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"Microscopic" Cleavages in Bornite from the Jinmu Mine, SW Japan and their Implications

By

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with 1 Table, 1 Text-figure and 2 Plates

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Abstract: During microscopic and electron probe investigation of the copper ores from the Jinmu mine, Hiroshima Prefecture, SW Japan, we have found well-developed "microscopic" cleavages oriented in two or three directions in the bornite matrix. They are represented by the regularly arranged intergrowths, lattice or lamellar. According to their distribution density and size (width), the cleavages are divided into three types. (1) Type 1, densely developed and very fine (less than about 0.1 micron in width), visible only under higher magnifications ($\times 400$ or greater); (2) Type 2, less densely developed and fine (about 1 micron in width); and (3) Type 3, sparsely developed and coarse (up to about 10 microns in width). The Type 1 cleavages are less common in the Jinmu ores, while they are very rare in natural sulfides. The very fine and coarse lamellae are always chalcopyrite, while the fine ones are mainly wittichenite and/or some chalcopyrite. Under the electron beam only the image of chalcopyrite forms a dark set of lines (backscattered image) and appears as dented (topographic image). It is important to note that their abundances of the cleavage types differ significantly from one place to another, even within a polished section. This fact suggests that there might be a compositional heterogeneity in the original solid solution, that is, a difference in the degree of supersaturation, with the higher degree for the Type 1 and Type 2 assemblages than for the Type 3 assemblages. As experimentally confirmed by Sugaki (1955), the crystallographic intergrowths described are concluded to have been formed by exsolution from the solid solution during cooling. In spite of the difference of the degree of supersaturation, the exsolution reactions under discussion are assumed to be of stepwise in such that the lamellae exsolved in the order of the Type 3→Type 2→Type 1 with decreasing temperatures.

Contents

I. Introduction

The existence of cleavages and their mechanisms of formation are of importance from the viewpoint of the development of crystallographic intergrowths.

A cleavage, parallel to {111}, is rarely observed in naturally-occurring bornite. Walker (1921) described an unusually perfect octahedral cleavage of bornite from an auriferous copper prospect, near Usk, B. C., Canada. The specimen consisted of bornite and chalcocite and the latter occurred chiefly along the cleavage planes in the former. Under the ore microscope, however, such cleavage as seen in galena is very rare, although RAMDOHR (1969) reported the existence of the polish cleavage parallel to {100} and {111} of bornite. As a general rule, cleavages found in natural sulfides under the microscope are represented by the regularly arranged exsolution textures (e.g., SCHWARTZ, 1927; EDWARDS, 1954).

During microscopical and microprobe investigation of bornite from the Jinmu mine, SW Japan, we have recognized well-developed "microscopic" cleavages with two or three directions, which form the lattice or lamellar intergrowths composed of chalcopyrite and/or wittichenite. However, they differ strikingly from those lattice intergrowths of chalcopyrite in bornite from this mine studied experimentally by SUGAKI (1955) in both their distribution density and size (width).

In the present article, the existence of the observed cleavages in bornite is reported with some genetical discussion. The detailed descriptions will be made somewhere.

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II. SAMPLE DESCRIPTIONS

The samples examined came from the Jinmu mine (now closed) and its location is shown in Fig. 1. The mining area is composed of the Permian sedimentary rocks including slate, sandstone, chert, limestone, and green rocks and unconformably overlying rhyolitic pyroclastic rocks of Cretaceous Period, which are intruded and thermally metamorphosed by the Late Cretaceous granitic rocks, mainly biotite granite (Fig. 1).

