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MOLYBDENUM DEPOSITS

A SHORT REVIEW

BY

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MOLYBDENUM DEPOSITS—A SHORT REVIEW

By Frank L. Hess

FOREWORD

The arms of commerce now reach so far, railroad and steamship lines that give rapid and easy transportation are spread so broadly, and diffusion of knowledge takes place so quickly that trade can not be local except in those articles which supply only local needs, which occur or are produced only in small quantities, or which are of small value compared to their bulk. A corollary of this statement is that one who wishes to enter any business not restricted to small or local needs should know the general conditions of the business.

These remarks apply to molybdenum mining. The mining of molybdenum, in common with nearly all mining except perhaps that of gold and the other precious metals, should be undertaken only after consideration of the demand and the available resources, and these are synonymous with the world's demand and resources.

The United States Geological Survey's annual publication "Mineral Resources of the United States" reviews uses, demand, and prices. An attempt is made in this paper to give an epitome of the world's larger molybdenum resources so far as they are known, in order that those who are interested in mining molybdenum may better appraise the competition that they must meet and that those who are interested in the use of molybdenum may estimate the probable supply. No effort has been made to refer to the smaller deposits unless for some special reason, and therefore the paper makes no pretense of cataloging all occurrences of molybdenum. The references given will help interested readers who are near libraries to pursue the subject much further if they wish.

CHARACTERISTICS OF MOLYBDENUM MINERALS AND DEPOSITS

The occurrences of molybdenum minerals in the United States are legion, and those in the world are countless, but the deposits that can be profitably worked are comparatively few. Molybdenum minerals are found in greater or less quantity almost everywhere that the nonferrous metals are mined and also in many magnetite-bearing areas, but they do not necessarily occur in the same deposits as the other metals nor even close to them. Molybdenite is also found at many places in igneous rocks and highly altered sediments where other metallic deposits are unknown or unimportant. Molybdenum is commonly associated with tin, tungsten, bismuth, and copper deposits, and wulfenite is in certain regions an oxidation product of lead veins.

The minerals of molybdenum are few. Only seven are surely known, and only three or possibly four are found in sufficient quantity to form ores. The known minerals are as follows:

Molybdenite, molybdenum sulphide, MoS_2; contains 60 per cent of molybdenum.

Wulfenite, lead molybdate, $PbMoO_4$; contains 26.16 per cent of molybdenum.

Chillagite, lead tungsto-molybdate, $Pb(W,Mo)O_4$; contains 11.68 per cent of molybdenum.

Molybdite, hydrous iron-molybdenum oxide, $2(FeO_2).6MoO_3.15H_2O$; contains 66.7 per cent of molybdenum.

Ilsemannite, possibly a molybdyl molybdate, $MoO_2.4MoO_3$.

Powellite, calcium molybdate, $CaMoO_4$; contains 39.05 per cent of molybdenum. Some specimens contain tungsten.

Koechlinite, bismuth molybdate, $(BiO)_2MoO_4$; contains 15 per cent of molybdenum.

Achrematite, a lead arseno-chlor-molybdate; belonesite, a magnesium molybdate; erosite, a vanado-molybdate of lead; jordisite, an amorphous sulphide of molybdenum; and pateraite, a cobalt molybdate, are all more or less questionable minerals that have been named from impure or insufficient materials. Halotrichite (hydrous iron-aluminum sulphate), aluminite (hydrous aluminum sulphate, containing more or less iron), and melanterite (hydrous iron sulphate) colored blue by molybdenum have been reported. The determination of the aluminite is possibly questionable. Some scheelite carries molybdenum, but I have found no record of such scheelite in North America. Only molybdenite, wulfenite, molybdite, and possibly ilsemannite have been found in commercially valuable quantities.

As is apparent from their chemical composition the molybdenum minerals are found under a variety of conditions.

Molybdenite is by far the most widely distributed molybdenum mineral, occurs in the greatest quantity in individual deposits, and is the molybdenum mineral in most of the ore produced. It is found in quartz veins, either as an original constituent or as a later filling of cracks; in pegmatite, though probably always deposited in the dikes after their solidification; in those deposits formed by the replacement of granitoid rocks that resemble pegmatite and take the form of pipes or more tabular masses; in greisen, a silicified granitic rock containing more or less muscovite (white mica); in granite, but probably not as an original constituent though often so described; in regionally metamorphosed rocks; and in contact-metamorphic deposits. Molybdenite has a bright metallic luster, like new sheet lead, and in many places occurs in thin flakes, like mica. Where the flakes are spread through white quartz or some other light-colored rock they give the impression of a quantity much greater than really exists. Owing to its attractive showiness and its evident metallic properties, it gains attention wherever found.

In general, though not exclusively, molybdenum is found in association with the siliceous igneous rocks. Analysis of a trachytic obsidian collected by Cross[1] in Hawaii showed a trace of molybdenum, but the quantity present, if any, as an original constituent of igneous rocks is so small that it is barely detectable by chemical means,[2] and all assured traces that Hillebrand found were in rocks that were at least as siliceous as monzonites. When the rocks cool the molybdenite seems to be almost totally pressed out with the watery fluids and is deposited in the zone that is cool enough for the deposition of quartz, mica, chalcopyrite, bismuth, and tungsten minerals. It is found in a few places with cassiterite and was probably either deposited there before the rocks were hot enough for tin in the ore-bearing solutions to reach these particular places or after they had cooled subsequent to the deposition of the cassiterite.

Quartz veins carrying molybdenite that has been deposited with the quartz are likely to have a border on each side of muscovite or biotite flakes standing normal to the vein, and the quartz is usually of the glassy, splintery varieties that seem to be commonly formed close to a magma from which the solution carrying the quartz has been squeezed out. I examined a clearly exposed vein of this sort on the Marta property, about 15 miles northeast of Quimsa Cruz (Tres Cruces) Pass, Bolivia. Here the veins run from the contact of quartz monzonite with quartzite into the quartzite. There is no trace of the veins in the monzonite, but they start abruptly from the contact. The veins are not long—possibly 150 feet—and the solutions probably cooled rather quickly.

In other quartz veins the molybdenite may be partly deposited with the quartz and partly in cracks in it. A few of the veins, like that above Hortense, Colo., carry beryl and feldspars and are apparently closely related to pegmatite.

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[1] Cross, Whitman, Lavas of Hawaii and their relations: U. S. Geol. Survey Prof. Paper 88, p. 51, 1915. Analysis by J. B. Ferguson.

[2] See analyses by Hillebrand, W. F., Distribution and quantitative occurrences of vanadium and molybdenum in rocks of the United States: U. S. Geol. Survey Bull. 167, pp. 50–51, 1900.

The molybdenite in quartz veins may be either in fine disseminated flakes or in excellently formed large crystals. (See Pl. I, *A* and *B*.) The largest crystals known to have been found in the United States are some about 3 inches across and an inch thick occurring in a quartz vein at the head of Railroad Creek, west of Lake Chelan, Wash., but plates 12 inches across by a quarter of an inch thick were found in quartz veins on Quetachu-Manikuagan Bay, on the north shore of the Gulf of St. Lawrence, Quebec.[3] In many veins molybdenite has been deposited in cracks after the formation of the veins, and a little movement has ground it to "paint" which smears the surfaces of the quartz. The siliceous solutions that in some places form simple quartz veins may in others replace the country rock, and the molybdenite they carried also replaces it.

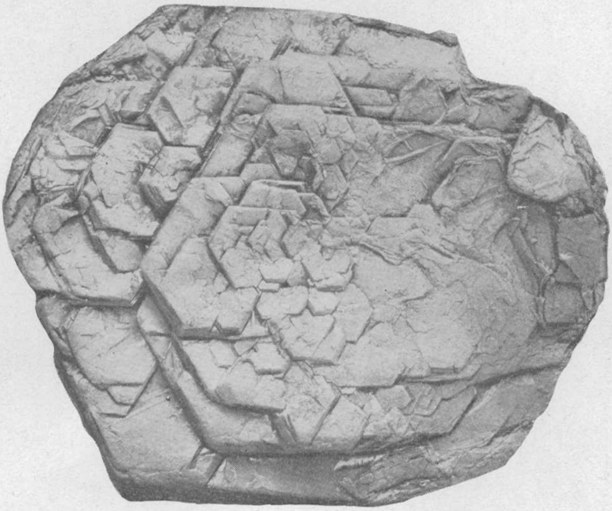
The deposits in pegmatite are probably to be classed here, for the molybdenite in these deposits has, so far as I have seen it, been brought in after the solidification of the pegmatite. Commonly, as in some granitic rocks, the cracks along which the ore-bearing solutions have moved are small and so well healed as to be almost or quite invisible to the unaided eye. The molybdenite is deposited molecule by molecule as the minerals of the pegmatite are removed, and from its appearance it might be supposed to be original in the rock. Such replacement occurs in granite, and a tiny, almost or quite invisible crack may lead to comparatively large masses of molybdenite in apparently solid granite. This is the origin of all the supposed original molybdenite in granite that has come under my observation. (See Pl. IV.)

In places, probably owing to the heat of the solutions, the pressure, and the compounds carried, the silica instead of merely filling openings replaces the country rock on each side, and if the process occurs in a greatly brecciated zone, the formation of a highly silicified deposit, with accompanying sericitization (see Pl. II), such as that at Climax, Colo., may result, or the country rock may be attacked and part of its substance exchanged without a total replacement, leaving it a comparatively soft mass of sericite or kaolin, like rock along the veins of Questa, N. Mex.,[4] or hard and vuggy—the "miarolitic" granite of petrographers—like the deposits at Tunk Pond and Cooper, Maine.[5] (See Pl. IV.) Flakes of molybdenite in

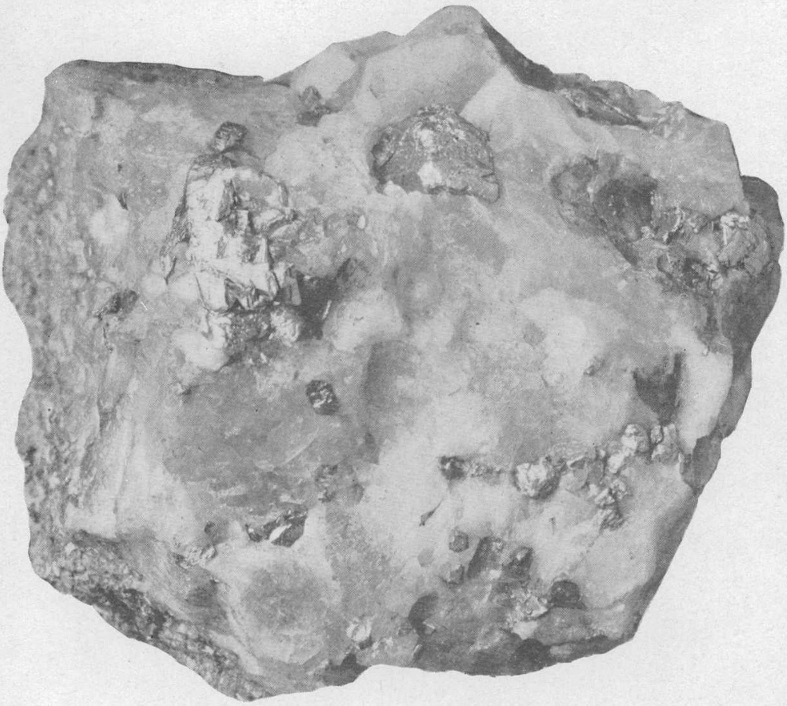
[3] Geology of Canada: Canada Geol. Survey, Report of progress from its commencement to 1863, p. 755, 1863.

[4] Larsen, E. S., and Ross, C. S., The R & S molybdenum mine, Taos County, N. Mex.: Econ. Geology, vol. 15, pp. 567–573, 1920. Although these authors say that there is almost no replacement of the "alaskite" (the country rock), on the same page they say that "sericitized alaskite lies between the small branching veins," and they also state (p. 570) that close at hand "The rapid erosion in these sericitized areas has exposed large patches of white iron-stained rock that can be seen on the mountain sides for many miles."

[5] Hess, F. L., Some molybdenum deposits of Maine, Utah, and California: U. S. Geol. Survey Bull. 340, pp. 231–236, 1908.



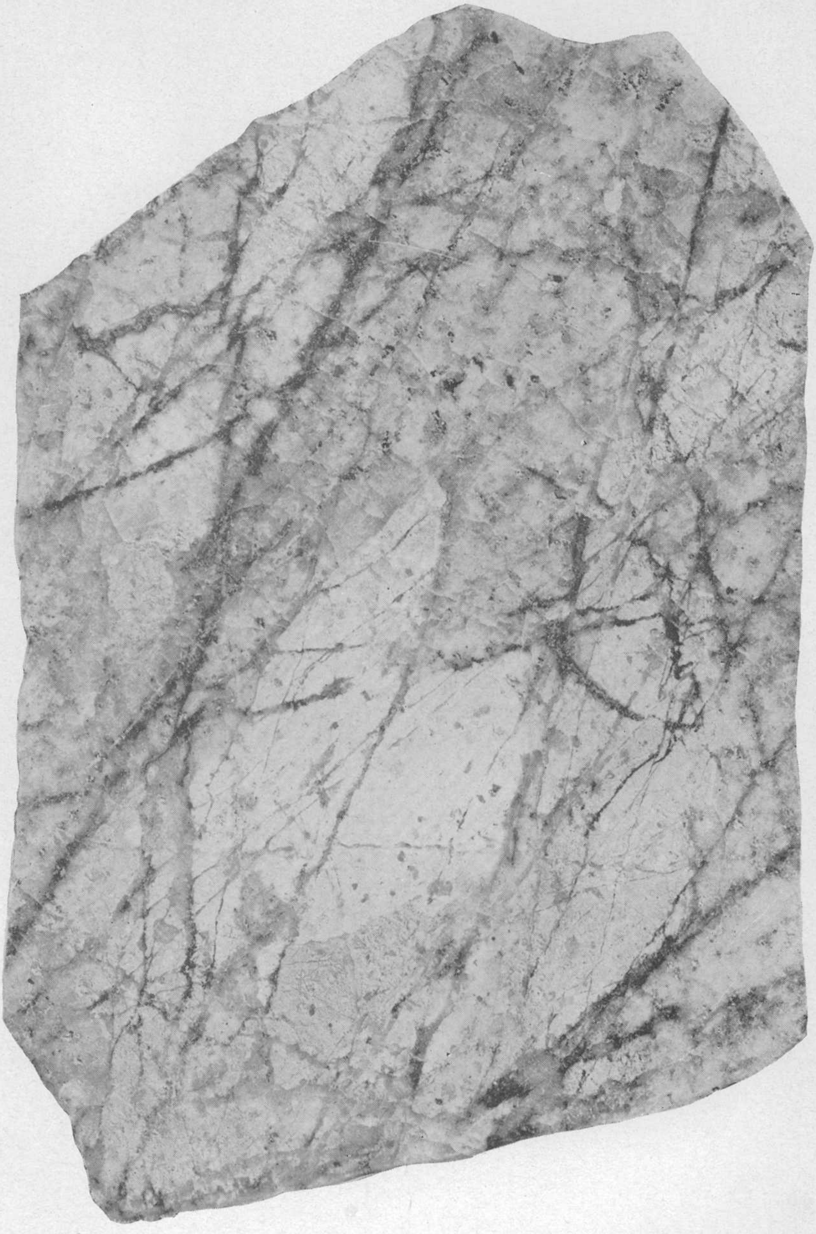
A.



