

EVIDENCE OF SULPHIDE-SILICATE IMMISCIBILITY AT
GAP NICKEL MINE, PENNSYLVANIALOUIS MOYD,
Bancroft, Ontario, Canada.

There has been much controversy over the importance of sulphide-silicate liquid immiscibility in the genesis of the nickel deposits that are associated with basic rocks. Except that the position of the ores in the igneous bodies supports the idea of gravitative settling of fluid sulphides, little field evidence in favor of the theory has been noted. Some observers require as proof the occurrence of globules of one component suspended in a matrix of the other. Grout¹ mentions that during slow crystallization, the globules might lose their rounded form, and believes that the sulphides at Sudbury have passed through this stage. In material from the Gap Nickel Mine in Pennsylvania, the writer believes that evidence of sulphide-silicate unmixing is offered by rounded masses of amphibole occurring in the sulphide matrix.

The Gap Nickel Mine is located on Mine Ridge, in Lancaster County, 3 miles southwest of the town of Gap, on the main line of the Pennsylvania Railroad and the Lincoln Highway, about 50 miles west of Philadelphia. Copper was mined here intermittently as early as 1718, with little success. In 1852, a miner who came from Cornwall, England, noticed that the pyrrhotite was being thrown on the dumps as worthless. He suggested that the company have this mineral analyzed and Dr. Fredrick A. Genth, noted Philadelphia chemist and mineralogist, found nickel in it. The mine was then worked for nickel, at first unsuccessfully. In 1862, Mr. Joseph Wharton took over the mine, remodeled the works, and established a nickel refining plant in Camden, New Jersey. He prospered in this venture, and in 1876 the mine produced one-sixth of the annual world's output of nickel. However, the next year the higher quality ores from New Caledonia entered the market. The commencement of production at Sudbury a few years later led to a complete shut-down of the Pennsylvania operations in 1893. At present the workings are inaccessible and any study of the deposit must be made from old reports and from material on the dumps, which are extensive. The sulphides exposed to the weather are becoming quite oxidized and in a few years will be completely broken down.

The ores occur in a lenticular body of amphibolite, about 2000 feet long and 800 feet across at its widest part. This mass intrudes a schistose facies of the pre-Cambrian Baltimore gneiss, the long axis of the lens paralleling the strike of the gneiss, roughly east-west. Kemp² noted that

¹ Grout, F. F., *Petrography and Petrology*, New York (1932), p. 223.

the amphibolite lens showed a marked lamination or gneissoid structure at the west end, but was more massive toward the east. The laminations run parallel to the major axis of the body and he ascribed this structure to dynamic metamorphism and shearing. The amphibolite is composed almost exclusively of green hornblende. Kemp considered most of this to be uralitic in origin and found traces of pyroxene and olivine, which he considered to have been the original minerals of the rock. Phemister³ believes that only a small portion of the hornblende is uralitic and that the major portion is a direct crystallization product of the magma, a view shared by the writer. Some plagioclase and sphene are present in the

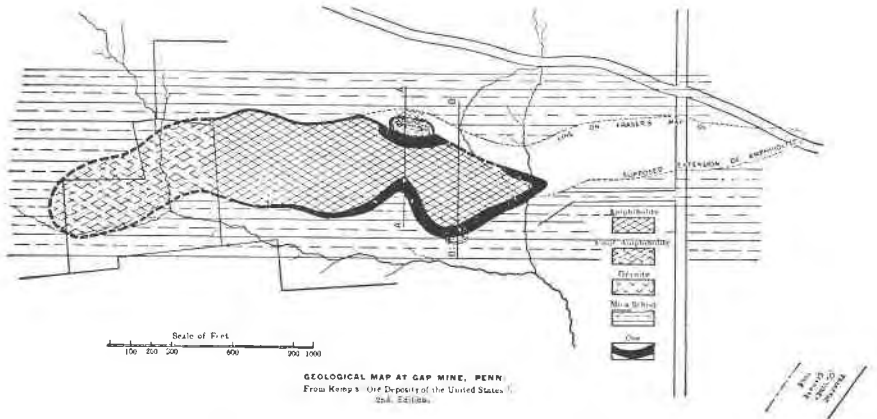


FIG. 1. Geological Map at Gap Mine, Pennsylvania, From Kemp's *Ore Deposits of the United States*, 2nd Edition.

