REPORT

of

COMMITTEE ON THESIS

THE undersigned, acting as a committee of the Graduate School, have read the accompanying thesis submitted by Julius Segall for the degree of Master of Science. They approve it as a thesis meeting the requirements of the Graduate School of the University of Minnesota, and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science.

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THE ORIGIN AND OCCURRENCE OF CERTAIN CRYSTALLOGRAPHIC INTERGROWTHS.

A Thesis Submitted to the Faculty of the Graduate
School of the University of Minnesota

by

Julius Segall.

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THE ORIGIN AND OCCURRENCE OF CERTAIN CRYSTALLOGRAPHIC INTERGROWTHS.

A relationship of minerals which is commonly referred to crystallographic or micrographic intergrowth is a feature of their paragensis. There is no uniform opinion as to the significance of these intergrowths. Laney[1] who first recognized them in sulphide ores, believes that the crystallographic intergrowth of bornite and chalcocite of Virgilina is evidence of the contemporaneous origin of these minerals. Gilbert and Pogue[2] hold that the graphic intergrowth of bornite and chalcocite of the North Mount Lyell Mine, Tasmania, shows clearly the contemporaneous development of these two minerals. Ransome[3] suggests that secondary processes may produce apparent intergrowths which would be difficult to distinguish from contemporaneous intergrowths. Rogers[4] who discovered such intergrowths in

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[1] Laney, F. B., The Relation of Bornite and Chalcocite in the Copper Ores of the Virgilina District of North Carolina and Virginia. Econ. Geology, Vol. 6, p. 408.

Graton, L. C. and Murdoch, J., The Sulphide Ores of Copper; Some results of Microscopic Study. Trans. A. I. M. E., Vol. 45, p. 77.

[2] Gilbert, C. G. and Pogue, J. E., The Mount Lyell Copper District of Tasmania. Proc. U. S. Nat'l Muss Vol.45, p.616

[3] Ransome, F. L., Copper Deposits near Superior, Ariz. U. S. G. S. Bulletin 540, p. 152.

[4] Rogers, A. F., Secondary Sulphide Enrichment of Copper Ores, with Special Reference to Microscopic Study. Mining and Scientific Press. Oct. 31, 1914, p. 686.

Butte ores, states that the so-called graphic intergrowths of bornite and chalcocite is but an irregular replacement of bornite by chalcocite.

The assignment of intergrowths of sulphides to contemporaneous solidification of the minerals from solution is undoubtedly due to the resemblance of the peculiar patterns formed by the sulphides to those of quartz and orthoclase in graphic granite. The micropegmatitic intergrowths of these silicates are supposed to represent contemporaneous separation from solution. Similar structures marking the final solidification of solutions are exhibited at the eutectic point of a great many alloys.

In the course of this investigation several new examples of micrographic intergrowths were discovered, and some evidence was obtained that some of these intergrowths may be of secondary origin.

The specimens under consideration were examined both megascopically and microscopically. In the microscopic examinations polished surfaces were employed and the specimens were studied by reflected light. The minerals were determined by means of physical and chemical tests.

Particular care was taken in the identification of bornite, as it had an important bearing on the problem. The appearance of bornite sometimes approached that of covellite, and in case of doubt the mineral in question was compared with a known polished surface of covellite.

An interesting series of relations of bornite to chalcocite were found in chalcocite ore from Butte, Mont. The samples were collected by Mr. Lynn Martin from the Leonard shaft at the depths of 1845 and 2200 feet. A megascopic examination of the specimens from this mine shows that the chief constituent of the ore is massive chalcocite. Distributed thru the chalcocite are grains of bornite varying in size up to one eighth of an inch in diameter. The other recognizable minerals are pyrite, enargite, and quartz. Under the microscope the most notable feature of the polished surface of the specimen from the 2200 foot level is the symmetrical distribution of the chalcocite and bornite. (See Figure 1.) The chalcocite, represented by the light colored lath-shaped figures, forms triangular areas which are filled by the bornite. The corresponding angles of the triangles are constant thruout the field of observation and it seems clear that the triangles are the expression of some definite crystallographic relation. They suggest directions of cleavage or of twinning. Gilbert and Pogue[1] developed a triangular pattern by etching chalcocite with nitric acid. These investigators refer to the lines limiting these patterns as characteristic cleavage lines. Ray[2] who obtains a microphotograph showing a structure similar to Figure 1, concludes that the chalcocite has "purified" along what he terms crystallographic planes.

Graton and Murdoch[3] obtain minute partings in three directions by etching massive chalcocite ore from the Bonanza Mine, Alaska. The same results were obtained by them by etching synthetic chalcocite, produced by fusion of copper and sulphur. They also interpret these partings as cleavages of the chalcocite. From the foregoing it appears that the patterns produced by the so-called cleavages along three directions are characteristic of chalcocite.