B.

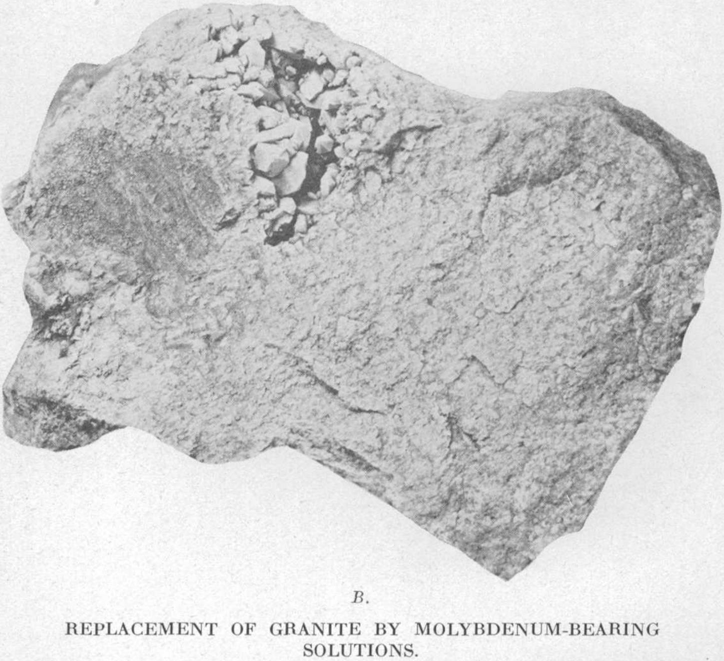
MOLYBDENITE FROM QUARTZ VEINS.

A. From Railroad Creek near Lake Chelan, Okanogan County, Wash.; *B*, from a prospect near Lake Tahoe, Calif.



SILICIFIED AND SERICITIZED QUARTZ PORPHYRY (?) CARRYING MOLYBDENITE ALONG VEINLETS, CLIMAX, COLO.

A.



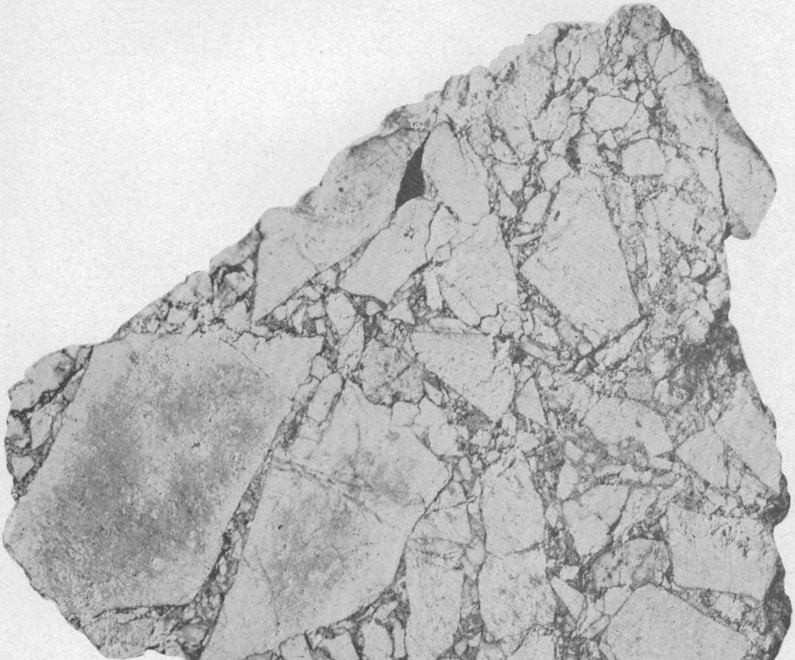
B.

REPLACEMENT OF GRANITE BY MOLYBDENUM-BEARING SOLUTIONS.

A, Radial mass of molybdenite brought in by solutions along crack, now healed and almost invisible, in fine-grained granite, Tunk Pond, Maine; *B*, "Miarole" where granite was removed and only partly replaced by molybdenum-bearing solutions traveling along minute cracks, now healed and invisible, Cooper, Maine.

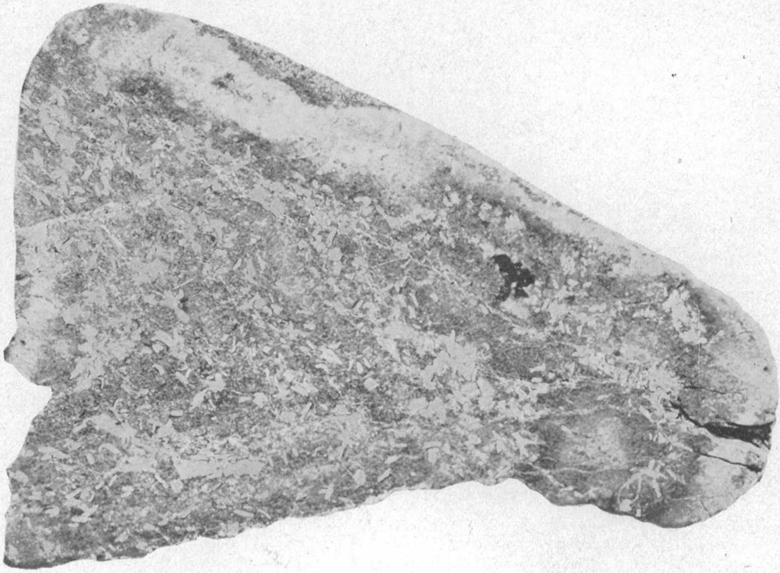
A. RADIAL SPHERULE OF POWELLITE, ALTERED FROM MOLYBDENITE.

From a pipe in quartz monzonite in the Deep Creek Mountains, 4 miles south of Gold Hill, Tooele County, Utah.



B. SERICITIZED QUARTZ PORPHYRY BRECCIA WITH A CEMENT OF QUARTZ, SERICITE, AND MOLYBDENITE.

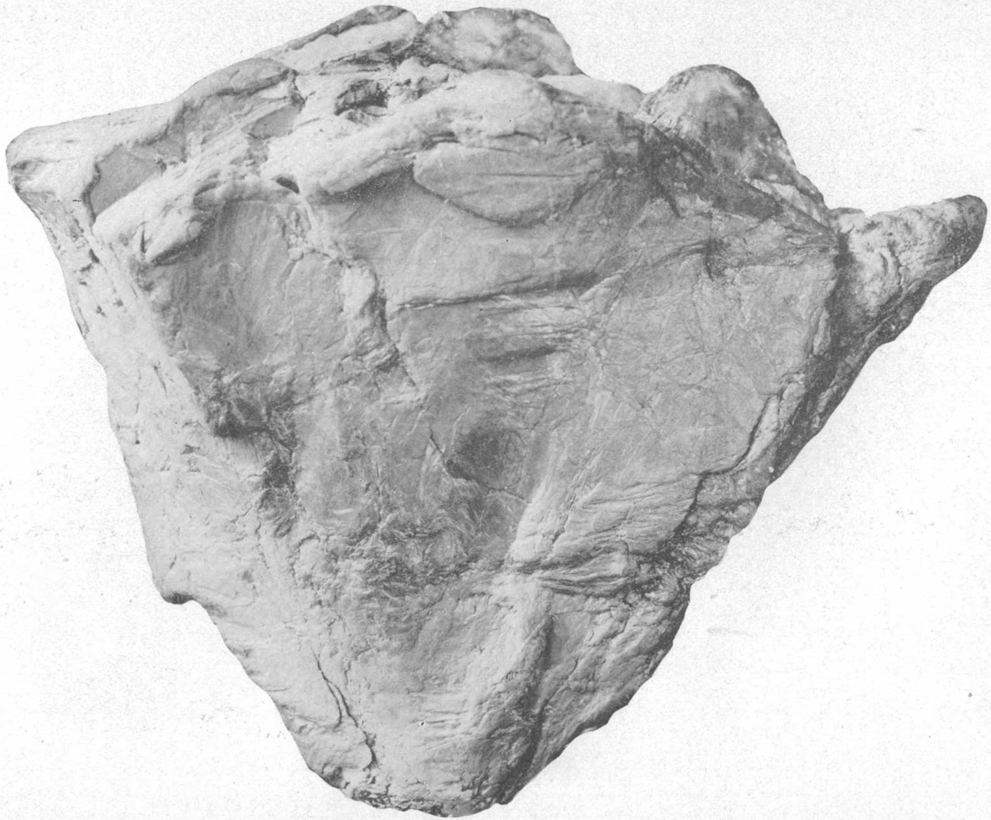
From Emigrant Creek, near Chico, Mont.



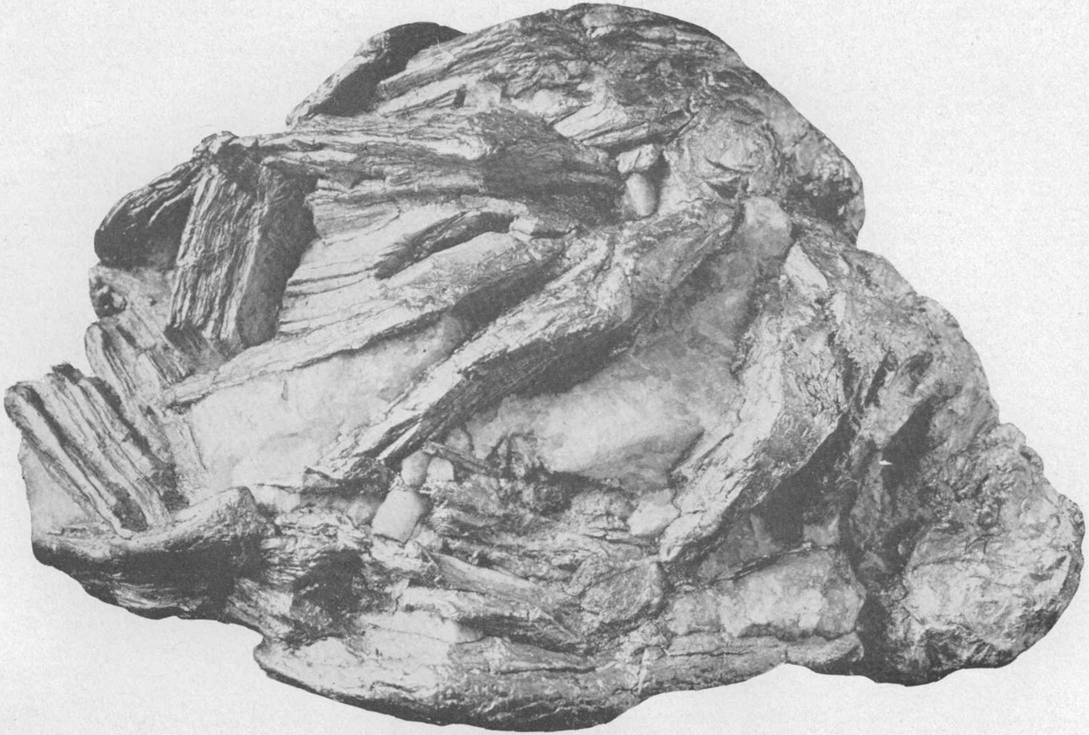
A. MOLYBDENITE FLAKES SCATTERED THROUGH CONTACT-METAMORPHOSED LIMY SEDIMENT, JOHNSON, ARIZ.

B. MOLYBDENITE FROM A PIPE NEAR GOLD HILL, UTAH.

Accompanying minerals are scheelite (*sh*), apatite (*a*), and sphene (*sp*) in a groundmass of partly altered hornblende.

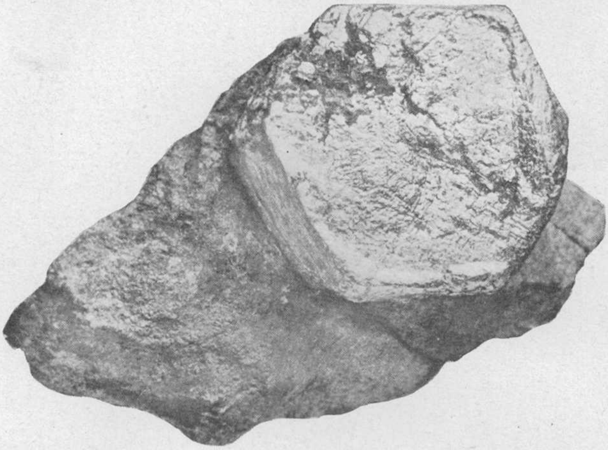


RADIAL MOLYBDENITE FROM PIPE (?) IN GRANITE, GEORGE FAST'S MINE, NEAR LA TRINIDAD, SAHUARIPA DISTRICT, SONORA, MEXICO.