basic rock and biotite replaces some of the hornblende. The sulphides are found along the margins of the body, favoring the east end and thinning toward the west. In some places the ore was as much as thirty feet thick. The sulphides fade out gradually into the amphibolite as the contact is left, although some workable masses of ore were found well within the lens. Little or no ore has penetrated the schistose country rock. Cutting the body are a few small pegmatites, also quartz veins bearing siderite, sulphides and crystallized vivianite. Joint planes are covered with crusts of millerite which added considerably to the value of the deposit. The ore itself is composed of pyrite, chalcopyrite, and pyrrhotite with exsolved pentlandite.

² Kemp, J. F., Nickel mine at Lancaster Gap, Pennsylvania, and the pyrrhotite deposits of Anthony's Nose: *A.I.M.E., Trans.*, **24**, 620-633 (1895).

³ Phemister, J. C., A note on the Lancaster Gap mine: *Jour. Geol.*, **32**, 500-502 (1924).

Campbell and Knight⁴ in their classic study of polished sections of nickel ores, describe the Gap ore as being composed of medium sized grains of pyrrhotite, which were apparently badly strained. Around the pyrrhotite are veins and masses of pentlandite with characteristic cleavage. Chalcopyrite is closely associated with the pentlandite and is probably later, as it is molded against and includes grains of it. Magnetite occurs as octahedra and there are crystals of hornblende with ragged terminations. Campbell and Knight studied only one section from the deposit, which did not contain pyrite. From blocks on the dumps, especially those in which the other sulphides are considerably weathered, well-formed octahedral crystals of pyrite up to $\frac{3}{4}$ inch in diameter can be obtained. Undoubtedly pyrite was the first of the sulphides to crystallize. Throughout the ore are masses of hornblende, many of them rounded and varying in size, but most of them are about an inch in diameter. These stand out as knobs where the ore has been exposed to the weather. Polished specimens show that beside these nodules, there are detached fragments of hornblende crystals in the sulphides, and sulphide veinlets cut across and seem to be replacing the masses of amphibole.

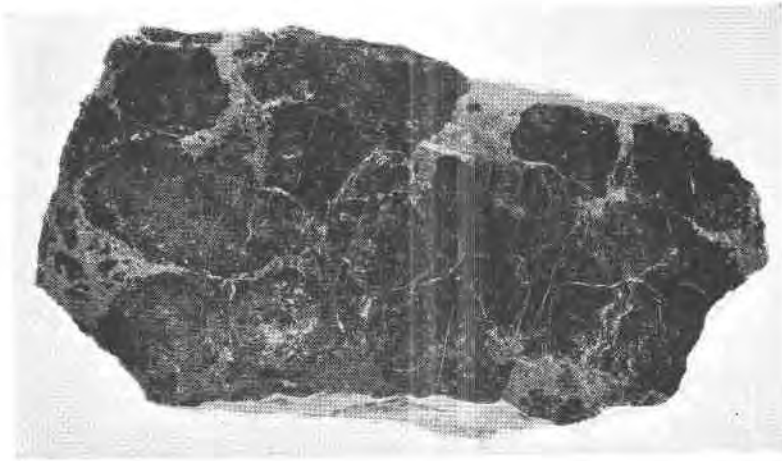


FIG. 2. Polished section from Gap Mine showing hornblende nodules in sulphide matrix. Fractures in the nodules are filled with sulphides.

