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TUNGSTEN MINERALS AND DEPOSITS

BY

FRANK L. HESS

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TUNGSTEN MINERALS AND DEPOSITS.

By Frank L. Hess.

INTRODUCTION.

INQUIRIES CONCERNING TUNGSTEN.

The United States Geological Survey daily receives numerous inquiries from people in many walks of life for information about tungsten. These inquiries come from school children who are writing essays; from prospectors who wish descriptions of tungsten minerals, a statement of the conditions under which they are found, and directions for testing the minerals; from owners of prospects or mines who want to know where ores may be sold and their prices and uses; and from brokers, dealers, and consumers who desire to know in what parts of this and other countries tungsten ores are found and the quantities produced. Some wish to know where the manufactured metal may be obtained, some inquire how it is reduced, and some ask what tungsten is and desire other general information about it.

SURVEY PUBLICATIONS ON TUNGSTEN.

Questions concerning the quantities produced, localities of production, and uses and tests for the minerals are considered in the chapter on tungsten in the volumes entitled "Mineral Resources of the United States," published annually by the United States Geological Survey, and some of the deposits in the United States have been described in other publications of the Survey. The papers listed below describe particular tungsten deposits or groups of tungsten deposits. Those for which a price is given are for sale by the Superintendent of Documents, Washington, D. C. The others may be obtained free by applying to the Director of the Survey.

Bancroft, Howland, Notes on tungsten deposits near Deer Park, Wash.: Bull. 430, pp. 214–216, 1910. 60c.

Describes, briefly, hübnerite deposits which lie a few miles northeast of Deer Park, Wash. The hübnerite is accompanied by argentiferous cosalite (lead-bismuth sulphide) and some smoky quartz. Parts of the vein contain mica and orthoclase feldspar.

——— The ore deposits of northeastern Washington: Bull. 550, pp. 29, 111–123, 130–133, ills., 1914.

Describes the Germania wolframite deposit (known also, though not so mentioned in the report, as the "Cedar Canyon," "Deer Trail," and "Roselle" deposit) and the Tungsten King hübnerite deposit near Loon Lake and Deer Park. The matter on pp. 130–133 is practically a reprint of the article by the same author in Bulletin 430. In the Germania deposits a black wolframite is found in white quartz veins cutting granite and quartz-mica schist. The wolframite is accompanied by considerable pyrite and a little arsenopyrite, galenobismutite, molybdenite, scheelite, and ferrotungstite. A very little silver and gold are also present. Some shipments of wolframite have been made.

HESS, F. L., Note on a tungsten-bearing vein near Raymond, Cal.: Bull. 340, p. 271, 1908. 30c.

A brief description of a wolframite-bearing quartz vein cutting schists near Raymond, Cal. The deposit is without economic value.

——— Tin, tungsten, and tantalum deposits of South Dakota: Bull. 380, pp. 149–157, 1909. 40c.

Describes the pegmatites and pegmatitic quartz veins near Hill City, Oreville, and Keystone, which carry tungsten minerals; mostly wolframites. A very little scheelite accompanies the other tungsten minerals. Also describes the wolframite deposits which are associated with gold ores near Lead.

——— Note on a wolframite deposit in the Whetstone Mountains, Ariz.: Bull. 380, pp. 164–165, 1909. 40c.

Describes a deposit of wolframite in the Whetstone Mountains, 12 miles southwest of Benson, which is apparently a segregation from granite.

HESS, F. L. and SCHALLER, W. T., Colorado ferberite and the wolframite series: Bull. 583, 75 pp., ills., 1914. 20c.

A detailed description of the mineralogy of ferberite, a consideration of the relations of the natural manganese-iron tungstates, and a comparison of analyses.

HILL, J. M., Note on the occurrence of tungsten minerals near Calabasas, Ariz.: Bull. 430, pp. 164–166, 1910. 60c.

Describes quartz veins carrying wolframite near Calabasas, 7 or 8 miles north and a little west of Nogales.

HOBBS, W. H., The old tungsten mine at Trumbull, Conn.: Twenty-second Ann. Rept., pt. 2, pp. 7–22, ills., 1901. $2.25.

——— Tungsten mining at Trumbull, Conn.: Bull. 213, p. 98, 1903. Exhausted.

Describes a deposit of scheelite (part of which is replaced by wolframite) in metamorphosed limestone in Long Hill, near Trumbull.

JOHNSON, B. L., Occurrence of wolframite and cassiterite in the gold placers of Deadwood Creek, Birch Creek district [Alaska]: Bull. 442, pp. 246–250, 1910. 40c.

The gold-bearing gravels yield 1 to 2 pounds of concentrates to the cubic yard, consisting mostly of wolframite and cassiterite. Relative proportions are not given.

KNOPF, ADOLPH, Geology of the Seward Peninsula tin deposits, Alaska: Bull. 358, pp. 38, 55–58, ills., 1908.

Gives a technical description of the occurrence of tungsten minerals in the tin-bearing regions of Seward Peninsula, Alaska. Scheelite is found in contact-metamorphic deposits on Cape Mountain, though not in commercially valuable quantity. Wolframite is found on Lost River with cassiterite and minerals characteristic of tin veins—topaz, zinnwaldite, arsenopyrite, chalcopyrite, and others—and less usual minerals, such as zinc blende and stannite. No production of tungsten has been made from the deposits.

KNOPF, ADOLPH, Tungsten deposits of northwestern Inyo County, Cal.: Bull. 640, pp. 229–249, 1917 (Bull. 640–L).

Describes contact-metamorphic deposits in limestone intruded by granite.

UMPLEBY, J. B., Geology and ore deposits of Lemhi County, Idaho: Bull. 528, pp. 73–74, 77, 79, 109–112, 2 ills., 1913.

Quartz veins carrying hübnerite with copper minerals, siderite, molybdenite, and galena cut schists of Algonkian age.

WEEKS, F. B., An occurrence of tungsten ore in eastern Nevada: Twenty-first Ann. Rept., pt. 6, pp. 319–320, 1901.

——— Tungsten ore in eastern Nevada: Bull. 213, p. 103, 1903. Exhausted.

——— Tungsten deposits in the Snake Range, White Pine County, eastern Nevada: Bull. 340, pp. 263–270, 1908. 30c.

All three papers describe hübnerite-bearing quartz veins carrying also a little scheelite and gold, which cut granite on the west side of Wheeler Peak, 12 miles south of Osceola. These are the deposits now worked by the U. S. Tungsten Corporation at Tungsten.

WINCHELL, A. N., Mining districts of the Dillon quadrangle, Mont., and adjacent areas: Bull. 574, p. 125, 1914.

Describes the occurrence of hübnerite in the Potosi district, 14 miles southwest of Pony, in veins cutting quartz monzonite that were formerly worked for silver. The hübnerite is commonly confined to streaks 1 to 18 inches thick, but a width of 20 inches was found on the Rockefeller claim, a sample from which assayed 4.5 per cent of tungstic acid. Hübnerite is one of the later-formed minerals in the vein; quartz crystallized simultaneously with the tungsten, and thin layers of chalcedony formed afterward. Fluorite is common and varies remarkably in color, being purple, green, blue, white, or black. The veins grade into pegmatite at the Strawberry mine.

SCOPE OF THIS REPORT.

Tungsten minerals have been briefly described in several Survey publications other than those listed above, but it has been found that prospectors and others who are relatively untrained in the study of minerals can not positively identify them from descriptions alone; it is necessary to use also colored plates showing their appearance, such as are given in this bulletin. An attempt is made to gather into this bulletin the known general facts about tungsten, the minerals in which it is found, the kinds of deposits from which these minerals have been obtained, and other information which will answer as many as possible of the questions asked the Survey, and to show by illustrations, colored and uncolored, the appearance of typical specimens of the various tungsten minerals. The purpose has been to make this paper of interest and use to the prospector and miner, and also to those who have no particular knowledge of minerals.

TECHNICAL TERMS.

Technical words are avoided in this paper as far as may be, but many technical terms are merely names for things or properties that are themselves unfamiliar, the names being unfamiliar for the same reason. Ten years ago the word tungsten itself was strange to most well-read persons, and it is yet strange to many. A "technical" word or expression belongs to some particular profession or trade. Miners and prospectors often speak of technical words as if they were used only by professional or scientific men who wish to write above the comprehension of the ordinary reader. As a matter of fact, persons in all trades and callings necessarily use words that apply only to their work and that are therefore technical. The simpler the subject or the more superficially it is treated the fewer are the technical terms used, but the most ordinary occupations have such terms. Farmers "list" corn and "drill" wheat, and those who really study their soils and fertilizers and the plants they raise add a great number of new words to their vocabularies. Mining is a calling which deals with subjects unfamiliar to the majority of people and which has developed a large number of technical words, and many of the terms in common use among miners and prospectors are wholly foreign to others. Such words as moil, stope, winze, drift, adit, gouge, singlejack, shoes, and dies mean little or nothing to most persons not familiar with the working of mineral deposits. The jokes told in every mining camp at the expense of the newcomer who is mystified about "horses" in the veins need only be mentioned to give point to this statement.

Technical words are necessary to express definite ideas, and each has a specific meaning and usually only one meaning, so that it is much easier to write exactly with them than without them and thus to save time and effort in writing and to insure clearness in expression. To appreciate this fact it is only necessary to attempt to indicate the objects mentioned above "in common language," intelligible to any person who knows nothing of mines or mining. As the knowledge of ore deposits grows, many terms which only a short time ago were considered the special property of the professional geologist or mining engineer are finding their way into everyday talk. Such words as rhyolite, dacite, diorite, hübnerite, alunite, and the chemical symbols for the rare and heretofore little-known minerals, all of which were, until the last few years, considered too technical for the ordinary man of the camp, have become or are fast becoming the common property of all miners and prospectors. Numerous letters received at the Geological Survey show that the prospector, by reading the technical periodicals and the reports of the State and national surveys and by studying textbooks, is making himself familiar with many of the less common phenomena of ore deposits and of general geology, and necessarily with the terms by which they are described.

TUNGSTEN.

CHARACTERISTICS AND PROPERTIES.

Tungsten is a metallic element, like iron, gold, lead, copper, and other well-known metals. It is never found native but must be reduced from its ores to the metallic condition by artificial means. The metal tungsten as thus obtained is a gray powdery or granular mass, from which wrought or ductile tungsten can be made.

In the wrought or ductile form tungsten looks very much like iron or steel and takes a very similar polish. Its unpolished surface, however, shows none of the discolorations common to iron or steel. Owing to its color and to its freedom from tarnish tungsten has been proposed as a substitute for platinum in jewelry, but it is not so white and is very difficult to work. As commonly seen the wrought metal is nearly black, being coated, possibly, with a suboxide, just as the "lead-gray" color of lead is due to an oxide, though the metal itself is silvery white.

The tungsten mineral wolframite was known in the tin mines of the Saxony-Bohemia region, and later in Cornwall, long before the element itself was discovered. It is said that it was at first taken for a tin mineral but was later considered detrimental to the tin ores and to "eat" the tin. Agricola (1490–1555) believed the name to have come from the German words "wolf," the same as the English word, and "ram" or "rahm," froth. His works are written in Latin, and in them he gives *lupi spuma* as the equivalent of wolfram. Although this derivation seems plausible some deny it, holding merely that the origin is unknown.

In 1781 the Swedish chemist Scheele[1] discovered a new mineral acid in the stony mineral which was afterward named for him—scheelite—and the element thus discovered was later named tungsten, from the two Swedish words "tung," heavy, and "sten," stone. The original pronunciation was therefore "tungstane," the "u" being sounded as in "run" and the "a" as in "plane." The word has been anglicized so that the "e" is pronounced as in "pen." In Great Britain and its provinces the word "wolfram" has been compelled to do duty for both mineral and metal, but there is now a distinct trend to the better usage of calling the metal tungsten and the mineral wolframite.

In 1785 the D'Elhujar[2] brothers, Juan, José, and Fausto, found that wolframite also contained tungsten and established the relation

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[1] Scheele, K. W., K. svenska Vet.-Akad. Handl., Stockholm, 1781. See following note.

[2] A chemical analysis of wolfram and examination of a new metal which enters into its composition, translated from the Spanish by C. Cullen, to which is prefixed a translation of Mr. Scheele's analysis of the tungsten or heavystone, with Mr. Bergmann's supplemental remarks, London, 1785. (This reference and the one preceding are taken from Roscoe, H. E., and Schorlemmer, C., A treatise on chemistry, vol. 2, p. 1083, 1913.)

of scheelite to wolframite. They also succeeded in obtaining metallic tungsten from the oxide and were probably the first to reduce the metal from its compounds. The chemical symbol for tungsten most generally used is W, the first letter of a partly Latinized form of the name, wolframium, and probably no other chemical symbol, except O for oxygen, is so well known to prospectors and miners, for tungsten ores are sold, not on their metallic content figured as such, but on their content of WO_3, tungsten trioxide. The French more reasonably use Tu as the symbol for tungsten.

The atomic weight—that is, the weight of the smallest quantity of the element capable of combining chemically with another element—is 184, the weight of the oxygen atom being taken as 16.

The hardness of tungsten ranges from 4.5 (razor steel is about 6) to 8, depending on the manner in which it is worked. The hardest is as hard as topaz and will readily scratch quartz, yet it is ductile.

Tungsten is very heavy. Its specific gravity[1] ranges from 19.3 to 21.4, depending on the mode of treatment of the metal. Fine wire has a greater density than the larger worked masses. The great weight of tungsten will be more apparent on comparing it with that of other and better-known metals. Thus, aluminum has a specific gravity of 2.7; iron, 7.8; copper, 8.9; lead, 11.4; and gold, 19.3; or, to put it another way, a piece of tungsten will weigh more than seven times as much as a piece of aluminum of the same size, 2½ times as much as iron, nearly twice as much as lead, and slightly more than gold. Only three known metals have a higher specific gravity than tungsten, namely, platinum, 21.5; iridium, 22.4; and osmium, 22.5.

The melting point of tungsten is higher than that of any other known metal. As determined by Langmuir,[2] it is 3,267° C. (5,913° F.), a temperature so high that it is impossible to attain it in commercial furnaces in which at the same time the tungsten can be kept free from oxygen, carbon, or other impurities.

Tungsten seems to be naturally crystalline and brittle but has a considerable degree of elasticity when worked sufficiently. Like zinc, its structure is changed by working, but unlike zinc it thus develops great tensile strength, and it can be drawn into wire less than four ten-thousandths of an inch in diameter, a sixth to a fourth of the diameter of a hair from the head of an adult. (See fig. 1.) Tungsten wires are said to have a tensile strength fully equal to that of the best steel, but incandescent lamp filaments made from tungsten wire return to a crystalline condition after they have been used a short time unless the tungsten is alloyed with some other substance

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[1] The specific gravity of a substance is its weight as compared with that of an equal bulk of water at the temperature of greatest density (4° C.=39.29 F.).

[2] Langmuir, Irving, quoted by Fink, C. G., in The mineral industry during 1914, p. 759, 1915.

such as thorium. Tungsten, like iron, becomes much more malleable on being heated to a red heat or above. It is not magnetic. Some of the principal physical characteristics of tungsten, aluminum, copper, nickel, and iron have been set forth by Colin G. Fink[1] in the following table:

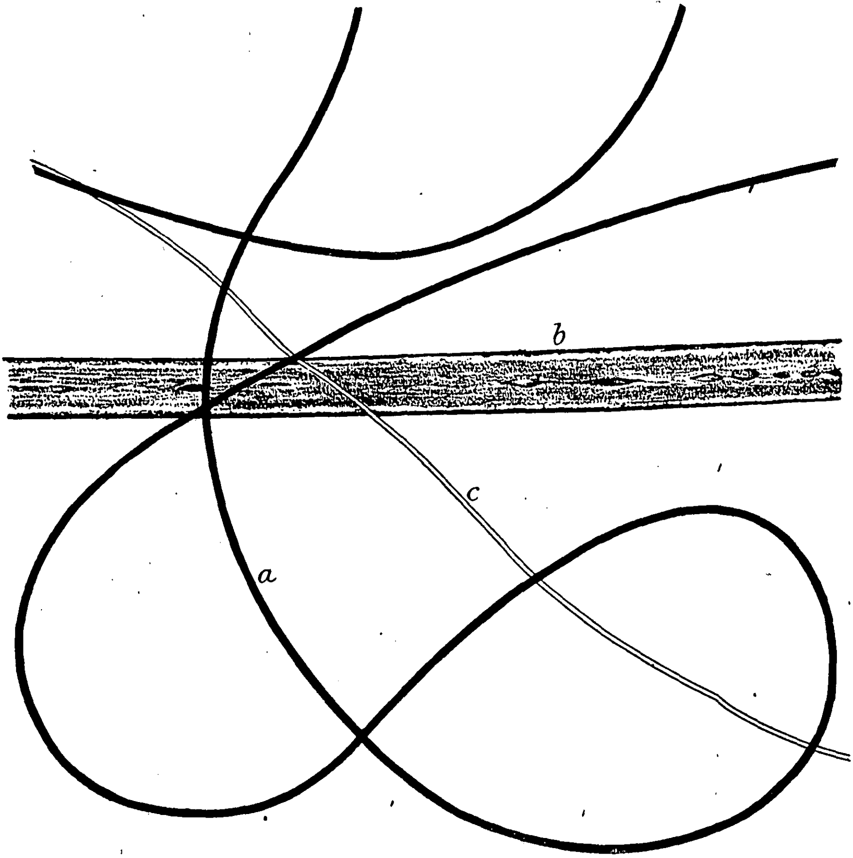

FIGURE 1.—Comparative sizes of (*a*) a tungsten wire, 0.0004 inch (0.01 millimeter) thick; (*b*) a human hair, 0.003 inch (0.075 millimeter) thick; and (*c*) a strand of spider's silk, 0.0002 inch (0.005 millimeter) thick. Greatly magnified. From a photomicrograph.

Physical properties of aluminum, copper, nickel, iron, and tungsten.

	Density at 18° C.	Coefficient of expansion at 18° C.	Tensile strength in pounds per square inch.	Modulus of elasticity in pounds per square inch.	Specific heat in calories, 1 gram −1° C.	Melting point in ° C.	Electric resistance in microhms per cubic centimeter.
Aluminum	2.7	21.8 by 10^{-6}	43,000	10 by 10^{-6}	0.214	660	2.62
Copper	8.87	15.9 by 10^{-6}	66,000	19 by 10^{-6}	.091	1,083	1.589
Nickel	8.75	12.7 by 10^{-6}	96,000	29 by 10^{-6}	.106	1,453	6.93
Iron	7.8	11.2 by 10^{-6}	450,000	30 by 10^{-6}	.105	1,600	8.85
Tungsten	19.6	3.5 by 10^{-6}	610,000	60 by 10^{-6}	.034	3,267	4.42

NOTE.—The figures given for iron in the third and fourth columns are for high tensile strength steel. Of the figures for tungsten those showing the specific heat are given by Honda, those showing the melting point by Langmuir; the others were determined by Fink.

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[1] Fink, C. G., The mineral industry during 1914, p. 759, 1915.

Tungsten is an acid-forming element—no mineral has been found in which it acts as a base; the important known salts of tungsten acid minerals are tungstates combined with other metals. Roscoe and Schorlemmer[1] give a list of 13 tungsten acids that have been artificially prepared, but salts of only one acid are known to occur in nature, those of H_2WO_4, the normal tungstic acid. The ordinary tungsten minerals, hübnerite, ferberite, wolframite, scheelite, stolzite, raspite, and cuprotungstite, are salts of this acid combined with manganese, iron, lime, lead, and copper. Besides these tungstates there have been found only insignificant quantities of tungsten oxides.

The metal is comparatively inert—that is, it is not attacked by many of the elements and compounds which combine chemically with other metals. It remains almost unaffected by air or water at ordinary temperatures, but when heated in air above 300° C. it oxidizes rapidly to the yellow trioxide (WO_3) and burns brilliantly when heated to bright redness.

It is attacked by fluorine at ordinary temperatures, with incandescence, and by chlorine at 250°–300° C. but does not react with nitrogen and phosphorus at a red heat; when heated with carbon, silicon, or boron in the electric furnace it yields crystalline compounds having a metallic luster, which are hard enough to scratch rubies. It is slowly attacked by fuming sulphuric acid and by fused alkalies.[2] It is slowly attacked by water containing carbon dioxide; it is readily oxidized when heated with oxidizing agents, such as lead dioxide or potassium chlorate. Sulphuric, hydrochloric, and hydrofluoric acids act upon it slowly (Fink[3] adds to these nitric acid), but it is readily dissolved by a mixture of nitric and hydrofluoric acids; the powdered metal is rapidly oxidized by aqua regia and dissolves in boiling caustic potash solution with formation of potassium tungstate and evolution of hydrogen, whereas the fused metal is not attacked by aqua regia but dissolves slowly in fused potash (Stavenhagen).[4]

Tungsten forms alloys with many of the common metals, and probably half of the ores used in the United States are reduced to ferrotungsten, an alloy of iron and tungsten, and sold in that form. With cobalt and chromium it forms one of the group of alloys known as stellite, which is used in cutting steel. Alloys with aluminum, copper, manganese, and nickel have been made but have not been extensively used.

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[1] Roscoe, H. E., and Schorlemmer, C., A treatise on chemistry, vol. 2, p. 1087, 1913.

[2] Reader, W. E., Solubility of wrought tungsten and molybdenum: Am. Chem. Soc. Jour., vol 34, pp. 387–388, 1912.

[3] Fink, C. G., Ductile tungsten and molybdenum: Am. Electrochem. Soc. Trans., vol. 17, p. 233, 1910.

[4] Roscoe, H. E., and Schorlemmer, C., op. cit., p. 1085.

Besides the alloys named, various compounds[1] with ammonium, arsenic, barium, boron, bromine, cadmium, carbon, chlorine, chromium, cobalt, fluorine, iodine, lithium, magnesium, mercury, molybdenum, phosphorus, potassium, silicon, silver, sodium, strontium, thorium, tin, vanadium, zinc, and zirconium have been formed artificially, but none, with the exception of one compound with molybdenum, have been found as minerals.

When treated with hydrochloric acid the tungsten compounds found in nature give up, though not always readily, the metals with which they are combined and leave the yellow tungsten trioxide (WO_3), and on adding zinc or tin to the acid solution, thus generating hydrogen, the yellow trioxide gives up a part of its oxygen and becomes the blue oxide (W_2O_5), which on further reduction gives purple and brown compounds containing less oxygen. This forms the commonest and easiest test for tungsten and will be treated elsewhere (pp. 66–67).

On being heated in an atmosphere of hydrogen the yellow oxide is reduced through the lower oxides to the metal, and this process is utilized in producing pure tungsten.

USES.

The greatest use of tungsten, a use that overshadows all others in the quantity of the metal utilized, is as a constituent of tool steels, especially of those known as "high-speed" steels. Of these steels as they are made in this country it forms percentages ranging from 13 to 20. Some European steels are said to contain still higher percentages, but the consensus of opinion among American makers is that the use of more than 20 per cent of tungsten in steel is practically valueless. High-speed tungsten steels have increased the efficiency of both machinists and lathes tremendously, and manufacturers working large groups of men say that from three to five times as much metal can be cut with such a steel as with the old simple carbon steel. In other words, under favorable conditions one man and one lathe can do as much work with high-speed tungsten steels as five men and five lathes could formerly do with simple carbon steels. (See fig. 2.)

Hundreds of millions of dollars' worth of labor is saved annually through the use of high-speed steels, and it would doubtless have been impossible to make the great quantities of turned and cut steel manufactured in this country in 1916 if it had been necessary to revert to the use of carbon steels. A striking statement of the results of this efficiency of high-speed steel was given to the Survey in 1911

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[1] Heinrich Leiser, in his "Wolfram, eine Monographie mit einem Anhang, Die Patentansprüche über Wolfram-Glühkörper," published at Halle an der Saale in 1910, has made an extensive compilation of the chemical compounds of tungsten. See also Roscoe, H. E., and Schorlemmer, C., A treatise on chemistry, vol. 2, pp. 1082–1104, 1913, and Thorpe, Edward, A dictionary of applied chemistry, vol. 5, pp. 566–571, 1912–13.

by Mr. Elwood Haynes, of the Haynes Automobile Co., who said that his company would be compelled to add $200 to the selling price of each automobile it produced if it should have to use carbon-steel tools in place of the high-speed tools which it then employed.

The value of high-speed tungsten steel depends not only on its greater hardness but on its quality of holding its hardness when heated to dull redness. This quality allows the tool to cut other metal at a rate which heats the point to about 535° C. (1,000° F.). Carbon steels fail long before they reach this temperature. This property of holding its temper while heated may be due to carbides of tungsten formed in the steel by the combination of the tungsten and carbon of the alloy, the steel proper being merely a medium that holds the tungsten carbide, which is harder than any known natural substance except diamond.[1]

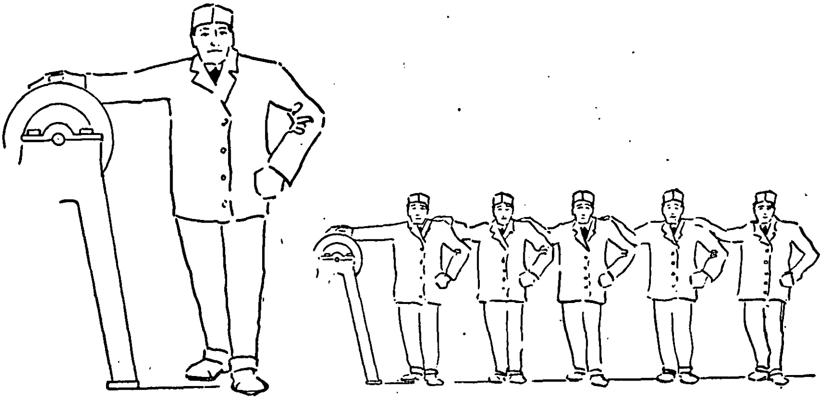

FIGURE 2.—Comparative efficiency in cutting steel of high-speed tungsten-steel tools and carbon-steel tools. Under favorable conditions the tungsten steel cuts five times as fast as the carbon steel.

High-speed tungsten steels are very complicated alloys, and, as would be expected of a compound containing so many elements, there is necessarily much uncertainty as to the value of each element, so that the composition of the steels varies with the maker. The following analyses represent steels marketed in this country:

Analyses of high-speed steels.[a]

	B-1.	G.	K-2.	D-1.		B-1.	G.	K-2.	D-1.
C	0.66	0.72	0.70	0.75	W	17.48	13.30	15.50	19.00
Mn	1.27	.37	Trace.	.28	V	.70	2.50	.88	.75
Si	.14	.18	.18	.36	Co	4.22	....	4.72	....
S	.04	.03	.01	.03	Ni	.17	....	.18	....
P	.05	.02	.02	....	Mo	....	....	.67	....
Cr	4.51	4.50	4.25	4.10					

[a] Hibbard, H. D., Manufacture and uses of alloy steels: U. S. Bur. Mines Bull. 100, p. 57, 1915.

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[1] Voigtländer & Lohmann Metall-Fabrikations Gesellschaft, m. b. H., German patent 286184, Apr. 14, 1914, quoted in Chem. Abstracts, vol. 10, pp. 860–861, 1916. According to the claims of the patentees tungsten carbide has a hardness of 9.8 compared with the diamond as 10.

Of these steels D-1 is said to have given excellent results and G was the winner in a competitive test.

Steels for light or finishing lathe work are made with only 3 or 4 per cent of tungsten and no other metallic constituents. Some saw steels contain 2 per cent of tungsten.

A considerable quantity of tungsten is also used in magnet steels, in proportions ranging from 0.8 to 8 per cent. One large automobile firm uses the smaller percentage in its magnet steels. A large electric firm uses 8 per cent, and this seems to be the percentage more generally used.

Tungsten is introduced into steel either as the powdered metal or as ferrotungsten, an alloy with iron containing 50 to 85 per cent of tungsten. One well-known automobile company, in making a low-tungsten steel, puts a small charge of tungsten in a heavy paper bag and throws it into the molten steel, into which it sinks with little opportunity for oxidation. Others are said to introduce the tungsten in steel tubes. Still others add ferrotungsten crushed to pieces less than an inch in diameter. The users of tungsten powder believe that it is dissolved by the steel more readily than ferrotungsten, but probably the principal reason for using tungsten powder instead of ferrotungsten is to prevent the introduction of carbon, for there is usually less carbon in tungsten than in ferrotungsten. The users of ferrotungsten believe that this objection is not serious and think that they avoid a considerable loss of tungsten through oxidation. The loss by either method, however, is said to be large, one steel maker estimating it at 20 per cent.

Probably the quantities of tungsten used in steel making in the form of tungsten and of ferrotungsten are nearly equal, tungsten constituting somewhat the larger part.

Its high melting point, the toughness and fineness of the wire into which it may be drawn, and its behavior when an electric current is passed through it make tungsten the best material now known for incandescent electric lamp filaments, so that for this use it is rapidly driving other material from the market. Incandescent lamps filled with nitrogen or argon and having tungsten filaments are taking the place of arc lamps for many purposes. Tungsten filament lamps are made in great numbers, but the filaments are so fine that an astonishingly small quantity of ore supplies the industry. Fink[1] states that "the total production of tungsten lamps, both vacuum and gas filled, in the United States in the year 1914 reached 100,000,000 (equivalent to 3 tons of tungsten concentrates)."

