The Abanico East Formation in the Chilean Andes (33°50's): Volcanism behind arc front in an extensional tectonic setting

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INTRODUCTION

The Andean Principal Cordillera in central Chile (33°-34°S) is mainly composed of Cenozoic volcanic and continental volcaniclastic rocks forming a N-S-trending continuous chain. These Cenozoic deposits unconformably overlie Mesozoic marine and continental units. Between 33° and 34°S, the Cenozoic deposits are known as Abanico Formation (Aguirre, 1960; Klohn, 1960) of late Eocene-early Miocene age (Charrier *et al.*, 2002) and Farellones Formation (Klohn, 1960) of Miocene age (Vergara *et al.*, 1988). The Abanico Formation displays two parallel, N-S-oriented bands, which has given origin to the informal terminology of Abanico West and Abanico East Formations (AWF and AEF, respectively). The AWF and AEF have been interpreted as deposited simultaneously along the two flanks of a volcano-tectonic intermontane basin (Vergara and Drake, 1979) or deposited in a N-S-oriented extensive and subsident intra-arc basin (Charrier *et al.*, 2002). Compared with the AWF, petrological and geochemical data of the AEF are extremely precarious, because the studies carried out in the AEF have been mainly of stratigraphic and structural nature (Baeza, 1999; Charrier *et al.*, 2002). Consequently, the understanding of the composition and origin of the volcanic rocks in AEF is still limited. This study represents a stratigraphic and petrological contribution to the knowledge of the AEF. An E-W-oriented cross-section 7 km long in the Andean Principal Cordillera in central Chile, east from Santiago and south of the Volcán River valley (33°50'S; 70°12'-70°05'W), was carried out (Fig. 1).

GEOLOGICAL SETTING AND VOLCANIC STRATIGRAPHY

The Cenozoic deposits studied are bounded to the east by the Colimapu Formation (Hauterivian-Albian) in a thrust fault contact (Bustamante, 2001). To the west, the Cenozoic deposits are bounded by the San Gabriel pluton with K/Ar ages of 10.6 ± 0.6, 11.6 ± 0.2, and 13.9 ± 1.6 Ma (Drake *et al.*, 1982), and a $^{40}Ar/^{39}Ar$ biotite plateau age of 11.4 ± 0.2 Ma (Kurtz *et al.*, 1997). Exposures of the AEF in the studied area consist of a ca. 3325 m thick series of volcanic and continental volcaniclastic rocks. Numerous dikes and sills cut this series, specially in its lower portions, increasing the estimated thikness. These subvolcanic intrusive bodies are possibly related to the magmatism that formed the lava flows from the AEF.

Rocks of the AEF can be grouped into four units on the basis of their lithologic features, that from older to younger are: Units I, II, III and IV. Unit I (1638 m thick) is made up of basaltic and andesitic lava flows with intercalations of breccias (flow breccias, lahars, detrital flows and pyroclastic deposits) and volcaniclastic rocks. These deposits indicate proximal facies to stratovolcanoes. Unit II (683 m thick) is mainly composed by andesitic ash tuffs with intercalations of volcaniclastic rocks, corresponding to proximal lacustrine facies. Unit III (664 m thick) consists of basic lava flows with intercalations of volcanic breccias (lahars, detrital flows and pyroclastic deposits) and volcaniclastic rocks. Unit IV (340 m thick) is composed by andesitic fall tuffs and lacustrine volcaniclastic rocks with intercalations of volcaniclastic breccias (pyroclastic flows) and basic lava flows. All rocks have been affected by a very low-grade non-deformative metamorphism in the prehnite-pumpellyite facies.

