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## MICROSCOPIC REPLACEMENT VERSUS INJECTION IN ORES

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Much emphasis recently has been placed on the relative importance of replacement and injection in ore deposition. As a phase of this discussion much attention has been paid to included fragments in veins. Microscopic examination of ores reveals much information on these processes. Until the publication of the "Ore Magmas"<sup>1</sup> many of the mineral relationships observed microscopically were attributed, and rightly so, it is believed, to replacement. There has been a growing tendency since then to interpret a later mineral as injected in the earlier, or as having consolidated from a more or less stationary ore magma.<sup>2</sup> It seems worth while, therefore, to present some of the microscopic evidences of replacement or of possible injection. This does not necessarily mean that the process observed microscopically was the dominant one on a large scale, but it is at least strongly indicated.

The evidence presented here has been accumulated incidentally to a microscopic study of ores for several years and without the specific problem in mind. Thousands of specimens have been examined and some of the examples presented might be multiplied several times. The specimens illustrated are in the Mineralogical Laboratory of the Department of Geology at the University of Minnesota. The criteria for processes active in ores as deduced from microscopic study have not been thoroughly worked out, but the textures due to the replacement or corrosion of preexisting minerals by a later mineral in primary ores may be recognized by comparison with the results of similar processes in the oxidation and secondary (supergene) enrichment of ores. It is assumed that no one would question the replacement relation when an oxidized mineral replaces a primary mineral of the same

<sup>1</sup> Spurr, J. E.: *The ore magmas.* McGraw-Hill Book Co., New York.

<sup>2</sup> See, for example, L. S. Ropes; *Eng. and Min. Jour.*, vol. 122, 899 (1926).

metal. The same is true of a secondary enrichment, with the fact acknowledged that it is not always possible to recognize supergene replacement without field evidence.

As examples of structures produced by the alteration to, or replacement of, ore minerals by oxidized minerals Figures 1, 2 and 3 are presented.

Figure 1 shows pyrite partly altered to limonite and the rounded, corroded nature of the pyrite particularly is to be noted. This structure is characteristic of ores in which one mineral has practically replaced another, especially when the replaced mineral is without cleavage or parting, as is usually the case with pyrite.

Figure 2 shows chalcocite partially altered to malachite. It is quite obvious that the fragments could not be fitted together although they are somewhat angular. Figure 3 shows a similar case of alteration of galena to cerussite with the alteration controlled by the cleavage. This structure might be mistaken for one showing a second vein filling, but the control by cleavage, as well as the nature of the alteration, shows this to be a replacement. The characteristics of these structures are of value for comparison with cases whose origin is more uncertain.

Figures 4, 5, 6, 7 and 8 represent replacement structures of both secondary (supergene) and primary (hypogene) origin.

Figure 4 is a micrograph of rich chalcocite ore from the Old Dominion mine, Globe, Arizona. In the chalcocite are rounded fragments of pyrite grouped in a manner plainly indicating that the pyrite fragments are the remains of a large grain now extensively replaced by chalcocite. This has been termed "ice cake" structure. The essential difference between the ore of Figure 1 and that of Figure 4 is that oxygen has been introduced and sulphur extracted in the first, and copper has been introduced and iron extracted in the second. In each case a new mineral has partially replaced the original mineral.

Figure 5, also from Globe, shows chalcocite largely replaced by a network of quartz. It is noteworthy that the chalcocite remnants are much less rounded than the pyrite fragments of Figures 1 and 4, and in this respect the texture is similar to that shown by Figure 2. It seems obvious that the structure of the replaced mineral exerts a strong control on the shape of the residual fragments. It is evident that the fragments of Figure 5 could not be fitted together and therefore corrosion has been active. Dr.