Patents have been issued for inclosed tungsten arc lamps, which the inventors claim will still further increase the efficiency of the

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[1] Fink, C. G., The mineral industry during 1914, p. 759, 1915.

tungsten lamp. Some makers have used a filament containing a small percentage of thorium alloyed with tungsten. Dr. W. R. Whitney, chief of the research laboratory of the General Electric Co., in a paper read before the Technology Congress at the Massachusetts Institute of Technology in 1911, said:

> A broader but perhaps less accurate impression of changes recently produced may be gained by considering the economy now possible on the basis of our present incandescent lamp purchases in this country and that which would have resulted if the lamps of only 10 years ago were used in their stead. On the assumption that the present rate of lamp consumption is equivalent to about eighty million 25-watt tungsten lamps per year, and on the basis of 1¼ watts per candlepower as against 3.1 of the earlier lamps and of charging power at 10 cents per kilowatt hour, we get as a result a saving of $240,000,000 per year, or two-thirds million per day. Naturally, this is a saving which is to be distributed among producers, consumers, and others but illustrates very well the possibilities.

Since that time the lamps filled with nitrogen and argon have been placed on the market and other improvements have been added which have made the incandescent electric lamp more efficient and have greatly extended its applicability, so that the annual saving in cost for electricity and the pleasure and comfort due to good lighting have thus been very largely increased. The electric-light plants find added profit in the more general use of electricity that has followed the recognition of better service.

The development of a process for making ductile or malleable tungsten from the brittle, almost infusible, and unworkable powdered tungsten forms one of the romances of American industrial accomplishment. The process of manufacture is well described in the patent (No. 1028933) granted W. D. Coolidge, December 30, 1913.

Concerning the tungsten wire used in tungsten lamps, it is said[1] that

> the filament in a regular 10-watt lamp is about three-fourths mil (0.00075 inch) in diameter, which is probably the finest wire ever produced by straight drawing. At a recent industrial exposition a wire manufacturer exhibited some wire 1½ mils (0.0015 inch) in diameter as a marvel of wire drawing.

The valves of some automobile engines are made of an iron-tungsten alloy and are said to stand the wear much better than iron or steel. Tungsten crucibles have also been made for use in vacuum furnaces or in furnaces filled with inert gases.

FORMS IN WHICH TUNGSTEN IS FOUND.

Tungsten has never been found as a native metal but always in chemical combination with other substances and in a small number of minerals, only nine being surely known. Comparatively few metals

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[1] Howell, J. W., The manufacture of drawn-wire tungsten lamps: General Electric Rev., vol. 14, p. 278, 1914.

occur in a less number of natural combinations, and numerous elements are found in very many more. Thus, arsenic is a component of about 130 minerals, antimony of nearly as many, and iron probably of many more. Another peculiar fact is that tungsten is the principal constituent of nearly all known tungsten-bearing minerals. So far as the writer is aware, it has been found in traces or in minor percentages only in a few of the minerals that occur in pegmatites or in veins closely connected with pegmatites, and these are tin, titanium, tantalum, and columbium minerals. A possible exception is powellite (calcium molybdate, $CaMoO_4$), in which Melville[1] determined a small percentage of tungsten. Examinations of powellite obtained from several other sources indicate that the tungsten may have been present as scheelite (calcium tungstate, $CaWO_4$) in a mechanical mixture with the powellite, like wheat and oats, rather than in a chemical compound like that which it might form with calcium and molybdenum. Most of the elements occur as traces in many minerals, and special search may show that tungsten occurs in many more.[2]

The highest content of tungsten noted in the tantalum-columbium minerals in the analyses quoted in Dana's "System of mineralogy" is 5.51 per cent of WO_3, in a mineral related to samarskite from débris at the foot of Devil's Head Mountain, Douglas County, Colo., analyzed by W. F. Hillebrand. Other analyses of the same mineral gave 2.08 and 2.25 per cent of WO_3. Small quantities of WO_3, mostly less than 1 per cent, are also reported in the other columbium-tantalum minerals—hatchettolite, microlite, fergusonite, sipylite, columbite, yttrotantalite, yttrocrasite, samarskite, and hielmite.

Many of the analyses show a percentage of "WO_3 and SnO_2," and it is perhaps just to regard a number of the determinations with suspicion. On the other hand it is possible that were a number of related minerals examined especially for tungsten it might be found in them.

TUNGSTEN MINERALS.

CHEMICAL AND PHYSICAL FEATURES.

The known minerals of tungsten are as follows:

The wolframites:

- Ferberite, iron tungstate ($FeWO_4$). Ferberite replacing scheelite (see Pl. XVI, *D*, p. 32) has been called reinite. Ferberite may carry 20 per cent hübnerite.
- Hübnerite, manganese tungstate ($MnWO_4$). Hübnerite has been described in some old works as megabasite. Hübnerite may carry 20 per cent ferberite.

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[1] Melville, W. H., Powellite, calcium molybdate, a new mineral species: Am. Jour. Sci., 3d ser., vol. 41, pp. 138–141, 1891.

[2] Since this bulletin was sent to the printer Melville's material has been examined microscopically by E. S. Larsen, and his determination seems to be confirmed, so that powellite may be regarded as a calcium tungsto-molybdate.

The wolframites—Continued.

Wolframite, iron-manganese tungstate [(Fe,Mn)WO_4]. The iron tungstate and manganese tungstate may bear any ratio to each other from 20 per cent iron tungstate (ferberite) and 80 per cent manganese tungstate (hübnerite) to 80 per cent ferberite and 20 per cent hübnerite.

Scheelite, calcium tungstate[1] ($CaWO_4$).

Stolzite, lead tungstate ($PbWO_4$).

Raspite, lead tungstate ($PbWO_4$), differs from stolzite only in crystal form.

Cuprotungstite, hydrous copper tungstate ($CuWO_4.2H_2O$).

Tungstite, hydrous tungsten trioxide ($WO_3.H_2O$), also known as tungsten ocher. Meymacite, although described as carrying more water, is probably the same mineral.

Ferritungstite, hydrous iron-tungsten oxide ($Fe_2O_3.WO_3.6H_2O$).

Tungsten minerals in common have a high specific gravity, show a general lack of good crystal form, and readily respond to tests for tungsten. According to their appearance they may be divided in a general way into two classes—the more or less metallic-looking minerals and those which have a stony appearance. To the first class belong the iron and manganese minerals, ferberite, wolframite, and hübnerite, though some forms of hübnerite can in no sense be referred to as metallic-looking, and to the other belong the remaining minerals, scheelite, stolzite, cuprotungstite, tungstite, and ferritungstite.

All these minerals except possibly ferritungstite show good cleavages in one or more directions—directions in which they split like wood. (See Pl. IX.) In many specimens the cleavage is not very apparent because the individual crystals are so small that no large plane surface can be obtained by splitting the crystal in any direction. This is true of the wolframite from Lead, S. Dak., of much of the ferberite of the Boulder field in Colorado, and of the scheelite and cuprotungstite from many localities. Most specimens, however, if they are gradually turned in a strong light, will have a shiny or satiny appearance in one or more directions as the light is reflected from the cleavage faces.

It may be wondered why the irregularly shaped particles that make up the massive aggregates of tungsten minerals should be called crystals. The reason is that crystal character in a substance is a feature of its internal structure, of which the regular forms sometimes found (see Pls. I, II, III, VI, VII, VIII, and XVI) are merely the outward signs. Ideally every original individual particle of a mineral would take some such symmetric outward form, but the individual crystals in tungsten deposits grow against and into each other and against other minerals, which are, perhaps, forming at the same time, so that their growth is checked in all directions and outward perfection of form is impossible. Only when the crystals grow

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[1] Calcium oxide (CaO) is lime, so that scheelite is also referred to as "lime tungstate."

in an open space or in some yielding, readily replaceable substance is outward crystal form developed.

The most perfect crystals of tungsten minerals found in this country are the ferberite crystals from the Boulder field in Colorado, where they occur in great beauty and much more plentifully than at any other known locality. (See Pls. I, II, and III.) Ferberite crystals are found also on Corral Creek, Blaine County, Idaho, but they are not so perfect as the specimens from Colorado. A few small but good crystals of wolframite have come from eastern San Bernardino County, Cal. (See Pl. VII.) In the lower levels of some of the gold and silver mines at Tonopah, Nev., hübnerite is found in slender reddish translucent crystals and in others of much darker color. A small number of imperfect reddish-brown crystals of hübnerite have been found in the Regan district, White Pine County, Nev. (See Pl. VI, *B*.) A few good crystals of scheelite have come from the Snake Range, White Pine County, Nev., near Osceola; from the Deep Creek Range, Tooele County, Utah (see Pl. XVI, *A* and *B*); from veins 4 miles north of Dragoon, Ariz.; and from Leadville, Colo. (See Pl. XIV, *A*.) Crystals of scheelite, more or less replaced by wolframite, have been found at Trumbull, Conn. The rarity of well-formed crystals of tungsten minerals is shown by the fact that such crystals have been found at only a few American localities, although many deposits are known.

THE WOLFRAMITES.

COMPOSITION.

Wolframite was the first tungsten mineral found, though for a long time its components were unknown. Careful studies showed not only that specimens of wolframite from different deposits differed greatly in chemical composition, but that specimens from the same deposit and even material from different parts of the same crystal were of unlike composition. In general the wolframites first known were a black tungstate of iron and manganese whose composition was expressed by the formula $(Fe,Mn)WO_4$. It is rather peculiar that nearly all the wolframites found in Europe are of the darker iron-rich varieties,[1] though manganese-rich species of brownish-red tints have been reported from Bayevka in the Urals of Russia,[2] from Schlaggenwalde, Bohemia,[3] and from Valcroze,

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[1] Hess, F. L., The mineral relations of ferberite: U. S. Geol. Survey Bull. 583, pp. 24–25, 1914.

[2] Kulibin, N. von, Manganhaltiger Wolfram aus der Grube Bajewsk am Ural: Russ. k. mineral. Gesell. Verh., 2d ser., vol. 3, p. 3, 1868.

[3] Rammelsberg, C. F., Handbuch der Mineralchemie, p. 309, 1860. Fine red-brown needles, with fluorspar and apatite.

France.[1] The nearly pure iron tungstate ($FeWO_4$) was found in Sierra Almagrera, southern Spain, and was described by Liebe[2] in 1863 under the name ferberite.

The nearly pure manganese tungstate (hübnerite, $MnWO_4$) was described by E. Riotte[3] from the Erie and Enterprise veins, Ellsworth, in the Mammoth district, Nye County, Nev., in 1865.

Efforts were made by a number of mineralogists and chemists to show that the wolframites were made up of relatively few chemical members, in which the proportion of molecules of manganese tungstate and iron tungstate were in ratios that could be expressed by comparatively small numbers, such as 1 part of $MnWO_4$ to 2 parts of $FeWO_4$, 2 $MnWO_4$ to 3 $FeWO_4$, and so on, but the writer[4] has shown that the series is composed of an infinite number of members and that its division into separate minerals must be made by fixing arbitrary limits. The following definitions were therefore proposed:

Ferberite should be considered an iron tungstate ($FeWO_4$) contaminated by not more than 20 per cent $MnWO_4$, a proportion equivalent to 4.69 per cent MnO, or 3.63 per cent Mn, in the pure tungsten mineral.

Hübnerite should be considered a manganese tungstate ($MnWO_4$) contaminated by not more than 20 per cent $FeWO_4$, a proportion equivalent to 4.74 per cent FeO, or 3.69 per cent Fe.

Wolframite should cover the ground between the limits above indicated. That is, wolframite should be considered a mixture of iron and manganese tungstates containing not less than 20 per cent nor more than 80 per cent of either.

Except the light-colored hübnerites, most of these mixtures can not be distinguished by the eye or by simple tests, and in the absence of analyses it is therefore convenient to refer to the dark minerals of the series as wolframites.

FERBERITE.

Physical features.—Ferberite is a black mineral and to the unaided eye is opaque, but under the microscope very thin edges, probably not more than 0.0001 or 0.0002 inch thick, show a red color by light passed through them. Ferberite may be so coated with hydrous iron oxide or so intergrown with it that both the outside and the parts exposed by fracture or cleavage may be brown. Some specimens are iridescent owing to thin films of the oxide. Much of the ferberite from the Rogers tract, near Nederland, Boulder County, Colo., and from veins north of Rollinsville, on the north edge of

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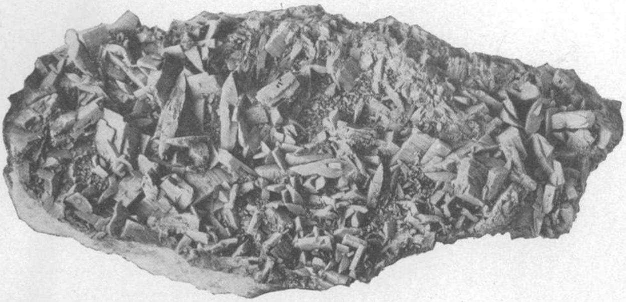
[1] Lacroix, A., Minéralogie de la France et ses colonies, vol. 4, pt. 1, p. 293, 1910.

[2] Liebe, K. L. T., Ein neuer Wolframit; ein Beitrag zur Mineral-Chemie: Neues Jahrb., 1863, pp. 641–653.

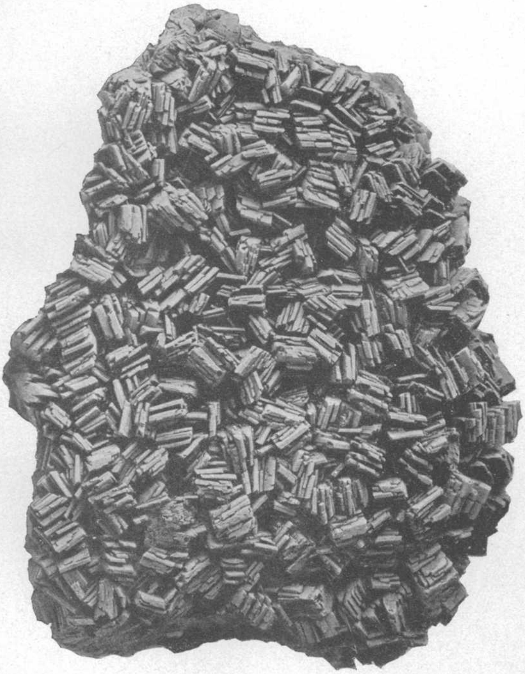
[3] Dana, J. D. and E. S., System of mineralogy, 6th ed., pp. 982–985, 1892.

[4] Hess, F. L., The mineral relations of ferberite: U. S. Geol. Survey Bull. 583, pp. 36–38, 1914.



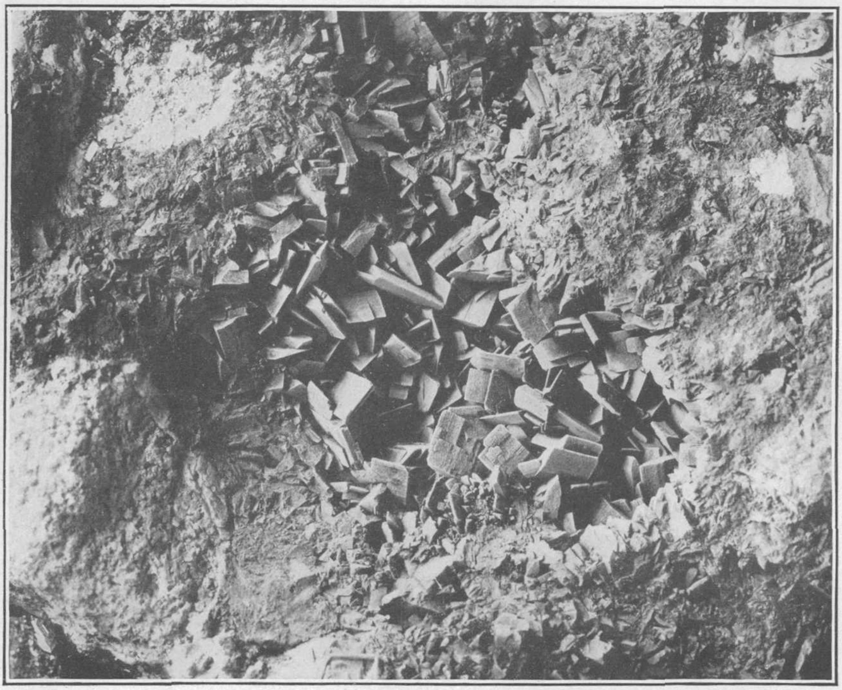
A. WEDGE-SHAPED FERBERITE CRYSTALS FROM "CROW PATENT," NEDERLAND, COLO.

Natural size.



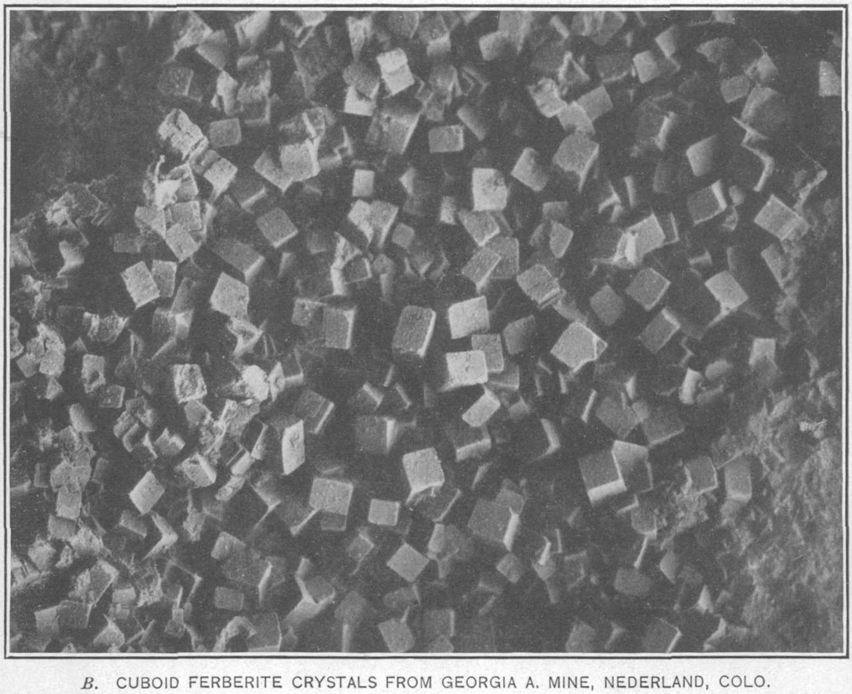
B. CRYSTALLIZED FERBERITE WITH ELONGATED RHOMBIC CRYSTAL FACES, FROM NUGGET MINE, GILPIN COUNTY, COLO.

Natural size.



A. WEDGE-SHAPED FERBERITE CRYSTALS FROM HOOSIER MINE, NEDERLAND, COLO.

Enlarged 2 diameters.



B. CUBOID FERBERITE CRYSTALS FROM GEORGIA A. MINE, NEDERLAND, COLO.

Enlarged 10 diameters.

Gilpin County, Colo., are so much stained with iron that even freshly broken pieces are light brown. The color is due to hydrous iron oxide, probably limonite,[1] which forms no part of the mineral. Plate VI, *A*, shows a polished section of a crystal of ferberite which contains cavities filled with limonite, disguising its color.

The specific gravity of ferberite is 7.499, or practically 7.5.

Ferberite shows a greater tendency to assume outward crystal form than other tungsten minerals, and some of its typical forms are shown in Plates I, II, and III. All the specimens shown are from the Boulder field, in Colorado, and are so typical that they can be at once told from minerals from any other locality, especially if the gangue is considered. Much the same tendency toward outward crystal form is shown by specimens of ferberite (?) found on Corral Creek, Blaine County, Idaho, but the crystal form of the specimens seen is not so perfect. Specimens from Elizabethtown, N. Mex., are very much like those from Corral Creek and are said to carry 2.16 per cent Mn. Ferberite found at Cave Creek, Ariz., shows a tendency toward coarser granular form and less regularity of outward shape.

The hardness[2] of ferberite is about 5, so that it is easily scratched by a pocketknife. Ferberite has one excellent cleavage, directly across the longer axis of the crystals as they are usually formed, and some specimens show another cleavage approximately at right angles, but it is not so perfect. Breaks other than with the cleavage show a rough "hackly" fracture.

If ferberite is scratched with a knife or is drawn across a streak plate made of unglazed china, the powder formed is dark brown to nearly black but never quite black. The powder formed by crushing the mineral is of the same color, for a streak is merely the powder formed by scratching or rubbing. The color of the streak may be disguised by iron oxide or other minerals. Thus the ferberite from the Rogers tract and some other places near Nederland, Colo., gives a light-brown streak on account of the limonite in and on it. At depths below which oxidation has penetrated limonite will no longer be present, and the darker iron mineral, hematite, from which it may have been formed, or possibly siderite (iron carbonate), will take its place, and probably neither will so much alter the appearance of the ferberite.

Other minerals may partly cover and disguise ferberite. Thus in many places the crystals are covered by chalcedony and clay, but on breaking the material across the mineral is exposed.

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[1] No analysis of the oxide has been made, but for convenience it will be called limonite, as it is at any rate closely related to limonite.

[2] The hardness of minerals is measured by what is known as the Mohs scale and is the resistance offered by a smooth surface to abrasion. The scale is: 1, Talc; 2, gypsum; 3, calcite; 4, fluorite; 5, apatite; 6, feldspar; 7, quartz; 8, topaz; 9, sapphire; 10, diamond.

Minerals of similar appearance.—Specular hematite (an iron oxide, Fe_2O_3) occurs in veins in the Boulder field and near Yucca, Ariz., as aggregates of very small flakes, which can not be readily distinguished by the unpracticed eye from ferberite or wolframite. Many specular hematites are blue-black, but although the mineral may appear as black as ferberite it gives a red-brown streak, which immediately identifies it, and it will, of course, give no test for tungsten.

Magnetite (another iron oxide, Fe_3O_4) may form veins and masses much like ferberite. It breaks with a smoother, more lustrous surface than the wolframites, except on cleavage surfaces. There is also a hint of purple on many fresh magnetite surfaces. The streak is black, but the streak of even the purest ferberites is somewhat brownish. The minerals may readily be separated by a magnet, for magnetite is strongly attracted by a horseshoe magnet, even at a distance of half an inch or more. Some specimens of ferberite when finely powdered are feebly attracted by a horseshoe magnet, but not sufficiently to be mistaken for magnetite.

Ilmenite (an iron titanate, $FeTiO_3$) may also be mistaken for ferberite, but it has no good cleavage and, like magnetite, it has, when newly broken, a rather lustrous surface which shows a tint of deep purple. It is not attracted by a magnet. Most ilmenite found in pegmatites occurs in nearly black, solid platy crystals set at angles of 30 to 60° with each other. Specimens showing such structure have at different times been sent to the Survey from the northern part of the Colville Indian Reservation, Wash., by persons who thought they were wolframite or some other valuable mineral. As a rule, the crystal surfaces of ilmenite have a steel-blue tint. The color, the luster of the broken face, and the lack of cleavage are usually sufficient to distinguish it from ferberite.

Summary of characteristics.—The notable characteristics of ferberite are its black color (in some specimens disguised by iron oxide); dark-brown or nearly black streak; excellent cleavage, showing lustrous black planes; hackly fracture; high specific gravity; and crystal form,[1] the character of which is shown in Plates I–III.

Distribution.—Ferberite has been found in the United States principally in the Boulder field, in Colorado. The Boulder field centers around Nederland, Boulder County, from which it extends about 10 miles northeast, and scattered deposits have been reported from points through a distance 10 or 12 miles south. The belt is 4 or 5 miles wide. The Boulder district is by far the most important ferberite-producing district of the world. The locality from which the original mineral came—the Sierra Almagrera, Spain—is not

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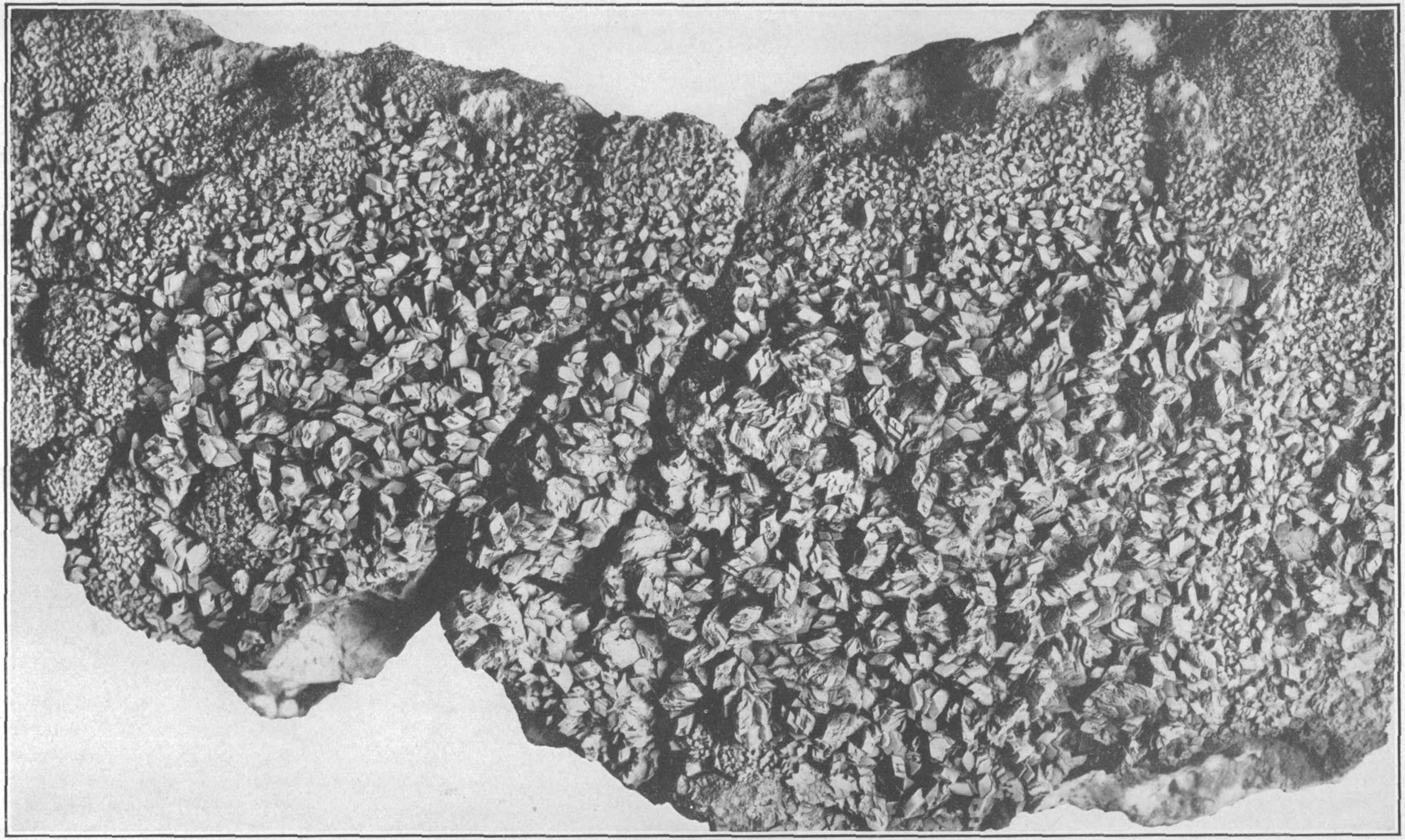
[1] The crystal forms of ferberite have been technically and rather elaborately described by W. T. Schaller and the writer. See Colorado ferberite and the wolframite series: U. S. Geol. Survey Bull. 583, 1914.



A VERY FINE SPECIMEN OF FERBERITE WITH RHOMBIC CRYSTAL FACES, FROM NUGGET MINE, GILPIN COUNTY, COLO.

A. HÜBNERITE FROM BIRDIE MINE, BUTTE, MONT.

B. HÜBNERITE FROM GLADSTONE, NEAR SILVERTON, COLO.

A. WOLFRAMITE WITH CINNABAR FROM JACK CLAIM, CLARK MOUNTAINS, NEAR NIPTON. CAL.

B. BLACK HÜBNERITE FROM WHITE OAKS, N. MEX.

known to have produced the mineral in commercial quantity; and although ferberite has been found in British Columbia, France, Italy, India, New South Wales, Siberia, and Greenland, very little is known to have been put on the market from these countries. It is possible, however, that more has been produced than is apparent, for published analyses of ore are few, and many ores may have been shipped under the better-known name of wolframite without real knowledge of their composition. In this country a little ferberite has been mined at Cave Creek, Ariz., and at a point 4 miles east of Hill City, S. Dak. The wolframite mined at Corral, Idaho, is probably ferberite, and specimens of ferberite have been sent to the Geological Survey from Elizabethtown, Colfax County, N. Mex. The ferberite mined in Colorado furnishes apparently between one-tenth and one-eighth of the world's tungsten production.

Importance as an ore mineral.—Ferberite is probably the most desirable of the tungsten minerals as an ore mineral for the manufacture of ferrotungsten, for there is little else in it than oxygen and the iron and tungsten desired in the product. For the manufacture of tungsten powder through roasting with soda and treatment with acids, it would seem to have no advantage over other tungsten minerals, and it is possibly somewhat more resistant to treatment.

A premium of 10 per cent over the price paid for other tungsten ores was advertised early in 1916 by certain buyers for ferberite ores in Colorado, but other buyers would not pay a premium for it.

HÜBNERITE.

Physical features.—Hübnerite is the pure or nearly pure manganese tungstate, and it has been proposed to limit the term to minerals that contain not less than 80 per cent $MnWO_4$, which, of course, can not then contain more than 20 per cent $FeWO_4$.

Hübnerite is typically reddish brown. (See Pl. IV, *B*.) Some specimens are almost garnet-colored, but a hübnerite from the Birdie mine, Butte, Mont., is in part light yellowish brown and in part caramel-brown, and a hübnerite from White Oaks, N. Mex., is to the eye opaque black. (See Pls. IV, *A*, and V, *B*.) Under the microscope, however, thin sections have light or dark yellowish-brown or dark-green colors by light passing through them, although parts of the same crystals may be opaque as seen in the section, which is 0.03 to 0.05 millimeter (0.0012 to 0.002 inch) in thickness. The mineral from White Oaks contains only a fraction of 1 per cent of iron (0.55 per cent FeO), and the reason for its dark color is unknown. Lighter-colored hübnerites may contain much more iron, like that from Dragoon, Ariz., an analysis of which shows 2.66 per cent FeO.[1]

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[1] Guild, F. N., The mineralogy of Arizona, p. 92, 1910.