The copper-fluorite deposits of the mine, genetically related to the granitic intrusives, are of contact metasomatic origin. The principal ore minerals are chalcopyrite, bornite, magnetite, and fluorite, which occur as the massive ores, banded ores, space-filling materials, or as impregnations in skarn silicates such as grandite garnets and amphiboles. In places, pyrrhotite predominates. Bornite with or without chalcopyrite occurs as the massive ores, space-fillings, or as impregnations with mainly grandite garnets. Under the microscope, the lattice or lamellar intergrowths of chalcopyrite and/or wittichenite are common in the host bornite, with sphalerite, galena, niccolite, and cobaltite-gersdorffite in trace amounts. Microprobe analyses of bornite are presented in Table 1 in which the presence of silver and bismuth in more than trace amounts is noted. Such Ag- and Bi-bearing bornite was described by OEN KIEFT (1976) in sulfide-rich samples from the Mangualde pegmatite, Portugal. It is also emphasized that under crossed nicols, the host bornite is appreciably anisotropic. According to SUGAKI et al. (1974), wittichenite from this mine has some iron, up to 1.5 wt. % Fe. A mineral of the system Cu–Fe–Bi–S is closely associated with bornite (SOEDA et al., 1983), which will be reported as a new mineral in another paper (SOEDA et al., in preparation). Sometimes bornite intergrown with "chalcocite" is observed.

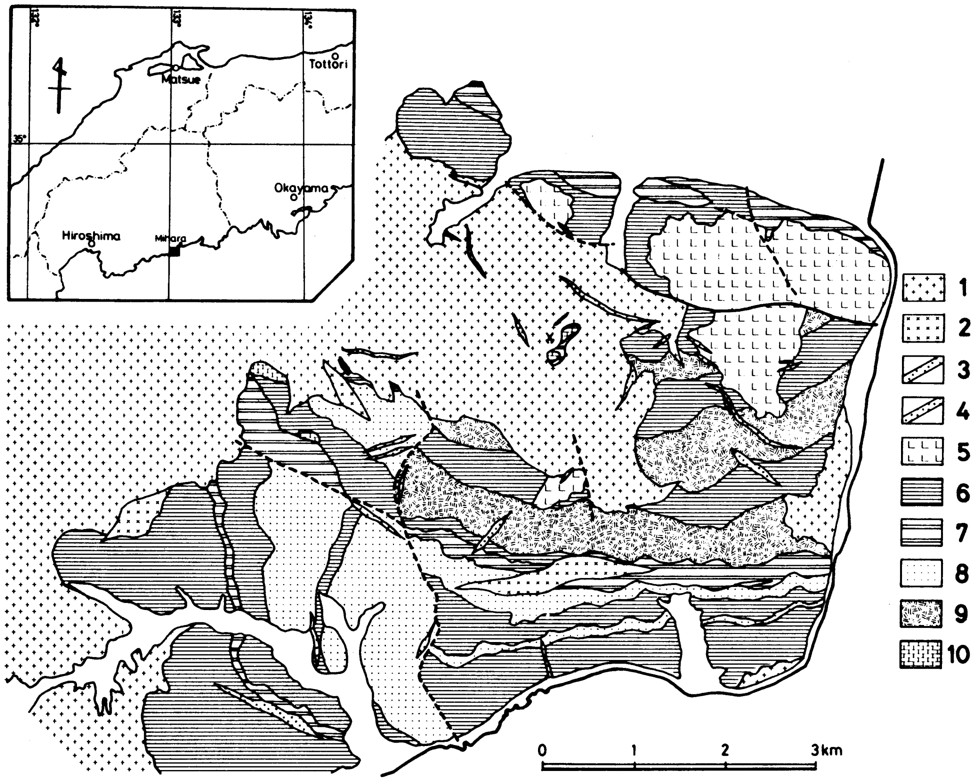

FIG. 1. Location map and surface geology of the Jinmu mine area, SW Japan (Modified from AOKI (1978)).

Numbers indicate as follows: 1. biotite granite; 2. porphyritic biotite granite; 3. granite porphyry; 4. aplite; 5. rhyolitic rocks; 6. slate; 7. chert; 8. sandstone; 9. green rocks; 10. limestone. The location of the mine is shown by the mark (x).

TABLE 1. MICROPROBE ANALYSES OF BORNITE FROM THE JINMU MINE, SW JAPAN.

