MAGMA SOURCES OF MAFIC DYKE SWARMS FROM CENTRAL CHILE (30º00' - 33º30' S) AND ITS RELATION WITH COEVAL MESOZOIC PLUTONISM

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1. INTRODUCTION AND GEOLOGICAL SETTING

Mesozoic mafic dyke swarms are well exposed along the Coastal Range, especially between 33º and 33º30' and in the Frontal Cordillera of the High Andes at 30º S (Elqui-Turbio Valley). These dyke swarms were emplaced in the upper crust during periods of continental extension occurred between the Late Triassic and Early Cretaceous. However, the possible genetic relationships between the tectonics and abundant Mesozoic plutonism are not clearly understood at this time. In the present work, we present new geochemical, isotopic and AMS (Anisotropy of Magnetic Susceptibility) data, with the aim to constrain source signature and location of possible reservoirs of the dyke swarms and decipher possible genetic relationships with the Mesozoic plutonism of the area.

1.1 COASTAL DYKE SWARMS

Most studied outcrops are located between 33º and 33º30' S, and occurs intruding foliated Late Paleozoic granitoids. The age of these dykes varies between 164 and 133 Ma and are nearly coeval with a prominent NW-elongated plutonic belt (Papudo-Quintero Complex, Parada et al., 1999) and volcanism (Horqueta and Lo Prado Formations). The magmatism of this age is probably related to the early stages of the "Andean Cycle" (Mpodozis and Ramos, 1989). In this area, we separate mafic dykes in three units:

Concón Dyke Swarm (CMDS): this swarm is recognized at 33ºS, near the city of Viña del Mar. This is composed of two generations (early thick dykes and late thin dykes) of NW-trending foliated basaltic dykes that intrude deformed Late Paleozoic granitoids. $^{40}Ar/^{39}Ar$ ages in hornblende constrain the emplacement of the swarm between 163 and 157 Ma (Creixell et al., submitted).

Cartagena Dyke Swarm (CrMDS): This swarm, located near 33º30' S, is petrographycally similar to the late thin dykes of the CMDS. The dykes of this unit are NW-SE to E-W basaltic dykes and intrude granitic gneisses of Paleozoic and Middle Jurassic ages and Late Triassic gneissic diorites (Hervé et al., 1988; Gana and Tosdal, 1996). An hornblende $^{40}Ar/^{39}Ar$ age of 157$\pm$2.4 Ma indicate that this swarm is coeval with the CMDS.

El Tabo Dyke Swarm (ETDS): This swarm is composed by two groups of dykes, one of NE-trending pyroxene-bearing basaltic dykes and other of NW-trending, basaltic dykes composed of brown hornblende and minor amount of clinopyroxene as mafic phases. Both dykes show mutual crosscutting relations and intrude foliated Late Paleozoic granitoids and locally Middle Jurassic gneisses. Irwin et al (1987) reported a K-Ar age in hornblende of 133.1$\pm$7.2 Ma for a dyke of this swarm. An hornblende $^{40}Ar/^{39}Ar$ spectra show two possible ages, one at ~140 Ma and a high temperature plateau at 175 Ma, the latter probably related to Ar excess by plagioclase inclusions.

1.2 ANDEAN DYKE SWARMS

Dykes that occurs in the Frontal Cordillera of Chile at 30º S, along the Elqui-Turbio Valley are assembled here in the Elqui Dyke Swarm (EDS).The EDS is composed of at least three generations of mafic dykes, where the older ones correspond to NW-trending basaltic dykes, intruded by ~E-W trending mafic dykes. The most abundant mafic dykes correspond to ~north-south trending basaltic dykes, 0.5-2 meters thick. These latter dykes intrude Late Paleozoic to Early Jurassic granitoids, but are intruded by pink felsic dykes associated to the Triassic Los Colorados granitic unit (Mpodozis and Kay, 1992, Martin et al., 1999). Additionally, some dykes are intruding the Early Jurassic Los Tilos pluton (Parada, 1988), which implies that the EDS would be a mafic magmatism associated with the protracted Early Mesozoic extensional tectonics.

