MAGMA SOURCES OF MANTOS BLANCOS COPPER DEPOSIT, COASTAL RANGE OF NORTHERN CHILE

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INTRODUCTION

During the Jurassic to Early Cretaceous a subduction-related magmatic belt developed along the present Coastal Range of northern Chile, where a large volume of mafic to intermediate mantle-derived magma intruded the Palaeozoic crust or deposited as subaerial lavas (La Negra Formation) in the Chilean Coastal Cordillera (Rogers nd Hawkesworth 1989; Lucassen and Franz 1994; Pichowiak 1994). The tectonic regime in the arc was transpressional to extensional (Scheuber et al. 1994).

The Coastal Range of Northern Chile hosts numerous copper deposits, constituting a NS-trending upper Jurassic to lower Cetaceous metallogenic belt, which extends for most of 200 km (22º to 24º S) (Fig. 1). The largest mine of this belt corresponds to the Mantos Blancos ore deposit, which produces the 50% of copper of the belt. Pre-mining resources of this deposit are estimated at 500 million metric tons with 1.0 % Cu, of which 200 million tons were extracted between 1960 and 2002 (Maksaev and Zentilli, 2002). The remaining ore reserves stand at 142 million tons with 0.86 % Cu, and a resource of 156 million tons with 0.89 % Cu (Anglo Base Metals Report, May 2003). It was formed due two main hydrothermal events (Ramírez et al., 2006): the first event (~155 Ma) was related to a rhyolitic magmatism and magmatic-hydrothermal breccias and the second event (~142 Ma) was related to a dioritic and granodioritic porphyries and magmatic-hydroyhermal breccias. In spite of the importance of the Mantos Blancos copper deposit in the Coastal Range metallogenic province in northern Chile, the link between the rhyolitic and other magmatic rocks related to the hydrothermal system is poorly known. Although the Jurassic magmas were mantle-derived (Rogers and Hawkesworth 1989; Lucassen and Franz 1994; Pichowiak 1994, Lucassen et al. 2002) is not clear the nature of the felsic and intermediate magmas and their relation with the mineralization.

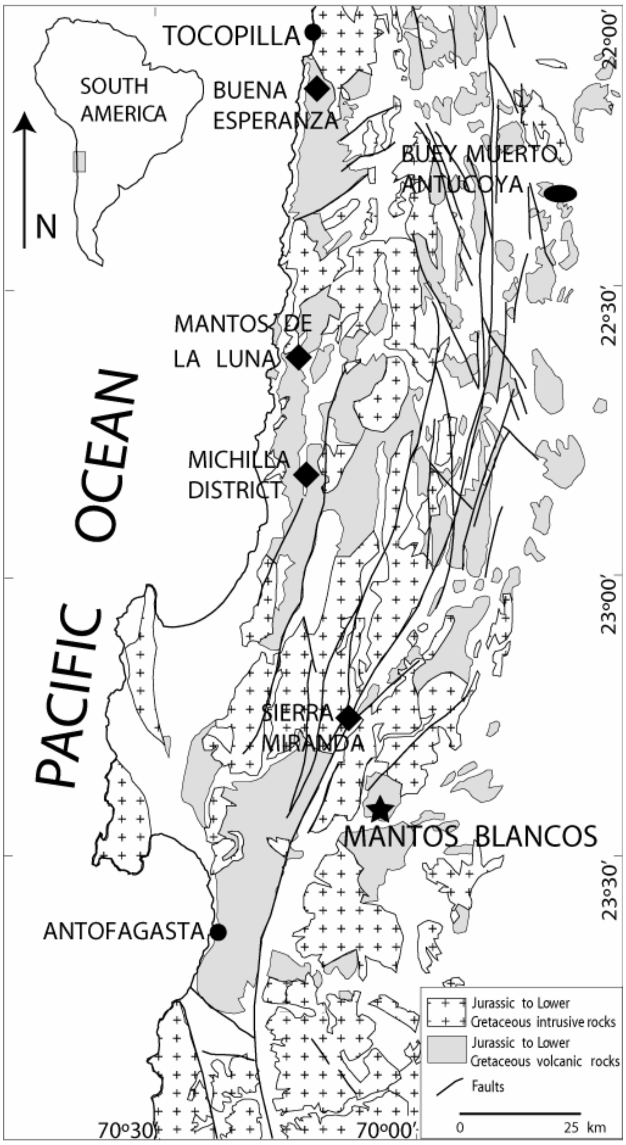

Figure 1. Geological sketch map of the Coastal Cordillera, northern Chile, and location of the Mantos Blancos district. Other copper deposit are also shown. Modified after Maksaev and Zentilli (2002).