Hübnerite shows a constant tendency to form thin, flat, radial, irregular crystals, and very few, if any, good crystals have been found. However, in all these tungsten minerals, as in many other minerals, should good crystals be formed they are likely to be embedded in a later growth of quartz and thus lost. Some crystals from Tungstonia, in the Red Hills, Regan district, White Pine County, Nev., courteously supplied by Mr. C. G. Simms, are shown in Plate VI, *B*. In some of the lower levels of the silver-gold mines at Tonopah, Nev., there are numerous thin platy crystals of red hübnerite which in form remind one of a small fragment split from a wheat straw. Some of them are nearly black and may be wolframite, but as black crystals are found in the hübnerite from White Oaks, N. Mex., and as some of the crystals from Tonopah are red, the material is possibly all hübnerite. Hübnerite is not known to occur in masses so fine grained as ferberite.

The specific gravity of hübnerite, about 7.2 to 7.3, is somewhat less than that of ferberite. Its hardness is nearly the same as that of ferberite, about 5—that is, it is easily scratched by the blade of a pocketknife.

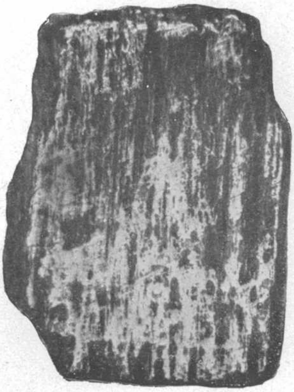
The streak of the reddish varieties is light brownish red, the streak of the material from Butte is light greenish yellow, and that from White Oaks, N. Mex., is somewhat greenish yellow. The varieties that contain iron and that thus approach wolframite in composition have darker streaks.

Hübnerite may be difficult to identify on account of coatings of manganese dioxide, which color it black, or of limonite, the brown iron oxide.

Minerals of similar appearance.—Sphalerite (zinc blende) and garnet have been mistaken for hübnerite, and some specimens have nearly the same reddish color. Sphalerite has excellent cleavages in several directions; hübnerite only one. Crystals of sphalerite tend toward equidimensional forms, hübnerite toward elongated radial forms. The specific gravity of sphalerite is only about 4, a little more than half that of hübnerite.

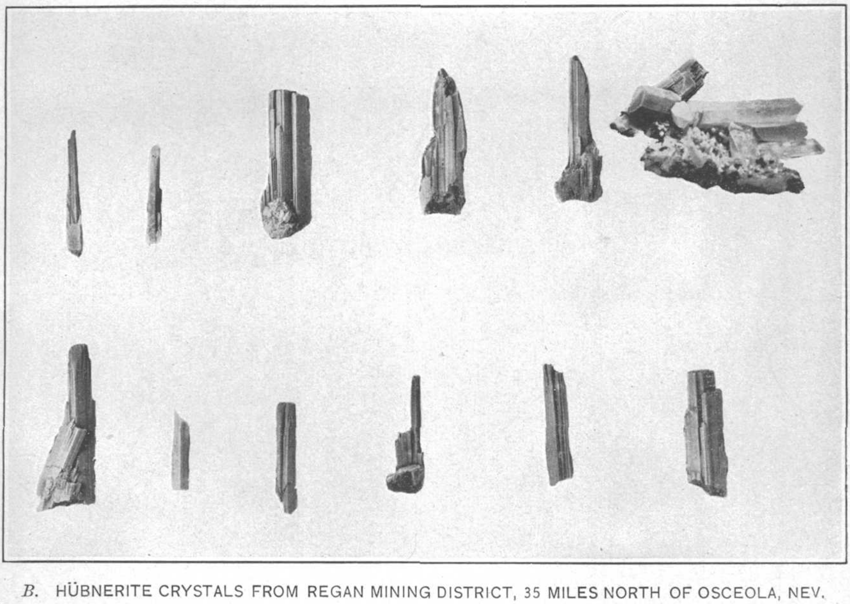
Garnet has no cleavage, broken faces of it have a greasy luster, and its crystals are chunky. Rutile may have a color very near that of some hübnerite, but it has no cleavage, or a very poor one, and can not be scratched with a knife.

Distribution.—Hübnerite is mined in this country at Tungsten, in the Snake Range, 12 miles south of Osceola, Nev.; at Tungstonia, 35 miles north of Osceola, Nev.; near Columbus, Mina, Spanish Springs, and Round Mountain, Nev.; on Patterson Creek, in the Blue Wing district, Idaho; Silverton, Colo.; White Oaks, N. Mex.; and Dragoon, Ariz. It is known also at some other places in the United States. The tungsten mineral mined at Arivaca, Ariz., greatly resembles



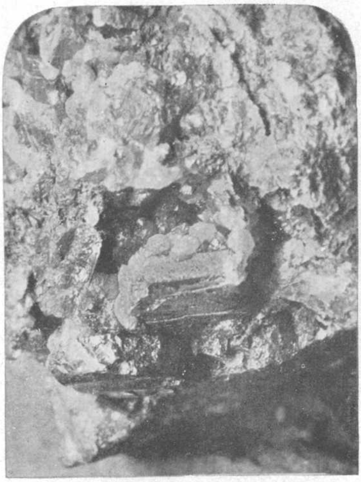
A. CUT AND POLISHED CRYSTAL OF BROWN FERBERITE FROM WINNEBAGO CLAIM, NEAR ROLLINSVILLE, COLO.

Enlarged 78 diameters. Shows spongy structure of the ferberite, the cavities of which (dark portions of the photograph), though invisible to the unaided eye, are filled with hydrous iron oxide, which colors the mineral.



B. HÜBNERITE CRYSTALS FROM REGAN MINING DISTRICT, 35 MILES NORTH OF OSCEOLA, NEV.

Natural size. In the figure at the right in the upper row the crystals at the left are hübnerite, the remainder quartz.



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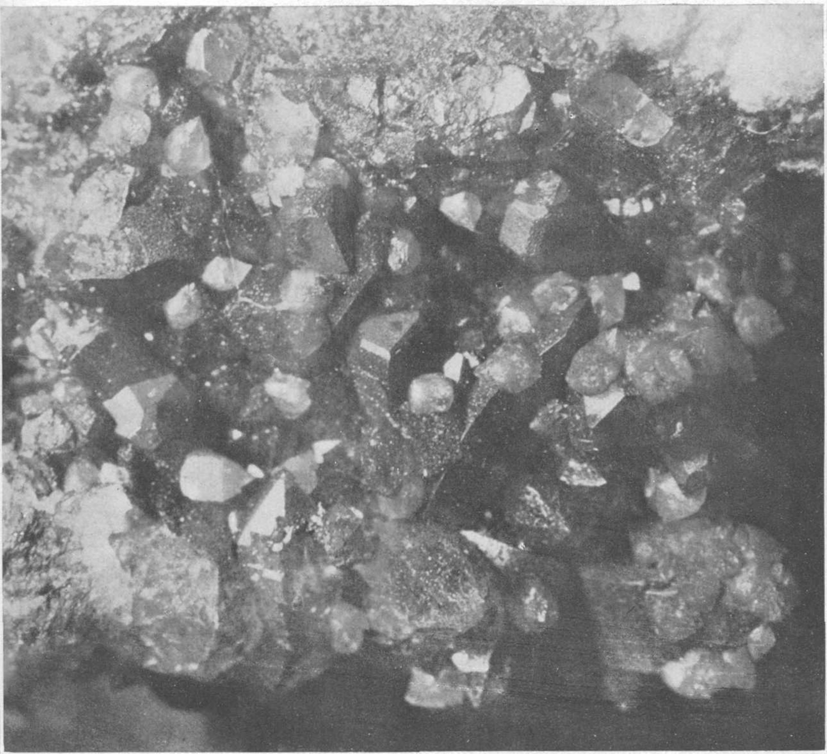

B

WOLFRAMITE CRYSTALS FROM JACK CLAIM, CLARK MOUNTAINS, NEAR NIPTON, CAL.

A. Wolframite crystal (in center) with rounded octahedra of scheelite perched upon it. Enlarged 2 diameters. Compare with individual ferberite crystals shown in Plate I, *B.*

B. Wolframite crystals, whose faces tend toward a square form, with rounded octahedra of scheelite. Enlarged 10 diameters. Compare with crystals shown in Plate II, *B.*

hübnerite, but A. L. Pellegrin[1] claims it contains enough iron to be considered a wolframite. It has not been analyzed by the Survey. At one time a few tons of the yellowish-brown hübnerite already referred to was taken from the Birdie mine, near Butte, Mont.

Abroad, hübnerite is mined in Peru and is shipped to this country. It is also mined in New South Wales and Queensland, and a little has been found in Canada, Germany, Siberia, and other countries.

Importance as an ore mineral.—Hübnerite is produced in small quantity and is therefore the least important of the four principal minerals, which, named in descending order of the quantity produced, are wolframite, ferberite, scheelite, and hübnerite.

Those who smelt ferrotungsten do not generally buy hübnerite so readily as ferberite or wolframite, but this discrimination seems to be due in part rather to a disinclination to change fluxes than to more real disadvantages. Some consumers make no distinction between hübnerite and the other minerals, and those who are seeking a market for ores should keep this fact in mind. If one buyer does not accept the mineral at the market price for other tungsten minerals another buyer should be sought.

WOLFRAMITE.

Physical features.—Wolframite is in general a black mineral, which rarely shows good outward crystal form. Characteristic crystals are shown in Plate VIII. These crystals are from Zinnwald, Bohemia. Very much smaller but more perfect crystals from the Clark Mountains, in eastern San Bernardino County, Cal., are shown in Plate VII. Large imperfectly terminated crystals embedded in quartz and chalcopyrite and other sulphides are shown in Plate IX. This specimen, which is from Cornwall, England, shows excellently the cleavage that is characteristic of all the wolframites. Most wolframite occurs in irregular aggregates of individuals showing no outward crystal form, and these may range in size from microscopic dimensions to 2 inches or more across. Thus in the wolframite from Lead, S. Dak. (Pl. X, *B*), the individual crystals are indistinguishable.

The specific gravity of wolframite ranges between that of hübnerite and that of ferberite, from 7.2 to 7.5.

The hardness of wolframite is also nearly the same as that of the two end members of the series, about 5.

The streak ranges from reddish brown in the minerals which are most like hübnerite in composition to dark brown in those that are near ferberite. The cleavage is as prominent in one plane as that of ferberite and hübnerite. (See Pl. IX.)

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[1] Personal communication.

As already stated, the composition of the wolframites grades by infinitesimal degrees from ferberite to hübnerite, and any division between the members must be arbitrary. Between 80 per cent of one and 20 per cent of the other there may be all possible combinations of the two molecules.

Wolframite may also be used as a family name for all the dark tungsten minerals whose composition is not definitely known except that they contain iron, manganese, and tungsten.

The same coatings of iron oxide and manganese oxide which may disguise ferberite and hübnerite may make it difficult to distinguish wolframite.

Minerals of similar appearance.—The principal minerals that may be mistaken for wolframite are specular hematite, manganese dioxide (psilomelane), magnetite, columbite, hornblende, and dark pyroxene.

Specular hematite gives a streak which is too red for wolframite, and when the flakes are large enough to be mistaken for the cleavage planes of wolframite, they are almost invariably curved and bluish black. Wolframite cleavage planes are not known to be curved and are never bluish.

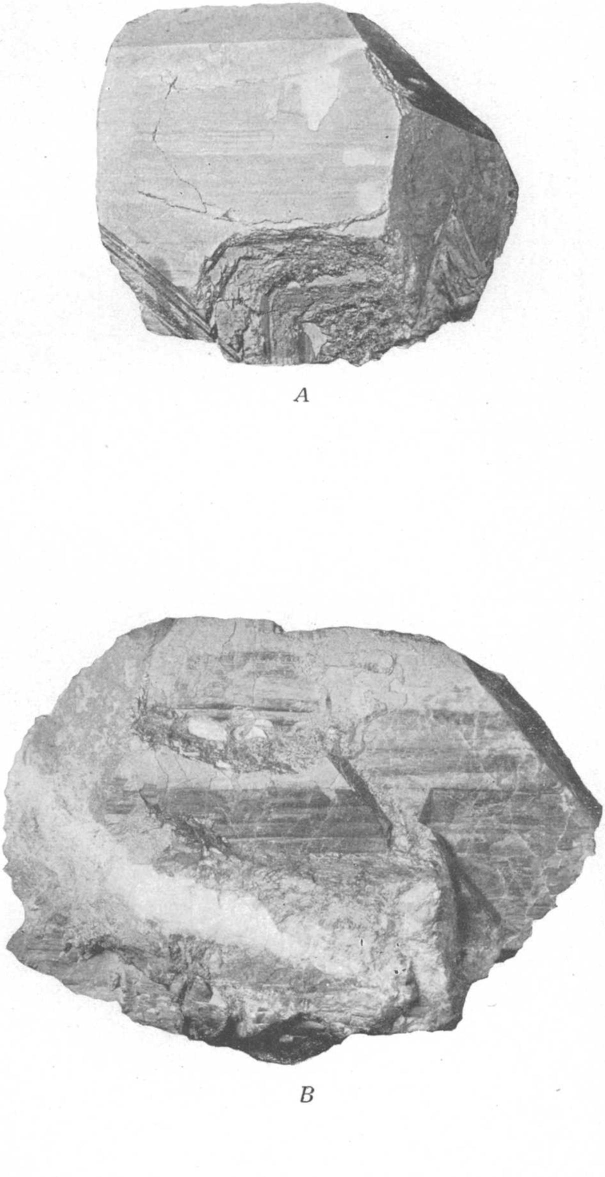
Manganese dioxide is iron-black to steel-gray, colors which are unlike the black of wolframite, and is invariably comparatively fine grained. The specific gravity (3.7 to 4.7) is also too low for wolframite.

Magnetite is readily distinguished by its lustrous fractured faces, its black streak, and especially by its attraction for a magnet. The prospector may well have the blades of his pocket knife magnetized for such determinations.

Columbite shows no cleavage, a test on which great dependence may be placed.

Hornblende and pyroxene are in some places found in dark stout crystals, an inch or more long, embedded in light-colored groundmasses, and may prove very puzzling. Both minerals are much too low in specific gravity (3 to 3.6) to be mistaken for wolframite, and they give light-colored stony powders or streaks.

Distribution.—Wolframite is mined in this country near Yucca, Columbia (Tip Top), Nogales, Hillside (Eureka district), and Benson (Whetstone Mountains), Ariz., though some of the Arizona mineral may be ferberite; in the Clark Mountains, Cal.; Penasco, N. Mex.; Hill City, S. Dak.; near Cathedral Peak, Okanogan County, and Cedar Canyon, Stevens County, Wash. Abroad it is mined in Bolivia, Argentina, Australia (Northern Territory, Queensland, New South Wales, Victoria), Tasmania, Burma, Federated Malay States, Siam, Japan, Chosen (Korea), Northern Shan States, England (Cornwall, Devonshire, and Cumberland), France, Germany, Portugal, Spain, and Austria (Bohemia).



A

B

WOLFRAMITE CRYSTALS FROM ZINNWALD, BOHEMIA.

Natural size. Compare with ferberite crystals shown in Plate II, *A*.

LARGE, IMPERFECT CRYSTALS OF WOLFRAMITE EMBEDDED IN QUARTZ AND CHALCOPYRITE FROM CORNWALL, ENGLAND.

Natural size.

The United States is unique in that it mines more of both ferberite and scheelite than of wolframite, and it seems probable that in 1916 it may also have produced more hübnerite than wolframite, but in most countries more wolframite is mined than all other tungsten minerals together.

Importance as an ore mineral.—Wolframite is apparently the favorite tungsten mineral, especially among foreign users, as has been explained, probably partly from habit and partly because it requires less fluxing than hübnerite or scheelite. But undoubtedly the preference is in part due to mere habit, because it was the first tungsten mineral used, and it seems likely that hübnerites from other countries are sold without question under the name wolframite. The demand for it in this country is probably second to that for ferberite.

SCHEELITE.

Physical features.—In appearance scheelite is totally different from minerals of the wolframite series. Most of them give at once the impression that they are metallic minerals, but scheelite is as stony looking as quartz, feldspar, or marble. It occurs chiefly in granular irregular masses, like the feldspars or like calcite in coarse marble. Crystals are found here and there, but they are scarce. The large scheelite deposits at Atolia, Cal., are not known to have yielded even a single imperfect crystal. As has been noted, a few crystals have been found at some places in the United States. (See Pl. XVI.) Scheelite has a characteristic, very noticeable greasy luster on freshly broken faces.

Scheelite is, as a rule, nearly opaque as seen in masses, and even in thin sections prepared for microscopic work (0.03 to 0.05 millimeter, 0.0012 to 0.002 inch thick) it is generally cloudy. All American crystals seen by the writer have been deep cloudy to translucent, but a transparent crystal weighing about 2 pounds has been reported from the east side of the Snake Range, Nev. Some crystals from other countries, especially from Japan, are beautifully transparent.

In color scheelite is nearly pure white (like the mineral from Atolia, Cal., and part of that from the Snake Range, Nev., and the deposit north of Lucin, Utah), creamy, straw-yellow, bright yellow, reddish caramel-colored, gray, or greenish gray. Generally the scheelite which appears yellow receives its color from tungstite formed along cracks. A small specimen from the Clark Mountains, San Bernardino County, Cal., is, however, a clear brilliant yellow. Plates XI to XV show a number of specimens of scheelite as nearly in their natural colors as it has been practicable to reproduce them. The nearly white scheelite from Atolia is shown in Plate X, *A*.

The specific gravity of scheelite is about 6, varying about one-tenth of a unit either way. It is a little less than that of the minerals of the wolframite group but more than twice that of quartz (2.65), calcite (2.71), or granite (about 2.80). Its hardness is 4.5 to 5, so that it is easily scratched by a knife. Scheelite cleaves fairly well in four directions and less well in four other directions, so that one or more of these cleavages may be seen in practically all broken specimens, if they are turned in the light until it is reflected by the cleavage planes.

When pure, scheelite contains 80.6 per cent tungsten trioxide (WO_3) and 19.4 per cent lime (CaO).

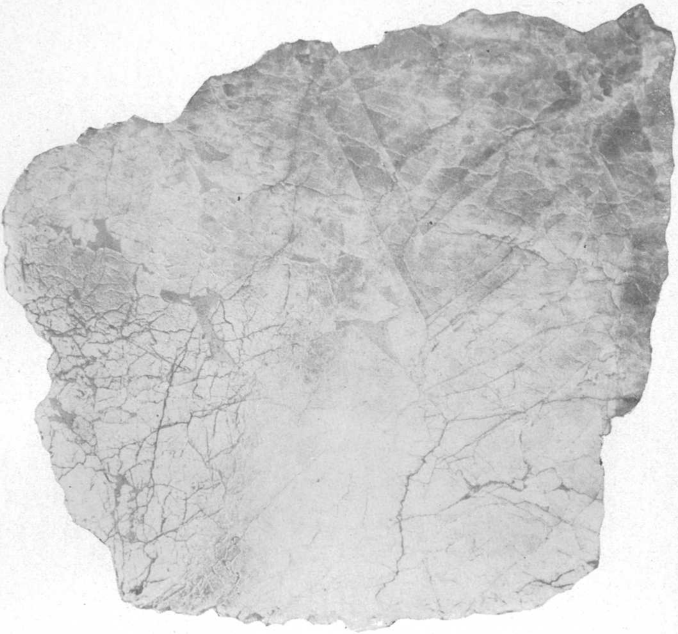
Scheelite is in some places found with the wolframite minerals. Plate XIII, *A*, shows part of a vein which had bristling crystals of wolframite along its walls, over which some quartz was deposited, and the middle of the vein was then filled with gray scheelite. Plate XI, *B*, shows hübnerite from Dragoon, Ariz., which was broken after crystallization and in the cracks of which scheelite was deposited. Scheelite is commonly found in small quantity in veins of ferberite, wolframite, and hübnerite, but these minerals are rare in scheelite veins, though they are not unknown. The great bulk of scheelite comes from veins that carry no other tungsten mineral.

Like the other tungsten minerals, scheelite may be so much discolored by iron oxide that its identification is difficult, especially if it is broken or crushed so that fresh surfaces can not readily be obtained.

Minerals of similar appearance.—Owing to its variation in color and size of grain scheelite may not be recognized by casual examination because of its resemblance to epidote, garnet, barite, apatite, and calcite, minerals that have frequently been mistaken for scheelite.

Epidote and garnet are much harder than scheelite; epidote can barely be scratched with a knife and garnet not at all. Garnet has no cleavage. Both have a greasy luster, and their specific gravities, 3 to 3.6 and 3.5 to 3.6, are much lower than that of scheelite. All three minerals are of many tints, but the color of scheelite as a rule is unlike that of the other minerals.

Barite has cleavages in three directions, so perfect that if it is coarsely crystallized it may be cleft into blocks that show rhombic faces and that may almost immediately be distinguished from scheelite. Barite is not so lustrous as scheelite, and it has a lower specific gravity (4.3 to 4.6). It is much softer than scheelite (its hardness is 3), so that one means of identification is to scrape a smooth surface of it with the back of a knife blade. A powder is in this way much more easily made from barite than from scheelite. Barite commonly crystallizes in thin plates, a habit totally unlike that of scheelite. Some barite, however, is fine grained and shows no cleavage, and its surface is so rough that the scraping test is inconclusive. Under



A

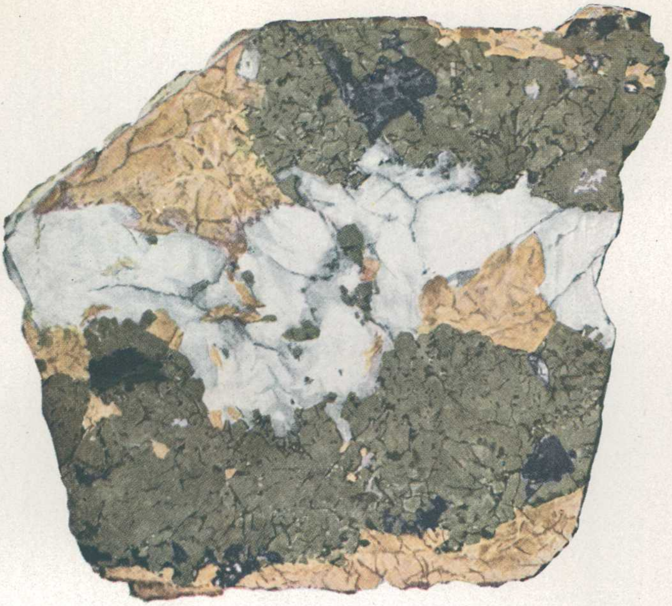
B

A. SCHEELITE FROM PAPOOSE MINE, ATOLIA, CAL.

Natural size. The straight lines show the edges of quartz plates and masses once deposited along cleavage planes in calcite, which has since been replaced by the scheelite.

B. WOLFRAMITE FROM WASP NO. 2 MINE, 2 MILES SOUTH OF LEAD, S. DAK.

Natural size. The wolframite has replaced Cambrian dolomite, and the white lines are the edges of shells that were not replaced.



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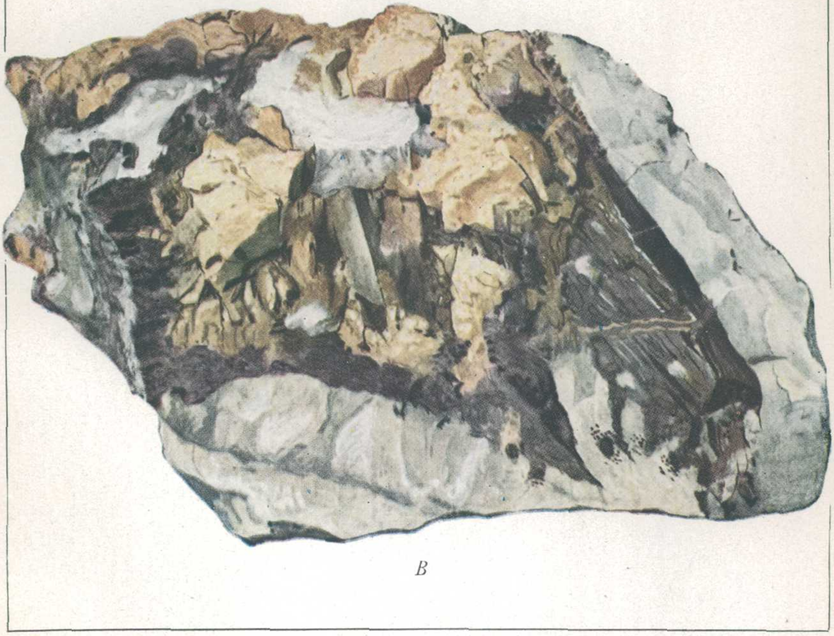

B

A. SCHEELITE (BUFF) WITH QUARTZ (WHITE), PYRITE (GREENISH), AND GALENA (NEARLY BLACK) FROM GOLDEN CHEST MINE, MURRAY, IDAHO.

B. SCHEELITE (CREAMY) WITH HÜBNERITE AND QUARTZ FROM VEIN 4 MILES NORTH OF DRAGOON, ARIZ.

A

B

A. SCHEELITE FROM CLIFTON MINING DISTRICT, DEEP CREEK MOUNTAINS, TOOELE COUNTY, UTAH.

B. SCHEELITE AND GRAY QUARTZ FROM KIMBERLY-MONTANA MINE, JARDINE, MONT.

A

B

A. SCHEELITE (GRAY) WHICH HAS FORMED OVER A COMB OF WOLFRAMITE (BLACK) AND QUARTZ.
From Jack claim, Clark Mountains, near Nipton, Cal.

B. SCHEELITE (LIGHT YELLOWISH AND GREENISH) WITH QUARTZ AND CHLORITE (NEARLY BLACK).
From a contact-metamorphic deposit on Coming Power claim, 15 miles north of Lucin, Utah.

A

B

A. SCHEELITE (IN CENTER) WITH PYRITE AND QUARTZ FROM BREECE HILL, LEADVILLE, COLO.

B. SCHEELITE AND QUARTZ FROM SCHEELITE, 6 MILES SOUTH OF OSCEOLA, WHITE PINE COUNTY, NEV.

A. STOLZITE FROM BROKEN HILL, NEW SOUTH WALES.
Courtesy of C. A. Süssmilch.

B. TUNGSTITE FROM KOOTENAY BELLE MINE, BRITISH COLUMBIA.
Courtesy of Dr. T. L. Walker, Geological Survey of Canada.

C. SCHEELITE STAINED WITH TUNGSTITE.
D. SCHEELITE STAINED BY IRON.
C and *D* from Zacatecas, Mexico. Exact locality unknown.

E. SCHEELITE WITH QUARTZ IN CHLORITE SCHIST FROM MOOSE RIVER, NOVA SCOTIA.

Later information shows that *C* and *D* are from Yaqui River, Sonora, Mexico.

such circumstances the test for tungsten (see p. 66) should be made and is conclusive.

Apatite in white masses an inch or more thick is found with scheelite in the Deep Creek Mountains, Utah, and greatly resembles white scheelite. Its specific gravity (about 3.2) is much less than that of scheelite, but its hardness and luster are about the same. A test for tungsten may be necessary to differentiate the two minerals.

Calcite has excellent cleavages in three directions and less perfect cleavages (called partings by crystallographers) in three other directions, so that, like barite, it may be cleft into regular four-sided blocks having rhombic faces, and the cleavage may be seen even in small fragments. Its specific gravity (2.7) is less than half that of scheelite. Its hardness (3) is also much less. An easy way of distinguishing calcite is by its effervescence with acids. If a little acid is put on calcite, especially powdered calcite, carbon dioxide gas is formed and bubbles through the liquid.

Summary of characteristics.—The most notable characteristics of scheelite are its high specific gravity, greasy luster, brilliant cleavage planes, and the ease with which it can be scratched with a knife. These, of course, are the characteristics of fresh, clean surfaces. Most of them may be hidden by dirt and abrasion.

Distribution.—Scheelite has been found in commercially valuable quantities at the places indicated below: In Alaska, 15 miles north of Fairbanks and in placers near Nome. In Arizona, at Oracle, Pinal County, 4 miles north of Dragoon, and near Duquesne. In California, at Atolia (Pl. X, *A*) and Randsburg, San Bernardino County; with wolframite in the Clark Mountains, San Bernardino County, 18 miles south of the Inyo County line and 9 to 10 miles from the Nevada boundary (Pl. XIII, *A*), at Amalie, in Jawbone Canyon, and near Weldon, Kern County; Grass Valley, Nevada County; and at several places near Bishop, Inyo County. In Connecticut, at Trumbull. In Idaho, at Murray, Shoshone County (Pl. XI, *A*). In Nevada, at Sacramento Pass, 10 miles north of Osceola; at Camp Bonita, on the opposite side of the Snake Range and southeast of Osceola; at Scheelite, 6 miles south (Pl. XIV, *B*); and in the Minerva district, 25 miles south of Osceola, White Pine County. In Utah, in the Deep Creek Mountains, Tooele County (Pls. XII, *A*, and XVI, *A* and *B*), and in the Grouse Creek Mountains, Box Elder County, 15 miles north of Lucin (Pl. XIII, *B*).

Scheelite has been mined on Moose River, Nova Scotia (Pl. XV, *E*); at McRaes Flat, New Zealand; at Hillgrove and other places in New South Wales; at Parada and other places in Queensland; at places in the Federated Malay States; and in Japan.

