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GEOLOGY OF THE PITCHBLENDE ORES OF COLORADO.

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The large amount of public interest that has recently been manifested in radium because of the apparent cures of cancer effected by certain of its emanations makes it desirable to place before the public as promptly as possible all available information in regard to the occurrence of the minerals from which radium may be derived. The following account of the mode of occurrence of pitchblende at Quartz Hill, in Gilpin County, Colo., is therefore published in advance of a much larger report on the same region in which many other types of ore deposits will be considered. The field studies were made in the fall of 1912. As the geologic relations at Quartz Hill differ in important particulars from those at foreign localities, a summary of the genetically important features of the principal European occurrences is included for purposes of comparison. My thanks are due to Mr. Frank L. Hess, of the Geological Survey, for generously placing at my disposal additional specimens for study.

SOURCES OF URANIUM IN THE UNITED STATES.

The quantity of uranium ore mined in the United States is exceedingly small and in 1913 appears to have been equivalent to about 38 short tons of uranium oxide (U_3O_8), or approximately 32 tons of metallic uranium.[1] This is considerably larger than the production in 1912, which was equivalent to about 26 short tons of uranium oxide, or in 1911, which was equivalent to about 25 short tons. Practically the entire production of 1911 and 1912 and about half that of 1913 went to foreign countries. Of this tonnage nearly all came from sandstones of the high plateau regions of southwestern Colorado and southeastern Utah, in which the uranium occurs disseminated as the canary-yellow mineral carnotite ($2UO_3.V_2O_5.K_2O.xH_2O$) or its calcium-bearing equivalent tjuyamunite ($2UO_3.V_2O_5.CaO.xH_2O$). The small remaining portion of uranium ore mined in the United States, amounting in 1912 to only 275 pounds, was uraninite, or pitchblende, a complex uranate of variable composition to which a definite chemical formula can not yet be assigned. This mineral occurs in two distinct ways—in small amounts in granite pegmatites, notably in North Carolina, and in intimate association with metallic sulphides in certain mineral veins of Quartz Hill, near Central City, Gilpin County, Colo. The mines from which pitchblende has been obtained are all located on Quartz Hill and include the Calhoun, Wood, Kirk, German, Belcher, and Alps mines. For many years a small and sporadic production has come from this group and has been used mainly for specimens and for experiments. Quartz Hill is not only the one important locality in the United States where pitchblende occurs in mineral veins but one of the few in the world.

PRINCIPAL FOREIGN OCCURRENCES OF PITCHBLENDE.

In preparing the following summary of the principal foreign occurrences, the writer has so far as possible consulted original sources. The chief localities outside of the United States at which pitchblende has been found in mineral veins are the western part of the Erzgebirge, near the German-Austrian boundary, and the Cornwall district in England. A brief summary of the geologic occurrence of uranium minerals is also given in a recent article by P. Krusch.[2]

[1] Hess, F. L., Preliminary statement of the production of uranium and vanadium: U. S. Geol. Survey Press Bulletin, January, 1914.
[2] Über die nutzbaren Radium-Lagerstätten und die Zukunft des Radium-Marktes: Zeitschr. prakt. Geologie, vol. 19, pp. 83-90, 1911.

THE ERZGEBIRGE.

Types of deposits.—Muller[1] recognized in and near the granite batholiths of the western Erzgebirge in Bohemia and Saxony four types of ore deposits, which he classified as follows:

A. Older ore-forming period:
  1. Veins of the tin type.
  2. Veins of the pyritic lead-zinc type.

B. Younger ore-forming period:
  3. Veins of the cobalt-silver type.
  4. Veins of the iron and manganese type.

Deposits of types 1 and 2 are connected by transitions. The tin ores are confined to the granite and its immediate vicinity, while the pyritic lead-zinc veins are a little farther removed from the granite batholiths. The veins of types 3 and 4 are later than those of types 1 and 2.

At Joachimsthal, in Bohemia, and at Schneeberg, Annaberg, and Johanngeorgenstadt, across the border in Saxony, the veins of principal economic importance belong to Müller's cobalt-silver type (No. 3). It is with the veins of this type that the pitchblende is characteristically and exclusively associated.

