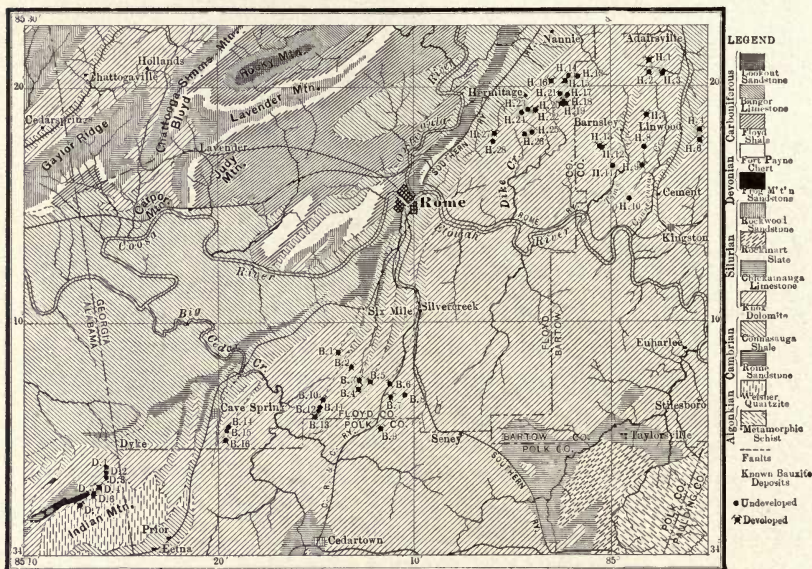


Fig. 267. — Geologic map of Alabama-Georgia bauxite region. (*After Hayes,*
*U. S. Geol. Surv., 16th Ann. Rept., III.*)

It is underlain by the Knox dolomite, and this in turn by the Con-
nasauga shales, which are several thousand feet in thickness, and
contain from 15 to 20 per cent of alumina and also pyrite. The
region is one of marked faulting.    Alteration of the pyrite by
percolating meteoric waters has yielded sulphuric acid, which
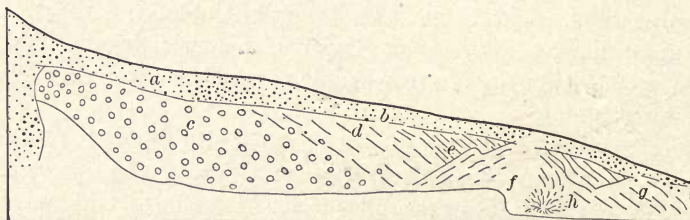


Fig. 268. — Section of bauxite deposit. (*a*) Residual mantle; (*b*) Red sandy
clay soil; (*c*) Pisolitic ore; (*d*) Bauxite with clay; (*e*) Clay with bauxite; (*f*)
Talus; (*g*) Mottled clay; (*h*) Drainage ditch. (*After Hayes.*)

attacked the alumina of the shale, with the formation of alum and also ferrous sulphate. Both of these have been carried toward the surface by spring waters, but since they had to pass through the higher-lying limestones, the lime carbonate acted on the dissolved alum according to the following equation : [1] —

$$Al_2(SO_4)_3 + 3\ CaCO_3 = Al_2O_3 + 3\ CaSO_4 + 3\ CO_2.$$
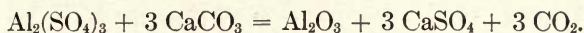
The alumina thus formed was a light, gelatinous precipitate, which was carried upward into spring basins on the surface, where it finally settled. The pisolitic structure is thought to have been caused by the balling together of the gelatinous mass by currents.

The Georgia-Alabama deposits, which represent a unique type of occurrence, were discovered in 1887, and have been worked steadily since that time. There have been some misgivings regarding the exhaustibility of the domestic supply, but the discovery and development of extensive deposits in Arkansas have allayed these fears.

*Wilkinson County, Georgia* (14). — This new bauxite-producing area lies within but near the margin of the Coastal Plain, about 30 miles east of Macon and the geological relations are entirely different from those of the principal belt in " Paleozoic Group " of Georgia and Alabama. The bauxite deposits, which occur apparently near the contact of the Tuscaloosa (Lower Cretaceous) and Claiborne (Tertiary) formations, form beds up to 10 feet in thickness, and the ore is generally either pisolitic or concretionary, but some forms exhibit an amorphous character and even flinty appearance. The color varies from white or cream to bright red. Analyses are given above.

The origin of the bauxite is a somewhat obscure problem, and as the field is but little developed, evidence is difficult to secure. Veatch points out, however, that all stages of transition from the clay to the bauxite can be observed, and suggests that the latter has been formed by a desilication of the kaolinite in the clay by circulating meteoric waters carrying some chemical that was capable of abstracting the silica from the hydrous aluminum silicate.

*Tennessee Field.* — Deposits of bauxite are known on the southeast slope of Missionary Ridge, near Chattanooga (1), and were worked for the first time in 1907. They are of the same character as those found in the Georgia-Alabama field, and may be regarded

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[1] For clearness, the water combined with alumina is left out.

as a northward extension of that region. A large quantity of ore has been taken out. At Keenburg, Carter County, bauxite is found at an elevation of 2200 feet in residual clays derived from the Watauga shale (Cambrian). Much of the ore is oolitic.

ANALYSES OF BAUXITE FROM MISSIONARY RIDGE, TENN.

|  | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Insoluble . . . . . | 12.13 | 11.15 | 11.33 | 11.07 | 13.12 | 12.65 |
| Loss on ignition . . | 28.97 | 30.04 | 30.20 | 30.00 | 30.39 | 30.31 |
| Alumina ($Al_2O_3$) . . | 57.56 | 57.63 | 57.37 | 57.83 | 55.11 | 55.50 |
| Iron oxide ($Fe_2O_3$) . . | 1.34 | 1.18 | 1.10 | 1.10 | 1.38 | 1.34 |

*Arkansas* (3, 7, 12). — The occurrence of bauxite in Arkansas has been known since 1891, but owing to a more accessible eastern supply, there was little development in the region until 1900. The deposits, which are much more extensive than the Georgia-Alabama ones, are found in two areas, one the Bryant district, lying 18 miles southwest of Little Rock, and the other the Fourche Mountain district, just south of Little Rock (12).

The ore consists of (1) horizontal, tabular, bodies of irregular outline, which grade downward into kaolin and this in turn into syenite; and (2) detrital deposits in Tertiary sediments.

The former is the more important type, and may be either pisolitic or granitic in texture. Some of the ore is amorphous or clay like.

The ore bodies average about 11 feet in thickness with a maximum of 35 feet. Gibbsite occurs chiefly in the granitic ore and bauxite in the pisolitic.

Several theories have been advanced to explain the origin of these deposits. According to Mead (12), the syenite was first weathered to kaolin, and the upper and more porous portions of this changed to bauxite by circulating surface waters. Contemporaneous with this, there occurred more or less erosion, which carried much of the bauxite into the Tertiary sea, where it was deposited with other sediments. Later the entire area became covered by these Tertiary deposits, after which another period of erosion occurred (Fig. 269).

Hayes (7) suggested that the bauxite was formed by the action of hot alkaline solutions on the syenite.

*Other Occurrences.* — Bauxite is known to occur in Botetourt County, Virginia, in residual clays with iron and manganese ores,

but the deposits have not yet proven to be of commercial value
(6). Deposits are also known near Silver City, New Mexico (2),
and appear to have been derived from a basic volcanic rock by
decomposition and alteration in place. Owing to their remoteness
from the railroad, they are of little commercial importance.
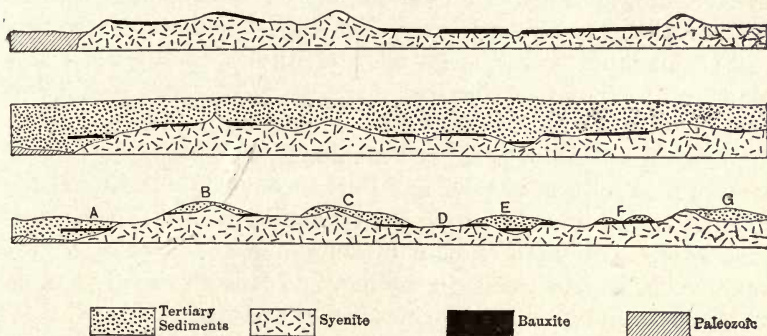


Fig. 269. — Generalized cross sections illustrating the geologic history of the
Arkansas bauxite occurrences. A, lens of bauxite interstratified with the
Tertiary sediments; B, Tertiary hill with bauxite exposed on both sides, but
prevented from extending through the hill by a rise in the syenite surface;
C, Tertiary hill with bauxite on right, but absent on left; D, bauxite capping
on syenite; E, hill of Tertiary sediments with bauxite on both sides, separated
by Tertiary valley between, in which is lens of detrital bauxite; F, Tertiary
hill, with valley exposing underlying bauxite; G, Tertiary hill with concealed
bauxite under it. (After Mead, Econ. Geol., X, 1915.)

**Foreign Deposits.**[1] — Bauxite has been found at a number of localities
in southern France. That at Baux, from which it is named, occurs in beds
associated with Cretaceous limestones and clays. In Germany and Ireland it occurs as a weathering product of basalt. Other deposits, associated
with limestones, are found in Austro-Hungary and Italy.

**Uses of Bauxite.** — The most important use of bauxite is for
the manufacture of aluminum, most of the Arkansas production
being employed for this purpose. A second important application is for the manufacture of aluminum salts, most of the
Georgia-Alabama product being sold for this purpose because
of its freedom from iron oxide, but chiefly because of its solubility
in sulphuric acid of a given strength.

**Uses of Aluminum.** — The chief use of this metal is for making
wire for the transmission of electric currents, but a large quantity
of it is also used in the manufacture of articles for domestic or
culinary use, instruments, boats, and other articles where light-

[1] Dammer und Tietze, Nutzbaren Mineralien, I: 262, 1913.

ness is wanted. It is also employed in the manufacture of special alloys, among which may be mentioned magnalium, an alloy of aluminum and magnesium; and wolframinium, a tungsten-aluminum alloy. One alloy of this type, known as partinium, is said to have a tensile strength of over 49,000 pounds per square inch; McAdamite, an alloy of aluminum, zinc, and copper, is said to possess a tensile strength exceeding 44,000 pounds per square inch; aluminum silver is an alloy of copper, nickel, zinc, and aluminum; aluminum zinc includes a series of alloys containing various proportions of these two metals. Another extending application is that of powdered aluminum for the production of intense heat by combustion, and in this connection it is used for welding tramway rails, or for the reduction of rare metals from their oxides. A small amount of aluminum added to steel prevents air holes and cracks in casting, and it is also used to clear molten iron and steel of all oxides before casting.

Alundum, an artificial abrasive, is made in large quantities at Niagara Falls, by fusing calcined bauxite in the electric furnace.

Bauxite is also employed for the manufacture of bauxite bricks.[1] Still another application of bauxite is for the manufacture of calcium aluminate to give a quick set to plasters.[2]

**Production of Bauxite and Aluminum.** — The production of bauxite in the United States has been as follows:—

PRODUCTION OF BAUXITE IN THE UNITED STATES, 1890–1914, BY STATES, IN LONG TONS

| YEAR | GEORGIA | ALABAMA | ARKANSAS AND TENNESSE | TOTAL | VALUE |
|------|---------|---------|-----------------------|-------|-------|
| 1890 | 1,844 | ——— | ——— | 1,844 | $ 6,012 |
| 1895 | 3,756 | 13,313 | ——— | 17,069 | 44,000 |
| 1900 | 19,739 | | 3,445 | 23,184 | 89,676 |
| 1905 | 15,173 | | 32,956 | 48,129 | 240,292 |
| 1910 | 33,096 | | 115,836 | 148,932 | 716,258 |
| 1911 | 30,170 | | 125,448 | 155,618 | 750,649 |
| 1912 | 19,587 | 14,173 | 126,105 | 159,865 | 768,932 |
| 1913 | 27,409 | | 182,832 | 210,241 | 997,698 |
| 1914 | 18,547 | | 200,771 | 219,318 | 1,069,194 |

The table on page 757 shows the annual production, imports, consumption, and value of bauxite in the United States during the last five years:—

[1] Aubrey, Min. Indus., XIV: 48, 1909; Kanolt, Bur. Standards, Tech. Pap. 10, 1912.

[2] U. S. Geol. Surv., Min. Res. 1911, Pt. 1: 931, 1912.

PRODUCTION, IMPORTS, AND CONSUMPTION OF BAUXITE IN UNITED STATES, 1910-1914, IN LONG TONS

| YEAR. | PRODUCTION | | IMPORTS | | CONSUMPTION | |
|---|---|---|---|---|---|---|
| | Quantity. | Value. | Quantity. | Value. | Quantity. | Value. |
| 1910 . . . . | 148,932 | $ 716,258 | 15,669 | $ 65,743 | 164,601 | $ 782,001 |
| 1911 . . . . | 155,618 | 750,649 | 43,222 | 164,301 | 198,840 | 914,950 |
| 1912 . . . . | 159,865 | 768,932 | 26,214 | 95,431 | 186,079 | 864,363 |
| 1913 . . . . | 210,241 | 997,698 | 21,456 | 85,746 | 231,697 | 1,083,444 |
| 1914 . . . . | 219,318 | 1,069,194 | 24,844 | 96,500 | 244,162 | 1,165,694 |

*World's Production.* — The following table shows the world's production of bauxite from 1911 to 1913, inclusive: —

WORLD'S PRODUCTION OF BAUXITE, 1911–1913, IN LONG TONS

| COUNTRY | 1911 | | 1912 | | 1913 | |
|---|---|---|---|---|---|---|
| | QUANTITY | VALUE | QUANTITY | VALUE | QUANTITY | VALUE |
| United States . | 155,618 | $750,649 | 159,865 | $768,932 | 210,241 | $997,698 |
| France . . . | 250,818 | 508,788 | 254,851 | 507,649 | 6,055[1] | 7,606[1] |
| United Kingdom | 6,007 | 6,297 | 5,790 | 6,881 | 6,843[1] | 16,101[1] |
| Italy . . . . | 5,600 | 12,300 | 6,596 | 20,618 | [1] | [1] |
| India . . . . | 12 | 24 | 950 | 2,511 | | |
| Total . . | 418,055 | 1,278,058 | 428,052 | 1,306,591 | . . . . . . . . | . . . . . . . . . |

[1] Statistics not available.

The production of aluminum in the United States since 1885 has been as follows: —

PRODUCTION OF ALUMINUM IN THE UNITED STATES

| YEAR | QUANTITY IN POUNDS | YEAR | QUANTITY IN POUNDS |
|---|---|---|---|
| 1885 . . . . . | 283 | 1910 . . . . . | [1] 47,734,000 |
| 1890 . . . . . | 61,281 | 1911 . . . . . | [1] 46,125,000 |
| 1895 . . . . . | 920,000 | 1912 . . . . . | [1] 65,607,000 |
| 1900 . . . . . | 7,150,000 | 1913 . . . . . | [1] 72,379,000 |
| 1905 . . . . . | [1] 11,347,000 | 1914 . . . . . | [1] 79,129,000 |

[1] Consumption 1913 does not include manufactured or leaf aluminum exports.

EXPORTS OF ALUMINUM FROM THE UNITED STATES, 1910–1914

| | | | |
|---|---|---|---|
| 1910 . . . . . | $ 949,215 | 1913 . . . . . | $ 966,094 |
| 1911 . . . . . | 1,158,603 | 1914 . . . . . | 1,546,510 |
| 1912 . . . . . | 1,347,621 | | |

IMPORTS OF "ALUMINA" AND EXPORTS OF ALUMINUM FOR CANADA, 1912–1914

| YEAR | IMPORTS OF ALUMINA | | EXPORTS OF ALUMINUM | | |
| | | | INGOTS, BARS, ETC. | | MANUFAC-TURES |
| | Pounds | Value | Pounds | Value | Value |
| 1912 . . . . | 22,400,500 | $448,061 | 18,285,700 | $2,002,363 | $10,898 |
| 1913 . . . . | 30,704,200 | 614,713 | 13,015,000 | 1,762,214 | 8,203 |
| 1914 . . . . | 28,557,000 | 571,419 | 14,510,800 | 2,364,907 | 5,571 |

No commercial ores of aluminum have been found in Canada.

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## MANGANESE

**Ore Minerals and Ores.** — While many different minerals contain this metal, practically the only ones of commercial value are the oxides and carbonates, and in this country only the former. The silicates are not used as a source of manganese, owing to their high silica percentage.

The important ore minerals of manganese are the following: *pyrolusite*, the black oxide ($MnO_2$, 63.2 per cent Mn); *psilomelane* (chiefly $MnO_2$, $H_2O$; K and Ba variable, 45 to 60 per cent Mn); *braunite* ($3Mn_2O_3$, $MnSiO_3$, 69.69 per cent Mn); *wad*, a low-grade earthy brown or black ore, with the percentage

of manganese varying from 15 to 40 per cent Mn); *manganite* ($Mn_2O_3$, $H_2O$; 62.4 per cent Mn); *rhodochrosite* ($MnCO_3$ 61.7 per cent MnO). To these should be added *franklinite* (FeZnMn) $O \cdot (FeMn)_2O_3$.

The manganese ores proper consist usually of a mixture of oxides, and indeed these compounds are really the only ones of importance in the United States. Pyrolusite and psilomelane are by far the most important, and are often intimately associated, the pyrolusite generally assuming a crystalline and the psilomelane a massive structure. They may locally have some admixtures of iron oxide, and then they are of use in the steel industry, but when free from iron they are, in addition, of value for oxidizing and coloring purposes. Wad is often of too low grade, due to impurities, to be used as an ore of manganese, but it is sometimes employed for paint. Rhodochrosite, though found as a common gangue mineral in some western mines (Rico, Colorado; Butte, Montana, silver mines), can hardly be regarded as a source of manganese. It has, however, been mined in some quantity in the Huelva district of Spain,[1] and in Merionethshire, Wales (6).

Manganese oxides, in addition to being associated with iron, as noted above, are sometimes mixed with zinc or silver. It is customary, therefore, to make a fourfold division into (1) manganese ores, (2) manganiferous iron ore, (3) manganiferous silver ore, and (4) manganiferous zinc residuum.

Manganiferous iron ores found in the United States consist chiefly of limonite or hematite mixed with psilomelane, pyrolusite, or wad, the mixture being an intimate one. The high-grade ores are of value for making spiegeleisen or ferro-manganese, but in those running low in manganese this element is usually regarded as an impurity.

Manganiferous silver ores are composed of a mixture of manganese and iron oxides, containing small amounts of silver minerals, lead carbonate, and sometimes even gold. In this class of ores, in which the iron usually predominates over manganese, the ores form the gossan of metallic sulphide bodies carrying iron, lead, zinc, and silver sulphides in a quartz or calcite gangue. Rhodonite and rhodochrosite sometimes occur in the unaltered ores.

This class of ores may be divided into three classes (4) according to their uses as follows: (1) ores used mainly for their silver and lead values, the

[1] Hayer, Zeitschr. prakt. Geol., 1911: 407.

manganese and iron content sometimes insuring a higher price because of their fluxing action ; (2) ores too low in silver and lead to serve as sources of these metals, but sufficiently high in iron and manganese to be employed in making ferro-manganese and spiegeleisen. If too low in manganese, it may be used as an iron ore ; (3) ores too low in silver and lead to be used as sources of these metals, and too low in iron and manganese to serve for alloys of these two ; such ore is sold for flux, and the lead-silver content ultimately saved.

Manganiferous zinc residuum is obtained from zinc volatilizing and oxidizing furnaces using New Jersey zinc ores, and consists largely of the iron and manganese oxide which remains after the zinc has been volatilized and collected as zinc oxide. The minerals present in the ore are franklinite, zincite, and willemite.

