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Hydrothermal alteration and its effects on the magnetic properties of Los Pelambres, a large multistage porphyry copper deposit

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ABSTRACT

The Los Pelambres porphyry copper deposit is located 190 km north of Santiago, Chile. A paleomagnetic and mineralogical study was conducted at this deposit to determine the effects of hydrothermal alteration on the magnetic properties and minerals of rocks within the deposit when compared to the surrounding country rock. In the Los Pelambres deposit, magnetic properties of rocks are carried by titano-hematite and titano-magnetite solid solution minerals, where the former commonly indicates the exsolution of rutile. Magnetic minerals of intrusive rocks from the greater Los Pelambres region show that magmatic titano-magnetites and magnetites are the main magnetization carriers. The hydrothermal fluid associated with rutile exsolution textures could have played an important role in the mineralization of Cu in this deposit. The paleomagnetic properties in the Los Pelambres deposit can be divided in three main groups: (i) HMRG (high magnetic remanence group), (ii) HMSG (high magnetic susceptibility group), and (iii) LMSG (low magnetic susceptibility/remanence group). *In-situ* magnetic properties of the HMSG and LMSG are similar to the formations and units present regionally, however HRMG samples clearly differ from the country rocks. The high variability of *in-situ* magnetic properties presented in the Los Pelambres deposit has also been characteristic of other porphyry copper deposits in Chile (e.g., Chuquicamata and El Teniente). Regarding the field of exploration geophysics and porphyry copper deposits, this study suggests that phyllic, chloritic, and potassic alterations are related to low, intermediate, and high *in-situ* NRM, respectively, suggesting that geophysical methods must target a noisy magnetic signal depending on the scale of the study. The knowledge and results obtained are especially meaningful because magnetic surveys conducted for exploration do not commonly allow for the detection of ore mineralization.

1. Introduction

Hydrothermal alteration processes indicate that mineral transformations are mostly controlled by fluid-rock interactions and are buffered by the pH and redox equilibrium (Reed, 1997). Mineral stability in hydrothermal ore deposits such as porphyry copper systems have a direct effect on the alteration of mineral associations, including ferromagnetic minerals (Astudillo et al., 2008; Riveros et al., 2014; Townley et al., 2007). Alteration mineral associations in porphyry copper systems are spatially and chronologically zoned (Lowell and Guilbert, 1970; Richards, 2003; Sillitoe, 2010); therefore the paleomagnetic properties of these alteration minerals may present spatial or temporal variations that are dissimilar from the country and host rock which can even differ between hydrothermal alteration zones or events (Alva-Valdivia et al., 2003a; Astudillo et al., 2010).

In porphyry copper systems, deposits of indisputable hydrothermal origin, Fe-Ti oxides, and sulfides are most commonly present (Beane and Titley, 1981; Brimhall, 1980; Meyer and Hemley, 1997; Richards, 2003; Sillitoe, 2010). Some of these minerals are capable of registering natural remanent magnetism (Astudillo et al., 2008, 2010, among others), an inherent property of ferromagnetic minerals. In general, porphyry copper deposits are hosted by older porphyritic intrusions or pre-existing rocks. These host rocks are characterized by an original ferromagnetic mineralogy from which initial, specific paleomagnetic properties derive that often change due to hydrothermal processes.

Most paleomagnetic studies of igneous rocks have been conducted on non-altered rocks, nevertheless some have explored the effects of hydrothermal alteration processes on the paleomagnetic properties of rocks (Alva-Valdivia and López-Loera, 2011; Alva-Valdivia et al., 2003a, 2003b; Astudillo et al., 2008, 2010; Faundez, 2002; Tapia, 2005;

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Tassara et al., 2000; Taylor, 2000; Townley et al., 2007). Despite a poor understanding of the effects of hydrothermal alteration processes on the magnetic properties of porphyry copper systems, airborne and ground magnetic surveys can be used as tools for locating prospective deposits because of the magnetic properties of rocks and expected magnetic contrasts assumed from geophysical interpretation models. For instance, most aeromagnetic interpretations assume that natural remanent magnetism (NRM) represents an intensity of at least one order of magnitude less than the induced magnetic component, excluding NRM. Yet, paleomagnetic studies of northern Chile rocks have demonstrated that NRM represents at least 50% or more of the measured magnetic intensity (Arriagada et al., 2000, 2003; Somoza et al., 1999); hence, NRM vectors may represent an important component of the total measured magnetic field and disregarding these properties may cause a major bias when interpreting aeromagnetic data.

In this study of the Los Pelambres porphyry copper system, one of the largest multi-stage porphyry copper deposits of the central Chilean Andes Miocene copper belt (see Atkinson et al., 1996; Perelló et al., 2012; Sillitoe, 1973; Fig. 1a), results of paleomagnetic data and possible interpretations for this deposit are presented, expanding on similar studies in Chilean mines of stratabound deposits (Carolina de Michilla; Townley et al., 2007), iron oxides copper gold deposits (El Laco; Alva-Valdivia et al., 2003a and El Romeral; Alva-Valdivia et al., 2003b), and porphyry copper deposits (Chuquicamata; Astudillo et al., 2008, El Teniente; Astudillo et al., 2010, and La Escondida; Riveros et al., 2014). In particular, this survey presents the results of a general paleomagnetic and mineralogic study of the Los Pelambres porphyry copper deposit in order to evaluate (i) the effects of distinct hydrothermal and mineralization stages on the magnetic properties of rocks, (ii) the potential zonation of magnetic properties, and (iii) the overall expected magnetic contrast as a result of hydrothermal processes.