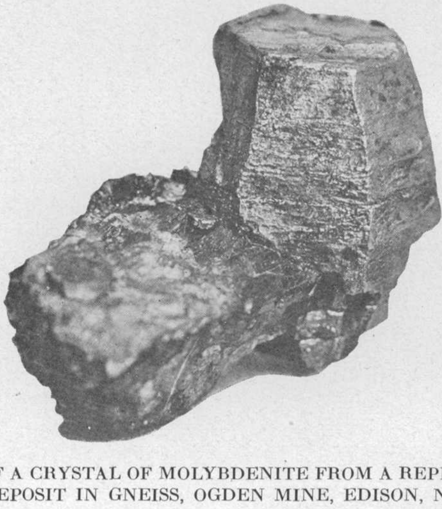


ENDS OF RADIAL PLATES OF MOLYBDENITE SHOWN IN PLATE VI.

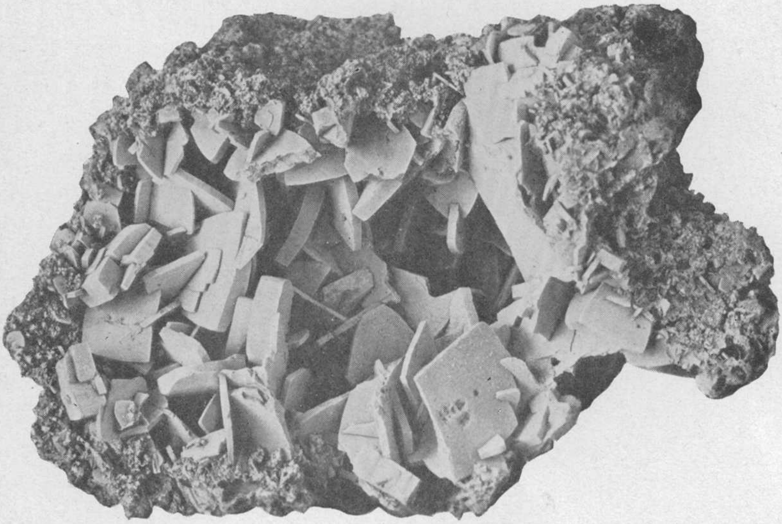
The white mineral is quartz.



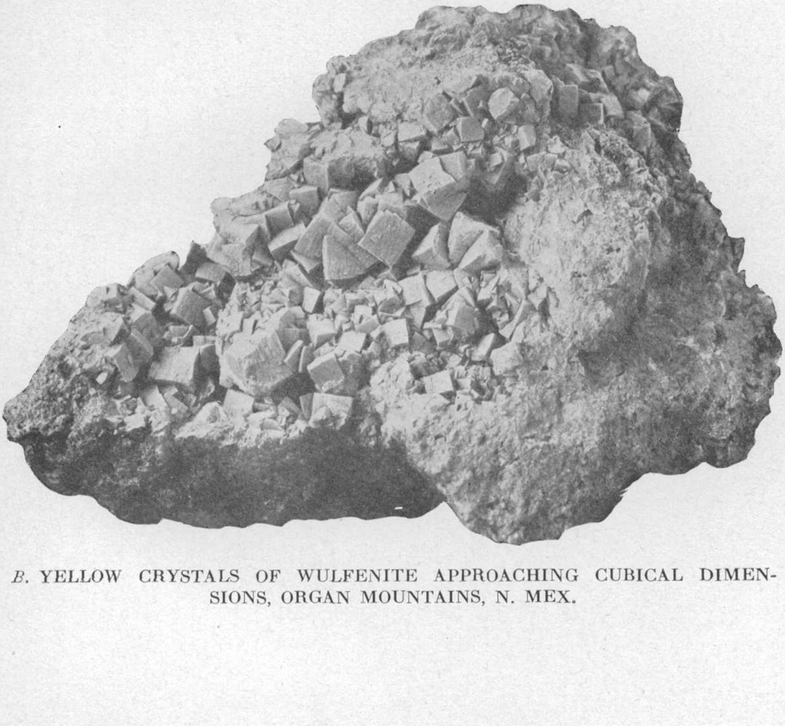
A. CRYSTAL OF MOLYBDENITE FROM CONTACT-METAMORPHOSED LIMESTONE, QUEBEC.



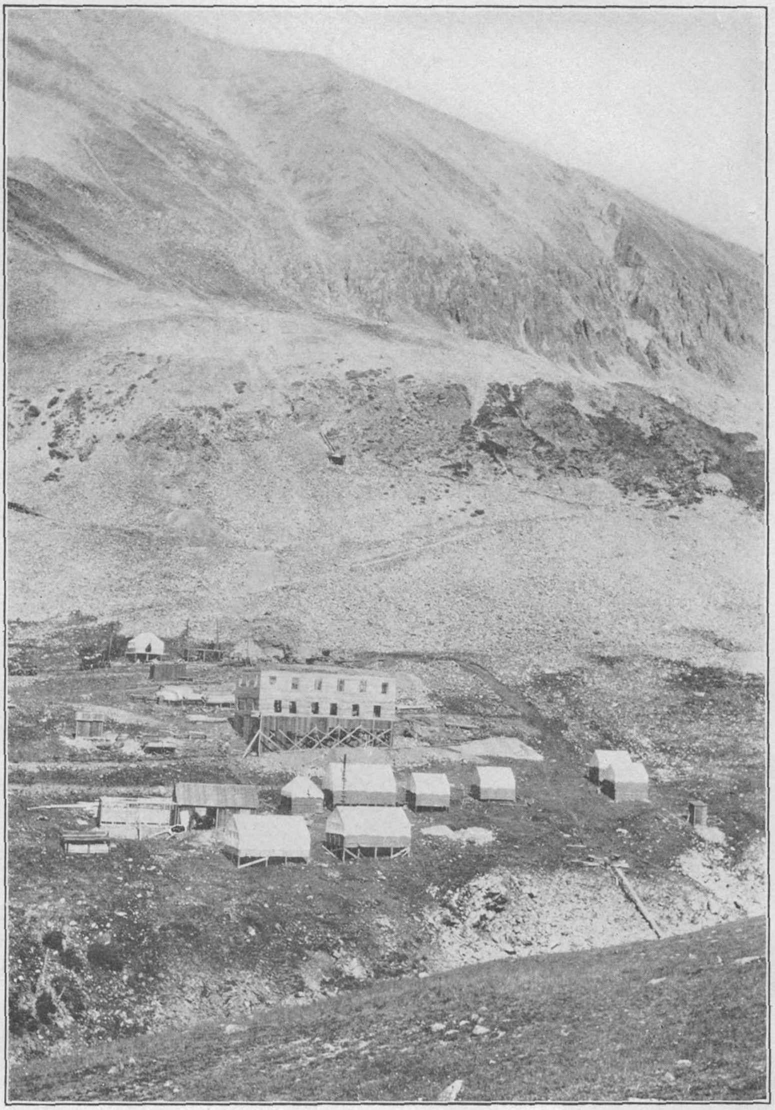
B. PART OF A CRYSTAL OF MOLYBDENITE FROM A REPLACEMENT DEPOSIT IN GNEISS, OGDEN MINE, EDISON, N. J.



A. TABULAR YELLOW CRYSTALS OF WULFENITE, VARYING CONSIDERABLY IN THICKNESS, ORGAN MOUNTAINS, N. MEX.



B. YELLOW CRYSTALS OF WULFENITE APPROACHING CUBICAL DIMENSIONS, ORGAN MOUNTAINS, N. MEX.



WORKINGS OF THE CLIMAX MOLYBDENUM CO., CLIMAX, COLO.

such granite have been referred to by many writers as original in the granite, but I believe that they are invariably introduced after the cooling of the granite and are replacement deposits, like the other minerals that usually surround or occupy the miarolitic cavities.

If sericitization is the more active process and the deposition of quartz comparatively much less, such deposits as that near Chico, Mont., result. (See Pl. III, *B*.) If the solutions are more complex the wall rock may be replaced by a surprising list of minerals forming pipes that are frequently called pegmatites, like those of the Deep Creek Mountains, Tooele County, Utah, and the Transvaal,[6] or some of those in Queensland[7] and New South Wales.[8] In the Deep Creek Mountains, 4 miles south of Goldhill, the molybdenite is radial and some masses form complete spheroids. (See Pls. III, *A;* V, *B*.) A specimen showing similar radial structure (see Pls. VI and VII) but with a radius of more than 5 inches, from what seems to be a deposit formed in the same way, was sent to the United States Geological Survey by George Fast from his mine near La Trinidad, in the Sahuaripa district of Sonora, 225 miles by trail south of Nacozari, Mexico (U. S. National Museum specimen No. 90438).

Molybdenite is found in many contact-metamorphic deposits, and although no large deposits of this kind are known in this country, some work has been done on deposits north of Golconda, Nev., near Baker City, Oreg., and on Pine Creek, near Bishop, Calif. A large contact-metamorphic deposit in limestone exists at Yetholme, New South Wales.[9]

The minerals accompanying the molybdenite are those usually found in tactites (the rocks formed by contact metamorphism)—namely, garnet, epidote, hornblende, pyroxenes, scheelite, sulphides of iron, copper, and zinc, zeolites, and others. The molybdenite may occur as mere flakes, but some deposits show more or less crystal form. Plate VIII, *A*, shows part of a crystal in the United States National Museum (No. 83985) from a deposit in Quebec, the exact locality of which is unknown. Plate V, *A*, shows flakes of molybdenite in a contact-metamorphosed gneissoid limy sediment from a prospect near Johnson, Ariz.

Molybdenite is sometimes found in gneiss and has apparently been introduced in solutions while the gneiss was under great heat and pressure at a considerable depth. In the occurrences I have seen the molybdenite was associated with glassy quartz and followed the glid-

[6] Wagner, P. A., The Mutue Fides-Stavoren tin deposits: Union South Africa Geol. Survey Mem. 16, pp. 127–128, 1920.

[7] Ball, L. C., The geology of Wolfram, N. Q.: Queensland Govt. Min. Jour., vol. 20, pp. 509–511, 1919; vol. 20, pp. 6–11, 50–56, 1921.

[8] Andrews, E. C., The molybdenum industry of New South Wales: New South Wales Geol. Survey Mineral Resources, No. 24, pp. 92–117, 1916.

[9] Idem, pp. 170–189.

ing planes. Cracks in quartz are so easily healed, however, that too much weight must not be given to such evidence of depth and high temperature. Molybdenite is found in gneiss accompanying sheets or broad lenses of magnetite in the Franklin Furnace area, N. J.,[10] and in limestone not far away, and the two occurrences seem very closely related. The crystal shown in Plate VII, *B*, came from the Ogden mine, at Edison, in this area. The original is in the museum of the University of Manitoba at Winnipeg.

Wulfenite occurs only in the oxidized parts of lead veins, and the veins that carry it are found in rather small areas, of which that embracing the southwestern United States and northern Mexico is the largest and most productive, but Spain, Austria, Yugoslavia (Slovenia), and Germany are also producers. Although wulfenite has been found as specimens in many other places, it is a remarkable fact that most of the large lead deposits in numerous mining centers carry none or almost none of this mineral in their oxidized zones.

Wulfenite is usually yellow, rare specimens are colorless, and some are brownish or reddish and many of the tints are very pleasing. The wulfenite crystals are ordinarily clean and splendent, and in those mines in which it has formed freely, such as some parts of the City Rocks mine, at Alta, Utah, and the mines at Shultz, Ariz., the effect given by the reflection of mine lights from the myriad of scintillating facets is marvelously beautiful. A red color in wulfenite seems to be due to vanadium, and apparently the depth of the red color is proportional to the quantity of vanadium present. Wulfenite usually forms in flat plates ranging in size from those that are microscopic to those that are more than an inch along the edge. The thickness of the plates varies in the same degree. Some are paper thin, though half an inch broad. Others thicken until they approach cubical form, or if the edges were truncated (beveled) when the crystal began growing they may make bipyramidal forms. Plates of moderate thickness are shown in Plate IX, *A*, and nearly cubical crystals in Plate IX, *B*. Wulfenite is undoubtedly formed from molybdenum original in the vein, though the original mineral has never been identified. It is possible that molybdenum may take the place of a small part of the lead in galena, and so wulfenite is formed through the oxidation of the galena. Numerous writers have believed that it is collected from the country rocks cut by lead veins, but, as in the Sierra de los Caballos, near Engle, N. Mex., veins cutting the same rocks may vary widely in their wulfenite content, though they may be equally rich in galena.

Some wulfenite carries a little tungsten, and concentrates of wulfenite and vanadinite from Shultz, Ariz., contain as much as 2 per

[10] Spencer, A. C., U. S. Geol. Survey Geol. Atlas, Franklin Furnace folio (No. 161), p. 9, 1908.

cent of tungsten, although no tungsten mineral can be identified, and the tungsten is probably contained in the wulfenite, which thus approaches chillagite in composition.

Naturally, wulfenite deposits can be expected to extend only to ground-water level or slightly below.

Molybdite is an oxidation product of molybdenite and was long considered to be an oxide of molybdenum, but Schaller [11] showed that all specimens contain iron in definite proportions. Guild [12] got the same results except that he found $7H_2O$ instead of Schaller's $7\frac{1}{2}H_2O$. (See p. 2.) By itself molybdite has no commercial importance, but taken in connection with the molybdenite in such great deposits as that at Climax, Colo., it forms a considerable part of the ore, carrying in the upper part of the Climax ore body about one-third of the metal.[13] (See Pl. X.) It may be sulphidized and floated with the molybdenite. In some places molybdite collects in showy masses. It is fairly soluble in water and migrates rather readily.

Ilsemannite is a water-soluble blue mineral of uncertain composition, is found in few deposits, and has so far not proved to be of commercial importance. Höfer [14] described it as $Mo_2.4MoO_3$. Schaller [15] thought the mineral to be a hydrous sulphate. Yancey [16] disagreed with both but was unable to suggest a formula that he believed would fit the mineral. That it is an oxide now seems to me the more likely. Ilsemannite is a rare mineral and has been noted at only a few localities. Deposits of ilsemannite at Ouray, Utah,[17] are large enough to have attracted some expenditure of capital.