The first impression gained from Figure 1 is that the chalcocite has developed along three directions within

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[1] Op. cit., p. 1.

[2] Ray, J. C., Paragensis of the Ore Minerals in the Butte District, Mont. Econ. Geol., Vol 9, July 1914, p. 479.

[3] Graton, L. C. and Murdoch, J., The Sulphide Ores of Copper; Some Results of Microscopic Study. Trans. A. I. M. E., Vol. 45, P. 79. Figs. 27 and 29.

the bornite; this, however, is improbable, as these three crystallographic directions are assigned to the chalcocite. It seems more probable to suppose that the bornite developed along the existing directions and thus gave rise to the triangular pattern. The transformation from chalcocite to bornite was probably accomplished by metasomatic replacement. The change is suggested by Figure 2. The path of the replacing solutions was a small fracture, indicated by the black strip which extends horizontally thru the photograph, from which the chalcocite was attacked on both sides. Replacement probably began along the minute partings of crystallographic directions. It gradually proceeded, changing the cross barriers of chalcocite to bornite, until the whole mass of the former was entirely replaced by the latter. The dark areas of bornite on both sides of the fracture are assumed to show this complete metasomatic replacement. Where the change had reached an advanced but not completed stage the chalcocite appears in needle-like forms arranged in one direction only. Where the replacement had been only partly completed the crystallographic features were retained in two, or in all three directions.

The intimate relation existing between the fractures and replacement along the crystallographic directions is shown more clearly by Figure 3. In the lower part of this photomicrograph the dark bornite areas within the triangular chalcocite outlines extend up to the black strip representing the fracture. Above the fracture the light gray area of chalcocite has not been affected. The replacing solutions, coming thru the opening, apparently confined their activity to one side. Figure 4 also represents a case in which the activity on one side of the fracture has been greater than on the other. The replacement, while more advanced in one direction, is not nearly so complete as in the other; the larger area of bornite still includes many needles of chalcocite.

The relation of replacement to defined openings is clearly illustrated by Figures 2, 3, and 4, and it seems plausible to suppose that these openings may vary in size even to minute fractures that can not be detected with powerful magnification. Sub-microscopic partings existing between planes of crystallographic directions undoubtedly allow the access of altering solutions. By such access there may be developed within the chalcocite a crystallographic intergrowth of bornite and chalcocite that has no connection with visible fractures. This feature is illustrated by Figure 5.

The transformation of chalcocite to bornite requires the addition of iron. That the solutions which affected the alteration carried iron is suggested by the presence of pyrite in some of the fractures from which the bornite extends in one or both directions. Where found, the pyrite is usually in the form of stringers within the openings, and it is clearly younger than the bornite. The age of pyrite and its relation to openings suggests that the solutions which formed the pyrite probably furnished the iron for the transformation of the copper sulphides.

The bornite that lines the fractures and extends from the openings into the mass of chalcocite is apparently of secondary origin. Consequently it follows that the triangular pattern produced by the replacement of chalcocite by bornite is also secondary. The shapes of the triangles composing the pattern may vary in the different parts of a specimen, depending on the orientation of the section to the crystallographic structure of the chalcocite.

In the change from the crystallographic intergrowth of bornite and chalcocite to the massive bornite there is a series of stages in which the bornite assumes various shapes. In the first stages of replacement the action is chiefly along crystallographic directions and the chalcocite is broken up into lath-shaped forms. (See Figure 1.) As the process continues these laths of chalcocite become narrower and narrower until they are entirely transformed into bornite. The replacement proceeds at an unequal rate in the three crystallographic directions, and grains of bornite are developed, which while irregular in outline tend to conform with the three directions. The latter feature is illustrated by Figure 5. In the upper left hand part of the photomicrograph the dark patches of bornite(marked A), still retain one or more of the three crystallographic directions. The dark patches of bornite to the right of the central triangular form (marked B) also show a tendency to preserve these directions. The relation of the regular to the irregular intergrowths is suggested by Figure 6. In the lower part of the photomicrograph the irregular figures, (marked A) appear to be the continuations of the upper triangular forms. To the right, (marked B) are the characteristic patches of bornite as they appear when a number of the smaller irregular forms are merged into one. This feature, which is more clearly expressed in Figure 7, is by far the more common of the two. As with the regular triangular forms, the irregular ones are in part at least modified by the orientation of the specimen with reference to its crystallographic directions. Since the bornite which forms part of the intergrowth is secondary it is evident that the pattern developed by the intergrowth of bornite and chalcocite is also secondary.

