

unsuccessful. Three samples of zircon separated from granite were run through a Franz Isodamic Separator and the fractions analyzed. The results are tabulated in Table 2.

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## HYPOGENE GOETHITE AT PEKO MINE, N.T., AUSTRALIA\*

A. B. EDWARDS, C.S.I.R.O., *University of Melbourne, Carlton, N. 3, Victoria, Australia.*

The primary copper ore at the Peko mine, Tennant Creek, Northern Territory, Australia, contains about 9 per cent copper and 4.5 dwt. gold per ton. It is associated with a lens of magnetite rock, and consists of remnants of the magnetite rock in varying stages of replacement by pyrite, chalcopyrite, pyrrhotite, marcasite and minor amounts of wolframite, cobaltite, (?)safflorite, sphalerite, galena, bismuthinite, native bismuth, matildite, tetrahedrite, native gold, hematite and goethite (Edwards, 1955). The gangue minerals include quartz, siderite and chlorite.

Three ore zones have been exposed in development. From 200 ft. to 270 ft. (vertical depth) the ore is intensely oxidized and consists essentially of cuprite and native copper with some residual chalcocite, pyrite and native bismuth. From 270 ft. to 315 ft. it consists largely of chalcocite and covellite with variable amounts of residual chalcopyrite, pyrite and other primary minerals. Below 315 ft. depth the ore consists of primary sulfides.

On the 400-ft. level, in a zone of high grade ore, there occur a number of ovoids, or near spherical, bodies of relatively coarse-grained, massive pyrite from 2 cm. to 15 cm. diameter, which interrupt the weak banding in the ore. The banding is marked by thin strings of residual magnetite crystals running through massive chalcopyrite, parallel to the bedding of the wall rocks. It continues undisturbed above and below, and on either side of each individual ovoid of pyrite.

The contacts of these pyritic ovoids with the chalcopyrite ore are marked by dark brownish-black rims. These dark rims are somewhat irregular in thickness and shape. They look like reaction rims, in that their width corresponds to the size of the particular pyritic ovoid, rang-

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ing from 1 to 2 mm. wide for 2 cm. ovoids, up to 10 to 15 mm. wide for larger ovoids (Fig. 1), and they enclose scattered residual crystals of pyrite.

The dark rims consist of goethite, quartz and siderite, the goethite predominating. The goethite occurs as more or less spherical radiating acicular growths (Fig. 2), which in polished sections are bluish-gray and anisotropic with reddish-brown internal reflections, and in thin section are translucent reddish-brown, pleochroic from red-brown to golden-brown, and anisotropic. The identification of the goethite was confirmed by microchemical tests and an  $x$ -ray powder pattern. The individual goethite needles are commonly minute—0.015 mm.  $\times$  0.002 mm.—though some are larger.

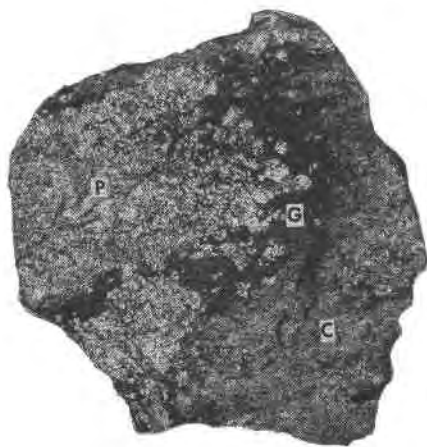


FIG. 1. Portion of a pyrite "ovoid," showing an irregular rim of dark goethite (G) separating the massive pyrite (P) from the enclosing chalcopyrite and magnetite (C).  $\times 0.7$ .

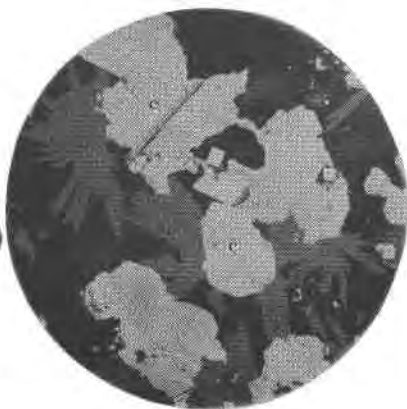


FIG. 2. Radial growths of goethite crystals (medium gray) moulded on chalcopyrite (c). The chalcopyrite encloses small corroded crystals of pyrite. Gangue is quartz (black).  $\times 164$ .

Polished sections of specimens from the outer margins of the goethite rims consist characteristically of clusters of goethite needles moulded on areas of chalcopyrite, which enclose small crystals of pyrite (Fig. 2). The goethite crystals project into the much coarser grains of quartz with which they are associated, and the chalcopyrite shows no evidence of corrosion, nor the least trace of oxidation.

Figure 3 shows a similar association of goethite, chalcopyrite and quartz, with clusters of minute crystals of pyrite fringing the central area of goethite.