Chillagite [18] is a yellow mineral with the appearance of wulfenite but with a composition between that of wulfenite ($PbMoO_4$) and stolzite ($PbWO_4$). So far as known it has been identified only at Chillagoe, Queensland. As already noted wulfenite from Shultz, Ariz., carries 2 per cent of tungsten trioxide (WO_3) and perhaps part of it is chillagite.

Powellite [19] is a calcium molybdate usually formed from the alteration of molybdenite. (See Pl. III, *A*.) As formed thus it is in thin

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[11] Schaller, W. T., The chemical composition of molybdic ocher; Am. Jour. Sci., 4th ser., vol. 23, pp. 297–303, 1907.

[12] Guild, F. N., The composition of molybdite from Arizona: Am. Jour. Sci., 4th ser., vol. 23, pp. 455–456, 1907.

[13] Haley, D. F., Molybdenite operations at Climax, Colo.: Am. Inst. Min. and Met. Eng. Trans., vol. 61, pp. 73, 75, 1920.

[14] Höfer, H., Studien aus Karten: Neues Jahrb., 1871, p. 566.

[15] Schaller, W. T., Ilsemannite, hydrous sulphate of molybdenum: Washington Acad. Sci. Jour., vol. 7, pp. 417–420, 1917.

[16] Yancey, H. F., Ilsemannite: Chem. and Met. Eng., vol. 19, pp. 186–190, 1918.

[17] Hess, F. L., Ilsemannite at Ouray, Utah: U. S. Geol. Survey Bull. 750, pp. 1–16, 1923.

[18] Ullman, A. T., A new mineral: Roy. Soc. New South Wales Jour. Proc., vol. 46, pt. 2, p. 186, 1912. Smith, C. D., and Cotton, L. A., Crystal measurements of chillagite: Idem, pp. 207–217.

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

white flakes having the shape of molybdenite foils. The type material, from the Peacock claim, in the Seven Devils district, 120 miles north of Boise, Idaho, was in small doubly terminated pyramidal crystals that were probaby formed in some other way. It contained 10.28 per cent of tungsten trioxide (WO_3) and looked like scheelite.

PRODUCTION OF MOLYBDENUM ORES

The production of molybdenum ores in any particular country during any particular period is an indication not so much of the potential importance of the country's deposits as of the ease of working under the conditions existing at the time in the country. The use of molybdenum has not yet been large enough nor its necessity sufficiently well proved to bring about, except in the United States and possibly New South Wales, developments that would show the possibilities of low-grade but large deposits, as has been done in the gold and copper industries.

The world's production of molybdenum so far as it can be ascertained from available data is shown in the following table. It is to be kept in mind that 1918 was the final year of the war, when the demand had reached its climax, and that in the British possessions production proceeded during 1919 under the war impetus and a promise of the Government to take the product for six months after the war at an agreed price of 105 shillings per long-ton unit for concentrates carrying 90 per cent or more of MoS_2. In order to have a common basis of comparison, the metal contained in the ore is estimated.

The world's output of molybdenum ore, 1918–1921, in terms of the metal contained, in tons of 2,000 pounds

Country	Ore	1918	1919	1920	1921
Australia:					
Northern Territory	Molybdenite		0.4		
New South Wales	do	51.4	36.3	22.0	
Queensland	do	60.7	64.9	15.4	4.4
South Australia	do	.1	.1		
Victoria	do	.7	4.2	2.6	3.0
West Australia	do	.8	1.0		
Canada	do	113.4	24.9		
Chile	do	19.3	.3		
China	do	([a])	([a])	[b] 7.7	([b])
Chosen (Korea)	do	11.8	.1	2.4	.8
Germany (Saxony)	do	.7	.3	([c])	
India	do	.1	.1		
Italy	Wulfenite		4.5	.5	
Japan	Molybdenite	77.5		50.3	
Mexico	do	15.0	1.1	3.2	2.5
Norway	do	93.6	34.1		
Peru	do	1.4	2.5	.2	.9
Sweden	do	24.3	.1	([a])	.4
United States	Molybdenite, wulfenite	390.8	198.6	17.5	
		861.6	373.5	121.8	

[a] No output recorded.
[b] Exports.
[c] Less than 0.1 ton.

MOLYBDENUM DEPOSITS

UNITED STATES

So far as present developments show, the United States possesses the largest known molybdenite deposits. It also has a rather large aggregate of wulfenite ores in the Southwest. Probably in every State that has outcrops of granitic rocks at least specimens of molybdenite can be found, and in a dozen States more or less serious attempts have been made to mine the mineral. (See fig. 1.)

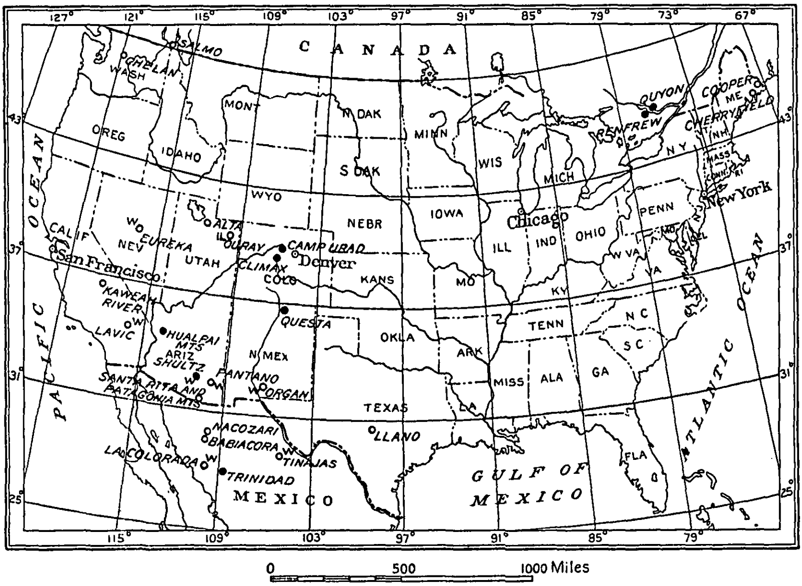

FIGURE 1.—Principal molybdenum deposits in Canada, the United States, and Mexico. W, Wulfenite; IL, ilsemannite; the others are molybdenite. ●, Productive mine; O, mine from which little or no production has been made

MOLYBDENITE

COLORADO

The largest output of molybdenum has come from the great deposit at Climax, Colo., and from the Camp Urad deposit, 11 or 12 miles up Clear Creek (west) from Empire, Colo. Both produce molybdenite.

The Climax deposit has been described by Brown and Hayward,[20] Haley,[21] Holland,[22] Horton,[23] and Worcester.[24] It is 15 miles north-

[20] Brown, H. L., and Hayward, M. W., Molybdenum mining at Climax, Colo.: Eng. and Min. Jour., vol. 105, pp. 905–907, 1918.

[21] Haley, D. F., Molybdenite operations at Climax, Colo.: Am. Inst. Min. and Met. Eng. Trans., vol. 61, pp. 71–76, 1920 (read September, 1918).

[22] Holland, L. F. S., Recent developments in molybdenum: Min. and Sci. Press, Oct. 19, 1918, pp. 529–531.

[23] Horton, F. W., Molybdenum—its ores and their concentration, with a discussion of markets, prices, and uses: Bur. Mines Bull. 111, pp. 68–69, 1916.

[24] Worcester, P. G., Molybdenum deposits of Colorado, with general notes on the molybdenum industry: Colorado Geol. Survey Bull. 14, pp. 87–94, 1919.

east of Leadville, at Fremont Pass (altitude 11,300 feet), in which lies the little village of Climax. The deposit lies a mile east of the village, at altitudes between 12,000 feet and 12,500 feet. Naturally at such an altitude in this latitude (about 39° 22′ N., longitude about 76° W.[25])

The climatic conditions are severe, and snow can be expected during any month of the year. Winter sets in not later than November 1, the snowfall is very heavy, and the ground remains covered with snow until June 1, and sometimes even later. From June 1 to October 1 there is much rain, and a little snow falls in the late afternoon nearly every day. In October, 1917, there was one of the biggest snowstorms and blizzards of the year. Being just on the divide, constant strong winds blow the fine, dry snow with such force that, during most of the winter, outside work of any kind is accomplished under most trying conditions.

The locality is on a high, rough, bare mountain ridge, running nearly north and south. A glacial cirque a mile long and half a mile wide is cut in the west side of the ridge and opens to the northwest at Fremont Pass. The mountain on the northeast side of the cirque is called Bartlett Mountain, and that on the southwest side Ceresco Mountain. A small stream drains the cirque, and along it on both sides, but especially on the slope of Ceresco Mountain, is a great accumulation of heavy débris.

Within the cirque on the lower slope of Barlett Mountain is the explored ore body, a huge mass of brecciated porphyry with granitic rocks of several kinds, in general rather quartzose, that seems to have a northwest elongation. However, it extends down to the creek, and above the wide band of débris on Ceresco Mountain many openings have been made on molybdenite-bearing outcrops that may be an extension of the same deposit, though the débris slope is too large to allow a definite correlation. If these openings, as believed by Worcester, are on the same ore body, then the greatest extension is about north and south. On the northeast side of the cirque the ore body is more than 1,000 feet wide from northeast to southwest and is at least 1,500 feet long from southeast to northwest and may be very much longer. All the molybdenum-bearing rock of consequence in this locality seems to be a part of this great ore deposit.

When the great size of the brecciated body is remembered, and when it is considered that the rock is not mashed, the thoroughness with which it is broken is wonderful. No uncracked piece containing as much as 2 cubic inches was seen in the main ore body. Solutions from the magma flowed through every tiny crack, sericitized and silicified the broken rock, and filled the cracks with quartz. As the cracks were filled molybdenite was deposited in thin films in most of the tiny veinlets, while the flow of siliceous solutions continued. The total quantity of silica introduced into the deposit was enormous.

[25] Haley, D. F., op. cit., p. 71.

On the deposit the Climax Molybdenum Co. owns a number of claims and the Molybdenum Products Corporation had one patented claim containing 5 acres. The following extract from the description by Brown and Hayward already cited applies to the ore on the holdings of both companies:

Erosion, due to climatic conditions, has been rapid and has kept pace with oxidation over practically all the mineralized area; sulphides of approximately the same grade encountered in the underground workings are exposed on the surface. * * *

The molybdenite values are remarkably uniform throughout the ore body.

In all the development work to date, amounting to over 5,000 feet, there have been no blank assays. In the mine workings, including those at a depth of 500 feet from the surface, considerable amounts of yellow oxide of molybdenum are found. Mineralization is invariably confined to fractures, which have allowed oxidation to take place as a result of the circulation of surface waters. Apparently there has been little or no migration of the molybdenum deposition and therefore no concentration of values in a zone of enrichment.

No other minerals occur in the deposits, with the exception of a small amount of pyrite. [After this article was written specimens of wolframite were found.—F. L. H.] Concentrates containing 75 per cent molybdenum sulphide show less than 0.1 per cent copper, the analysis showing, besides the molybdenite, only insolubles and iron. The ore body is apparently terminated on the northeast by a regular fault dipping 60° NE., but while the present opinion is that this fault is the limit of the ore body, this conclusion has not yet been proved.

Development work of the Climax Molybdenum Co. has been confined to an area of 25 acres of patented ground, although the company holdings comprise in all more than 600 acres. From the mouth of the tunnel back to the fault an area approximately 1,000 by 800 feet has been completely blocked out and contains over 6,000,000 tons, averaging 1 per cent molybdenum sulphide. Another tunnel has been started 200 feet below these workings and shows ore of the same grade and character. Owing to the dip of the fault, the mineralized area of this tunnel probably will be nearly double that of the upper level, thus indicating the ultimate development of considerably more ore than now estimated.

The method of mining contemplated calls for a series of parallel stopes, 800 feet long and 25 feet wide, with pillars between of the same width. The stopes will be carried as shrinkage stopes to the surface. After the shrinkage stopes are through to the surface it is planned to break the pillars down into these stopes. This method is to be adopted wherever a height of 200 feet will carry the stopes to the surface, and where, owing to the contour, it is less than this distance to the surface, the idea being to drive a series of parallel drifts and raises to the surface and glory hole from the surface to the drifts on the tunnel level.

Surface mining can be carried on only during four months of the year, for while commercial ore outcrops on the surface, with no overburden, the climatic conditions are such that a scheme of mining had to be outlined which would permit underground work during that part of the year when the surface could not be attacked. The ore is ideal for shrinkage stopes, as it contains no talc and breaks short.

The ore now mined from the upper adit is delivered to bins at the mouth of the tunnel and then carried 500 feet down the mountain by means of a two-bucket tramway to the crusher plant. The elevation of the lower tunnel is the same as that at the crusher plant, and it is planned to eventually bring all of the ore down to this level and to do away with the two-bucket tramway.

Haley,[26] who wrote at a later date, says that the ore as fed to the mill carried 0.92 per cent of molybdenite, estimating all the molybdenum as MoS_2. However, there is really present 0.25 to 0.3 per cent of molybdenum trioxide (MoO_3) contained in molybdite. The ore contains about three times as much pyrite as molybdenite. About 82 per cent of the molybdenite in the ore was saved, and before the plant was closed sulphidation and flotation of the molybdite was accomplished.

The Climax Molybdenum Co. first erected a mill capable of handling 300 tons of ore a day and increased it to handle 1,000 tons a day. The Molybdenum Products Corporation built a 300-ton plant. Both also erected headquarters houses and other buildings, and both put up aerial tramways.

The Pingrey Mines & Ore Reduction Co. has claims on Ceresco Mountain and according to Worcester[27] has "demonstrated beyond any question that the ore continues across from Bartlett Mountain to the west slope of Mount Ceresco. * * * The country rock, fracturing, occurrence, and values of the ore seem to agree closely with those on Bartlett Mountain."

The origin of the ore is probably connected with the intrusion of a quartz porphyry, now so altered by sericitization and silicification as to be difficult of differentiation from the granites, large volumes of which are also altered in the same manner. Owing to the altered condition of the rock it is not possible to prove that this is or is not one of the porphyries described by Emmons,[28] but it is probably a dike form of the rhyolite he described.[29] That it is not the ordinary granite of the region is shown by the sparse, rounded grains of quartz. (See Pl. II.) It is not unusual to find molybdenite accompanying intrusive rhyolite.