Figure 1. Rounded fragments of pyrite (P) partially altered to limonite, 9th level, Old Dominion mine, Globe, Arizona. Mag. 52X

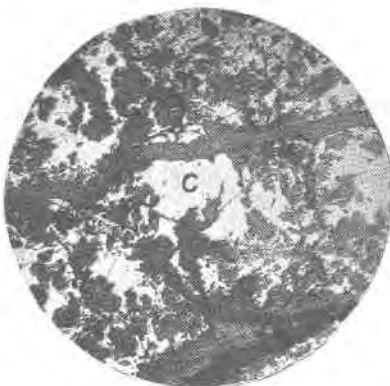


Figure 2. Irregular fragments of chalcocite (C) largely altered to malachite (dark), 6th level, Old Dominion Mine, Globe, Arizona. Mag. 30X

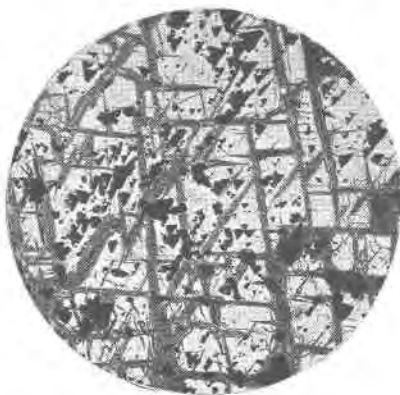


Figure 3. Galena partially altered to cerussite developed mainly along cleavage planes. Kent Mine, Bannack District, Montana. Mag. 62X.

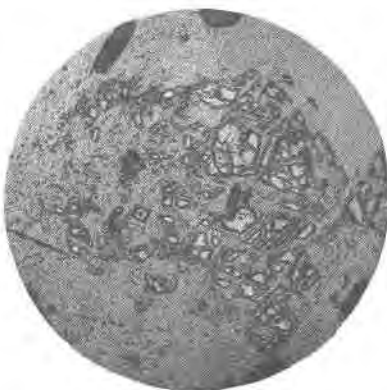


Figure 4. Rounded fragments of pyrite grain partially replaced by chalcocite. 14th level, Old Dominion mine, Globe, Arizona. Mag. 72X.

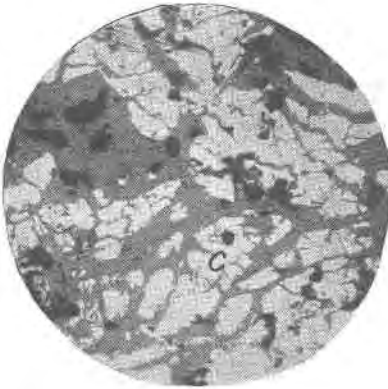


Figure 5. Irregular fragments of chalcocite (C) in quartz. Replacement shown by rough and rounded form of chalcocite. 14th level, Old Dominion mine, Globe, Arizona. Mag. 56X.

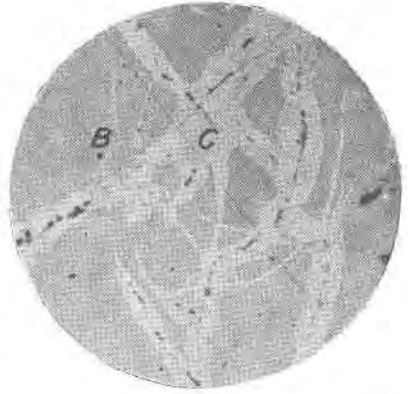


Figure 6. Bornite (B) cut by veinlets of chalcocite (C). An early stage of replacement doubtless supergene. 15th level Old Dominion mine, Globe, Arizona. Mag. 56X.



Figure 7. Rounded fragments of pyrrhotite (Pr) in galena. A primary ore showing replacement. Sullivan mine, Kimberley, B. C. Mag. 33X.

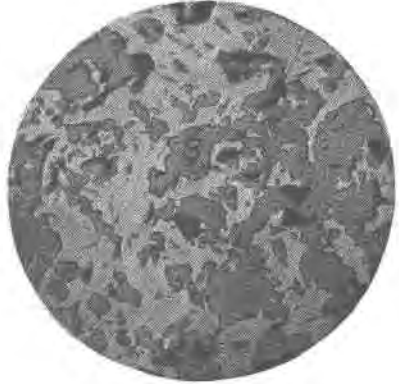


Figure 8. Irregular to rounded fragments of sphalerite (S) in galena. Not as far advanced as Figure 7. Sullivan mine. Mag. 36X.

