

METALLIC COPPER IN A METEORITE VEIN.

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A meteorite which fell June 30, 1918, twenty miles south of Richardton, N. D., affords an interesting occurrence of metallic copper, hitherto unknown in meteorites. The copper is in veins of metallic nickel-iron and iron sulphide. The meteorite is of the veined, gray chondrite type (Cca) of Brezina's classification, composed chiefly of olivine and monoclinic pyroxene, subordinate amounts of glass and troilite, and almost 20 per cent. of an alloy of iron and nickel (Plate XXV *a*).

Minerals.—The minerals of the veins are: (1) An alloy of iron and nickel in the proportion of 10 to 1; (2) troilite, FeS, magnetic iron sulphide, unknown among terrestrial minerals, but very closely related to pyrrhotite, and (3) a few flecks of metallic copper. Iron and nickel constitute about four fifths of the vein filling material, troilite about one fifth, and copper a small fraction of one per cent. Iron and nickel are scattered throughout the stony mass of the meteorite, troilite is scanty outside of the veins, and copper has been found only in the veins. These veins illustrate a type of metallic and sulphide deposits without parallel in ore deposits. They are of interest as illustrative of what has happened under conditions marked by the absence of oxidation agents.

In some veins of the Richardton meteorite, iron and nickel are the dominant vein minerals, containing little blebs and irregular grains of troilite, in other veins troilite is the chief constituent, surrounding globules and irregular pieces of nickel-iron. In two polished sections flecks of metallic copper are included in troilite, which in turn is surrounded by metallic iron (Plate XXV *b*). Three flecks of copper have been discovered on polished surfaces totalling ten square centimeters, the largest piece of copper being about 0.6 by 0.08 millimeters in area.

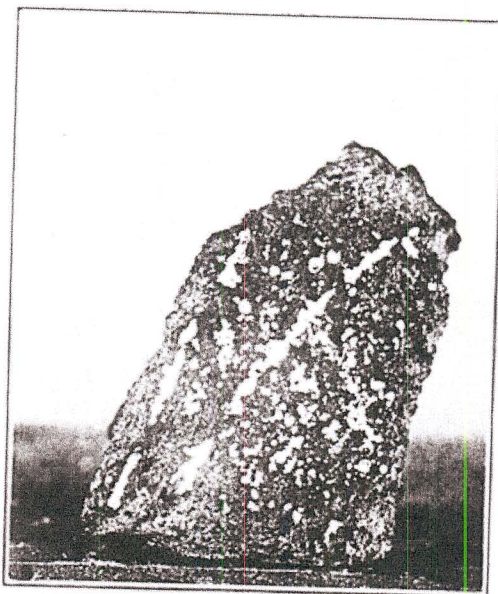
Mineral Relations.—The relations of the vein minerals to the stony part of the meteorite are not entirely clear. Metallic iron is scattered throughout the meteorite and is concentrated irregularly along the veins. Troilite is irregularly distributed along the veins and is disseminated less abundantly than the metals throughout the groundmass of the meteorite. The outer parts of some of the chondrules are impregnated with very fine grains of troilite, but no iron has been discovered with such relations. Many of the chondrules are partly or completely surrounded by iron and troilite, but none are cracked and penetrated by iron, nor does any surround or include a metallic grain. But since troilite does intrude the chondrules, and since it is syngenetic with the iron, it follows that both metals and sulphide are epigenetic. They have formed in fissures in the stony portion of the meteorite.

Veins.—The veins are only a few millimeters wide, in form resembling fissure veins. In several specimens there are two systems of sub-parallel veins at approximately right angles to one another, similar to common terrestrial fissure systems. In some cases veins are offset slightly by others cutting them, and some split into subsidiary veins, in rare cases reuniting in other places. The veins are clearly planes of weakness, for many small specimens of the meteorite are bounded in part by planes embossed with melted and partly fused blebs and globules of vein material. Merrill¹ notes that many meteorites have veins clearly due to fractures formed previous to their entrance into our atmosphere, and it seems safe to conclude that the veins in the Richardton meteorite follow fracture planes. Other meteorites are known to contain iron and troilite veins, but few show so clearly the syngenetic relation of the metal and troilite.

The manner of the filling of these veins has always been uncertain. Quoting Merrill:² "The position occupied by the metallic constituent in a stony meteorite or pallisite is such as to indicate plainly its secondary origin or introduction after the consolidation of all other constituents except the sulphides. While its

¹ Merrill, Geo. P., United States Nat. Mus. Bull. 94, 1916, p. 21.

² *Idem*, pp. 20-21.



a

FIG. *a*. Metallic iron and nickel in veins and scattered throughout groundmass of Richardton meteorite.



b

FIG. *b*. Photomicrograph of polished surface of a meteorite vein showing streak of metallic copper imbedded in troilite, itself in contact with metallic nickel-iron.

melting point (about 1500° C. or 2132° F.) is somewhat lower than that of the associated silicates, the manner in which it frequently penetrates the fractures of these constituents (see *Admire pallasite*) is so strikingly like that of the native copper in the siliceous breccia of the Lake Superior region as to suggest that it results not from a condition of dry fusion, but rather from the reduction of some easily reducible iron-rich compound like lawrencite. Such a reduction, as noted by Nordenskiöld³ and others, must have taken place outside of our atmosphere and in an atmosphere deficient in oxygen."