On Red Mountain, at the head of Clear Creek, in Clear Creek County about 35 miles northeast of Climax and 12 miles west of Georgetown, is Camp Urad, at which is the molybdenum mine opened and for several years operated by the Primos Chemical Co. but now belonging to the Vanadium Corporation of America. This mine has been one of the largest producers of molybdenum and has been described by both Horton[30] and Worcester.[31] The principal workings,

[26] Haley, D. F., op. cit., p. 75.

[27] Worcester, P. G., op. cit., p. 91.

[28] Emmons, S. F., Geology and mining industry of Leadville, Colo.: U. S. Geol. Survey Mon. 12, Atlas, p. 6, 1886.

[29] Emmons, S. F., U. S. Geol. Survey Geol. Atlas, Tenmile district special folio (No. 54), p. 3, 1898.

[30] Horton, F. W., op. cit., pp. 66-67.

[31] Worcester, P. G., op. cit., pp. 47-50.

though in unsurveyed land, are probably in sec. 29, T. 3 S., R. 75 W., and are at an altitude of about 11,300 feet; the camp is at 10,200 feet. From the descriptions given the mine seems to be on a sheared zone 200 feet wide, striking N. 65° W., in which are granite and alaskite(?) porphyry. In this zone are quartz veins carrying molybdenum and pyrite. The veins range from a small fraction of an inch to 3 or 4 feet across, and there is some ore-bearing breccia. The molybdenite is altered to molybdite near the surface, and the ore is said to be wholly free from copper. The rock is fairly soft and is apparently more or less sericitized. Horton says that the ore averaged approximately 2 per cent of molybdenum, but it is reliably reported as carrying only 0.5 to 0.6 per cent. Coghill and Bonardi[32] simply say that it "is of about the same grade as that of other workable molybdenite deposits." As to the size of the molybdenite particles they say, "The molybdenite ranges in size from large beautiful specimens to the minutest specks firmly locked in the siliceous gangue." Data as to the quantity of ore developed or in reserve are not at hand.

There are many other molybdenite deposits in Colorado, from several of which some production has been made.

NEW MEXICO

Seven miles east of Questa, N. Mex., just south of the Colorado State line and a short distance east of the Rio Grande, the Molybdenum Corporation of America, successor to the R & S Molybdenum Co., has a rather extensive molybdenite deposit that in its general features seems to be of the same type as the deposit at Camp Urad, Colo. It has recently been described by Larsen and Ross.[33] The grade of the ore is very much higher than that of the Climax ores, but the quantity is much less.

ARIZONA

In Arizona some ore has been produced from claims in Copper Canyon, about 25 miles southeast of Yucca. Copper Canyon drains southeastward in a trough about 3 miles long that has been cut longitudinally in the east side of the Hualpai Mountains and joins, at nearly right angles, Deluge Wash, which slopes eastward to Big Sandy River.

Beginning with the claims of the Arizona Molybdenite Consolidated, which are just across the narrow divide (north) from the head of Copper Creek, a succession of groups of claims held for molybdenum extends to Deluge Wash and spreads both up and down the

[32] Coghill, W. H., and Bonardi, J. P., Flotation of molybdenite at Empire, Colo.: Eng. and Min. Jour., vol. 109, p. 1210, 1920.

[33] Larsen, E. S., and Ross, C. S., The R & S molybdenum mine, Taos County, N. Mex.: Econ. Geology, vol. 15, pp. 567–573, 1920.

wash. Nearly all the workings are on the east side of the Copper Creek canyon and are on quartz veins cutting granite. The veins are all similar in character and differ only in size and richness. They were deposited near the surface of a granitic intrusion as comparatively pure white quartz, probably with a small quantity of pyrite, chalcopyrite, sphalerite, and galena and possibly some molybdenite. Movement along the veins continued, the quartz was broken, and in cracks molybdenite and more pyrite and chalcopyrite were deposited.

The Leviathan Mines Co. has been the largest operator and has a mine in Copper Canyon, about a mile from Deluge Wash. The company had sunk a shaft 220 feet deep on the Leviathan vein, a prominent quartz vein that crosses from one side of the canyon to the other and is as much as 20 feet but in most places is probably nearer 7 feet wide. The shaft, following the vein, has an inclination of 8 feet in 100 feet. Water was so scarce in 1917, when the mine was last operated, that the mill could run only two shifts a day, although a pipe line had been run 4 miles to a point in Deluge Wash, from which it was expected a plentiful supply would be obtained, but it gave out in August. Water was obtained from the shaft, but a strong taste of pine oil in the water showed that it was receiving the drainage from the mill. Counting the back flow, the shaft was furnishing about 5,000 gallons of water a day. The ore carried about 1 per cent of molybdenite, nearly as much copper in chalcopyrite, and less pyrite. Low-grade concentrates carrying 20 to 30 per cent of molybdenite and 18 to 25 per cent of copper were made by oil flotation. No pay was received for the copper in the concentrates. Several hundred feet of drifting had been done on the 100-foot level, and a considerable quantity of ore had been broken down on the stulls when I visited the mine in 1917.

There are many other molybdenite-bearing outcrops in the Hualpai Mountains, on some of which considerable work has been done and a small production made.

Molybdenite has been mined at Helvetia, Ariz.,[34] where it is found in both contact-metamorphic deposits and quartz veins cutting pre-Cambrian granite and associated with aplite; and at Duquesne and San Antonio Canyon, where it occurs in altered granite porphyry and altered granite, respectively.

OTHER LOCALITIES

In Alaska a deposit at Shakan, in the northwestern part of Prince of Wales Island, has been developed by the Alaska Treadwell Co. It is in a mineralized shear zone in hornblende diorite, 600 feet above Shakan Bay.[35] The zone crops out for 500 feet. The ore averages

[34] Schrader, F. C., and Hill, J. M., Some occurrences of molybdenite in the Santa Rita and Patagonia mountains, Ariz.: U. S. Geol. Survey Bull. 430, pp. 154–163, 1910.

[35] Mertie, J. B., jr., Lode mining in the Juneau and Ketchikan districts: U. S. Geol. Survey Bull. 714, pp. 118–119, 1921.

from 1 to 2.28 per cent MoS_2 in large lots; 6,270 tons of the high-grade ore was blocked out, and 100,000 tons of ore assaying 1.58 per cent was indicated.[36]

A little molybdenum ore has been mined from contact-metamorphic deposits near Bishop, Calif., and Golconda, Nev. Attempts to mine molybdenite have been made at many other places in this country, in California, Idaho, Maine, Montana, Nevada, Oregon, Texas, Utah (Alta), and Washington, probably without profit.

WULFENITE

Wulfenite has been produced mostly from the old Mammoth mine, at Shultz, Ariz., about 40 miles north of Tucson. The mine was first worked for gold. The ore was transported to Mammoth, on San Pedro River, 3 miles away, where it was treated by crushing and amalgamation. Some years later the tailings were treated by cyanidation, and still later they were run through sluice boxes to save the wulfenite. The ore had been so finely crushed that the friable particles of wulfenite were too small to be easily saved in this manner, but some concentrate was obtained. The tailings were spread over a considerable area of ground and lay so long undisturbed that they had been in part farmed as if they were soil. R. O. Boykin then sampled and later, with Frank H. Hereford, bought them, formed the Arizona Rare Metals Co., and erected a mill in which they were treated. After all these handlings a little wulfenite still remained in the tailings, and they were being treated by sulphidation and flotation when the armistice was signed and work had to stop for lack of market.

In 1916 the Mammoth mine, which had long lain idle, was taken over by Col. Epes Randolph and associates under the name Mammoth Development Co., and work on it was begun. The mine had been worked down to about 760 feet—somewhat below water level. With the Mammoth, the Collins mine, a few hundred feet west, was also purchased. The mines are in brecciated zones, 10 to 20 feet across or even wider, in granite and later porphyries. The broken rock is loosely cemented, and in the cracks are wulfenite crystals. With the wulfenite is some vanadinite, descloizite, cuprodescloizite, and, in the Collins mine, considerable cerusite and some copper carbonates. The wulfenite is yellow, brownish yellow, carrot-red, brownish red, and bright red. The crystals bristle from the fragments of the breccia, so that the light from a lamp is reflected from thousands of facets, giving the appearance of myriads of tiny flames. The stopes hold up almost without timber, even though so loosely cemented. Not nearly so much work has been done in the Collins mine as in the Mammoth mine.

[36] Bradley, F. W., Min. and Sci. Press, vol. 117, p. 48, 1918.

A few hundred feet east of the Mammoth mine the old Mohawk mine, also worked for gold, reaches a depth of about 700 feet. The surface is here considerably below that at the Mammoth and the Collins. The Mohawk has lain idle for years. Several of the upper levels have large stopes with thousands of tons of broken ore ready for removal, but apparently too lean in gold to be worked for that metal. The stopes have the same beautiful appearance in the lamp-light as those of the Mammoth, but they appear from inspection without sampling to be less rich and to contain a larger proportion of vanadinite. The mine has not yet been worked for these minerals, but the appearance of the stopes suggests the possibility of drawing the broken ore at a profit, even if no other work could be done, provided, of course, that a market could be found for the concentrates.

Although no tungsten mineral has yet been identified in these mines, the concentrates are said to carry as much as 2 per cent of tungsten trioxide.

Among the numerous other wulfenite-bearing mines in Arizona one at Pantano has made some production, but most of them are very much smaller. Some wulfenite is found also near Lavic and at other places in California and at Eureka and other places in Nevada, and some has been produced at Organ, N. Mex.

CANADA

Canada, like the United States, has many deposits of molybdenite. (See fig. 1.) In 1911 the then known deposits were well described by Walker,[37] but since that time many deposits have been found and deposits known before have been given an entirely different complexion through active development. By far the largest deposit now known is that opened in the Moss mine of the Dominion Molybdenite Co. (Ltd.), 3 miles north of Quyon, Quebec. The mine is also known as the Wood mine [38] because of its part ownership by Henry E. Wood. Camsell [39] and Wilson,[40] each of whom has described the deposit, agree on most details.

A pink fine-grained hornblende-quartz syenite is intruded into an older porphyritic gray syenite and is itself cut by pegmatite and aplite dikes. There are a number of ore bodies in a zone 500 feet long, 60 feet wide, and at least 250 feet deep. The largest ore body is 50

[37] Walker, T. L., Report on the molybdenum ores of Canada, 64 pp., illus., Canada Dept. Mines, Mines Branch, 1911.

[38] Dresser, J. A., A note on the Wood molybdenite mine near Quyon, Quebec: Canadian Min. Inst. Bull. 59, pp. 206–208, 1917.

[39] Camsell, Charles, Molybdenite deposits of the Moss mine, Quyon, Quebec: Canada Geol. Survey Summary Rept. for 1916, pp. 207–208, 1917.

[40] Wilson, M. E., Molybdenite deposits of Quyon district, Quebec: Canadian Min. Jour. vol. 39, pp. 78–80, 1918; Molybdenite in the lower Ottawa Valley: Canadian Inst. Min. and Metallurgy Bull. 192, pp. 749–754, 1920.

feet wide, 200 feet long, and 75 feet deep. The deposits all have an elongated form and are made up of masses of granular quartz, feldspar (chiefly gray or greenish-gray microcline), pyrite, pyrrhotite, fluorite, magnetite, limonite, and molybdenite. The ore is mostly medium grained and of granitic appearance but is in places coarse and pegmatitic, and black pyroxene crystals are locally abundant and in part radially disposed. Pyrite occurs usually in cubes. The molybdenite and other sulphides in lean ore are commonly distributed in zones parallel to the longer dimension of the deposit.[41] Camsell thought the deposits to be pegmatites, but Wilson thinks that they are due to magmatic segregation. From the descriptions they seem very similar to deposits in other countries that have ben determined as pipes or other deposits formed by the replacement of granitic rocks. Hand-picked ore carried as much as 6 per cent of molybdenite, but Wilson thought that the ore in the bottom of the open pit on the largest deposit did not carry more than 0.75 per cent and that of the next largest deposit 0.5 per cent. Other mines in Quebec are described by Gwillim [42] and Mailhiot.[43]

In eastern Ontario there are numerous molybdenite deposits, but their mode of occurrence " is such that a person reading the ordinary descriptions of the occurrence of this mineral would be likely to look in almost any other place than where it is likely to occur," [44] for nearly all the deposits are of contact-metamorphic origin,[45] having been formed where pegmatite, granite, or syenite has cut the Grenville limestone. The deposits carry large quantities of green pyroxene (diopside) and considerable scapolite, pyrrhotite, and pyrite.[46] The principal mine is that of the Renfrew Molybdenum Mines (Ltd.). An ore body has been traced 100 feet on the surface, and another one at a depth of 100 feet is 10 to 15 feet wide and carries 1 per cent MoS_2. The ore bodies are apparently as erratic as most other contact-metamorphic deposits.

During the war some molybdenite was produced by a number of mines in other districts of Canada, among which was the Molly mine, on Lost Creek, in the Nelson mining division, 15 miles from Salmo, B. C.[47] This mine is on stockworks and impregnation deposits in intrusive granite near its contact with slate and limestone.

[41] Wilson, M. E., unpublished manuscript.

[42] Gwillim, J. C., Molybdenite in Nova Scotia, Quebec, Ontario, and British Columbia: Canada Munitions Resources Comm. Final Rept., November, 1915, to March, 1919, pp. 108–133, 1920.

[43] Mailhiot, A., Molybdenite deposits of Lacoine Township, Abitibi, Province of Quebec, Canada: Min. Jour., vol. 41, pp. 135–138, 1920.

[44] Parsons, A. L., Molybdenite deposits of Ontario: Ontario Bur. Mines Twenty-sixth Ann. Rept., p. 275, 1917.

[45] Ellis Thomson (A pegmatitic origin for molybdenite ores: Econ. Geology, vol. 13, pp. 302–313, 1918) believes that these ores have a pegmatitic origin.

[46] Wilson, M. E., private communication. I have to thank Mr. Wilson for courteously correcting the section on Canadian molybdenum deposits.

[47] Drysdale, C. W., Notes on the geology of the Molly molybdenite mine, Lost Creek, Nelson mining division, B. C.: Canadian Min. Inst. Trans., vol. 18, pp. 247–255, 1915.