Importance as an ore mineral.—The deposits at Atolia are the largest and most productive scheelite deposits known, and the output has in some years equaled or exceeded that of ferberite from Boulder County, Colo.

Scheelite, under normal ore prices, has sold at about 50 cents a unit below ferberite and wolframite. This difference in price is, in part at least, apparently due to rule-of-thumb methods of smelting, for one tungsten smelter, who had on hand a stock of ferberite when it was selling for $7.50 a unit, is known to have sold it and bought scheelite at $7 a unit. The methods of fluxing must, of course, be changed when the smelter has been using wolframite alone, and this change makes more or less trouble. One manufacturer uses a mixture of scheelite and ferberite or wolframite in his charge. Others prefer scheelite alone, and it seems probable that any discrimination against it will disappear.

CUPROTUNGSTITE.

Cuprotungstite is a hydrous copper tungstate of a bright yellowish-green color. It has been found in only small quantities and is of little importance commercially. Dana[1] gives its composition as $CuWO_4$ and $(Cu,Ca)WO_4$, but an analysis of material from Cave Creek, Ariz., by W. T. Schaller, of the United States Geological Survey, shows that it contains water and that the formula should be $CuWO_4.2H_2O$. Three of the four analyses quoted by Dana show water, and in the fourth analysis, which totals only 97.85 per cent, apparently no determination of water was made. Dana seems to apply the name cuprotungstite to the copper tungstate and cuproscheelite to the supposed tungstate of copper and calcium, such a mineral from Lower California having been described by Whitney. Whitney's original specimen is in the United States National Museum, and examination shows it to be a mixture of cuprotungstite and scheelite. A specimen from New South Wales labeled "cuproscheelite and scheelite" is a similar mixture.

Cuprotungstite appears to be formed by the alteration of scheelite, the changes taking place along its outer surface and along cracks and extending inward. It naturally happens that the outer part may be more completely altered to cuprotungstite than the inner parts (Pl. XVII, *B*), so that some reports are like that made by Domeyko, a noted geologist of Chile, who states that cuprotungstite from a vein rich in copper near Santiago enveloped kernels of cuproscheelite and clear yellow scheelite,[2] though he does not use these names. This cuproscheelite is therefore, like Whitney's, merely a mixture of cuprotungstite and scheelite.

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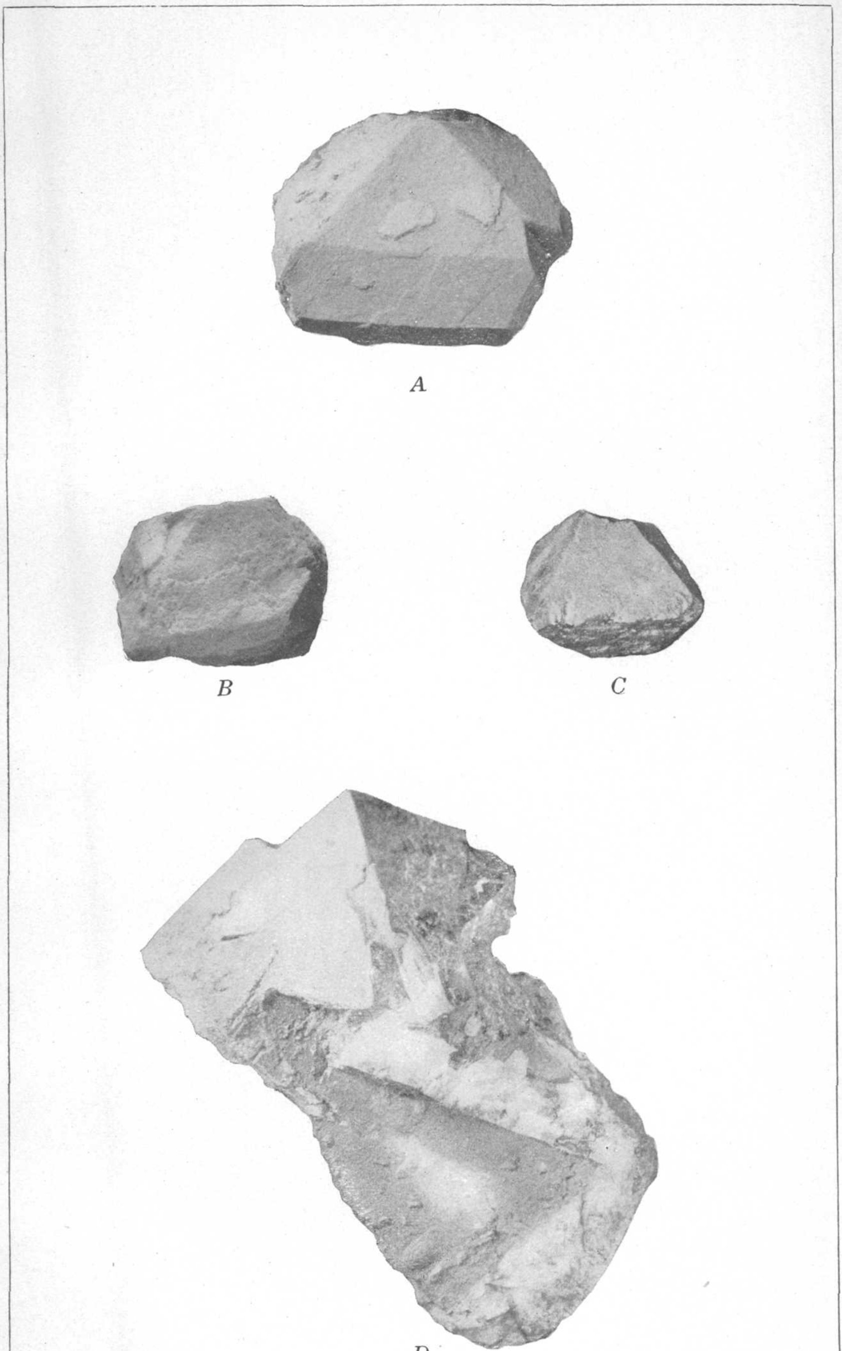
[1] System of mineralogy, 6th ed., p. 988, 1892.

[2] Domeyko, Ignacio, Note sur quelques minéraux du Chili: Annales des mines, 6th ser., vol. 16, pp. 537–538, 1869.



CRYSTALLIZED SCHEELITE.

All natural size.

A, *B*, Light-gray, slightly translucent specimens from Clifton mining district, Deep Creek Mountains, Tooele County, Utah.
C, Specimen of reddish-caramel color, translucent, from Tungsten, 12 miles south of Osceola, Nev.
D, Scheelite partly replaced by ferberite (reinite) and tungstite, from Kurasawa mine, Koshu, Japan. Courtesy of S. Katsuno.

A. CUPROTUNGSTITE (GREEN) AND FERBERITE (BLACK) FROM CAVE CREEK, ARIZ.

B. SCHEELITE (WHITE) BEING REPLACED BY CUPROTUNGSTITE (GREEN).

Photomicrograph of specimen from Peelwood, New South Wales. Magnification 20 diameters.

In hardness and cleavage cuprotungsite is very similar to scheelite. Cuprotungstite has never been found in any considerable quantity, and has thus not entered into commerce, but certain buyers have refused to buy ferberite from Cave Creek, Ariz., because it contained cuprotungstite. Others, however, will purchase it.

The only known considerable deposit of cuprotungstite in this country is that just mentioned, at Cave Creek, Ariz., where it occurs with ferberite and copper minerals, from the mutual decomposition of which it may have been formed. (See Pl. XVII, *A*.) Specimens of wolframite from the Copper Mountain (Picuris) district, near Rinconada, N. Mex., contain small quantities of a green mineral which may be cuprotungstite. It is found in Lower California; Lannico and Santiago, Chile; Southwest Africa; and Peelwood, New South Wales. (See Pl. XVII, *B*.)

TUNGSTITE.

Tungstite (hydrous tungsten oxide, $WO_3.H_2O$), or tungsten ocher, was originally described as free from water, and was later named meymacite by Carnot,[1] a French chemist, who thought he had discovered a new mineral because it contained water, but Walker [1] has shown that water is a normal constituent of tungstite. Tungstite is a bright-yellow mineral which is formed by the decomposition of scheelite and the wolframites. It usually occurs as a yellow coating on those minerals or fills cracks in them. It is generally powdery, but it also forms visible crystals. Some scheelite is made yellow, from tungstite that has formed along small cracks which penetrate the entire mass. (See Pl. XV, *C*.) Some specimens are so perfectly replaced that the cleavage of the original mineral is preserved. A specimen of tungstite from the Kootenay Belle mine, 10 miles southeast of Salmo, British Columbia, furnished through the courtesy of Dr. T. L. Walker, of Montreal, Canada, is shown in Plate XV, *B*. Dr. Walker [3] reports that

> Mr. John Bell, of Salmo, who operated the Kootenay Belle when the best tungsten ores were obtained, informs me that on one occasion fully half a car of high-grade tungstite ore was shipped to the smelter. In this ore free gold occurs in the tungstite as well as in the quartz. Only gold values were obtained, the tungsten apparently going to waste, as its value was not known at the time.

Under prices prevailing late in 1915 and early in 1916 such ore would probably have been much more valuable for its tungsten

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[1] Carnot, A., Sur quelques minéraux de tungstène de Meymac (Corrèze): Compt. Rend., vol. 79, p. 639, 1874.

[2] Walker, T. L., A review of the minerals tungstite and meymacite: Am. Jour. Sci., 4th ser., vol. 25, pp. 305-308, 1908.

[3] Walker, T. L., Report on the tungsten ores of Canada: Canada Dept. Mines, Mines Branch, p. 37, 1909.

content than for its content of gold and silver, but tungstite is not known to have occurred at other places in quantity comparable with that found at this mine.

Tungstite has been found at many places in this country but in insignificant quantities. It may, however, indicate to the prospector the occurrence of other tungsten minerals below the surface, as in some places it lines parts of cavities from which such minerals have been weathered.[1]

FERRITUNGSTITE.

Ferritungstite, hydrous ferric tungstate ($Fe_2O_3.WO_3.6H_2O$), is a light-yellow mineral much paler than tungstite. It is friable or powdery and looks very much like iron-stained clay. Under the microscope it is seen to be made up of small hexagonal plates. It was found on specimens of wolframite collected by Howland Bancroft, of the United States Geological Survey, in the Deer Trail mining district, Stevens County, Wash., and has been described by W. T. Schaller.[2]

Ferritungstite has been found only as a product of the decay of wolframite, and, like tungstite, may be left in spaces from which wolframite has been weathered, and it may thus show the prospector that other tungsten minerals lie below the weathered outcrop.

Although it has been reported only from the Deer Trail (Cedar Canyon) district, Stevens County, Wash., it has probably in many places been taken for tungstite or an iron mineral. On the other hand, a claylike mineral stained with iron and covering hübnerite, from Tungstonia, in the Regan mining district, 35 miles north of Osceola, Nev., could not be distinguished from ferritungstite without careful testing.

STOLZITE.

Stolzite, lead tungstate ($PbWO_4$), is a rare mineral, which is generally found in forms very much like those of scheelite but has never been discovered in large quantity. It is as diverse in its colorings as scheelite and is described by Dana[3] as green, yellowish gray, brown, and red. It is faintly translucent. The streak and powder are uncolored.

It contains 51 per cent tungsten trioxide, WO_3 (40.5 per cent tungsten) and 49 per cent lead oxide, PbO (45.5 per cent lead). Stolzite and raspite are the only known tungsten minerals in which another metal exceeds the tungsten in quantity.

A little stolzite has been found in specimens from the scheelite deposits in the Grouse Creek Mountains, 15 miles north of Lucin,

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[1] See appendix (p. 76).

[2] Schaller, W. T., Mineralogical notes, series 2: U. S. Geol. Survey Bull. 509, pp. 83–84, 1912.

[3] System of mineralogy, 6th ed., p. 989, 1892.

Utah, and it is reported from Silvermine, Mo., and from Loudville and Southampton, Mass. It is apparently a secondary mineral and is reported to occur in the wulfenite and vanadinite ores of the Southwest, from which it must be removed if the ores are to be used for their molybdenum or vanadium content.

It is reported from Zinnwald, Bohemia; Province of Coquimbo, Chile; Bena e Padru, Ozieri, Sardinia; Marianna de Itacolumy, Minas Geraes, Brazil; and Broken Hill, New South Wales. The specimen figured in Plate XV, *A*, is from Broken Hill.

RASPITE.

Raspite is a lead tungstate which has the same composition as stolzite but which crystallizes in forms different from those of stolzite. It has been found only as a mineral curiosity in New South Wales and Brazil. It is unknown in the United States.

TUNGSTEN DEPOSITS.

ASSOCIATED ROCKS.

Tungsten deposits seem to be invariably in or associated with granitoid rocks—that is, with rocks resembling granite in texture—though they may be with their porphyritic facies, and, so far as is known, only with rocks that contain considerable quantities of free quartz, and usually if not always with the lighter-colored rocks.

Generally the deposits are obviously connected with the granitoid rocks—either in them or in rocks that are plainly in contact with them. Near the wolframite deposits at Lead, S. Dak., no granite is found, but probably no one who has studied them doubts that granite lies not far below the deposits. The wolframite deposit in the Hachita district, near Gage, N. Mex., is in limestone, but here, too, granitoid intrusions will probably be found at no great distance from the deposit, either vertically or horizontally, for, according to Lindgren,[1] the limestones are cut by numerous dikes and sheets of quartz monzonite porphyry.

Tungsten deposits, like tin deposits, appear to be connected with the upper and outer part of intrusive masses of granitoid rocks, so that if a considerable thickness of the rocks has been eroded the tungsten deposits may have been removed, and thus lost to man, and this may account for the absence of tungsten deposits in the neighborhood of some great granite masses. On the other hand, the rock core of the earth apparently varies considerably in composition from place to place, so that the different kinds of ore deposits are very unequally distributed.

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[1] Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, p. 336, 1910.

DISTRIBUTION IN THE UNITED STATES.

The tungsten deposits of the United States, as would be expected from the statements just made, occur only in States where there are areas of quartzose granitoid rocks, but, as has been intimated, not all areas of granitoid rocks contain tungsten deposits.

Most of the tungsten deposits of the country are in States that lie in and west of the Rocky Mountains—South Dakota, Montana, Colorado, New Mexico, Idaho, Utah, Arizona, Nevada, California, Oregon, and Washington—all of which contain at least small deposits. Wyoming is the only State in this whole great western area in which no tungsten is known to have been found. In the southeast quarter of Missouri, at Silvermine, Madison County, there is a small area of granitoid rocks containing wolframite, and it has also been reported, though without confirmation, from one or two other points in this area. In the granites and related rocks exposed from Maine southward to Georgia, however, very little tungsten has been found. Scheelite has been mined on a small scale at Trumbull, Conn., but at no other point in this whole eastern area have tungsten minerals been exploited, although sporadic occurrences have been noted at several places and pieces of wolframite can be picked out of the dumps of the old Irish Creek tin mine, in Rockbridge County, Va., 5 miles east of Vesuvius.

There are areas, some very large, of granitoid rocks in Alaska, Arkansas, Michigan, Wisconsin, and Minnesota from which no tungsten minerals have been reported. In Texas there are small areas of granitoid rocks in which a few tungsten minerals have been found, and in Alaska further discoveries are to be expected.

The wolframite minerals, particularly hübnerite, seem to occur preferentially with silver deposits and scheelite with gold deposits. Thus the Rocky Mountain and Great Basin States, which are preeminently silver-producing areas, carry the largest deposits of ferberite, wolframite, and hübnerite, and in the Sierra Nevada, which is a gold-producing area, the greatest known scheelite deposits are found at Atolia, at the south end of the range. Randsburg, a large gold-producing camp, and Atolia are really parts of the same mineral-bearing area. The point may not be pressed too far, however, for there are numerous exceptions, such as the wolframite deposits found in connection with the gold deposits of Lead, S. Dak.

It is not yet possible to show that the tungsten minerals occur in one granitoid rock more than another, but they have not been found in rocks (such as the gabbros) that carry no free quartz—that is, quartz occurring in grains through the rock.

The country rock cut by the granite has apparently something to do with the distribution of the deposits. Rocks that retain open spaces when cracked are the most congenial hosts. Schists under heat, pressure, and moisture seem to squeeze together too easily to make good places for veins to form.[1] If conditions are favorable, however, veins of fair width and length may form in them, as near Hill City, S. Dak., and Yucca, Ariz., particularly if the veins cut across the schistosity—that is, across the grain of the schist. Limestones make excellent hosts for veins, for besides being brittle and retaining cracks well they are easily replaced by other minerals. Most igneous rocks, such as dikes and other intruded masses, retain open cracks when broken, so that veins may form in them readily.

FORMS.

Tungsten deposits may be placed in six groups—segregation deposits, pegmatite dikes, veins, replacement deposits, contact-metamorphic deposits, and placers. The deposits will be described in this order, which is, however, not the order of their importance but represents in general the way in which they grade into one another.

SEGREGATION DEPOSITS.

At some places the igneous rocks, rocks that were once molten, such as granite, contain a much larger proportion of certain minerals than at other places in the same body of rock, and such masses are known as segregations. Many of them contain the heavier minerals, among which may be tungsten minerals. It is as if a fruit cake before baking had been tipped to one end of the pan so that the raisins had settled at that end. Only one such occurrence of wolframite is known—a deposit in the Whetstone Mountains, Cochise County, Ariz., 12 miles south-southwest of Benson. Here wolframite, in small flat crystals, is distributed through a very pure potash granite in irregular masses that lie close to small, irregular gash quartz veins.[2] A few tons of concentrates have been produced from the deposit. The ore is remarkably like some of that from a pegmatitic deposit on Blue Grouse Mountain, Stevens County, Wash. (See Pl. XVIII, *A*.)

PEGMATITE DIKES.

When masses of molten (igneous) rocks, such as granite, diorite, and related rocks, are forced toward the surface of the earth, they cool and freeze, or, in other words, become solid, just as water does when the temperature falls below 32° F. (0° C.). In cooling, the rocks shrink, new adjustments of position are made, and the mass is cracked. By the shrinkage of the mass, or by other forces, parts of

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[1] See appendix.

[2] Hess, F. L., Note on a wolframite deposit in the Whetstone Mountains, Ariz.: U. S. Geol. Survey Bull. 380, pp. 164–165, 1909.

the rock which are still molten, and which may contain large quantities of water, are forced up into the cracks, forming dikes.

Reverting to a figure already used, it may be said that pegmatites are formed somewhat like parts of a cake that is baked in too hot an oven. A crust is formed that shrinks and cracks, and the pasty central mass is forced up into the cracks. In a general way the minerals of the dikes resemble those of the surrounding rock mass. Thus most of the rocks that form dikes in granite contain potash feldspars, and most of those that form dikes in the less siliceous rocks contain soda or lime feldspars. Part of the dikes are coarse, uneven grained, and generally not homogeneous in composition, and these are known as pegmatites. Many pegmatites carry numerous rare minerals, among which may be tungsten minerals. These rare minerals are either lacking or present only in very small quantities in the parent mass, and the pegmatites may therefore be considered a type of segregation deposit. Scheelite is uncommon in pegmatites but has been found in them in small quantities. Near Oreville and Hill City, S. Dak., wolframite is found in pegmatite, and specimens of wolframite from Blue Grouse Mountain, near Loon Lake, Stevens County, Wash., are embedded in a fine-grained pegmatite. (See Pl. XVIII, *A*.) Specimens of scheelite sent to the Survey by Margarito Romero from El Porvenir, El Porvenir district, N. Mex., are in a pegmatite gangue of quartz, feldspar, and fluorspar, and contain also molybdenum and copper minerals. Scheelite has been found in pegmatite on the north side of Tunk Pond, near Cherryfield, Maine. Specimens from a deposit near Rinconada, Rio Arriba County, N. Mex., which carry wolframite, with tourmaline, quartz, copper, and other minerals, are possibly from a pegmatite or a vein closely related to pegmatite.

Probably the most remarkable tungsten-bearing pegmatite known is that which contains the great cryolite deposit at Ivigtut, Greenland, in which is found a ferberite containing nearly 1 per cent of columbic and tantalic oxides.

Many quartz veins that carry tungsten minerals appear to be pegmatites from which most of the minerals have been frozen or precipitated at lower levels. Such are the veins at Hill City, S. Dak., some of which carry cassiterite (tin oxide, SnO_2), apatite, mica, and a little feldspar in the quartz. On Irish Creek, Rockbridge County, Va., there is a deposit, generally called a vein, which shows some of the characteristics of a pegmatite. It carries cassiterite and wolframite in a gangue of quartz, arsenopyrite, and pyrite, with beryl, muscovite (white mica), and probably other minerals.

A vein system near Pony, Mont., that carries hübnerite grades into pegmatite.[1] Some of the tin-bearing and tungsten-bearing veins of

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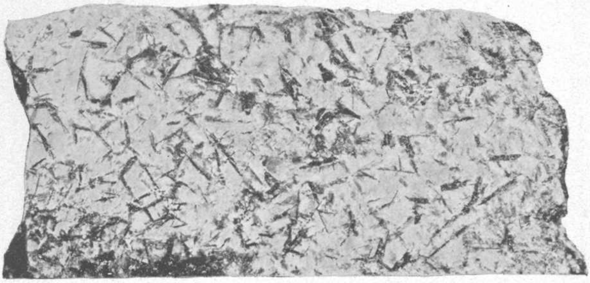
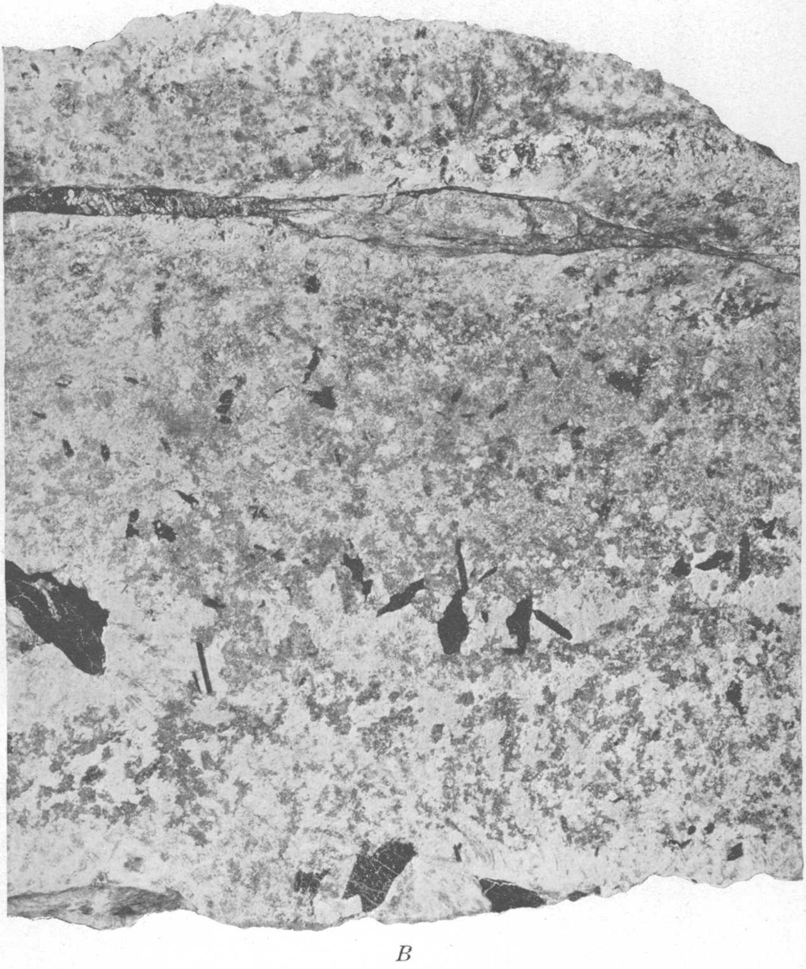
[1] Winchell, A. N., Mining districts of the Dillon quadrangle, Mont., and adjacent areas: U. S. Geol. Survey Bull. 574, p. 125, 1914.



A



B

A. POLISHED SPECIMEN OF FINE-GRAINED PEGMATITE CARRYING WOLFRAMITE, FROM BLUE GROUSE MOUNTAIN, STEVENS COUNTY, WASH.

Natural size. The wolframite is in thin, broad plates, only the edges of which show.

B. POLISHED SPECIMEN OF PEGMATITE WITH FERBERITE, CUTTING GRANITE, FROM CAVE CREEK, ARIZ.

Three-fifths natural size. The pegmatite runs from left to right and grades into the granite on both sides.

POLISHED SPECIMEN FROM HUMBUG MINING DISTRICT, YAVAPAI COUNTY, ARIZ., SHOWING ANASTOMOSING WOLFRAMITE VEINLETS.

Natural size. Lighted so that the wolframite appears white in the largest vein (at the right). A vug into which wolframite crystals grew has been filled with hydrous iron oxide (black).

Cornwall are much like pegmatites. Thus the veins of the East Pool and adjoining properties at Carn Brea, Cornwall, carry "remarkable intergrowths of wolframite, pyrite, arsenopyrite, quartz, and microcline,"[1] a mixture of minerals which might well be part of a pegmatite dike. The wolframite-bismuth deposits at Torrington, New South Wales, seem to be in part pegmatites, in part replacement deposits in granite, and in part veins connected with or proceeding from the pegmatites.[2]

At Mount Carbine, Queensland,[3] "Some parts of the veins are chiefly composed of feldspar, * * * [though] from end to end it will probably not exceed 10 per cent, while it may be as low as 5 per cent of the whole gangue." The veins also contain some mica and tourmaline, the tourmaline generally invisible to the unaided eye, and altogether the veins seem not many degrees removed from pegmatite dikes.

So far no large production has been made in the United States from deposits that are essentially pegmatitic.

VEINS.

Veins are relatively thin bodies that fill cracks in rocks and have been deposited from solution. Most of them are different from the rocks that form their walls. Such are the familiar quartz and calcite veins.

All the tungsten minerals have been found in veins and most tungsten deposits are of this form. The tungsten minerals are accompanied by a considerable variety of others, though as a rule not many of them occur in any one vein. In known veins the following minerals are associated with tungsten minerals: Adularia, ankerite, apatite, arsenopyrite, beryl, bismuth, bismuthinite, calcite, cassiterite, chalcopyrite, chalcocite, chlorite, cinnabar, cosalite, covellite, dolomite, fluorspar, gahnite, galena, gold, graphite, hamlinite (?), lepidolite, molybdenite, muscovite (including sericite), pyrite, quartz, siderite, silver, specularite, sphalerite, stibnite, sylvanite and related minerals, triplite, tourmaline, and topaz, and oxidized veins in which stolzite is found contain vanadinite, endlichite, pyromorphite, and other oxidized minerals. Some wolframites carry within themselves tantalum, columbium, and scandium, and some scheelites carry small quantities of molybdenum and the rare-earth metals.[4]

This list includes a number of unusual vein minerals, some of which—beryl, cassiterite, tourmaline, apatite, muscovite, fluorspar,

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[1] Dewey, Henry, and others, Tungsten and manganese ores: Great Britain Geol. Survey Mem., Special reports on the mineral resources of Great Britain, vol. 1, p. 20, 1915.

[2] Carne, J. E.. The tungsten mining industry in New South Wales: New South Wales Geol. Survey Mineral Resources No. 15, pp. 33–46, 1912.

[3] Ball, L. C., The wolfram mines of Mount Carbine: Queensland Geol. Survey Pub. 251, pp. 31–32, 1915.

[4] See appendix.

molybdenite, topaz, tantalum, and columbium—suggest connection with pegmatites, so that it is not suprising to find that some tungsten-bearing quartz veins are really pegmatites from which most or all of the feldspar and most of the mica have probably crystallized at greater depths, as noted on page 38.

A tungsten vein may show all the vagaries of other veins. It may be a single simple veinlet of "knife-edge" thickness, or a single vein many feet wide, or it may consist of compound veins with many anastomosing (interlacing) veinlets (see Pl. XIX) or criss-crossing veins, some of them several inches wide, or it may consist of short "stepped" veins that form one series which is yet not continuous. It may swell or pinch to a stringer, or it may disappear entirely for a distance. The minerals in a vein are generally in shoots of more or less good ore alternating with barren parts. This variation, however, is not peculiar but is a characteristic of most if not all veins of metallic minerals. The occurrence of shoots in gold, silver, and other veins is familiar to miners and prospectors.

Most tungsten veins have a quartz filling in which the tungsten minerals are embedded, but some, such as the thin veins in the Boulder field, carry comparatively little quartz; most of the vein is ferberite. In fact, ordinary white quartz is so scarce in these veins that miners have sent specimens to the Geological Survey as curiosities, a greatly appreciated courtesy.[1] In the deposits at Atolia, Cal., also, there is comparatively little quartz; calcite carrying some iron is the principal gangue mineral. A vein may solidly fill the space between its walls or it may contain numerous hollows, known as vugs.[2] The vugs are generally lined with crystals (Pl. XIX) formed of the mineral last deposited in the vug. In the Boulder field some vugs are lined with beautiful crystals of ferberite; others are lined with chalcedony and opal. A few vugs in the same field are lined or filled with scheelite. In other fields the vugs are lined with quartz, calcite, hübnerite, or other minerals, in many places coated with silica. Vugs that were once lined with wolframite, scheelite, or other crystals have been filled by other minerals as deposition proceeded and are now parts of a solid vein.

REPLACEMENT DEPOSITS.

The rock in an area where veins traverse easily soluble rocks is commonly replaced by the vein matter, and the replacement may be so complete and extensive as to obliterate all trace of the original opening through which the solutions passed, and such bodies are naturally called replacement deposits.

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[1] See appendix.

[2] Vug is an old Cornish word coined by miners to mean just this thing. The term, although well known to most miners, is called by some "vug holes"; by others, who have evidently in the first place misunderstood the word, "bug holes."

