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Origin and age of Cu-stratabound ore deposits: Michilla district, Northern Chile

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INTRODUCTION

The copper stratabound ore deposits hosted in the Jurassic volcanic sequence of La Negra Formation, represent, after the porphyry copper deposits, the second most important source of copper in Chile. These deposits form a metallogenetic province that extends throughout the present Coastal Cordillera of northern Chile, between 22° and 26° Latitude S (Figure 1).

Direct ages of Cu mineralization are not available and most geochronological constraints are inferred from the hosting volcanic rocks and gabbroic-dioritic intrusions spatially related to the ore bodies and thought to postdate the main mineralization event (e.g. Niemeyer et al., 1990). The ages obtained for the hosting La Negra Formation volcanic rocks ranging between 186 ± 14 Ma and 172.3 ± 0.9 Ma (e.g. Rogers, 1985; Venegas et al. 1991; Oliveros et al. 2004a). Intrusives cutting volcanic sequence range in age from 112 to 168 Ma (e.g. Astudillo, 1983; Boric et al., 1990; Venegas et al., 1991; Oliveros et al., 2004b). Consequently, mineralization occurred some time between 186 and 112 Ma. The Michilla District represents the largest and most important district in this Cu-stratabound metallogenetic province and includes some of the most representative cupriferous deposits. The Lince-Estefanía deposit, the most important ore body in this district, was selected to carry out Re-Os and sulfur isotopic studies in order to better constrain the age of mineralization and the origin and nature of mineralizing fluids.

LINCE-ESTEFANÍA GEOLOGY

The Lince – Estefanía deposit is located 130 km NNE from Antofagasta, northern Chile. At the deposit, La Negra Formation consists exclusively of a thick sequence of andesitic lava flows forming a monoclinal structure with a general orientation N60°E/45°NW. The volcanic sequence is intruded by numerous dykes and small stocks of gabbroic-dioritic composition (Figure 1). Some intrusives, mainly small stocks, form a breccia body with volcanic clasts and intrusive matrix. The main orientation of these bodies is NE with dip SE. Although intrusives have been classically considered to postdate the main mineralization event, our observations and the high Cu contents recorded in some intrusions (Minera Michilla S.A report 2003, unpublished data), strongly suggest that some intrusives were affected by the mineralization and accordingly, predate it. Both, volcanic rocks and intrusives are covered with semi-consolidated coarse-grained sediments of Cenozoic age (e.g. Boric et al., 1990).

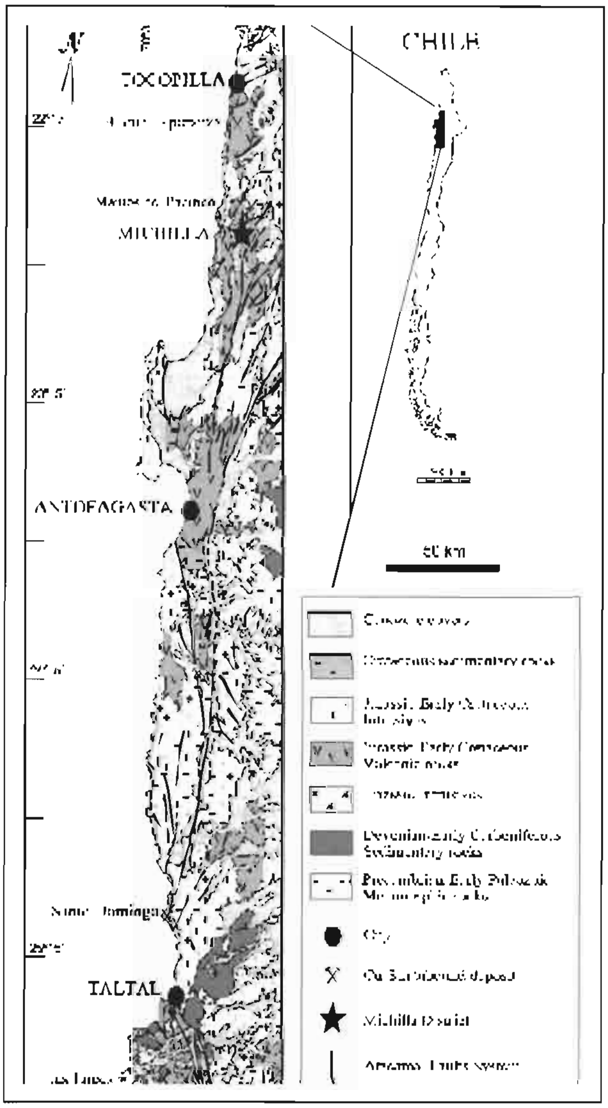

Figure 1. Geologic map and distribution of the main Cu-stratabound deposits at the Coastal Cordillera, northern Chile, between 22° - 26° Latitude S.

MINERAL PARAGENESIS

Ore minerals consist principally of Cu sulfides and Cu oxides. Sulfides include chalcocite ($Cu_{1.8-1.94}S$), bornite ($Cu_{5-5.3}Fe_{0.85-0.93}S_4$), covellite ($Cu_{1-1.35}S$) and chalcopyrite. Cu oxides include predominantly atacamite and chrysocolle. These minerals occur in permeable zones of the wall-rocks. The ore minerals form a recognized mineralized column of ~ 1000 m, and they form a vertical zoning with sulfide phases occurring mainly in the deepest levels and oxides dominating near surface.