The granite is here closely sheeted and besides molybdenite carries pyrite and pyrrhotite. The ore zone appears to be about 10 feet thick, but blocky granite outside the sheeted ore zone is somewhat impregnated with molybdenite, and contact-metamorphosed sediments also carry some molybdenite, though not enough to be economically valuable. Shipments of ore ran as much as 16.59 per cent of molybdenite, and several thousand tons was thought to carry about 4 per cent. There are many other deposits in British Columbia,[48] Nova Scotia,[49] and Manitoba.[50]

MEXICO

Little has appeared in print about the molybdenum deposits of Mexico (see fig. 1), but it is known that molybdenite ores in small quantity from Lower California have been treated at Nogales, Ariz., and molybdenite ores from Nacozari have been treated by the American Smelting & Refining Co., at El Paso, Tex. The International Commission Co., of Douglas, Ariz., mined molybdenite 20 miles east of Nacozari and had it milled at Nacozari.

George Fast, of Douglas, Ariz., has mined molybdenite near La Trinidad, in the Sahuaripa district, Sonora. The ore is said to be in a pegmatite, but the appearance of specimens suggests that the ore body is a pipe, and some masses of very pure molybdenite that weighed 100 or 200 pounds apiece have been extracted. Considerable masses of scheelite are associated with the molybdenite. The ore mined was so rich that during the period of high prices Mr. Fast was able to make a profit after transporting it on pack mules 225 miles through the mountains to the railroad at Nacozari.

The Colorado mine, at La Colorada, Sonora, has, according to one estimate, 1,000,000 tons of ore carrying 1 per cent of wulfenite left in the pillars and walls, but the accuracy of the estimate is unknown.

Near Tinajas, Chihuahua, the Madero estate has a mine in which considerable quantities of wulfenite are associated with vanadinite.

VIRGIN GORDA

Some molybdenite is reported to have been mined in connection with copper from a granite mass on Virgin Gorda Island, in the Caribbean, one of the Virgin Islands owned by Great Britain (see fig. 2), but few details are at hand.

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[48] Gwillim, J. C., Molybdenite in Nova Scotia, Quebec, Ontario, and British Columbia: Canada Munitions Resources Comm. Final Rept., November, 1915, to March, 1919, pp. 108–133, 1920.

[49] Hays, A. O., Investigations in Nova Scotia: Canada Geol. Survey Summary Rept. for 1917, p. 28–F, 1918.

[50] De Lury, J. S., Molybdenite at Falcon Lake, Manitoba: Canadian Min. Jour., vol. 38, pp. 360–462, 1917. Bruce, E. L., Molybdenite near Falcon Lake, Manitoba: Canada Geol. Survey Summary Rept. for 1917, pp. 22–25, 1918.

PERU

Peru produced from 2.7 to 7 metric tons of molybdenum ore annually in the years 1913 to 1918, inclusive.[51] It was concentrate "laboriously picked by hand from superficial workings" in the department of Lima; the Cajatambo district, Ancachs; and the Prov-

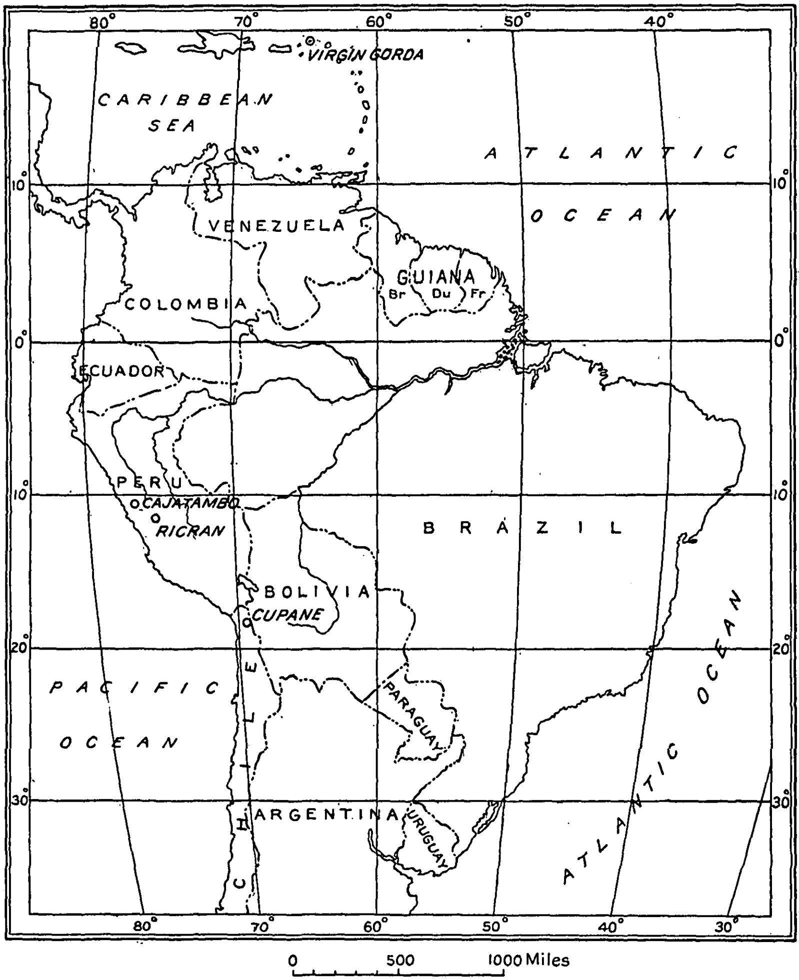

FIGURE 2.—Principal known molybdenum deposits of South America and the West Indies. All the known deposits carry molybdenite

ince of Huari; and some concentrates made by a small plant at Ricran, near Jauja, Junin. (See fig. 2.) Small quantities have been produced at other times in the departments of Huanuca and Cuzco. The deposits in Ricran are said to be very large but must be worked by machinery to give large yields.[52] They are 18 miles (30 kilo-

[51] Jiminez, C. P., Estadística minera en 1918: Cuerpo ing. minas Perú Bol. 96, pp. 134–135, 1920.

[52] Idem, 1917: Bol. 95, pp. 219–220, 1919.

meters) northwest of Jauja and are molybdenite-bearing quartz veins cutting granite. The average content is said to be 2 to 3 per cent MoS_2, and they are claimed to be among the largest deposits in the world,[53] to be easy to work, and to concentrate at low cost.

BOLIVIA

A little molybdenite has been produced in Bolivia by arduous hand picking, but no deposits offering effective competition to the large North American deposits are known to exist.

CHILE

Comparatively small quantities of molybdenite have been produced at Cupane, near Tacna, in the northern part of Chile,[54] and occurrences have been reported in other parts of the country, but no large deposits are known. (See fig. 2.)

AUSTRALIA

All the States of Australia except Tasmania have produced some molybdenite, but by far the largest part has come from the States along the eastern coast—Queensland, New South Wales, and Victoria. (See fig. 3.) South Australia, Western Australia, and Northern Territory have so far produced only small quantities, and at present there seems to be little promise of large production from any of them, for South Australia is lacking in known deposits of large size, and in the other two the deposits seem to be of modest size and transportation is a serious problem. None of the deposits so far described are comparable in size with that at Climax, Colo.

QUEENSLAND

Queensland has many deposits of molybdenite, with which are commonly associated wolframite and bismuth. All the deposits are either within intrusive granite or in the adjacent country rock. A number of the deposits of commercial value are in pipes, some are in veins, and others are in rocks called "greisen"—that much-abused term which is commonly used to cover all sorts of altered granitic rocks. Queensland was a steady producer of molybdenite from 1900 until 1920, when the British Government's war control of the industry ceased and, as in all other parts of the world, demand stopped and the mines had to close.

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[53] Jiminez, C. P., Estadística minera en 1916: Cuerpo ing. minas Perú Bol. 94, p. 136, 1917.

[54] Ossa, J. D., Depósito de molibdeno i tungsteno de Campanani, Arica: Soc. nac. minería Bol. 223, vol. 28, pp. 203–213, 1916.

The largest molybdenite producer at present is the Wonbah mine, near Wonbah, not far from the crossing of the parallel of 25° S. and the meridian of 152° E. As described by Reid,[55]

The ore deposit is a white quartz pipe in granite, which for its size and regularity must be unique in Australian occurrences. The shaft is down a

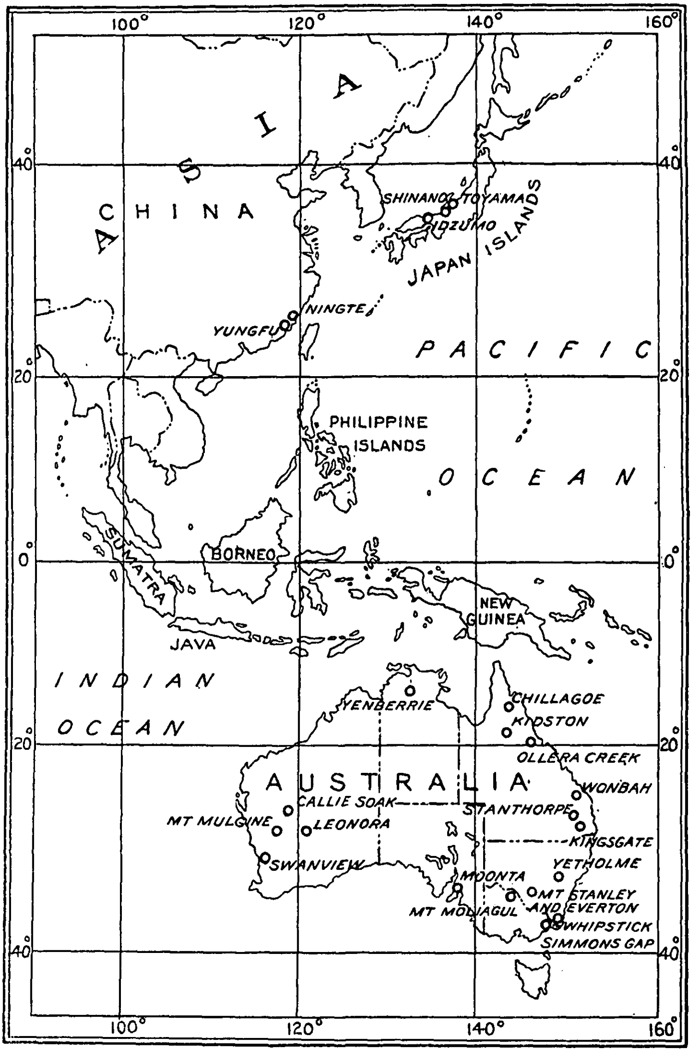

FIGURE 3.—Principal known molybdenum deposits of Australia and Asia. All the known deposits carry molybdenite. The positions of Stanthorpe and Kingsgate are indicated too far north, as the State line runs between them

vertical depth of 180 feet, and the pipe, which is approximately cylindrical, appears to be increasing in size, as at No. 1 level its diameter was about 42 feet, and at No. 2 level, at a vertical depth of 160 feet, it has increased to 58 feet. So far as penetrated, the pipe is not at all tortuous and appears

[55] Reid, J. H., Wonbah molybdenite mine: Queensland Govt. Min. Jour., vol. 20, p. 465, 1919.

to have a regular inclination of about 10° to 20° from the vertical. The whole pipe practically consists of white quartz, with which there is a good deal of calcite, especially in segregations. The occurrence of the molybdenite is less sporadic than is usual in similar pipes in this State and New South Wales and appears to be more concentrated toward the outer periphery of the pipe. Thus they are working a face 16 feet wide around the outer periphery, leaving a central core about 25 feet through, which is relatively poor. This working face shows molybdenite rather regularly scattered through it. The ore is clean, and so far there have been no metallurgical difficulties. In the face of the central core some small masses of other sulphides were seen in a calcite gangue. These consist of chalcopyrite, pyrite, galena, and zinc blende. Up to the present they have not been a source of trouble to the flotation of the ore, and as they occur more or less segregated, no trouble is anticipated.

In 1918, according to Reid, 2,435 tons of ore gave 13.95 tons of concentrates, valued at £6,052, and in the first nine months of 1919 4,068 tons of ore gave 28.15 tons of concentrates, valued at £12,285. The entire output for the year was 38 long tons of concentrates, valued at £16,400.[56]

Among the principal molybdenite-bearing districts are those at Wolfram, Bamford, and Khartoum (formerly Sandy Tate), in the Chillagoe mining field, northern Queensland, between 17° and 18° south latitude and 144° and 146° east longitude. Other producing deposits are at Kidston, in the Etheridge gold field (19° south latitude, 144° east longitude); Ollera Creek, in the Star River mineral field, near Townsville (19° south latitude, 145° east longitude); and Stanthorpe, near the New South Wales border (28° 39′ south latitude, 151° 58′ east longitude).[57] Mineralogical occurrences are of course numerous through the whole length of the eastern coastal belt, which contains many granitic intrusions.[58]

The camp at Wolfram is on the edge of a granodiorite mass adjoining Paleozoic porphyry and slate, into which it has been intruded. The ore deposits are quartz pipes in the granodiorite, and the location of the pipes has been fixed by the intersection of joints.[59] Around the pipes the granodiorite is greisenized—that is, changed to a mixture of quartz and mica. The pipes are extremely irregular in dip and range from less than a foot to 20 feet in diameter but average less than 5 feet. They have yielded principally wolframite but carry also molybdenite and bismuth minerals.

The largest of the pipes is on the Murphy & Leisner property, and from it 150 tons of wolframite, 100 tons of molybdenite, and 4

[56] Queensland Govt. Min. Jour., vol. 21, p. 143, 1920.

[57] Dunstan, B., Queensland mineral deposits—a review of occurrences, production, values, and prospects: Queensland Govt. Min. Jour., vol. 17, pp. 314–316, 1916.

[58] Ball, L. C., personal communication. I am under obligations to Dr. Ball for correcting the part of this paper that deals with Queensland.

[59] Ball, L. C., The geology of Wolfram, N. Q.: Queensland Govt. Min. Jour., vol. 20, pp. 509–511, 1919; vol. 21, pp. 6–11, 50–56, 1920.

tons of bismuth were taken in three years.[60] The average diameter of the working in the pipe was somewhat more than 20 feet. In general the pipes "are peculiar in shape, being typically bent and contorted." There appear to be many such pipes in the State,[61] but they are not large producers.