Certain rocks are rather easily dissolved in the solutions from which tungsten and other minerals are deposited, particularly rocks that are largely or wholly made up of carbonates, such as limestone, which is more or less pure calcite, calcium carbonate; dolomite, the magnesium-calcium carbonate; and siderite, the iron carbonate. Under certain conditions other rocks are also fairly soluble. Generally, however, a sedimentary rock that has been extensively replaced naturally creates the impression that it probably was a rock containing a large percentage of carbonates.

At Lead, S. Dak., wolframite was apparently brought from the depths by solutions that flowed through thin cracks known as "verticals." Where the solutions reached a bed of dolomite they spread out through the rock, replacing it and depositing wolframite and small quantities of scheelite, gold, silver, pyrite, and other minerals. Many fragments of shells of Cambrian age are preserved in the ore. (See Pl. X, *B*.) Local variations in the rock made variations in the outline of the ore body, but at most places it is rounded and bulbous.

Granitic rocks may be replaced in much the same way, though most of the known replaced bodies are much smaller. Plate XVII, *A*, shows a specimen from the claims of the Pittsburgh Tungsten Mines Co., at Cave Creek, Ariz., furnished by the courtesy of Mr. S. H. Brockunier. In this specimen a micaceous phase of a granite has been in part replaced by cuprotungstite and ferberite. The ferberite looks like drops of ink in a blotter; if the blotter instead of being in a thin sheet were in the form of a block, so that the ink could spread equally through three dimensions, the comparison would be very close.

Such deposits, on account of the exceptional conditions required for their formation, are naturally unusual. In this country only those in the vicinity of Lead, S. Dak., have so far been productive. They have paid considerable profits on their exploitation during 1915 and 1916. The scheelite deposit at Long Hill, near Trumbull, Conn., is in many ways similar. At this place a greatly metamorphosed limestone, lying between gneisses, which Hobbs[1] calls diorite but which may be highly metamorphosed tuffs, contains replacement bodies now composed of quartz, zoisite, epidote, and other minerals with which is associated nearly white scheelite. These replaced bodies are more or less closely connected with thin vertical veins, as are the Lead deposits, and pegmatites cut the same rocks.

As a matter of fact, however, the larger veins of ferberite in Boulder County, Colo., and the wider scheelite veins at Atolia, Cal., are replacement bodies, for the crevices which existed when the veins

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[1] Hobbs, W. H., The old tungsten mine at Trumbull, Conn.: U. S. Geol. Survey Twenty-second Ann. Rept., pt. 2, p. 16, 1901.

were formed were probably rather narrow, and much of the fine-grained quartz (see Pl. XXIV, *A*) found in both sets of veins has probably replaced granite or granodiorite.

In Cornwall, Saxony, and other places where tin and tungsten-bearing veins are found granite is altered to greisen[1] in considerable bodies. Here the original quartz is probably left, but the feldspars have been removed by hot ascending solutions, which have replaced them by quartz, mica, cassiterite, and wolframite. Similar deposits are found near Torrington, New South Wales, and the descriptions indicate to the writer that they are of similar origin, though J. E. Carne[2] and E. C. Andrews do not seem to think so. No large deposits of this sort are known in the United States, but similar conditions are found on a small scale in the pegmatites near Hill City, S. Dak., where solutions carrying quartz, wolframite, and possibly cassiterite and muscovite (white mica) have here and there replaced parts of the dike, probably only a short time after it had hardened.

Pegmatite pipes—crooked, roughly cylindrical bodies of pegmatite—are another form of replacement bodies in granite. Wolframite deposits are found in such forms in Queensland[3] and New South Wales.[4] Though not now known in this country, they may yet be discovered.

CONTACT-METAMORPHIC DEPOSITS.

When granitic rocks or their porphyritic variants are intruded into some kinds of sedimentary rocks, particularly limestones or dolomites, the hot water which accompanies the intrusive rock and probably comes from it, and which is loaded with much mineral matter in solution, attacks the country rock and may alter or metamorphose it until it loses all semblance to the original rock, though to the trained eye the altered appearance usually suggests the original rock and the process through which it has passed. In many places the original carbonate of lime or the dolomite are in part removed, a part is recrystallized and remains, and another part combines with the mineral matter introduced in solution from the intrusive rock and forms new minerals, such as garnet, vesuvianite, epidote, zoisite, hornblende, and tremolite. Other new minerals form from the clay, iron, and other impurities contained in the limestone and the mineral matter of the intrusive water, and still others, such

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[1] Greisen, as the word was originally used, is rock composed of quartz and lithium mica, but the term is ordinarily used to mean any silicified granitic rock containing more or less mica.

[2] Carne, J. E., The tungsten-mining industry in New South Wales: New South Wales Geol. Survey Mineral Resources 15, pp. 33–46, 1912.

[3] Ball, L. C., Rare-metal mining in Queensland; Résumé of recent field studies: Queensland Government Min. Jour., vol. 14, pp. 4–7, 1913.

[4] Andrews, E. C., The geology of the New England Plateau [New South Wales], with special reference to the granites of northern New England: New South Wales Geol. Survey, vol. 8, pt. 2, pp. 138–141, 1905.

as pyrite, chalcopyrite, and magnetite, crystallize from the solution and occupy spaces in the formerly solid limestone. Rocks so altered are called contact-metamorphic rocks and the volumes so altered are known as zones, because they usually form more or less irregular bands around the intrusive mass. Not only is the limestone metamorphosed by the contact with the heated waters issuing from or with the intrusive mass, but the intrusive itself may be altered, though in less degree, by the introduction of other minerals, particularly lime taken by the water from the surrounding rocks. Specimens from deposits 15 miles northwest of Seven Troughs, Nev., show granite thus replaced by epidote, scheelite, and other minerals. The acquirement of mineral matter from the country rock by the intrusive is also shown by the presence of graphite in pegmatite dikes cutting graphitic schists near Hill City, S. Dak., and in veins that are probably extensions of pegmatite dikes.

Among the less common minerals deposited from intrusive water is scheelite. It is distributed through the rock and may occur in kernels ranging in size from $\frac{1}{250}$ of an inch (0.1 millimeter) to several inches (a decimeter or more) in diameter but that are commonly less than half an inch (1 centimeter) in diameter.

Contact-metamorphic deposits have been found at the south end of the Trinity Range near Browns (Toy) and in adjacent areas in Humboldt County, and near Montgomery, Mineral County, Nev.; in the Grouse Creek Range, Box Elder County, 15 miles north of Lucin, and in the Deep Creek Mountains, Tooele County, Utah; west and south of Bishop, Inyo County, Cal.; in the Apache No. 2 mining district, 6 miles south-southeast of Hachita, N. Mex. Specimens from a point near Weldon, Kern County, Cal., are evidently from contact-metamorphic deposits. Some of the deposits near Browns have been actively exploited, and a small production has been made from the others. In a specimen from one of the claims near Browns the scheelite occurs in particles $\frac{1}{250}$ to $\frac{1}{35}$ of an inch (0.1 to 0.7 millimeter) in diameter, so small that they can not be distinguished by the unaided eye from the brownish mixture of minerals making up the rock. In another specimen the grains are the size of small peas. In the Grouse Creek Mountains the grains are half an inch (1 centimeter) or more in diameter and are comparatively easy to recognize. In the Deep Creek Mountains some of the masses are as large as a man's fist or larger.[1] On Cape Mountain, near Cape Prince of Wales, Alaska, Knopf[2] found a little scheelite in microscopic particles in contact-metamorphosed limestone.

Some deposits in contact-metamorphosed rocks may have remained undiscovered, because the scheelite is so fine grained that it has

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[1] B. S. Butler, personal communication.

[2] Knopf, Adolph, Geology of the Seward Peninsula tin deposits: U. S. Geol. Survey Bull. 358, pp. 24, 30, 31, 1908.

escaped notice, and in others, such as part of those near Bishop, the scheelite grains are comparatively small and so white that they would ordinarily be mistaken for calcite. But scheelite is not a common mineral in such rocks, for though hundreds of specimens from many parts of the United States have been examined microscopically at the Geological Survey, the only specimen that contained it was that from Cape Mountain, Alaska, a locality to which reference has just been made. Deposits near Browns and Toulon, Nev., and Bishop, Cal., are being actively exploited on a large scale, though except at Browns the developments are all new. Similarly metamorphosed rocks worked for gold by the Seoul Mining Co. on the Suan concession, Chosen (Korea), carry scheelite in crystals as much as 2 inches thick.[1]

PLACERS.

As the earth's features are worn away by the action of water, by changes in temperature—from cold to hot and hot to cold—and by wind and the other agencies of destruction, minerals are broken out of the exposed parts of veins and become mingled with fragments of the country rocks to form the débris slopes of the hills, whence they are gradually moved by gravity, water, wind, and frost into the gravel deposits of the valleys. It is generally known that gold placers are formed in this way, but the similar formation of tungsten placers has apparently not been so generally recognized. Scheelite has been found in gold placers near Nome, and wolframite in gold placers near Circle, Alaska. Tungsten minerals, mostly wolframite, are found with stream tin in placers from which production has been made in Siam, the Malay Peninsula, Banka, and Billiton; scheelite has been found in gold placers in the Caribou district, British Columbia, and wolframite placers have been exploited on the Bodmin Moors, Cornwall, England;[2] and examples might be multiplied.

The first scheelite produced at Atolia, Cal., was float material picked up in the desert sands. Some scheelite has been dug from Baltic Gulch, between Atolia and Randsburg, for several years, and during the last year considerable quantities have been mined from the desert débris of the region. In Boulder County, Colo., a large quantity of float ferberite has been dug from the dirt near the outcrops of the tungsten veins. Not until the high prices of 1915 and 1916 gave the great impetus to tungsten mining, however, was there very extensive placer mining for tungsten in this country; then it was taken up with enthusiasm in Arizona, California, Nevada, and Colorado. Some of the residual pieces of scheelite found near Atolia have been large, one is reported to have weighed more than 100

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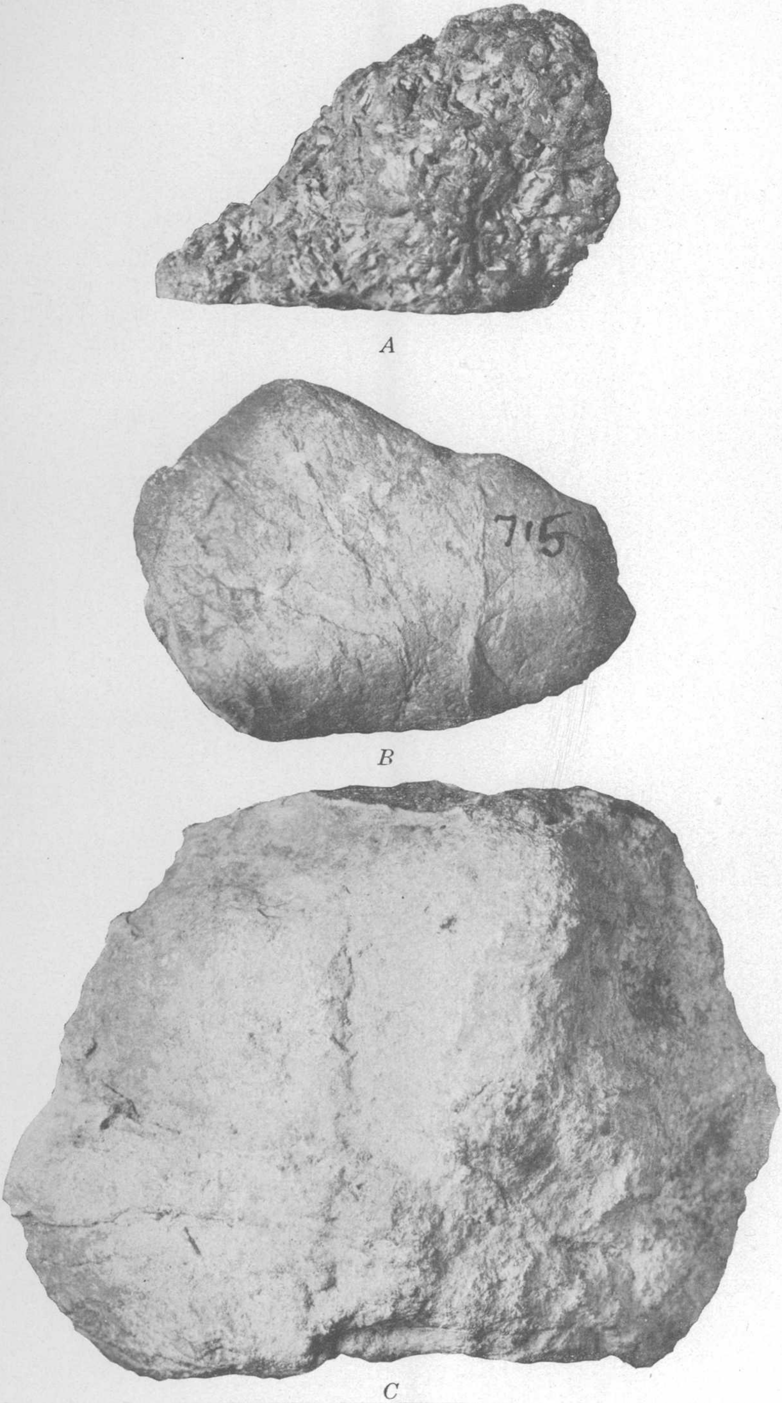
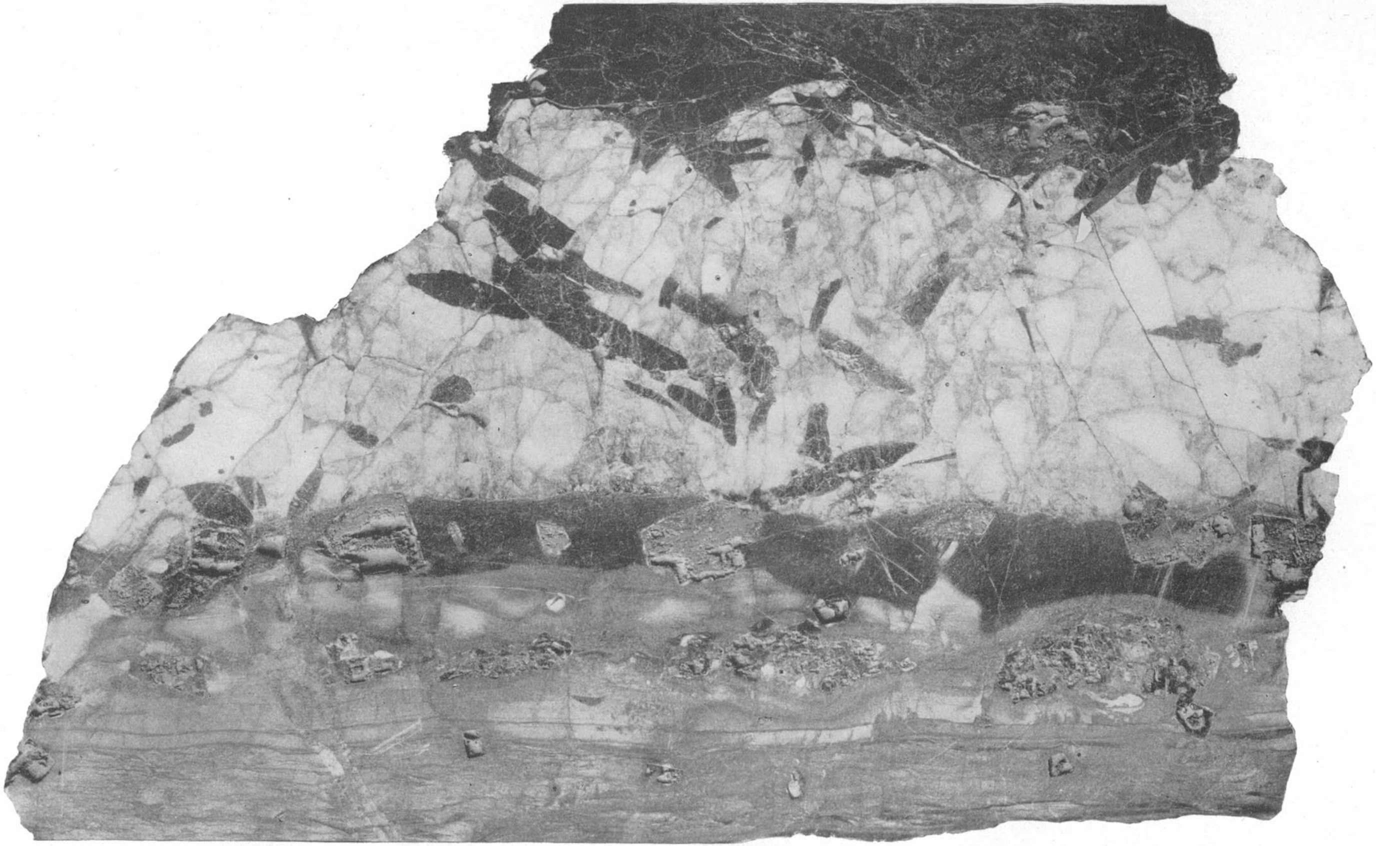
[1] Oral communication from J. F. Manning and E. W. Mills.

[2] Dewey, Henry, Tungsten and manganese ores: Great Britain Geol. Survey Mem., Special reports on the mineral resources of Great Britain, vol. 1, pp. 33–35, 1915.



A. PART OF A FERBERITE PEBBLE FROM NEDERLAND, COLO.
B. SCHEELITE PEBBLE FROM BALTIC GULCH, BETWEEN RANDSBURG AND ATOLIA, CAL.
C. RESIDUAL SCHEELITE PEBBLE COATED WITH CALICHE (CALCIUM CARBONATE), FROM ATOLIA, CAL.

All natural size.



HÜBNERITE-BEARING QUARTZ VEIN IN QUARTZ-MICA SCHIST, FROM TUNGSTEN KING MINE, NEAR DEER PARK, WASH.

Nearly natural size. Showing distribution of hübnerite in the vein and pyrite in the country rock. Owing to poor lighting the pyrite appears to be blistered. (After Howland Bancroft.)

pounds and at the prevailing prices in the spring of 1916 was worth several hundred dollars. The residual pieces found near Atolia are covered with caliche—calcium carbonate, much like a spring deposit. (See Pl. XX, *C*.) Most of the pieces found in the watercourses, even in the infrequently wet stream beds of the desert, are clean (see Pl. XX, *B*), and many of the scheelite pebbles from the Nome placers are crumbly, showing that they are gradually being dissolved. A part of a ferberite pebble from Nederland, Colo., is shown in Plate XX, *A*.

TUNGSTEN VEINS.

MINERALS.

As already stated a considerable number of minerals are found in tungsten-bearing veins. Brief descriptions of the principal minerals that have been so found—not the detailed descriptions demanded by the mineralogist—are given below in the hope that some of them may be of use to prospectors and miners.

The minerals are in general grouped after the plan used in the sixth edition of Dana's "System of mineralogy."

NATIVE ELEMENTS.

Bismuth.—Bismuth is a bright tin-white metal, very brittle, easily cut with a knife, and easily melted (melting point, 270° C. or 518° F., considerably below a red heat). It changes under the influence of the atmosphere to the hydrous oxide, bismuth ocher, and to carbonate, both of which may be white but are generally yellow, probably from iron, and may be green from copper. Bismuth is not found in large quantity in the tungsten deposits of the United States, but is common in some of the foreign deposits, particularly those of Queensland.[1]

In this country bismuth is found in wolframite deposits in the Eureka district, 45 miles west of Prescott, Ariz. Oxidized bismuth minerals are found with scheelite 3 miles north of the Dona Ana County line, 37 miles west of Tularosa, N. Mex.; in the Ruby Mountains, 10 miles south-southwest of Ruby Valley post office, Elko County, Nev.;[2] and with wolframite in the Hachita district near Gage, N. Mex.

Gold.—Gold is found in many tungsten-bearing veins, but seems to be associated with scheelite more commonly than with the wolframites. Gold is found with scheelite in the Union Hill and Empire mines at Grass Valley, Cal., and in specimens from the Union Hill

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[1] Ball, L. C., Rare metal mining in Queensland; Résumé of recent field studies: Queensland Government Min. Jour., vol. 14, pp. 4–7, 1913. Cameron, W. E., Wolfram and molybdenite mining in Queensland: Queensland Geol. Survey Rept. 188, p. 13, 1904.

[2] Hill, J. M., Notes on some mining districts in eastern Nevada: U. S. Geol. Survey Bull. 648, pp. 62–63, 1916.

mine gold can be seen in narrow quartz veinlets cutting the scheelite, though not in the scheelite itself. At Randsburg, Cal., scheelite is found in many of the gold veins; at Murray, Idaho, and Amalie, Cal., scheelite has been mined with gold-bearing galena and pyrite. (See Pl. XI, *A*.) At Leadville scheelite and less wolframite are found in a quartz-pyrite vein carrying 0.8 ounce of gold and 0.5 ounce of silver to the short ton of ore.[1] (See Pl. XIV, *A*.) Gold is found in scheelite-bearing quartz veins in the Sheepeater district, near Jardine, Park County, Mont. (Pl. XII, *B*); near Baker City, Oreg.; at Oracle, Ariz., where the veins are worked for both gold and scheelite; and in other places. At Hillgrove, New South Wales, and MacRaes Flat, New Zealand, veins have been worked for both scheelite and gold. Gold has been reported in hübnerite deposits at Tungsten, 12 miles south of Osceola, Nev.; Patterson Creek, Idaho; White Oaks, N. Mex. (Pl. V, *B*); and Silverton, Colo. (Pl. IV, *B*); with wolframite in the Hachita district, N. Mex., and at Lead, S. Dak. (Pl. X, *B*); with ferberite at Cave Creek, Ariz.; and some of the ferberite veins in Boulder County, Colo., carry a little gold. The gold and tungsten minerals in many of these deposits may have been deposited at different times.[2]

Graphite.—Graphite, familiar to all in lead pencils, as a lubricant, and in stove polish, is one of the forms of carbon. It is found in wolframite-bearing quartz veins on the May Day and Vida May claims near Hill City, S. Dak. The veins are closely related to pegmatites and cut graphitic schists, from which the graphite has been concentrated in the veins and in the walls next to the veins.

SULPHIDES, ARSENIDES, ANTIMONIDES, AND TELLURIDES.

Arsenopyrite.—Arsenopyrite ($FeAsS$), the arsenide and sulphide of iron, a silvery-white mineral, is not found in many American tungsten deposits. It occurs with wolframite on Irish Creek, Rockbridge County, Va.; in small quantity with the wolframite at Lead, S. Dak.; and in the Etta dike at Keystone, S. Dak. It is reported in Bolivian ores and is common in the wolframites from tin mines.

Bismuthinite.—Bismuthinite, bismuth sulphide (Bi_2S_3), a lead-colored to tin-white mineral that has one excellent cleavage, is generally found in those tungsten deposits which carry other bismuth minerals. It is easily cut with a knife. Most buyers object to bismuth minerals in tungsten ores, though others who use different processes of reduction raise no objection to them.

Chalcocite.—Chalcocite, copper glance (Cu_2S), a dark-gray to nearly black mineral, is found in only a few tungsten veins. It has been noted at Patterson, in the Blue Wing district, Lemhi County,

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[1] Fitch, R. S., and Loughlin, G. F., Wolframite and scheelite at Leadville, Colo.: Econ. Geology, vol. 2, pp. 30–36, 1907.

[2] See appendix.

Idaho,[1] and with wolframite in Powers Gulch, 18 miles west of Globe, Ariz. At Butte, Mont., hübnerite is found in copper deposits that carry great quantities of chalcocite, and at Woody, Cal., a wolframite that is possibly ferberite is found in gold-bearing copper deposits that carry chalcocite.

Chalcopyrite.—The copper-iron sulphide, chalcopyrite ($CuFeS_2$), a bright brassy-yellow mineral, is found in many tungsten deposits. The presence of copper in tungsten minerals, like that of bismuth, is objected to by some buyers but not by others, the preference of the buyer depending on the process of reduction he uses.

Cinnabar.—Cinnabar, mercury sulphide (HgS), a beautiful vermilion-colored mineral, has been found in only a few tungsten deposits. John H. Williams sent to the Survey specimens from the Jack claim in the Clark Mountains, eastern San Bernardino County, Cal., showing cinnabar in the middle of a thin wolframite vein (Pl. V, *A*), and specimens of wolframite from the Tip Top district, Yavapai County, Ariz., contain tiny specks of cinnabar. The cinnabar in the specimens from the Clark Mountains, San Bernardino County, Cal., was deposited after the wolframite had been formed, possibly at a very much later time.

Cosalite.—The bismuth-lead sulphide known as cosalite occurs as a tin-white fibrous, metallic mineral, in hübnerite deposits 5 or 6 miles northeast of Loon Lake, Stevens County, Wash., in the SE. ¼ sec. 16, T. 30 N., R. 42 E., where it contains about 0.8 of 1 per cent of silver. It weathers to a buff-yellow oxide.

Covellite.—The copper sulphide, covellite (CuS), a beautiful bluish mineral formed by the alteration of chalcopyrite, is found in the oxidized and in the enriched parts of deposits that carry chalcopyrite.

Galena.—Galena, lead sulphide (PbS), though by no means a common mineral in tungsten deposits, is found in a number of veins. When fresh it has an almost silvery metallic luster, which changes on exposure to the air to "lead gray." It has good cleavages in three directions at right angles to each other, so that it may be cleaved into cubes. It is easily cut with a knife and is very heavy, having a specific gravity of 7.4 to 7.5. Galena is found with hübnerite at Silverton, Colo.; in small quantity with hübnerite at Tungsten, 12 miles south of Osceola, Nev., and on Patterson Creek, Idaho; and with wolframite near Pioche, Nev., and Silvermine, Mo. In the ferberite veins on the edges of the Boulder field in Colorado a little galena is found. It occurs with scheelite in the Golden Chest mine at Murray, Idaho (Pl. XI, *A*) and at Covada, Wash.

Molybdenite.—Molybdenite, molybdenum sulphide (MoS_2), a lustrous metallic lead-gray mineral, occurs in lumps or thin flakes that

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[1] Umpleby, J. B., Geology and ore deposits of Lemhi County, Idaho: U. S. Geol. Survey Bull. 528, p. 111, 1913.

tend toward six-sided forms. The lumps are easily cleavable with the finger nail into thin leaves, which are flexible but not elastic and mark paper similarly to graphite, though with an olive-green tint. Molybdenite has been found with wolframite near Daisy, Wash., with ferberite at Cave Creek, Ariz., and with scheelite in the Deep Creek Mountains, Utah.

On Lost River, Alaska, wolframite and molybdenite are found in closely associated veins, though they are not known to be mixed together in the same vein. Molybdenite and scheelite, the molybdenite largely altered to powellite, occur together at Oak Springs, Nye County, Nev., and in the vicinity of Black Mountain, 15 or 20 miles northwest of Randsburg, Cal., but the deposits have so far not proved to be commercially valuable.

Pyrite.—The yellow iron sulphide, pyrite (FeS_2), is common in veins formed at all depths and, as would be expected, it is found in most tungsten veins, though in many of them it occurs only in small quantity. Some deposits, such as the scheelite veins of Atolia, Cal., and the ferberite veins of Boulder County, Colo., are remarkably free from pyrite.[1] In some veins pyrite forms in greater quantity in the country rock than in the vein itself. Plate XXI shows a part of a hübnerite-quartz vein near Deer Park, Wash., in which pyrite in cubical crystals occurs in the country rock but not in the vein. Some specimens from the vein, however, contain cubes of pyrite an inch square. The scheelite from Leadville (Pl. XIV, *A*) is accompanied by large crystals of pyrite formed in a vug, but pyrite usually occurs in irregular masses.

Silver minerals.—The form in which silver occurs in most tungsten-bearing veins is obscure. It is probably never native except in the oxidized or enriched parts of veins or where it is alloyed with gold, and in most deposits it is probably combined with sulphur or other elements. In deposits at Loon Lake, Wash., it occurs in cosalite;[2] at Patterson, Idaho, in tetrahedrite,[3] of which it forms 1.9 per cent; at Silvermine, Mo., in argentiferous galena; and in the contact-metamorphic deposits in the Apache No. 2 district, near Hachita, N. Mex., as horn silver.[4] As already noted, silver seems to occur more plentifully with the wolframites than with scheelite.

Sphalerite.—The zinc sulphide, sphalerite (ZnS), is found in only a few tungsten-bearing veins in the United States,[1] though it is reported from tungsten veins in England.[5] It is found in hüb-

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[1] See appendix.

[2] Bancroft, Howland, Ore deposits of northeastern Washington: U. S. Geol. Survey Bull. 550, p. 132, 1914.

[3] Umpleby, J. B., Geology and ore deposits of Lemhi County, Idaho: U. S. Geol. Survey Bull. 528, p. 111, 1913.

[4] Lindgren, Waldemar, The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, p. 343, 1910.

[5] Dewey, Henry, and others, Tungsten and manganese ores: Great Britain Geol. Survey Mem., Special reports on the mineral resources of Great Britain, vol. 1, pp. 24, 37, 38, 1915.

nerite veins at Patterson, Idaho, and resembles the hübnerite so closely that the two are difficult to distinguish by their appearance alone, but the streak of the sphalerite is gray and that of the hübnerite is brown.[1]

The thin quartz veins at Long Hill, Trumbull, Conn., contain a black sphalerite which is difficult to distinguish by its outward appearance from wolframite. Its specific gravity, however (about 4), is much less than that of wolframite (7.2 to 7.5), its streak is light brown, and when the sphalerite is heated it turns buff.

Another zinc mineral, the spinel, gahnite (a zinc aluminate, $ZnAl_2O_4$), is found in quartz veins with wolframite and cassiterite in the Tin Mountains, Stewart Island, New Zealand,[2] but is not known in the tungsten veins of this country.