2. Regional and local geology

2.1. Regional geology

The Los Pelambres porphyry copper deposit is located 190 km north of Santiago within the main Andes Range (31°43′S; 70°70′W), between 2200 to 4500 m. a.s.l. The geology of the central zone of Chile, at the latitude of Los Pelambres, consists of stratified volcanic and sedimentary rocks whose ages span from the Middle Triassic until Recent, and intrusive bodies that range from the Cretaceous to the Miocene (Fig. 1b). Middle Triassic rocks correspond to greywackes and shales that are located along the western margin of the region (El Quereo Formation; Cecioni and Westermann, 1968; not shown on Fig. 1b). These are overlain by Jurassic volcanic rocks (Ajial and Horqueta Formations; Vergara et al., 1995), and continuing to the east by Cretaceous rocks: (ii) the Quebrada Marquesa Formation (Aguirre and Egert, 1961), a volcano-sedimentary sequence which occurs in the Precordillera, followed by (ii) both members of the Viñitas Formation (Rivano and Sepúlveda, 1991), constituted by lavas, tuffs, and breccias of andesitic composition with rhyolitic intercalations and calcareous sedimentary beds, and by

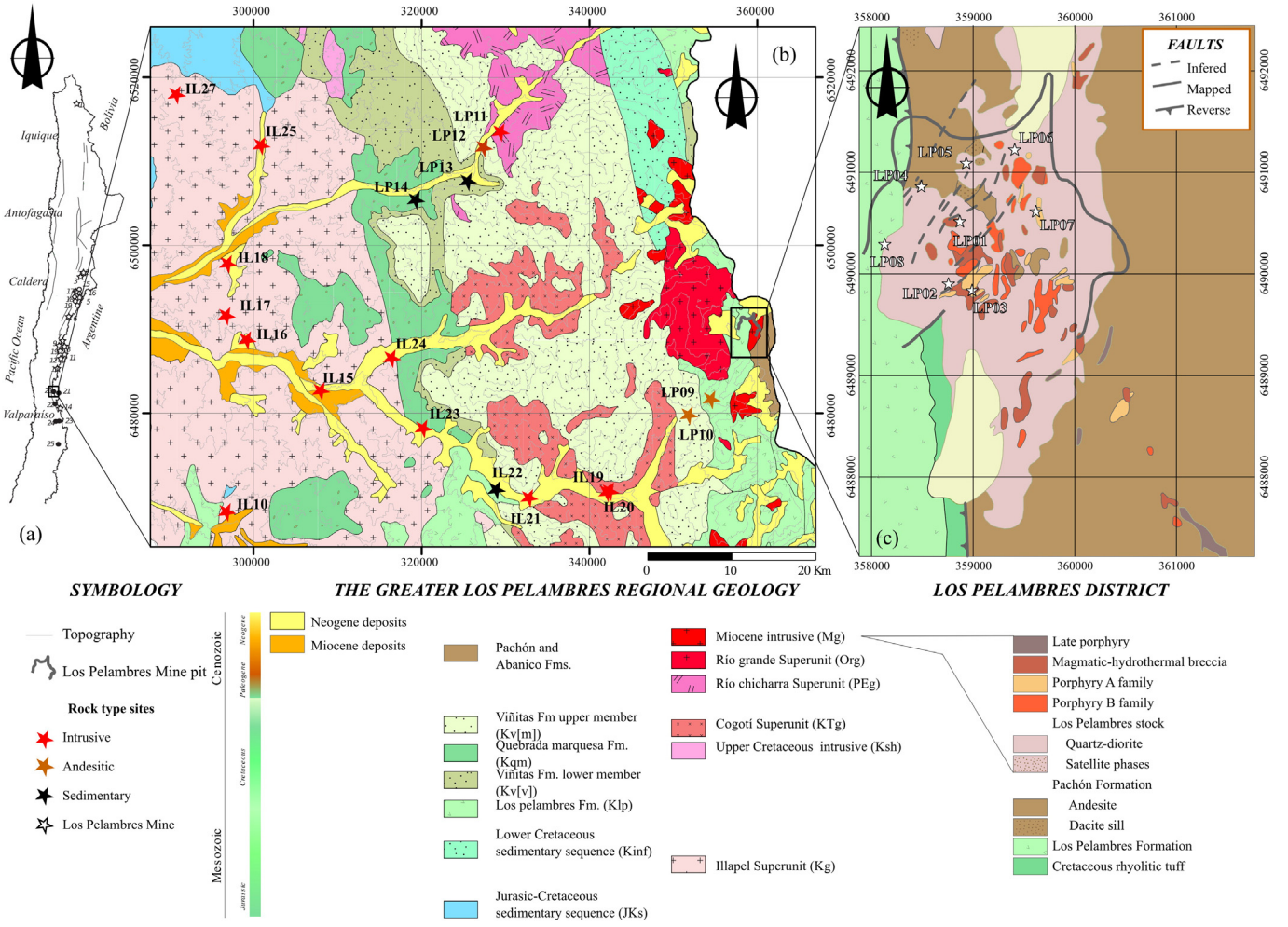

Fig. 1. Study area location and sampling sites. (a) Location of deposits within the Upper Miocene-lower Pliocene metallogenic belt of Chile; (b) The greater Los Pelambres region geology and sampling sites; (c) The Los Pelambres porphyry copper deposit local geology and sampling sites.