The occurrence of another intergrowth of bornite and chalcocite was found in a sample furnished by the U. S. Nat'l. Museum. The specimen was labelled Silver Copper Ore, Bevelheymer Mine, Peavine District, Washoe Co., Nevada. Most of the sample is covered with a thin coating of chrysocolla. A fresh surface exhibits chalcocite of exceptionally brilliant luster. In addition to these two minerals the microscopic examination of the unetched polished surface reveals the presence of bornite which constitutes about 5% of the specimen. The chalcocite appears silvery white and the bornite has the characteristic lavender color. The chrysocolla has a dark green color and is largely confined to the fractures. The relation of chalcocite to bornite is illustrated in Figure 8. The bornite, the darker of the two main constituents, has the characteristic branching form assumed to be due to the crystallographic intergrowth of the bornite and chalcocite. Similar to the bornite in Figure 6, the small irregular forms are seen to merge into larger massive patches. The lack of a clearly defined crystallographic arrangement in this specimen prohibits conclusive statements as to the origin of this intergrowth.

The district from which this specimen was obtained produses some gold and silver. Very little is known of the geology of the Peavine district. It is known, however, that the veins in which the ore is found are in granites and schists. This information was kindly furnished by Mr. R. W. Fulton, of Reno, Nevada.

The intergrowths of metallic sulphides that have been described heretofore are all of copper minerals. It is therefore interesting to note an intergrowth of galena and tetrahedrite. The specimen exhibiting this occurrence was obtained from the Ward Natural Science establishment, and was labelled Tetrahedrite, Kristeid, Norway. The sample is composed chiefly of quartz, with which is associated a green schistose mineral, probably chlorite. Next in abundance is tetrahedrite, which occurs as massive patches and small grains in the quartz. Chalcopyrite and a few grains of pyrite complete the list of minerals that can be recognized with the aid of a hand lens. A microscopic examination of the polished surface reveals the presence of galena. The striking feature of the specimen is the intimate intergrowth of the galena and tetrahedrite. The galena, represented by the white mineral in Figure 9, has the appearance of a sponge, the openings of which are filled with little dark particles of tetrahedrite. Along the contact of the two minerals the galena fingers into the tetrahedrite. At the base the galena forms an irregular contact with chalcopyrite. Since there is no available information as to the origin of the ore it is not advisable to draw any conclusions as to the mode of formation of the intergrowths.

Other intergrowths of galena and tetrahedrite are represented in Figures 10 and 11. Both of these are photomicrographs of a sample from the Elkhorn Mine, Elkhorn District, Jefferson Co., Mont., donated by the U. S. Nat'l Museum. The specimen is composed of quartz, tetrahedrite, galena, sphalerite, and pyrite. The galena and tetrahedrite are the chief metallic sulphides; under the microscope the former appears silvery white and the latter light gray. The contact between the two minerals is at some places well defined, but at others very irregular in outline. When irregular, the forms assumed by the galena resemble those of the characteristic branching intergrowths. These irregular patterns, as far as examined, are always confined to the contacts, and it appears that they are the result of an uneven gradation from one to the other. Weed[1] in his paper on the Elkhorn mine concludes that the ores have been formed by ascending waters, by replacement of the country rock. To find ore of such pattern replacing

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[1] Weed, W. H., Geology and Ore Deposits of the Elkhorn Mining District, Jefferson Co., Mont., 21st Ann. Rept. U. S. G. S., Part 2, p. 496.

limestone was unexpected, since ordinarily such structures are assumed to represent free crystal growth. Bastin[1] finds similar irregular borders between galena and polybasite. He concludes that galena was replaced by polybasite with the development of a very "ragged" boundary. If it were assumed that some of the tetrahedrite of the Elkhorn mine were secondary, the irregular distribution of the galena at the contact could be interpreted as an irregular replacement of galena by tetrahedrite.

From the relations presented in the previous pages it is inferred that intergrowth of sulphides may be formed by secondary processes. These intergrowths may have a close resemblance to what are known as contemporaneous intergrowths. Since the exact nature of the replacing solutions is not known, no inferences can be drawn as to whether the solutions were descending or ascending.

The writer is much indebted to Dr. W. H. Emmons for his helpful criticisms of this paper.

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[1] Bastin, E. S., Metasomatism in Downward Sulphide Enrichment. Econ. Geol., Vol. 8, p. 56, 1913.