Stibnite.—Stibnite, antimony sulphide (Sb_2S_3), is a soft, lustrous metallic gray mineral, which may be scratched with a hard finger nail. It has one excellent cleavage plane, so that when freshly broken it shows bright, shining faces. The crystals are generally needle-shaped, though they may be short and as broad as long. Stibnite occurs with scheelite at places, but has rarely been found with the wolframites. At Atolia, Cal., a little stibnite is found with scheelite and in the quartz gangue there are slender cavities, 3 inches by one-eighth inch, which are now nearly filled with pinkish quartz but which apparently were once occupied by stibnite. (See Pl. XXII.) Similar cavities in a specimen from the Hachita mining district, near Gage, N. Mex., were so well preserved that the angles of a wax impression could be measured with considerable accuracy, and Dr. E. T. Wherry found that they had the angles of stibnite crystals. Stibnite and scheelite are found together at Hillgrove, New South Wales;[3] on Stony Creek, 9 miles from Waipori, New Zealand;[4] and at Genna Gureu, Italy.[5] Stibnite, largely altered to oxide, has been found in the middle of a wolframite vein an inch wide in the Clark Mountains, San Bernardino County, Cal. A similar association has been reported from the Tip Top district, Yavapai County, Ariz., but the report is unconfirmed. At the Pucka antimony mine, Lionsville, New South Wales, a vein of mixed wolframite and stibnite has been worked.[6]

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[1] Umpleby, J. B., op. cit., p. 111.

[2] McKay, Alexander, On the geology of Stewart Island and the tin deposits of Port Pegasus district: New Zealand Colonial Mus. and Geol. Survey Rept. Geol. Expl. during 1888–89, p. 84, 1890.

[3] Longbottom, W. A., Scheelite mining; Occurrence and treatment in New South Wales: Min. and Eng. Rev., vol. 3, pp. 199–200, Sydney and Melbourne, 1911.

[4] Finlayson, A. M., The scheelite of Otago: New Zealand Inst. Trans. and Proc., vol. 40, p. 112, 1908.

[5] Lovisato, Domenico, Giacimento di minerali di tungsteno a Genna Gurèu ai limiti fra Nurri ed Orroli (Cagliari): R. accad. Lincei Atti, ser. 5, vol. 16, pt. 1, pp. 632–638, 1907.

[6] Carne, J. E., The tungsten mining industry: New South Wales Geol. Survey Mineral Resources No. 15, pp. 63–64, 1912.

At all these places the stibnite was probably introduced into the veins before or after the tungsten minerals were deposited.

Sylvanite.—Sylvanite, gold-silver telluride [(Au,Ag)Te_2], is found in some of the ferberite veins in the Boulder field, in Colorado, mostly around the outer edges of the field, where the gold veins and ferberite veins come together. In this field veins carrying both minerals have been found at Magnolia, in the Wheelmen tunnel in Boulder Canyon, and at Sunshine.[1]

Calaverite.—At Cripple Creek, where gold is found combined with tellurium in the mineral calaverite, which contains less silver than sylvanite, some hübnerite has been found in the Puzzle vein.[2]

Tetrahedrite.—Tetrahedrite is a mineral of variable chemical composition. In its simplest form it is a copper sulphantimonide ($Cu_8Sb_2S_7$). Some tetrahedrites contain less antimony and copper than is indicated in the formula; they contain instead one or more of the elements arsenic, iron, silver, mercury, zinc, lead, bismuth, cobalt, and nickel. Tetrahedrite is a metallic, steel-gray to dark-gray or iron-black massive mineral with no cleavage; it breaks with an uneven surface. Its hardness ranges from 3 to 4.5. Its streak is of nearly the same color as the mineral itself but has a brownish or reddish tint.

It is found with hübnerite at Patterson, Lemhi County, Idaho, and at Spanish Springs, 7 miles southeast of Manhattan, Nev.

Tetrahedrite on weathering makes green and blue copper stains as do other copper minerals.

FLUORIDES.

Fluorite, or fluorspar, the calcium fluoride (CaF_2), is colorless and transparent, pink, lilac, amethystine, dark purple, green or black. It has a hardness of 4, is easily scratched with a knife, but will scratch calcite. In many places it crystallizes in cubes. It has a perfect cleavage in eight directions, which allows it to be split into an octahedron. Its streak is white. When heated gently it glows beautifully. Hübnerite is found with colorless fluorite at White Oaks, N. Mex., and Silverton, Colo.; with lavender-colored fluorite on the west side of the Desatoya Mountains, and with deep amethyst-colored fluorite at the old mining camp of Ellsworth, in northwestern Nye County, Nev. Colorless, green, and deep amethystine fluorite are found with wolframite on Tin Creek, a tributary of Lost River, 110 miles northwest of Nome, Alaska. Fluorite, in part white and in part black, is found with ferberite at Cave Creek, Ariz. Fluorite is of common occurrence with the wolframites, but it is known to occur with scheelite at only one locality, the El Porvenir district, 18

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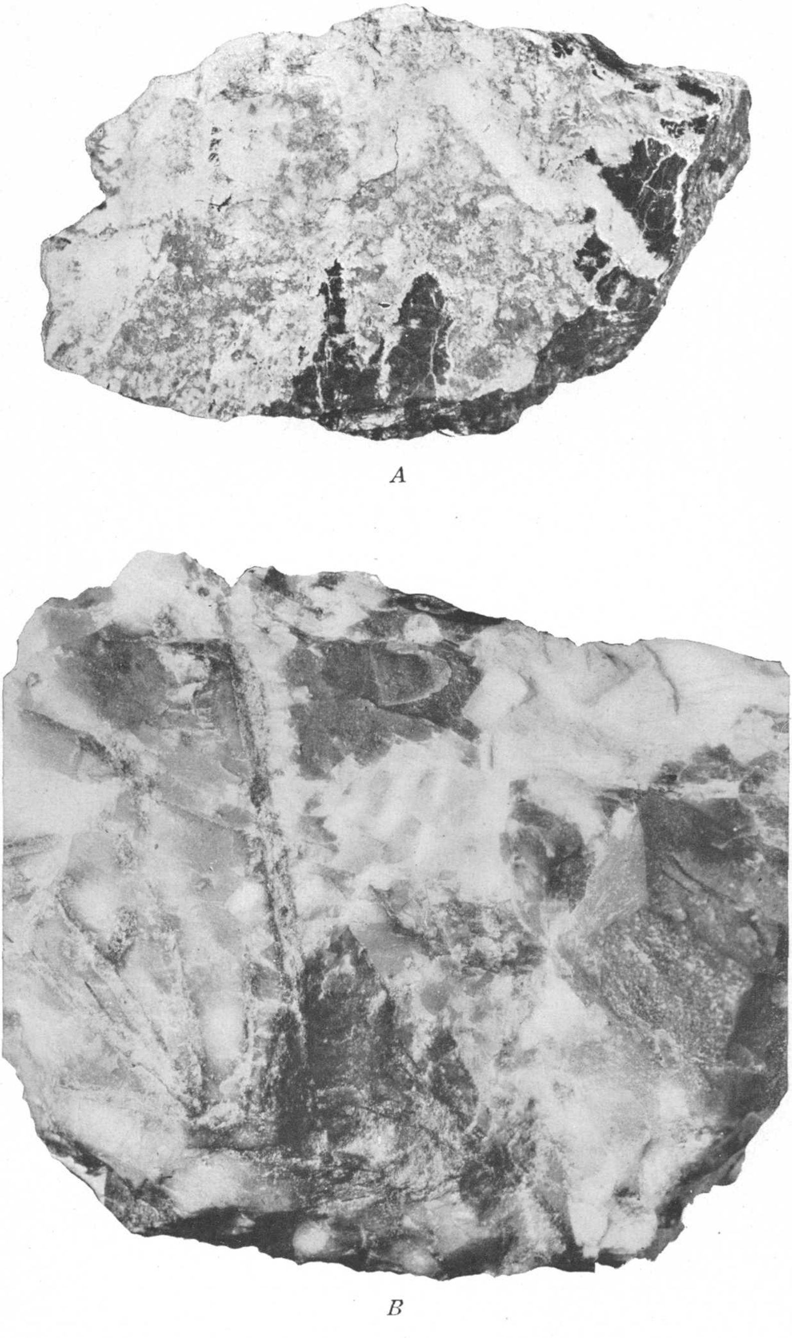
[1] See appendix.

[2] Lindgren, Waldemar, and Ransome, F. L., Geology and gold deposits of the Cripple Creek district, Colo.: U. S. Geol. Survey Prof. Paper 54, p. 127, 1906.



A. IRREGULAR MASSES OF STIBNITE IN QUARTZ GANGUE OF SCHEELITE VEIN, ATOLIA, CAL.
B. CAVITIES FORMERLY FILLED BY SLENDER CRYSTALS OF STIBNITE, NOW PARTLY FILLED BY PINKISH QUARTZ, IN QUARTZ GANGUE OF SCHEELITE VEIN, ATOLIA, CAL.

Both natural size.

A

B

A. HYDROUS IRON OXIDE REMAINING AFTER DECOMPOSITION OF FERBERITE FROM GOOD LUCK CLAIM, NEAR HILL CITY, S. DAK.

B. WOLFRAMITE (BLACK) AND CASSITERITE (GRAYISH BROWN) IN QUARTZ FROM BLACK METAL CLAIMS, NEAR HILL CITY, S. DAK.

miles northwest of Las Vegas, N. Mex., where green, white, and amethystine fluorite is found with scheelite.

Other fluorides are discussed under tourmaline, lepidolite, and topaz, of the silicates, and apatite and triplite, of the phosphates.

OXIDES.

Cassiterite.—Tin oxide (SnO_2) accompanies wolframite at very few places in the United States, but wolframite and, to a less extent, scheelite are common in tin veins. Cassiterite is about as hard as quartz, has a greasy luster, and is generally dark rosin-brown or nearly black, though exceptionally it is colorless, translucent white, creamy, gray, pinkish, or ruby-colored. It has a glassy fracture, and a very few specimens show a noticeable cleavage.

Cassiterite is found with wolframite in quartz veins near Hill City, S. Dak. (see Pl. XXIII, *B*), with wolframite and arsenopyrite on Irish Creek, Rockbridge County, Va., and is reported from scheelite veins near Mina, Mineral County, Nev., but the report has not been confirmed. On Tin Creek, a tributary of Lost River, 100 miles northwest of Nome, Alaska, wolframite is found close to cassiterite; in the Franklin Mountains, 15 miles north of El Paso, Tex., wolframite is found in small quantity in veins of cassiterite.

At Kuils River, South Africa, there is an association of minerals apparently very much like that at Hill City.[1]

Wolframite and cassiterite are commonly associated in Cornwall, Saxony, Austria, Spain, Queensland, Tasmania, Malay Peninsula, Burma, Siam, and the Shan States.

A considerable part of the world's annual output of tungsten is produced as a by-product of tin mines.[2] Not nearly so much scheelite as wolframite is found in tin ores, but perhaps the proportion is not much less than the proportion of scheelite in the total world's production of tungsten minerals.

Chalcedony.—Chalcedony is a form of quartz that does not break with the smooth, glassy fracture of common quartz, but that has a fracture resembling ground glass. By the eye alone no difference can be told between very fine grained quartz and chalcedony.

Quartz that appears to be chalcedonic is found in many parts of the veins of the Boulder area, in Colorado (Pl. XXIV, *A*), at Silverton, Colo., and at Atolia, Cal., but when examined microscopically it all proves to be merely fine-grained quartz. However, chalcedony mixed with opal forms a white coating over some of the ferberite crystals of the Boulder area.

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[1] Rumbold, W. R., The South African tin deposits: Am. Inst. Min. Eng. Trans., vol. 39, p. 783, 1909.

[2] For titles and brief abstracts of books, papers, and items on the association of cassiterite and tungsten minerals see Hess, F. L. and Eva, Bibliography of the geology and mineralogy of tin: Smithsonian Inst. Pub. 1987, 408 pp., 1912.

Opal.—Opal is a variety of quartz or silica that is combined with water. It is softer than quartz and breaks with a smooth, glassy fracture. The precious opal is made up of thin plates that refract or break up light so as to give "fire" effects, but most opal does not do this. Specimens sent by the Spanish Springs Mining Co. from Spanish Springs, at the south end of the Toquima Range, 7 miles southeast of Manhattan, Nev., contain brownish-yellow opal in masses half an inch to three-quarters of an inch across. As already stated, opal mixed with chalcedony forms a thin coating on ferberite crystals from the Boulder tungsten field.

Quartz.—Silica, silicon dioxide (SiO_2), is limpidly colorless, milky, yellowish, brown ("smoky"), or amethystine and is too hard to be scratched with a knife. Its specific gravity is 2.65. The streak is colorless or its color is like that of the quartz itself but fainter.

Quartz is the universal vein mineral. Nearly all waters that deposit vein materials deposit quartz with them, and it forms the larger part of most metalliferous veins. In tungsten veins the quartz is usually colorless or milky, but a vein near Loon Lake, Stevens County, Wash., carries some smoky quartz. In the veins of the tungsten area in the Boulder field much of the quartz resembles chalcedony and is of a greenish-gray color.

In veins that contain vugs quartz ordinarily forms projecting crystals. In some tungsten-bearing veins the quartz was deposited at the same time as the tungsten minerals; in others it was deposited without tungsten minerals; these were next laid down and then another deposit of quartz; and in the Clark Mountains, Cal., this deposit was in turn succeeded by that of another tungsten mineral, scheelite. (See Pl. XIII, *A*.)

Hematite.—The iron oxide known as hematite (Fe_2O_3) is a rather common and frequently a puzzling constituent of tungsten ores. It is generally dark steel gray to iron black, but at some places it has a reddish-brown tint, probably due to its alteration in part to limonite, the hydrous iron oxide. Its hardness ranges from 5.5 to 6.5—from a little less to a little more than the hardness of a pocketknife. Its specific gravity ranges from 4.2 to 5.3 and is less than that of the wolframites (7 to 7.5). Hematite occurs in tungsten veins in two principal forms—in scales or thin plates and in massive form. The plates range from microscopic size to an eighth of an inch or more across. The flat sides of most of the scales are bluish black. All hematites give a reddish-brown to cherry-red streak or powder, which distinguishes them from the wolframites, for which they are frequently mistaken. Specular hematite (specularite, hematite in scaly forms) occurs in parts of the ferberite veins of the Boulder tungsten field and greatly resembles fine-grained ferberite.[1] Speci-

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[1] See appendix.

A

B

A. FERBERITE WITH FINE-GRAINED QUARTZ HAVING THE APPEARANCE OF CHALCEDONY, FROM CONGER MINE, NEDERLAND, COLO.

B. POLISHED SPECIMEN OF SCHEELITE (ABOVE) WITH A THICK CRUST (BELOW) OF CALICHE (CALCIUM CARBONATE), FROM WICKARD MINE, NEAR ATOLIA, CAL.

Both natural size.

mens sent from the Yucca district of Arizona are remarkably like some of the "peanut ores" of the Boulder area. Many specimens of specular hematite are sent to the Survey under the impression that they contain tungsten.

CARBONATES.

Calcite, dolomite, ankerite, and siderite.—Carbonates are common in tungsten veins and grade into one another by stages so easy that it is impracticable to distinguish them except by chemical analyses. Calcite, lime carbonate ($CaCO_3$), is a mineral familiar to nearly all prospectors and miners as dog tooth spar when crystallized or as "lime" when it shows no outward crystal form. It is mistaken for scheelite only by the "tenderfoot" or by the beginner in prospecting. Its specific gravity is low, about 2.7; it is easily scratched with a knife (hardness, 3); and it may generally be easily cleft into parallel-faced six-sided shapes.

Siderite, iron carbonate ($FeCO_3$), is so similar to calcite that the molecules crystallize together as ferruginous calcite [$(Ca,Fe)CO_3$], which may contain a rather large proportion of iron, yet the mineral may be clear white, as it is in the gangue of the largest veins of scheelite at Atolia, Cal., or gray, as it is in other veins of the same region. It turns rusty when weathered. Veins at Hillgrove, New South Wales, have as outcrops a gossan or residue of iron oxide, probably due to the iron in the calcite.[1]

No dolomite, the calcium-magnesium carbonate [$(Ca,Mg)CO_3$], has been recognized by the writer in tungsten deposits but is reported to occur in them, and a number of analyses of scheelite show the presence of magnesium, which, however, may be contained in ankerite, the calcium-iron-magnesium carbonate [$(Ca,Fe,Mg)CO_3$].

In the tungsten deposits at Atolia, Cal., quartz is deposited along cleavage cracks in the calcite, so that if the calcite is dissolved with acid a skeleton of quartz is left, which shows the form, direction, and extent of the cracks. The scheelite of the deposit has largely replaced calcite, and polished specimens show the silica skeleton of the calcite that originally occupied the space. (See Pl. X, *A*.) Specimens from the Minerva district, near Shoshone, White Pine County, Nev., show the replacement of ferriferous calcite by scheelite, and Hill[2] reports the replacement of calcite by scheelite on the east side of the Ruby Range, 10 miles south-southwest of Ruby Valley post office, Elko County, Nev.

In weathered specimens calcite may be difficult to distinguish from scheelite by the eye alone, but in broken specimens the jagged sur-

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[1] Longbottom, W. A., Scheelite mining; Occurrence and treatment in New South Wales: Min. and Eng. Rev., vol. 3, p. 200, Sydney and Melbourne, 1911.

[2] Hill, J. M., Notes on some mining districts in eastern Nevada: U. S. Geol. Survey Bull. 648, pp. 62–63, 1916.

face formed by the visible parts of the cleavage planes of the calcite and the cleavage lines that may be seen on any flat cleavage surface will at once show the difference, as will the poorer luster and lower specific gravity. The application of any acid, even strong hot vinegar, to calcite will at once make it throw off bubbles of carbon dioxide.

Owing to its low specific gravity calcite is readily separated from scheelite in panning or milling.

SILICATES.

Feldspars.—Adularia, a potassium-aluminum silicate ($K_2O.Al_2O_3.6SiO_2$) is a variety of orthoclase feldspar which crystallizes in peculiar forms, many of the sections of which are rhombs. It is found in the ferberite veins of the Boulder tungsten field, but invariably in small quantity, and it is of little or no importance. Orthoclase and albite are reported from some foreign tungsten veins.

Beryl.—Beryl, a silicate of aluminum and the rare metal glucinum (commonly known as beryllium) ($3GlO.Al_2O_3.6SiO_2$), generally forms in six-sided prisms and may be white, buff, yellow, pink, or green. The transparent emerald-green variety is the gem stone known as emerald, the bluish-green variety is that known as aquamarine. Beryl has a hardness of 7.5 to 8, a little greater than that of quartz, and a specific gravity of about 2.7, practically the same as that of quartz. Nearly opaque buff beryl is found in a tin-tungsten vein on Irish Creek, Rockbridge County, Va. It is not known to have been found in other veins of the United States, though it occurs in many tungsten-bearing pegmatites. Dunstan states that it is one of the common minerals in tungsten deposits in Queensland.[1]

Chlorite.—Chlorite is a name for a group of mica-like minerals, most of which are green and can not readily be distinguished in the field. They occur usually in very small plates. Chlorite is found in a few tungsten-bearing veins but is not common in such veins in this country.

Muscovite.—Muscovite is the ordinary white mica, a hydrous potassium-aluminum silicate ($2H_2O.K_2O.3Al_2O_3.6SiO_2$). Muscovite that occurs in plates so small as to be nearly or quite microscopic is called sericite. In this form it is found in many quartz-tungsten veins, and in some, such as those near Hill City, S. Dak., the plates reach an eighth of an inch or more across. Its characteristics are well known; it has a glistening silvery appearance and is easily cleft into thin scales or leaves, which are flexible and elastic. It is easily scratched with the finger nail. Muscovite is the form of mica that is used in stoves and lamps and is erroneously called "isinglass."

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[1] Dunstan, B., Wolfram in Queensland: Under Secretary for Mines Ann. Rept. for 1903, p. 151, 1904. Also, Queensland Government Min. Jour., vol. 6, p. 334, 1905.

Lepidolite.—Lepidolite is a lithium-bearing mica, in general appearance much like muscovite, but it may be pink, red, lilac, lavender, or other colors. It is known in only one tungsten vein, that at Silvermine, Madison County, Mo.[1] Lepidolite is considered an almost typical pegmatite mineral and is rarely found in veins.

Topaz.—Topaz is a mineral containing aluminum, oxygen, fluorine, and silicon ($AlF_2.AlSiO_4$). It commonly occurs in nearly opaque or translucent masses, but may be limpidly colorless or transparently pale blue, pink, yellow, and other tints. It has a hardness of 8, so it will scratch quartz. It has a specific gravity of 3.4 to 3.65, a third greater than that of quartz.

It is found in fibrous masses an inch or more thick in the veins on Tin Creek, Lost River, 110 miles northwest of Nome, Alaska, and in microscopic crystals in specimens sent by John L. Gardiner from the Humbug district, Yavapai County, Ariz. It is common in tungsten-bearing veins in Queensland[2] and in veins in New South Wales.[3] Yellow topaz is found in "considerable amount" in the wolframite-bearing veins of Tavoy.[4] It is uncommon and of little importance in prospecting or mining in this country.

Tourmaline.—Tourmaline is a complex silicate of boron and aluminum with fluorine, iron, magnesium, sodium, potassium, or lithium, and in some specimens with other elements. Most iron tourmaline is black and most magnesium tourmaline is brown; the tourmalines found in American tungsten veins are of these colors. Tourmaline normally occurs in six-sided prisms, generally slender. It has a hardness of 7 to 7.6, equal to or slightly higher than that of quartz.

Black tourmaline is found with wolframite in veins on the Black Metal claims, a mile northeast of Hill City, S. Dak., and on the Black Horse claims near Daisy, Stevens County, Wash. Brown tourmaline in mats of slender, silky crystals is found with wolframite in specimens sent by Peyer & Gallup from the Copper Mountain (Picuris) mining district near Rinconada, N. Mex. In thin sections the tourmaline shows a beautiful brownish-orange color. In a specimen sent by Wilson Jones from a vein cutting schist in sec. 6, T. 30 S., R. 40 E., near Randsburg, Cal., tourmaline in microscopic crystals gives a black color to part of the calcite, which is so thoroughly impregnated with the tiny crystals that its color is changed. Under

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[1] Haworth, Erasmus, A contribution to the Archean geology of Missouri: Am. Geologist, vol. 1, pp. 294–295, 1888.

[2] Macdonald, A. R., The Queensland mining industry; Review of the year 1910; Wolframite, molybdenite, and bismuth: Queensland Government Min. Jour., vol. 12, p. 110, 1911.

[3] Carne, J. E., The tungsten mining industry in New South Wales: New South Wales Geol. Survey Mineral Resources No. 15, pp. 43, 44, and 93, 1912.

[4] Page, J. J. A., Remarks on E. Maxwell-Lefroy's "Wolframite mining in the Tavoy district, Lower Burma": Inst. Min. Met. Bull. 138, p. 47, 1916.

the microscope the crystals appear faintly blue. A specimen from Bolivia shows tourmaline, and the mineral is common in many foreign tungsten deposits.[1]

PHOSPHATES.

Apatite.—Apatite is of two general varieties, one containing fluorine, a calcium fluoride and phosphate, $CaF.Ca_4(PO_4)_3$, and one containing chlorine, a calcium chloride and phosphate, $CaCl.Ca_4(PO_4)_3$. Both varieties form six-sided crystals, which may be white or colored green, yellow, gray, flesh-red, red, or brown. Apatite has a hardness of 5, so is harder than fluorite or calcite but is easily scratched by a knife. Its specific gravity is about 3.2.

Small light-green masses of apatite one-eighth of an inch thick are found in the veins at Hill City, S. Dak. Small brownish-yellow prisms one thirty-second of an inch thick and white irregular masses an inch thick are found in and with scheelite in the Clifton district, Deep Creek Mountains, Tooele County, Utah. It is reported to occur in some deposits in western Nevada, but the Survey has not verified the reports. Apatite is an undesirable mineral in a tungsten ore, for it carries phosphorus, and phosphorus in any but the most minute quantities is ruinous to steel. It can be largely or wholly eliminated, however, by careful milling. Ordinarily 0.05 per cent of phosphorus is the uppermost allowable limit.

Hamlinite (?).—Practically all the ferberite ores of the Boulder tungsten field carry traces of phosphorus, which apparently come from a mineral found particularly in the highly siliceous ores but only in microscopic particles. The optical properties of these particles seem to correspond to those of hamlinite, a hydrous strontium-aluminum phosphate ($2SrO.3Al_2O_3.2PO_3.2P_2O_5.7H_2O$). Material sufficiently pure for a good quantitative analysis could not be obtained, but qualitative determinations of that in hand showed that it contained the elements of hamlinite, which is probably the phosphorus-bearing mineral of the Boulder field. It has not been found in other tungsten ores. It has about the same specific gravity as apatite (3.2) and is easily removed from the ores by fine crushing and good milling. Because of its presence rich hand-picked ores are not so desirable as milled concentrates of the same richness, for it will have been largely removed with the other gangue minerals in the milling process.

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[1] Bleeck, G. W. A., On some occurrences of wolframite lodes and deposits in the Tavoy district of Lower Burma: India Geol. Survey Rec., vol. 43, p. 69, 1913.

Dunstan, B., Wolfram in Queensland: Queensland Government Min. Jour., vol. 6, p. 334, 1905.

Granigg, B., and Koritschoner, J. H., Die turmalinführende Kupferkies-Scheelitlagerstätte am Monte Mulatto bei Predazzo (Südtirol): Zeitschr. prakt. Geologie, Jahrg. 21, p. 484, 1913.

Faribault, E. R., Structure of the tungsten deposits of Moose River, Nova Scotia: Nova Scotia Min. Soc. Jour., vol. 15, p. 62, 1910.

Bronckart, F., Le wolfram en Portugal: Soc. géol. Belgique Annales 1908, p. B–182, 1909.

Triplite.—Triplite ($3MnO.P_2O_5.MnF_2$), a manganese phosphate and fluoride, occurs as a flesh-pink mineral in small quantity with hübnerite in the Regan district, Nev.,[1] and a little has been noted with hübnerite in specimens from a deposit 8 or 10 miles north of Goffs, Cal. Its specific gravity is low, 3.79, about equal to that of quartz, so that it may be readily separated from tungsten minerals. Its hardness is 4 to 4.5.

MINERALS CONTAINING COLUMBIUM AND TANTALUM.

Columbium and tantalum minerals as such are unknown in tungsten-bearing veins in this country. Bleeck[2] states that columbite is found in all the wolframite-bearing veins in the Tavoy district, Burma, but no references to its occurrence in tungsten veins of other countries are known. Columbium and tantalum oxides are found in some American wolframites in quantities which reach more than 2 per cent, but the form in which the elements occur is unknown.

In this country columbium and tantalum oxides have been reported as follows:

Columbium and tantalum oxides in tungsten minerals.

	Per cent
Hübnerite from Ouray County, Colo., Cb_2O_5 (?)	0.05
Hübnerite from White Oaks, N. Mex., $(Cb,Ta)_2O_5$ (?)	Trace.
Wolframite from Irish Creek, Va., $(Cb,Ta)_2O_5$, etc	.96
Wolframite from Pioche, Nev., $(Cb,Ta)_2O_5$	.82
Wolframite from Cave Creek, Ariz., $(Cb,Ta)_2O_5$	2.20
Ferberite from Boulder County, Colo	(3)

Tantalum is reported to have been found in the wolframite of the Tip Top and Humbug districts of Arizona. The Survey has made no determinations of tantalum in ores from these districts, but as the ferberite from Cave Creek, Ariz., is rich in tantalum and columbium, the discovery of these metals in wolframites from other districts of the State would not be particularly surprising.

These metals have been reported to occur in wolframite or ferberite obtained from nearly a dozen places outside of the United States, in amounts ranging from traces to 1.22 per cent. From Lake Couchiching, Ontario, there is doubtfully reported 1.95 per cent of columbium pentoxide (Cb_2O_5).[4]

The slimes from the tin-dressing plants around Camborne, Cornwall, flow into Red River and by it are concentrated along its banks

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[1] Hess, F. L., and Hunt, W. F., Triplite from eastern Nevada: Am. Jour. Sci., 4th ser., vol. 36, pp. 51–54, 1913.

[2] Bleeck, G. W. A., On some occurrences of wolframite lodes and deposits in the Tavoy district of Lower Burma: India Geol. Survey Rec., vol. 43, p. 69, 1913.

[3] Columbium pentoxide (Cb_2O_5) present in small quantity.

[4] See Hess, F. L., and Schaller, W. T., Colorado ferberite and the wolframite series: U. S. Geol. Survey Bull. 583, pp. 18, 24–35, 1914, for analyses of wolframites.

and by the sea at Gwithian. Holloway[1] estimates that more than 100 tons of tungsten annually go to waste in these slimes. They contain also tantalum, columbium, uranium, vanadium, and molybdenum.

MINERALS FOUND IN TUNGSTEN-BEARING PEGMATITES.

The minerals of the pegmatites are ordinarily those of the parent rock mass. The commonest minerals are quartz, feldspar, and muscovite mica, and in the United States tungsten occurs in dikes composed of these minerals, especially in dikes that contain quantities of quartz so large that the dikes approach quartz veins in composition. Some pegmatites, however, carry a great variety of minerals, many of them rare. In pegmatites that contain a multiplicity of minerals, tungsten, like tin, seems to occur only in small quantity. In New South Wales many large masses of wolframite, one weighing 300 pounds, have been found in pegmatites that contain many other minerals, but the percentage of tungsten in the dikes as a whole seems to be low, and they are of doubtful value as a source of tungsten.[2] Considerable masses of wolframite have been taken from pegmatite of simpler composition in the Mount Carbine tungsten district, Queensland.[3] The following list of minerals found in the Etta dike, 1½ miles south of Keystone, S. Dak., shows how many minerals may be contained in a complex pegmatite.[4] The minerals indicated by italics occur in large quantity.