Joachimsthal, Bohemia.—According to Stěp and Becke[2] the ores of the cobalt-silver type in the Joachimsthal district may be further subdivided into two classes—cobalt-nickel-arsenic ores and rich silver ores. In my opinion the ores of the first class represent the primary ore deposition, and those of the second class are in all probability the result of sulphide enrichment acting on the primary ore. The pitchblende, with its accompanying gangue minerals, quartz and dolomite, has rarely been observed in actual contact either with the rich silver ores or with the cobalt-nickel-arsenic ores. Usually the uranium and its gangue minerals have as metallic associates only variable amounts of pyrite and chalcopyrite, which appear to be in part earlier and in part later than the pitchblende. In a few places, however, the pitchblende, quartz, and dolomite coat ore containing cobalt or nickel minerals (smaltite, chloanthite, or niccolite), and therefore apparently are later than those minerals. The relation of the uranium ores to the rich silver ores can be inferred only from museum specimens in which ruby silver or proustite occurs in vugs in the pitchblende ore and in minute veinlets traversing it. It appears fairly well established, therefore, that the uranium ores of Joachimsthal were deposited somewhat later than the nickel-cobalt-arsenic ores but before the development of rich silver sulphides, which in these deposits were probably formed by enrichment due to the action of meteoric waters. The deposits are now controlled by the Austrian Government.

Annaberg, Saxony.—In the Annaberg region also the cobalt-silver type of ore is economically the most important, and its veins in many places cut or even materially displace the earlier tin, copper, and pyritic lead-zinc veins. According to Müller[3] the pitchblende is characteristically though nowhere abundantly associated with the cobalt-silver type of veins. It usually forms compact spherulitic or grapelike masses, some of which have shell-like or concentric structure, as a coating on siderite and fluorspar. Rarely it forms layers as much as 7 centimeters thick.

The primary minerals of the cobalt-nickel veins are, according to Müller, barite, fluorite, quartz, siderite, rammelsbergite ($NiAs_2$), niccolite, chloanthite, smaltite, native bismuth, tetrahedrite, stibnite, chalcopyrite, pyrite, reddish sphalerite, and berthierite ($FeS.Sb_2S_3$). The pitchblende, together with siderite, calcite, and some pyrite and chalcopyrite, is later than the cobalt-nickel group of minerals but earlier than the rich silver minerals whose origin, in my opinion, may be attributed with much probability to downward enrichment.

Johanngeorgenstadt, Saxony.—In the Johanngeorgenstadt district, which has been described by Viebig,[4] the most valuable uranium ores also belong genetically with Müller's cobalt-silver type, but they are characterized by an unusual abundance of native bismuth and bismuth compounds and are valuable mainly as a source of that metal and only subordinately for the

[1] Müller, Hermann, Die Erzgänge des Annaberger Bergrevieres, Erlauterungen zur Specialkarte des Königreichs Sachsen, p. 66, Leipzig, 1894.

[2] Stěp, Josef, and Becke, F., Das Vorkommen des Uranpecherzes zu St. Joachimsthal: K. Akad. Wiss. Sitzungsber., vol. 113, pp. 585–618, Wien, 1904.

[3] Müller, Hermann, op. cit, pp. 94, 98–100.

[4] Viebig, W., Die Silber-Wismutgänge von Johanngeorgenstadt in Erzgebirge: Zeitschr. prakt. Geologie, vol. 13, pp. 89–115, 1905.

nickel, cobalt, or silver they carry. The principal primary minerals of these veins are arsenopyrite, cobaltite, chloanthite, native bismuth, quartz, dolomite, siderite, calcite, and rarely barite and fluorite. The pitchblende is invariably associated with the veins of this type. It is in part disseminated and in part in solid crusts or bands some of which reach a thickness of 6 to 8 centimeters. Kidney-shaped and concentric forms are common. Characteristic metallic associates are fine-grained galena and chalcopyrite and native bismuth, small masses of these minerals being locally inclosed in the pitchblende ore. The common gangue mineral is an iron-manganese carbonate. In other parts of the Erzgebirge the pitchblende is irregularly distributed in nests, but in the Gottes Segen Spat mine, in this region, it occurs in considerable quantities and with much regularity.