	J#9–02	J#9–07	J#9–09	J#9–19
Cu wt.%	62.28	59.72	59.91	62.44
Fe	11.34	10.98	11.13	11.38
Ag	0.70	0.49	0.40	0.39
Bi	0.55	0.44	0.18	0.12
S	26.47	25.76	25.54	26.18
Total	101.34	97.39	97.16	100.51

III. RESULTS AND DISCUSSION

Bornite concerned was observed and analysed with an electron microprobe analyser, Type JEOL JCXA-733 and JEOL JXA-5A with take-off angle of 40°. Experimental conditions were as follows: accelerating voltage of 20 KV, absorption current of 0.02 mA on MgO, and beam size less than 1 to 3 microns in diameter. Standards used are: natural chalcopyrite for Cu, Fe, and S and synthetic Bi_2S_3 for Bi.

Mainly from the regular distribution, the cleavage-like patterns which we have recognized are considered to be the cleavages in bornite, not radiation damages. According to their distribution density and size (width), the cleavages, lamellar or lattice intergrowths, are grouped into three types: (1) Type 1, densely developed and very fine (less than about 0.1 micron in width), visible only under higher magnifications ($\times 400$ or greater); (2) Type 2, less densely developed and fine (about 1 micron in width); and (3) Type 3, sparsely developed and coarse (up to about 10 microns in width). Of these three types, the Type 1 are less common in the Jinmu ores, while they are very rare in natural sulfides, in general. The only example other than the present case may be found in the bornite from the Akayama mine described by SUGAKI (1951), as far as we know. These three types occur separately or together. The type 2 are corresponding to those reported by SUGAKI (1955). The EPMA back-scattered images and microphotographs are given in Plates 19 and 20 which show their mutual relations among the three types of the cleavages. In Plate 19 (B and C) the Type 1 cleavages are presented. As is clear in these photographs, the lamellae are regularly arranged in two or three directions, which are assumed to be parallel to the crystallographic orientations of the host bornite. In the EPMA images, the dark matrix is bornite, while the dark lamellae, bright ones, and grayish grains are chalcopyrite, wittichenite, and unknown phase mentioned before, respectively. That the very fine cleavages which appear as a dark set of lines are composed of chalcopyrite is in good accordance with its smaller mean atomic number $\bar{Z}$ compared with the coexisting bornite and wittichenite (Plates 19 and 20). For comparison, the two images are given; one is the back-scattered image and another is the topographic image, which are shown in Plate 20 (A and B). As is evident, only chalcopyrite appears as the dark lamellae and as dented.

In anyhow, here described are the three types of the cleavages, which are presented by the lattice or lamellar intergrowths of chalcopyrite and/or wittichenite in the bornite matrix. Although they mostly are parallel to each other, they deviate slightly from the parallel arrangement in some case as illustrated in Plate 19 (B). Then, the formation mechanisms of the crystallographic intergrowths described are discussed as follows.

As clearly seen in the photographs (Plates 19 and 20), it is important to note that the abundances of the cleavage types stated before differ significantly from one place to another in both their distribution density and size (width), even within a polished section. This fact suggests that there might be a compositional heterogeneity in the original solid solution, that is, a difference in the degree of supersaturation with chalcopyrite and/or wittichenite in the solid solution. Namely, a site occupied by the Type 1 and Type 2 lamellae is higher in the volume % of chalcopyrite than that done by the Type 3. The degree of supersaturation is such that the former is higher than the latter.

Irrespective of the difference in the degree of supersaturation, the regularly distributed patterns in which the chalcopyrite lamellae contract at intersections instead of enlarging as in replacement textures (e.g., SCHWARTZ, 1931a, 1931b) can be regarded as the results from exsolution from the original bornite solid solution during cooling. This was confirmed experimentally by SUGAKI (1955), who performed the thermal experiments on the lattice intergrowths of chalcopyrite in bornite from this mine. Based on the heating and annealing experiments, he found that among the exsolution products, the lattice-like or lamellar chalcopyrite is a low temperature type (less than 250°C) due to high supersaturation, while drop-like forms correspond to high temperature type, with other lenses and wedges being an intermediate type.