The Kitchener mine, at Khartoum, which has been one of the largest producers but is now idle, is on a mica-bearing quartz vein cutting granite. The vein contains no tungsten, bismuth, iron oxide, or iron or copper sulphides.[62] The molybdenite "occurs mostly as flakes, frequently displaying crystal outlines, and also as massive lumps and shotty pieces." At the time of his examination Saint-Smith thought the lode averaged 4 feet 6 inches in width and that it would average between 3 and 4 per cent of molybdenite. Mining costs were estimated at £1 10s. a ton.

NEW SOUTH WALES

The coastal ranges extend from Queensland southward through New South Wales, and it is not surprising that this State also has numerous molybdenum deposits. Andrews[63] divides the deposits into five classes—"pipes, pegmatite and aplitic segregations, pegmatitic veins, true quartz veins, and contact deposits." The largest deposits seem to be the contact-metamorphic deposits, though they have not yet produced much ore. The greatest production has heretofore come from pipes.

The largest contact-metamorphic deposits are around Mount Tennyson, near Yetholme, and at Gemalla and Tarana, a few miles east. They are a short distance east of Bathurst, not far from the point where the meridian of 150° E. crosses the Great Western Railway (about 33° 30′ south latitude), 125 miles, more or less, from Sydney. Here granitic rocks have intruded Paleozoic beds containing limestone, and masses of typical garnet-wollastonite tactite carrying molybdenite have been formed.[64] The tactite is of remarkable extent. During the excitement over molybdenum caused by the demand incident to the war, several companies started rather extensive operations on the deposits.[65] The Mammoth Molybdenite Mines, N. L., put up a mill and treated 4,424 tons of ore, from which it recovered 9 tons of concentrates. The grade is not given but was probably not over 90 per cent MoS_2, giving a recovery of less than

[60] Ball, L. C., Rare-metal mining in Queensland: Queensland Govt. Min. Jour., vol. 14, pp. 4–6, 1913.

[61] Dunstan, B., Queensland mineral index and guide: Queensland Geol. Survey Pub. 241, pp. 748–750, 1913.

[62] Saint-Smith, E. A., The Kitchener molybdenite mine, Khartoum: Queensland Govt. Min. Jour., vol. 18, pp. 226–229, 1917.

[63] Andrews, E. C., The molybdenum industry in New South Wales: New South Wales Geol. Survey Mineral Resources No. 24, p. 26, 1916.

[64] Idem, pp. 170–189.

[65] New South Wales Dept. Mines Ann. Rept. for 1919, p. 56, 1920.

0.2 per cent, although "a trial parcel * * * gave a return of 1.7 per cent molybdenum disulphide."[66] The Mount Tennyson Molybdenite Mining Co. (Ltd.) also put up a mill, and the Broken Hill Proprietary Co. did a large amount of testing and drilling. The deposits have proved to be of too low grade to allow profitable exploitation under prices so far offered (105 shillings per long-ton unit for concentrates carrying 90 per cent or more MoS_2, c. i. f. London, was paid by the British Government during the Great War.

The best known and heretofore the most productive of the New South Wales deposits are pipes near Kingsgate, on the New England Plateau, 20 miles east of Glen Innes and probably less than 50 miles from Stanthorpe, Queensland. Glen Innes is on the Northern Railway in about 151° 45′ east longitude, 29° 45′ south latitude. The pipes have been described by several writers, but best by Andrews,[67] who in 1916[68] listed 51 pipes at Kingsgate. The Department of Mines[69] in 1919 mentions 54 pipes on the property of Kingsgate Molybdenite, N. L. The pipes are tortuous irregular masses of quartz from 18 inches to 30 feet in diameter, as irregular in dip as in thickness, and have been followed as much as 350 feet. From the pipes irregular masses or "droppers" protrude. The pipes carry molybdenite, bismuth, and bismuthinite. In a few pipes arsenopyrite, a little wolframite, cassiterite, gold, and silver are associated with the molybdenite, and at various times they have been worked unsuccessfully for the precious metals or for tin. One single piece of molybdenite found in Sach's or No. 45 pipe weighed more than a ton. The average content of the pipes is of course variable, and few data bearing on it are at hand. Forty tons of "rich stone"[70] from one pipe was expected to give 1½ tons of bismuth and molybdenite.

Similar pipes are found at Deepwater, Bolivia, and Rocky River, north of Kingsgate. At Whipstick, in the southeast corner of New South Wales, pipes also are worked. The pipes are large, and in some places several branch from a common root. They have manganiferous gossans, which Andrews considers to be derived from the alteration of garnet, and besides molybdenite carry mica, garnet, gold, silver, bismuth, bismuthinite, and joséite (telluride of bismuth).

New South Wales also has many lesser occurrences of molybdenite in veins, greisens, and other forms of deposits.

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[66] Molybdenite and wolfram: Chem. and Eng. Rev., vol. 10, p. 150, 1917.

[67] Andrews, E. C., The geology of the New England Plateau, with special reference to the granites of northern New England: New South Wales Geol. Survey Rec., vol. 8, pp. 242–243, 1904–1907.

[68] Andrews, E. C., The molybdenum industry of New South Wales: New South Wales Geol. Survey Mineral Resources No. 24, pp. 92–117, 1916.

[69] New South Wales Dept. Mines Ann. Rept. for 1919, p. 56, 1920.

[70] Andrews, E. C., The molybdenum industry in New South Wales: New South Wales Geol. Survey Mineral Resources No. 24, p. 114, 1916. I owe my thanks to Dr. Andrews for courteously correcting this section on New South Wales.

VICTORIA

Victoria has made only a negligible production of molybdenum, and not much had been published on the deposits before the Great War. Then, owing to the importance given to molybdenum ores by the sudden and insistent demand, the known deposits were examined by the Victoria Geological Survey, and in 1921 several short articles describing them were published.

After a study of the deposits Herman [71] concluded that those at Mount Stanley (near 146° 50′ east longitude, 36° 30′ south latitude), Mount Moliagul (near 143° 40′ east longitude, 36° 45′ south latitude), Simmons Gap (near 147° 30′ east longitude, 37° 30′ south latitude), and Everton (near 146° 30′ east longitude, 36° 20′ south latitude) were worthy of more prospecting than had been done on them.

All the deposits are in granite near its contact with rocks into which it was intruded and are more or less closely connected with quartz veins of various sizes. The deposits at Everton seem to be the most valuable, and during the war the Everton Molybdenite Mining Syndicate (which was succeeded by the Standard Molybdenite Mining Co., N. L.) and five other companies with capital ranging from £2,000 to £3,000 attempted to work them. The deposits are 2 miles north of Everton station on the Everton-Beechworth Railroad. Molybdenite has been found [72] over an area a quarter of a mile wide by 3 miles from north to south, in several granite bosses (probably protuberant from a single mass) intruded into slate and sandstone that seem to be of lower Ordovician age. The granite is cut by pegmatite dikes, but few of the dikes carry molybdenite, and in these it is accompanied by quartz. The molybdenite in the granite occurs with quartz veins, the largest of which is 1 foot thick. When examined by Kenny the main molybdenite-bearing body was in the Standard mine, near the north end of the area, and was dome shaped, the apex not cropping out, but coarse molybdenite was found near the surface, accompanied by molybdite. The dome was 27 feet across, roughly circular, and in concentric layers. In March, 1919, it had been proved to a depth of 23 feet. Finely disseminated pyrite accompanies the molybdenite. At the contact the slate is changed to hornfels, and a little molybdenite is found both in quartz veins cutting the rock and in the rock itself.

Half of the rock mined carried less than 1 per cent of molybdenite and was treated as waste. The other half was hand picked; one fourth of it carried 10 per cent and was shipped to Melbourne, and the other three-fourths, carrying 3 to 4 per cent, was piled. The

[71] Herman, H., Molybdenite occurrences in Victoria: Victoria Geol. Survey Rec., vol. 4, pt. 3, p. 203, 1921.

[72] Kenny, J. P. L., The Everton molybdenite field: Victoria Geol. Survey Rec., vol. 4, pt. 3, pp. 295–299, 1921.

total yield of the mine to March 28, 1919, had been nearly 42 short tons of ore, picked so that it carried from 7.3 to 10.53 per cent, valued at about $5,400 at normal exchange. Afterward a mill with a capacity of about 55 short tons a week was erected to treat ore carrying 1 per cent or more. From 280 short tons of ore 95.3 short tons of concentrates carrying 85 per cent is said to have been obtained.[73] Such a result indicates remarkably rich ore.

At Mount Moliagul molybdenite is reported as occurring in a partly decomposed eurite or binary granite,[74] and in less quantity in quartz veins. The Mount Moliagul Molybdenite Syndicate cut more than 2,000 feet of trenches 3 to 10 feet deep in a granite area measuring about 1,300 by 2,600 feet, but no production is reported, and no record has been found of the molybdenum content of the rock.

Smaller deposits have been prospected more or less seriously at Wangrabelle, Croajingolong.[75] Other small deposits are known at Maldon, Mount William, Kitchington Creek, Yea, Neerim, and other places.

SOUTH AUSTRALIA

In South Australia a few hundredweight of molybdenite has been obtained from the Yelta copper mine, at Moonta[76] (about 137° 5′ east longitude, 34° 5′ south latitude), on the Yorke Peninsula, east of Spencer Gulf, where it occurs with copper minerals and magnetite in a quartz vein cutting granite.[77] Molybdenite is also reported from a few other localities.[78]

WESTERN AUSTRALIA

Western Australia has produced only modest quantities of molybdenite, and though there are many occurrences, none seem to be very large. At Mount Mulgine (Warriedar) a gneissoid granite is impregnated with quartz and molybdenite.[79] There are "fair quantities" of ore carrying 1 and 2 per cent of MoS_2.

Molybdenite deposits at Leonora, Callie Soak, Westonia, Swan View, and North Dandalup are noted by Simpson,[80] Maitland,[81] and other workers on the Western Australian Geological Survey.

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[73] The Standard molybdenite mine, Everton, Victoria: Chem. Eng. and Min. Rev., vol. 12, pp. 448–449, 1920.

[74] Baragwanath, W., Prospecting at the Mount Moliagul molybdenite mine, Mount Moliagul: Victoria Geol. Survey Rec. vol. 4, pt. 3, pp. 228–229, 1921.

[75] Herman, H., Recent mining in Croajingolong: Victoria Geol. Survey Rec., vol. 4, pt. 2, pp. 169–170, 1920.

[76] South Australia Dept. Mines, Mineral resources for half year ended Dec. 31, 1917, p. 9, 1918.

[77] Brown, H. Y. L., Record of the mines of South Australia, 4th ed., p. 156, Adelaide, 1908.

[78] Idem, p. 368.

[79] Blatchford, T., On the molybdenite occurrences at Mount Mulgine (Warriedar), Yalgoo gold field: Western Australia Dept. Mines Ann. Rept. for 1918, pp. 77–78, 1919.

[80] Simpson, E. S., The rare metals and their distribution in Western Australia: Western Australia Geol. Survey Bull. 59, p. 52, 1914.

[81] Maitland, A. G., The molybdenite deposits of Western Australia: Western Australia Geol. Survey Mem. 1, chap. 2, pt. 3, sec. 7, 1919.

TASMANIA

Small deposits of molybdenite have been reported from various parts of Tasmania, but no production is known to have been made from them.

NORTHERN TERRITORY

Northern Territory has exported a few small lots of molybdenite, but transportation of ore and supplies is difficult and expensive, and if such deposits as that at Climax, Colo., existed in the Territory, it is not likely that they would pay for working. Only comparatively rich, easily separated ore can be handled profitably even when there is a market for molybdenite. At Yenberrie molybdenite is found in greisen with wolframite.[82]

NORWAY

Norway has been for years one of the principal producers of molybdenum ore. Most of the deposits are south of a line drawn west from Kristiania,[83] in Lister, Mandals, and Stavanger amts. but the ore is also found in notable quantities in Nordlands Amt.[84] (See fig. 4.)

Before the Great War only two or three mines were actively worked, but on the beginning of hostilities the miners found themselves in a position to sell to both groups of contenders. Germany would take the product at very high prices; the Allies did not want Germany to have it, and to prevent sales to her agreed to buy all that was offered at $4 a pound for the contained MoS_2, though for a time the price was 26,250 kroners a metric ton for material carrying 75 per cent of MoS_2, equivalent to about $4.25 a pound for the contained MoS_2. As Woakes[85] strikingly puts it, ore carrying 0.5 per cent of MoS_2 was as valuable as quartz carrying 2.75 ounces of gold ($56.84) to the metric ton. The established companies made undreamed of profits, and those who had or could obtain deposits, even poor ones, made haste to get rich while the prices born of desperation lasted, sinking shafts and erecting mills as feverishly as the climate and circumstances permitted, but when the armistice was signed many undoubtedly had not recovered their expenditures and lost money by the sudden termination of the demand. These high prices contrasted strongly " with the stories in those parts

[82] Gray, G. J., and Winters, R. J., Report on the Yenberrie wolfram and molybdenite field: Northern Terr. Bull. 15A, 4 pp., 1916.

[83] Woakes, E. R., Molybdenum in Norway: Inst. Min. and Met. (London) Bull. 160, p. 5, 1918.

[84] Private communication from Prof. J. Schetelig, Kristiania, who was good enough to correct the section on Norway. See also Falkenberg, E. O., footnote 88.

[85] Woakes, E. R., op. cit., p. 2.

about mountain peasants bringing ore over the mountain to Kristiansand and Stavanger, where they exchanged a pound of molybdenite for a pound of butter," the molybdenite being known as

FIGURE 4.—Principal molybdenum deposits of Europe. For location of deposits at Bleiberg, Austria, and Meiss, Yugoslavia, see text. W, Wulfenite; the others are molybdenite. ●, Larger producer; O, smaller producer

" silver stone " and " lead-pencil stone " and used as a lubricant and for stove polish.[86]

Claudet [87] quotes Falkenberg [88] on the geology as follows:

The most important discoveries in Norway are at Knabeheiem, near Kvinas Valley, north of Flekkefjord. The occurrences are associated with granite and partly granite gneiss. They appear to some extent in intimate association with massive pegmatite, and specially at the boundary of the pegmatite with the surrounding granite. In other places one can best speak of molybdenite-bearing quartz rock, and finally there are occurrences of ore direct in the

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[86] Falkenberg, E. O., Norske molybdengruber: Teknisk Ukeblad, vol. 68, pp. 6–11, 1921; trans. in Eng. and Min. Jour., vol. 111, pp. 1021–1023, 1921.