Referring to the veins in the Farmington meteorite, Farrington⁴ writes as follows:

The following suggestion as to the origin of the veins was made by Preston:

That as the meteor struck our atmosphere the concussion was so great that the mass was fractured in various places, of course extending from the surface inward, and the larger of these fissures or fractures were then filled by the metallic iron which was fused on the exterior surface of the mass due to its velocity through the atmosphere, and was thus forced in a molten state into its present position, thus forming the metallic veins.

This explanation was questioned by Farrington. His conclusion was that the veins were phases of structure of the metallic constituents of the mass, his objections to Preston's view being the following:

(1) The interior of a meteoric mass of any considerable size is so cold that portions of molten metal would be chilled before penetrating to any appreciable distance. (2) The metallic constituents of the Farmington meteorite are its least fusible ones.

It may be added that lawrencite, FeCl_2 , might be reduced to metallic iron if some means were provided for getting rid of the chlorine. If the stony meteorites contained any stable chloride, that suggestion would be most attractive. However, stable chlorides are unknown in stony meteorites either with or without metal. Furthermore, in the case of Richardton, the suggested introduction of lawrencite does not explain the presence of from 7 to 10 per cent. of nickel, neither does it explain the abundance

³ Nordenskiöld, *Zeits. d. D. geol. Ges.*, 1881, p. 25.

⁴ Farrington, O. C., *Nat. Acad. Sci., Mem.*, XIII., p. 187, 1915.

of syngenetic troilite, nor does it touch the matter of segregation of these minerals in veins. In the case of terrestrial deposits we might suggest the introduction of metals and sulphides in aqueous solutions, but meteorites are typically lacking in water. The suggestion that the metals were poured into the crevices while molten during the meteorite's brief passage through our atmosphere is scarcely probable as noted by Merrill and Farrington. However, the Farmington meteorite shows the tops of troilite crystals melted into globules, and little streams of troilite frozen while running in the openings of the meteorite. The troilite in this meteorite might have melted during flight through the air. The Farmington meteorite, however, is unusually porous, and, as it passed through the air, the enormously compressed air in front of it might have penetrated its interior and melted the troilite. According to Ward,⁵ a meteorite going 60 miles per second causes the air crowded in front of it to attain a temperature of over 5000° C. by reason of its compression. The Farmington meteorite probably did not fall at such a high velocity, but it probably fell fast enough to compress the air until it reached a temperature considerably above that at which troilite melts. However, such a case could apply only to the most fusible minerals in an unusually pervious and porous meteorite like the Farmington; not to a dense stone like the Richardton, and surely not to metallic iron and nickel, even if it might apply to troilite. Whatever caused the deposition of the iron, deposited also the troilite, for the metal and sulphide are clearly syngenetic. It is clear, also, that the veins were filled previous to the advent of the meteorite into our atmosphere.

The history of the veins seems to be that at some time the meteorite was fractured, later the fractures were filled with iron, nickel, troilite and copper, contemporaneously deposited, and that the veins were filled neither by aqueous solutions nor by fusion of the constituents. First, suppose that the vein material is a concentration of the essential constituents of the meteorite, neither introduced from outside the meteorite nor formed in veins pre-

⁵ Quoted by Farrington, *idem*, p. 492.

vious to its separation from some larger body; otherwise the veins, probably, but not necessarily, would be offset or shattered by fractures of a later non-mineralized type. What agencies remain as means of concentration after discarding aqueous solutions and dry fusion? Supposing the concentration of the vein minerals to have taken place while the meteorite was in space, the conditions must have been marked by extreme scarcity of oxygen, water, atmospheric pressure and heat, a coincidence of conditions unknown on our planet. Where so many factors are unknown, hypotheses naturally are advanced with diffidence; however, progress cannot be made except by the examination of alternate working hypotheses.

Eliminating fusion and solution, the only means of movement remaining to the minerals seems to be molecular. Solids have a vapor pressure, which is very small at normal temperatures, and must be much smaller in the extremely cold reaches of space. However, in space the vaporization must be continuous, because a balance can never be attained where the vapors are dispersed as soon as produced. Given time enough, vaporization of solids in space might amount to an appreciable sum. Would the minerals tend more to become inert and stable because of the scarcity of heat than they would tend to become molecularly mobile on account of the reiterated removal of vapor? And if they become more mobile, would the metals and troilite be more mobile than the silicates? If so, would that mobility bring them from the interior of the stone to the exterior and into the fractures? If all that happened, then naturally it follows that the iron, nickel and copper must remain metallic in the absence of oxidizing agents, and whatever sulphur there is would combine with the least easily reduced (and most readily oxidized) metals, forming ferrous sulphide, FeS (troilite), leaving the remainder of the iron, all the copper, and all the nickel in metallic state. The highly speculative nature of these surmises is apparent. A conservative conclusion seems to be that the veins and fractures were formed before the meteorite started on its travels through space, and that no later fractures due to parental disruption happen to traverse

the mineralized veins of the meteorite. According to this hypothesis, the vein filling is a concentration of material scattered throughout the stony mass, which was brought about in the absence of oxidizing conditions by agencies and processes unknown.

The conclusion remains that the Richardton meteorite contains metalliferous veins of iron sulphide, metallic iron, nickel and copper along fractures, which are epigenetic to the stony constituents of the meteorite.