2. COMPOSITIONAL FEATURES

2.1 COASTAL DYKE SWARMS

The coastal mafic dykes show a marked primitive signature in terms of major and trace elements. The low SiO_2 contents (<55 wt%) and generally high #mg (50-80) indicates that magmas were poorly differentiated and, probably, derived from mantle melts. In each coastal dyke swarm, two compositional groups can be clearly defined in terms of major, trace and rare earth elements. In Middle Jurassic dyke swarms (CMDS and CrMDS) we can recognize that early thick dykes are characterized by high TiO_2, Nb, Zr and Th and REE with respect to the late dykes. Late dykes are poorer in SiO_2 and rich in MgO (7.4 to 15.6 wt%) and Cr (82-900 ppm). In general, early and late dykes are characterized by a trace element pattern characteristic of continental basalts, including Ta-Nb depletion. In the ETDS, the same compositional separation can be made. The group of NE-trending dykes show similarities with early dykes of the Middle Jurassic swarms, with high REE, Nb, Zr, Th and low Cr and MgO and also high alkalies (around 4.7 wt%) and P_2O_5 (1.08 wt%). Both groups of dykes can be referred as a group of high-Ti basalts. The group of NW-trending dykes have a more primitive affinity, in a similar way that Middle Jurassic late dykes. These NW-trending dykes are characterized by low SiO_2, Nb, Zr and high MgO (10.2 – 14.3 wt %) and Cr (480-950 ppm). Likewise the Jurassic late dykes, these dykes can be grouped as a low-Ti basaltic dykes.In terms of Sr and Nd, isotopic composition of Middle Jurassic dykes, characterized by εNd of +2.02 and +1.29 and low $(^{87}Sr/^{86}Sr)_0$ of 0.7034 and 0.7036 (early and late dykes respectively) fall into the field defined by Middle Jurassic plutons of central Chile (Fig. 1). Isotopic composition of ETDS show notable different isotopic signatures, characterized by negative εNd (-1.59 and –1.52 for high-Ti and low-Ti dykes respectively). NW-trending dykes (low-Ti dykes) have also higher $(^{87}Sr/^{86}Sr)_0$. than the NE-trending dykes (0.7060 and 0.7036 respectively, Fig. 1). The isotopic composition of the ETDS marks a sharp break with respect to the isotopic evolution of the Mesozoic magmatic rocks of central Chile, that is characterized by a progressive more primitive signature from the Triassic to the Early Cretaceous.

2.2 ANDEAN DYKE SWARM

In the EDS, all dykes are characterized by low SiO_2 (46.5-56.9 wt %) and variable mg# (0.54-0.75). In a general view, is not possible to make a compositional separation in terms of major and trace elements as in coastal dyke swarms. Trace elements patterns are homogeneous and characterized by LILE enrichment, Nb depletion and Yb close to N-MORB (discarding effects of residual garnet in the source). REE patterns tend to be flat in all samples.Isotopic composition of EDS (Fig. 1) are relatively homogeneous in terms of $(^{87}Sr/^{86}Sr)_0$ varying between 0.7040 and 0.7050(all these ratios calculated at 220 Ma). In terms of εNd, the two samples located in the eastern part of the valley have similar values with respect to Jurassic magmatism (+2.14 and +3.01, a E-W and a N-S-trending dyke respectively), meanwhile the other two, located in western positions along the valley, have higher values (+5.18 and +5.51, both corresponding to N-S-trending dykes), comparable to those of Late Triassic gabbros of Limarí Complex and Early Cretaceous granitoids (Parada et al., 1999).

3. IS THERE A GENETIC RELATIONSHIP BETWEEN MAFIC DYKE SWARMS AND COEVAL PLUTONISM?

3.1. MAGMA FLOW PATTERNS FROM FIELD AND AMS DATA

In Middle Jurassic dyke swarms, is hard to constrain flow vectors from AMS data, because the dykes show important tectonic effects of sinistral shearing produced during the emplacement (Creixell et al., submitted). Field indicators of magma flow in the CMDS are limited to some dyke branches and in the CrMDS to mineral lineations in some chilled margins. In both cases, these features suggest magma flow coming from SE to NW. In the ETDS, field indicators are common and suggest important component of vertical magma flow in NE and NW-trending dykes. These indicators include dyke segmentations in horizontal view, dyke branches and vertical alignment of phenocrysts. AMS data on these dykes show normal magnetic fabrics nearly parallel to dyke trends, but with highly variably dip of magnetic lineation towards the SE. Magma flow estimations following the procedure of Geoffroy et al (2002) give flow vectors ascending from SE to NW, but also with variable dip. These estimations indicate a magma provenance from a different reservoir of that of the coeval plutonism.In the large vertical exposures of the EDS along the Turbio Valley (30º S), patterns of dyke segmentation are very abundant in N-S dykes, suggesting a lateral magma flow during dyke emplacement. AMS data for N-S dykes are in most cases characterized by magnetic lineation dips gently to the NNE, but with some important scattering in some dykes. Flow vector determination following the procedure of Geoffroy et al (2002) are strongly variable for these dykes, but most data suggest southward ascent magma flow vectors. For E-W trending dykes, magnetic fabrics indicates magma flow from W to E, with tendency to horizontal component of flow.