As to the genesis of the ore-body, Kemp considered the sulphides to have crystallized contemporaneously from the igneous mass. Campbell and Knight believed that the sulphides, carried by solutions, penetrated

⁴ Campbell, W. and Knight, C. W., On the microstructure of nickeliferous pyrrhotites: *Econ. Geol.*, 2, 350-366 (1907).

and replaced the fractured basic rock. Phemister notes the evidence in favor of each hypothesis. He finds that an igneous view is favored by the fact that the contact of the ore and amphibolite is gradational, while the contact of ore and schist is sharp. Also, that the amphibolite shows the presence of sulphides throughout its extent. He considers as insurmountable evidence against magmatic origin of the sulphides that they are distinctly later than the silicates and replace them, this replacement having proceeded in many cases along small fractures. He gives as the sequence of formation of the ore, the intrusion and crystallization of the basic body which was followed by forces causing fracture and deformation, then, the ascent of ore-bearing solutions along the contacts, reacting with and replacing the silicates. As a possible source of these solutions, he refers to the pegmatites and quartz veins throughout the area. However, these are notably barren of ore minerals and nowhere have large concentrations of sulphides been introduced into the seemingly favorable schistose country rock adjacent to the deposit.

If what has been regarded as insurmountable evidence of replacement of the amphibolite by sulphides can be explained in another manner, then nothing would stand in the way of considering the Gap ore-body as an example of the syngenetic emplacement of basic rock and nickel ore. Should the nodules of hornblende, surrounded and penetrated by sulphides, be considered as the crystallized remnants of once-liquid silicate globules suspended in a bath of molten sulphide, then the following succession of events in the genesis of the deposit becomes apparent.

First, the intrusion at a high temperature of a small basic laccolith into the Baltimore gneiss. As the magma cooled, sulphide and silicate became less soluble in each other and began to separate, the heavier sulphide being carried toward the base of the body by gravity. With continued cooling, the magma became more viscous and the settling of the components was hindered, causing the sulphides separating from solution in the upper levels to be trapped in the silicate, and the silicate material coming out of solution in the lower zones to form globules in the fluid sulphide matrix. Then the silicate crystallized, but with the interstitial and underlying sulphide still fluid. At this stage the body was subjected to dynamic action which caused it to buckle into its present lens form, and sheared the amphibolite into gneissic form in the portions where interstitial sulphide was sparse, but caused only fracturing where the rock was protected by the molten sulphide. The fluid sulphide penetrated the small fractures, isolating fragments, and formed a structure resembling somewhat that resulting from metasomatic processes. The first sulphide to crystallize was pyrite, in euhedral form, then pyrrhotite. Dynamic action was continued to this point, causing the strain noted

earlier, and making channels for the last of the sulphides, chalcopyrite, to penetrate. At this stage, solid pentlandite was thrown out of the cooling pyrrhotite, in accordance with the findings of Newhouse,⁵ and chalcopyrite crystallized around them. Some time after the complete crystallization of the body, it was penetrated by pegmatities and quartz veins, which might possibly have re-activated some of the sulphides to form the quartz-siderite-sulphide-vivianite veins, and which could have caused a minor amount of replacement of the silicates by sulphides. The millerite coatings on the joint planes were probably deposited by downward penetrating surface waters, as a considerable gossan was found.

⁵ Newhouse, W. H., Equilibrium diagram of pyrrhotite and pentlandite and their relations in natural occurrence: *Econ. Geol.*, **22**, 296 (1927).

Attention is called to the new Special Paper #36, "Handbook of Physical Constants" of geological materials published January 31, 1942, by The Geological Society of America. The volume contains 21 sections prepared by 19 specialists cooperating through the Divisions of Chemistry, Physics and Geology of the National Research Council. Copies may be consulted in geological libraries and are available to the public at a price of \$1.40 on application to The Geological Society of America, 419 West 117 Street, New York, N. Y.

Professor C. K. Leith of the University of Wisconsin, at present Adviser to the Materials Division of the United States War Production Board, gave a series of ten lectures under the auspices of the Division of Geology and Geography of Columbia University, entitled "Minerals in Peace and War."

Sir William Bragg, Fulleren professor of chemistry of the Royal Institution, London; director of the Davy-Faraday Research Laboratory; and president of the Royal Society from 1935-1940, died on March 13 in his eightieth year. In 1915 he shared the Nobel prize with his son, William Lawrence Bragg, for their work on x-rays and crystal structure.