GEOLOGY OF THE DEPOSIT

The lithological units recognized within the Mantos Blancos ore deposit consist of a rhyolitic dome and monomictic magmatic-hydrothermal breccias of the same composition, intruded by dioritic and granodioritic stocks and sills. The dioritic and granodioritic stocks locally grade upwards into polymictic magmatic-hydrothermal breccias. These rock units are all mineralized to variable degrees. Late mafic dike swarms crosscut all previously mentioned rock units and are essentially barren (Ramírez et al., 2006).

The deposit displays two overprinted hydrothermal events: (1) a phyllic alteration event related to rhyolitic dome emplacement and felsic magmatic-hydrothermal brecciation that took place at ~155 Ma, (2) a potassic - propylitic - sodic alteration event developed) at ~141-142 Ma, coeval with dioritic and granodioritic stocks and sills. This second hydrothermal event is related to the main mineralization pulse, which mainly occur disseminated or in stockwork in the polymictic hydrothermal breccias. Hypogene sulfide assemblages show a vertical and lateral zoning, within the magmatic and hydrothermal polymictic breccia bodies. A barren pyrite root zone is overlain by pyrite-chalcopyrite, and followed upwards and laterally by chalcopyrite-digenite or chalcopyrite-bornite. The assemblage digenite-supergene chalcocite characterizes the central portions of high-grade mineralization in the polymictic breccia bodies (Ramírez et al., 2006).

WHOLE ROCK CHEMISTRY

Because the widespread of the alteration the lithological nomenclature has been defined using the immobile elements classification of Floyd and Winchester, (1978). Figure 2 shows that the dioritic and granodioritic stocks and sills fall in the andesite and dacite field, respectively. Most rocks of the felsic dome have rhyolitic composition and rocks of the mafic dike swarm plot in the basaltic field.

The REE chondrite-normalized patterns for different rock-types in the Mantos Blancos district are shown in Figure 3. Rhyolites show strong fractionated LREE patterns strong negative Eu anomalies and flat HREE patterns. Two different types of granodioritic porphyries can be distinguished: GP I and GP II. The GP-I, which occur in the vicinity of the Mantos Blancos ore deposit, have concave-up REE pattern and no Eu anomaly. GP-II, which crops out along the walls of the pit, differ from GP-I in the negative Eu anomalies and in the less fractionated HREE patterns. Mineralized dioritic stocks and sills and late-mineral basalt dikes exhibit similar REE patterns characterized by a gently-dipping behavior from LREE to HREE in some cases with a small Eu depletion.

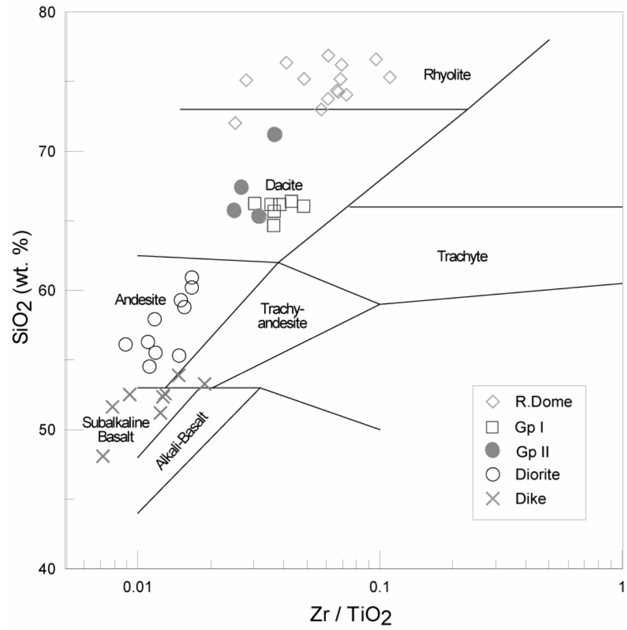

Figure 2. Inmobile element classification of Mantos Blancos mayor rocks units. After Floyd and Winchester, (1978).

