Geology and preliminary REE and trace elements geochemistry of Boris Ángelo Cu-(Ag) deposit, Central Chile

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Abstract Boris Ángelo Cu-(Ag) deposit, located in Central Chilean Coastal Cordillera, is included within Jurassic to Cretaceous copper Chilean Manto type (CMT) deposits belt. It is hosted by Lower Cretaceous volcanoclastic sequences of the Las Chilcas Formation and by Upper Cretaceous – Paleocene small sub-volcanic bodies. Based in this geological context we consider the Boris Ángelo deposit as one of the youngest deposits from CMT deposits belt. In this paper we describe the behaviour of REE and trace elements from Boris Ángelo Cu-(Ag) deposit and compare this feature with "fresh" host rock and with other copper deposit-types. The Boris Ángelo geochemical signatures are similar to Las Chilcas ("fresh" host rocks) samples, but with a general depletion in all REE and trace elements. They also show great similarity in REE and trace element patterns with others CMT deposits.

Keywords. CMTdeposit, Cu-(Ag) deposit, Boris Angelo

1 Boris Ángelo deposit geology

The Boris Ángelo Cu-(Ag) deposit is located in the Coastal Cordillera, Central Chile, at longitude 32º30'S and latitude 70º40'W and it is included within the Jurassic to Cretaceous Cu-(Ag) Chilean Manto type (CMT) deposit belt (Maksaev and Zentilli 2002). This deposit is hosted by Lower Cretaceous volcanoclastic sequences of the Las Chilcas Formation (Rivano 1996) and by small sub-volcanic bodies assigned, according to Rivano (1996), to the Upper Cretaceous – Paleocene San Lorenzo Unit. In contrast most of the CMT deposits in Central Chile are hosted by sedimentary and volcanic rocks from the Lower Cretaceous which are related to coeval and generally barren batholiths (e.g., Maksaev and Zentilli 2002; Carrillo-Rosúa et al. 2006). Based in this geological context the Boris Angelo deposit could be consider as one of the youngest deposits from CMT deposits belt.

The study area comprises a volcanoclastic sequence of Las Chilcas Formation and three main different sub-volcanic intrusive units: a) the porphyritic Boris Ángelo stock, b) the Soledad stock and c) porphyritic to aphanitic andesitic dykes. The Boris Ángelo stock is intruded by the Soledad stock. Finally, the dykes cut all the volcano-sedimentary and intrusive units.

These units, with the exception of the Soledad stock, display variable degree of alteration characterized by albitization of plagioclase, and by epidote, chlorite, quartz, hematite and minor calcite formation. In contrast, the Soledad Stock has a different and strong alteration pattern, where quartz, clay minerals, epidote and some Fe oxides with "box-work" texture are recognized.

The ore bodies are hosted by Las Chilcas volcanoclastic sequence and by Boris Ángelo stock. They are associated with pervasive epidote alteration and have a strong structural control related with NS-NNE and EW-NW fault systems and barren dyke intrusions that constitute en echelon fault system.

Ore mineralization occurs mainly in veins and veinlets or fine disseminations in the rock. The primary ore mineralogy is characterized by bornite, chalcopyrite and chalcocite, while sphalerite and galena are present as accessory phases.

2 REE and trace elements geochemistry

For this study six drill core samples representative of different host rock lithologies were selected. The samples are classified as barren (CuT%<0.3%, n=2) or mineralized (CuT%>1.0%, n=4). These samples were analysed for REE and Li, Rb, Ba, Th, U, Ta, Nb, Sr, Zr, Y, Be, Sc, U, Cr, Co, Ni, Cu, Zn, Ga, Hf, Mo, Sn, Tl and Pb, by ICP-MS. The Boris Angelo geochemical signature is compared with Las Chilcas "fresh" host rocks (Hollings and Cooke 2005) and with different types of copper deposits, specifically: CMT deposits (Cabildo, Moreno unpublished; El Soldado, Boric et al. 2002; Mantos Blancos, Ramirez et al. 2008; Buena Esperanza, Palacios et al. 1986); IOCG deposits (Mantoverde, Rieger et al. 2010; Candelaria-Punta del Cobre district, Marschik and Fontboté 2001); and porphyry copper deposits (Los Pelambres, Reich et al. 2003; El Teniente, Vry et al. 2010; Ok Tedi, Van Dongen et al. 2010).