Schneeberg, Saxony.—In the Schneeberg district, according to Müller,[1] pitchblende is a characteristic though not an abundant accompaniment of the cobalt-silver type of veins. Its kidney-shaped or rounded shell-like masses are ordinarily associated with chalcopyrite, galena, and brown carbonate. Müller regarded the pitchblende and its accompanying minerals as of slightly later formation than the primary cobalt and nickel minerals and earlier than the rich silver minerals.

CORNWALL DISTRICT, ENGLAND.

In and near the granite batholiths of Cornwall occur not only tin and copper lodes but also, usually at a greater distance from the granite, younger lodes of two types—(1) those containing uranium and nickel ores and (2) iron-manganese lodes.[2] In the vicinity of Bodmin, for example, there occur certain lodes containing arsenic and copper minerals and smaller quantities of uranium, cobalt, and nickel ores. These lodes cross the tin and copper lodes that are the main mineral resources of the district and are therefore somewhat younger, although it is believed that all the lodes are genetically connected with the granitic intrusives of the region.

In the St. Austle Consols mine, according to Williams,[3] uranium minerals have been found in certain small veins that cross the main tin-copper lode. The associates of the uranium minerals in the cross veins are locally copper ores but more commonly ores of nickel and cobalt. The uranium minerals also occur on the sides of the veins.

At Dolcoath, according to Pearce,[4] pitchblende occurred "associated with native bismuth and arsenical cobalt in a matrix of red compact quartz and purple fluorspar." At South Tresavean it occurs with "kupfer-nickel, native silver, and rich argentiferous galena." "I believe," says Pearce, "in all the localities I have named, it was found in little veins crossing the lodes" (that is, the tin lodes).

At the South Terras or Uranium mine, in Cornwall,[5] "The uranium lode * * * is said to vary in width from 3 to 5 feet, but the uranium ore is confined to a leader a few inches in width, consisting partly of pitchblende and calc and copper uranites with copper pyrites, mispickel, and galena, and small quantities of nickel, cobalt, and chromium ore in a veinstone of quartz and green garnet rock."

PITCHBLENDE IN THE QUARTZ HILL DISTRICT, COLO.

GENERAL GEOLOGIC RELATIONS.

The predominant rocks of Quartz Hill and neighboring parts of Gilpin County are pre-Cambrian igneous and sedimentary rocks and Tertiary intrusive rocks in the form of dikes and stocks.

The oldest pre-Cambrian rocks are those of the Idaho Springs formation, predominantly a quartz-mica schist, which is believed to be a metamorphosed sediment. This schist is intruded by

[1] Müller, Hermann, Der Erzdistrikt von Schneeberg in Erzgebirge, in B. von Cotta's Gangstudien, vol. 3, pp. 129–138, 1860.

[2] Ussher, W. A. E., Barrow, G., and MacAlister, D. A., The geology of Bodmin and St. Austell: Geol. Survey England and Wales Mem., Expl. Sheet 347, p. 134, 1909.

[3] Williams, R. H., Notice of the occurrence of nickel and cobalt at St. Austle Consols mine, near St. Austle, Cornwall: Roy. Inst. Cornwall Thirty-ninth Ann. Rept., pp. 32–34, 1857.

[4] Pearce, Richard, Note on pitchblende in Cornwall: Roy. Geol. Soc. Cornwall Trans., vol. 9, pp. 103, 104, 1875.

[5] Ussher, W. A. E., Barrow, G., and MacAlister, D. A., op. cit., p. 157.

pre-Cambrian granites of at least two ages—an older granite that has been dynamometamorphosed to a granite gneiss and a younger granite that has not been notably dynamometamorphosed and is commonly massive. Granite pegmatite offshoots from both these granites are numerous and in places intrude the Idaho Springs formation so intimately as to produce an injection gneiss. Where the Idaho Springs formation lies near or is inclosed by considerable bodies of granite rock, it has commonly been contact-metamorphosed to a hornblende schist.