Sulfides occur in multi-stages of mineralization. The earliest stage is characterized by pyrite and chalcopyrite. Contents of both pyrite and chalcopyrite are minor compared with the other sulfides (chalcocite and bornite). Pyrite is rarely associated with Cu sulfides and occurs mainly in the breccia zones and also disseminated in some afanitic andesitic (generally, below 250 m a.s.l). The chalcopyrite mainly occurs below 250 m a.s.l. The main cupriferous mineralization corresponds to abundant whitish-gray chalcocite and minor bornite. When they appear together, they form intergrowth textures that may have formed either by chalcocite replacement of bornite, or by exsolution. The occurrence of myrmekitic textures between these minerals, mutual smooth boundaries of the bornite grains against chalcocite, and grains of chalcocite within bornite coexisting with grains of bornite within chalcocite, suggest the latter. Native copper and native silver occur in small amounts associated mainly to chalcocite.

An important characteristic observed in many samples, is the textural relationship between chalcocite, bornite and hematite. Hematite forms a clear textural relationship that suggests it was deposited after these Cu sulfides. The minerals of alteration related to the cupriferous mineralization comprise chlorite – epidote – albite (±) – quartz (±), actinolite (-). Covellite, chalcocite, atacamite and chrysocolle are principal products of supergene mineralization. Covellite replaces chalcopyrite, chalcocite and bornite. Secondary chalcocite (bluish color) is observed in discrete abundance and forms replacement textures after chalcopyrite and bornite. The copper oxides show intergrowth textures between them. It is common to observe replacements of chalcocite by chrysocolle and cuprite. In this paragenetic stage, calcite is the most abundant alteration mineral. Quartz and minor gypsum also occur in this stage. Hematite is locally replaced by goethite.

RE-OS ISOTOPIC GEOCHEMISTRY

Osmium concentrations of 4 samples of chalcocite and chalcocite+bornite association range from 0.012 to 0.031 ppb, with rhenium concentrations from 0.186 to 1.789 ppb. Measured $^{187}Re/^{188}Os$ ratios range from 75.801 to 366.782 and the $^{187}Os/^{188}Os$ ratios vary between 1.26629 and 2.07729. These samples form an isochron age of 159 ± 16 Ma (2σ) (MSWD = 1.8) and an initial $^{188}Os/^{187}Os$ ratio of 1.059 ± 0.084.

The Re-Os chalcocite and minor chalcocite-bornite association age of 159 ± 16 Ma obtained from samples without hematite and covellite is interpreted as the best age of the main mineralization event of Lince-Estefania deposit. Results suggest that the occurrence of hematite, and probably covellite as mineral alteration in the chalcocite and chalcocite+bornite association, produce disturbance in the Re-Os systematic and, consequently, erratic ages can be obtained in comparison with the main mineralization age of the Lince-Estefania deposit. In fact, both a gain and loss of Re is observed, when hematite is present. This fact suggests that the Re-Os isotope in the hematite-bearing samples is mainly disturbed by the hematite occurrence. The results would indicate that Os was not a mobile element when is compared with Re during post-depositional process. In this sense, our assumption is agree with evidence that suggest that Os is not mobile element in arc environments (Becker, 2000) and that Re is 10^2 – 10^4 times more soluble than Os in high fO_2 fluids (Xiong and Wood, 1999). The abundant hematite content at Lince-Estefanía deposit would indicate high fO_2 conditions and according Xiong and Wood (1999), would favor the Re mobility.

All $\delta^{34}S$ values of the Cu-sulfides (chalcocite and bornite) vary in a narrow range from –1.6 to +0.4 ‰, including $\delta^{34}S = 0$ ‰ for a chalcopyrite sample, indicating a magmatic origin for the ore-forming sulfur. However, the initial $^{187}Os/^{188}Os$ ratio obtained for an age of 159±16 Ma of the Lince-Estefanía deposit, is 1.059 ± 0.084. This value is much more radiogenic than the chondritic reference $^{187}Os/^{188}Os$ ratio of 0.1259 at this age. This suggests a significant crustal contribution for the source of Os in the Cu sulfides analyzed.

CONCLUSIONS

The age of the main Cu sulfide mineralization event obtained to Lince-Estefanía deposit is 159±16 Ma. This age would indicate that the principal mineralization event for the stratabound Cu deposits hosted in La Negra Formation occurred during evolution of the Jurassic to Early Cretaceous magmatic arc developed in the present Coastal Cordillera, northern Chile.

A magmatic origin is proposed for sulfur of the principal Cu sulfides occurring in the mineralization, meanwhile some contamination of the mantle-derived fluids with the lower crust is necessary to explain the initial $^{187}Os/^{188}Os$ ratios of 1.059 ± 0.084 ($\gamma Os = (+723.8 - +776.9)$ obtained from the hypogene Cu and Cu-Fe sulfides in this Jurassic Cu-stratabound ore deposit from the Coastal Cordillera in northern Chile.

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