It is also possible that despite of the difference of the degree of supersaturation, the exsolution reactions under discussion are assumed to be of stepwise as follows. First, the chalcopyrite lamellae of the Type 3 were formed at rather higher temperatures, followed by a significant growth, resulting in a depletion of chalcopyrite component. For this reason, they are not accompanied by other types, Type 1 and Type 2, in many cases. With lowering temperatures, accompanying the decrease of diffusion rate, the Type 2 lamellae appeared without subsequent significant growth. Finally, the Type 1 lamellae exsolved from the above solid solution depleted in chalcopyrite component with a little growth, as suggested by the common coexistence of the Type 1 and Type 2.

On the contrary, the exsolved lattices or lamellae of bornite in the chalcopyrite matrix have never been observed, as pointed out by BRETT (1964).

Well, there have been much debates on the mechanisms of exsolution textures found in natural sulfides or synthetic products, including, for instance, SCHWARTZ (1931a, 1931b), EDWARDS (1954), SUGAKI (1955), BRETT (1964), RAMDOHR (1969), YUND and HALL (1970), YUND and MCCALLISTER (1970), and DURAZZO and TAYLOR (1982a, 1982b). As well as the theoretical considerations, systematic heating experiments under the controlled conditions on the chalcopyrite-bornite pairs both from synthetic products and from various geological occurrences will give a clue for solving the problem. In particular, the development of a reliable method is required for estimating the modal composition of chalcopyrite exsolved. This is because the difference in the concentration of exsolved phase results in the different disappearing temperatures of the phase when heated, as emphasized by SUGAKI (1955).

IV. SUMMARY AND CONCLUSIONS

The cleavages which are represented by the regularly arranged lattice or lamellar intergrowths of chalcopyrite and/or wittichenite were recognized in the host bornite from the Jinmu mine, Hiroshima Prefecture, SW Japan. According to their distribution density and size (width), they are grouped into three types: (1) Type 1, densely developed and very fine (less than about 0.1 micron wide), visible only under higher magnifications (×400 or greater); (2) Type 2, less densely developed and fine (about 1 micron wide); and (3) Type 3, sparsely developed and coarse (up to about 10 microns wide). To our knowledge, the Type 1, consisting of chalcopyrite alone, are very rare in natural sulfides. It should be emphasized that their abundances of the cleavage types differ significantly from one place to another, even within a polished section. This fact suggests a possible existence of a difference in the degree of supersaturation with chalcopyrite and/or wittichenite in the original solid solution. It is concluded that these crystallographic intergrowths originated from exsolution from the solid solution during cooling, as confirmed experimentally by SUGAKI (1955). The exsolution reactions under discussion are assumed to be of stepwise in such that the lamellae exsolved in the order of the Type 3→ Type 2→Type 1 with lowering temperatures.

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EXPLANATION OF PLATE XIX

EPMA back-scattered images showing the cleavage types represented by chalcopyrite lamellae in the bornite matrix. Note their distribution density and size (width). The slight variation from the parallel arrangement displayed by chalcopyrite and wittichenite (B) is also noted.