Figure 4 shows a typical occurrence of goethite moulded on the edge of a crystal of pyrite, which is corroded where it is in contact with goethite or chalcopyrite. The goethite is also moulded on a grain of magnetite which shows no sign of oxidation, whereas in the zone of oxidation most magnetite in the Peko ore is more or less completely altered to martite.

Several of the pyrite ovoids were broken free from the enclosing chalcopyrite ore, which revealed that the goethite rims are not inter-connected, and have no extension through the ore away from the pyritic ovoids.

Similar goethite, less prominently developed, occurs in a zone of coarse pyrite forming the footwall of the lode and below the 400-ft. level. Here

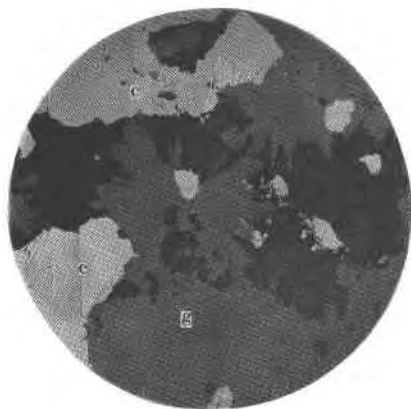


FIG. 3. Radiating clusters of goethite crystals (medium gray—*g*) moulded on chalcopyrite (*c*) and projecting into quartz (black). Clusters of minute pyrite crystals (white) occur on and in the margin of the central goethite cluster.  $\times 164$ .

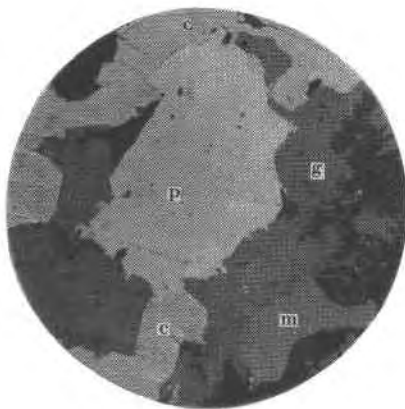


FIG. 4. Goethite (medium gray—*g*) moulded on pyrite (*p*), chalcopyrite (*c*) and magnetite (*m*). The pyrite is corroded at its contacts with goethite and chalcopyrite, but neither chalcopyrite nor magnetite shows any trace of oxidation.  $\times 123$ .

the goethite is associated with small rosettes of hematite, many of which are moulded on minute crystals of magnetite. Generally the radial growths of goethite needles are embedded in the quartz and siderite in the interstices of the hematite rosettes, but in places the goethite is moulded on the hematite, or intergrown with it. The magnetite crystals do not appear corroded, and show no trace of martitization. In places the hematite rosettes are moulded on areas of chalcopyrite, and these also show no traces of oxidation.

It is apparent that the goethite is not the product of supergene oxidation. It occurs well below the base of the zone of secondary sulfide enrichment, and its individual occurrences are isolated in completely

unoxidized ore. It is regarded therefore as a primary, hypogene mineral, deposited at a late stage of mineralization, along with quartz and siderite, as a result of a reaction between late ore solutions and earlier crystallized pyrite.

Since goethite converts to hematite above  $125^{\circ}\text{C.} \pm 15^{\circ}$  under neutral conditions, and above  $165^{\circ}\text{C.} \pm 5^{\circ}$  under alkaline conditions, independently of pressure (Smith and Kidd, 1949), it would appear that mineralization at Peko continued until the temperature fell below  $165^{\circ}\text{C.}$ , and possibly below  $125^{\circ}\text{C.}$ , in so far as the presence of marcasite points to acid conditions.

The occasional occurrence of wolframite, which appears to have been the earliest formed of the ore minerals, in conjunction with the presence of pyrrhotite in some abundance, indicates that mineralization began at a temperature of about  $500^{\circ}\text{C.}$  The presence of sphalerite studded with minute oriented ex-solution bodies of chalcopyrite points to a temperature of formation of  $400\text{--}500^{\circ}\text{C.}$  for these minerals.

Presumably, therefore, mineralization at Peko extended over a temperature range of from  $500^{\circ}\text{C.}$  to below  $165^{\circ}\text{C.}$  and possibly below  $125^{\circ}\text{C.}$  This is comparable with the temperature range shown by a number of orebodies (Edwards, 1954, pp. 161–163).

If both ore and *country rock* at Peko cooled through  $350^{\circ}\text{C.}$  during the mineralization, then the mineralization was a long continuing process. This seems unlikely in view of the general preservation of fine-textured exsolution intergrowths of chalcopyrite in sphalerite in small areas of sphalerite throughout the primary ore.

The alternative interpretation is that the mineralizing fluids reached their locus of deposition at a temperature well above that of the adjacent *country rock*.

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