Albite.
Andalusite.
Apatite.
Arsenopyrite.
Autunite.
Barite.
Beryl.
Biotite.
Bismuth.
Cassiterite.
Chalcocite.
Columbite.
Corundum.
Epidote.
Graphite.
Griphite.
Grossularite.
Heterosite.
Ilmenite.
Lepidolite.
Lithiophilite.
Löllingite.
Melanite (andradite).
Microcline.
Molybdenite.
Monazite.
Muscovite.
Orthoclase.
Petalite.
Quartz.
Rutile.
Scheelite.
Scorodite.
Sphene.
Spinel.
Spodumene.
Stannite.
Strüverite.
Tourmaline.
Triphylite.
Triplite.
Wolframite.
Zircon.

Wolframite is the tungsten mineral most commonly found in pegmatites. In many dikes it is accompanied by small quantities of scheelite, and in a few pegmatites scheelite is the only tungsten mineral present. Like cassiterite (tin oxide), the tungsten minerals seem not to have crystallized in quantity in such rocks, even where

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[1] Holloway, G. T., The relation between the mineral and the chemical industries: Soc. Chem. Ind. London Jour., vol. 29, p. 59, 1910.

[2] Conder, Hartwell, The wolfram deposits of New England [New South Wales]: Min. Jour., vol. 78, pp. 170–171, 1905.

[3] Ball, L. C., The wolfram mines of Mount Carbine, North Queensland: Queensland Geol. Survey Pub. 251, p. 34, 1915.

[4] O'Harra, C. C., Mineral resources of South Dakota: South Dakota Geol. Survey Bull. 3, p. 64, 1902. This list has been somewhat altered in the light of more recent investigations.

they were in the solutions that accompanied the injected pegmatite, until after most of the mica, feldspar, and other minerals crystallized. No large production of tungsten has yet been made, at least in this country, from pegmatites, the term being strictly interpreted.

OUTCROPS OF TUNGSTEN VEINS.

The outcrops of tungsten veins resemble those of other veins, and their character depends on the geologic history of the country, the minerals of the veins, the composition of the country rock, and the climate. In those parts of the country over which glaciers have moved in comparatively recent geologic time the surface rock is generally planed down, so that though the veins may be harder or softer than the country rock they are not likely to rise above or to be depressed below the general level, for weathering may not have gone far enough to show much difference between veins and country rock. In unglaciated country the form of the outcrops of veins depends on a variety of factors.

In general, tungsten veins (among which are not classed pegmatite dikes or contact-metamorphic deposits) fall into three classes: Quartz veins, carbonate veins, and thin veins carrying comparatively little gangue.

Quartz veins of course resist weathering better than most rocks and stand somewhat above the country rock unless they have been so much shattered that water collects in cracks and by freezing disintegrates them rapidly, or unless they originally contained many comparatively soluble or easily altered minerals that have been removed by weathering, which thus produces cavities in which water freezes and breaks down the veins. Thus the barren quartz may form a prominent outcrop, whereas the ore shoots may weather down to or below the general surface.

Carbonate veins—that is, veins composed largely of carbonate minerals, calcite or the closely related calcium-magnesium-iron carbonates—disintegrate under weathering rather easily and are not likely to protrude above the country rock unless they contain considerable quartz. They are likely to be somewhat lower than the general level except where the country rock is limestone. None of the veins at Atolia, Cal., project above the ground because nearly the whole area is covered with desert débris, so that outcrops are difficult to find. Thin veins, like those of the Boulder field, are too weak to withstand much pressure from mud and débris and therefore conform to the general level.

Whether a vein projects above the surface or not depends almost as largely on the country rock as on the vein.

In general granitoid rocks, such as granite, granodiorite, and diorite, waste under weathering slowly but faster than quartz. Some such rocks, however, weather rapidly, especially where they have been altered by vein-forming solutions. Hübnerite veins are reported to stand as much as 10 feet above the surrounding granitoid rock at Camp Signal, 8 miles north of Goffs, Cal.[1] Schists usually weather faster and dolomite and limestone much faster than quartz veins. Thus at Patterson, Lemhi County, Idaho, quartz veins carrying hübnerite project as much as 30 feet above the schist surface on one side, though the schist on the other side of the vein is weathered away to a much less depth.[2] Some of the veins in the Snake Range, White Pine County, Nev., are reported to stand a number of feet above the surface, and those at Dragoon, Ariz., stand somewhat above the surface. Some of the wolframite-bearing pegmatite dikes that cut the schists near Hill City, S. Dak., stand 12 or 15 feet above the country rock.

There is a great difference in the way in which the different tungsten minerals stand weathering, and consequently in the quantity of them which may be left in the outcrops. The ferberite of the Boulder tungsten area remains unaltered, so the veins are generally about the same at the surface as at depth, and the pieces that have broken off the weathered vein remain in the soil and have formed valuable placers. Ferberite, near Hill City, S. Dak., weathers to a mass of iron oxide (Pl. XXIII, *A*), which may yet show a sheen along the original cleavage planes. Wolframite in the Kootenay Belle mine, near Salmo, British Columbia, in a cool, moist climate, weathers and leaves behind a deposit of tungstite.[3] (See Pl. XV, *B*.) No deposit so large is known in this country. In the Malay Peninsula and in Siam, where the climate is hot and wet, wolframite is found in placers with cassiterite. At Dragoon, Ariz., Round Mountain and Spanish Springs, Nev., and other places commercially valuable hübnerite placers have been formed by the weathering of veins. At Silverton, Colo., hübnerite is weathered from the quartz gangue, which contains the cavities it once occupied. In the Snake Range, Nev., scheelite weathers from the outcrops, leaving cavities in the quartz, though it also forms float.[4] Near Loon Lake, Wash., where the climate is comparable to that of Silverton, hübnerite forms float. Sulphides occur with the tungsten minerals both in the Snake Range and at Loon Lake. In both the wet country around Nome and the desert around Atolia and Randsburg scheelite forms placers.

Why tungsten minerals should decay in one place and not in another is not invariably clear. The difference does not seem to be due

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[1] Main, J. F., personal communication.

[2] Lind, J. G., Geology and tungsten deposits of the Patterson Creek district, Idaho, p. 8, 1912. (Private report.)

[3] Walker, T. L., Report on the tungsten ores of Canada: Canada Dept. Mines, Mines Branch, Pub. 25, p. 37, 1909.

[4] MacVichie, Duncan, personal communication.

to differences in climate, but probably decay is generally caused by the breaking down of accompanying sulphides, which form sulphuric acid that attacks the tungsten minerals. Differences in the physical structure of the minerals and the presence of impurities in the minerals may also cause some differences in weathering. The principal sulphides from which sulphuric acid may be formed by weathering are pyrite and chalcopyrite. Both form iron oxides, which stain other minerals and rocks, greatly disguising them. Copper carbonates also in some places cover scheelite and infiltrate along cracks in it, making it less easy to recognize. Manganese oxides weathered from the country rocks or even from hübnerite or triplite in a vein give a smutty coating to quartz and other vein minerals, which may make their identification more difficult.

DOWNWARD EXTENT OF TUNGSTEN VEINS.

A question in the mind of nearly every owner or operator of a tungsten mine or locator of a tungsten prospect is, "To what depth does the tungsten reach?" and the value of the property depends in large measure on the answer. Few tungsten mines have been worked to great depths, but the East Pool & Agar (Ltd.) mine at Carn Brea, Cornwall, England, has been worked below the 300-fathom (1,800-foot) level on the Great Lode. At these mines wolframite, cassiterite, arsenopyrite, and chalcopyrite are saved. On the Middle Lode work is being prosecuted at the 240-fathom (1,440-foot) level.[1] In the South Crofty property, which adjoins the East Pool and on which the same lodes are worked,

> The distribution of the wolfram is irregular; it is most abundant in the middle levels and can not be depended on below 245 fathoms (1,470 feet). The best lode is not payable below 205 fathoms (1,230 feet), at which level the average yield of tin and wolfram together is 23 pounds a ton [2,240 pounds]. A rise from this level in the western part of the mine showed as much as 40 pounds a ton. The average content of the ore crushed during 1914 was as follows (in pounds per ton): Tin, 20.66; wolfram, 3.63; arsenic, 22.67; copper and sundry products, 26.96; giving a total value at the average prices for the year of £1 2s. 9.72d. per ton of ore crushed.[2]

In the eastern part of the South Crofty property, known as "Bickford's," at the 310-fathom (1,860-foot) level the lode is apparently as rich as the average of other parts of the mine.

Of the scheelite deposits at Hillgrove, New South Wales, J. E. Carne says:[3]

> Whilst the individual lenses and thin veins of ore are extremely capricious in occurrence, there is no reason to doubt their persistence at great depths. In

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[1] Dewey, Henry, and others, Tungsten and manganese ores: Great Britain Geol. Survey Mem., Special reports on the mineral resources of Great Britain, vol. 1, pp. 20–21, 1915.

[2] Idem, p. 17.

[3] Carne, J. E., The tungsten mining industry in New South Wales: New South Wales Geol. Survey Mineral Resources No. 15, p. 49, 1915.

> fact, nature has already demonstrated this by exposing scheelite deposits in the sides and bed of Bakers Creek Gorge to a depth of 1,400 to 1,600 feet, or more. * * *
>
> This view is strengthened by the wonderful persistence of the extremely thin Smiths Gold Reef, in Bakers Creek Gorge, which outcrops about 1,500 feet below the level of Hillgrove, and which has been followed down in the Bakers Creek and Proprietary mines for 2,000 feet and still persists strongly.

Gray and Winters,[1] after studying the wolframite and molybdenite deposits in aplites at Yenberrie, Northern Territory, Australia, conclude that:

> The uniformity of the aplites in a rapidly varying granite mass indicates that the aplite is not a separation from the surface granite but from some underlying source; and the fact that their direction is that of the main and regional intrusions points to a reservoir controlled by regional rather than local forces.
>
> These conditions decidedly point to a considerable depth as the source of the aplite and quartz, and give to the ore deposits promise of a considerable persistence in depth.

At White Oaks, N. Mex., hübnerite has been found at a depth of 1,350 feet. In the Boulder field, Colo., no ferberite ores have been found at a depth greater than 900 feet, but the question of depth can not be considered as settled for the field. At the East Union mine, Atolia, Cal., the greatest quantity of ore was found on the eighth level (about 800 feet deep along the vein and about 400 feet below the surface vertically) and the mine still yields good ore at a depth of 1,000 feet along the vein, which is equivalent to a vertical depth of about 510 feet.

A study of the accompanying minerals in tungsten-bearing veins gives some basis for estimating the depth to which tungsten deposits may have extended below the surface at the time the deposits were formed. Tourmaline, topaz, cassiterite, beryl, arsenopyrite, and apatite are among the minerals that are usually considered characteristic of deposits that have been formed at considerable depths below the surface, and all are found in some tungsten deposits. Pegmatites, it is thought, were extruded from great depths, and the occurrence of tungsten minerals in pegmatites has been noted at several places in this bulletin (see pp. 58–59), as has the fact that many veins that carry tungsten minerals are evidently closely related to pegmatites in origin.

Lindgren, in writing of the ferberite veins of Boulder County, Colo., puts them in a class wholly different from veins closely related to the pegmatites. He says:[2]

> Although the filling of these veins is very different from that of the telluride veins at Eldora, there is unquestionably a strong resemblance between them

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[1] Gray, G. J., and Winters, R. J., Report on Yenberrie wolfram and molybdenite field: Northern Territory of Australia Bull. 15A, p. 3, 1916.

[2] Lindgren, Waldemar, Some gold and tungsten deposits of Boulder County, Colo.: Econ. Geology, vol. 2, p. 462, 1907.

> as far as the structure of the vein and sericitization of the country rock are concerned, and this leads to the belief that the tungsten veins are also a product of comparatively recent thermal activity, and that they are deposited at only a moderate depth below the original surface.
>
> Wolframite is found in pegmatite veins, in company with cassiterite and other minerals of rarer kind. More commonly it is found in quartz-filled veins similar to the ordinary gold quartz deposits of California. The tungsten deposits of Boulder County differ from both of these types.

Some ferberite veins, however, cut through or lie near pegmatite dikes, but the connection between the two may be accidental, and the veins are, at least in part, undoubtedly later.[1]

Different tungsten deposits may have been formed at different depths, but most tungsten deposits doubtless extend to depths as great as those reached by deposits containing other metals. Many tungsten veins, like veins carrying deposits of gold, silver, tin, copper, and other metals, will give out at shallow depths, and only the exceptional mine may be expected to yield ore of good quality in commercially valuable quantities to great depths. Probably not one in five hundred gold-bearing veins carries commercially valuable ore below a depth of 100 feet. Possibly tungsten veins may carry ore at depths greater than those reached by workable gold veins, but this possibility has not yet been demonstrated by actual developments.

In a general way the depths that are reached by gold-bearing veins are indicated by the length of their outcrops, but tungsten deposits whose outcrops are comparatively small seem to reach relatively greater depths, especially those that have pegmatitic characteristics. In Queensland pipes only a few feet in diameter that carry tungsten, molybdenum, and bismuth minerals have been worked to considerable depths.[2] Nothing like these tungsten-molybdenum-bismuth bearing pipes, however, is known in the United States.

In writing of the ferberite deposits of Boulder County, Colo., George[3] says:

> The ore is distributed along the veins in bunches and pockets or rarely shoots, and up to the present nothing has occurred to suggest that the downward distribution is less regular than the lateral. In fact, a considerable number of the best ore bodies have had greater vertical than lateral dimensions.

This statement applies also to the scheelite deposits at Atolia, Cal.

UNEVEN DISTRIBUTION OF TUNGSTEN IN THE VEINS.

It has often been said that tungsten veins are more erratic than veins carrying other metals, and that the distribution of the ore in them is more irregular, so that the deposits can not be depended

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[1] See appendix.

[2] Cameron, W. E., Wolfram and molybdenite mining in Queensland: Queensland Geol. Survey Rept. 188, p. 13, 1904. Anonymous, Wolfram mining in North Queensland: Australian Min. Standard, vol. 45, p. 614, 1914.

[3] George, R. D., The main tungsten area of Boulder County, Colo.: Colorado Geol. Survey First Rept., 1908, p. 85, 1909.

upon as well as deposits of other metals, but of this statement there is at present no proof. Most vein deposits carry their valuable minerals in shoots, and the erratic occurrence of the constituents of pegmatites is well known. The history of most gold, tin, silver, or other mines working on veins, except possibly those working in well-defined zones of reconcentrated ores, has been a history of the working out of one ore body after another. In most of the larger mines exploratory work is pushed along while the known ore bodies are being extracted. The precious-metal mines in which the ore bodies are very constant, such as those of the Rand, in the Transvaal, are not vein deposits in the ordinary sense of that term; they approach bedded deposits, in form at least, and so are not to be compared with vein deposits. The mine map that does not show a constant change in the metallic content of the veins is the record of a very exceptional mine, and many tungsten-bearing veins are at least as even in content as the average metal-bearing vein of other kinds.

WILL TUNGSTEN DEPOSITS GROW RICHER WITH DEPTH?

There is a widespread belief that most veins grow richer with depth and this fallacious belief has led to the expenditure of a great deal of money, labor, and time on worthless veins, and the constant repetition of this specious statement by many mistaken and some swindling promoters has encouraged the investment of money by the unknowing in the schemes.

A few valuable minerals, especially the sulphides of silver and copper, are leached by ground waters, carried downward, and redeposited at or below the level of the ground water, and by this process the veins are impoverished above and enriched below. Below the enriched zone the veins carry their normal content of minerals, which may be too low to be commercially valuable, although the enriched portion may have been a bonanza. It has often been remarked that the same processes may have operated on tungsten ores, and Surr[1] thought that this was possible.

Tungsten minerals decay from the outcrops of veins, in some places leaving behind small quantities of tungstite and ferritungstite. In other places the wolframites leave behind iron oxide. (See Pls. XV, *B*, and XXIII, *A*.) At Cave Creek, Ariz., cuprotungstite seems to have been formed by the decomposition of copper sulphides and ferberite and has spread through the rocks. At Hill City, S. Dak., the writer collected a specimen in which a little scheelite seemed to have been deposited in a crack that had been formed since the vein had been mineralized, and above this crack ferberite (wolframite?) had been weathered out.

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[1] Surr, Gordon, Tungsten deposits and surface enrichment: Min. World, vol. 30, p 19, 1909.

Stolzite and raspite are apparently secondary minerals, but their origin is obscure, and, like cuprotungstite, they have never been found in large quantity.

It therefore seems possible that there may be some downward enrichment of veins carrying cuprotungstite, scheelite, stolzite, and raspite, but no corresponding redeposition of the wolframites has, to the knowledge of the writer, ever been noted.

No enrichment of ferberite, hübnerite, or wolframite is believed to be possible, though some enrichment of scheelite may occur.

Chase[1] expresses the same view of the ferberite veins in the Boulder area, as follows:

> My observation goes to show that any ordinary depth is going to cut little figure with the ore occurrences. They are neither going to be better nor worse in depth. In other words, there is no evidence that I can see of any secondary enrichment or any different arrangement of the ore minerals after their original deposition. Many gold mines show an unusual high value on this account for the first 100 feet or so, and everybody knows there would be no commercial ore bodies in the "porphyry coppers" were it not for the secondary enrichment extending down a few hundred feet; they will all meet the lean primary ore at some depth. But I believe nothing of this kind has occurred with the tungsten, which exists as first deposited. The fact that the solutions came from great depths proves nothing, for I presume all ore bodies had their ultimate source in great depths. But what can be assumed is that the present manner of occurrence of the tungsten ore within 100 feet of the surface may be counted on for a repetition downward for 1,000 feet at least. The ore is and will be erratic. One day the face looks fine and to-morrow it gives one the blues.

WHERE TO PROSPECT FOR TUNGSTEN.

As has been stated, tungsten is invariably associated with granitoid rocks, but tungsten-bearing veins may, and many do, cut through sedimentary beds, such as sandstones (including quartzite, which is only a strongly cemented form of sandstone), limestones, schists, slates, and the varieties of these rocks. Some veins have also been found in tuffs (hardened beds of small volcanic fragments) and lavas overlying granite. Areas of any of these rocks close to granitoid outcrops are therefore those in which prospecting may meet with success.

Areas of dark igneous rocks, including serpentine, are unpromising, as are all the lavas, except such as may lie near granitoid rocks. No tungsten deposits are known to have been found in the very dark (basic) granitoid rocks, but it is not possible to say how far this fact may be used for generalization.

In most places the tungsten minerals set free by the weathering and erosion of the country rocks and the consequent exposure and breaking down of the veins form placers, many of them of consider-

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[1] Chase, E. E., An engineer's observations on the tungsten belt: Min. American, vol. 73, p. 4, 1916.

able extent, such as those of Queensland, Burma (Tavoy), and the smaller ones at Round Mountain and Spanish Springs, Nev. Such placers, of course, should ordinarily be looked for in stream beds, arroyos, or older accumulations of gravel. In places tungsten minerals may be traced by panning from the streams or gulch bottoms through the dirt of the hillsides to the vein from which they came. This is the old familiar method of the "pocket hunter" and has been successfully used at many places in tungsten prospecting.

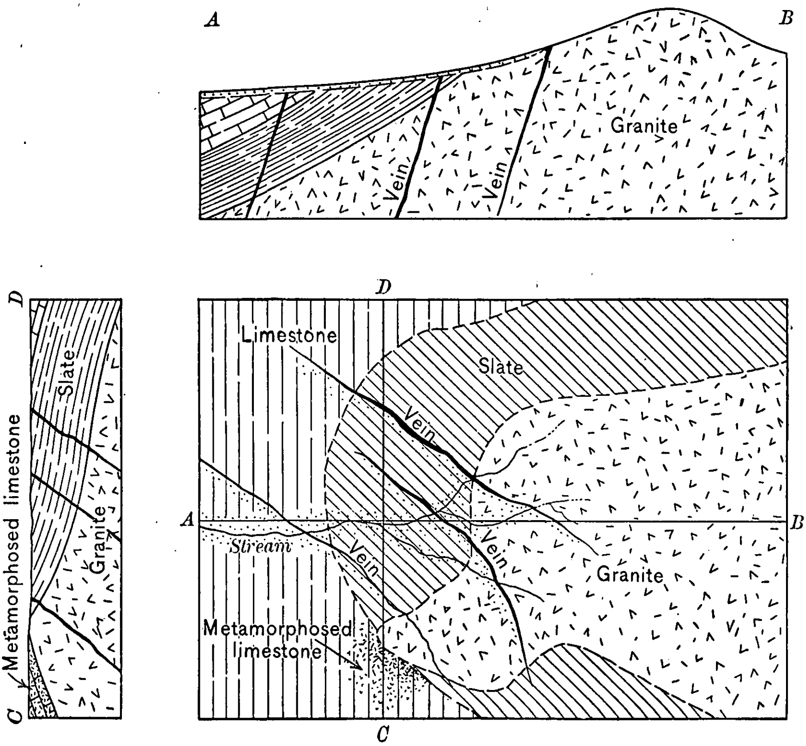


FIGURE 3.—Relation of tungsten veins to country rocks. Dotted areas along veins represent residual placers and along creeks stream placers. Contact-metamorphic deposits are represented as metamorphosed limestone.

Figure 3 shows the relation of rocks, tungsten veins, and placers.

FIELD TESTS FOR TUNGSTEN MINERALS.

GENERAL INSTRUCTIONS.

The tests given below are not new, but are easy and definite. They are given for the use of the man in the field, where conveniences may be few and new supplies may be far away, rather than for the man with a laboratory at hand. The writer has made these tests many times under conditions similar to those in the field and with materials that may be obtained at a minimum of expense and effort and may be carried in the field.

Simple acid test.—A piece of the mineral to be tested, half the size of a pea, should first be finely pulverized and then digested with hydrochloric (muriatic) acid. This test may be made in any receptacle that is not attacked by the acid—a tumbler, bottle, teacup, or test tube, but the liquid should be in as compact a bulk as possible, so that a test tube is best. If the mineral is scheelite the digestion will need to be carried on only a few minutes, but wolframite, hübnerite, or ferberite should be boiled for 10 to 30 minutes or be heated to a lower temperature for a longer time. If the specimen tested contains tungsten minerals a yellow powder, tungsten trioxide (WO_3), will be produced, though the color may be masked by iron or other impurities. On the addition of metallic zinc the solution will turn indigo blue if sufficient tungsten trioxide has been formed. The depth of the color, and even the color itself, will depend largely on the extent of the digestion and the quantity of tungsten in the specimen tested. If only a little tungsten trioxide has been formed the blue will be light, or even indistinguishable, and will be followed by violet and later by brown. It may even happen that no color is shown, but the powder itself will turn blue. If a considerable quantity of the trioxide has been formed the blue of the solution will be very deep and the violet will probably not appear, a muddy brown color succeeding the blue more or less quickly.

The fusion test.—For a test of scheelite the use of acid alone is very satisfactory, but for the wolframites it does not serve so well, because they are not rapidly attacked by hydrochloric acid. A fusion test is simple and in general may be performed in less time than a test that requires boiling and digesting with acid alone, and the results are more positive.

The test consists in powdering a piece of the mineral (a piece one-fourth the size of a grain of wheat is large enough), fusing it in a soda bead, digesting the bead in hydrochloric acid, and adding zinc to the acid solution, by which the characteristic blue color is obtained.

To make the bead, a platinum or iron wire is bent into a loop about one-eighth of an inch across, moistened to make the soda adhere, and dipped into sodium carbonate or sodium bicarbonate (ordinary bicarbonate, the baking soda of the kitchen, is as good as any), then held in a flame for two or three minutes to sinter slightly, and is then fused with a blowpipe flame. It is much easier to fuse the soda after it is sintered, for it is then not so liable to be blown from the loop by the flame of the blowpipe.

When the bead is fused it is dipped into the powdered tungsten mineral and again fused before the blowpipe.

After thorough fusion the bead is plunged into a mixture composed of half hydrochloric acid and half water. This mixture is heated over the flame until the bead is dissolved. If tungsten is present the bead, as it dissolves, usually takes a bright-yellow color from the tungsten trioxide formed. After the bead is dissolved zinc is added and if tungsten is present an indigo-blue color appears.

NECESSARY MATERIALS.

Wire.—Platinum is preferable for the wire because it is not attacked by single acids. However, it is very expensive, costing from two to more than five times as much as gold, and it is attacked by sulphur and alloys easily with some of the metals. Iron wire is a good substitute, and its cost is negligible. A piece of wire from a broom handle will do well, though finer, softer wire is preferable on account of the greater ease with which it can be heated and worked. Lengths of 5 or 6 inches, which may be put in a test tube and easily taken out without inverting the tube, are convenient. Copper wire may be used, but it conducts heat so rapidly that it adds greatly to the difficulty of fusion.

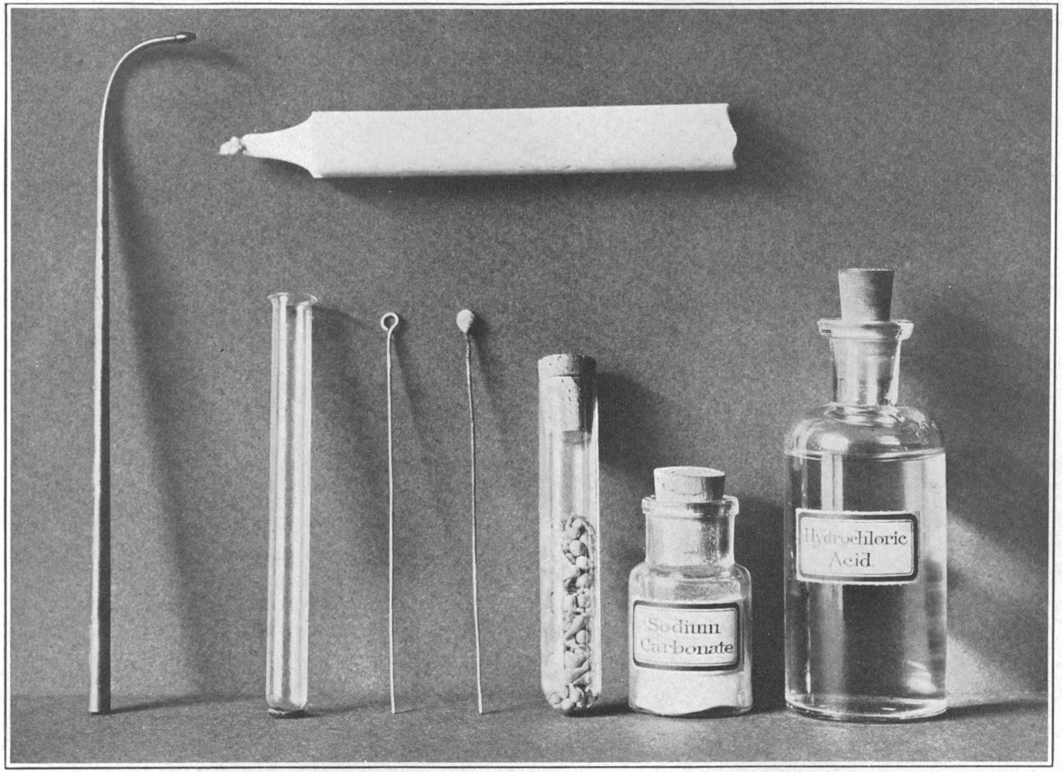
Flame.—A candle furnishes an easily usable flame, is easily carried, is in stock at every metal mine, and can be purchased at almost any store. A small kerosene lamp may be used, and paraffin or alcohol lamps are better than either, but are more troublesome to carry and for the alcohol lamp a special supply of fuel is necessary.

Blowpipe.—The simple brass blowpipe is sufficient and is cheap. The hole in the tip should be small and the pipe should be about 10 inches long in a direct line from the tip to the mouth. Some blowpipes have a slipjoint in the middle and can be taken apart and more easily carried.

Test tubes.—Test tubes 4 inches long and half an inch in diameter are of convenient size. They are inexpensive and take up little room. Six such tubes and six smaller tubes that nest inside of them make a good supply, weigh but little, and are of small bulk. It is much easier to make a test in one of these tubes than in other receptacles, because of the compact bulk of the liquid and because a minimum quantity may be used.

Acid.—Concentrated hydrochloric acid, preferably chemically pure, should be used, as more can be carried in the same bulk than of the dilute acid, and it can be diluted as needed. A rubber-stoppered bottle is best for carrying it, as glass-stoppered bottles that will not leak are difficult to get and corks are rapidly destroyed by the acid. Do not use too much acid. Ordinarily, half an inch in a test tube is more than sufficient, and to this quantity about as much water should be added.

Zinc.—Zinc is used to generate hydrogen, which is set free from the hydrochloric acid when it attacks the zinc. The hydrogen then takes oxygen from the yellow tungsten trioxide, leaving the blue oxide. Almost any substance which sets hydrogen free may be used instead of zinc, but zinc is the best, for it is easy to obtain, acts more rapidly than other easily obtained metals, and is cheap. Tin, solder (an alloy of tin and lead), or sheet tin may be used as substitutes. Zinc may be obtained as shavings, shot, granules, sheets, or sticks.



MATERIALS NECESSARY FOR TESTING TUNGSTEN MINERALS.

From left to right: Blowpipe, candle (above), test tube, iron wires (one shows soda bead), zinc shot, sodium carbonate, hydrochloric acid.

Granulated and shot zinc are the handiest. Granulated zinc may be made by melting, cooling almost to the solidifying point, and then pouring into some vessel in which it may be shaken sharply while it is hardening. Solder in the form of wire may be bought from any electrical supply firm and makes a good, easily carried substitute. A piece from a tin can works fairly well and may be made to do when better material is unavailable.