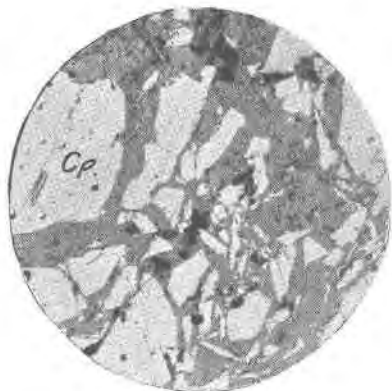


Figure 9. Chalcopyrite (Cp) as angular fragments in a quartz-hematite matrix. No corrosion by later material. Iron Cap mine, Globe, Arizona. Mag. 40X.

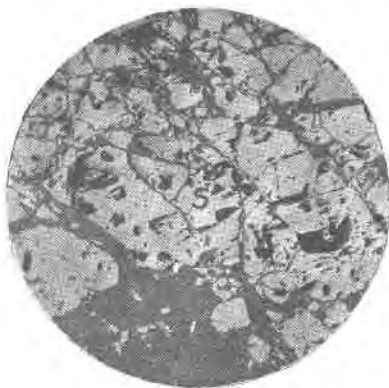


Figure 10. Angular fragments of sphalerite in quartz. Little evidence of replacement by later quartz. Butte and Superior mine, Butte, Mont. Mag. 72X.



Figure 11. Angular fragments of arsenopyrite in quartz with but slight corrosion. Stannite-wolframite ore, East Pool mine, Cornwall, England. Mag. 36X.



Figure 12. Micrograph of a thin section of a sulphide diabase. Note fresh olivine (O), augite (A) and plagioclase (P). Euhedral feldspar crystals are embedded in sulphides (black). Exploration pit, Cook County, Minnesota. Mag. 16X.

Bateman<sup>3</sup> has presented a discussion of angular inclusions which is of interest in connection with some of the figures of this type.

Figure 6 shows an incipient state of replacement where chalcocite, presumably supergene, is replacing bornite. The bornite fragments are angular and to some extent can be fitted together, but a study of a larger field reveals a far from complete fit at many places. It is known in the case of supergene replacement that the alteration is performed by slowly percolating waters, thus allowing the removal of material not needed in the new minerals. This alteration characteristically follows fractures existing in the ore.

Figures 7 and 8 are from primary ores of the Sullivan mine and are reproduced from a previous article.<sup>4</sup> Figure 7 shows rounded residual fragments of pyrrhotite in galena and Figure 8 shows similar fragments of sphalerite in galena. The resemblance of Figure 7 to Figure 4 is obvious. The sphalerite of Figure 8 is not as much corroded as the pyrrhotite of Figure 7, but the process is evident. Whether the galena was brought in by dilute solutions or injected as an ore magma, there has been considerable corrosion of the preexisting minerals. Inasmuch as dilute solutions would more easily carry away the material such evidence is usually taken to indicate the activity of solutions in the deposition of ore. The analogy between these textures and the texture of oxidized and secondarily enriched ores is striking.

Examples of possible injection of minerals into preexisting minerals without replacement are by no means as common as the type described above. No good example is at hand of the ore mineral acting as a matrix in brecciated preexisting ore minerals. The cases cited show brecciation of ores and later injection of quartz.

Figure 9 was taken from a primary ore from the Iron Cap mine, Globe, Arizona. Chalcopyrite has been shattered and the angular fragments are scattered in a matrix of quartz and hematite. This structure has been called "exploding bomb" structure by Graton and Murdock.<sup>5</sup> There has been no corrosion of the fragments by

<sup>3</sup> Bateman, A. M.; Angular inclusions and replacement deposits: *Econ. Geol.*, vol. 19, 504-520 (1924).

<sup>4</sup> Schwartz, G. M.; Microscopic character of ores from the Sullivan mine, Kimberley, B. C.: *Eng. and Min. Jour.*, vol. 122, 375-377 (1926).

