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Phyllosilicates geochemistry and distribution in the Altar porphyry Cu-(Au) deposit, Andes Cordillera of San Juan, Argentina: Applications in exploration, geothermometry, and geometallurgy

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ABSTRACT

Biotite, chlorite, muscovite, illite, and kaolinite from the Altar porphyry Cu-(Au) deposit of the Andean Main Cordillera of San Juan Province (Argentina) were constrained using X-ray diffraction, electron microprobe, and infrared spectroscopy analyses to map compositional variations.

Magmatic and hydrothermal biotites from the andesite-dacite mineralized porphyries have higher X_{Mg}, K, and F contents and lower Fe/(Fe + Mg) ratios compared to the magmatic biotites from the andesite-dacite barren porphyries of the district Hydrothermal biotites from deep levels with potassic alteration and high Cu grades have the highest X_{Mg} ratios and high F contents. The similarity of the log fH_2O/fHF, log $fHF/fHCl$, and log $fH_2O/fHCl$ fugacity ratios of biotites from Altar mineralized porphyries and from the neighbouring Los Pelambres porphyry copper deposit suggests that these parameters may be a function of the magmatic source. Chlorite crystals associated with Cu mineralization (0.2 to 1.2% Cu) show lower Fe and Mn and higher Mg contents than chlorite from shallow and distal zones. Potassic dioctahedral phyllosilicates are the most abundant phyllosilicates in the Altar deposit, occur in the phyllic and chloritic zones, and are superimposed on potassic alteration. In zones of high copper grades (>0.8% Cu), potassic dioctahedral phyllosilicates have total Al (apfu) between 2.4 and 2.8 and intermediate compositions between muscovite, phengitic muscovite, and illite, whereas those with higher and lower Al contents come from zones with lower Cu grades.

Temperatures obtained from X_{Mg}-Ti equilibria in biotite (691–800 °C) and ^{IV}Al occupancy in chlorite (214–340 °C), agree with previous temperature estimates based on Ti in quartz and fluid inclusion microthermometry. Muscovite is stable at temperatures higher than ~300 °C, whereas phengitic muscovite indicates temperatures between 280 and 400 °C and higher K^+/H^+ conditions (less acidic environment) compared to muscovite. Illite represents a younger and cooler (220 to 310 °C) hydrothermal alteration event, and kaolinite in late veins halos reflects a decrease of the temperature (<200 °C) of late hydrothermal fluids.

Our study demonstrates that variations in phyllosilicate composition have the potential to be used as vectors in ore exploration and to differentiate between barren and fertile intrusions. A detailed analysis of type and proportion of phyllosilicates, as well as the presence of ore minerals in fine fractions, should be undertaken to optimize metal recoveries during the upcoming benefaction of these ores.

1. Introduction

Early studies of porphyry copper systems have used the geochemical and mineralogical zoning patterns of these deposits as a footprint guide for exploration (e.g., Meyer and Hemley, 1967; Lowell and Guilbert, 1970; Gustafson and Hunt, 1975; Dilles and Einaudi, 1992). However, understanding the controls on the formation of these alteration zones, discriminating mineralized and barren environments and recognizing the centers and fringes of the ore systems continue to be great challenges to the exploration industry (Wilkinson et al., 2015).

Recent investigations in porphyry copper deposits showed that white mica compositions and illite crystallinity can be used to map fluid temperature and pH gradients and to predict unexposed mineralization zones in areas where the surface has a strong supergene overprint (e.g., Franchini et al., 2007; Cohen, 2011). Trace elements are enriched in phyllosilicates along a near-vertical pathway of the magmatic hydrothermal plume extending from the ore zone of the