**Origin** (7, 4). — Manganese oxide deposits are usually of secondary origin, having been formed by weathering processes, which caused the decay of the parent rock containing manganiferous silicates, and the change of these latter to oxides. By circulating ground water they have often been concentrated in residual clays. Although iron also may have been present in the parent rock, and the two are sometimes deposited together, still they have in many instances been separated from each other, due to the fact that conditions favorable for precipitation are not the same for both, or because the soluble compounds of manganese formed by weathering are sometimes more stable than corresponding iron compounds, and hence may be carried farther by circulating waters before they are deposited.

Manganese oxides may be precipitated from sea-water, as nodules of this composition have been obtained by dredging from the sea bottom.

They are also known to occur as replacements of quartzite (Piedmont region, Virginia).

The carbonate and silicate may occur as constituents of ore veins (Butte, Montana) or as bedded deposits in sedimentary rocks (Wales).

**Distribution of Manganese-bearing Ores in the United States.** — Although the manganese-bearing ores are widely distributed in the United States, only a few localities are of commercial importance, and the manganese-mining industry has been shrinking for several years.

The reason for this is that the domestic ores are of much lower grade than the imported ones, and often require washing and sorting to render them marketable. Moreover, they occur in small,

scattered pockets, often remote from lines of transportation, and may carry a high percentage of phosphorus and silica.

The demand is therefore supplied largely by high-grade ores from India, Brazil, and Russia, but the closing off of many of these sources during the European war has stimulated manganese mining in the United States.

The occurrence of the four classes of domestic ores may be referred to separately.

**Manganese Ores.** — The most important occurrences of this somewhat widely scattered type of ore are the Appalachian and Piedmont regions, southern Mississippi Valley, and Pacific coast, but the chief producing districts have been the James River Valley and Blue Ridge regions in Virginia; Cave Springs and Cartersville districts in Georgia; Batesville district, Arkansas; and the Livermore-Tesla district in California.

**Eastern Area.** — Manganese deposits are found in the Atlantic states from Vermont to Alabama, and two states in this belt, Georgia and Virginia (17, 6), lead in the domestic production. In the crystalline rocks of the Piedmont province, deposits of commercial value have been proven only in Virginia. In this state the manganese area lies chiefly northeast and southwest of Lynchburg. The ore minerals are mostly granular pyrolusite and psilomelane, commonly occurring as nodules in residual clays from mica schists, quartzite and limestones of Cambrian age. Umber is sometimes present. In several mines where the workings have extended into hard rock, the ore occurs near the contact of quartzite, at times replacing the latter. Crystalline limestone is found closely associated with the ore deposits, but its relations to the ore are not definitely known.[1]

The Appalachian Valley deposits occur in two districts, viz., the Blue Ridge and New River.

The ores of the first district, which are the most important of the two, occur in a series of irregularly distributed deposits along the west foot of the Blue Ridge from Front Royal to Roanoke, a distance of about 150 miles. This same belt includes the Blue Ridge iron-ore deposits, which may sometimes contain an appreciable amount of manganese. So, too, iron may be found in the manganese deposits.

The manganese ore occurs in pockets in clays of residual or sedimentary character, along the contact of the Lower Cambrian

[1] Supplied by T. L. Watson.

quartzite with the overlying formation, and more rarely in fissures penetrating the quartzite.

Four types of ore are found, all of which may occur in the same deposit. They are: (1) black psilomelane kidneys in clay; (2) irregular, often porous masses of psilomelane with layers of crystalline pyrolusite, also in clay; (3) breccia ore in large masses consisting of sandstone or chert fragments, with pyrolusite or psilomelane filling; (4) replacements or cavity fillings, mainly pyrolusite, in sandstone or sandy clay. The mine at Crimora (Fig. 270 and Plate LXXII) is one of the best known. The ore forms pockets 5 to 6 feet thick, and 20 to 30 feet long in a deposit of clay 276 feet thick.
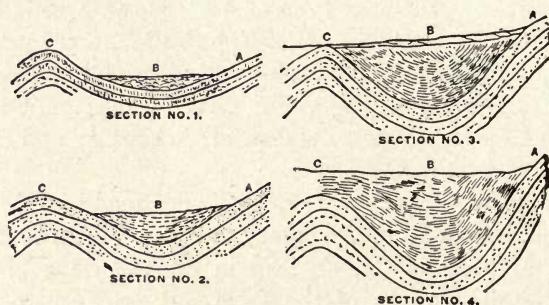


FIG. 270. — Sections of Manganese deposit. Crimora, Va. (*After Hall.*)

In the New River district, the ore, which is mainly psilomelane, occurs as large masses mixed with iron ores in residual clay, but is of little commercial importance.

The Virginia areas mentioned extend southward into Tennessee, and some ore is mined there, (6, 9a)
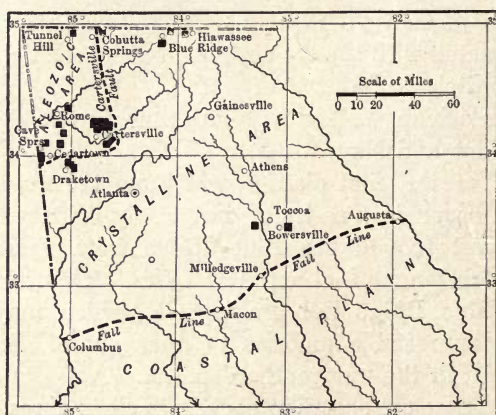


FIG. 271. — Map showing Georgia manganese areas. (*After Watson, Amer. Inst. Min. Engrs., Trans. XXXIV.*)
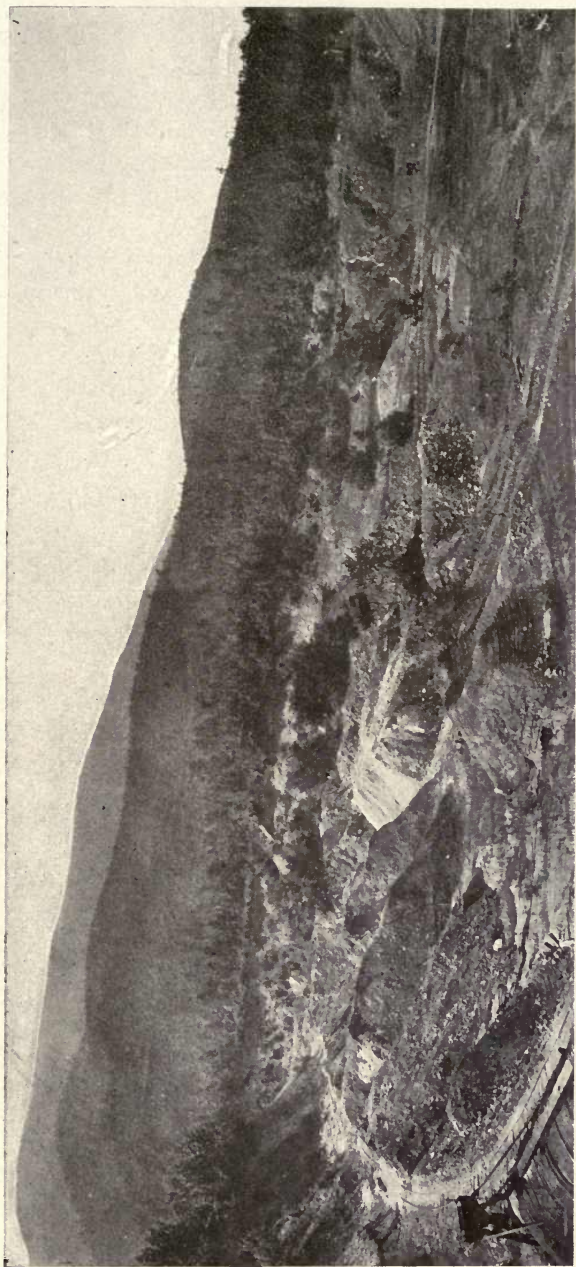
PLATE LXXIII. — Panoramic view of Crimora Manganese Mine, Virginia. Ridges in background are quartzite of Blue Ridge. (*H. Ries, photo.*)

(763)

*Georgia.* — In northern Georgia (7, 16) the ore results from the
decay of limestones and shales, Cave Spring and Cartersville
being important localities (Fig. 271). The deposits are found in
the areas underlain by both the crystalline and Palæozoic rocks,
but only those associated with the latter have proven to be of
importance. In this region the rocks consist of Cambro-Silurian
limestones and quartzites, which have been much folded and
faulted, and have been weathered down to a residual clay, which
is often not less than 100 feet thick. The ore occurs as pockets,
lenticular masses, stringers, grains, or lumps, irregularly scattered
through the clay, and rarely forming distinct beds. None of the
deposits are large, though some 30 feet in length have been worked.



FIG. 272.— Section in Georgia manganese area, showing geologic relations of
    manganese, limonite, and ocher. (*After Watson, Amer. Inst. Min. Engrs.
    Trans. XXXIV*).

More or less limonite, barite, ocher, and bauxite may be associated
with the ore (Fig. 272), and, indeed, complete gradations from man-
ganese to iron are found, as shown by the following analyses:

| Mn | . | . | . | . | . | 60.61 | 54.94 | 41.98 | 15.26 | 2.30 |
| Fe | . | . | . | . | . | 1.45 | 3.62 | 16.22 | 39.25 | 52.02 |
| P | . | . | . | . | . | .052 | .034 | .227 | .193 | .24 |

The better-grade ores are usually low in silica, iron, and phosphorus.
In the Cartersville district, which is the more important, the ore is
found in residual clays derived from the Beaver limestone and Weis-
ner quartzite, while in the Cave Spring area it occur only in the clays
overlying the Knox dolomite.

Penrose (10) thought that the manganese was derived from the
underlying Cambro-Silurian sediments, while Watson, on the con-
trary, believes that the crystalline rocks to the east and south have
furnished the ore, as none is found in the parent rock from which
the clays were derived. The manganese was probably taken into
solution as a sulphate, and concentrated by circulating waters of
meteoric origin in the residual clays where now found.

PLATE LXXIV



Fig. 1. — View of bauxite bank, Rock Run, Ala. (*H. Ries, photo.*)



Fig. 2. — Furnace for roasting mercury ore, Terlingua, Tex. (*H. W. Turner, photo.*)

(765)

The Georgia (15) deposits have been worked for a number of years, and the manganese was formerly marketed chiefly in England; but the output is now sold entirely in the United States. The ore, which has to be purified by washing and crushing, is used in part for paint and in part for steel manufacture.

*Other Eastern Occurrences.* — Deposits are known at several localities in Vermont (6), North Carolina, (6) South Carolina (6), and Pennsylvania (6).

**Lower Mississippi Valley and Gulf Region.** — The Arkansas deposits are the only important ones in this region.

*Arkansas.* — Manganese ore is found in the region around Batesville (10, 13), associated with horizontally stratified limestones and shales, ranging from Ordovician to Carboniferous Age (Fig. 273). The Cason shale, of Silurian Age, occurring near the
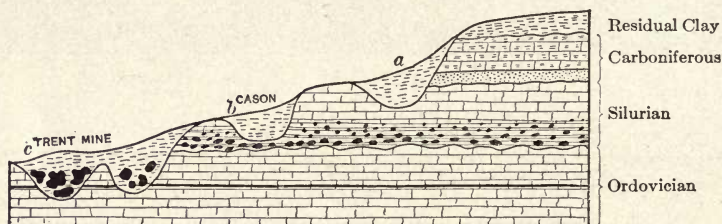


Fig. 273. — Section in Batesville, Ark., manganese region, illustrating geological structure and relation of different formations to marketable and non-marketable ore. (*After Van Ingen, Sch. of M. Quart., XXII.*).

middle of the section (Fig. 273*b*), carries manganese nodules high in phosphorus, which are not marketable, and others are found in the pits of residual clay derived from it. Farther down the slopes marketable ore (Fig. 273*c*), which has been derived by leaching of the first-mentioned ore, is found occurring in residual pockets in the lower-lying limestones, while the residual clays (Fig. 273*a*), formed at a higher level than the Cason shale, are barren of manganese.

*Other Occurrences.* — Small deposits are said to occur in Hickman County, Tennessee, and Llano County, Texas.

**Western States.** — Two types of ore are found in California. The first of these consist of veins of pyrolusite, and psilomelane in the Calaveras (Carboniferous) formation, occurring near Meadow Valley, Plumas County, and at other points in the Sierra Nevada. The second occurs near the coast north and south

of San Francisco, as local thin lenses, interbedded with jaspers of the Franciscan (Jura-Trias) formation. At the Ladd mine near Livermore, the ore lies in a fault fissure, 4 to 5 feet in width, and forms cavity fillings, infiltrations, and replacement deposits in red and yellow clays, and as veins and breccia cement in the wall. The wall rock is jasper (6).

Small deposits are also known in Utah where, in Grand County, the ore occurs as replacements in Triassic limestone (6), and near Golconda, Nevada. The latter, which is bedded, and is interstratified with calcareous and siliceous tufa, appears to be a hotspring deposit in a small tufa basin.

**Manganiferous Iron Ores.** — Those of the Appalachian Valley have already been referred to in connection with the manganese ores. The most important deposits are in Vermont, Virginia and Tennessee, and consist chiefly of psilomelane and limonite mixtures. Much iron ore of the Lake Superior district carries from 1 to 10 per cent metallic manganese, and some large bodies are known on the Cuyuna range. Other occurrences have been noted from Gunnison County, Colorado (10), Juab County, Utah, and Missouri, but they are not of commercial value.

**Manganiferous Silver Ores.** — The most important deposits are those found at Leadville, Colorado. Manganiferous silver and iron ores are important in the oxidized zone of the Leadville district, forming large masses adjacent to the sulphide deposits. Some (4) have suggested that they represented infiltrations from the porphyry, but P. Argall (1) has shown that manganiferous siderite in irregular masses is abundant as a limestone replacement. He therefore suggests that weathering of the siderite has yielded the manganese. The ores range as follows: Manganese, trace-40 per cent; iron, 8-50 per cent; lead, trace-5 per cent; insoluble, 5-34 per cent; silver (in 1914) 2-25 ounces per ton; gold, trace. Ores of similar character are found at Neihart and Castle, Montana. Manganese is also found in the silver veins at Butte, Montana, but is of little commercial value. Still other manganiferous silver ores have been noted from scattered localities in New Mexico, Arizona, Utah, and Nevada, but appear to be of little commercial importance. Some found in the Tintic district, Utah, are used as flux at the local smelters.

**Canada** (8). — The Canadian production is very small. A number of scattered deposits are known in Nova Scotia, New Brunswick, and Quebec.

**Other Foreign Deposits** (6). — Russia [1] is by far the largest producer, most of the ore coming from the Sharopan district of the Caucasus, where it occurs as a stratified deposit of oolitic oxides between Eocene sandstone and Cretaceous limestone. The beds do not exceed a foot in thickness, but the ore is high grade.

*India.* — Much manganese ore is mined in the Madras and Bombay Presidencies of Central India.[2] The ores are all oxides and occur: (1) Associated with or derived from manganese-bearing silicates, as bands or lenticles, in Archaean gneisses and schists; (2) as superficial formations on the outcrops of such rocks as quartzites, shales, slates, and hematite-schists; and (3) as concretions in laterite.

*Brazil,*[3] the third largest world's producer, has important deposits in the province of Minas Geraes. The manganese is associated with iron ores; and may be of bedded character or detrital nature.

**Uses of Manganese.** — Manganese is used in the manufacture of alloys, whose value depends not only on the amount of manganese, but also on the absence of sulphur and phosphorus. Spiegeleisen contains under 20 per cent manganese, and ferromanganese, a similar alloy, has from 20 to 90 per cent of it. The amount of silicon and carbon present in these varies.

Other alloys are manganese bronze, manganese and copper, with or without iron. Some alloys of manganese, aluminum, and copper, known as Heusler's alloys, are important because of their magnetic properties. Other elements alloying with manganese are zinc, tin, lead, magnesium, and silicon.

Manganese oxide is used: (1) as a substitute for iron oxide in copper and silver reduction; (2) as an oxidizing agent in the manufacture of chlorine, bromine, and disinfectants; (3) as a decolorizer of green glass; (4) as a coloring agent in calico printing and dyeing, in the making of glass, pottery, bricks, and also paints; (5) in the manufacture of the Leclanché battery and of dry cells, for which purpose a considerable amount is consumed annually.

Some manganese compounds have a medicinal value, and rhodonite is sometimes cut for a gem stone.

**Production of Manganese.** — Although much used in steel manufacture, the domestic production is small because of the inferior character of the native ores, therefore the largest consumers rely upon foreign sources of supply.

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[1] Cauldwell, Min. and Sci. Pr., CV: 113, 1912. Harder, Amer. Inst. Min. Engrs., Bull. 113, 1916.

[2] Fermor, Geol. Surv., India, Mem. XXXVII, 1909.

[3] Harder loc. cit. p. 785.

The following table gives the total quantity of the several kinds of ore produced in the United States. The annual production since 1885 has fluctuated more or less, and there has been a strong decline in the production of the straight manganese ores.

PRODUCTION OF MANGANESE ORES IN THE UNITED STATES, 1912 TO 1914, IN LONG TONS

| YEAR | MANGANESE | MANGANIFEROUS IRON ORE AND MANGANIFEROUS SILVER ORE | MANGANIFEROUS ZINC RESIDUUM |
|---|---|---|---|
| 1912 [1] . . . . . . . | 819,883 | 48,618 | 104,670 |
| 1913 . . . . . . . . | 622,393 | 49,753 | 102,239 |
| 1914 . . . . . . . . | 405,946 | 39,881 | 100,198 |

[1] From 1909 to date the U. S. Geological Survey has not given separate returns for the several classes of ore.

MARKETED PRODUCTION OF MANGANESE ORE IN THE UNITED STATES, 1912 TO 1914, BY STATES, IN LONG TONS

| STATE | 1912 | | | 1913 | | | 1914 | | |
|---|---|---|---|---|---|---|---|---|---|
| | QUANTITY | VALUE | AVERAGE PRICE PER TON | QUANTITY | VALUE | AVERAGE PRICE PER TON | QUANTITY | VALUE | AVERAGE PRICE PER TON |
| California . | [1] | [1] | —— | | | | [2] | [2] | —— |
| South Carolina | [1] | [1] | —— | | | | [2] 911 | [2] $8,812 | $9.67 |
| Virginia . . | [1] 1664 | [1] $15.73 | $9.45 | [3] 4048 | [3] $40,480 | $10.00 | 1724 | 18,565 | 10.77 |
| Total . | 1664 | $15,723 | 9.45 | 4048 | $40,480 | $10.00 | 2635 | $27,377 | $10.39 |

[1] Virginia includes California and South Carolina.
[2] South Carolina includes California.
[3] Includes small quantity produced in 1911 and 1912, but not reported for those years.

The average price per long ton for Colorado manganiferous silver ores in 1914 was $2.86, silver content inclusive, and of manganiferous zinc residuum, $2.63.

The prices of manganese ores used in the steel industry normally vary from $8 to $13.50 per long ton, according to grade, but during the war manganese has commanded much higher prices.

They are governed by the following schedule of prices established by the Carnegie Steel Comapny, the price being for delivery at Pittsburgh or South Chicago.

Prices are based on ores containing not more than 8 per cent silica or .20 per cent phosphorus, and are subject to deductions as follows: For each 1 per cent in excess of 8 per cent silica there shall be deduction of 15 cents per ton; fractions in proportion.

For each .02 per cent, or fraction thereof, in excess of .20 per cent phosphorus, there shall be a deduction of 2 cents per unit of manganese per ton.

Ores containing less than 40 per cent manganese or more than 12 per cent silica or .225 per cent phosphorus are subject to acceptance or refusal at the buyer's option.

| PERCENTAGE OF METALLIC MANGANESE IN ORE | PRICE PER UNIT OF MANGANESE IN CENTS |
|---|---|
| Over 49 | 26 |
| 46 to 49 | 25 |
| 43 to 46 | 24 |
| 40 to 43 | 23 |

Settlements are based on analysis of sample dried at 212° F., the percentage of moisture in the sample as taken being deducted from the weight.