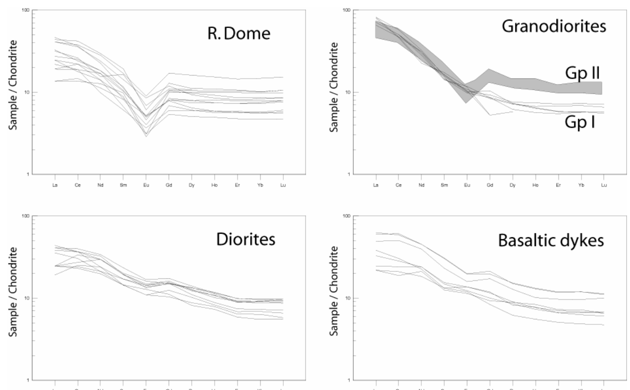

Figure 3. Chondrite normalized REE patterns of Mantos Blancos rocks units.

SR-ND ISOTOPES AND THE NATURE OF THE MAGMA SOURCES

Despite the limited number of Sr-Nd isotopic data, the analyzed samples of Mantos Blancos district (Fig. 4) show different isotopic signatures. Two samples from GP-I have low initial $^{87}Sr/^{86}Sr$ ratios (0.7036-0.7039) and εNd values close to +3.5. Unlike the mantle-dominated signature of the GP-I, the rhyolitic dome is isotopically more enriched, typical of a crustal-dominated source. A sample from the igneous matrix of the Mantos Blancos polymictic central breccia shows initial $^{87}Sr/^{86}Sr$ ratio similar to that of the rhyolitic dome, and εNd values intermediate between rhyolitic dome and GP-I. The εNd value of the central breccia is close to 0, suggesting a mixed source. The diorites (Munizaga, F. unpublished data) have also intermediate compositions between the field of La Negra Fm. and rhyolitic dome sample. No isotope data exist for the basaltic dykes in the deposit, however, a mantle isotopic signature is assumed based on the restricted isotopic compositional field within the mantle array defined by lavas from La Negra Formation and Cretaceous dikes (Lucassen et al 2002).

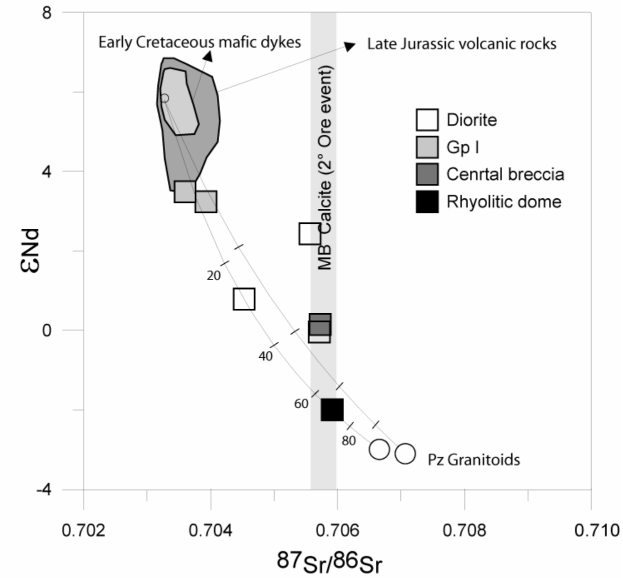

Figure 4. εNd and $^{87}Sr/^{86}Sri$ isotope data from Mantos Blancos samples, with reference data from Late Jurassic volcanic rocks and Cretaceous dikes of the Coastal Range (Rogers and Hawkesworth ,1989; Lucassen and Franz, 1994; Lucassen et al., 1999; Lucassen et al. 2002). Line represent mixing model where dots are 20% of increment. The end members of the mixing models are mafic Jurassic lavas (Rogers and Hawkesworth,1989) and Paleozic granitoids which represents the composition of the local crust (Lucassen et al., 1999). The gray vertical field represents the $^{87}Sr/^{86}Sr$ ratio of calcites from the propilitic assemblage (Tassinari et al. 1993). All values were recalculated to the original age of the rocks.

DISCUSION

Available sulfur isotope analyses in pyrite, chalcopyrite and digenite of Mantos Blancos deposit, gave $\delta^{34}S$ data between -2 and +1.2 per mil, consistent with a largely magmatic source (Ramírez et al., 2006, Sasaki et al., 1984; Vivallo and Henríquez, 1998). Additionally, carbon isotope values of -4.37 to -6.71 have been obtained in calcite veins associated with the second event of mineralization suggest a mantle-derived carbon (Ramírez et al. 2006). This mantle provenance of the hydrothermal alteration contrasts with the important crustal participation in the origin of the rhyolitic and intermediate rocks hosting the Mantos Blancos mineralization.