A. Coexistence of the Type 1 and Type 2 lamellae of chalcopyrite and wittichenite

B. Enlarged view of PLATE 19 (A).
C. Type 1 lamellae of very fine chalcopyrite.
D. Type 3 lamellae of chalcopyrite.

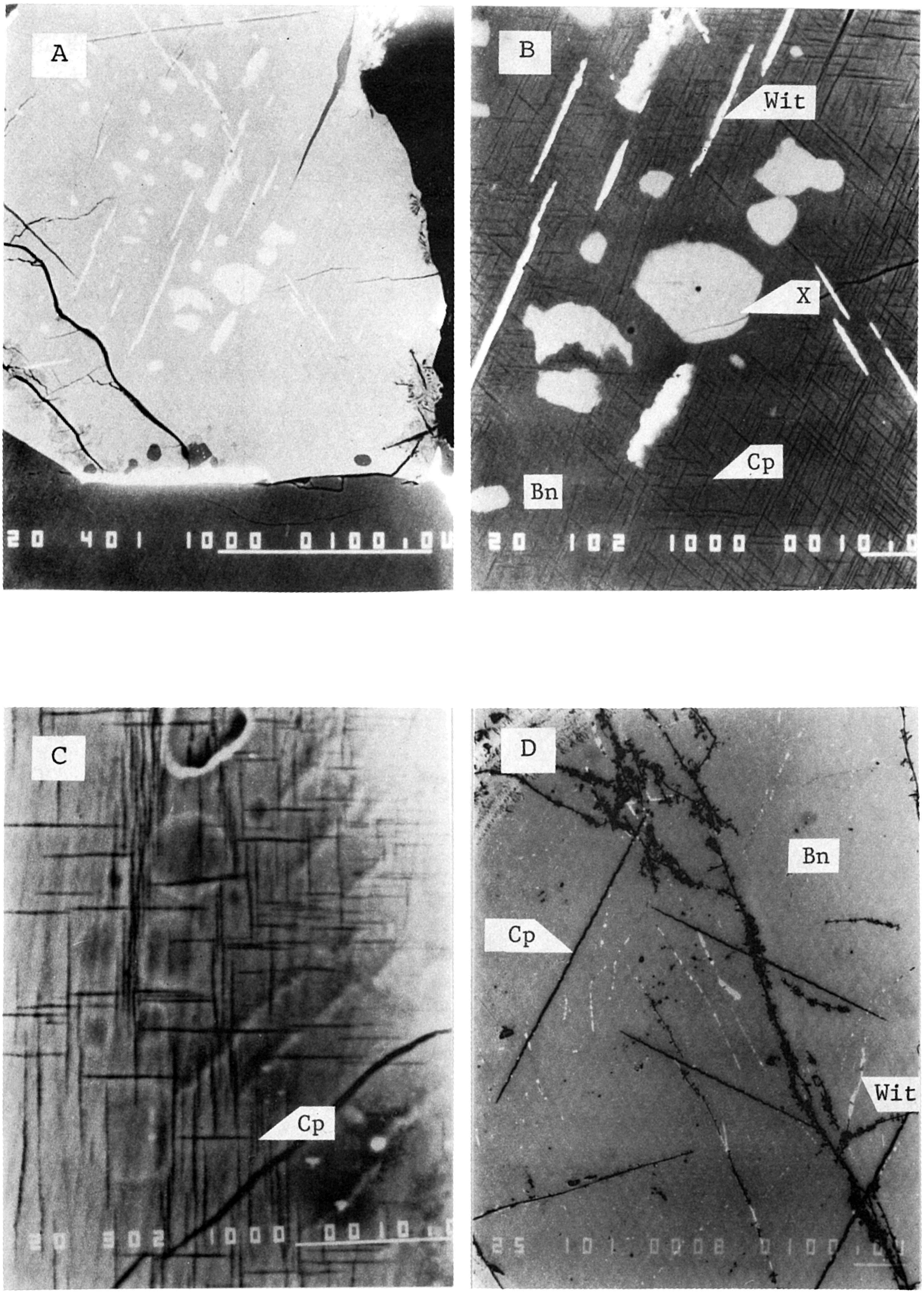
Abbreviations are: Cp, chalcopytite; Bn, bornite; Wit, wittichenite; X, unknown phase. Bar scales are: 100 μ long (A and D) and 10 μ long (B and C).

EXPLANATION OF PLATE XX

EPMA images and microphotographs showing the cleavage type. Note that only chalcopyrite appears as dark lemellae and as dented (A and B).