The manganese ores for oxidizing and coloring purposes are valued according to the quantity of manganese peroxide present, their consistency, etc. An ore for use as an oxidizer must contain at least 80 per cent manganese dioxide, and not more than 1 per cent iron. There is no established schedule, and such ores have usually been obtained largely from the Caucasus region of Russia. Owing to the war, prices went as high as $70 a ton. Few deposits in the United States can supply this demand.

Manganiferous iron ores containing 15 to 35 per cent manganese range from $3.50 to $6 per ton.

The imports in 1913 amounted to 345,090 long tons valued at $2,029,680, and in 1914 to 283,294 long tons valued at $2,024,120. These came chiefly from Brazil, British India, Russia, and the United Kingdom.

The production of Canada in 1914 amounted to 28 short tons valued at $1120. The exports for the same year were 30 short tons, valued at $750.

*World's Production.* — The following table gives the latest available statistics with regard to American and foreign production of manganese ore.

WORLD'S PRODUCTION OF MANGANESE ORE, IN LONG TONS

| COUNTRY | YEAR | QUANTITY | COUNTRY | YEAR | QUANTITY |
|---|---|---|---|---|---|
| North America: | | | Eupore—*Continued*: | | |
| Canada | 1914 | 25 | Russia | 1913 | 1,289,370 |
| Nova Scotia | 1912 | 208 | Spain | 1913 | 21,254 |
| United States | 1914 | 2,635 | Sweden | 1913 | 3,938 |
| South America: | | | Turkey | 1910 | 12,008 |
| Brazil | 1913 | 180,738 | United Kingdom | 1914 | 3,439 |
| Europe: | | | Asia: | | |
| Austria | 1913 | 16,280 | India | 1913 | 718,520 |
| Bosnia and Herze- | | | Japan | 1912 | 11,862 |
| govina | 1913 | 4,626 | Africa: | | |
| France | 1913 | 7,610 | Cape Colony | 1911 | 116 |
| German Empire | 1911 | 85,921 | Natal | 1910 | 51 |
| Greece | 1913 | 547 | Oceanica: | | |
| Hungary | 1913 | 18,706 | Australia | 1914 | 6 |
| Italy | 1913 | 1,596 | New Zealand | 1910 | 5 |

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## MERCURY

**Ore Minerals.** — While mercury is sometimes found native in the form of *quicksilver*, the most common ore is *cinnabar* (HgS), which contains 86.2 per cent mercury. Native amalgam of mercury and silver is known, and *calomel*, the chloride, as well as other compounds, are sometimes found.

Among the less common ones may be mentioned: *montroydite* (HgO); *tiemannite* (HgSe); *onofrite* (Hg(S,Se)); and *coloradoite* (HgTe)$_4$. *Schwatzite*, the mercurial tetrahedrite, is not uncommon, being known from a number of localities in Europe and South America. In the United States it is known in the Blue Mountains, Oregon, and may have been the original ore mineral, whose decomposition formed the present mercurial ore minerals at some other localities (Plomosa district. Arizona and La Plata district, Colorado).

The commercial sources of mercury contain a comparatively small amount of other metallic minerals, although a number of different ones have been found and cinnabar may at times occur in small quantities in veins of the other metals. Thus it is a frequent accompaniment of stibnite, and is also found in some

gold and copper deposits. The dyscrasite found in the Cobalt, Ontario, silver veins, also carries mercury.

**Mode of Occurrence.** — Mercury ores are not confined to any particular formation, but are found in rocks ranging from the Ordovician to Recent age in different parts of the world. Nor are they peculiar to any special type of rock, although igneous rocks are often found in the vicinity of them. They occur as veins, disseminations, or as masses of irregular form. Silica, either crystalline or opaline, and calcite are common gangue minerals, while pyrite or marcasite are rarely wanting, and bitumen is widespread.

Many mercury deposits occur along lines of fissuring, and these may be marked by hot springs.

The commercially valuable occurrences have apparently been deposited at shallow depths, although mercury minerals are sometimes found in small quantities of the intermediate and even deeper vein zone.

**Origin.** — The origin of mercury ores has been studied chiefly by Becker (3) and later by Schrauf (17). The former points out that silica (either crystalline or amorphous) and calcite are common gangue minerals, but pyrite or marcasite are almost equally abundant, as is also bitumen. In addition to these, the ores show an irregular association with other metallic minerals, such as antimony, silver, lead, copper, arsenic, zinc, or even gold. Becker believes that the cinnabar has been precipitated from ascending waters by bituminous matter, having come up in solution as a double sulphide with alkaline sulphides. He further suggests that the deposits represent impregnations and are not replacements.

Hot springs carrying mercury in solution are known at Steamboat Springs, Nevada (Pl. XXXIX, Fig. 2), and Sulphur Bank, California.

**Distribution in the United States.** — California has always been the most important, and in fact, at times, the only producing state. Deposits are, however, also known in Texas, Oregon, Utah, Nevada, New Mexico, and Arizona.

*California* (3, 4) (Fig. 274). — The California ores occur chiefly in metamorphosed Cretaceous or Jurassic rocks, with some in the Miocene and even Quaternary. The deposits, which are termed "chambered veins" by Becker, are fissured zones. Eruptive rocks seem in many cases to be involved in the ore formation,

and at New Almaden a rhyolite dike runs parallel with the ore body. The ore here occurs along the contact between serpentine and shale, filling in part the interstices of a breccia. These mines, which are the largest in the state, have been worked to a depth of over 2,500 feet.

At the New Idria mine, located in southeastern San Benito County, and which has been worked almost continually since 1853, the ore bodies occur as stockworks in metamorphic rocks of Lower Cretaceous age, just south of their contact with the unaltered sediments of the Chico (Lower Cretaceous) formation. The ore, which consists of a mixture of pyrite and cinnabar, with a gangue of silicified and brecciated metamorphic sandstones



FIG. 274. — Map of California mercury localities.

and shales, may occur as veins, stockworks or impregnations. It is interesting to note that in driving a tunnel to connect with the 1060-foot level considerable natural gas was encountered, and that at another locality, New Almaden, exhalations of carbon dioxide were encountered in some of the lower levels.

Other occurrences are in Colusa County, where the cinnabar is found in altered serpentine, and in Napa County, where it occurs along the contact of sandstone and slate. The minerals associated with these are bitumen, free sulphur, stibnite, mispickel, gold and silver, chalcopyrite, pyrite, millerite, quartz, calcite, barite, and borax. The vein is a fissure filled with brecciated fragments, and cuts through sandstone, shale, and augite andesite, the cinnabar cementing the breccia together, but at times also impregnating the walls. Hot waters which circulate through the vein still deposit gelatinous silica.

At Steamboat Springs the waters carry gold, sulphide of arsenic, antimony, and mercury, sulphides or sulphates of silver, lead, copper, zinc, iron oxide, and possibly other metals. They also contain sodium carbonate, sodium chloride, sulphur, and borax.

Cinnabar is known in Lane and Douglas counties, Oregon.

*Texas* (6, 14, 19). —The Terlingua district of Brewster County, Texas (Fig. 275), has aroused much interest in recent years.

The area of importance is about two miles wide north and south and fifteen miles east and west, and lies in southern Brewster County, about 300 miles southeast of El Paso, and 110 miles south of Marfa. It is 7 miles to the Rio Grande and



Fig. 275. — Map showing Texas mercury region. (*After Hill, Eng. and Min Jour., LXXIV.*)

Mexican border. The remoteness from the railroad and lack of water have formed serious obstacles in the development of the district.

The rocks are sediments of Upper and Lower Cretaceous age cut by Tertiary volcanics, and the following section is involved:

Tertiary tuffs and lavas, forming sheets, dikes, laccoliths, and surface flows. The rock types included are andesites, rhyolites, phonolites, and basalts.

Upper Cretaceous.

| | |
|---|---:|
| Ponderosa marls | 200 ft. |
| Austin chalk | 100 ft. |
| Eagle Ford shales | 400 ft. |

Lower Cretaceous.

| | |
|---|---:|
| Vola limestone | 75 ft. |
| Arietina clays or Del Rio shales | 75 ft. |
| Washita or Fort Worth limestone | 100 ft. |
| Fredericksburg or Edwards limestone | 1000 ft. |

There has been important faulting, the strike of the chief dislocation being northwest-southeast, but that of the ore-filled fissures is northeast-southwest.

The ore bodies have thus far been found chiefly in the Washita and Fredericksburg limestones, but more recently in the Eagle Ford shales. The ore is most frequently found in fissure veins (Fig. 277), but some occurs in breccias and as lateral-enrichment deposits.

The chief ore mineral is cinnabar, which is often closely associated with pyrite or its oxidation products, especially in the breccia lodes. Calcite is the most important gangue mineral. Gypsum (probably secondary) is common and hydrocarbons may be present. It is of interest to note that three new minerals, terlinguaite, eglestonite, and montroydite, all oxy-



FIG. 276. — Vertical section of California Hill, Terlingua, Tex. (*After Turner, Econ. Geol., I.*)

chlorides of mercury, were discovered in these ores.

The ore treated in the furnaces varies from .75 to 2.5 per cent mercury, while that sent to the retorts runs 4 per cent or over.

Most of the workings are open pits, there being few shafts, so no definite idea of the underground reserves exists.
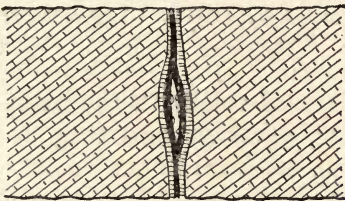


FIG. 277. — Section of cinnabar vein in limestone, Terlingua, Tex. (*After Phillips, Univ. Tex. Min. Surv., Bull.* 4).

**Foreign Deposits.**[1] — Spain is the largest producer, followed by Italy and Austria. In the first-named country, the Almaden deposit is the world's greatest producer. Here the ore forms impregnations and replacements of three steeply dipping beds of Silurian quartzite. The principal bed is 8 to 14 meters thick, and the ore averages about 8 per cent mercury. This deposit, unlike most others, extends to a considerable depth.

At Monte Amiata in Tuscany the ore occurs as disseminations, chimneys, etc., in Cretaceous and Tertiary limestones, shales and sandstones associated with trachyte.

A third large deposit is that at Idria, Austria, where the ore, chiefly cinnabar, but sometimes native mercury, is found forming impregnations,

[1] Vogt, Krusch and Beyschlag, Translation by Truscott, I: 464, 1914.

stockworks and veins in limestones, shales, marls, and dolomites of Triassic age. There seems to be a connection between the ore deposition and a large overthrust of post-Cretaceous times.

Mexico and Peru contribute some mercury to the world's production.
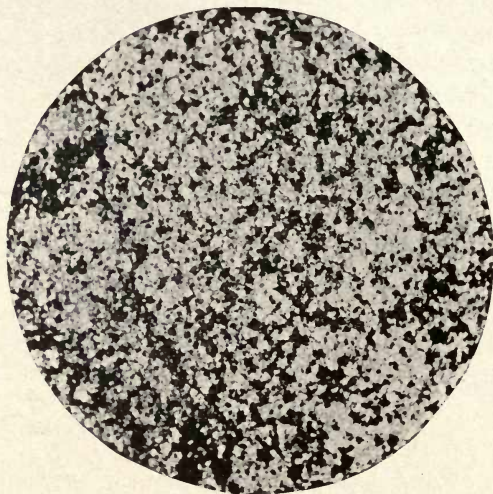


Fig. 278. — Thin section of limestone impregnated and replaced (?) by cinnabar, Idria, Austria.   ×33.

**Uses of Mercury.**  Quicksilver is used chiefly in the manufacture of electric appliances, drugs, scientific apparatus, and fulminate for explosive caps.  About one-third of the domestic output is said to be employed for the last-named purpose in normal times.   It is used in decreasing quantity for the recovery of precious metals, especially gold, because of the increased use of the cyanide process, the decrease of free-milling gold ores and placer gravels, and the increased efficiency and economy in stamp-milling, resulting in a decreased loss of quicksilver.  Mercuric oxide (red oxide of mercury) is the active poison in antifouling paint for ships' bottoms.  Quicksilver, though formerly much used for silvering mirrors, is now largely replaced by silver nitrate

**Extraction.** — Cinnabar is easily decomposed by heat, giving off when heated in air, or retorted with quicklime, the mercury vapors and sulphur dioxide in one case, or mercury, calcium sulphide, and calcium sulphate in the other.

The mercury is collected by subsequent condensation.

Retorts are adapted only to ores carrying 4 per cent or more of mercury, while low-grade ores are treated in shaft furnaces, some of the more modern ones being capable of treating an ore running as low as .25 per cent metal.

**Production of Mercury.** — California was for many years practically the only domestic source of mercury, but in 1898 Texas became a producer, and will no doubt continue so. The output of mercury is quoted in flasks of 75 pounds net.

PRODUCTION OF QUICKSILVER IN THE UNITED STATES, 1912, 1913, AND 1914, BY STATES, IN FLASKS OF 75 POUNDS

| STATE | 1912 | | 1913 | | 1914 | |
|---|---|---|---|---|---|---|
| | QUANTITY | VALUE | QUANTITY | VALUE | QUANTITY | VALUE |
| Arizona . . . | —— | —— | [1] | [1] | [1] | [1] |
| California . . | 20,524 | $863,034 | 15,591 | $627,228 | 11,303 | $554,414 |
| Nevada . . . | [1] | [1] | 1,645 | 66,178 | 2,089 | 102,465 |
| Texas . . . . | [1] | [1] | [1] | [1] | [1] | [1] |
| States not shown separately [2] . | 4,540 | 190,907 | 2,977 | 119,765 | 3,156 | 154,801 |
| Total | 25,064 | $1,053,941 | 20,213 | $813,171 | 16,548 | $811,680 |

[1] Included in States not shown separately.
[2] Nevada and Texas combined in 1912; Arizona and Texas in 1913 and 1914.

In addition to the production from ore and furnace material (soot and cleanings) given above, there is an annual output of secondary metal from the clean-up of old gold and silver amalgamation mills and from other sources. This probably tends to reduce the market for new metal only to a small degree.

The average domestic price of quicksilver per flask in San Francisco in 1914 was $49.05.

The imports in 1913 amounted to 171,653 pounds, valued at $75,361, while those of 1914 amounted to 614,869 pounds, valued

QUICKSILVER ORE TREATED IN RETORTS AND IN FURNACES IN 1914, BY STATES

| STATE | ORE TREATED, SHORT TONS | | QUICKSILVER RECOVERED, FLASKS | | PERCENTAGE OF METAL RECOVERED PER TON OF ORE TREATED | |
|---|---|---|---|---|---|---|
| | Retorts | Furnaces | Retorts | Furnaces | Retorts | Furnaces |
| California . . | 4411 | 97,142 | 367 | 10,936 | 0.31 | 0.42 |
| Nevada . . . | 1110 | 13,001 | 544 | 1,545 | 1.84 | .45 |
| Other States [1] . | 4 | 7,330 | 6 | 3,150 | 5.63 | 1.61 |
| Total . | 5255 | 117,473 | 917 | 15,631 | .62 | .50 |

[1] Arizona and Texas.

at $271,984. The exports for 1913 were 1140 flasks, valued at $43,574, while those for 1914 included 1446 flasks, valued at $70,753. The exports went to nearly all parts of the world.

The imports are greater than formerly while the exports are less.

WORLD'S PRODUCTION OF QUICKSILVER, 1911–1914, IN FLASKS OF 75 POUNDS EACH

| COUNTRY | 1911 | 1912 | 1913 | 1914 |
|---------|------|------|------|------|
| United States . . . . . . | 21,256 | 25,064 | 20,213 | 16,548 |
| Austria-Hungary . . . . | 23,310 | 23,016 | [1] 26,720 | [2] |
| Italy . . . . . . . . | 27,367 | 28,983 | [1] 29,513 | [1] [3] 22,340 |
| Russia . . . . . . . | — | — | — | [2] |
| Spain . . . . . . . . | [3] 43,681 | [3] 43,799 | [3] 43,799 | [2] |
| Mexico and other countries . | [4] 4,409 | [4] 4,409 | [4] 4,409 | [2] |
| Total . . . . . . | 120,023 | 125,271 | 124,654 | — |

[1] The Mineral Industry.                        [3] Export figures only.
[2] Statistics not available.                    [4] Estimated.

In recent years the world's production has probably exceeded the demand, but at the outbreak of the war the foreign sources of supply were cut off from the United States.

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## ANTIMONY

**Ore Minerals.** — *Stibnite* ($Sb_2S_3$) is the most important ore of antimony, and the metal is rarely obtained from any other mineral, although native antimony has been sparingly found. The oxide *senarmontite* ($Sb_2O_3$) seldom occurs in any quantity. A small amount of antimony is present in some silver-lead ores. The stibnite, together with a gangue of quartz, and frequently calcite, usually forms veins cutting igneous, sedimentary, or metamorphic rocks, and less often is found in replacement deposits. Other metallic sulphides may be associated with the antimony; some deposits are auriferous, and less often argentiferous.

Stibnite is not necessarily a mineral of the shallow-vein zone, for it may occur in deposits formed at intermediate depths, or even in the deep-vein zone, but commercial deposits occur chiefly in the shallow zone.

Cairnes (2) classifies antimony deposits as follows:

I. Ores deposited in cavities, chiefly fissure veins.
    *a.* Of value, chiefly or entirely for antimony
    *b.* Auriferous stibnite.
    *c.* Antimony and silver.
II. Replacement, chiefly in limestone.

**Distribution of Antimony in United States.** — Antimony has been found at a number of localities in the Cordilleran region, but the great distance of the deposits from the railroad has helped to make them of little commercial value, and the domestic production is very small and irregular.

It is therefore only the richest and best-located deposits that are worked. Some of the known ore bodies are also said to lack value because of their content of arsenic, zinc, or lead minerals,

and hence are refused by the buyers so long as they can get purer ores (Hess).

Many gold and silver ores carry some antimony, and in smelting it combines with the lead, giving a product known as antimonial lead, much of which is produced in the United States.

The large amount of antimony now manufactured in the United States is obtained: (1) as a by-product from the smelting of foreign and domestic lead-silver ores containing small quantities of antimony; (2) from antimony regulus, or metal from foreign countries; (3) from foreign ore; and (4) from some copper ores.

Hess states that in 1914 a few tons were separated from the anode muds of blister copper made from Butte ores.

Very little has been published regarding the occurrence of antimony ores in the United States. Hess has described some deposits in Arkansas (4), where the antimony occurs as bedded veins in sandstones and shales, with a quartz gangue, and associated with a number of different metallic minerals. The deposits are of doubtful value, except possibly when high market prices prevail.

Along Coyote Creek, in Garfield County, Utah (7), there are found flat-lying deposits of stibnite and its oxidation products in Eocene (Tertiary) sandstone and conglomerates. The ore in sight is all low grade, although some rich pockets have been worked out in the past.

Stibnite veins in rhyolites and basalts are known in western Nevada, and have been specially referred to in the National district (6). There, the fissures, which have a quartz gangue, all carry more or less stibnite, together with small amounts of pyrite, blende, etc.

**Canada.** — The Canadian production of antimony is small and spasmodic.

It occurs at West Gore, Nova Scotia (4) in fissure veins in Cambrian slates. The minerals are stibnite, native antimony, pyrite (auriferous), mispickel, kermesite ($Sb_2S_2O$) in a gangue of crushed slate, quartz and calcite. Other veins are found at Prince William, near Fredericton, New Brunswick, (8). An interesting series of veins in granite is found in the Wheaton River district, Yukon Territory. The veins, which occur chiefly in granite and vary from a few inches to 5 feet in width, carry stibnite, sphalerite, tetrahedrite, argentiferous galena and antimony ochre, in a gangue of quartz (2).

**Other Foreign Deposits.** — China is the largest producer of the world, the deposits of the Hunan Province [1] being of importance. There the ore near Hsinhua is distributed in seams, pockets and bunches in Carboniferous dolomite, while at the Pan-shi mines it occurs as fissure veins in sediments.

