Nevado de Longaví volcano (Chilean Andes, 36.2°S): The origin of adakitic magmas by fractional crystallization of amphibole-rich assemblages from water-rich parent magmas

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INTRODUCTION

Until recently, models for the formation of adakitic magmas have focused on partial melting of oceanic lithosphere in regions where young, hot slabs are subducted. Nevertheless, adakitic-like rocks also occur in continental arcs related to subduction of colder oceanic lithosphere, where they have been explained in terms of remelting of basaltic material underplated at the base of thickened orogenic crust (e.g., Petford *et al.*, 1996; Kay and Mpodozis, 2002) or as the result of modification of the sub-arc mantle related to tectonic erosion of the forearc crust (e.g. Kay *et al.*, 2004). Nevado de Longaví volcano (NLV; 36°12'S – 71°10' W) located just to the south of the region that has been strongly affected by Tertiary crustal shortening and thickening and associated eastward arc migration (Fig.1), is the only occurrence of Quaternary magmas with an unequivocal adakitic signature in the accessible part of the Andean Southern Volcanic Zone (SVZ 33-41° S). In this contribution we propose a fractional crystallization model to explain the occurrence of adakites at NLV related to highly hydrous mafic melts.

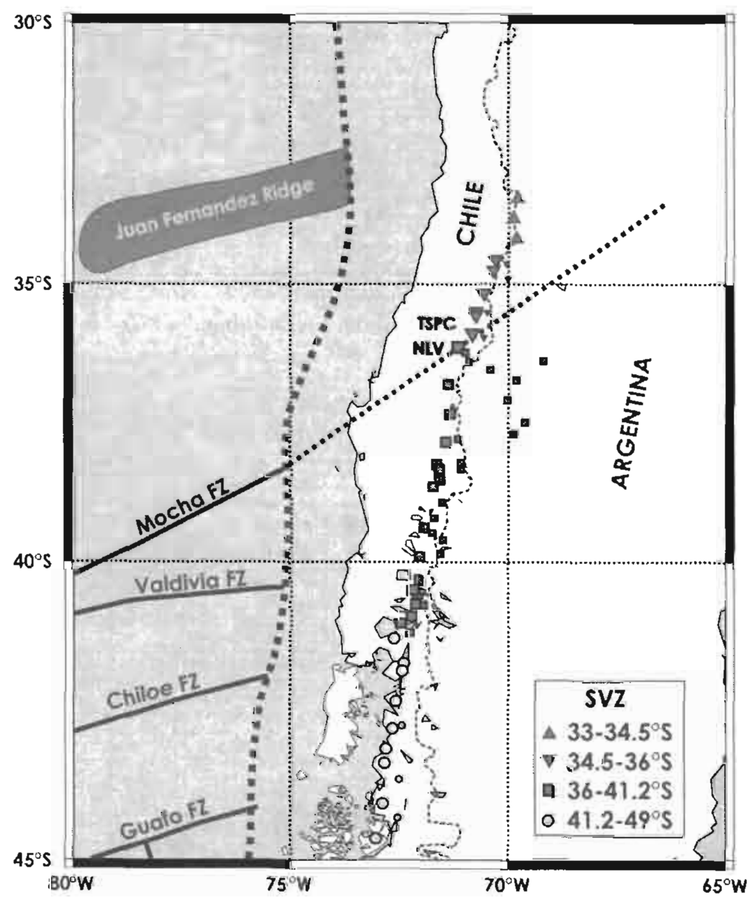

Fig. 1: Location Map. SVZ segments after Dungan *et al.*, 2001. Nevado de Longaví volcano (NLV) is located just to the south of Tatara-San Pedro complex (TSPC). Principal fracture zones (FZ) on the Nazca Plate are showed, including the corrected projection of the Mocha fracture under the continental plate.

