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Chronology of Exotic Mineralization at El Salvador, Chile, by 40Ar/39Ar Dating of Copper Wad and Supergene Alunite

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Abstract

Exotic copper mineralization is a complex hydrochemical process linking supergene enrichment, lateral copper transport, and precipitation of copper oxide minerals in the drainage network of a porphyry copper deposit. At the El Salvador porphyry copper deposit in northern Chile the majority of the exotic ore comprised a mixture of copper-bearing manganese oxyhydrates termed "copper wad." X-ray diffraction, scanning electron microscopy, and electron probe microanalysis show that the copper wad is composed of copper-bearing cryptomelane [$K_{1-2}(Mn^{3+}Mn^{4+})_8O_{16} \cdot xH_2O$] and birnessite [$K_{0.33}Mn_7^{3.9+}O_{14} \cdot 7H_2O$] structures. These natural occurrences within the exotic ore provide the opportunity to directly date the formation of these deposits using recent advances in $^{40}Ar/^{39}Ar$ geochronology of supergene K-Mn oxides formed by weathering.

A suite of copper-bearing cryptomelane and birnessite samples from exotic deposits within the El Salvador district were characterized and dated by $^{40}Ar/^{39}Ar$ laser step heating. Supergene alunite [$KAl_3(SO_4)_2(OH)_6$] found in paleospring feeder systems leading from the source zones of copper outward to the exotic mineralization was dated to independently constrain the age of exotic ore formation.

Although the Ar retentivity of the layered birnessite structure has been questioned by others, the Ar retentivity of these samples is thought to be a function of their natural preservation and limited postcrystallization ground-water interaction in the hyperarid Atacama desert. The $^{40}Ar/^{39}Ar$ analytical results show that Ar and/or K losses after crystallization, excess ^{40}Ar, and ^{39}Ar recoil do not pose significant problems; therefore, in the context of exotic copper deposits within hyperarid environments this dating method is applicable to both cryptomelane and birnessite within copper wad.

The $^{40}Ar/^{39}Ar$ dating of exotic mineralization at El Salvador indicates that supergene and exotic mineralization processes were active at ~35 Ma, about 5 m.y. after the emplacement of hydrothermal mineralization, and continued until the middle Miocene. The majority of exotic mineralization extends from the Oligocene-Miocene (24 Ma) boundary through the middle Miocene (11 Ma) and relates to supergene fluid emanating in multiple directions from the source of copper in Indio Muerto, which represents a topographic high above the exotic deposits.

One reconnaissance date of exotic mineralization at the Chuquicamata porphyry copper deposit yielded an age of 17.03 ± 0.03 Ma coincident with the known supergene alunite dates for this deposit. Reconnaissance dating at Exotica-Mina Sur and El Abra proved problematic due to the presence of contaminant silicate minerals within the copper wad.

Ages derived here for exotic mineralization are similar to the known supergene ages throughout northern Chile. The dates indicate that supergene exotic mineralization began at the Eocene-Oligocene boundary and continued through the Oligocene, eventually ceasing in the middle Miocene due to desiccation of the Atacama desert.

A series of 10-cm-thick supergene alunite veins were microsampled across their widths and dated to address the kinetics of alunite vein growth. Apparent growth rates of the veins vary from 71 to 100 mm/m.y. in the horizontal direction to 24 mm/m.y. in the vertical, presumably caused by differences in pressure regimes due to their orientation.