France has also been a large producer, numerous deposits being found in the Central Plateau region. The veins, which cut schists, granite, and also clastics, carry stibnite in a quartz gangue.

The Japanese veins are found chiefly in Mesozoic and Paleozoic sediments, often near quartz prophyry, or even in it.

Replacement deposits are known in Italy,[2] Algeria,[3] and Mexico.[4]

**Uses.** — Antimony metal is used chiefly in the manufacture of alloys of lead, tin, zinc, etc. Type metal, which is an alloy of lead, antimony, and bismuth, has the property of expanding at the moment of solidification. Britannia metal is tin with 10 to 16 per cent antimony and 3 per cent copper. Babbitt, or antifriction metal consists of antimony and tin, with small amounts of lead, copper, bismuth, zinc, and nickel. Tartar emetic, a potassium-antimony tartrate, antimony fluoride and ammonium sulphide, and other double salts are used in medicine and as a mordant for dyeing, while antimony persulphide is employed for vulcanizing and coloring rubber. Antimony trioxide is employed as a substitute for white lead, zinc oxide, etc., in pigments. It is also used in a glaze for coating enameled iron ware, as a reducing agent in chemical work, and as a detector of alkaloids and phenols. The trichloride is used in bronzing gun barrels, in coloring zinc black, and as a mordant for patent leather and silver. Antimony trisulphide is used in pyro-

PRODUCTION OF ANTIMONY IN THE UNITED STATES, 1912–1914, IN SHORT TONS

| YEAR | CONTAINED IN ANTIMONIAL LEAD OF DOMESTIC ORIGIN | | CONTAINED IN ANTIMONIAL LEAD OF FOREIGN ORIGIN, BUT SMELTED IN UNITED STATES | | RECOVERED FROM OLD ALLOYS, SCRAP, DROSS, ETC. | |
|------|----------|-------|----------|-------|----------|-------|
| | Quantity | Value | Quantity | Value | Quantity | Value |
| 1912 . . . . | 1224 | [1] $209,059 | 725 | [1] $123,830 | 2506 | [1] $428,025 |
| 1913 . . . . | 2204 | [1] 375,562 | 304 | [1] 53,801 | 2705 | [1] 460,932 |
| 1914 . . . . | 2530 | [1] 529,740 | 175 | [1] 36,750 | 2645 | [1] 555,450 |

[1] Estimated, using the average price for the year.

[1] Wheeler, Eng. and Min. Jour., CI: 637, 1916.

[2] Bergeat, Erzlagerstätten, II: 883.

[3] Fuchs and de Launay, Gîtes Minéraux, 2: 205.

[4] Cox, Amer. Jour. Sci., XX: 421, 1880; Halse, Trans. Fed. Inst. Min. Engrs., VI: 290, 1893–1894.

technics for making " Bengal fire." Antimony chromate, or " Naples yellow," if used for coloring.

**Production of Antimony.** — The production of metallic antimony from domestic and foreign ores since 1912 was as shown in the table on page 781.

ANTIMONY, ANTIMONY ORE, AND SALTS OF ANTIMONY IMPORTED AND ENTERED FOR CONSUMPTION IN THE UNITED STATES, 1912–1914, IN POUNDS

| YEAR | [1] METAL (REGULUS) | | [2] CRUDE ANTIMONY AND ORE | | OXIDE AND SALTS OF ANTIMONY | | TOTAL VALUE |
|---|---|---|---|---|---|---|---|
| | Quantity | Value | Quantity | Value | Quantity | Value | |
| 1912 | 13,936,873 | $808,473 | 1,562,066 | $ 51,444 | [3] 1,759,908 | $ 81,077 | 940,994 |
| 1913 | 12,479,727 | 798,581 | 4,021,486 | 137,780 | [4] 1,968,475 | 117,169 | 1,053,530 |
| 1914 | 13,110,426 | 736,420 | 2,606,349 | 75,345 | 2,744,406 | 315,001 | 1,126,766 |

[1] "Regulus" is a term which has been handed down from the alchemists and should be allowed to become obsolete. As now used it merely "means metal," so that "antimony," "regulus," and "refined antimony," which from year to year are noted in the reports of various governments, are redundants.

[2] "Crude antimony" is an awkward and misleading term meaning "liquidated stibnite." It is also known as "needle antimony."

[3] Oxide only. No figures showing the imports of antimony salts were given in the customs returns.

[4] Includes imports of salts for the last three months of 1913.

The last reported production of antimony in Canada was in 1909 and consisted of 364 tons of antimony concentrates, valued at $13,906, shipped from West Gore, Nova Scotia.

The imports of antimony into Canada in 1914 amounted to 694,150 pounds, valued at $57,715.

WORLD'S PRODUCTION OF ANTIMONY IN 1912

(In metal unless otherwise noted. Tons of 2000 pounds.)

| | 1912 | | 1912 |
|---|---|---|---|
| Algeria (ore) | 5,139 | Hungary: | |
| Australia: | | "Crude" and metal | 947 |
| New South Wales (ore and | | Ore | 72 |
| metal) | 71 | Italy (ore) | 2,070 |
| Victoria (ore) | 2,722 | Japan: | |
| Austria (ore) | 4,983 | Crude | 14 |
| Bolivia (ore) | 100 | Refined | 69 |
| China, exports: | | Mexico: | |
| Metal | 14,914 | Ore | 17 |
| Ore | 2,265 | Metal | 3,849 |
| France (ore) | 12,147 | Portugal (ore) | 110 |
| | | Servia (ore) | 327 |
| | | Spain (ore) | 551 |

In 1914 the value of the antimony content of antimonial lead was 10.5 cents per pound.

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## ARSENIC

**Ore Minerals.** — Although arsenic-bearing minerals are widely distributed in many countries, the commercially valuable occurrences are few, and moreover few arsenic-bearing minerals are important as sources of the metal. *Arsenopyrite* (FeAsS with 46.02 As) is the most important and the most widely distributed of the arsenic minerals. It may occur in schists, gneisses, pegmatites, contact-metamorphic deposits or quartz veins, and usually favors deep-zone conditions. Other sulphides may be associated with it, as well as gold and silver.

*Orpiment* ($As_2S_3$, 60.96 As) and *realgar* ($As_2S_2$, 70.08 As) may be both original and secondary minerals, formed usually at shallow depths, but comparatively unimportant as ores, although considerable quantities of the latter are said to be mined in China (4). The two occur in some quantity also at Mineral Creek, Lewis County, Washington.

*Native Arsenic*, though occasionally found, is never in commercial quantities, and the oxides arsenolite and claudetite, of secondary nature, are likewise unimportant.

Arsenic is found combined with a number of metals, or with a metal and sulphur in many primary ore deposits. Among the better known of these compounds occurring in ore deposits of the United States or Canada alone, may be mentioned enargite ($Cu_3AsS_4$), tennantite ($Cu_8As_2S_7$), proustite ($Ag_6As_2S_6$), smaltite ($CoAs_2$), niccolite (NiAs), chloanthite ($NiAs_2$), cobaltite (CoAsS), and sperrylite ($PtAs_2$). Of these, the enargite is the second most important ore mineral at Butte, Montana.

Great quantities of arsenic are lost annually in this country by allowing it to pass off with the smelter fumes, and it has been

estimated that from 14,000 to 15,000 tons of arsenic trioxide are being set free from the Butte ores every year. Hess states that other localities in the United States probably supply an additional 5000 tons annually.

**Distribution in the United States.** — Little has been published on the occurrence of arsenic ores in the United States, and indeed there appear to be comparatively few discovered deposits of commercial importance. Arsenopyrite has been mined in Washington, where the mineral is used for making arsenious oxide. The ore is said to average about 14 per cent arsenic, .7 ounce gold and 3 ounces silver per ton.

In Virginia (9), arsenopyrite has been found at Rewald, Floyd County. The material occurs as a series of lenses in quartz-sericite schist, the principal lens being 3 feet at the surface, but thickening to 14 feet at a depth of 120 feet. In Rockbridge County, in the same state, the arsenopyrite is found in association with pyrite and cassiterite in quartz-greisen-bearing tin veins, but it is not worked.

Arsenopyrite and subordinate pyrite with a quartz gangue, forming a series of parallel stringers in gneiss, close to a basic dike, is found near Carmel, Putnam County, N. Y. (5). The product of the mine when concentrated averages 25 per cent arsenic.

A number of these occurrences are known but they are not worked. (See references.) White arsenic has been produced at Everett, Washington, since 1901, but as all the white arsenic is made in the West, and the markets are in the East, the product has to compete with Canadian and other foreign supplies.

**Foreign Deposits.** — White arsenic is made as a by-product in Canada, being saved by the smelters at Thorold, Copper Cliff, and Orillia, Ontario, from arsenical silver ores from Cobalt, Ont.

White arsenic has been produced at Mapimi, Mex.

**Uses of Arsenic.** — Arsenopyrite is used chiefly for the manufacture of arsenious oxide. Arsenic is employed in medicine, as a pigment, and as an alloy with lead for making shot. Arsenious oxide is used for making paris green, in glassware for counteracting the iron coloration, in certain enamels, and as a fixing and conveying substance for aniline dyes. It is also important as a weed killer. Realgar, the disulphide, is used in printing, tanning, and also in pyrotechnics, since it burns with a white light. Orpiment is used chiefly in textile dyeing.

**Production of Arsenic.** — The production and imports from all sources are given below.

PRODUCTION AND IMPORTS OF ARSENIC, UNITED STATES, 1912–1914

| YEAR | PRODUCTION OF WHITE ARSENIC | | IMPORTS | | | |
|---|---|---|---|---|---|---|
| | | | "ARSENIC OR ARSENIOUS ACID" AND "ARSENIC AND ARSENIC SULPHIDE OR ORPIMENT" | | PARIS GREEN AND LONDON PURPLE | |
| | Short Tons | Value | Short Tons | Value | Pounds | Value |
| 1912 . . . . | 3141 | $190,757 | 6156 | $428,741 | 162,272 | $6950 |
| 1913 . . . . | 2513 | 159,236 | 4701 | 410,446 | 99,692 | 4431 |
| 1914 . . . . | 4670 | 313,147 | 3628 | 273,713 | 15,476 | 2235 |

The production of white arsenic in Canada in 1914 was 1,737 short tons, valued at $104,015. The exports for 1914 amounted to $18\frac{3}{4}$ tons, valued at $132,567.

WORLD'S PRODUCTION OF ARSENIC, 1911–1912, BY COUNTRIES, IN SHORT TONS

| COUNTRY | 1911 | | 1912 | |
|---|---|---|---|---|
| | Quantity | Value | Quantity | Value |
| Great Britain: | | | | |
| Arsenopyrite . . . . . . | —— | —— | 1,310 | $ 6,276 |
| Arsenic . . . . . . . | —— | —— | 2,401 | 70,124 |
| Canada ¹ . . . . . . . . | 2097 | $76,237 | 2,045 | 89,262 |
| China: | | | | |
| Exports . . . . . . | 246 | —— | 186 | —— |
| Orpiment—exports ² . . . | 366 | 23,138 | 377 | 21,635 |
| France (arsenopyrite) ³ . . . | —— | —— | —— | —— |
| Germany (arsenic ore) . . . | 5356 | 105,084 | 24,369 | 656,775 |
| Japan (metal) . . . . . . | 7 | 384 | —— | —— |
| Mexico ⁴ . . . . . . . . | 2000 | —— | 2,000 | —— |
| Portugal . . . . . . . . | 987 | 38,356 | 1,047 | 45,416 |
| Spain (arsenopyrite) ⁵ . . . | 1164 | 34,931 | —— | —— |
| United States . . . . . . | 3132 | 73,408 | 3,142 | 190,757 |

¹ McLeish, John, Annual report on the mineral production of Canada during the calendar year 1913. Ottawa, p. 191, 1914.

² "Orpiment, yellow sulphide (As₂S₃), is obtained from mines near Chaochow and Menghua, in the Tali prefecture, about 24 miles from Hsia Kuan, in the province of Yunnan. In 1912, 273 metric tons (301 short tons) were exported from Teng Yueh and 69 tons (75 short tons) from Mengtsz." The exports as given in the Reports of the Maritime Customs of China give no orpiment, but call it realgar.

³ Large quantities of arsenical gold ore—in 1912, 165,380 metric tons, valued at 9,574,000 francs, and in 1911 162,499 metric tons, valued at 8,055,000 francs—were mined in France, but no statement is made of the quantity of white arsenic in the ore or saved. See Statistique de l'industrie minérale et des appareils à vapeur en France et en Algérie pour l'anneé 1912, Paris, pp. 32 and 34, 1914.

⁴ Estimate, Mineral Industry, 1912, p. 45.

⁵ Mineral Industry, 1913, p. 32, gives Spain credit for 331 metric tons of white arsenic in 1911.

### REFERENCES ON ARSENIC

1. Dunn, Amer. Inst. Min. Engrs., Trans. XLVI: 687, 1914. (Smelter gases.)  2. Hess, U. S. Geol. Surv., Min. Res., 1913: 953, 1914.  3. Hess, U. S. Geol. Surv., Bull. 470: 205, 1911. (Brinton, Va.)  4. Hess, U. S. Geol. Surv., Minn. Res., 1914, Pt. I: 947, 1916. (General.)  5. Newland, N. Y. St. Mus., Bull. 120: 12, 1908. (N. Y.)  6. Richardson, U. S. Geol. Surv., Bull. 340: 255, 1908. (S. Utah.)  7. Spencer, U. S. Geol. Surv., Bull. 450: 54, 1911. (Llano-Burnet region, Tex.)  8. Spurr, U. S. Geol. Surv., 22d Ann. Rept., Pt. 2: 837, 1901. (Monte Cristo, Wash.)  9. Watson, Min. Res. Va., 1907: 210. (Va.)  10. Weed and Pirsson, Amer. Jour. Sci., XLII: 403, 1891. (Orpiment and realgar, Yellowstone Park.)  11. Wells, Ont. Bur. Mines, XI: 101, 1902. (Ont.)  See also Cobalt, Ont., refs. under Nickel.)

## BISMUTH

**Ore Minerals.** — The principal ores of this metal, together with percentage of metallic bismuth which they contain, are: *Bismuthinite* ($Bi_2S_3$, 81.2); *bismite* ($Bi_2O_3$, 96.6); and *bismutite* ($Bi_2O_3$, $CO_2$, $H_2O$, 80.6). Although all of these contain a high percentage of metallic bismuth, the content of the ore as mined does not usually exceed ten or fifteen per cent. Native bismuth is likewise found at a number of localities.

Bismuth ore minerals are almost invariably associated with other metallic minerals, which are the primary object of mining operations, the bismuth being a by-product obtained in the treatment of these.

**Distribution of Bismuth in the United States.** — Very little bismuth ore is mined as such in the United States, and in 1914 the only locality reported producing it, was one in the Clifton district, Tooele County, Utah. Bismuth occurs in some of the Tintic, Utah, lead and copper ores, and is saved at the electrolytic lead-refining plant at Grasselli, Ind. Some was also separated at Omaha, Neb. Experiments (1, 3) show that the flue dust of Anaconda, Mont., smelter carried 1.15 per cent bismuth trioxide, and amounted to about 275 tons per year. This may be saved in the future. Similar quantities might be recovered elsewhere.

Some of the gold ores on Breece Hill near Leadville, Colorado, carry as much as 5 to 8 per cent bismuth,[1] and nearly all of the gold ores at Goldfield, Nevada (q.v.), carry this metal, partly

[1] George Argall, private communication.

in the form of bismuthinite. Other western ores also carry bismuth.

**Foreign Deposits.** — The deposits of economic value in foreign countries are comparatively few. The mines of Schneeberg, Altenberg, Annaberg and Johann-Georgenstadt, in Saxony, have contributed considerable bismuth ore in the past. The bismuth here is chiefly native. At Schneeberg the ores are chiefly in cobalt-bearing veins. At Joachimsthal, Austria, the metal occurs in argentiferous veins. Bismuth as native metal, ochre and carbonate, associated with gold, silver and tin, have been found at Tasna and Chorolque, Bolivia. The former occurrence is in slates, and the latter in porphyry. This country is the world's chief source of supply. At Meymac, France, bismuth ores have been found in veins in granite, together with wolframite and arsenopyrite.

The only Australian colony producing bismuth in any quantity is Queensland.

In New South Wales native bismuth, and bismuthinite associated with molybdenite in quartz gangue, forms pipes in granite in the Kingsgate district (5).

**Uses of Bismuth.** — Bismuth is chiefly valuable on account of the easily fusible alloys which it forms with lead, tin, and cadmium; the melting-point of some of these lies between 64° C. and 94.5° C. They are therefore employed in safety fuses for electrical apparatus, safety plugs for boilers, dental amalgams, and for automatic sprinklers. Several compounds of bismuth are of value in medicine and chemistry.

**Production.** — The imports for consumption of metallic bismuth into the United States for several years have been as follows: 1912, 182,840 pounds, value $316,440; 1913, 117,747 pounds, value $213,257; 1914, 90,505 pounds, value $165,208. The increasing domestic production is reflected in the decreasing

WORLD'S PRODUCTION OF BISMUTH

| COUNTRY | YEAR | POUNDS | VALUES |
|---|---|---|---|
| Bolivia (ore) . . . . . . . . . | 1913 | 861,134 | 774,781 |
| Queensland (ore) . . . . . . . | 1913 | 205,500 | 46,482 |
| Peru (metal) . . . . . . . . | 1913 | 55,786 | 46,198 |
| Tasmania (ore) . . . . . . . | 1913 | 12,379 | 7,917 |
| New South Wales (ore and metal) . | 1913 | 19,488 | 5,850 |
| Spain (ore) . . . . . . . . . | 1912 | 160,965 | 1,801 |
| Saxony (metal) . . . . . . . | 1912 | 7,145 | 12,763 |

imports, it is claimed. The price of bismuth in the United States was $2.75 per pound at the beginning of 1915, but by the end of the year it had risen to $4 per pound.

### REFERENCES ON BISMUTH

1. Dunn, Amer. Inst. Min. Engrs., Trans. XLVI: 648, 1914. (Smelter fumes.) 2. Eilers, Amer. Inst. Min. Engrs., Trans. XLVII: 217, 1914. (Rarer metals in blister copper.) 3. Harkins and Swain, Amer. Chem. Soc., Jour., XXIX: 992, 1907. (Smelter smoke constituents.) 4. Hess, Chapters on Bismuth in Mineral Resources of U. S. Geological Survey. 5. Pittman, Min. Res. New South Wales, p. 256, 1901.

## CADMIUM

The chief ore mineral of cadmium is *greenockite* (CdS), but no deposits of this mineral are known, and it is found chiefly in association with sphalerite. Greenockite occurs in the Joplin, Missouri, district as a greenish yellow coating on sphalerite, being a secondary deposit which has been caused by the decomposition of cadmium-bearing blende in the upper part of the ore body, and the precipitation of the sulphide at lower levels. The average percentage in several thousand shipments from the Joplin district was .358 per cent. The table on page 789 gives the analyses of a number of samples of Missouri ore and their cadmium contents.

The calamine ores from Hanover, New Mexico, also contain cadmium in sufficient quantity to give a yellow tint to the zinc oxide made from them.

Cadmium has been obtained from zinc ores in the United States, but at present most of the output is said to be gained from bag-house fumes of lead smelters which treat lead ores containing more or less zinc.

The Silesia zinc regions are the chief source of supply, the cadmium being obtained as a by-product in the distillation of zinc.

The domestic production has varied, and is not published. The imports in 1913 amounted to 1656 pounds, valued at $1232, and in 1914 to 441 pounds, valued at $368.