A FRACTION CRYSTALLIZATION MODEL FROM WET MAFIC MELTS

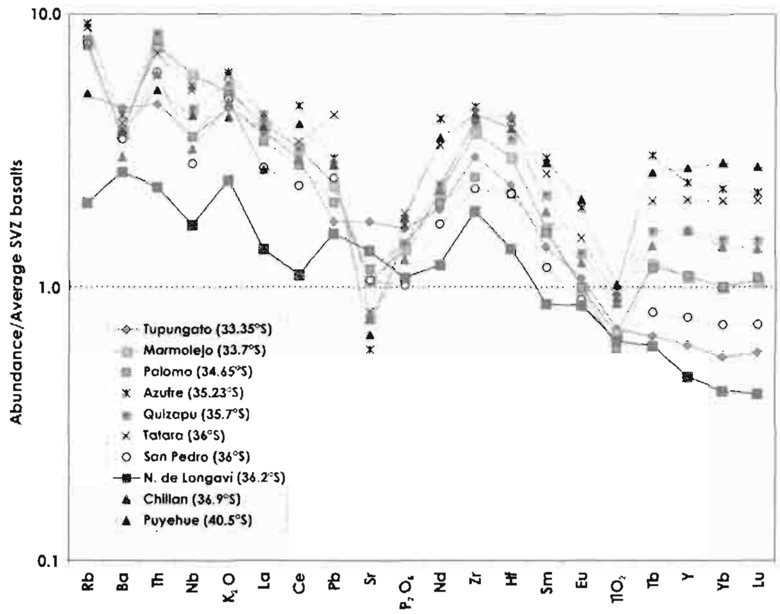

Fig.2: Multielement diagram for NLV dacites in comparison with others dacites (~64 wt % SiO_2) from the SVZ. Values normalized respect to an average for SVZ basalt. Note the impoverished character in incompatible elements of NLV dacites in comparison with the others dacites from the arc.

NLV is a mainly andesitic late Quaternary edifice whose magmatic suite progressively evolves from early basalts and basaltic andesites towards dacites by a trend characterized by a low increase rate of K_2O and other incompatible trace elements compared to the rest of SVZ volcanoes, and decreasing concentrations of Y and HREE, contrary to the observed trend for the other volcanoes in the arc. These features are most extreme in the Holocene dacitic products (63-65 wt% SiO_2) which are characterized by high Sr and low incompatible element contents (especially K, Y and HREE) (Fig.2), a mineral assemblage with amphibole as the main mafic phase, an unusually high fO_2 (NNO+1.7) and elevated water contents of 5-6 wt % H_2O (as inferred from experimental results on closely comparable Pinatubo 1991 dacite; Scaillet and Evans, 1999). On the other hand, mafic magmas preserved as enclaves on these dacites (53-56 wt % SiO_2; MgO <6 wt %) are in many respects unlike other SVZ mafic magmas. They have relatively low contents of many incompatible elements, notably Th, U, Zr, Nb, Hf and REE, in combination with high B (19-25 ppm), Be, Cs, and Li contents and high Ba/Th, Ba/Zr, Pb/Th ratios (Fig.3). These features are consistent with these mafic magmas being derived from high degrees of melting of the mantle source as a consequence of being fluxed by anomalously high amounts of slab-derived fluids. This highly wet character of enclaves is put in evidence by an amphibole rich (30 vol %) mineralogy and a notably oxidized (NNO+2) character.

The low incompatible element contents of NLV dacites are inconsistent with assimilation of upper crustal rocks as well as with fractionation of typical anhydrous pyroxene+plagioclase dominated assemblages that are proposed for the rest of the arc. Nevertheless, the similarities between adakitic dacites and mafic quenched enclaves (low incompatible element contents, oxidized, water-rich), suggest a possible cogenetic relation between them. In order to evaluate the feasibility of fractional crystallization to produce the NLV adakitic melts from the wet mafic melts, we have developed a major elements mass-balance model combined with Raleigh fractional crystallization that considers 50% fractionation of an assemblage composed of: 0.5 Hbl + 0.37 Plag + 0.07 Opx + 0.03 Aug + 0.03 Mgt + 0.7 Ap + 2 Gt (Fig.4). These models successfully reproduce the major and trace element characteristics in NLV dacites. This process is supported by abundant amphibole-bearing cumulates whose mineralogy agrees with the assemblage considered in the model (except for garnet). This combination of fractionating phases also explains the observed Y+HREE depletions in NLV andesites and dacites relative to mafic magmas, as well as minimal enrichments in elements that are incompatible relative to anhydrous silicates.