ORIGIN OF THE RHYOLITIC MELTS

Despite the small volume of differentiated rocks in the Mantos Blancos district, the rhyolitic dome is a distinct lithological feature within the Jurassic magmatism, strongly dominated by basic to intermediate rocks of the La Negra Formation. The enriched Sr-Nd isotopic signature of the dome, compared with the Jurassic-early Cretaceous magmatic rocks of the region, is indicative of crust-dominated source derivation. At this temperature a rhyolitic melt with near Ab-Or-Qz minimum composition would have undergone significant crystal fractionation if it was derived by fractionation of more basic parental melt. However, the shape of the REE patterns shown in figure 3, precludes hornblende participation in the magma fractionation and suggest that almost the only insoluble components of the initial melt are those of the plagioclase. It is likely, therefore that this rhyolites formed by partial melting of crustal source dominated by quartz-feldspatic rocks instead of either advanced fractionation of more primitive parental magma or partial melting of basic source equilibrated under amphibolite facies conditions.

The coeval development of mantle-derived mafic magmatism and crustal-derived felsic magmatism in the Mantos Blancos district appears to be a cause-and effect relationship, in which the heat source for the rhyolite melts generation, would be the newly injected mafic magma into the felsic crust. This scenario could be favorable for mixing between two contrasting magmas at the source region. Simple mixing models (Fig 4; Faure, 1986) are shown in figure 4, to roughly test the degree of crust and mantle involvement to reproduce the isotopic signature of rhyolitic magmas. The boundary conditions for our modeling are defined by the starting compositions we choose; one extreme composition is represented by the average composition of the La Negra Formation lavas (Rogers and Hawkesworth, 1989) and the other, by the composition of the Paleozoic granitoids of the Coastal range near Mantos Blancos (Lucassen et al., 1999). Despite the wide range of the calculated crust/mantle ratios in the source (Fig. 4), a crust-dominated source would better explain the isotopic signatures of the rhyolitic magmas.

HYDROTHERMAL FLUIDS

Many of the analyzed rocks in Mantos Blancos have similar Sr initial ratios than the ore-bearing calcite reported by Tassinari et al. (1993). According to these authors this fact suggests that isotopic equilibrium between host and the hydrothermal fluids ocurred (Fig. 4). This imply that the range of crustal assimilation given above is only an indicator, but as shown by εNd isotopes, obviously these altered rocks are more radiogenic and differs to the "normal" isotopic signature of upper Jurassic Coastal Range magmatic rocks.

However, is interesting to note the more radiogenic character of hydrothermal fluids at Mantos Blancos, compared with others Andean copper deposit, probably due to the crustal origin of some rocks in the deposit. This suggest that in the first stages of Andean evolution within an extensional setting for arc magmatism along the active margin of South America, copper deposits were form due to the interaction of mantle and crustal derived magmas.

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RESUMEN

El depósito cuprífero Mantos Blancos del Jurasico Superior, ubicado en la Cordillera de la Costa del norte de Chile, muestra dos eventos hidrotermales sobre impuestos: (1) alteración fílica relacionada al emplazamiento de un domo riolítico a los ~155 Ma, (2) alteración potásica, sódica y propilítica a los ~142 Ma, contemporánea a stocks y sills dioríticos y granodioríticos, constituye el principal evento hidrotermal. Un enjambre de diques máficos tardi-mineralización cortan todas las rocas en el depósito. Datos geoquímicos e isotópicos indican diferentes fuentes para las rocas magmáticas de Mantos Blancos. La signatura isotópica de Sr-Nd enriquecida del domo riolítico, es indicativa de una fuente cortical dominante. Estas riolitas probablemente fueron formadas por fusión parcial de una fuente dominada por rocas cuarzo-feldespáticas. Las rocas magmáticas del Jurasico Superior en la Cordillera de la Costa definen un campo composicional isotópico restringido dentro del arreglo del Manto, diferente de las rocas alteradas en el depóito mas radiogénicas, las cuales probablemente fueron re-equilibradas isotópicamente con los fluidos hidrotermales asociados a la mineralización.. Datos de campo, geocronológicos y petrográficos sugieren una mezcla de magmas dioríticos y fundidos silicios. El depósito Mantos Blancos se formo debido a la interacción de magmas derivados del manto con magmas corticales.