**Uses of Cadmium.** — Cadmium is used chiefly by manufacturers of silverware, since the addition of only .5 per cent imparts malleability to the alloy and prevents the formation of blisters. While cadmium, like bismuth, reduces the melting-point of the

## Analysis of Cadmiferous Zinc Blendes
### (W. George Waring, analyst.)

| Ore | Zinc | Iron | Lead | Copper | Cadmium |
|---|---|---|---|---|---|
| Sphinx mine, Neck City, Mo. | 65.77 | 0.55 | 0.00 | 0.077 | 0.135 |
| Ore from Golconda, Ill. | 60.55 | 1.18 | .51 | .046 | .110 |
| Standard mine, Fortuna, Mo. | 61.97 | .55 | .815 | .133 | .436 |
| Maude B. mine, Webb City, Mo. | 55.70 | 4.90 | Trace | Trace | .227 |
| Big Six mine, Aurora, Mo. | 56.75 | 1.88 | None | .004 | .018 |
| McKinley mine, Prosperity, Mo. | 57.20 | 1.25 | 5.29 | None | .550 |
| Hudson mine, Pleasant Valley, Mo. | 62.05 | .61 | None | .030 | .322 |
| Underwriters' mine, Webb City, Mo. | 57.95 | 1.60 | 1.62 | — | .710 |
| Blende from Kentucky fluorspar mines | 53.50 | .77 | .76 | None | .211 |
| Average of 2270 carloads from Webb City, Mo., 1902 | 57.08 | 2.60 | .90 | .050 | .337 |
| Average percentage of cadmium in 10,906 shipments, mostly carload lots | — | — | — | — | .358 |

alloys into which it enters, it also produces more malleable and ductile ones in most cases, gold, platinum, and copper being exceptions. Dental amalgam has 26 per cent cadmium and 74 per cent mercury. The salts of cadmium are used in dentistry, dyeing, glass making, photography, and pyrotechnics.

### REFERENCES ON CADMIUM

1. Siebenthal, U. S. Geol. Surv., Min. Res., 1908. (General.) Also *Ibid.*, Bull. 606, 1916. 2. Branner, Ark. Geol. Surv., Ann. Rept., 1892, V, 1900.

## CHROMIC IRON ORE

**Ore Minerals.** — *Chromite* (FeO, $Cr_2O_3$) is the chief source of the compounds of the metal chromium which are used in the arts. This mineral occurs in basic rocks like peridotites or in the serpentines derived from them.

The chromite may occur as disseminated grains, irregular

bunches, or in stringers, and is usually a product of magmatic segregation. In most cases the igneous rock is almost completely serpentinized.

*Analyses.* — The following table gives the composition of several of the types of chromic iron ores: —

| | FRANCE | COLERAINE, CAN., Concentrated Product | ASIA MINOR | STYRIA | CALIF. | RUSSIA |
|---|---|---|---|---|---|---|
| $Cr_2O_3$ . . | 37.00 | 53.64 | 53.00 | 53.00 | 42.20 | 59.00 |
| $SiO_2$ . . | 2.53 | 2.31 | 2.15 | 2.50 | 5.48 | 2.20 |
| $Al_2O_3$ . . | 13.15 | 14.02 | 7.62 | 8.00 | 13.60 | 10.00 |
| MgO . . | 12.53 | 15.75 | 13.31 | 11.58 | 14.88 | 11.62 |
| FeO . . . | 34.79 | 11.47 | 24.92 | 24.92 | 23.84 | 18.18 |
| CaO . . . | — | 2.81 | — | — | — | — |

The price of chromic iron ore is based on its percentage of chromic oxide, the standard ore containing 50 per cent. Every



122° 30′
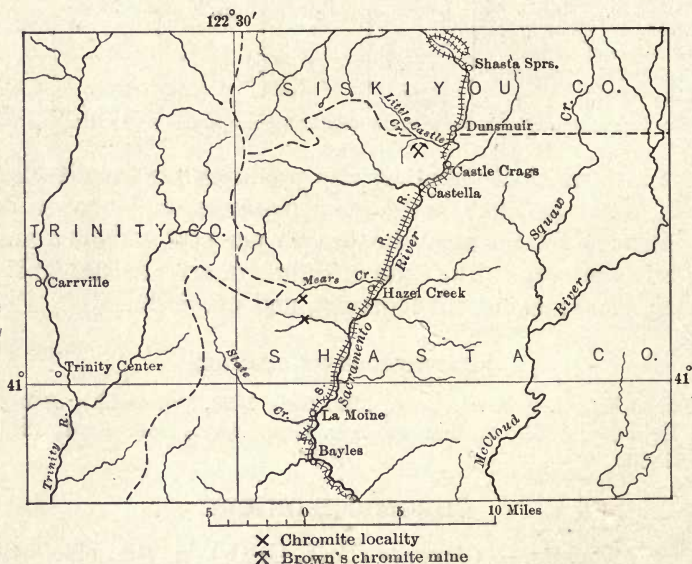
FIG. 279. — Map showing chromic iron ore localities in Shasta County, Calif. (After Diller.)

unit above this is usually valued at from 50 to 60 cents per ton; but when the percentage is below 50 per cent, the value decreases at an even greater rate. However, ores carrying only 45 per

cent of chromic oxide are easily marketable. Low silica is desirable. The silica permissible in 50 per cent ore is 8 per cent. In 1915, owing to the war, prices of imported 50 per cent ore rose to $25 to $35 per ton in large lots. California ore ranged from $11 to $18 per ton f.o.b.

**Distribution of Chromite in the United States** (8). — Chromite mining is an industry of very little importance in the United States, because the deposits, though widespread, are rarely of workable size. Deposits are known in Maryland, Pennsylvania (11, 12), North Carolina (7), Wyoming and California (4, 5).

The ore was at one time obtained from Chester and Delaware counties, Pennsylvania, and Baltimore County, Maryland, but these are no longer worked. Chromite sand is, however, obtained from stream deposits within the chromiferous serpentine area of Maryland.

California (4, 5) contains a number of chromic iron ore deposits, scattered through the serpentine and closely related intrusive rocks of the Coast Range and the Sierra Nevada, but the production from these is usually small, as the transcontinental transportation problem is a serious one.

The deposits of Shasta County (Fig. 279), which have in recent years attracted the most attention, occur in a mass of serpentine and allied rocks. In one of these (Fig. 280) an ore body about 25 feet wide and 100 feet long is found.



FIG. 280. — Section of Brown's chromic iron ore mine, Shasta County, Calif. *a*. Pyroxenite, in some places saxonite or dunite; *b*, lean ore granular groups of chromite in pyroxene and olivine; *c*, ore richer in chromite, pyroxene, and olivine (?) altered to chlorite and chromic chlorite. (*After Diller.*)

**Canada** (3, 2). — The Canadian production is generally small. Deposits are known to occur in the serpentine rocks of the Quebec asbestos area (see p. 302), where they form irregular or lens-shaped bodies of workable size, and also nodules and grains disseminated through the serpentine and pyroxenite.

**Alaska** (1). — Chromic iron ore is said to occur as a lode deposit near Port Chatham on Kenai Peninsula, and chromite fragments have also been found in the gold placers of Shungnak in the upper Kobuk basin.

**Other Foreign Deposits.**[1] — The principal foreign sources of chromite, and of the world are New Caledonia, Rhodesia, Turkey in Asia, and Greece, but during the war most of these have been practically closed to the United States.

*New Caledonia.* — The ore in the southern part of the island occurs as rich, soft, masses in ferruginous clay, and as veins and irregular masses in serpentine. That found in the northern part of the island is more important, and may run 67 per cent $Cr_2O_3$.

*Rhodesia.* — This is an important producer. The ore occurs in talc schist and serpentine, usually as disseminations, but at times forming massive lenses which range from 150 to 450 feet in length.[2]

*Turkey.* — In Turkey in Asia, the chromite ore occurs in serpentine, while that of Greece is associated with both basic rocks and limestone.

Interesting but not very important deposits are found in Norway, at Mount Dun in New Zealand, and at Kraubat in Styria (Fig. 135).[3] Some is also found in the Cuban iron ore deposits.

**Uses.** — Metallic chromium has no direct use; but raw chromite and chromium salts have a variety of applications. Owing to its great heat-resisting qualities, chromite is employed in the manufacture of refractory bricks. Such bricks are sometimes used for lining basic open-hearth furnaces, and as a hearth lining for water-jacket furnaces in copper smelting. They stand rapid changes of temperature well, and are not attacked by molten metals.

In the presence of carbon, chromium makes steel extremely hard and resistant to shocks; therefore chrome steel is suited to a variety of uses, as in the manufacture of plates, hard-edged tools, etc. An alloy of iron and chromium is used in armor plates, alloys of ferrochromium and ferronickel being added to the molten steel before casting. Most of the chromite mined is used for pigments because of the red, yellow, and green color of its compounds, chromate and bichromate of potash. In these forms the substance is employed in dyeing, calico printing, and the making of pigments useful in painting, printing wall papers, and coloring pottery. Alkaline bichromates are employed for tanning skins, and some chromium salts have a medicinal value.

**Production of Chromite.** — The amount of chromite produced in the United States is small, and California has usually been the only source of supply, although Wyoming produced a small amount in 1908 and 1909, and Maryland in 1914. The United

[1] Bull. Imp. Inst., VIII, Nos. 3 and 4, 1910.
[2] Min. Mag., Feb., 1915.
[3] Vogt, Krusch and Beyschlag, translation by Truscott, I : 244, 1914.

States production in 1914 was 591 long tons, valued at $8715, or $14.75 per ton, but in 1915, owing to war conditions, it rose to 3281 long tons, valued at $36,744.

The world's production in part, is as follows: New Caledonia (1913), 62,352 long tons; Rhodesia (1913), 62,365 long tons; Russia (1912), 20,934 long tons.

The imports into the United States in 1914 were as follows: Chromic iron ore, 80,736 long tons, value $695,645; chromic acid, 9164 pounds, value $1597; chromate and bichromate of potash, 31,858 pounds, value $2375.

Canada in 1914 produced 136 short tons of chromite, valued at $1210, but in 1915 the production amounted to 14,291 short tons, valued at $208,718, ore averaging from 30 to 35 per cent finding a ready market.

### REFERENCES ON CHROMIC IRON ORE

1. Brooks, U. S. Geol. Surv., Bull. 592 : 36, 1914. (Alaska.)  2. Camsell, Can. Geol. Surv., Mem. 26 : 56, 1913. (B. C.)  3. Cirkel, Can. Dept. Mines, Mines Branch, No. 29, 1909. (Quebec.)  4. Diller, U. S. Geol. Surv., Min. Res., 1914 and 1915. (Calif.)  5. Dolbear, Min. and Sci. Pr., CX : 356, 1915. (Calif.)  6. Maynard, Amer. Inst. Min. Engrs., XXVII: 283, 1898. (N. F.)  7. Pratt and Lewis, N. Ca. Geol. Surv., I: 269, 1905. (Origin.)  8. Harder, U. S. Geol. Surv., Min. Res., 1908. (U. S.)  9. Anon., Cal. State Ming. Bur., Bull. 38: 266. (Calif.)  10. Mathews, Md. Geol. Surv., Rept. on Cecil County. (Md.)  11. Rogers and others, Second Pa. Geol. Surv., C 4 : 92. (Chester Co.)  12. Hall, Second Pa. Geol. Surv., C 5. (Delaware Co.)  13. Emerson, U. S. Geol. Surv., Atlas Fol. 50, 1898. (Chester, Mass.)  14. Dresser, Can. Geol. Surv., Mem. 22 (Que.)

## MOLYBDENUM

**Ores and Occurrences.** — *Molybdenite* ($MoS_2$) and, less commonly, *wulfenite* ($PbMoO_4$) are the chief sources of this metal.

Molybdenite may occur as a constituent of pegmatite veins; it also forms irregular masses or disseminations in crystalline rocks, and many occurrences are known in the West, for example, in California, Washington, Montana, Utah, Arizona, New Mexico, and in the East, in Maine (4).  Wulfenite is found in the oxidized zone of lead ores in a number of western states.  Numerous references to different occurrences are found in the Mineral Resources issued by the United States Geological Survey.

Several occurrences have been described from Quebec and Nova Scotia (7).

Marketable molybdenum ores should carry at least 25 per cent molybdenum oxide and be free from copper, vanadium, tungsten and chromium.

**Uses.** — The chief use of molybdenum is in making "high speed" steels, and this apparently caused its price to rise from 20 or 30 cents a pound in 1912, to $2 a pound in 1914. Ammonium molybdate is a chemical reagent. Metallic molybdenum is used in resistance furnaces, as supports for filaments in electric incandescent lamps, as parts of Roentgen ray tubes, and as one of the alloying metals in stellite.

**Production of Molybdenum.** — The production of molybdenum is small, but there was a greater demand for it in 1914.

### REFERENCES ON MOLYBDENUM

1. Andrews, N. S. W. Geol. Surv., Min. Res. No. 11, 1906. (N. S. W.) 2. Cameron, Queensland Geol. Surv., Rept. 188, 1904. (Queensland.) 3. Crooks, Bull. Geol. Soc. Amer., XV : 283, 1904. (N. Y.) 4. Sm th, U. S. Geol. Surv., Bull. 260 : 197, 1905. (E. Me.) 5. Hess, U. S. Geol. Surv., Bull. 340 : 231, 1908. (Me., Utah, Calif.) 6. Baskerville, Eng. and Min. Jour., LXXXVI : 1055, 1908. 7. Walker, Dept. Mines Can., 1911. (Can.)

## NICKEL AND COBALT

**Ore Minerals.** — These two metals can best be treated together, for nearly all the ores containing the one are apt to carry some of the other, and furthermore, in smelting, the two metals go into the same matte, and are separated later in the refining process.

The ore minerals of nickel and cobalt, of recognized occurrences, together with their composition and the percentage of nickel or cobalt they contain, are shown in the table on page 795. Of these some occur only in small amounts as millerite, pentlandite, genthite, and chloanthite.

The nickeliferous pyrrhotite is the most widely distributed of the economically important nickel ore minerals and may carry small amounts of cobalt. It is also called magnetic pyrites. The percentage of nickel ranges from a trace to 6 per cent, but an increase above this brings it into pentlandite. Millerite is sometimes found associated with pyrrhotite ores.

| Ore | Composition | Ni | Co |
|---|---|---|---|
| Pyrrhotite (nickeliferous) | FeS | 0–6 | — |
| Millerite | NiS | 64.6 | — |
| Pentlandite . . . . . | (FeNi)S | 22 | — |
| Genthite . . . . . | $2NiO_2, 2MgO, 3SiO_2, 6H_2O$ | 22.46 | — |
| Niccolite . . . . . | NiAS | 43.9 | — |
| Linnæite . . . . . | $(CoNi)_3S_4$ | 30.53 | 21.34 |
| Chloanthite . . . . . | $NiAs_2$ | 28.1 | — |
| Smaltite . . . . . | $CoAs_2$ | — | 28.1 |
| Cobaltite . . . . . | $CoS_2, CoAs_2$ | — | 35.4 |
| Erythrite (Cobalt bloom) | $Co_3As_2O_8 + 8H_2O$ | — | 37.47 |
| Annabergite (Nickel bloom) | $Ni_2As_2O_8 + 8H_2O$ | — | — |
| Garnierite . . . . . | $H_2(NiMg)SiO_4$ | 5–20 | — |
| Gersdorffite . . . . . | NiAsS | 35.4 | — |
| Cobalt-arsenopyrite . . | (FeCo)AsS | — | 6–25 |
| Skutterudite . . . . | $CoAs_3$ | — | 88.2 |

**Distribution in the United States.** — The United States is of little importance as a producer of nickel and cobalt from domestic ores, and the known occurrences have not been worked for several years. At Mine la Motte, Missouri, some nickel and cobalt have been obtained as a by-product in lead mining. Nickeliferous pyrrhotites are known in Virginia and Pennsylvania, while in Oregon and Idaho some nickel and cobalt ores have been found.

*Missouri.* — The ore at Frederickstown, Missouri, is a mixture of chalcopyrite, galena, linnæite, and pyrite. The lead is removed as far as possible in concentration, and the iron by roasting and magnetic separation. The resulting concentrate is smelted (12).

*Eastern Occurrences of Nickel.* — The Gap Nickel Mine, Lancaster County, Pennsylvania, is the most important eastern occurrence. It was actively worked from 1863 to 1880, being during that period the only nickel ore mined on this continent. In 1902 the mine was again operated for a short time. The ore is pyrrhotite associated with amphibolite, an altered intrusive, the whole inclosed by mica-schist. The pyrrhotite is believed to have originated by magmatic segregation (9).

Nickel has been reported from a number of localities in the Piedmont region of Virginia (14), especially in association with the pyrrhotite bodies of the Floyd-Carroll-Grayson counties plateau in southwest Virginia, as well as at several other points. No steady production has been made, but the locality in northern Floyd County is encouraging. There the ore which occurs in a mica gabbro is said to average 1.75 per cent nickel, and under 1 per cent copper. Cobalt is usually very low. Nickel minerals have also been found in the basic magnesian rocks of North Carolina.

*Western Occurrences.* — Deposits of nickel and cobalt ores are known in Idaho and Oregon, but they have not yet assumed importance.

The only production in 1907 was near Prairie City, Grant County, Oregon, but the deposits which have attracted the most attention from time to time are those of Piney or Nickel Mountain near Riddles (8), Douglas County, in the same state.

The ore, which is genthite in a quartz gangue, occurs as flat-lying deposits cn the surface of post-Cretaceous pre-Eocene peridotite, or as veinlets in the peridouite and serpentine. The former deposits occur as brecciated and conglomeratic masses, and consist of silica, nickel silicate, ferric oxide, and serpentine with very subordinate chromite. Prolonged weathering in some cases has removed the nickel.

It is thought that the genthite represents a decomposition product of the peridotite, for nickel is found in the fresh rock. The hydrated nickel-magnesian silicates and silica formed by weathering were subsequently in part dissolved and carried down into crevices of the underlying peridotite. Such a theory limits the depth. If formed by ascending hot waters, as some believe, a greater depth would be assured.

Nickel occurs in a great many blister coppers, and the quantity reported in various ones in pounds per hundred tons was as follows: Anaconda, Mont., 22; Great Falls, Mont., 68; Garfield, Utah, 40; Steptoe, Nev., 64; Omaha, Neb., 944; Mountain, Cal., 172; Tacoma, Wash., 770; Aguascalientes, Mex., 132; Cerro de Pasco, Peru, 32; Mount Lyell, Tasmania, 166.

The electrolytic refining of these coppers has yielded considerable nickel.

**Canadian Occurrences.** — Canada is the most important source of the nickel and cobalt ores in North America, and indeed in the world, but much of the mine production is shipped to the United States for treatment and consumption. It is therefore of interest to refer to the two important producing localities, viz., Sudbury and Cobalt, both in the province of Ontario.

*Sudbury, Ontario* (2, 3, 4, 5, 8a). — This district is the main source of supply for the nickel used on this continent (Fig. 281).