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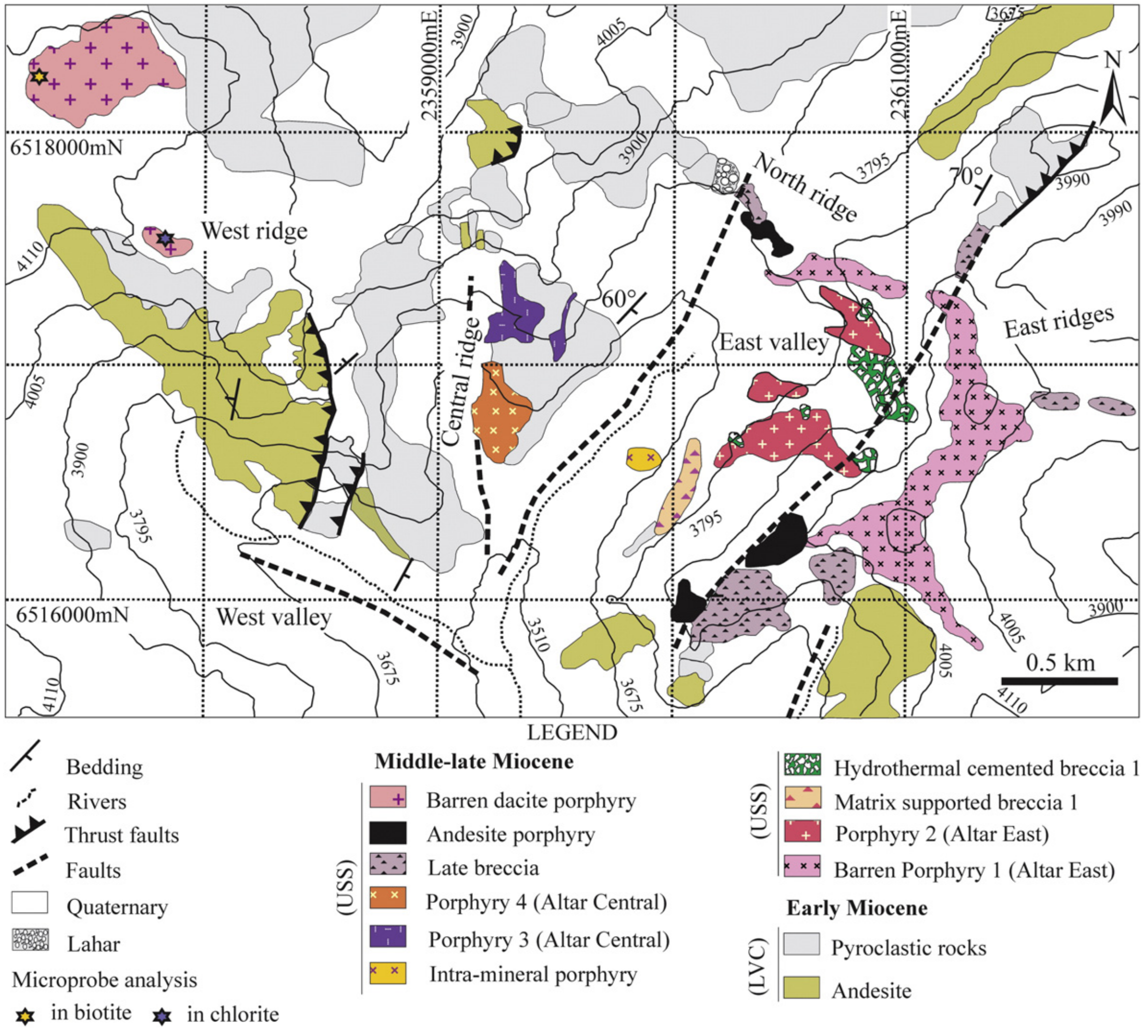

Fig. 1. Detailed map of Altar geology. Locations are given in Gauss Krueguer coordinates, Inchauspe. Locations of biotite and chlorite samples from outcrops are shown. LVC: lower volcanic complex, USS: upper subvolcanic suite (modified from Maydagán et al., 2011).

porphyry deposit upward to the surface environment (e.g., W, Sn and Tl in muscovite and Li in chlorite, Cohen, 2011). A variety of elements, including K, Li, Mg, Ca, Sr, Ba, Ti, V, Mn, Co, Ni, Zn and Pb are probably incorporated in the chlorite lattice and display systematic spatial variations relative to the porphyry center (Wilkinson et al., 2015). In addition, the mineralogy and distribution of phyllosilicates have implications in the metallurgy of these ores (Bulatovic et al., 1999). However, few studies document in detail the compositional variations and distribution of these minerals within ore deposits.

The Altar porphyry Cu-(Au) deposit (31° 29′ S, 70° 28′ W), located in the Cordillera Principal of SW San Juan Province, Argentina, is a large copper deposit (995 Mt, 0.35% Cu, 0.083 g/t Au; Marek, 2014) and is one of the few examples in the world in which it is possible to observe the transition between the epithermal high sulfidation siliceous ledges and the associated porphyry deposit. Maydagán et al. (2011, 2014) conducted the first geological mapping, geochronologic and geochemical investigation of the Altar magmatic rocks. A subsequent study of the different generations of Altar veins based on cathodoluminescence (CL) imaging, trace elements in quartz, and fluid inclusion microthermometry permitted differentiate quartz generations precipitated during different mineralization and alteration events and relate sulfides to a specific generation of quartz (Maydagán et al., 2015). In this contribution we present a detailed mineralogical study of phyllosilicates, clays, and their distribution along the best explored sections of the Altar deposit. The objective is to provide information on these hydrothermal minerals necessary to precisely document the thermal and chemical evolution of the Altar hydrothermal system, try to identify vectors for ore exploration and to optimize benefaction of metals from orebody metallurgy management.

2. Regional geology

The Altar region is located in the Andean Main Cordillera over the flat-slab segment (27–33° S) of the Southern Central Andes. The subducting slab in this segment has a relatively smooth transition to the north, toward the Central Volcanic Zone, and a southerly transition to segments with a steeper subduction angle (30°; Cahill and Isacks, 1992; Anderson et al., 2007; Gans et al., 2011). From 35 to 21 Ma, in the western part of the Cordillera Principal between 32° and 37° S, thick volcano-sedimentary sequences accumulated under an extensional tectonic regime (Charrier et al., 2002) in volcano-tectonic depressions or intra-arc basins, which in the study region is the Abanico basin (Muñoz et al., 2006; Mpodozis and Cornejo, 2012). These sequences were assigned to Abanico, Coya-Machalí, and Cura-Mallín formations (e.g., Jordan et al., 2001; Charrier et al., 2002; Kay et al., 2005; Farías et al., 2008). During the early Miocene (27–20 Ma), this segment had a subducted slab geometry similar to that currently observed in the normal-slab segment at 35° S, and a crustal thickness of 35–40 km