A. EPMA back-scattered image.
B. EPMA topographic image.
C. Microphotograph. (Reflected light, in oil)
D. Microphotograph. (Reflected light, in air)

Bar scales are 10 μ long (A, B, and C) and 100 μ long (D).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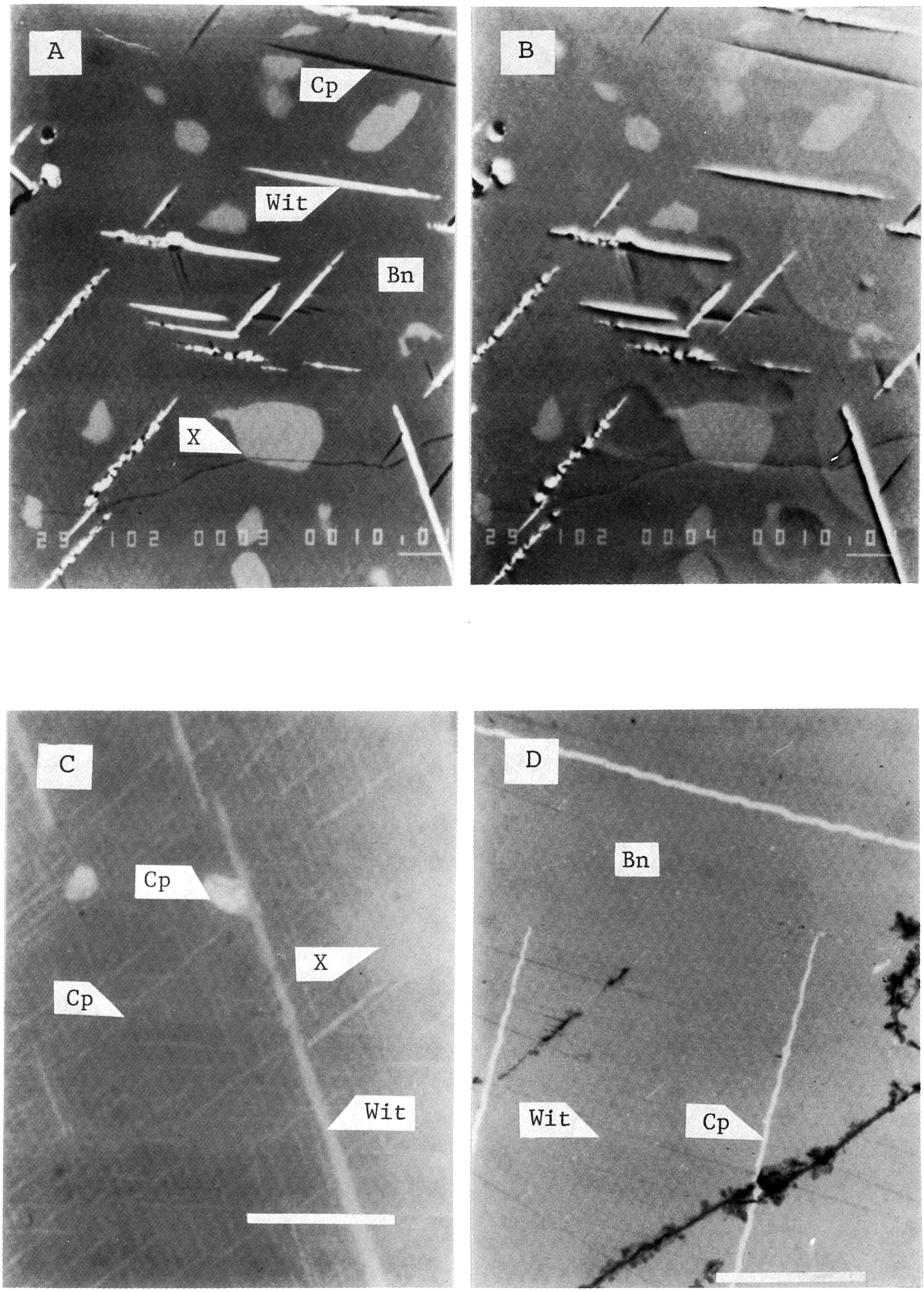
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