All the pre-Cambrian rocks are intruded by dikes and stocks of monzonite porphyry and of bostonite porphyry (entirely orthoclase). These are believed to be of Tertiary age.

The mineral veins of the vicinity are the result of combined fissure filling and replacement along a series of fractures characterized by easterly to northeasterly strikes and commonly by steep dips. The veins cut both the pre-Cambrian rocks and the Tertiary intrusives. On the basis of mineral composition they can be divided into two types, which may be designated the pyritic type and the lead-zinc type. They have been worked principally for their precious-metal content, though yielding also considerable amounts of copper and lead.

The principal primary minerals of the pyritic type are pyrite and quartz; chalcopyrite and tetrahedrite are almost invariably present in subordinate amounts, and enargite, fluorite, and rhodochrosite occur here and there. The primary minerals commonly present in the veins of the lead-zinc type are galena, sphalerite, pyrite, chalcopyrite, quartz, and calcite. Some parts of the district are characterized solely by one or the other of these types of mineralization, but in many of the veins both types are present. In such veins it has been demonstrated by repeated exposures that the lead-zinc type is somewhat later than the pyritic type and that the minerals of the former commonly line vugs or fractures in those of the latter. It is believed, however, that the lead-zinc mineralization followed close upon the heels of the pyritic mineralization, and that the two types represent merely successive epochs in one great vein-forming period. Although the mineral veins cut the monzonite prophyry dikes and stocks, it is believed that both came from a common deep-seated source, the ore-bearing solutions following the monzonite intrusion after a short interval.

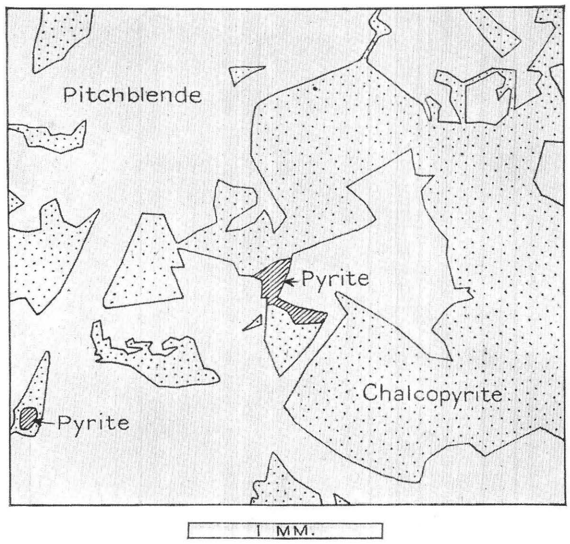
Sulphide enrichment in the upper portions of many veins of the lead-zinc type has developed secondary silver minerals in considerable abundance, and such veins are known as "silver veins," their principal value being in that metal.

PITCHBLENDE ORES.

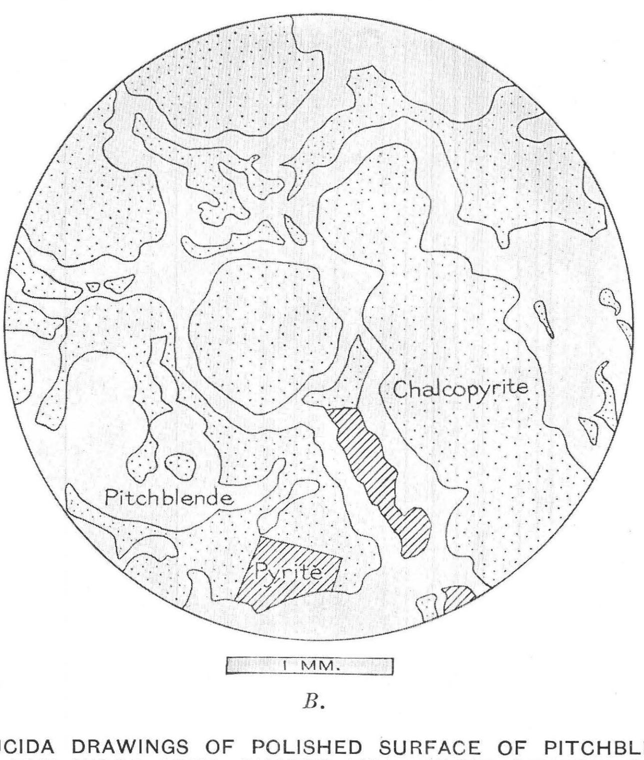
Although few opportunities were afforded for studying the richer pitchblende ores in place, because of suspension of mining at most of the mines, numerous specimens presented to the Survey by men interested in these mines were polished and studied under the reflecting microscope and found to show clearly the relations of the pitchblende to the sulphides which accompany it in the veins.