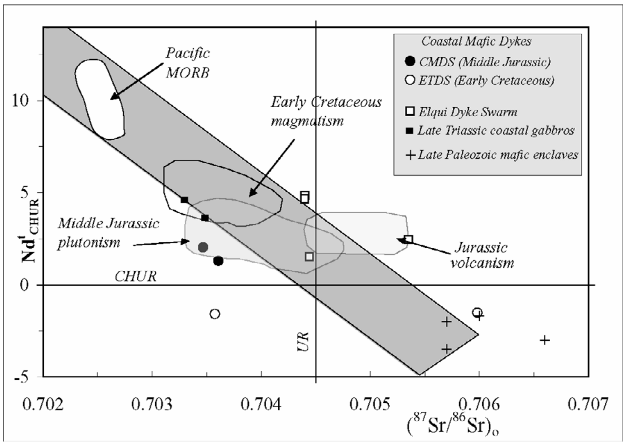

Figure 1. Sr and Nd isotopic composition of central Chile dyke swarms and related Late Paleozoic and Mesozoic magmatic units. Data on plutons (Papudo-Quintero Complex) from Parada et al (1999) and volcanic rocks from Morata et al (2001).

3.2 COMPOSITIONAL AND GENETIC RELATIONSHIPS

A clear observation in coastal dykes is that a separation between geochemically enriched and depleted (high-Ti and low-Ti dykes) basaltic dykes can be made. This feature appears to be common in mafic provinces associated to the fragmentation of Gondwana (e.g.. Storey et al., 1999). From the isotopic data, dykes and mafic enclaves hosted in calc-alkaline plutons appear to be derived both from mantelic sources, however unlike the asthenospheric-dominated source of the mafic enclaves, the dykes were derived from mixed mantle sources. In fact, the high-Ti dykes of the ETDS have a isotopic composition that resemble that of the old lithospheric mantle as seen in the Paraná Province and the Cretaceous Salta Rift in Argentina (e.g.. Lucassen et al., 2005), whereas the high and low-Ti dykes of the CMDS have asthenospheric signatures with variable input of more enriched mantle sources. Additionally, trace and REE composition of coastal dykes is clearly different from those of the mafic enclaves, because these latter are enriched with respect to low-Ti dykes and more depleted than high-Ti dykes. The same differences can be observed in terms of REE, where high-Ti dykes are more enriched rocks than mafic enclaves and low-Ti dykes. Accordingly, the mafic dykes and the coeval plutons appear to be extracted from different reservoirs. The vertical magma flow together with magma flow from SE to NW in the ETDS (parallel to the plutonic belt located further east and north) constitutes and additional evidence to discard that magmas of this swarm were extracted from the same reservoirs of the plutonism.In the EDS, the high εNd values (+1.99 to +5.85, Fig. 1) indicate that the source was dominated by asthenospheric components. Variations in εNd and positive correlations between εNd and parameters such as Th/Yb in the EDS are probably related to influence of a second and more enriched, mantelic source. The geochemical and isotopic composition of the EDS show strong similiarities with those of the mafic enclaves of the Jurassic plutonism that suggest that both are probably related to similar sources. Indeed, AMS data in some of the E-W trending dykes of the swarm indicate that probable reservoirs were located to the west, where Jurassic plutonic belt is currently located. However, in the case of the more abundant N-S dykes of the swarm, in spite of the similarity in composition with Jurassic plutonism, injection of magma from north and south is hard to relate to reservoirs associated to this plutonism. On the other hand, field relationships also indicates that at least an important part of this swarm can be Late Triassic in age.

4. ACKNOWLEDGMENTS

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RESUMEN

Enjambres de diques máficos del Jurásico Medio a Cretácico temprano ocurren en forma abundante en la Cordillera de la Costa de Chile central entre los 33º y 33º30' S, en tanto que diques máficos del Triásico Superior al Jurásico ocurren en la Cordillera Frontal (30º S). La composición química de los enjambres de diques costeros es contrastante con respecto a la de enclaves máficos contenidos en plutones contemporáneos con estos diques (Complejo Plutónico Papudo-Quintero), en tanto que la composición química de los diques andinos es similar a la de estos enclaves. La composición isotópica de Sr y Nd de los enjambres de diques costeros jurásicos cae en el campo definido por los plutones de la misma edad, pero las diferencias geoquímicas ya mencionadas descartan que diques y plutones se deriven de los mismos reservorios. Para los diques cretácicos costeros, su composición isotópica está marcada por valores negativos de εNd, lo que sugiere que éstos se derivan de fuentes mantélicas litosféricas, totalmente diferentes a lo observado en plutones mesozoicos del área. Por otra parte, las observaciones de terreno y de Anisotropía de Susceptibilidad Magnética (ASM) también descartan una relación genética con los complejos plutónicos del área. La composición isotópica de los enjambres andinos, caracterizada por elevados valores de εNd es, en parte, similar a la de los complejos plutónicos Jurásicos y Triásicos. Los datos de terreno y de ASM indican, además, que estos diques han sido inyectados desde W a E, lo cual permitiría relacionarlos con los posibles reservorios del plutonismo Jurásico.