ADAKITIC MAGMATISM AT THE LOS PELAMBRES GIANT PORPHYRY COPPER DEPOSIT, CHILE

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INTRODUCTION

The Andes of central Chile host several Miocene-Pliocene world-class porphyry copper deposits such as Los Pelambres, Río Blanco-Los Bronces and El Teniente. Their formation has been related to crustal thickening, rapid uplift and exhumation of plutonic systems, together with exsolution of copper-bearing magmatic fluids responsible of brecciation, alteration and mineralization [1]. In this paper we focus on the petrogenesis of the copper porphyries at the Los Pelambres deposit (31º43'S, 70º29'W), located in the high Andes 190 km north of Santiago, near the Chile-Argentina border. The aim of this study is to constrain the nature and source(s) of the magmas associated with the formation of the Los Pelambres porphyry copper deposit, based on whole-rock major and trace elements data. The chemical composition of the Los Pelambres porphyries is then compared with the coeval and barren La Gloria pluton and Aconcagua volcanics, within the same Late-Miocene belt. Whole rock, major and trace elements data from Los Pelambres, La Gloria and Aconcagua magmatic rocks are reported by [2], [3] and [4], respectively.

GEOLOGIC BACKGROUND

The Los Pelambres deposit (32ºS) is located in the flat-slab segment (28-33ºS) of the Chilean Andes, below which the angle of subduction zone dips gently 10-15º to the east, and which displays a lack of recent volcanic activity. The Los Pelambres porphyry copper mineralization is hosted in an intrusive complex emplaced in andesitic rocks of the Los Pelambres Formation (Late Cretaceous). The intrusive complex has an age of about 10 Ma [5,6] and consists of a main tonalite stock, porphyry dykes of quartz diorite, quartz monzodiorite and

quartz monzonite, and minor post-mineralization andesite and aplite dykes. Magmatic/hydrothermal breccia pipes are also present within the deposit. A detailed petrographic description and characterization of these bodies is given in [6].

GEOCHEMISTRY OF THE LOS PELAMBRES INTRUSIONS

The Los Pelambres fresh (LOI<1.5wt%) mineralized intrusions (tonalite stock, tonalite porphyry and quartz monzodiorite porphyry) form a calc-alkaline suite covering a SiO_2 range from 62 to 72 wt% (Fig.1). They are characterized by high Al_2O_3 (15.2-17.8 wt%) and Na_2O (4.8-6.6 wt%) abundances, with K_2O/Na_2O<1 (0.23-0.71). The Na-rich intrusive rocks from Los Pelambres, when plotted on an Ab-An-Or normative diagram show a trondhjemitic character (Fig.2). Trace element abundances of the Los Pelambres intrusions show high Sr (306-750 ppm) and low Y (1.6-6.6 ppm), with high Sr/Y ratios (~100-300) (Fig.3). Cr (1-17 ppm), Ni (2-12 ppm) and Nb (1-10 ppm) contents of the Los Pelambres rocks are low. Chondrite-normalized rare earth element (REE) patterns of Los Pelambres rocks are strongly fractionated, with light rare earth element (LREE) enrichment and heavy REE (HREE) depletion (low Yb (0.143-0.592) and high [La_N/Yb_N] ~25-60) (Fig.3). REE patterns display a steep negative slope with an inflection at Tb, and no positive or negative Eu anomalies are recognized ([Eu/Eu*]~1). When compared to the La Gloria and Aconcagua coeval and barren magmatic rocks, the Los Pelambres porphyries are Al_2O_3 and Na_2O-enriched, together with higher Sr/Y and La/Yb ratios. These particular geochemical features reflect a deeper, high pressure (>15 kbar), and garnet-bearing magmatic source [7,8].

ADAKITIC SIGNATURE: AN ODDITY IN THE LATE MIOCENE MAGMATISM OF CENTRAL CHILE

The intrusive rocks from the Los Pelambres porphyry copper deposit display an adakitic signature, according to the criteria given in [8]. The principal differences between adakitic and "normal" calc-alkaline rocks are recorded by REE, Y and Sr. These relationships can be clearly seen in the [Sr/Y]*vs.*Y and [La_N/Yb_N]*vs.*Yb_N discrimination diagrams (Fig.3). Along the Chilean Andes (18-54ºS), adakitic volcanoes (i.e. slab melts) are documented only in the Austral Volcanic Zone (AVZ, 49-54ºS) [9], where young, hot and buoyant oceanic lithosphere (<24 Ma) is subducted under a relatively thin crust (<35 km). The Late Miocene adakitic plutons at Los Pelambres formed closely related in time and space with a changing subduction geometry. In fact, tectonic reconstructions by [10] revealed that the Juan Fernández Ridge (JFR) migrated from north to south along the Chilean margin since Early Miocene to its actual position in central Chile. At the end of the Miocene (~10-7 Ma), the JFR was subducting exactly under the Los Pelambres area, producing relevant modifications of the thermal structure of the subducted lithosphere [11], and thus providing favorable conditions for slab melting. A recent thermal model by [12] has shown that slab melting is viable under flat-slab conditions. Slab melting would occur at an early stage of flat subduction (10-7 Ma), which is consistent with the main shallowing phase of the subduction zone [11] and coeval emplacement of adakitic intrusives at Los Pelambres. In a later stage of flat subduction (6-4 Ma), the model predicts eastwards migration of adakitic magmatism until the slab cools down and the present volcanic gap is formed. Melting of newly underplated

basalts at the base of an overthickened crust has been suggested as an alternative explanation for adakitic signatures in magmatic arcs associated with older subducted crust [13]. However, the southernmost portion of the segment (32-33ºS), which includes the Los Pelambres, Aconcagua and La Gloria igneous rocks, never reached more than 35 km of crustal thickness in the Late Miocene, as documented by [4]. Under this setting, the extreme HREE depletion of the Los Pelambres magmas is an exception that can not be explained by partial melting of lower crust, which would require an unlikely crustal overthickening (> 50 km) in the Los Pelambres area in order to stabilize a garnet residue in the source.