In a number of specimens it is evident that the pitchblende crystallized contemporaneously with chalcopyrite, pyrite, and probably gray quartz. A specimen from the Wood mine, obtained through the courtesy of Mr. W. C. Denison, when polished and studied presented the appearance shown in Plate I. Some of the intergrown chalcopyrite and pitchblende show angular outlines, as indicated in Plate I, *A*, but more commonly the pitchblende areas are ringlike in cross section with chalcopyrite occupying the center of the ring and inclosing it, as indicated in Plate I, *B*. Pyrite and gray quartz, apparently contemporaneous with the pitchblende and chalcopyrite, are present in small amounts. Specimens from the Wood and German mines in the mineral collections at the State Capitol in Denver show chalcopyrite and pitchblende so intimately intergrown as to leave little doubt of their contemporaneous crystallization. In other specimens from the Wood mine botryoidal pitchblende has cores of pyrite and is in places fringed with pyrite, as shown in Plate II, *B*. To summarize, the manner in which the minerals are intergrown in several specimens shows conclusively that pitchblende crystallized contemporaneously with chalcopyrite and probably with minor amounts of pyrite and gray quartz.

In other specimens the relations between pitchblende and sulphides are entirely different. A specimen of rich ore from the Calhoun mine, obtained through the courtesy of Mr. Hugh C.



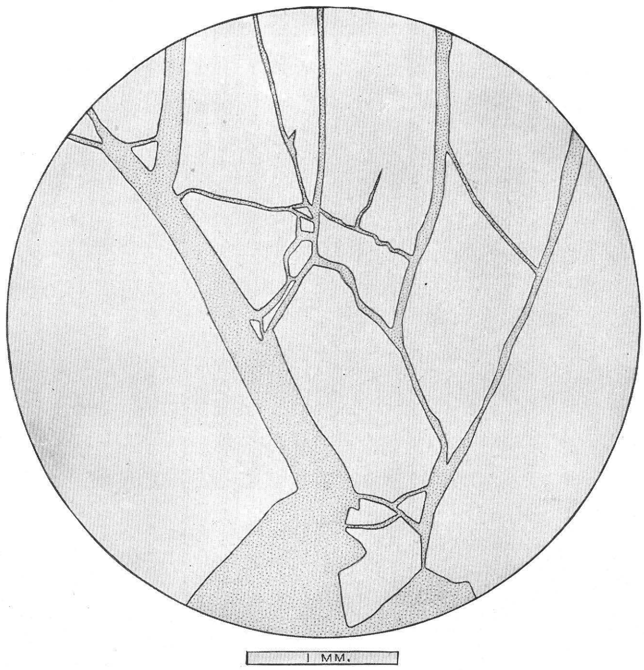
A.



B.

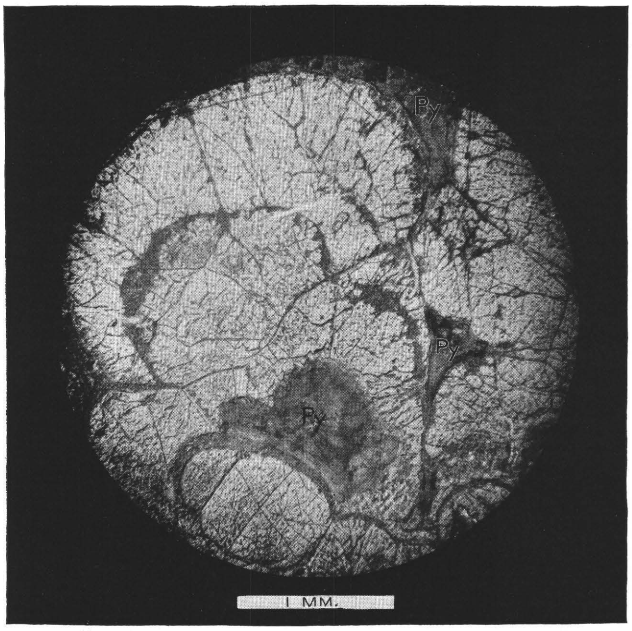
CAMERA LUCIDA DRAWINGS OF POLISHED SURFACE OF PITCHBLENDE ORE FROM THE WOOD MINE, QUARTZ HILL, GILPIN COUNTY, COLO.

