Microscopic Secondary Sulphide Enrichment in the 'Kuromono' Ore from the Kosaka Mine, in the Province of Rikuchū, Japan.

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I. Introduction.

This paper deals with the interesting facts on microscopic secondary sulphide enrichment, observed in an ore-specimen collected by the present writer about 13 years ago at a working in the Kosaka mine. It is an usual 'kuromono' ore,⁽¹⁾ being an intimate mixture of zincblende, galena, pyrite, chalcopyrite, barite and others. All components occur in minute irregular grains except pyrite, which shows rounded crystals and small massive forms. Macroscopically any sign of secondary sulphide enrichment⁽²⁾ can not be recognized in this specimen, though under the microscope conspicuous changes have been observed.

(1) 'Kuromono' or the black ore is a peculiar sort of ore occurring abundantly and widely in Japan. The ore forms irregular massive deposits of metasomatic origin enclosed in Tertiary sedimentary rocks and younger volcanic rocks such as liparites, dacites and andesites, with which the deposits are genetically connected. The 'kuromono' deposits have been thoroughly studied by T. Hirabayashi, the results being published in the following valuable papers:—

"Reports on the 'kuromono' deposits," I, II (in Japanese). [黒鑛々床調査報文]
"Kurokō, or the black ore." Beiträge zur Mineralogie von Japan, Nr. 4, pp. 151-156.

(2) It is well known that at Kosaka, there lay a zone of secondary enrichment below the oxidized ore called 'dokō' or the earthy ore, clearly due to the addition of copper washed out of the weathering zone. Below this zone the primary 'kuromono' occurs, which contains 2 to 3 % copper on an average, and is being smelted at present. This secondary enrichment was recognized by chemical analyses of ore-samples, but the enriched ores appeared quite similar to the unaltered ones to the naked eye.

The specimen now in question is evidently from the zone of secondary sulphide enrichment.

The description and discussion in this paper are based chiefly on a mineralogical study or investigation of polished specimens with the reflected light.

Engineers who are engaged in mining and smelting in connection with the 'kuromono' deposits are advised, therefore, to bear in mind that the secondary sulphide enrichment takes place not only macroscopically,⁽¹⁾ but also microscopically in the ore, and that the latter case is of no less importance economically than scientifically, though its recognition is very difficult or hardly possible to the unaided eye.

II. Modes of Occurrence of the Microscopic Secondary Sulphides, and Their Mutual Relations.

BORNITE. Microscopic specks of bornite are abundantly found largely in association with primary pyrite and chalcopyrite, but less commonly with other sulphides. It is characterized by its reddish brown colour⁽²⁾ in contrast with the bright yellow colour of chalcopyrite and the light yellow colour of pyrite.

This mineral occurs apparently enclosed in chalcopyrite in the form of minute irregular masses (Pl., Fig. 3) and also in pyrite as clusters of microscopic irregular specks (Pl., Fig. 4). Most characteristic is the development of bornite around the crystals and masses of pyrite enclosed in chalcopyrite (Pl., Figs. 1, 2, 5); in this case pyrite is often intensely replaced and embayed by the bornite, the former frequently remaining as small rounded cores enveloped in the latter. Both pyrite and chalcopyrite have been replaced by

(1) In the Kosaka and other similar deposits, macroscopic veinlets of covellite have been repeatedly observed, beautiful hexagonal plates of the mineral with a diameter up to 5 mm. or more having been occasionally found. These veinlets occur in the 'kuromono' proper as well as in the associated 'ōkō' or the pyritic ore consisting essentially of minute crystals and grains of pyrite, below the under-ground water level.

(2) J. Murdoch: Microscopic Determination of the Opaque Minerals, 1916, p. 65.

bornite, but the former seems to have been more replaced.

Rarely, streaks and patches of bornite are found microscopically in zincblende grains.

CHALCOCITE. Chalcocite is developed far more rarely and scarcely than bornite. It is characterized by a grayish or bluish white colour,⁽¹⁾ and very smooth surface under the microscope. It is usually closely associated with bornite, and is almost contemporaneous with, or a little earlier than, bornite in generation.

Irregular specks of chalcocite in contact with bornite, enclosed in chalcopyrite, sometimes accompanied by pyrite, are frequently found (Pl., Fig. 5); this is the case in which both minerals have been formed almost contemporaneously by replacement of chalcopyrite and pyrite. Occasionally, chalcocite specks altered to bornite along the margins (Pl., Fig. 7) or bornite masses with residual cores of chalcocite (Pl., Fig. 3) have been observed; these represent the cases where chalcocite was formed a little earlier than bornite.

Chalcocite is sometimes found alone in chalcopyrite and along the boundaries between chalcopyrite and enclosed pyrite, being chiefly replacement of the former sulphide. Chalcocite embaying or cutting through pyrite is also rarely met with.

COVELLITE. Covellite is the most characteristic secondary sulphide, and can be easily recognized by its splendid blue colour⁽²⁾ under the microscope. It is the last mineral formed, being due to the alteration chiefly of bornite and occasionally also of chalcocite. Along the margins of bornite specks, covellite is almost invariably developed in the form of thin crust (Pl., Figs. 1, 2, 3, 5). It is also very common in the form of veinlets through bornite and chalcocite (Pl., Figs. 1, 2, 3, 5, 7) or as irregular specks embaying the same minerals.

Covellite specks with residual bornite cores, and the same mineral

(1) J. Murdoch, loc. cit., p. 107.