DISCUSSION

The proposed model requires high water contents in the mafic melts in order to stabilize early amphibole instead of anhydrous mafic phases and to reduce the stability field of plagioclase (*e.g.* Grove *et al.*, 2003). Highly wet melts also permit the crystallization of garnet at crustal pressures similar to those expected in the lower crust under NLV (35-40 km) (Müntener *et al.*, 2001; Ulmer *et al.* 2003). The projection of the Mocha fracture zone (Eocene-age Nazca plate) under NLV is our favored candidate to explain the occurrence of the unusually wet mafic melts at NLV (Sellés *et al.* 2004). This feature of the slab can probably contain variable serpentinized bodies that dehydrate during subduction and release large amounts of fluid to the mantle, resulting in high degrees of melting and the generation of water-rich mafic melts. This also explains the extremely local occurrence of the NLV adakites in the geodynamic context of SVZ.

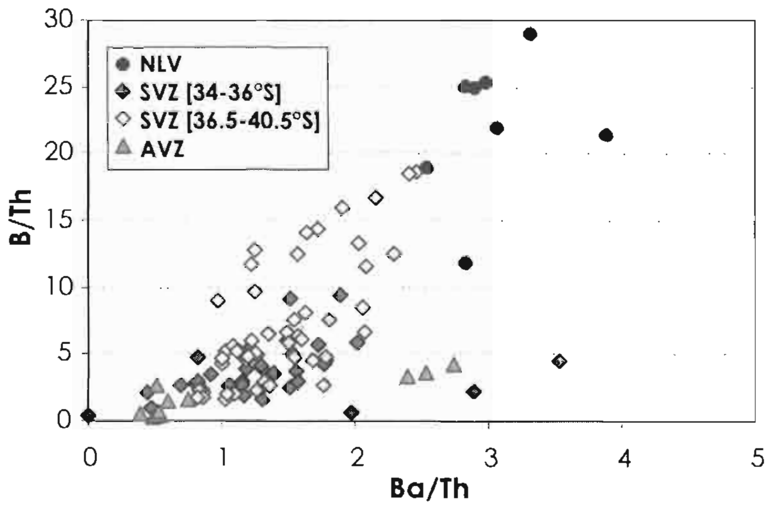

Fig.3: B/Th vs. Ba/Th diagram for NLV Holocene dacites and enclaves in comparison with samples from volcanoes to the north (SVZ [34-36°S]) and south (SVZ [36.5-40.5°S]) of NLV, and the adakites from the Austral Volcanic Zone (AVZ). NLV samples record unusually high fluid mobile elements (B and Ba) vs Th ratios in comparison with normal ranges of the arc, and also respect to the slab-derived AVZ adakites.