Boris Ángelo whole rock geochemical data present a rather flat pattern of REE (La/Yb_N=4.2-5.9), a slight LREE-enrichment (La/Sm_N=1.8-2.3) and a moderate fractionation of HREE (Sm/Yb_N =2.3-2.7 (Fig.1 and 2). A significant characteristic is that the samples with the highest copper grade are more depleted in REE (Fig. 1).

In comparison with Las Chilcas "fresh" host rock, the Boris Ángelo samples show a general depletion in REE (slightly higher in HREE) and absence of negative Eu anomaly (Fig. 1).

In the case of CMT deposits, a similar REE trend is observed, however the CMT deposits present a higher and wider range of LREE (La/Yb_N=1.0-15.1; La/Sm_N=0.8-5.4) and slightly higher fractionation of HREE (Sm/Yb_N=1.0-2.8) than Boris Ángelo samples (Fig.1).

In the IOCG type deposits, it is observed that the REE pattern shows a wide range in LREE (La/Yb_N=0.8-71.1) with a strong enrichment in some samples (La/Sm_N=1.1-11.2) in relation with Boris Ángelo samples (Fig. 1).

In comparison to porphyry copper deposits, there is a similar content in LREE and higher fractionation of MREE and HREE (La/Yb_N=9.3-46.9; La/Sm_N=2.31-5.5; Sm/Yb_N=3.4-10.5) than Boris Ángelo samples (Fig. 1).

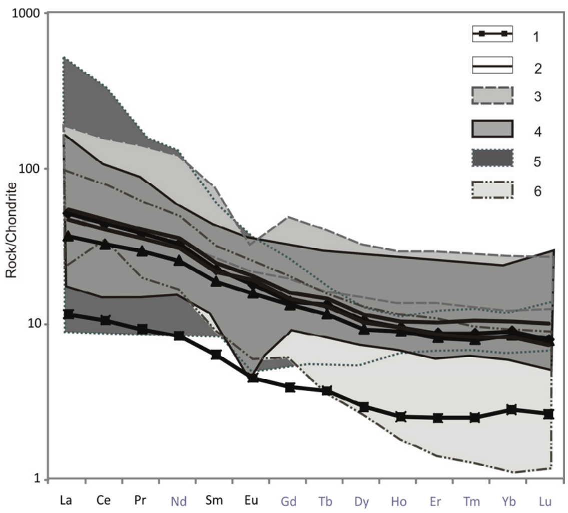

Figure 1. REE Chondrite normalized (McDonough and Sun, 1995) diagram. (1) Mineralized Boris Ángelo samples, (2) barren Boris Ángelo samples, (3) Las Chilcas lavas, (4) CMT deposits, (5) IOCG deposits and (6) porphyry copper deposits. 3, 4, 5 and 6: see text for references.

The La/Sm_N and Sm/Yb_N ratios diagram show that the Boris Ángelo samples define a quite limited field with low and almost constant La/Sm_N and Sm/Yb_N ratios compared to others Cu-type deposits. This field overlaps and is very similar to the Las Chilcas Formation lavas (Fig. 2). In addition, this also overlaps the fields defined by CMT and ICOG deposits. However, the CMT deposits shows a wider range of La/Sm_N and Sm/Yb_N ratios than the Boris Ángelo deposit (Fig. 2), whilst the IOCG deposits show the widest range of La/Sm_N ratios in relation of all other Cu-type deposits, although they show the highest LREE content (Fig. 2). In contrast, porphyry copper deposits show higher La/Sm_N and Sm/Yb_N ratios than Boris Ángelo samples, tending to a higher fractionation of HREE (Fig. 2).

Trace elements plotted in a spider diagram show that Boris Ángelo samples present a Ba, Th, Sr, Tb and U positive anomalies and Rb, Nb, Zr and Tl negative anomalies, similar than the Las Chilcas lavas trend (Fig. 3). Nevertheless Boris Ángelo samples are depleted in all elements in relation with the Las Chilcas samples.