The geological formations present in the region according to Coleman (5) are as follows:

| | |
|---|---|
| Pleistocene. | Sand and clay. |
| Paleozoic? | Diabase and granite dikes. |
| Keweenawan. | Sudbury nickel-bearing eruptive. |
| Animikie or Upper Huronian. | ⎧ Chelmsford sandstone. ⎨ Onwatin slate. ⎪ Onaping tuff. ⎩ Trout Lake conglomerate. |

| Lower Huronian. | Conglomerate. |
| Laurentian. | Granitoid gneiss and hornblende schist. |
| Sudbury series. | Chiefly quartzite, also acid and basic eruptives. Equivalent (?) to Temiskaming of Cobalt area. |
| Grenville series. | Quartzite, and fine-grained gray gneiss and schist. |
| Keewatin. | Chiefly greenstone and greenstone schists. |
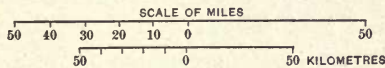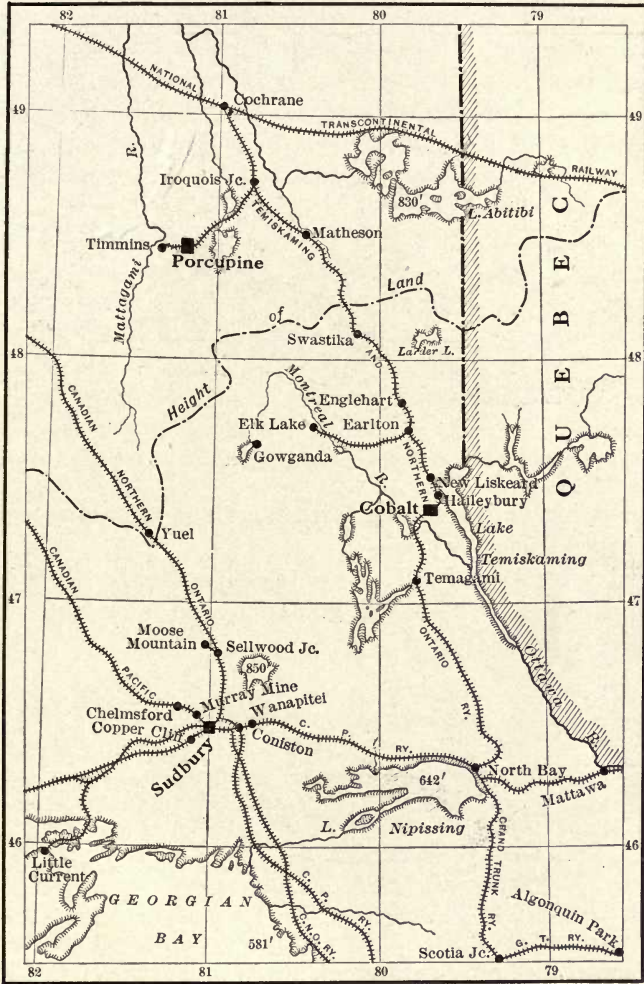


Fig. 281. — Map of Cobalt— Porcupine — Sudbury region. (*Ont. Bur. Mines.*)

Reference to the section (Fig. 283) will show that the nickel-bearing laccolith appears to rest on ancient crystallines and is covered by metamorphosed Animikie sediments; that, moreover,
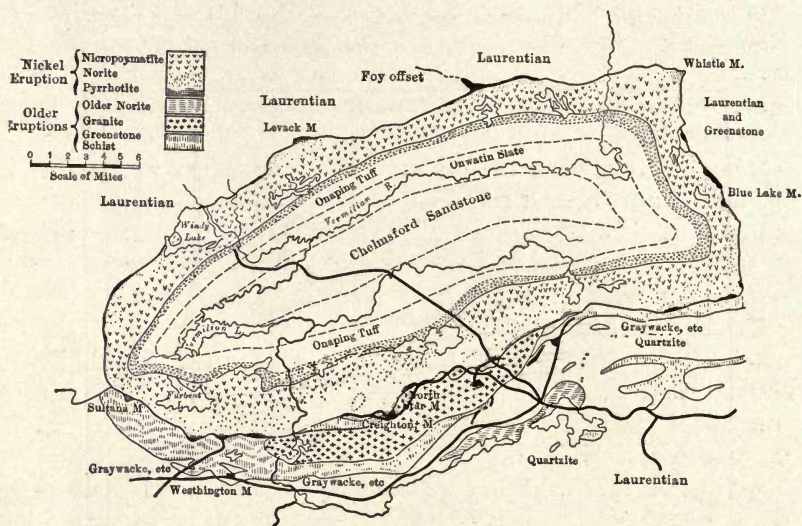


FIG. 282. — Geologic map of Sudbury, Ont., nickel district. (*After Coleman.*)

the underlying and overlying formations are bent into a great canoe-shaped trough or basin.

The intrusive where fresh is a norite on its outer border or lower part, and passes by insensible gradation into a granite on its inner edge (Fig. 283).
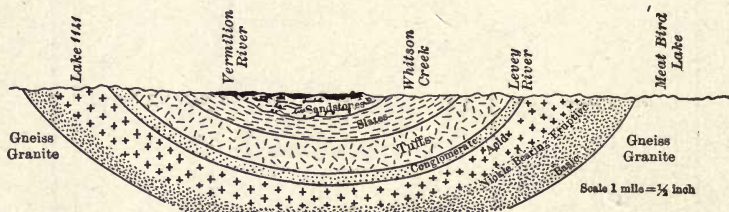


FIG. 283. — Geologic section of Sudbury, Ont., nickel district. (*After Coleman.*)

The ore bodies are found at or near the margin of this great laccolithic sheet, which covers over 500 square miles.

Coleman believes that following the eruption of the nickel-bearing magma there was a long-continued process of segregation, resulting in an accumulation of the more basic elements of the

molten mass in its lower part, and the more acid elements in its upper portion, the sulphides sinking into the depressions of the Archæan substratum. The collapse of the underlying Archæan, due to the upflow of the magma from underneath, is supposed to have caused a sinking of the overlying rocks, and formation of the trough. The ore bodies occur only in the norite, around its margin, or in some of the dike-like offsets.

The ores, which are of remarkably uniform character, consist mainly of pyrrhotite, chalcopyrite, and pentlandite, and though the last is important, it is rarely visible to the naked eye. Variations in the proportions of these three may, however, occur. Thus, in the Copper Cliff mine, the percentages were 4.65 Cu to 4.46 Ni one year, while in another they were 7.81 Cu to 2.37 Ni.

The ore bodies are sometimes found on the margin of the eruptive, and have a foot wall of the older rocks, but an ill-defined hanging wall. These form irregular sheets dipping towards the synclinal axis. Others, of irregular shape, are found in the dike-like projections of the basic edge.

Several theories have been advanced to account for the origin of these ore bodies. Coleman and others believe that the ore is of magmatic origin because they claim: (1) it is everywhere associated with norite, and grades into it, (2) the adjoining rocks are never spotted with ore, and separated bodies of ore are never inclosed in them, but veinlets of ore may penetrate them, (3) there is little evidence of hydrothermal or pneumatolytic action, such as one might expect if the deposits were other than magmatic segregations, and (4) the largest bodies are in the offsets, which represent the lowest portions of the laccolith, and into which the ore would naturally settle. Barlow, who also made a somewhat careful study of this district, concurs with Coleman regarding the origin of the ore by magmatic segregation. It is, of course, not improbable that the ore bodies have been rearranged somewhat later by circulating water.

At some variance with these views are those expressed by Dickson (6). His theory is that the ore occurs as a cement for brecciated rock fragments and along shearing planes which are of pre-mineral age, the ore minerals having been deposited by solutions and by a process of replacement. This view seems to be confirmed by the examination of the minerals of this district by metallographic methods, which show the following order of succession: (1) Magnetite, (2) silicate, (3) pyrrhotite, (4) pentlandite, (5)

chalcopyrite. And following a long line of investigators, Knight (8a) presents most interesting evidence to show that the ores have been deposited from solution. He points out that the granite floor of the laccolith is younger than the norite because it sends dikes into it, and that the ore is found not only in the norite, but also in the graywacke and the granite, and concludes that solutions rising along the granite norite contact deposited the ore.

According to Coleman, the percentage of sulphides in the ores varies from 50 to 80, while the nickel contents ranges from 1.5 to 5 per cent. The cobalt is present in amounts varying from $\frac{1}{40}$ to $\frac{1}{133}$ of the nickel present.

An analysis of a high-grade matte gave: NiCo, 48.82; Cu, 25.92; Fe, 2.94; S, 22.50; Au, .02 oz.; Ag, 3.14 oz.; Pt, .13; Irid., .02; Os, .02; Rh and Pal., tr.

*Cobalt, Ontario* (10). — The silver-cobalt-nickel veins found at this locality present one of the most remarkable series of ore deposits found in recent years, and have their analogue only in certain foreign occurrences. The district lies near the boundary of the provinces of Ontario and Quebec, and west of the northern end of Lake Temiskaming (Fig. 281).

The ores occur in mostly well-defined veins, which range from less than an inch to as much as a foot or more in thickness, and occupy narrow, almost vertical fissures or joints, cutting through a series of slightly inclined metamorphosed fragmental rocks of Lower Huronian Age. Some are also found in the diabase and Keewatin, although these last two are never so productive.

The geological section at this locality is as follows:

Glacial drift.
Silurian.
  Niagara limestone.
  Great unconformity.
Pre-Cambrian.
  Later dikes of aplite, diabase and basalt.
  Nipissing diabase, probably of Keweenawan age.
  Cobalt series. Conglomerate, greywacke, and other fragmentals.
    Unconformity.
  Lorrain granite.
  Lamprophyre dikes. Near some of mines.
  Temiskaming series. Conglomerate and other fragmental rocks.
  Keewatin complex. Includes basic volcanics, now altered to schists and greenstones; also altered sediments including jaspilyte, slates, and greywacke.

The veins are narrow, practically vertical fissures and joint-like cracks, cutting the Cobalt series. A few productive ones are found in the Nipissing diabase and in the Keewatin (Fig. 284). Most of the ore has come from veins or parts of veins that originally lay beneath the sill.

The important ores are native silver, smaltite, and cobaltite, but associated with them in varying quantities are niccolite, chloanthite, millerite, argentite, dyscrasite, pyrargyrite, arsenopyrite, etc. The oxidized zone, which is usually but a few feet in
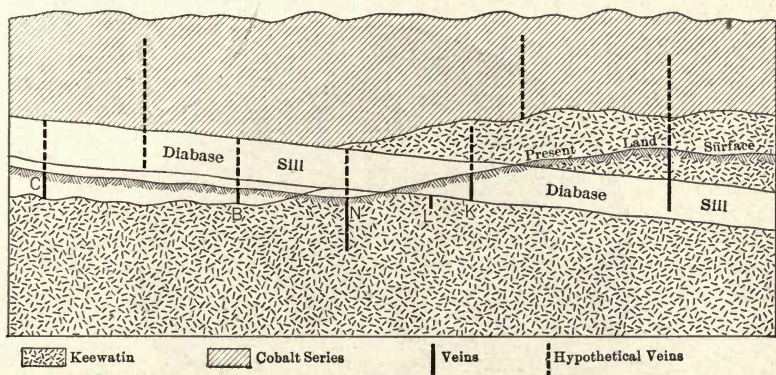


FIG. 284. — Generalized vertical section through the productive part of the Cobalt Ont., area.

The section shows the relations of the Nipissing diabase sill to the Keewatin and the Cobalt series, and to the veins. The eroded surface is restored in the section, and the sill is less regular than the illustration shows. *B* and *C* represent a large number of veins that are in the fragmental rocks, Cobalt series, in the foot wall of the eroded sill; *N* represents a type of vein, in the Keewatin below the eroded sill; *L* a vein in Keewatin footwall, but not extending upward into the sill; *K* a vein in the sill itself; *T* a vein in Keewatin hanging wall and extending downward into the sill. (*After Miller, Ont. Bur. Mines, XIX, Pt. II*, 1913.)

depth, shows native silver, erythrite (cobalt bloom), and annabergite (nickel bloom). Calcite is the chief gangue mineral, quartz being much less common.

W. G. Miller (10), who has given more careful study to this region than any one else, believes that the ore was deposited by highly heated impure waters circulating through cracks and fissures following the post-middle Huronian diabase eruption. The metals may have been brought up by these waters from a great depth, or they may have been leached out of the now folded and disturbed greenstones and other Keewatin rocks. He inclines

to the theory, however, that the diabase magma was the source of both the cobalt-nickel minerals and the silver.

The cobalt arsenides were probably the first minerals deposited, and this was followed by a slight disturbance of the veins, resulting in the formation of cracks and openings in which the silver and later minerals were deposited. Veins which escaped this latter disturbance contained no silver. Many of the veins of this district are fabulously rich, but all are not so. As an example of the former, an open cut on the Trethewey vein, 80 feet long and 25 feet deep, yielded $200,000 of ore from an 8-inch vein. A
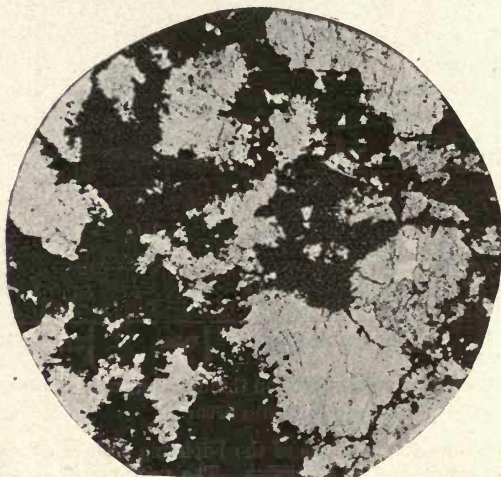


Fig. 285. — Section of calcite, and native silver, the latter in part replacing the former. Cobalt, Ont. ×30.

shipment of 80 tons of this ore gave approximately: As, 38 per cent; Co, 12 per cent; Ni, 3.5 per cent; and 190,000 ounces silver. Pay was received only for the cobalt and silver.

The veins at Cobalt are unique among North American ones, but resemble those of Annaberg, Joachimsthal, and other localities, referred to below.

The discovery of these deposits was made in building the Temiskaming and Northern Ontario railroad, and their development has made Ontario one of the leading silver producers of the world. Moreover, it practically controls the world's supply of cobalt, and the arsenic shipped from the Cobalt camp equals about one-half of the world's production, but much of it is not saved.

Milling plants have recently been installed for concentrating the lower grade ores. The ores are treated in part in the United States, but there are now plants erected for this purpose at Copper Cliff, Deloro, and Thorold, Ontario.

**Other Foreign Deposits.** — Deposits of nickeliferous pyrrhotite in basic eruptive rocks are known at a number of localities in Norway, the ore averaging 1.5 to 2.5 per cent nickel.[1] Deposits of a similar type are known in Italy, Spain, and Russia, but they are of little economic importance.

Next to Sudbury, New Caledonia is the most important source of nickel in the world.[2] The island consists of ancient schists and Mesozoic sediments, pierced by eruptives, especially peridotite. The latter is more or less altered to serpentine. The ore minerals are hydrated silicates, chiefly garnierite. They occur as veinlets and concretionary masses in the serpentine and peridotite. There are also green siliceous masses carrying 9 to 10 per cent nickel. Most of the ore is low-grade, averaging 7 per cent nickel after drying at 100° C.

Deposits of cobalt-silver ore similar to those of Cobalt, Ont., are found in Germany and Austria, viz., Joachimsthal and Annaberg. The ores of these two districts include compounds of cobalt, nickel, bismuth, and silver, and in addition uranium, which has not been found in the deposits of Cobalt, Ontario.

At Joachimsthal, Bohemia, there is a series of mica schists, calc schists, and limestones cut by dikes of basalt. The veins, which antedate the basalt, but cut the other rocks, are narrow, often brecciated, and contain hornstone, quartz, calcite, and dolomite as gangue material. Various silver, nickel, cobalt, bismuth, and arsenic minerals are present, as well as lead, zinc, iron, and copper sulphides, together with uraninite.[3] The cobalt and nickel ores are generally the older, and the silver ones younger.

At Annaberg, Saxony, the veins occur in gray gneiss. There are two groups, the younger and most important carrying silver-cobalt ores, with nickel and bismuth in a gangue chiefly of barite, fluorite, quartz, and brown spar. The older veins carry tin and lead.

The veins at Schneeberg, Saxony,[4] occur in contact-metamorphic clay slates, but become poorer on passing into the underlying granite.

The ore minerals are smaltite, chloanthite, niccolite, bismuthinite, and native bismuth in a gangue of quartz, hornstone, calcite, and dolomite. Silver minerals are rare.

New South Wales was formerly the second largest world's producer of cobalt.[5]

**Uses of Nickel.** — The most important and increasing use of nickel is for the manufacture of nickel and nickel-chromium steel. This, on account of its great hardness, strength, and

[1] Vogt, Krusch and Beyschlag, Translation, I.

[2] Glasser, Ann. de Mines, 15th ser.,Tome IV; 299 and 397, 1903; Colvocoresses, Eng. and Min. Jour., LXXXIV: 522, 1907.

[3] Vogt, Krusch und Beyschlag, Lagerstätten, II: 173, 1912. Also Miller, Ont., Bur. Mines, XIX, Pt. II: 213, 1913.

[4] Vogt, Krusch und Beyschlag, Lagerstätten, II: 173, 1912; Dalmer, Kohler, and Müller, Section Schneeberg, Geol. Spez. Karte Sachsen, 1883.

[5] Pittman, Mineral Resources, New South Wales, N. S. W. Geol., Surv. 1901.

elasticity, is used for making armor plate, gun shields, turrets, ammunition, hoists, etc. Krupp steel, which may be taken as a type, has approximately 3.5 per cent nickel, 1.5 per cent chromium, and .25 per cent carbon. Owing to its abrasive resistance, nickel steel is now much used for rails. Other important uses are for large forgings, marine engines, wire cables, and electrical apparatus. A steel with 25 to 30 per cent nickel shows high resistance to corrosion by salt, fresh or acid waters, or by superheated steam. German silver is an alloy of zinc, copper, and nickel. Monel metal is an alloy containing 68 per cent nickel, 1.5 per cent iron, and 30.5 per cent copper.

**Uses of Cobalt.** — Cobalt steel, while having a high elastic limit and breaking strength, cannot compete with nickel steel on account of its high cost, and the main use for cobalt is as a pigment, it being used to color glass and pottery. Stellite is an alloy of cobalt, chromium and other metals.

Nickel ores were not mined in the United States in either 1913 or 1914, but in the latter year the equivalent of 845,334 pounds of metallic nickel, valued at $313,000, is said to have been saved as a by-product in the electrolytic refining of copper. Probably one-third to one-half of this came from domestic ore.

The United States is the largest nickel refining country of the world, most of the metal being derived from Canadian matte, and some indirectly from New Caledonia. The total imports of nickel alloys, pigs, etc., ore and matte (nickel content), and nickel oxide imported into the United States in 1914 amounted to 35,098,958 pounds, valued at $5,000,594. The exports of nickel and nickel oxides from the United States in 1914 amounted to 27,595,152 pounds, valued at $9,455,528.

Canada in 1914 produced 46,396 short tons of matte, valued at $7,189,031 and containing 28,895,825 pounds of copper, and 45,517,937 pounds of nickel. There is also a small recovery of nickel in the form of nickel oxide from the Cobalt district ores, the production in 1914 being reported as 391,312 pounds of oxide valued at $26,483.

The exports in 1914 amounted to 46,538,327 pounds of nickel in matte.

*Production of Cobalt.* — No cobalt was produced in the United States in 1914. The imports into the United States of cobalt oxide, cobalt ore, and zaffer (an impure cobalt oxide), amounted to 334,556 pounds, valued at $274,538.

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## PLATINUM GROUP OF METALS

**Platinum.** — The ore minerals of platinum are *native platinum*
(100 per cent Pt) and *sperrylite*, $PtAS_2$ (56.5 per cent Pt). The
former is commonly found in placer deposits, but its original
occurrence is in associations with chromite in peridotite, or in
serpentine derived from it, although such deposits are nowhere
found in workable quantity. Sperrylite never occurs in large
quantities, but is found in association with sulphide minerals in
basic igneous rocks such as gabbro and diabase. Where occur-
ring in igneous rocks it represents a crystallization product of
the magma.

In addition to these two types of occurrence platinum has also
been found in quartz veins as in Nevada (p. 806), Canada,[1]
Finland [1] and New Zealand, and also in at least one case
(Sumatra) in a contact-metamorphic deposit. Iridosmine and
osmiridium are also known to carry platinum, and it also occurs
as an alloy with other members of the platinum group.

Most of the world's supply of platinum is obtained from
placer deposits.

The nuggets found in placers are commonly regarded as being
pure native platinum, but this, according to Kemp (5), is only
true in part, most of those assayed yielding between 70 and 85

[1] Bell, Econ. Geol. I: 749, 1906.

per cent, and the richest recorded being 86.5 per cent. The balance is made up largely of iron, the highest percentage of this noted being 19.5 per cent in a Ural specimen. Iridium, rhodium, and palladium are always present. Until the platinum falls below 60 per cent the iridium rarely reaches 5 per cent, rhodium 4 per cent, while palladium is less than 2 per cent. Other elements that have been detected in the nuggets are osmium, ruthenium, copper, and even gold, while chromite is a common associated mineral (5).

