

The crystal system is evidently, therefore, monoclinic and the elongation of the fibres is probably parallel to the ortho axis. Assuming this to be the case, the best cleavage is in the zone parallel to this axis and may be assumed to be basal.

In the examination of crushed fragments of the mineral most of the fragments rest upon the good cleavage face. The interference figure for such a section is biaxial with one axis emerging nearly normal to the cleavage face. There is strong dispersion  $\rho > \nu$ . In fragments which show lath shapes, the optic axial plane is normal to the elongation and is, therefore, probably parallel to the 010 face. The mineral is negative and the mean index of refraction is 1.72.

Although the low index of refraction agrees with the index of the variety of epidote given the species name fouqueite by Lacroix,<sup>1</sup> comparison with his original description shows that there are marked differences. In the analysis of fouqueite no  $\text{Fe}_2\text{O}_3$  is recorded, although FeO in one variety of fouqueite was found to be 4.4%. Lacroix found fouqueite to be positive, whereas the Porcupine mineral is negative.

The Porcupine mineral is probably more nearly like a white epidote from Tierra del Fuego, described by Lacroix,<sup>2</sup> although the analysis of that specimen shows a higher percentage of alumina and the iron is recorded as entirely ferrous. Lacroix remarks that the mineral resembles zoisite in appearance but that its crystallization and optical properties are those of epidote.

It seems likely that this low iron variety of epidote at Porcupine must have crystallized from vein forming material simultaneously with the quartz. Any inclusion of the basic wall rocks metamorphosed by solutions would seem necessarily to be higher in iron than the Porcupine epidote.

## BORNITE AS A FURNACE PRODUCT

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During the latter part of 1923, the writer's attention was called to some crystalline material obtained from the partly fused mass of one of the smelter furnaces of the International Smelting Co., Miami, Arizona. The material was found by Mr. Emrich, assistant superintendent, while engaged in dismantling one of the furnaces.

<sup>1</sup> Bull. Soc. franc. Min., **XII**, p. 327.

<sup>2</sup> Bull. Soc. franc. Min., **X**, p. 150.

The crystals appeared as incrusting fused material and filling cavities. Many crystals extending into the cavities were so loosely attached that on handling they easily broke free, forming a granular mass consisting of distorted but well developed crystals. These averaged about a millimeter in diameter. Elongated dodecahedrons with modifications by the cube seemed to be the predominant forms. They had already been identified from a chemical analysis as bornite by Mr. F. G. Hawley, chief chemist of the company, who sent the material to the writer for crystallographic identification. Mr. Hawley suggests the possibility of the limestone flux, contained in the partly fused material, having been concerned in the development of the bornite. This may be indirectly true as the presence of unfused material would assist in the formation of cavities, as would also the escape of carbon dioxide from the reacting mixture. Another important factor in the development of the crystals has been the undisturbed condition of the material, the product having been found along the side of the furnace where the charge may have been unmolested for months. The crystals then have probably been segregated by the long continued action of the gases from the reacting mixture.

Synthetic bornite, both as a furnace product and as the result of definite laboratory experiments, has been frequently described, though in more recent years there seems to have been some doubt expressed as to its formation directly from a fused mass. In 1855 Böcking<sup>1</sup> obtained bornite as a regulus by heating together copper, iron and excess of sulphur under a cover of common salt. Marigny<sup>2</sup> also obtained it by heating pyrite, copper and sulphur under a borax cover. The product was described as a crystalline aggregate. Doelter<sup>3</sup> obtained it without melting, by the action of hydrogen sulphide on a mixture of copper and iron oxides. The bornite appeared, mingled with other sulphides, in the form of aggregates of small cubes. It was thought that these had formed at a temperature of from 100 to 200 degrees. As a furnace product it has been observed by Ruess<sup>4</sup> at Trautenau in Bohemia, together with chalcopyrite in a semi-fused silicious aluminous mass mixed with slag. A. N. Winchell<sup>5</sup> found it with chalcopyrite as a product of

<sup>1</sup> Inaug. Diss., Göttg., 29, 1855. Also Hintze, Mineral., 1, 914.

<sup>2</sup> *Compt. Rend.*, 58, 967, 1864.

<sup>3</sup> *Zeit. f. Kryst.*, 11, 36.

<sup>4</sup> *N. Jahrb.*, 79, 1861.

<sup>5</sup> *Am. Geologist*, 28, 244, 1901.

the furnaces at Butte, Montana. It was thought that here it may have been produced by sublimation. It has further been noted in small crystals as an alteration product on Roman coins in various hot springs where it was associated with chalcopyrite.<sup>6</sup>

From a consideration of the above facts, it would seem that bornite has developed both from the condition of dry fusion and lower temperature conditions, though in the former case it is doubtful whether the mineral formed directly on consolidation of the fused mass or by subsequent transformations in the solid state. These transformations, although possibly of various types, may all roughly be grouped under the term of unmixing. Doubtless the presence of gases and solutions assist in the unmixing process. The study of equilibrium curves between cuprous sulphide and iron sulphide has yielded different results in the hands of various workers. Some have reported that various compounds result between the two limits, while others<sup>7</sup> have found a series of mixed crystals with an eutectic range. In the interpretation of results it should be remembered that a microscopic study when taken by itself records only the final results, after transformations in the solid state, if sufficient time has been given, have brought about a new state of equilibrium. On the other hand, a thermo-analysis of the system usually gives only the result of the state of equilibrium at the point of crystallization from a molten mass. In most cases the transformations that take place in the solid state are too slow for detection by thermochemical means. The possibilities of alteration after consolidation has taken place are much greater than the simple unmixing of the two or more components. There is the possibility, (a) of the formation of polymorphous forms at lower temperatures. These may enter into different states of equilibrium than the original form. Thus one of our compounds,  $\text{Cu}_2\text{S}$ , is known to exist as isometric at certain temperatures while it becomes orthorhombic at lower temperatures. It is reasonable to suppose that the orthorhombic form would enter into different kinds of combination than the isometric. (b) Peaks on a curve representing the formation of double salts may occur at various places below the temperature of consolidation, all representing transformations taking place in the solid condition. These would all show under