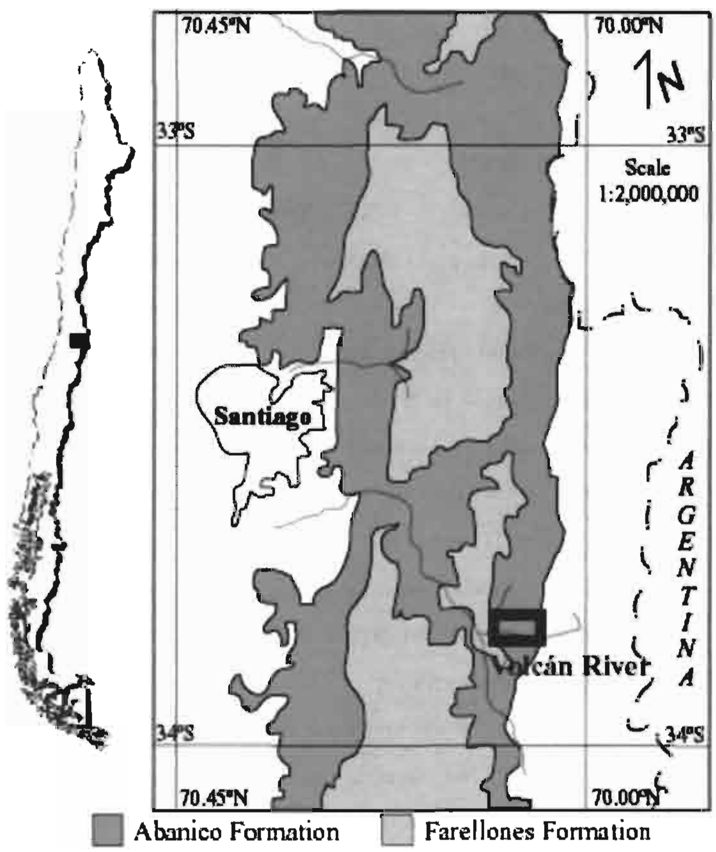

Figure 1. Location map of the studied area (black rectangle) and distribution of Cenozoic units in central Chile.

PETROGRAPHY AND MINERALOGY

The AEF is composed of three main lithologic types: basaltic-basaltic andesite lava flows, andesite-dacite flows, and volcaniclastic rocks. The first type contains phenocrysts of plagioclase, clinopyroxene, olivine pseudomorphs and Fe-Ti oxides, in a groundmass with similar mineralogy. Plagioclase phenocrysts are labradorite ($An_{70-50}Ab_{30-48}Or_{0-2}$) and clinopyroxene phenocrysts are augite and diopside ($En_{24-48}Wo_{31-47}Fs_{7-29}$). The low Ti in clinopyroxene (< 0.07 apfu) is characteristic of sub-alkaline rocks and the igneous paragenesis olivine-plagioclase-clinopyroxene-Fe-Ti oxides suggests low pressures of crystallization in basaltic magmas. Andesites and dacites are porphyritic and contain phenocrysts of plagioclase and microphenocrysts of clinopyroxene in an groundmass composed by microlites of plagioclase and Fe-Ti oxides. The sills and dikes are mainly andesites with phenocrysts of plagioclase, clinopyroxene and amphibole (pargasite).

$^{40}Ar/^{39}Ar$ AGES

Four samples of basic lava flows were analyzed using plagioclase crystals. Almost all age spectra are characterized by a saddle-shape, which is explained by both excess argon and younger K-rich alteration phases. The intermediate temperature integrated ages have been considered as representing the estimate of the maximum age of these rocks. Thus, within a 2σ error confidence interval, the maximum age for Unit I is 34.3 ± 0.4 Ma, and for Unit II, 31.8 ± 1.0 Ma. The plateau age of 21.4 ± 1.0 Ma obtained in a sample from Unit III is the best estimate for the age of the volcanism of the upper part of the AEF. Consequently, the AEF would have been emplaced between late Eocene and early Miocene.

GEOCHEMISTRY AND Sr-Nd ISOTOPES

The composition of the twenty-three volcanic rocks analyzed in this study ranges from 47 to 70% SiO_2, showing a continuity from basalts to dacites, and correspond to the sub-alkaline series. According to the K_2O content, the samples belong to a medium-K to high-K calc-alkaline series. Major and trace element variations suggest olivine, clinopyroxene and plagioclase fractionation. All samples have slightly fractionated REE patterns and abundances over 8 times chondrite, which increase with SiO_2 content. Although plagioclase is a significant fractionating phase, no pronounced negative Eu anomaly is observed. To similar HREE content, the basalts and basaltic andesites show an enrichment in LREE from Units I to III. Thus, the $(La/Yb)_N$ ratios range between 2.2 and 3.9 for Unit I, from 4.1 to 5.5 for Unit II, and is of 5.8 for Unit III. N-MORB normalized trace element plots display features considered distinctive of subduction-related magmas, and the basalts and basaltic andesites have similar HFSE patterns. Tectonic discrimination diagrams (Cabanis and Lecolle, 1989; Gorton and Schandl, 2000) suggest that the AEF magmatism was essentially calc-alkaline in a continental margin.

Six initial $^{87}Sr/^{86}Sr$ ratios and ε_{Nd} values of the analyzed samples range from 0.7035 to 0.7038 and +4.0 to +5.2, respectively. On a ε_{Nd} versus initial $^{87}Sr/^{86}Sr$ ratio diagram, all analyzed samples fall within the mantle array between the N-MORB and Central Southern Volcanic Zone (CSVZ) fields. In this same diagram, the AEF samples fall within the Farellones Formation field (Nyström *et al.*, 1993) and are more enriched in radiogenic isotopes than the AWF (Nyström *et al.*, 2003; Fuentes, 2004).