**Distribution in the United States.** — The domestic supply of platinum, never large, is obtained from gold-placer deposits in Oregon and California, and while its occurrence has been reported in many other gold placers of the Northwest and Alaska, still none of them have proven sufficiently rich to work. Most of the California production comes from the dredges at Oroville, in Butte County. The platinum is usually panned from the black sand, but a small quantity is entangled with the amalgamated gold and recovered in refining at the mint. Iridosmine and a natural alloy of iron and nickel called josephinite are found associated with the gold.

In addition to the above sources, platinum is also found in the copper ores of the Rambler mine, Wyoming, and has been saved from the slimes obtained in treating the copper ore and matte at this locality. The covellite in the ore is said to assay .06 to 1.4 ounces per ton of platinum.

A remarkable find of platinum and palladium was made in 1914, in the Yellow Pine mining district of Clark County, Nev. (6). According to Knopf the deposit consists of a fine-grained quartz mass, irregularly replacing Carboniferous limestone along a series of vertical fractures. A dike of granite porphyry is found not far from the ore body, but no basic intrusives are known in the district. The ore bodies developed are oxidized copper shoots and gold-platinum-palladium shoots, the latter consisting of a fine-grained quartzose ore containing a small amount of a bismuth-bearing variety of plumbojarosite (6). The ore averaged in ounces per ton: gold, 3.46; silver, 6.4; platinum, .70; and palladium, 3.38. The deposit differs greatly from any known deposit carrying platinum metals, and is further remarkable because of its probable genetic connection with acid igneous rocks. Moreover the lode is one of the few primary deposits in which platinum metals occur in more than traces.

**Canada.** — In the nickel deposits of Sudbury, Ontario (p. 796), platinum arsenide, accompanied by palladium probably also as arsenide, is found, the Bessemer mattes carrying from .17 to .5 ounce of the platinum metals. Platinum has also been found in the dunites of the Tulameen district, British Columbia, but not in commercial quantities.

**Other Foreign Deposits.** — The platinum placers of the Urals in Russia form the most important source of the world's supply, the two principal centers of production being Blagodat on the Asiatic slope, and Nizhni-Tagilsk, on the European slope.[1] Second in importance is Colombia, where placers are worked along the Choco and its tributaries. Like the Russian placers, the platinum is obtained in greater proportion than gold.[2]

**Uses.** — Platinum was first used as an adulterant of gold, and in Russia it was used for coinage from 1823 to 1845. At the present time it is employed for crucibles and other chemical apparatus which are to be subjected to high temperatures or strong acids. It is also of value in dentistry, for electric lamps and electric apparatus, for jewelry, and in photography. An important use is as a catalyzer in what is technically known as " contact mass " in the manufacture of fuming sulphuric acid and sulphur trioxide. The price of it has risen steadily in recent years, so that it is more valuable than gold.

**Production.** — A considerable output of platinum is annually made in the United States from the refining of gold and copper bullion of both domestic and foreign origin.

WORLD'S PRODUCTION OF NEW PLATINUM IN 1913–1914, BY COUNTRIES, IN TROY OUNCES

| Country. | 1913 | 1914 |
|---|---|---|
| Russia, crude................................................ | [1] 250,000 | [1] 241,200 |
| Canada, crude.............................................. | 50 | [1] 30 |
| New South Wales and Tasmania, crude [2]............... | 1,275 | [1] 1,248 |
| Colombia, crude............................................ | 15,000 | [1] 17,500 |
| United States, domestic crude.......................... | 483 | 570 |
| United States, refined from foreign and domestic matte and bullion [3]........................................... | [3] 1,100 | 2,905 |
| Borneo and Sumatra and other crude [4]................ | 200 | [5] |
| Total........................................................ | 268,108 | 263,453 |

[1] Estimated.
[2] Chiefly iridosmine.
[3] Does not include refined platinum from domestic crude.
[4] Includes small production in Madagascar.
[5] No basis for estimate.

[1] U. S. Geol. Surv., Min. Res., 1913, Pt. I: 451, 1914.
[2] Kimball, Min. and Met. Soc. Amer., Bull. 65, 1913.

In 1914, California produced 463 ounces of crude platinum (about 80 per cent fine), and Oregon 107 ounces (about 70 per cent fine), the total value of these being $18,240. The total quantity of refined platinum produced in the United States in 1914 was 3430 ounces.

During 1914 the average price of refined metals of the platinum group, per troy ounce was: platinum, $45; iridium, $65; iridosmine (osmiridium), $33; palladium, $44.

The imports of platinum, both crude and manufactured, into the United States in 1914 had a total value of $2,908,353, as compared with $5,040,210 in 1913, the decrease being due to the unsettled conditions abroad.

**Palladium.** — This metal is found associated with platinum and also native and alloyed with gold (Brazil). It is of silver-white color, ductile and malleable, and is unaffected by the air. Its great rarity and consequent high value has restricted its use, but a small amount is used for some mathematical and surgical instruments, for compensating balance wheels and hairsprings for watches, and for finely graduated scales.

In the United States it has been reported from the platinum deposits of the Pacific coast and from the Rambler mine in Wyoming.

**Osmium.** — This, the heaviest and most infusible metal known, occurs alloyed with platinum and also with iridium in iridosmine. In the United States small quantities have been found in the platinum placers of California. It is also obtained from Tasmania (10).

Iridosmine is employed for pointing pens and fine tools, while osmic acid is used for staining anatomical preparations in microscopic work.

**Iridium.** — Iridium is found chiefly in Russia and California, alloyed with platinum or osmium. It is a lustrous, steel-like metal of great hardness, and is, next to osmium, the most refractory metal known.

An alloy of iridium and platinum has been used for standard weights and measures, and iridium is also used in photography.

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## SELENIUM

This rare and little-known element, which forms not over .0002 per cent of the known rocks, is not known to occur in deposits by itself, even though it forms combinations with a number of other metals, which are found in nature. It is found in some gold, silver and copper ores.

Thus Spurr has called attention to its presence in the gold ores of Tonopah, Nevada, where it is found, at least in part as a silver selenide. It is associated with gold in the Republic district of Washington (6).

Selenium in some form also occurs in nearly all the vanadium-bearing sandstones of Colorado and Utah.

Pyrite ores may also carry it.

The commercial supply of the United States, however, is furnished by the electrolytic copper refineries, as nearly all blister copper contains it.

The 1914 United States production, saved in copper refining, was 22,867 pounds, valued at $34,277.

**Uses.** — Selenium is used as a red colorant of glass, while selenite of soda gives a bright red color to enamels used for covering steel. Owing to its low electrical conductivity in the light, and higher conductivity in the dark, selenium wire is used in automatically lighting and extinguishing gas buoys.

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## TANTALUM

This element has attracted some attention because of its use in electric lamps.

Tantalite ($FeTa_2O_6$) and columbite [(Fe, Mn)$Nb_2O_2$] are the only minerals found in the United States from which tantalum could be produced. They occur in pegmatite veins, and are said to be found in some abundance in those of the Black Hills of South Dakota. Other occurrences are near Canyon City, Colorado; near Spruce Pine, North Carolina; near Amelia, Virginia, etc.

The tantalum market is now said to be supplied mainly by the rich mangano-tantalates from western Australia (2). Scandinavia has also supplied some (1).

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## TELLURIUM

This element has but slight commercial value, as little use has been found for it. The somewhat widely distributed telluride of gold and silver ores form a comparatively common source of it, but owing to the lack of demand, no attempt is made to save the tellurium. Cripple Creek, Colorado, is the best-known occurrence in the United States, the tellurium minerals present being sylvanite (AuAg)$Te_2$ and calaverite (AuTe$_2$). Tetradymite ($Bi_2Te_3$) is found at a number of localities.

The tellurium of commerce is all obtained as a by-product from copper ores.[1]

**Uses.** — Unsuccessful attempts have been made to utilize tellurium in bearing metals. It gives glass a reddish tint. An alloy of aluminum, zinc and tellurium has been patented.

## TIN

**Ore Minerals.** — *Cassiterite* ($SnO_2$), with 78.6 per cent metallic tin, is the principal ore mineral of this metal, but owing to the presence of impurities it rarely shows this composition.

[1] Eilers, Amer. Inst. Min. Engrs., Trans. XLVII: 217, 1914.

Its hardness (6–7), imperfect cleavage, non-magnetic character, high specific gravity (6.8–7.1), and brittleness help to distinguish it from other minerals that are liable to occur with it. Ilmenite and magnetite have sometimes been mistaken for it.

*Stream tin* is the name applied to cassiterite found in placers. *Wood tin* is a variety of cassiterite having a fibrous structure. *Stannite*, or tin pyrites, a complex sulphide of copper, iron, and tin, rarely serves as an ore mineral.

**Mode of Occurrence.** — Cassiterite may occur in the following ways, not all of them being of commercial importance:

(1) As an original constituent of igneous rock; (2) as veins, formed under pneumatolytic or hydrothermal conditions; (3) as contact-metamorphic deposits; (4) as hot-spring deposits; and (5) in placers.

Of these Nos. 2 and 5 are of commercial importance, the others being rarely so.

**Cassiterite in Igneous Rocks** (9). — Cassiterite is known to occur as an original constituent of granite, but there are no known magmatic segregations of economic importance. It may also occur as a primary constituent of pegmatite dikes, associated with lithium and phosphorus minerals, as near Gaffney, South Carolina (10), or in the Black Hills, South Dakota (23). These dikes exhibit sharp walls, and there is no replacement of the wall rock by cassiterite.

**Contact Metamorphic Deposits** (9, 19). —This type is known at a few localities. Those of Pitkäranta, Finland, show cassiterite associated with scheelite, topaz and fluorite in limestone near its contact with granite.[1]

Another interesting deposit occurs on Lost River, Seward Peninsula, Alaska (15). Here the invasion of limestone by granite has produced a contact zone, carrying pyroxene, tourmaline, axinite, pageite, ludwigite, vesuvianite, fluorite, scapolite, scheelite, cassiterite, magnetite, galena and sphalerite.

Other cases are known at Schwarzenberg and Berggiesshübel, Saxony, and the Zeehan district, Tasmania (19).

**Tin Veins.** (9). — Tin veins or lodes, carrying usually cassiterite as the chief ore mineral of this metal, may evidently be formed under different physical conditions.

**Pneumatolytic Veins.**— The commonest type is that of pneumatolytic origin found usually in granite, or close proximity

[1] Vogt, Krusch and Beyschlag, Ore Deposits, Translation, 1: 405.

to it, and showing a rather uniform group of minerals (Fig. 286), the metallic ones including cassiterite, wolframite and scheelite, arsenopyrite, bismuth, and others in lesser amounts, while the gangue minerals include quartz (important), lithia mica, topaz, tourmaline, fluorite, etc. Cassiterite is the chief ore
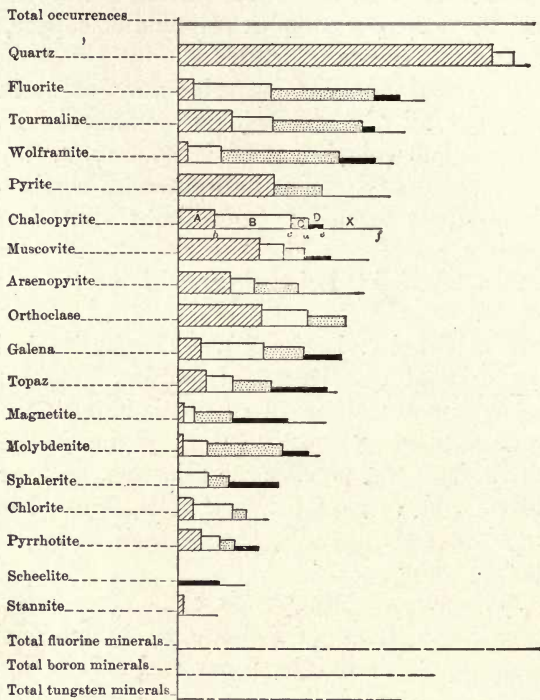


Fig. 286. — Approximate quantitative distribution of the more important minerals associated with cassiterite. Length of line is proportional to the number of occurrences. Height represents relative abundance. $A$ = very abundant; $B$ = plentiful; $C$ = prominent; $D$ = rare; $X$ = quantity unknown. (*After Ferguson and Bateman, Econ. Geol. VII.*)

mineral, but the tin content is generally low, often under one per cent. The cassiterite frequently occurs in the wall rock on either side of the fissures, and where these are abundant a considerable mass of rock may be impregnated with ore.

A characteristic feature of tin veins is the metasomatic alteration of the wall rock, resulting in a coarse-grained mixture of quartz, muscovite, lithia mica, topaz and tourmaline, called *greisen*. If tin is present in the vein, it usually occurs in the

greisen, replacing the feldspar. The tourmaline and topaz are not always equally prominent, and one or the other may be absent.

Greisenization is not confined to granites, but may also be developed in shale, slate, limestone and diabase.

The two following analyses, represent, I, the fresh granite, and II, greisen derived from it.

| | I | II | | I | II |
|---|---|---|---|---|---|
| $SiO_2$ | 74.68 | [1]70.41 | $Na O + Li O$ | 1.54 | 0.98 |
| $Al_2O_3$ | 12.73 | [1]13.06 | $K O$ | 4.64 | 3.01 |
| $Fe_2O_3$ | | 1.42 | $H_2O$ | 1.17 | 0.76 |
| $FeO$ | 3.00 | 5.09 | $TiO_2$ | 0.71 | 0.49 |
| $MgO$ | 0.35 | 0.09 | $SnO$ | 0.09 | 0.49 |
| $CaO$ | 0.09 | [2] | $AlF_2$ | ..... | [3]3.91 |
| $CuO$ | 0.50 | ...... | $CaF_2$ | ..... | 0.29 |
| | | | | 99.50 | 100.00 |

[1] After deduction of part of Al.   [2] CaO calculated as $CaF_2$.   [3] Calculated value.

The change in general indicates addition of iron, lithium, tin, fluorine and boron, with subtraction of lime, potash and soda.

Vogt, Beaumont, Daubrée, and others believe that the tin veins were formed immediately after or even during granitic eruptions, and that the mineral solutions originated by the action of hydrofluoric or hydrochloric acid on the magma, still entirely or partly in igneous fusion. These extracted fluorides of silicon, tin, boron, and lithium as well as phosphoric acid. The type of alteration of these pneumatolytic emanations varies somewhat, schist being altered somewhat differently from granite.

*Hydrothermal Veins.* — These are represented by vein types found in the Zeehan field of Tasmania,[1] and the Cerro de Potosi district of Bolivia.[2] At the former crustified veins carrying stannite, pyrite, siderite, galena, chalcopyrite and some cassiterite are found, representing a lower-temperature condition of deposition than the cassiterite granite veins, and cassiterite contact-metamorphic deposits found in the same district.

*Shallow depth veins* are represented by those found in rhyolite of the Guanajuato district, Mexico.[3]

[1] Twelvetrees and Ward, Dept. Mines, Tasmania, Bull. 8.
[2] Singewald, Econ. Geol., VII: 272, 1912.
[3] Wittlich, Zeitschr, prak. Geol., 1910: 121.

**Hot Spring Deposits.** — Tin appears to be formed in some cases by precipitation at normal pressure from thermal waters, for a stanniferous siliceous sinter has been deposited by a hot spring in Malacca. It contains $SiO_2$, 91.8; $SnO_2$, .5; $Fe_2O_3$, .2; and $H_2O$, 7.5 (quoted by Lindgren).
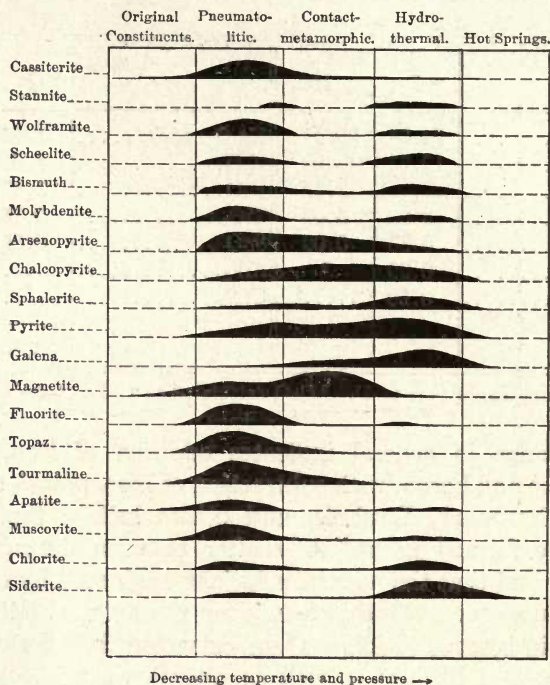


Fig. 287. — Diagram to illustrate the genetic distribution and gradation of some of the more common minerals in their association with cassiterite only. (*After Ferguson and Bateman, Econ. Geol. VII.*)

**Placer Deposits** (8, 9). — These form the most important source of tin ore, and have been formed in the manner described on p. 433. Accompanying the cassiterite there may be wolframite, and other heavy minerals.

**Distribution of Tin Ores in the United States** (13). Tin has been found at many localities in both the eastern and western United States as well as in Alaska, but most of the deposits have thus far proved to be of little or no commercial value.

*North Carolina and South Carolina* (10, 11). — In these two states there is a belt of tin ore which extends from near Gaffney,

Cherokee County, South Carolina, across parts of Cleveland and Gaston Counties, North Carolina, to near Lincolnton, being in all 35 miles long. The cassiterite is irregularly distributed in pegmatite dikes in schists, the latter being metamorphosed sediments interstratified with slates, marbles, and quartzites. Gabbro, diabase, and granite intrusions are also present. This belt has not yet proved to be of commercial value although some mining has been done in years past, and a little ore shipped.
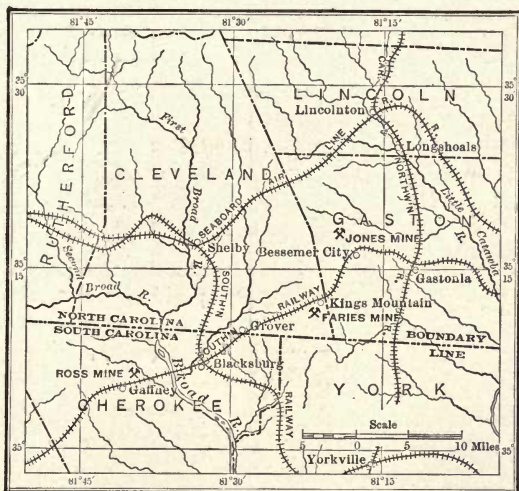


FIG. 288. — Sketch map showing location of Carolina tin belt. (*After Graton, U. S. Geol. Surv., Bull.* 260.)

*South Dakota and Wyoming* (14, 23). — The most widely known occurrence of tin ores in the United States is in the Black Hills. Tin was discovered in the Harney Peak district and later in Nigger Hill. The tin ore (cassiterite) occurs as disseminations in pegmatites, in quartz veins, and in placers. The occurrences have never amounted to much.

**Alaska** (7, 15). — Tin is found in the York region of the Seward Peninsula, where it occurs chiefly in placers and lodes and at a number of other places, but as yet there has been little production. The lode deposits show the following types: (1) quartz veins cutting phyllites or metamorphic slates; (2) disseminations in more or less altered granite rocks; (3) in quartz porphyry dikes cutting limestone, and accompanied by fluorite, zinnwaldite, etc.

**Foreign Deposits.** — Cassiterite veins are known in many parts of the world (8). The Cornwall, Eng., deposits, worked for many years, show tin veins occurring in post-Carboniferous granites, and also in slates (*killas*) intruded by them. An interesting feature is the presence of copper with little tin in the upper parts of the veins, which changes to a straight tin ore where the veins pass from slate to granite. Not a little tungsten is also obtained from some of the workings.