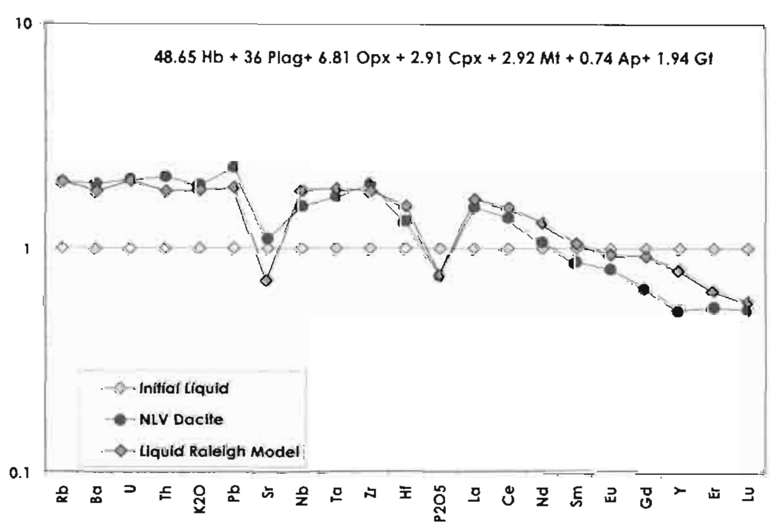

Fig.4: Multielement diagram showing the Raleigh FC model for adakitic NLV dacites considering a starting liquid with compositions similar to hydrous mafic enclaves and an mineral assemblage dominated by amphibole and plagioclase with less pyroxene, magnetite, apatite and garnet (proportions indicated at top of the figure).

We propose that adakites in cold subduction zones can alternatively be formed by fractional crystallization of amphibole-rich assemblages from hydrous mafic melts. NLV constitutes a case of study in which lack of evidence for upper crustal assimilation, hornblende-bearing cumulates throughout the volcano, increasing modal abundances of hornblende toward Holocene magmas, and the unusually incompatible element-depleted character of the melts appear to be ultimately related to an exceptionally high fluid-flux from the subducted Mocha Fracture Zone which projects beneath NLV, and which is inferred to have generated water-rich but incompatible element-poor basalts through flux-melting.

References

Dungan. M, Wulff, A. & Thompson, R. 2001. Eruptive stratigraphy of the Tatara-San Pedro complex, 36°S, Southern Volcanic Zone, Chilean Andes: Reconstruction method and implications for magma evolution at long-lived arc volcanic centers. Journal of Petrology, Vol. 42, N. 3, p. 555-626.

Grove, T.; Elkins-Tanton, L.; Parman, S.; Chatterjee, N.; Müntener, O.; Gaetani, G. 2003. Fractional crystallization and mantle-melting controls on calc-alkaline differentiation trends. Contributions to Mineralogy and Petrology, Vol. 145, No. 5, p.515-533.

Kay, S; Godoy, E.; Kurtz, A. 2004. Episodic arc migration, crustal thickening, subduction erosion, and magmatism in the south-central Andes. Geological Society of America Bulletin, p.67-88.

Kay, S.; Mpodozis, C. 2002. Magmatism as a probe to the Neogene shallowing of the Nazca plate beneath modern Chilean flat-slab. Journal of South American Earth Sciences, Vol. 15, p. 39-57.

Müentener, O.; Kelemen, P.; Grove, T. 2001. The role of H_2O during crystallization of primitive arc magmas under uppermost mantle conditions and genesis of igneous pyroxenites: an experimental study. Contributions to Mineralogy and Petrology, Vol.141, p.643-658.

Petford, N.; Atherton, M.; Halliday, A. 1996. Rapid magma production rates, underplating and remelting in the Andes: isotopic evidence from northern-central Peru (9-11°S). Journal of South American Earth Sciences, Volume 9, Issues 1-2, 3, p. 69-78.

Scaillet, B.; Evans, B. 1999. The June 15, 1991 eruption of Mount Pinatubo. I. Phase equilibria and pre-eruption of P-T-fO_2-H_2O conditions of the dacite magma. Journal of Petrology, Vol.40, p. 381-411.

Sellés, D.; Rodríguez, C.; Dungan, M.; Naranjo, J.; Gardeweg, M. 2004. Geochemistry of Nevado de Longaví volcano (36.2°S): a compositionally atypical arc volcano in the Southern Volcanic Zone of the Andes. Revista Geológica de Chile, Vol.31, No.2, p.293-315.

Ulmer, P.; Müntener, O.; Alonso-Pérez, R. 2003. Potencial role of garnet fractionation in H_2O-undersaturated andesite liquids at high pressure: an experimental study and a comparison with the Kohistan arc. Geophysical Research Abstract, Vol.5, 08308.