DISCUSSION AND CONCLUSIONS

Calculations of fractional crystallization of trace elements, together with trends in major and trace element variation, indicate that fractionation of plagioclase, clinopyroxene, olivine and magnetite was the most important control in the geochemical variation from basalt to dacite. Furthermore, geochemical modelling suggest that the magmas of the AEF were possibly generated by partial melting percentages around 12-18% of a spinel lherzolite source. Because the geochemical features of the AEF at 33°50'S suggest the presence of an arc during the late Eocene-early Miocene, the volcanic rocks would have been originated by partial melting of the mantle wedge followed by fractional crystallization. On the other hand, the enrichment in radiogenic isotopes and incompatible trace elements of the AEF lavas in comparison with those of the AWF, is more easily explained by crustal contamination of the parental magmas. Finally, because the AWF represents the volcanic front during the late Eocene-early Miocene (Fuentes, 2004), the AEF corresponds to another volcanic chain behind the AWF, and its higher crustal contamination would suggest a larger crustal thickness away from the trench.

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References

Aguirre, L.. 1960. Geología de los Andes de Chile Central (provincia de Aconcagua). *Instituto de Investigaciones Geológicas, Boletín*, No. 9, 70 p. [con mapa a escala 1: 100.000]. Santiago.

Baeza, O. 1999. Análisis de litofacies, evolución depositacional y análisis estructural de la Formación Abanico en el área comprendida entre los ríos Yeso y Volcán, Región Metropolitana. Unpublished Memoir Thesis, Departamento de Geología, Universidad de Chile, Santiago, 120 p.

Bustamante, M. A. 2001. Análisis del contacto Meso–Cenozoico en el valle del río Volcán, Cordillera de los Andes de la Región Metropolitana. Unpublished Memoir Thesis, Departamento de Geología, Universidad de Chile, Santiago, 54 p.

Cabanis, B., Lecolle, M. 1989. Le diagramme La/10-Y/15-Nb/8: un outil pour la discrimination des séries volcaniques et la mise en evidence des processus de melange et/ou de contamination crustale. *Compte Rendus de l'Academie des Sciences*, Vol. 2, p. 2023-2029.

Charrier, R., Baeza, O., Elgueta, S., Flynn, J. J., Gans, P., Kay, S. M., Muñoz, N., Wyss, A. R., Zurita, E. 2002. Evidence for Cenozoic extensional basin development and tectonic inversion south of the flat-slab segment, southern Central Andes, Chile (33°-36°S.L.). *Journal of South American Earth Sciences*, Vol. 15, p. 117-139.

Drake, R. E., Vergara, M., Munizaga, F., Vicente, J. C. 1982. Geochronology of Mesozoic-Cenozoic Magmatism in Central Chile, Lat. 31°-36°S. *Earth-Science Reviews*, No. 18, p. 353-363.

Fuentes, F. 2004. Petrología y metamorfismo de muy bajo grado de unidades volcánicas oligoceno-miocenas en la ladera occidental de los Andes de Chile central (33°S). PhD thesis, Departamento de Geología, Universidad de Chile, Santiago, 407 p.

Gorton, M. P., Schandl, E. S. 2000. From continents to island arcs: a geochemical index of tectonic setting for arc-related and within plate felsic to intermediate volcanic rocks. *The Canadian Mineralogist*, Vol. 38, p. 1065-1073.

Klohn, C. 1960. Geología de la Cordillera de los Andes de Chile central (provincias de Santiago, O'Higgins, Colchagua y Curicó). *Instituto de Investigaciones Geológicas, Boletín*, No. 8, 95 p. Santiago.

Kurtz, A., Kay, S. M., Charrier, R., Farrar, E. 1997. Geochronology of Miocene plutons and exhumation history of the El Teniente region, Central Chile (34°-35°S). *Revista Geológica de Chile*, Vol. 24, p. 75-90.

Nyström, J. O., Parada, M. A., Vergara, M. 1993. Sr-Nd isotope compositions of Cretaceous to Miocene volcanic rocks in Central Chile: A trend toward a MORB signature and a reversal with time. Paris ORSTOM Editions. Second International Symposium on Andean Geodynamics, Oxford, Extended Abstracts Volume, p. 411-414.

Nyström, J. O., Vergara, M., Morata, D., Levi, B. 2003. Tertiary volcanism during extension in the Andean foothills of central Chile (33°15'-33°45'S). *Geological Society of America Bulletin*, Vol. 115, p. 1523-1537.

Vergara, M., Drake, R. 1979. Edades K/Ar en secuencias volcánicas continentales postneocomianas de Chile Central; su depositación en cuencas intermontanas restringidas. *Revista de la Asociación Geológica Argentina*, Vol 34, p. 42–52.

Vergara, M., Charrier, R., Munizaga, F., Rivano, S., Sepúlveda, P., Thiele, R., Drake, R. 1988. Miocene volcanism in the central Chilean Andes (31°30'S-34°35'S). *Journal of South American Earth Sciences*, Vol. 1, p. 199-209.