Another classic district is that of the Erzgebirge [1] in Saxony, and neighboring parts of Bohemia. At Altenberg (Fig. 289), the ores form a stockwork of small veins cutting a post-Carboniferous granite (Plate XLI, Fig. 2,



Fig. 289. — Geologic map of Altenberg-Zinnwald tin district, Saxony. 1. Porphyritic granite; 2. Teplitz quartz porphyry; 3. Granite with flat tin lodes; 4. Silicified porphyry; 5. Quartz porphyry impregnated with tin ore; 6. Steep tin lodes; 7. Tin gravel. (*After Vogt, Krusch, und Beyschlag, I.*)

and Plate LXXV, Fig. 1) and an older granite porphyry, the development of greisen being quite extensive. In the neighboring Zinnwald deposits, the flat veins appear to be formed largely by filling.

Interesting and important deposits are those of Mount Bishoff, Tasmania, where the schists have been cut by dikes of granite porphyry, both rocks being replaced by tourmaline and topaz, and the entire mass carrying veins of cassiterite.[2]

Curious because of their mineralogical relations are the Bolivian veins.[3] The country rock, which is Devonian slate, intruded by granite porphyry dikes, is extensively tourmalinized. Associated with the cassiterite is stannite, stephanite, ruby silver, tetrahedrite, blende, wolframite, arsenopyrite, etc.

The Mexican ores are unique because of their occurrence in rhyolite, but of little commercial value.

The chief source of the world's production is the Malay Peninsula, and Banka and Billiton Islands off Sumatra. The ore here is obtained chiefly from placers.[4] Tin veins are also known in both districts.

[1] Singewald, Econ. Geol. V: 166 and 265, 1910.
[2] Krusch, Zeitschr. prak. Geol., 1900: 86.
[3] Rumbold, Econ. Geol., IV: 321, 1909.
[4] Penrose, Jour. Geol. II: 135, 1903.

Plate LXXV



Fig. 1. — Old workings of tin mine, Altenberg, Saxony. (*H. Ries, photo.*)



Fig. 2. — Rutile mine, near Roseland, Va. (*H. Ries, photo.*)

(817)

**Uses of Tin.** — Tin is used chiefly for the manufacture of bronze and tin plate, and to a smaller extent in plumbing as well as less important purposes. Britannia metal is composed of from 82 to 90 parts of tin alloyed with antimony, copper, and sometimes zinc.

**Production of Tin.** — The amount of tin produced in the United States including Alaska is entirely too small to supply the demand, and the main source of supply for this country, and indeed for the world, is the Malay peninsula, while other regions of commercial importance are Australia and Bolivia. The available figures are given below.

The tin ore produced in Alaska in 1914 amounted to 157.5 tons of concentrates, carrying 104 tons of tin, worth $66,560. The only tin produced in the United States came from near Tinton, S. Dak.

The tin imported into the United States in 1914 amounted to 52,919 short tons, valued at $32,943,059.

WORLD'S PRODUCTION OF TIN IN 1914, IN SHORT TONS

| | |
|---|---:|
| London deliveries | 23,335 |
| Continent of Europe | 22,747 |
| Cornwall (production) | 6,720 |
| Bolivia (shipments) | 21,000 |
| South Africa (shipments) | 5,600 |
| China (shipments) | 2,128 |
| United States (receipts) | 48,505 |
| Total | 130,035 |
| Deductions of Straits, etc., from continent and English, Bolivia, etc., Arriving in United States | 9,635 |
| Total | 120,400 |

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LVIII, No. 2, 1912. (Bibliography.) 13. Hess and Graton, U. S. Geol. Surv., Bull. 260: 161, 1905. (Occurrence and distribution.) 14. Hess, U. S. Geol. Surv., Bull. 380: 134, 1909. (S. Dak.) 15. Knopf, U. S. Geol. Surv., Bull. 358, 1908. (Alas.) 16. Miller, Can. Min. Jour., XXXII: 582, 1911. (Ont.) 17. Piers, Nova Scotia Inst. Sci., Proc. and Trans., XII, Pt. 3: 239, 1912. (N. S.) 18. Richardson, U. S. Geol. Surv., Bull. 285: 146, 1906. (Franklin Mts., Tex.) 19. Singewald, Econ. Geol., VII: 263, 1912. (Genetic relationships.) 20. Umpleby, U. S. Geol. Surv., Bull. 528, 1913. (Lemhi Co., Ido.) 21. Watson, Min. Res. Va., 1907: 567. (Va.) 22. Weed, U. S. Geol. Surv., Bull. 213: 99, 1903. 23. Ziegler, Min. and Sci. Pr., CVIII, Nos. 15 and 16, 1914. (Harney Peak, S. Dak., pegmatites.)

## TITANIUM

**Ore Minerals.** — While more than sixty mineral species contain titanium, the largest concentrations of the element occur as rutile ($TiO_2$, 60 per cent Ti when pure), ilmenite, or titaniferous magnetite (see p. 520). Rutile is at present the chief source of the element, but even the workable deposits of this are few, widely separated, and insufficient to supply the world's demand, so that it has been necessary for some uses to turn to ilmenite or highly titaniferous magnetites.

**Mode of Occurrence** (4). — Rutile is formed as a constituent of: (1) igneous rocks: (2) pegmatite dikes: (3) contact-metamorphic deposits; (4) veins; and (5) regionally metamorphosed rocks. Of these, 1 and 2, rarely 3 and 5, serve as important sources of rutile.

While rutile may occur in both volcanic and plutonic igneous rocks, most of the known commercially important deposits are associated with gabbro (including anorthosite), and usually formed by magmatic differentiation. The region of Amherst and Nelson counties in Virginia, Bay St. Paul, Quebec, Canada, and Kragero area in southern Norway, are of this type. A second important type found in Virginia, occurs as dike-like bodies of the ultrabasic igneous rock nelsonite (4).

Rutile and ilmenite have been found in apatite veins in Norway and Sweden, and in pegmatite dikes in Virginia (4) and Texas (4).

It may also be found in placer deposits, as it is resistant to weathering.

**Distribution of Rutile in the United States** (4). — Although found in the eastern United States from New England to Alabama, only the Virginia deposits are of commercial value

and have supplied the entire domestic production since 1902.

Here there are two areas, viz., the Amherst-Nelson County (Fig. 290), one on the northwest edge of the Piedmont Plateau, and the Goochland and Hanover counties area, near the central-eastern margin of the same province.
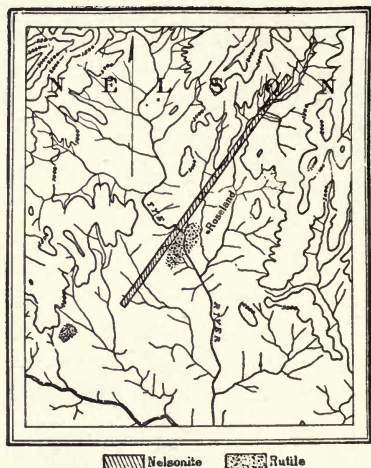


FIG. 290. — Map showing location and relations of rutile deposits in Nelson County, Va. (*After Watson, Min. Res. Va.*, 1907.)

In the Nelson county area the rocks are all igneous, derived from a common parent magma, and characterized by the prominence of apatite, ilmenite, rutile, and more rarely titaniferous magnetite. The rock types present are: (1) Biotite - quartz monzonite gneiss and schists, which form the country rock; (2) syenite, the most important rock type of the rutile district, consisting chiefly of andesine feldspar and a little blue quartz, a hornblendic (secondary from pyroxene) facies containing abundant blue quartz and andesine feldspar, and near its margin, rutile, and lesser amounts of ilmenite and apatite; (3) gabbro; (4) nelsonite, a rock occurring usually along the border portion of the syenite, and composed chiefly of apatite, with ilmenite or rutile, or both in varying proportions; (5) gabbro-nelsonite intermediate between 3 and 4; 6, diabase dikes.

The rutile occurs as grains and segregations in the syenite, or as a constituent of the dike-like nelsonite bodies. In the former it varies in quantity from sparsely disseminated grains, up to 30 per cent of the mass, but in the quarries near Roseland (Plate LXXV, Fig. 2) averages 4 or 5 per cent.

The rock is milled and both the rutile and ilmenite saved. Nelsonite rutile was also mined (Fig. 291) formerly.

In the Goochland-Hanover counties area the rutile occurs in pegmatite.

**Canada** (3). — The chief known occurrence of Canadian rutile is near St. Urbain, north of Bay St. Paul, Quebec. The ilmenite-

rutile deposits occur in anorthosite. The larger ilmenite bodies form elongated masses, with usually sharp boundaries, and most of them are free from rutile. A second, and more important type is a rutile and sapphirine-bearing ilmenite. Both types are magmatic differentiation products. A considerable quantity of ore was shipped in 1910.

**Other Foreign Deposits** (4). — At Kragero, Norway,[1] rutile occurs in a large aplite dike, either as disseminated grains, or more important as schlieren, representing local enrichments of the mineral. In South Australia, (4) rutile is known to occur near Mount Crawford, about 25 miles northeast of Adelaide, the enclosing rock being presumably pegmatite.

**Uses.** — Titanium is used for producing yellow underglaze colors on pottery, and also in the manufacture of artificial teeth, to give them an ivory tint. Another use is in the alloy ferro-titanium. Its commercial values as a steel-hardening metal are not



FIG. 291. — Plans and vertical section in General Electric Company's mine, Nelson County, Va. (*After Watson and Taber, Va., Geol. Surv., Bull. III–A.*)

yet thoroughly proven, but from .5 to 3 per cent titanium appears to materially increase the transverse and tensile strength of steel. By the use of the electric furnace, ferro-titanium can be produced directly from the ores, which would open a use for our American titaniferous magnetites. Rutile is used in electrodes for arc lamps.

**Production.** — The domestic production in 1914 came from Roseland, Nelson County, Va., and amounted to 94 tons of rutile, carrying 95 per cent $TiO_2$ and, as a by-product, 89 tons of ilmenite, carrying about 55 per cent of $TiO_2$. Concentrated

[1] Watson, Amer. Jour. Sci., XXXIV: 509, 1912; Vogt, Amer. Inst. Min. Engrs., XXX: 646, 1901.

rutile sells for $50 to $400 per ton, depending on purity, fineness of crushing, and quantity purchased.

ANALYSES OF RUTILE

|                    | I     | II     | III   | IV     |
|--------------------|-------|--------|-------|--------|
| $TiO_2$            | 95.71 | 98.80  | 53.35 | 97.68  |
| $FeO$              | 2.35  | 1.68   | 24.49 | .81    |
| $SiO$              | .92   | .2 )   | 2.24  | 1.06   |
| $Cr_2O_3$          | .02   | .07    | ..... | .39    |
| $V_2O_3$           | .15   | .20    | ..... | .55    |
|                    | 99.15 | 101.01 |       | 100.49 |

I. Nelson County, Va., syenite rutile; II. Nelson County, Va., nelsonite rutile; III. Rutile and sapphirine-bearing ilmenite, St. Urbain, Que., partial analysis; IV. Kragerite rutile from Kragero, Norway.

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## TUNGSTEN

**Ore Minerals.** — Four minerals may serve as important sources of tungsten, viz.: *hübnerite* ($MnWO_4$, 76.6 per cent $WO_3$); *wolframite* (($FeMn)WO_4$, 76.4 per cent $WO_3$); *scheelite* ($CaWO_4$, 80.6 per cent $WO_3$); *ferberite* ($FeWO_4$, 76.3 per cent $WO_3$).

Of these the wolframite is the most abundant, while scheelite and ferberite are somewhat rare. The commercially important occurrences include: (1) quartz veins; (2) pegmatite dikes (or veins); (3) placers; (4) contact metamorphic zones; and (5) replacement deposits.

The inclosing rocks may be volcanic or plutonic igneous ones, metamorphic gneisses and schists, or even sedimentaries. The tungsten mineral forms the most prominent mineral in a deposit, or occurs as a subordinate one in veins carrying tin, gold, or silver.

Among the minerals that may be found accompanying tungsten are galena, pyrite, siderite, quartz, chalcopyrite, pyrrhotite, fluorite, tetrahedrite, sphalerite, barite, cassiterite, topaz, arsenopyrite, etc.

The tungsten minerals may occur in the deposits as disseminations, pockets or masses, or in some veins in bands.

**Distribution in the United States.** — Tungsten minerals are known to occur at a number of localities in the United States, and yet but very few of these are normally of commercial importance, the quantity available usually exceeding the demand. The abnormal conditions produced by the European war, and consequent enormously high prices, have stimulated the development of tungsten deposits in the United States.

A few of the occurrences are referred to below, partly to give some idea of the mode of occurrence.

*Colorado* (10). — The most important tungtsen deposits of Colorado are found in southeastern Boulder County. The country rock, which is pre-Cambrian granite and gneiss, has been subjected to fissuring accompanied by crushing and brecciation, and in the open spaces thus formed the ore mineral ferberite has been deposited. The metalliferous solutions also carried much silica, and the following important periods of mineralization have been distinguished, each separated by secondary movement and brecciation along the veins: 1, silicification and partial cementation of breccia with slight deposition of tungsten; 2, deposition of tungsten; 3, precipitation of silica followed by second important deposition of tungsten. There is also a strong suggestion of solution and secondary enrichment. The friable character of the ferberite and the highly siliceous nature of some of the ores cause some difficulty in concentration.

These deposits form an important domestic source of tungsten at the present time.

*Arizona* (3, 16, 22). — Hübnerite is found irregularly distributed in vertical quartz veins cutting granites and gneissic rocks, near Dragoon, Cochise County.

*California* (1). — In the Atolia district of San Bernardino County (24), the second important domestic source, the ore mineral scheelite occurs in veins with quartz and calcite in grano-diorite and schist. The veins occupy a shear zone.

*Nevada* (26). — Veins of hübnerite are found in a granite por-

phyry in the Tungsten mining district southeast of Ely. The gangue is quartz with a little fluorite, pyrite, and scheelite.

*South Dakota* (14). — Wolframite is found near Lead City as flat, horizontal, but irregular masses, associated with the oxidized, refractory siliceous gold ores. These ores are replacements of a dolomite deposited by uprising thermal solutions.

**Canada** (7, 15, 25). — Tungsten ores have been reported from a number of localities in Canada, but the production is small and irregular, and comes from the scheelite-quartz veins of Nova Scotia. Other occurrences have been recorded from Beauce County, Quebec, and the Slocan district of British Columbia (15, 25).

**Other Foreign Deposits.** — Burma and the Shan States form the most important source of the world's supply, the wolframite being obtained from placers, derived from lodes, where it is associated with cassiterite and quartz.

Queensland [1] and New South Wales [2] have wolframite in quartz veins, greisen and placers.

In Portugal, the third largest producer, wolframite, associated with scheelite and tungstite ($WO_3$), as well as cassiterite, pyrite, arsenopyrite, tourmaline and fluorite, is found in veins and stockworks.

**Uses of Tungsten.** — Most of the tungsten produced is used in the manufacture of tool steel, and the industry therefore depends to a large extent on the condition of the steel industry. Tungsten forms a number of alloys with other metals such as iron, aluminum, nickel, copper, titanium, tin, etc. It is also employed to a considerable extent for incandescent lamp filaments. Ferrotungsten is used in the manufacture of tungsten steel, and the fluorescent properties of tungstate of lime make it useful in the Röntgen ray apparatus. Tungsten is also employed for coloring glass, sodium tungstate is used in fireproofing curtains and draperies, while other tungsten salts are used for weighting silks.

**Production.** — The United States production in 1914 amounted to 990 short tons of concentrates carrying 60 per cent $WO_3$, valued at $435,000, which was 547 tons less than 1913. For the first time the Atolia, Calif., district exceeded the Boulder County, Colo., one.

The world's production for 1912, the last year for which

[1] Cameron, Queensland Geol. Surv., Rept. 188, 1904.
[2] Carne, N. S. W. Geol. Surv., Min. Res. No. 15, 1912.

practically complete statistics are available, was 9654 short tons of concentrates carrying 60 per cent $WO_3$.

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## URANIUM AND VANADIUM

**Ore Minerals.** — The minerals which carry one or the other, or both of these elements, and which are of commercial importance are: *carnotite* $(K_2O \cdot 2UO_3 \cdot V_2O_5 + 8H_2O)$; *roscoelite* or vanadium mica $(H_8K(MgFe)(AlV)_4(SiO_3)_{12})$; *pitchblende* or *uraninite* $(U_3O_8)$; *uvanite* $(2UO_3 \cdot 3V_2O_5 \cdot 15H_2O)$; *descloisite* $(ZnPb(OH)VO_4)$; *patronite* $(V_2S_5)$; and *vanadinite* $(Pb_5Cl(PO_4)_3)$.

Of these carnotite is the most important ore in the United States, not only because of its uranium content, which is in more demand than the vanadium, but also because it carries radium, so much sought after now because of its radio-active

properties. Associated with the carnotite is more or less roscoelite.

**Distribution of Uranium and Vanadium in the United States** (2, 12). — The chief source of uranium and vanadium in the United States is a somewhat extensive area in western Colorado and adjoining portions of Utah (6, 8). The ore minerals occur in the lower member of the La Plata (Jurassic) sandstone, being found either in the disseminated form, or in joint fractures of the rock.

The deposits follow a seam which indicates an apparent unconformity, and vary in thickness from 1 or 2 inches to over 30 feet. Much of the ore is low grade, and sorting is necessary to give a shipping product averaging 2 per cent $U_3O_8$. Locally it may run much higher. The vanadium content in a large proportion of the ore is 1 per cent $V_2O_5$, but some of it runs considerably higher.

The origin of these deposits has been a puzzling problem. Vanadium is known to occur in small quantities in many sedimentary rocks, and the present deposits may represent concentrations by surface waters, although Hess suggests that the dikes found in this region may have some connection with the mineralization of the sandstone.

Deposits of carnotite in sandstone are also being worked near Green River, Utah (8), and the year 1914 saw the first commercial production of this mineral from the Henry Mountains, Utah, while near Temple, Utah, there was begun the production of uvanite,[1] a radium-bearing mineral new to science.

At Cutter, Sierra County, N. Mex. (7), vanadinite associated with lead, zinc and copper, has been found in veins cutting Carboniferous limestone.

Pitchblende has been found at a number of localities in the United States, but the most important deposits are those found near Central City, Gilpin County, Colo. The mines were originally worked for gold (12, 14).

**Foreign Deposits.** — The important European deposits of pitchblende are found at Joachimsthal,[2] Austria, and at Johanngeorgenstadt, Marienberg, Freiberg and Schneeberg, in Saxony. The veins are referred to under nickel and cobalt.

Of great importance are the vanadium deposits at Minassagra, 20 miles

[1] Hess and Schaller, Wash. Acad. Sci., Jour., IV: 576, 1914.
[2] Becke, Zeitschr. prak. Geol., 1905: 148.

from Cerro de Pasco, Peru.[1]  The ore mineral, patronite ($V_2S$), is found as a lens-shape mass in red shales, associated with a black hydrocarbon called *quisquerite*.

**Production.** — The United States in 1914 produced 4294 short tons of dry ore, carrying 87.2 tons of uranium oxide, and 22.3 grams of metallic radium.  The ore was valued at $441,300, and the production is the largest yet made.

Little is paid for the vanadium, it being the uranium and radium that are chiefly desired.  Unfortunately most of the ore has been shipped abroad in the past, but several companies have been started in the United States for producing radium salts.

**Uses of Uranium.** — Uranium minerals are radio-active, and the oxide is used to some extent as a coloring agent in pottery glazes and iridescent glass.  Certain salts have a limited use in chemistry and medicine.

Uranium can be alloyed with steel, but alloys of other metals having similar properties are cheaper to produce.

**Uses of Vanadium.** — The main use of vanadium is as an alloy in steels where great toughness and torsional strength are needed.  It is sometimes used in certain tungsten alloys for making high-speed tool steel.  Metavanadic acid has been used as a substitute for bronze paint, and vanadium chloride is used as a mordant in printing fabrics, and the trioxide as a mordant in dyeing.

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[1] Hewett, Amer. Inst. Min. Engrs., Trans. XL: 274, 1910.

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