In the case of CMT deposits, a similar behaviour is observed, with exception of Sr, which presents a negative anomaly in some samples (specifically from Mantos Blancos). The same feature is seen in IOCG deposits, as well as an enrichment of La and Ce. In the case of porphyry copper deposits they present a similar trend to the Boris Ángelo samples (Fig. 3).

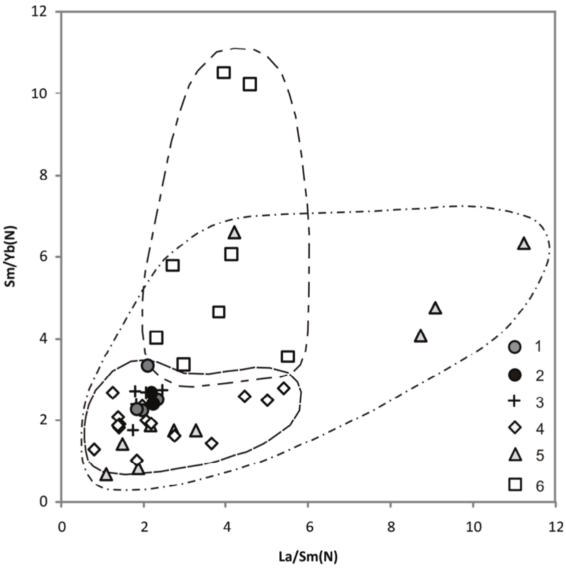

Figure 2. Chondrite normalized (McDonough and Sun, 1995) La/Sm vs. Sm/Yb diagram. (1) Mineralized Boris Ángelo samples, (2) barren Boris Ángelo samples, (3) Las Chilcas lavas, (4) CMT deposits, (5) IOCG deposits and (6) porphyry copper deposits. 3, 4, 5 and 6: see text for references.

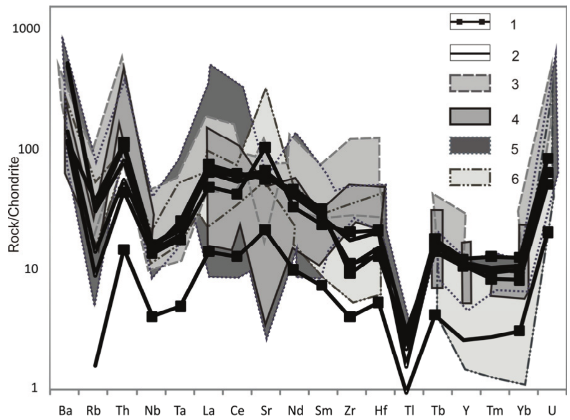

Figure 3. Chondrite normalized (McDonough and Sun 1995) spider diagram. (1) Mineralized Boris Ángelo samples, (2) barren Boris Ángelo samples, (3) Las Chilcas lavas, (4) CMT deposits, (5) IOCG deposits and (6) porphyry copper deposits. 3, 4, 5 and 6: see text for references.

3 Discussions and conclusions

REE and trace elements from Boris Ángelo samples describe a similar and homogeneous pattern both in barren and ore mineralized samples and by porphyritic subvolcanic and volcanoclastics rocks samples.

REE have long been considered being immobile during hydrothermal alteration processes (Bau, 1991). However some authors have argued that the REE could be potentially mobile during hydrothermal and supergene alteration (Palacios et al. 1986; Torres-Alvarado et al. 2007; Van Donguen et al. 2010).

The REE signature and incompatible element behaviour of Boris Ángelo show the same pattern to the Las Chilcas samples. Nevertheless the former are depleted in all REE and incompatible elements in relation with las Chilcas samples. This depletion has been observed in other ore deposits like OK Tedi (Van Dongen et al. 2010) where REEs were most depleted in zones of greatest hydrothermal alteration. This corresponds to our observations from Boris Ángelo, where the most altered sample is the most REE depleted.

Van Dongen (2010) argues that this depletion is due to a destruction of REE-rich accessory minerals, particularly apatite that leads to hydrothermal remobilization and depletion of REEs. However, these characteristics have not yet been observed in Boris Ángelo samples.

On the other hand the similar pattern between Boris Ángelo and Las Chilcas samples could be due to a minor lixiviation of the rocks due to hydrothermal fluids which are less effective with the LREE (slight depletion in HREE in Boris Ángelo compared with Las Chilcas).