<sup>5</sup> Graton and Murdock; The sulphide ores of copper: *Trans. Am. Inst. Min. Eng.*, vol. 45, 29-93 (1913).

the quartz-hematite solution. An examination of this type of ore at higher magnification shows numerous small crystals of hematite in the quartz and these are more or less oriented as in the trachytic texture of petrology. The hematite gives an undeniable impression of having been oriented by the flowing of the materials around the chalcopryrite fragments. The chalcopryrite, however, shows no evidence of orientation as might be expected, and one is left somewhat in doubt as to the interpretation. A mixture of quartz and specular hematite suggests a moderate or high temperature of formation. The series of specimens of this type are the best indication found microscopically of injection of a viscous material such as the ore magma.

Figure 10 shows a case of quartz cementing a microscopic breccia of sphalerite. There has obviously been little if any corrosion, by the entering quartz solution.

Figure 11 shows a case somewhat similar to Figure 10. Arsenopyrite fragments are cemented by quartz with no apparent corrosion. The ore is from the Cornwall tin deposits.

Figure 12 is a micrograph of a thin section of a sulphide rock previously described by the writer.<sup>6</sup> The rock is composed of fresh olivine, augite, plagioclase, and sulphides (pyrrhotite and chalcopryrite). Euhedral crystals of plagioclase are embedded in the sulphides with no evidence of replacement or later introduction of any sort. This is interpreted as a case of ore minerals crystallizing as part of the rock, apparently an uncommon phenomenon, even in magmatic segregation deposits.<sup>7</sup> Dr. Emmons<sup>8</sup> has described two practically identical cases. Both apparently represent sulphides as original constituents of a granite. At one place galena encloses euhedral feldspar and at another molybdenite plays the same role.

Textures which indicate the more or less simultaneous development of two or more minerals have been omitted. There are several textures which indicate that relation, but they do not reveal, in most cases, the manner of introduction of the ores. Textures of that type might well deserve a separate discussion.

<sup>6</sup> Schwartz, G. M.; A sulphide diabase from Cook County, Minnesota: *Econ. Geol.*, vol. 20, 261-265 (1925).

<sup>7</sup> Tolman and Rogers; Magmatic sulfid ores: *Pub. Leland Stanford Junior University*.

<sup>8</sup> Emmons, W. H.; Some ore deposits in Maine, and the Milan mine, New Hampshire: *U. S. Geol. Survey Bull.* 432, pp. 34 and 42, and Plates I and III (1910).

Emphasis has been placed on angularity as contrasted with rounded fragments. Dr. Bateman<sup>9</sup> has presented evidence showing that fragments microscopically and in hand specimen may retain their angularity during replacement. This is to some extent shown in Figures 3, 4 and 6, and adds emphasis to Dr. Bateman's conclusions which are stated as follows. "The evidence drawn on above, though by no means all that exists, is sufficient to illustrate without further burden to the reader, that angular fragments exist as inclusions—and unsupported ones—in deposits that are considered to have been formed by replacement."

There is, however, an obvious difference between the angularity of Figure 4 and that of Figure 9; in the former replacement is obvious and in the latter the manner in which the fragments fit precludes replacement. It is obvious from Dr. Bateman's discussion that too much reliance must not be placed on one type of texture and the writer does not consider the criteria illustrated here as rigid tests of one or another type of origin. They are presented to show the kind of evidence which may be utilized in microscopic work to indicate the activity of certain processes. The criteria must be used with judgment and in conjunction with all available evidence of field and laboratory. Everyone admits the inadvisability of neglecting field evidence in favor of microscopic work, and it is practically as unwise to neglect microscopic study in favor of field evidence.

It is noteworthy that examples of replacement and of angular unreplaced fragments may be taken from the same deposit. Replacement may, of course, take place to some extent in an ore magma as stated by Mr. Spurr, and therefore microscopic evidence of replacement does not necessarily preclude formation from an ore magma. It is true, however, that replacement occupies a much more important place in the conception of ores being deposited by dilute solutions than by the much more concentrated ore magma. Microscopic study leads one to favor the older conception as indicated especially by the work of Lindgren, Graton, Emmons, Bateman, and others. The more in detail the ores are studied, the more convincing is the evidence of replacement as an important process in most epigenetic ore deposits. In this connection it may be well to emphasize that ores do not commonly show textures similar to those found in igneous rocks. There is normally a clear sequence of introduction although two minerals may be apparently of the same age in some ores.

<sup>9</sup> *Op. cit.*