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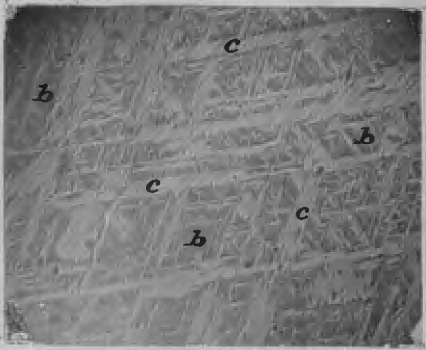

Fig. 1

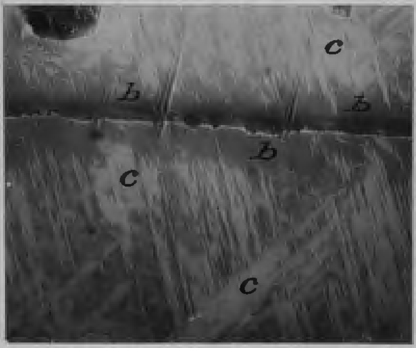

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

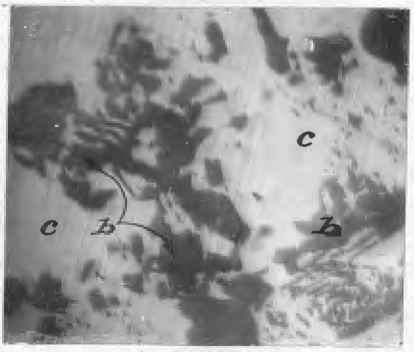

Fig. 7

Fig. 8

Fig. 9

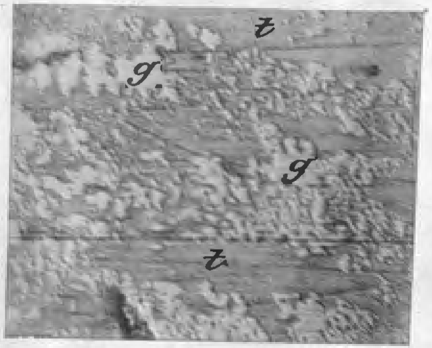

Fig. 10

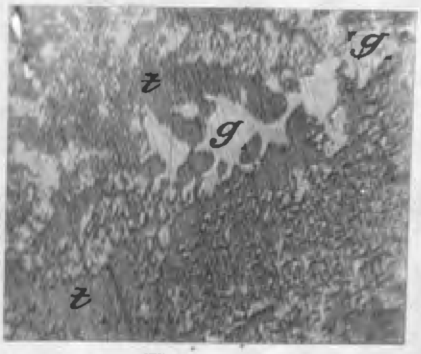

Fig. 11

Figure 1. Leonard Mine,
Butte, Mont.

Crystallographic intergrowth of chalcocite (c) and bornite (b). The crystallographic directions are assigned to the chalcocite. The bornite presumably developed along the existing directions thus giving rise to the triangular patterns.

Magnification: x 700 (approx)

Figure 2. Leonard Mine,
Butte, Mont.

Relation of replacement to open fractures. The dark areas of bornite (b) on both sides of the black strip representing the fracture, are assumed to show the replacement of chalcocite (c) by bornite.

Magnification: x 400 (approx)

Figure 3. Leonard Mine,
Butte, Mont.

Illustrates relation between fracture and replacement along crystallographic directions. In the lower half of the photomicrograph the triangular pattern extends from the fracture downward.

Magnification: x 350 (approx)

Figure 4. Leonard Mine,
Butte, Mont.

This photomicrograph shows that the replacement of bornite (b) by chalcocite (c) has been greater below the fracture than above it.

Magnification: x 350(approx)

Figure 5. Leonard Mine,
Butte, Mont.

Illustrates the tendency of the massive bornite (b) to develop along the three crystallographic directions.

Magnification: x 700 (approx)

Figure 6. Leonard Mine,
Butte, Mont.

Suggests that the irregular forms of bornite (b) in the lower part of the photomicrograph are the continuations of the regular triangular forms of the upper part.

Magnification: x 350 (approx)

Figure 7. Leonard Mine, Butte, Mont.

Characteristic patches of bornite (b) as they appear when a number of smaller irregular forms are merged into one.

Magnification: x 700 (approx)

Figure 8. Bevelheymer Mine, Washoe Co., Nev.

Typical intergrowth of bornite (b) and chalcocite (c).

Magnification: x 250 (approx)

Figure 9. Kristeid, Norway.

Intergrowth of galena (g) and tetrahedrite (t). At the base of the galena it forms an irregular contact with chalcopyrite (cp).

Magnification: x 700 (approx)

Figures 10 & 11. Elkhorn Mine, Jefferson Co., Nev.

Galena (g) and tetrahedrite (t) forming patterns which resemble characteristic branching intergrowths.

Magnification: x 700 (approx)