Showing contemporaneous growth of pitchblende, chalcopyrite, and pyrite. In *B*, drawn from another part of the same specimen as *A*, the pitchblende areas show rounded outlines.



A. CAMERA LUCIDA DRAWING OF POLISHED SURFACE OF PITCHBLENDE ORE FROM THE CALHOUN MINE, QUARTZ HILL, GILPIN COUNTY, COLO.

Showing pitchblende traversed by later veinlets of sphalerite, pyrite, and galena.



B. MICROPHOTOGRAPH OF POLISHED SECTION OF PITCHBLENDE ORE FROM THE WOOD MINE, QUARTZ HILL, GILPIN COUNTY, COLO.

Showing botryoidal forms characteristic of much of the pitchblende. Py, Intergrown pyrite.

Brown, consists principally of pitchblende, but this mineral is sharply cut by veinlets one-eighth inch or less in size, composed of sphalerite, pyrite, and some galena. An enlarged view of some of the smaller veinlets as seen under the reflecting microscope is shown in Plate II, *A*. Another specimen from this mine shows pitchblende in botryoidal forms fractured and traversed by minute veinlets consisting predominantly of pyrite, chalcopyrite, and dark-gray quartz, but containing some galena and sphalerite. In the more shattered portions fragments of pitchblende lie in a matrix of these sulphides. A specimen from the Calhoun mine, obtained from Mr. Percy R. Alsdorf, shows altered schist traversed across its foliation by a $\frac{1}{8}$-inch to $\frac{3}{16}$-inch veinlet of pitchblende. A polished section shows that the pitchblende has in places been shattered and that fragments of it lie in a matrix of galena, sphalerite, chalcopyrite, and gray quartz, while other parts are traversed by minute veinlets of galena. It is clear, therefore, that there has been some sulphide mineralization subsequent to the deposition of the pitchblende.

The pitchblende ores of Quartz Hill are believed to represent merely a local and unusual variation in the main sulphide mineralization of this region—a variation of the same order as the occurrence of enargite in a neighboring group of veins near South Willis Gulch. I found no evidence to support Rickard's opinion [1] that the pitchblende mineralization is genetically connected with the intrusion of the granitic rocks, whose age is pre-Cambrian; on the contrary, I believe that, together with the sulphides that accompany them, they are genetically related to the Tertiary monzonite intrusives.

The significance of the contrasting and apparently contradictory modes of association of the pitchblende with the sulphide minerals becomes apparent when it is recalled that the Central City district is in general characterized by two types of mineralization, an earlier pyritic mineralization and a later lead-zinc mineralization. It is believed that the pitchblende was deposited during the earlier or pyritic mineralization, that it was afterward fractured, and that the fractures thus formed were filled by sulphides of the later or lead-zinc mineralization.

The general geologic relations and the absence of characteristic high-temperature minerals in the deposits of Quartz Hill, as well as in those of Cornwall and the Erzgebirge, indicate that the pitchblende was deposited under conditions of moderate temperature and pressure. Unlike the European pitchblende, however, the pitchblende of Quartz Hill is not associated with nickel and cobalt minerals, which so far as known have never been found in that region even in small quantities. The occurrence of pitchblende in pegmatite as well as in mineral veins of the type here described shows that the mineral may also form under conditions of high temperature and pressure.

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[1] Rickard, Forbes, Pitchblende from Quartz Hill, Gilpin County, Colo.: Min. and Sci. Press, June 7, 1913, pp. 851–856.