Recently, a causal relationship between adakitic magmatism and the size of porphyry copper in northern Chile has been suggested by [14]. They proposed that Late Eocene-Early Oligocene giant porphyry copper deposits like Chuquicamata, with no clear volcanic connections, are intrinsically related to adakitic, highly oxidized, water rich intrusions. They suggested that these magmas were eventually derived from a slab source under flat subduction conditions, evolving in depth as closed systems. We see a similar pattern for the Los Pelambres porphyry copper deposit. The Los Pelambres region during the Miocene-Pliocene is characterized by flat subduction, adakitic magmatism, lack of significant coeval volcanism, and the formation of a giant porphyry copper deposit. Unlike the typical sulfur-poor calc-alkaline barren rocks from La Gloria and Aconcagua, the Los Pelambres slab-derived adakitic porphyries might have contributed with at least part of the sulfur budget of the hydrothermal system. Their inherent oxidation state favors the mineralization, since in the upper part of the system, hydrothermal copper mobility is largely controlled by oxidation state – f H_2S/f SO_2 –, in which much higher Cu solubility in oxidized fluid systems is buffered by magnetite-series porphyries. The Juan Fernandez Ridge-trench collision (and probably its subduction) at time of the ore deposit formation would has played a role maintaining a major thermal gradient in the zone, allowing the partial melting of the oceanic basaltic crust.

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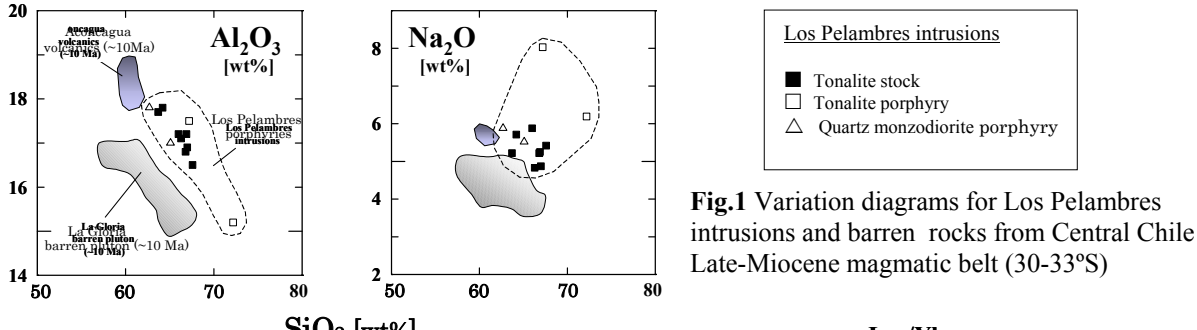

Fig.1 Variation diagrams for Los Pelambres intrusions and barren rocks from Central Chile Late-Miocene magmatic belt (30-33ºS)

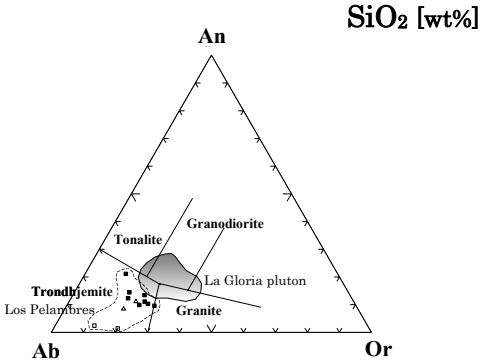

Fig.2 Ab-An-Or normative diagram for Los Pelambres rocks.

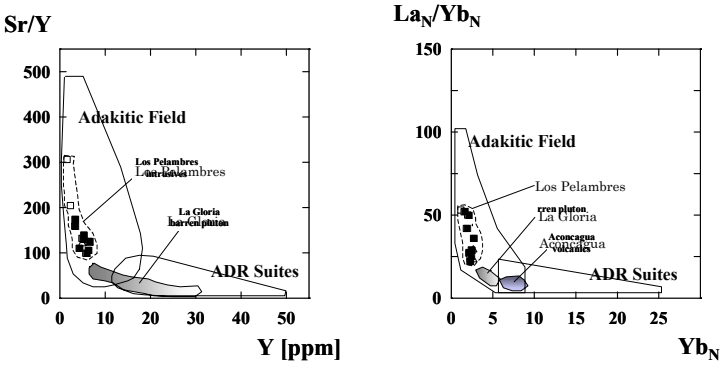

Fig.3 Sr/Y and La_N/Yb_N discrimination diagrams for adakitic rocks from Los Pelambres deposit.