<sup>6</sup> Daubrèe, *Compt. Rend.*, **80**, 461, 1875, and **81**, 182. Lacroix, *Min. de France*, **2**, 677, 1897.

<sup>7</sup> Carpenter and Hayward, *Eng. and Min. Jour. Press*, **115**, 1055, 1923.

microscopic study a structure suggestive of an unmixing of the constituents or an eutectoid intergrowth. The formation of these compounds (peaks on the curve) cannot be determined by thermochemical means as the transformation points take place too slowly. By identifying the compounds on polished surfaces by means of the microscope an hypothetical curve may be constructed, the peaks of which represent definite compounds or double salts. These are located below the curve found by thermo-analysis and though the temperature of unmixing cannot be determined at present, they may be sketched in showing the probable result. Some of these transformations have been fairly well worked out by the metallographists especially in the case of the iron-carbon system.

Carpenter and Hayward<sup>8</sup> have recently shown by thermo-analysis that no compounds form in the system  $\text{Cu}_2\text{S} - \text{FeS}$  at the temperature of consolidation. Therefore the compounds recognized by the microscope in a copper matte must have resulted from an unmixing after solidification. Thus in our specimen of furnace bornite, the massive matte with which it was associated showed intergrowths between bornite and chalcopyrite similar to those found in some ore deposits. These natural intergrowths have been the subject of much discussion in the microscopic study of ores, some holding to the view of simultaneous deposition, others to secondary replacement along crystallographic or less regular directions, while still others favor the theory of unmixing. The last view is favored by Dr. Hans Schneiderhöhn,<sup>9</sup> perhaps the chief exponent of "Chalcographic" methods in Germany. He has outlined, after the method of the metallographer, some of the changes that might take place after deposition.

If the sulphide ore deposit could be looked upon as an injected mass of fused material,<sup>10</sup> then the principle of unmixing would be almost as good as established, as many cases of the phenomenon have been observed in the laboratory with fused melts. These show a characteristic structure (eutectoid) like that often met with in ore deposits. Since, however, many of us are unable as yet to

<sup>8</sup> *Loc. cit.*

<sup>9</sup> Entmischungsscheinungen innerhalb von Erzmischkristallen und ihre Bedeutung für Lagerstättenkunde und Aufbereitung. *Metall und Erz*, XII, 501, 517, 1922. Anleitung zur mikroskopischen Bestimmung und Untersuchung von Erzen und Aufbereitungsproducten besonders in auffallenden Licht. *Berlin*, 1922.

<sup>10</sup> Spurr, J. E., *The Ore Magmas*, 1923.

accept this as a working hypothesis, the strong point in the theory of unmixing, viz:—the idea of an initial melt, is lacking. This presents a real difficulty for which no satisfactory explanation seems available.

### FURTHER NOTE ON SARCOPSIDE

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In 1920 the writer described sarcopside from Deering, N. H., the second known locality for that mineral.<sup>1</sup> Since then further details regarding sarcopside and its associated minerals have been noted, and they are given in this supplementary paper.

Websky,<sup>2</sup> in describing the original sarcopside from Michelsdorf in Silesia, did not give its optical properties. Mr. W. A. Roebing very kindly lent the writer a specimen of Silesian sarcopside for comparison with the Deering mineral. The two are identical in optical properties, that from Michelsdorf having  $n$  approximately 1.72, agreeing very closely with the value previously given for the New Hampshire specimens, 1.725. Under the microscope, however, Websky's mineral was found to contain bluish and greenish altered areas scattered through the colorless sarcopside, while the American specimens are much purer. This is also indicated by the analyses as given in the writer's previous paper. The iron of the New Hampshire sarcopside is nearly all in the ferrous state (39.87% FeO, 1.70% Fe<sub>2</sub>O<sub>3</sub>) while Websky's analysis shows a larger proportion of ferric iron (30.53% FeO, 8.83% Fe<sub>2</sub>O<sub>3</sub>), which is undoubtedly due to alteration. A further difference is that the sarcopside from Michelsdorf occurred in small confused aggregates not exceeding an inch in diameter, while, as noted below, the mineral from the newer locality has been found in pieces as large as a foot in length, with a straight fibrous structure.

Since the New Hampshire occurrence was first described more blasting has been done by the Gingrass brothers, who own the prospect. This has uncovered several large pieces of sarcopside, one of which was about three decimeters long and one decimeter in diameter. Unfortunately most of these newer specimens have

<sup>1</sup> Edw. F. Holden. An American Occurrence of Sarcopside. *Am. Min.*, 5, 99-102, (1920).

<sup>2</sup> M. Websky. *Z. Deutsche Geol. Ges.*, 20, 245, (1868); abstracted in *Jahrb. Mineral.* 606, (1868).