The materials necessary for the tests that have been described are shown in Plate XXV.

APPROXIMATE DETERMINATION OF PERCENTAGE OF TUNGSTEN IN ORES.

The miner may not be able to make chemical determinations of the percentage of tungsten or tungsten trioxide in his ore, because he lacks both the laboratory appliances and the technical knowledge and skill, but under some conditions he can make rough tests by taking the specific gravity of the ore, especially if the ore contains no other heavy metals and if the gangue is of nearly the same specific gravity in all parts of the deposit. A rough method used in the Mount Carbine district, Queensland, for estimating the richness of the ore mined is described by Lionel C. Ball:[1]

> The "gougers" gage of specific gravity is the 1-pound tea tin, which is 4½ inches cube, and the greater the weight of a tin full the higher grade the wolfram is considered, 14 pounds being the maximum. Some of the Carbine wolfram (Iolanthe) is said to weigh only 10 pounds to the tin, but the Little Nell runs 12 pounds. It has also been noticed that the coarser the grain of the concentrate the higher the specific gravity, there being a difference of one-half to 1 pound per tin in favor of the grains one-half inch in diameter as against fines. Further, Mr. West assures me that the wolfram from the deeper ground is certainly of greater specific gravity than that from the surface. These facts are probably to be accounted for by the perfect cleavage of the mineral resulting in open partings during weathering or crushing.

A somewhat better method has been used by A. D. Cox at the Union Hill mine, Grass Valley, Cal., where scheelite is mined with gold.[2]

> Mr. Cox's method of grading the scheelite for shipment to the buyer is as follows: The scheelite ore is dried, cobbed, and picked. As is usual with most scheelite ores, what is apparently pure scheelite will be seen, if examined closely, to contain minute stringers of quartz. The specific gravity of chemically pure scheelite (containing 80.5 per cent of WO_3) is 6, that of quartz about 2½ [really about 2.65]. The specific gravity of a piece of apparently pure scheelite was determined by test and found to be 5.42, showing the presence of a small amount of quartz as an impurity.
>
> By proportioning the specific gravities of scheelite and quartz it was computed that "pure" scheelite, as found in this mine, contains 84 per cent scheelite and 16 per cent quartz, which means an estimated amount of 67.6 per

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[1] Ball, L. C., Wolfram mines of Mount Carbine, No. 1: Queensland Government Min. Jour., vol. 14, p. 70, 1913.

[2] McDonald, P. B., Scheelite mining and grading: Min. and Sci. Press, vol. 112, pp. 40–41, 1916.

cent of WO_3. Continuing this computation, it was determined that ore that looked to be three-fourths (by volume) of "apparent" scheelite, as judged by the man sorting it, contains 58 per cent of WO_3; that one-half "apparent" scheelite contains 46 per cent of WO_3; that one-third "apparent" scheelite contains 35 per cent of WO_3; that one-fourth "apparent" scheelite contains 28 per cent of tungstic acid. These figures seem high, but the apparent discrepancy is due to the high specific gravity of scheelite as compared with that of quartz, it being remembered that the sorting is done by volume.

In the first lot that was shipped, the mine estimate of its No. 1 grade, as averaging 65 per cent of WO_3, checked closely with the analysis of the buyer, which was 65.4 per cent. The second grade, which was judged at the mine to be 50 per cent of WO_3, proved to be 45.7 per cent. The third grade, estimated at the mine at 25 per cent of WO_3, ran 26.2 per cent. In the sorting for shipment at the Union Hill mine the No. 1 grade is usually made up of apparently pure scheelite; the No. 2 grade embraces the picked ore between apparently pure scheelite and one-half apparent scheelite by volume. The proportions of the No. 2 grade would thus lie between 46 and 67.6 per cent WO_3; the final percentage is adjusted after looking it over carefully and would be probably nearer to 46 than to 67.6 per cent rather than the numerical average, because there is usually more ore slightly above 46 per cent than there is slightly below 67.6 per cent. The No. 3 grade is between one-eighth and one-half apparent scheelite judged by volume. The usual grades shipped are: First, 65 per cent; second, 50 per cent; third, 25 per cent.

Mr. Cox's figures on specific gravities and volumes are as follows:

With three-fourths apparent scheelite by weight, the other one-fourth assumed to be quartz:

0.75×5.42 (specific gravity apparent scheelite)	4.06
0.25×2.5 (specific gravity quartz)	.63
Specific gravity of specimens	4.69

Proportion of apparent scheelite by weight, 4.06÷4.69=87 per cent.

Proportion of WO_3, 0.87×0.676 (percentage of WO_3 in apparent scheelite)=58.8 per cent.

With two-thirds apparent scheelite by volume, the other one-third assumed to be quartz:

0.67×5.42	3.63
0.33×2.50	.82
Specific gravity of specimens	4.45

Proportion of apparent scheelite by weight, 81.5 per cent.

Proportion of WO_3 in specimen, 0.815×0.676=55.1 per cent.

With one-half apparent scheelite by volume, the other one-half assumed to be quartz:

0.5×5.42	2.71
0.5×2.50	1.25
Specific gravity of specimens	3.96

Proportion of apparent scheelite by weight, 68.3 per cent.

Proportion of WO_3 in specimen, 0.683×0.676=46.2 per cent.

With one-third apparent scheelite, the proportion of WO_3 is 35 per cent.
With one-fourth apparent scheelite, the proportion of WO_3 is 28 per cent.
With one-fifth apparent scheelite, the proportion of WO_3 is 24 per cent.
With one-sixth apparent scheelite, the proportion of WO_3 is 20.3 per cent.
With one-eighth apparent scheelite, the proportion of WO_3 is 16 per cent.

The Wolf Tongue Mining Co. originated a method which has been used by it and others on the ferberite ores of the Boulder field with excellent results, and the constants used there have been found serviceable in other fields. The mode of operation is as follows:

The articles needed are a flask holding about 1,500 cubic centimeters of water and scales weighing in grams up to 3 or 4 kilos. The flask is counterbalanced, then 1,500 grams of water is weighed into it and the height marked on the neck.

For determinations, 1,300 grams of water is weighed into the flask and then dry ore is poured in until the water is raised to the 1,500-gram (c. c.) mark. This means, of course, that the ore occupies 200 cubic centimeters and that an equal bulk of water weighs 200 grams. The weight of the water in the flask, 1,300 grams, is subtracted from the total weight, and the difference, which is the weight of the ore, is divided by 200 grams, the weight of the water displaced, thus giving the specific gravity, which is compared with a table giving the equivalent percentage of WO_3.

At the Wolf Tongue mill the table has been elaborated so that weights may be directly read into percentages by referring to the table, as shown below.

Percentage of tungsten trioxide indicated by weights of 200 cubic centimeters of ferberite ore plus 1,300 cubic centimeters of water, in Boulder field, Colo.

Weight of ore and water (grams).	Specific gravity corresponding to weight of ore.	Specific gravity for given percentages of WO_3 in ore.	Percentage of WO_3 in ore.
1,815	2.575		
1,820	2.600		
1,825	2.625	2.650	
1,830	2.650	2.650	
1,835	2.675		
1,840	2.700		
1,845	2.725	2.724	1
1,850	2.750	2.748	2
1,855	2.775	2.772	3
1,860	2.800	2.796	4
1,865	2.825	2.821	5
1,870	2.850	2.847	6
1,875	2.875	2.873	7
1,880	2.900	2.899	8
1,885	2.925	2.925	9
1,890	2.950	2.951	10
1,895	2.975	2.979	11
1,900	3.000	3.007	12
1,905	3.025	3.035	13
1,910	3.050	3.063	14
1,915	3.075		
1,920	3.100	3.096	15
1,925	3.125	3.129	16
1,930	3.150	3.162	17
1,935	3.175		
1,940	3.200	3.195	18
1,945	3.225	3.228	19
1,950	3.250		
1,955	3.275	3.263	20
1,960	3.300	3.296	21
1,965	3.325	3.329	22
1,970	3.350	3.362	23
1,975	3.375		
1,980	3.400	3.395	24
1,985	3.425	3.432	25
1,990	3.450		
2,000	3.475	3.471	26
2,005	3.500	3.510	27
2,010	3.525		
2,015	3.550	3.549	28
2,020	3.575		
2,025	3.600	3.588	29
2,030	3.625	3.629	30
2,035	3.650		
2,040	3.675	3.673	31
2,045	3.700		
2,050	3.725	3.717	32
2,055	3.750	3.761	33
2,060	3.775		
2,065	3.800	3.805	34
2,070	3.825		
2,075	3.850	3.850	35
2,080	3.900	3.899	36
2,085	3.925		
2,090	3.950	3.948	37
2,095	3.975		
2,100	4.000	3.997	38
2,105	4.025		
2,110	4.050	4.046	39
2,115	4.075		
2,120	4.100	4.094	40
2,125	4.125		
2,130	4.150	4.155	41
2,135	4.175		
2,140	4.200	4.211	42
2,145	4.225		
2,150	4.250		
2,155	4.275	4.267	43
2,160	4.300		
2,165	4.325	4.323	44

Percentage of tungsten trioxide indicated by weights of 200 cubic centimeters of ferberite ore, etc.—Continued.

Weight of ore and water (grams).	Specific gravity corresponding to weight of ore.	Specific gravity for given percentages of WO_3 in ore.	Percentage of WO_3 in ore.	Weight of ore and water (grams).	Specific gravity corresponding to weight of ore.	Specific gravity for given percentages of WO_3 in ore.	Percentage of WO_3 in ore.
2,170	4.350			2,340	5.200		
2,175	4.375	4.383	45	2,345	5.225		
2,180	4.400			2,350	5.250		
2,185	4.425			2,355	5.275	5.266	57
2,190	4.450	4.448	46	2,360	5.300		
2,195	4.475			2,365	5.325		
2,200	4.500			2,370	5.350	5.355	58
2,205	4.525	4.513	47	2,375	5.375		
2,210	4.550			2,380	5.400		
2,215	4.575	4.578	48	2,385	5.425		
2,220	4.600			2,390	5.450	5.444	59
2,225	4.625			2,400	5.475		
2,230	4.650	4.643	49	2,405	5.500		
2,235	4.675			2,410	5.525		
2,240	4.700	4.709	50	2,415	5.550	5.553	60
2,245	4.725			2,420	5.575		
2,250	4.750			2,425	5.600		
2,255	4.775	4.783	51	2,430	5.625		
2,260	4.800			2,435	5.650	5.639	61
2,265	4.825			2,440	5.675		
2,270	4.850	4.858	52	2,445	5.700		
2,275	4.875			2,450	5.725		
2,280	4.900			2,455	5.750	5.745	62
2,285	4.925	4.933	53	2,460	5.775		
2,290	4.950			2,465	5.800		
2,295	4.975			2,470	5.825		
2,300	5.000	5.008	54	2,475	5.850	5.851	63
2,305	5.025			2,480	5.875		
2,310	5.050			2,485	5.900		
2,315	5.075	5.088	55	2,490	5.925		
2,320	5.100			2,495	5.950	5.957	64
2,325	5.125			2,500	6.000		
2,330	5.150			2,505	6.025		
2,335	5.175	5.177	56	2,510	6.050	6.060	65

The figures given are, of course, not exact specific gravities but are approximations close enough to give valuable data as to the probable metallic content of the ore. Such a method is applicable wherever there are no other heavy minerals in the ore and wherever the gangue is of fairly constant composition. Corrections would have to be made for use with particular ores. For example, the specific gravity of the Boulder ferberite is 7.499, or, say, 7.5, and the specific gravity of scheelite is about 6, so that for equally high percentages the scheelite ore, if free from heavy minerals, such as galena, pyrite, and hematite, will have a somewhat lower specific gravity.

J. J. Runner[1] has described experiments in determining the percentage of WO_3 present in wolframite and scheelite ores by measuring the specific gravity and has constructed curves, largely interpolated (see fig. 4), to show the relations between the values. Very small quantities of ores were used, and comparatively few points on the curves were determined.

A beautifully simple process used in the Atolia district and said to give excellent results is briefly described as follows:[2]

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[1] Runner, J. J., Specific method for tungsten analysis: Min. and Sci. Press, vol. 133, pp. 11–13, 1916.

[2] See appendix.

A graduate with a scale reading to 1,000 cubic centimeters is filled with water to the 500 cubic centimeter mark. Into it a weighed quantity of ore, about 500 grams, is poured and a reading again taken. The difference represents a quantity of water equal in bulk to that of the ore. A cubic centimeter of water at 4° C. (38° F.) weighs a gram, so that the water displaced may be read as grams instead of cubic centimeters. Dividing the weight of the ore by this weight gives the specific gravity, and by comparison with a table similar to that given for ferberite ores or a diagram like that of Runner's the approximate percentage is at once obtained.

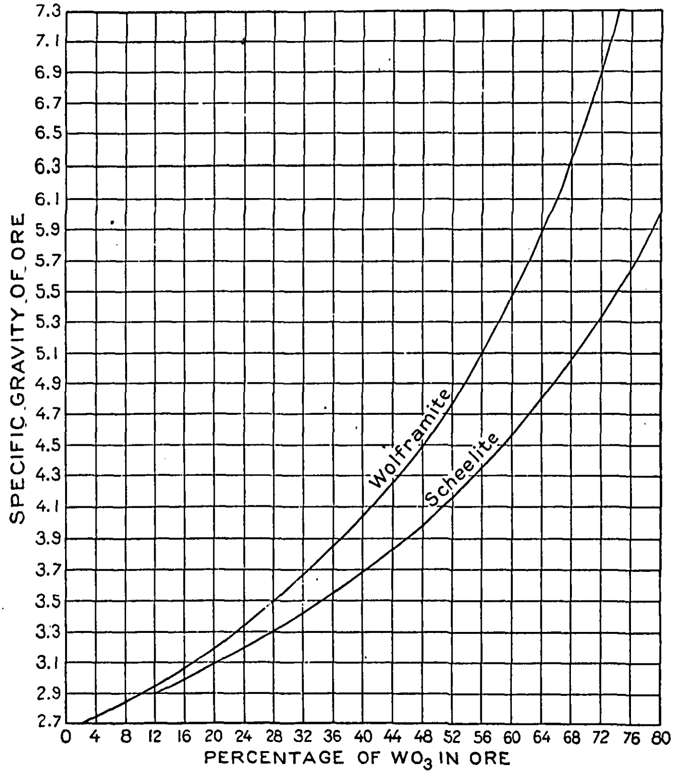

FIGURE 4.—Curves showing the relations between the specific gravity of tungsten ores and the percentage of contained WO_3. (After J. J. Runner.)

In all the determinations of specific gravity in which water is used trouble is had in thoroughly wetting the tungsten ore. Unless the ore is boiled air bubbles persist and the results are by so much made less reliable. To avoid this trouble the method followed in obtaining the specific gravity of cement is employed—that is, kerosene or benzene (62° naphtha) is used as a comparative medium. If the ore is dry the oil wets it immediately, and the method is said to give very accurate results, especially for ores carrying more than 30 per cent WO_3. The method as applied to cement is carefully described by T. B. Stillman.[1]

QUALITY OF ORE DEMANDED BY USERS.

Inquiries were addressed by the Geological Survey to firms known to be reducing tungsten ores, asking what, for their purposes, was the relative desirability of the tungsten-ore minerals, the impurities most hurtful, and the limiting percentages of impurities that would be accepted.

Eight firms courteously gave the desired information in considerable detail, and another with less detail.

Of these firms, one reduces its ores by fusing with sodium carbonate (Na_2CO_3), leaching with water, separating tungsten trioxide (WO_3) by hydrochloric acid, and reducing the trioxide to a metallic powder; two reduce the ores by other wet chemical processes; two use both the sodium carbonate fusion process and direct reduction in an electric furnace; two use an electric furnace only; one uses processes in which the ores are first treated with wet chemicals and reduction is then completed in an electric furnace. Another firm, the Crucible Steel Co., has in use a number of processes, part of which are covered by the Johnson patents.[2]

By the sodium carbonate fusion process only powdered metallic tungsten is obtained. One of the other wet chemical processes produces powdered tungsten and another makes powdered ferro-tungsten. The electric furnaces produce only ferro-tungsten.

Most of the processes used for reducing tungsten from its ores also partly or wholly reduce nearly all the metallic and some other impurities in the ores, and these impurities are carried with the tungsten into the steel to which it is added. For such use iron makes no difference, but a number of other elements are not wanted, either because, like copper and phosphorus, they are detrimental to the steel or because, like manganese, if they are wished in the steel they can be added more advantageously in some other way. Objectionable impurities found in tungsten ores are antimony, arsenic, bismuth, copper, lead, manganese, nickel, tin, zinc, phosphorus, and sulphur. Few of these occur in large quantity in ores found in this country. Copper is perhaps the commonest hurtful impurity, and therefore most is said about it, but ores from some foreign countries contain nearly all the impurities mentioned. During the early part of 1916 tungsten ores were so eagerly sought that nearly all offered were bought with little objection to impurities, but under more normal conditions consumers are much more particular.

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[1] Stillman, T. B., Engineering chemistry, 4th ed., pp. 343–348, 1910.

[2] Johnson, C. M., U. S. patents 964868, 964869, 964870, 964871, 977096.

The wet chemical processes give more opportunity to get rid of most impurities than the electrolytic process, so that companies using wet chemical processes are, as a rule, though not uniformly, least particular about the ores they buy. Two of the firms that use wet chemical processes buy tungsten ores almost without regard to the impurities present, but one objects to more than 2 per cent copper, and both buy ores containing as little as 20 per cent WO_3.

Only the one firm mentioned is known that does not object to copper in any grade of ore. Another will take cupriferous ore if "the content of WO_3 is sufficiently high." The others either will not take copper-bearing ore when other ores are to be obtained or set limits of 0.2 to 2.0 per cent copper and not less than 50 per cent WO_3, except that one firm will take ores that carry 5 per cent or more copper, for such a percentage will pay for separation.

Two companies take ores without regard to impurities other than copper, provided the content of WO_3 is sufficiently high. Most of the companies object to tin, sulphur, phosphorus, antimony, arsenic, bismuth, lead, and zinc, two of them object to manganese, and one to nickel. The last company referred to set extreme limits of 0.25 per cent for phosphorus, 0.25 per cent for nickel, 6.0 per cent for manganese, and a trace of arsenic.

As to the different tungsten ore minerals—ferberite, wolframite, hübnerite, and scheelite—two companies using wet chemical processes reported that they made no discrimination; a company using both processes reported that it made no discrimination if the ores carried more than 60 per cent WO_3; one company uses ferberite and scheelite and will not use wolframite or hübnerite; another prefers scheelite but will take any tungsten ore mineral; a user who does not make steel and whose product does not enter into steel also prefers scheelite. Three others gave their estimates of the comparative values as follows (the estimates being stated in the same order): If ferberite can be bought at $7 per unit then wolframite is worth $7, $6.30, $6.25; hübnerite, $6.50, $5.60, $6.25; scheelite, $6, $6.60, $6.50.

So far as can now be learned, the foreign buyers are quite as various in their demands as the domestic users and are in general more strict in the limits set, and they also demand a purity of 65 to 70 per cent WO_3, which means loss in concentration, for ores can not ordinarily be concentrated to so high a percentage without great waste in slimes.

Brokers are naturally ruled by the consumers to whom they sell and make the same restrictions as to quality of the ores bought.

From the very different ways in which the ores are valued by different buyers, it will be seen that, in general, a seller should know the market well, especially what the different buyers will pay, before disposing of his product.

APPENDIX.

Note 1, p. 34. Yellowish minerals which owe their color to iron and contain no tungsten coat tungsten minerals in many places and are frequently mistaken for tungstite. Such a substance is found in a number of the ferberite mines of Boulder County, but, unlike tungstite, it is soluble in hydrochloric acid and is unaffected by ammonia. No tungstite is known to have been found in the Boulder field.

Note 1, p. 37. The same remarks apply to gneiss, which may be considered as a very coarse schist. Thus in the Boulder County tungsten field the ferberite veins that lie in the gneisses are rarely of value, though the veins may be rich in the adjoining granite or along a contact between granite and gneiss.

As used in this bulletin the term schist indicates a metamorphic rock in which the minerals are disposed in parallel planes so as to give it a distinct, fairly closely spaced cleavage. In gneiss also the minerals, or a part of them, usually the dark minerals, are disposed in parallel planes; but gneiss has a poor cleavage or none at all.

Note 4, p. 39. Hugh Watts, the well-known assayer of Boulder, Colo., says that hübnerite has been found in small particles in roscoelite, the vanadium mica, on a claim on Governor Hill, on the northwest side of Left Hand Canyon, near Jamestown, Colo. This locality is at the northeast side of the Boulder tungsten field. Roscoelite, therefore, is also to be added to the list.

Note 1, p. 40. The remarks on quartz in the Boulder veins apply only to the ordinary varieties of milky or clear quartz. In many of the veins in the Boulder field there is a considerable quantity of "horn," or "horn rock," as it is locally known (from its resemblance to horn), that is a very fine grained quartz. It is partly a vein deposit and partly formed by the replacement of granite. In one deposit it reached a width of 10 feet and was cut by thin veins of very fine grained ferberite. The "horn" is usually gray, but some is white and some reddish. It is usually older than the ferberite but is in part of the same age.

In the Atolia field a somewhat similar form of quartz is found in the scheelite veins, but in smaller quantity.

Note 2, p. 46. A small specimen from the dump of the Wild Cat Leasing Co.'s workings at White Oaks, N. Mex., is composed of hübnerite penetrated by tiny crystals of gold.

In the Logan mine at Crisman, Boulder County, Colo., free gold has been found embedded in ferberite.

Note 1, p. 48. Pyrite is becoming much more plentiful in some of the ferberite veins of Boulder County as depth is reached, and it forms a considerable part of a few ores, but as compared with some fields this field still shows pyrite in small quantity. Beautiful light greenish-yellow crystals of sphalerite form crusts in vugs at one end of a shoot in a ferberite vein in Gordon Gulch, in the Sugar Loaf district of the Boulder tungsten field.

Note 1, p. 50. Very rich sylvanite is found at the junction of a gold-bearing vein and a ferberite vein in the Red Signe mine at Ferberite, Boulder County, Colo. H. Gillingham Hibbs believes that the gold-bearing vein is the older.

Note 1, p. 52. In some of the deeper workings of the Boulder tungsten field specular hematite is becoming prominent. Concentrates are found to carry a considerable excess of iron oxide over the theoretical quantity which should be contained, and when ores from some mines are treated the concentrating tables, especially the longer ones, 14 or 15 feet in length, separate a very distinct reddish-brown streak of iron oxide next to the inner side of the ferberite streak. The hematite is fairly well distributed over the field. The presence of this hematite makes trouble in estimating the percentage of WO_3 in the ore by specific-gravity determinations (see p. 71), and may account for the greater density of the deeper ores in other fields (see p. 69). The hematite is probably, in part at least, leached from the surface ores.

Note 1, p. 63. The connection or lack of connection between the pegmatite dikes and the veins needs much more study. In a reconnaissance of the Boulder field since this bulletin was in type I have made some further observations on these relations. In the ferberite veins of the field the ferberite is commonly later than the older "horn" (fine-grained quartz, which may be of two ages). Thus the outer parts of the vein may be of "horn" and the center of nearly pure ferberite, as in parts of the Luckie 2 vein, near Boulder Falls. This vein cuts a pegmatite dike about 5 inches thick at a sharp angle, and although on each side the vein contains "horn," in the pegmatite it contains none. I saw no "horn" in any of the veins cutting pegmatite. I do not believe that this is due to a difference in the composition of the pegmatite and the country granite, but it seems to mean that the pegmatite was intruded during the formation of the veins, after the older "horn" at any rate and before the ferberite. It is possible that there were several periods of pegmatitic intrusion, and some may be entirely older than the veins.

Note 2, page 72. The method as outlined in the text is given as described by a visitor to the plant. Mr. Marshall D. Draper gives the following authoritative details:

> I bought a great many small lots of scheelite ore from the various small producers, principally from small placer operations, in 1916, and to facilitate these small purchases devised a set of specific-gravity tables which I am sending herewith, thinking they may be of some interest. These were checked by analyses at various times, and the table was found to be quite accurate. Naturally a buyer had to be careful that extraneous material was not included in scheelite offered for sale. The principal thing I had to look out for was barite. On one or two occasions there were attempts made to include some with the scheelite, but it was generally a simple matter to discover the presence of barite[1] or other such components.
>
> It is of interest also to note that the curve for scheelite concentrate made in the local plant at Johannesburg, which was installed by me, does not at all follow the curve for crude ore. I made no definite attempt to ascertain the cause of difference, but the difference nevertheless remained. The table was based on the assumption that the mineral was scheelite and the gangue was quartz. The small amounts of dolomite or calcite contained in the vein material did not, as might have been assumed, make a material difference in the estimate of content. By means of these curves I was able to buy outright many small lots of ore and pay the producer without waiting for an analysis. Most large lots were, of course, bought by preliminary payment on the basis of specific gravity and final settlement on analysis.
>
> The apparatus used by me in making these specific-gravity determinations was a small scale for weighing out from 1 to 4 kilos of the scheelite ore. I had a 2,000 cubic centimeter glass graduate which was about 18 or 20 inches in height and some 2½ inches in diameter. I filled this with water, generally for convenience to the 1,000 cubic centimeter mark, and then introduced the charge of 1 or more kilos. The displacement of the ore was noted and the specific gravity calculated from it. Then by reference to my chart, which was being made more accurate all the time by reason of the various analyses to check the specific gravity, I was able to get at an extremely close idea of the content—so close, in fact, that I latterly came to rely more on it than on analyses, more particularly for the reason that at that time many chemists used different schemes and there were many discrepancies between them for a time.
>
> Later I made also the accompanying table of specific gravity as against WO_3 content and did not then have to refer to the chart.
>
> It may be of interest to note that I always required scheelite ores to be clean—that is, with the usually accompanying magnetite removed, as it is quite evident that otherwise my specific-gravity determinations would have been vitiated.

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[1] The presence of barite and other impurities in tungsten ores must of course be carefully noticed. One tungsten buyer was financially ruined in 1916 through buying, on specific-gravity tests, scheelite ores salted with barite.—F. L. H.

The table compiled by Mr. Draper and Mr. F. H. Lerchen is as follows:

Per cent of tungsten trioxide indicated by specific gravity of scheelite ores of the Atolia field.

Specific gravity.	Per cent.	Specific gravity.	Per cent.	Specific gravity.	Per cent.	Specific gravity.	Per cent.
3.00	15.40	4.77	61.80	5.19	68.00	5.60	73.20
3.10	18.40	4.78	62.00	5.20	68.10	5.61	73.30
3.20	21.20	4.79	62.00	5.21	68.20	5.62	73.40
3.30	24.50	4.80	62.10	5.22	68.40	5.63	73.50
3.40	28.00	4.81	62.20	5.23	68.50	5.64	73.60
3.50	31.20	4.82	62.40	5.24	68.60	5.65	73.70
3.60	34.00	4.83	62.80	5.25	68.70	5.66	73.80
3.70	37.00	4.84	63.00	5.26	69.00	5.67	73.90
3.80	39.60	4.85	63.20	5.27	69.10	5.68	74.00
3.90	42.20	4.86	63.30	5.28	69.20	5.69	74.10
4.00	44.80	4.87	63.40	5.29	69.40	5.70	74.20
4.10	47.30	4.88	63.60	5.30	69.60	5.71	74.32
4.20	49.60	4.89	63.70	5.31	69.70	5.72	74.44
4.30	51.60	4.90	63.80	5.32	69.80	5.73	74.56
4.40	54.00	4.91	64.10	5.33	70.00	5.74	74.68
4.50	56.20	4.92	64.20	5.34	70.10	5.75	74.80
4.51	56.40	4.93	64.30	5.35	70.20	5.76	74.92
4.52	56.70	4.94	64.40	5.36	70.40	5.77	75.04
4.53	57.00	4.95	64.50	5.37	70.60	5.78	75.16
4.54	57.30	4.96	64.70	5.38	70.70	5.79	75.28
4.55	57.50	4.97	64.80	5.39	70.80	5.80	75.40
4.56	57.60	4.98	65.00	5.40	71.00	5.81	75.54
4.57	57.80	4.99	65.20	5.41	71.10	5.82	75.68
4.58	58.00	5.00	65.40	5.42	71.20	5.83	75.82
4.59	58.20	5.01	65.50	5.43	71.30	5.84	75.96
4.60	58.40	5.02	65.60	5.44	71.40	5.85	76.10
4.61	58.60	5.03	65.80	5.45	71.50	5.86	76.24
4.62	59.00	5.04	66.00	5.46	71.60	5.87	76.38
4.63	59.20	5.05	66.10	5.47	71.70	5.88	76.52
4.64	59.30	5.06	66.30	5.48	71.80	5.89	76.66
4.65	59.50	5.07	66.40	5.49	71.90	5.90	76.80
4.66	59.80	5.08	66.60	5.50	72.00	5.91	76.94
4.67	60.00	5.09	66.80	5.51	72.10	5.92	77.08
4.68	60.10	5.10	66.90	5.52	72.24	5.93	77.22
4.69	60.20	5.11	67.00	5.53	72.36	5.94	77.36
4.70	60.40	5.12	67.10	5.54	72.48	5.95	77.50
4.71	60.60	5.13	67.20	5.55	72.60	5.96	77.64
4.72	60.70	5.14	67.30	5.56	72.72	5.97	77.78
4.73	61.00	5.15	67.60	5.57	72.84	5.98	77.92
4.74	61.20	5.16	67.70	5.58	72.96	5.99	78.06
4.75	61.40	5.17	67.80	5.59	73.08	6.00	78.20
4.76	61.60	5.18	67.90				

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