Boris Ángelo presents a homogeneous and almost constant behaviour of REE fractionation, similar to that shows by Las Chilcas samples. This feature could indicate that the Boris Ángelo host rocks (Boris Angelo stock and volcanoclastics rocks) and Las Chilcas lavas could have originated under similar conditions and genetic process.

The slight Eu anomaly observed in Las Chilcas lava samples is not present in Boris Ángelo. This feature could be due to the fact that Eu^{+2} is dominated by the chemical substitution for Ca^{+2} and Sr^{+2} in plagioclase, during plagioclase albitization, or in the epidote (Palacios 1986).

Nevertheless the narrow field that define the strata-bound deposits in La/Sm vs. Sm/Yb diagram together with the trends defined in REE and spider diagrams present the biggest affinities with Boris Angelo samples than other copper deposits.

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References

Bau M (1991) Rare-earth element mobility during hydrothermal and metamorphic fluid-rock interaction and the significance of the oxidation state of europium. Chem Geol 93:219-230

Boric R, Holmgren C, Wilson NSF, Zentilli M (2002) The Geology of the El Soldado Manto Type Cu (Ag) Deposit, Central Chile. In: Porter TM (ed) Hydrothermal Iron Oxide Copper-Gold & Related Deposits: A Global Perspective, Vol. 2; PGC Publishing, Adelaide, pp 163-184

Carrillo FJ, Boyce AJ, Morales S, Morata D, Roberts S, Fallick AE, Belmar M (2006) Cu-(Ag) mineralizations from Melipilla (Central Chile): Geochemical evidences of existence of different hydrothermal parent fluids. In: Minerals, magmas and megastructures. The Fermor Flagship Meeting of the Geological Society, London. 50 p

Hollings P, Cooke D et al. (2005) Regional Geochemistry of Tertiary Igneous Rocks in Central Chile: Implications for the Geodynamic Environment of Giant Porphyry Copper and Epithermal Gold Mineralization. Econ Geol 100: 887-904

Maksaev V, Zentilli M (2002) Chilean Strata-bound Cu-(Ag) Deposits: An Overview. In: Porter TM (ed) Hydrothermal Iron Oxide Copper-Gold & Related Deposits: A Global Perspective, Vol. 2; PGC Publishing, Adelaide, pp 185-205

Marschik R, Fontbote L (2001) The Candelaria-Punta del Cobre Iron Oxide Cu-Au(-Zn-Ag)Deposits, Chile. Econ Geol 96:1799-1826

McDonough WF, Sun S. (1995) The composition of the Earth" Chem Geol 120:223-253

Palacios C, Hein U et al. (1986) Behaviour of rare earth elements during hydrothermal alteration at the Buena Esperanza copper-silver deposit, northern Chile. Earth Planet Sci Lett 80:208-216

Ramírez LE, Parada MA et al. (2008) Magmatic evolution of the Mantos Blancos copper deposit, Coastal Range of northern Chile: insight from Sr–Nd isotope, geochemical data and silicate melt inclusions. Resour Geol 58:124-142

Reich M, Parada MA et al. (2003) Adakite-like signature of Late Miocene intrusions at the Los Pelambres giant porphyry copper deposit in the Andes of central Chile: metallogenic implications. Miner Deposita 38:876-885

Rieger AA, Marschik R et al. (2010) The Hypogene Iron Oxide Copper-Gold Mineralization in the Mantoverde District, Northern Chile. Econ Geol 105:1271-1299

Rivano S (1996) Geología de la Hojas Quillota y Portillo.1:250000.Servicio Nacional de Geología y Minería. 191 p

Torres-Alvarado IS, Pandarinath K et al. (2007) Mineralogical and geochemical effects due to hydrothermal alteration in the Los Azufres geothermal field, Mexico. Rev Mex Cs Geol 24:15-24

Van Dongen M, Weinberg R et al. (2010) REE-Y, Ti, and P Remobilization in Magmatic Rocks by Hydrothermal Alteration during Cu-Au Deposit Formation. Econ Geol 105:763-776

Vry VH, Wilkinson JJ et al. (2010) Multistage Intrusion, Brecciation,and Veining at El Teniente, Chile: Evolution of a Nested Porphyry System. Econ Geol 105:119-153