(2) Ibidem, p. 58.

in the form of streaks enclosed in chalcopyrite have been observed. Covellite streaks are sometimes developed in zincblende.⁽¹⁾

III. Conclusions.

As fully described in the foregoing article, the presence of microscopic bornite, chalcocite and covellite in the ore under consideration is worthy of special attention. Most characteristic is the occurrence of these sulphides apparently enclosed in chalcopyrite as irregular, rounded masses, often in association with pyrite which is usually more or less replaced and rounded, and occasionally remains as minute cores. Bornite and chalcocite are sometimes associated in irregular intergrowth, though frequently both are developed separately as minute patches and streaks. Covellite, on the other hand, occurs always along the cracks and margins of bornite and chalcocite, occasionally, however, along minute fissures in primary pyrite, chalcopyrite and zincblende.

In all cases, there is no room for doubt that bornite and chalcocite have developed mostly by the metasomatic action of certain cupriferous solutions on pyrite and chalcopyrite, though the question remains as to whether the sulphides are products of enrichment by ascending hot alkaline solutions or by descending cold ones.

Covellite has doubtless been formed by descending acid solutions. Bornite and chalcocite, on the other hand, occur as irregular replacements of pyrite, chalcopyrite etc., without accompanying anastomosing channels,⁽²⁾ and at first sight remind us of their primary formation.⁽³⁾ But the facts that the ore under consideration was

(1) Graton and Murdoch: The Sulphide Ores of Copper. Some Results of Microscopic Study. Tr. Am. Inst. Min. Eng., Vol. XLV, 1914, p. 52.

(2) A. F. Rogers: Secondary Sulphide Enrichment of Copper Ores with Special Reference to Microscopic Study. Mining and Scientific Press, Oct., 1914, p. 686.

(3) Formed by ascending hot alkaline solutions.

Refer, L. C. Graton and J. Murdoch, loc. cit., p. 45.; and also F. B. Laney:

"The Relation of Bornite and Chalcocite in the Copper Ores of the Virgilina District of North Carolina and Virginia." Econ. Geol., Vol. VI, 1911, pp. 399-411.

collected at a level, not very deep below the cover of the oxidized ore (earthy ore), corresponding to the deepest portion of the so-called secondary enrichment zone as shown by chemical analyses, and that the primary ore being worked at present contains no such enriched copper sulphides under the microscope, suggest that the cupriferous solutions to which the formation of the secondary sulphides is due were meteoric in origin and their copper content was extracted from the oxidation zone above.

The relation between bornite and chalcocite is noteworthy. Among the so-called typical secondary sulphides bornite is the most unstable mineral and alters with exceeding readiness to covellite and chalcocite under usual conditions of enrichment.⁽¹⁾ If my microscopic observations on the ore under consideration are correct, bornite and chalcocite have been formed contemporaneously at the expense of pyrite, chalcopyrite and others, while in places bornite is developed by replacement of chalcocite (Pl., Fig. 7). This represents clearly an unusual type of secondary enrichment. As generally accepted,⁽²⁾ the development of secondary bornite and chalcocite from chalcopyrite seems confined to the lower portions of the zone of enrichment, the cause of such secondary products being possibly the scarcity or deficiency of acid and the excess of copper in the descending cupriferous solutions. The development of unstable bornite from chalcocite, on the other hand, indicating a reversal of the usual order, is explained by assuming that chalcocite formed by replacement of pyrite and chalcopyrite by the action of descending, probably more or less acid, cupriferous solutions has been later affected by downward-penetrating solutions, which while still containing iron as well as copper at the lower limits of the zone of enrichment, may have had their supply of acid depleted by reac-

(1) Graton and Murdoch, loc. cit., p. 47 et seq. and p. 52.

(2) Ibidem, p. 50 and p. 64.

tions higher up.⁽¹⁾ Under these conditions bornite could be formed only temporarily at the expense of chalcocite.

EXPLANATION OF THE PLATE.

(Camera lucida drawings of microscopic secondary sulphides developed in the 'kuromono' ore from the Kosaka mine. Reflected light. Magnified 150 diameters.)

Figs. 1 and 2. Bornite (B) developed in chalcopyrite (Ch), with remnants of pyrite (P). Along the minute cracks and margins of bornite deep blue coloured covellite is developed. It is well shown that the bornite was formed by the metasomatic action of cupriferous solutions which infiltrated along the boundary of pyrite and surrounding chalcopyrite and chiefly replaced the former. Covellite was formed at the expense of bornite by later meteoric waters which infiltrated through the cracks and along the margins of the latter mineral.

Fig. 3. Bornite (B) and chalcocite (CC) formed in chalcopyrite (Ch). Chalcocite is often enclosed as small cores in bornite, suggesting that the latter was formed at the expense of the former by a process of metasomatism. Covellite is produced along the cracks and margins of the bornite as in the cases of figs. 1 and 2.

Fig. 4. Cluster of bornite specks formed in pyrite. Bornite has evidently developed by the metasomatic action of descending cupriferous solutions which penetrated through minute cracks in pyrite.

Fig. 5. Chalcocite (CC), bornite (B) and covellite (C) developed in chalcopyrite (Ch), in close association with pyrite (P). Chalcocite and bornite appear to be contemporaneous in generation, both

(1) It should be borne in mind that the replacements in secondary enrichment have been accomplished by downward-circulating solutions which are constantly changing in composition and supplying new materials.

being formed metasomatically at the expense of chalcopyrite as well as pyrite. Covellite is evidently later in generation than chalcocite and bornite, being developed along their margins and fissures through them.

Fig. 6. Pyrite (P) enclosed in zincblende (Zn), replaced along the margins and fissures by bornite (B) which is replaced in turn by covellite (C).

Fig. 7. Chalcocite (CC), bornite (B) and covellite developed in pyrite (P). Chalcocite was formed evidently first, and afterwards replaced by bornite. Covellite obviously replaces both chalcocite and bornite.