[87] Claudet, H. H., Notes on molybdenite operations in Norway: Canadian Min. Inst. Trans., vol. 19, pp. 125–126, 1916.

[88] Falkenberg, E. O., Om molybdenmalmer deres forekomst, opberedning, anvendelse, etc.: Tidskrift Kemi, Farmaci og Terapi, 1915.

granite without any accompanying kind of vein matter. This last is, however, of little extension and seems to be confined to small veins which intersect the granite. * * *

The ore-bearing zone is about 1 kilometer broad and has a longitudinal dimension from north to south of 20 kilometers. A further continuation is not out of the question.

Woakes[89] divides the deposits into (1) quartz lodes; (2) fissured granite, more or less decomposed, carrying molybdenite with little quartz, having a flat dip and little depth; (3) impregnated granite or norite. Some pyrite, chalcopyrite, a little pyrrhotite, feldspar, mica, and hornblende are found with the deposits.

In the Knaben mine some of the stopes are 10 meters across, and although the molybdenite is in general finely disseminated, some large rich masses have been mined. In many places the ore disappears at shallow depths, either pinching out or leaving a barren vein,[90] and Falkenberg thinks that this will prove generally true.[91]

On the Hovlands farm, Orsdal, Bjerkreim Parish, a little wolframite and scheelite are found with the molybdenite.[92]

The Dalen mine in 1917 produced 27,000 metric tons of rock, of which 8,000 tons was ore; from this was picked 2.4 tons carrying about 90 per cent of MoS_2, 4.8 tons carrying 70 per cent, and 9.4 tons carrying 50 per cent. After picking, 38.4 tons of concentrates carrying 75 per cent of MoS_2 and 48.9 tons carrying 65 per cent were obtained by the Elmore flotation process. The total content of the hand-picked and mechanical concentrates was 69.96 tons of MoS_2—a yield of 0.875 per cent of the rock treated.[93]

The ore of the Lille Knaben mine carried 0.39 per cent of MoS_2, and that of the Knaben mine No. 1 carried 0.56 per cent. The Knaben mine No. 2 had in sight 1,170,000 tons of ore carrying 0.5 per cent of MoS_2.

The total Norwegian production to the end of 1920 is estimated by Falkenberg to have been about 8,800 tons of pure molybdenite.

There are many deposits in Norway that can be worked only under excessive prices or are of purely mineralogic interest.

Lloyd[94] says that wulfenite has been mined near Egersund, but this is apparently an error.[95]

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[89] Woakes, E. R., op. cit., p. 3.

[90] Claudet, H. H., op. cit., p. 126.

[91] Falkenberg, E. O., op. cit. (Teknisk Ukeblad), pp. 6–11.

[92] Norges Bergverksdrift, 1917, p. 55, Statistiska Centralbyra, 1918.

[93] Idem, p. 16.

[94] Lloyd, G. C., Report on the sources and production of iron and other metalliferous ores used in the iron and steel industry, p. 146, Advisory Council, Dept. Sci. and Ind. Research, London, 1918.

[95] Personal communication from Prof. J. Schetelig.

SWEDEN

In 1918 the Udd mine, in Ljusnarsberg Parish, Örebrolan, Sweden (see fig. 4), produced 7,545 metric tons of rock from which 1,035 tons of ore carrying 36.4 per cent of MoS_2, valued at 10,920 kronor, was hand picked, and 6,045 tons carrying 0.77 per cent was concentrated, giving 73 tons carrying 55 per cent of MoS_2, valued at 1,069,260 kronor.[96]

GERMANY

Some wulfenite has been mined in the Hollenthal, near Garmisch,[97] in southern Bavaria, close to the Austrian border. (See fig. 4.) The mineral occurs with galena in brecciated limestone. This deposit was worked for molybdenum during the Great War.

AUSTRIA

Several wulfenite deposits have been worked in Austria. (See fig. 4.) One deposit is near Nassereit,[98] in the Tyrol, near the Swiss border, only 20 or 25 miles southwest of the German deposit at Garmisch. At Bleiberg, on the southeastern border, wulfenite has been known for many years. Both deposits furnished molybdenum to the Central Powers during the Great War. Mezica or Meiss, in Yugoslavia, is a few miles directly south of Bleiberg.

YUGOSLAVIA

At Mezica (Meiss or Meissdorf), 8 kilometers (5 miles) southwest of Prevaljo, Carniola, Yugoslavia, with which it is connected by a narrow-gage railroad, is a lead-zinc mine with a considerable quantity of wulfenite in the oxidized part.[99] Before the Great War the mine was worked by the Kleiberger Bergwerks Union, but after the war it was sequestrated by the Yugoslavian Government.

Some of the deposits are lens shaped, 0.5 to 3 meters or more thick, 150 meters or more long, and 100 meters or more deep. Others are in chimneys or spirals, commonly with a horizontal section of only 4 to 9 square meters and reaching to depths of 30 to 40 meters. The associated minerals are quartz, calcite, barite, marcasite, pyrite, gypsum, and secondary minerals. There is no gold, silver, or anti-

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[96] Sveriges Officiella Statistik, Bergshantering berattelse for år 1918, pp. 92, 93, 96–97, 1919.

[97] Schmidt, C., Das Vorkommen von Gelbbleierz im Höllental bei Gormisch: Zeitschr. prakt. Geologie, vol. 23, pp. 93–102, 1915.

[98] Krusch, P., Ueber die Stellung des Gelbbleierzes (Wulfenit) in der Reihe der Leiterze im Lichte der im Kriege geschaffenen Aufschlusse (Karnten, Werdenfels in Hollenthal, Dirstentritt bei Nassereit, u. s. w.): Zeitschr. Berg-, Hütten- u. Salinenwesen preuss. St., vol. 66, Heft 1, pp. 56–69, 1918.

[99] Smith, H. I., Index of mines in Slovenija, Technical Mission to the Serbs, Croats, and Slovenes, Reports on the mines of Slovenia, Sept. 5, 1920 (MS.).

mony. The ore bodies are in limestone or dolomite[1] cut by granite and basic dikes.

From 1902 to 1913, inclusive, there was produced 714 tons of wulfenite concentrates, said to carry usually about 27 per cent of molybdenum trioxide, but ranging from 26 to 34.18 per cent, with one small lot going down to 13 per cent. No figures for production during or since the war are available. At the time of Smith's visit 70 tons containing 25 per cent of molybdenum trioxide was on hand. It was proposed to trade both lead ore and wulfenite to Germany for coke.

SPAIN

Some wulfenite has been produced near Quentar, in the Province of Granada, Spain,[2] 14 kilometers (about 9 miles) east of Granada. (See fig. 4.) A number of other mines, 12 to 20 miles south of Granada, also carry some wulfenite. In the Province of Almeria small deposits have been found near Oria. All are in limestones.

JAPAN

Few details are known of the Japanese molybdenum deposits. T. Hirabayashi[3] briefly outlined the occurrences as known in 1909, and according to his description molybdenite occurs in (quartz?) veins, pegmatitic veins, and contact-metamorphic deposits. The veins contain the most, and some carry wolframite and bismuth with the molybdenite. Veins in granite are known in the Provinces of Hida (about 36° north latitude, 136° east longitude), Bizen (about 34° 45′ north latitude, 134° east longitude), and Idzumo (about 35° 30′ north latitude, 133° east longitude), and contact-metamorphic deposits in Yechigo (given on some maps as Echigo and on others as Nigata, near 37° north latitude and 139° east longitude). (See fig. 3.)

In 1917 Okura & Co.[4] wrote that the principal molybdenum mines of Japan were as follows:

Shirokawa mine, Shirokawamura, Oonogun, Toyama Province (given on some maps as Etchu; most of the province is between 36° 30′ and 37° north latitude and 137° and 138° east longitude); output 500 catties (667 pounds) a month.

Miyamotomura, Kumagun, Toyama Province; output 250 catties (334 pounds) a month.

Matsukawamura, Chikumagun, Shinano Province (near 36° north latitude, 136° east longitude); output 250 catties (334 pounds) a month.

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[1] Granigg, B., and Koritschoner, J. H., Die geologischen Verhältnisse des Bergbaugebietes von Miess in Karnten: Zeitschr. prakt. Geologie, vol. 22, p. 172, 1914.

[2] Rubio, J. M., and Gavala, Juan, Yacimientos de molibdeno en las provincias de Granada y Almeria: Inst. geol. España Bol., vol. 39, pp. 167–193, 1918.

[3] Mining in Japan, past and present, pp. 111–112, Japan Bur. Mines, 1909.

[4] Cunningham, E. S. (American consul general, Hankow, China), report to Sec. of State, Mar. 28, 1917.

Tamatsukurimura, Iyugun, Idzumo Province (near 35° 30′ north latitude, 133° east longitude); output 250 catties (334 pounds) a month.

In 1918 the Kogurobe mine, in Toyama, produced about 3.5 short tons of molybdenite, valued at about $6,500.[5] This was apparently the only mine that produced molybdenum ore to the value of 10,000 yen.

CHOSEN

Some molybdenite has been mined in Chosen, but no descriptions of the deposits are known to have been published. In 1916 about 6.5 tons, worth $2,500, was mined.[6]

CHINA

Prior to 1921 a little hand-picked molybdenite had been shipped from southern China, the whole amounting to only a few tons. It apparently was all obtained from the outcrops of quartz veins and "in fair to large sized chunks and flakes." In 1916 6,500 pounds was shipped from the districts of Yungfu (25° 14′ north latitude, 118° 51′ east longitude) and Ningte (26° 34′ north latitude, 119° 36′ east longitude), Fukien Province (see fig. 3), through the port of Foochow, and during the first three months of 1917 5,600 pounds. No later reports have been obtained from these localities, but it was thought at the time that shipments would increase.[7]

In 1917 small quantities were shipped from Hongkong to Great Britain and France and larger quantities to Canada for concentration and reexport to Great Britain. There seemed to be no question that the ore could be obtained in considerable quantities under similar market conditions, for it was just becoming known in the country, yet it had come in from a wide area.[8] It comes in part at least from quartz veins.

In 1921 it was reported[9] that 31,684 piculs (2,112 short tons) of "molybdenum," presumably molybdenite, was exported. No trace of this ore could be found in foreign trade, and none was recorded as exported from China in 1922. Inquiry among firms and individuals acquainted with the Chinese mineral industry disclosed no source for such a quantity of molybdenum ore, so that it seems probable that there may be some mistake in the figures.

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[5] The mining industry of Japan to 1918, p. 20, Japan Bur. Mines, 1919.

[6] Miller, R. W. (American consul general, Keijo), report to Sec. of State, Apr. 13, 1917.

[7] Pontius, A. W. (American consul, Foochow), report to Sec. of State, Apr. 20, 1917.

[8] Anderson, G. E. (American consul, Hongkong), Molybdenum in South China: Commerce Repts., Jan. 30, 1918, p. 390.

[9] Foreign trade of China, 1921: China Maritime Customs, Statistical ser., Nos. 2–5, pt. 1, p. 24, Shanghai, 1922.

TRANSVAAL

A few tons of molybdenite ore has been shipped from the Mutue Fides-Stavoren tin fields (about 24° 45′ south latitude, 29° 25′ east longitude), on the west side of Olifants River a short distance north of its junction with the Elands, in Transvaal. The molybdenite occurs in pipes in granite.[10] The pipes carry principally calcite and fluorite in their centers, with cassiterite, wolframite, arsenopyrite, bismuth minerals, raven mica (a black lithia mica), quartz, and other minerals between the core and the sericitized or greisenized walls. The molybdenite is particularly abundant in aureoles of raven mica surrounding some of the pipes.

OTHER COUNTRIES

Burma, Russia, Siberia, and other countries contain molybdenum deposits, but none of them are known to have made any production of consequence.

SUMMARY

The world contains innumerable molybdenum deposits, mostly small, all of which, except in the oxidized parts, carry the metal, so far as is now known, in the form of molybdenite. Some of the molybdenite deposits, however, are extensive and contain large quantities of the metal. Wulfenite is of much less common occurrence, and the deposits are smaller and extend only as deep as the zone of oxidation. The form of the molybdenum below the oxidized zone is unknown. Molybdite is of value as an ore mineral only when mined with molybdenite, and deposits of other molybdenum minerals have not yet proved to be of commercial value. Compared with tungsten deposits there are many more occurrences of molybdenite, and the largest deposits are much larger than those of tungsten. A few, like those at Climax, Colo., and Yetholme, New South Wales, are very large, though of comparatively low grade, carrying only about 1 per cent or less of MoS_2, and it is likely that under the stimulus of a continuous demand a larger number of such deposits might be found. There are numerous areas where such developments would not be surprising, such as the mountain region extending from Mexico to Alaska; eastern Canada; Scandinavia; Siberia; the mountain region extending along the west coast of the Pacific from Tasmania to Siberia—anywhere, in fact, that large areas of granite exist whose upper parts have not been deeply and

[10] Wagner, P. A., The Mutue Fides-Stavoren tin fields: Union of South Africa Geol. Survey Mem. 16, pp. 127–128, 1921.

generally eroded—or, in other words, in the newly exposed granitic areas of the world.

Whenever the world is ready to take molybdenum ores in large quantity at a price that will pay for extraction they will be produced. The United States has been the largest producer of molybdenum ores, and in the event of an absorbent market appearing, it is more than likely to be again the foremost in rank. What is the lowest price that will bring out the ores is hard to estimate, but it seems sure that if there were an open and continuous market for ores carrying 60 per cent of MoS_2 at 50 cents a pound for the contained MoS_2 several thousand tons a year would be forthcoming soon after it became apparent that the market was steady.

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