



XII Congreso Geológico Chileno
Santiago, 22-26 Noviembre, 2009



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S7_016

Main differentiation processes of Curacautín Ignimbrite (Llaima Volcano, Southern Chilean Andes)

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Introduction

Curacautín ignimbrite is a late glacial, basaltic to andesitic (51-59% SiO₂) deposit of Llaima volcano (Figure 1). It marks the beginning of an explosive period which extended between ~13 and ~7 ka B.P. ^[1,2]. While the internal stratigraphy of the ignimbrite has been mentioned elsewhere ^[2], this contribution focusses on compositional, mineralogical and pre-eruptive characteristics of the deposit, in order to evaluate the differentiation processes involved in the Curacautín magma.

Geochemistry

The juvenile material of Curacautín ignimbrite forms an independent evolutionary trend with respect to other Llaima deposits. This is shown by higher TiO₂, Fe₂O₃*, V, Sc and lower Al₂O₃, Cr, Ni and Sr concentrations compared to units of similar differentiation degree (Figure 2a). Major and trace element compositions of the ignimbrite products display linear trends on Harker variation diagrams, with slope changes at about 54% silica (Figure 2a). Additionally, a compositional gap exists between 54 and 56% SiO₂ which divides the Curacautín ignimbrite into a *basic* (51-54% SiO₂) and an *acid group* (56-58% SiO₂) (Figure 2b).

Mineralogy and pre-eruptive conditions

Several mineralogical characteristics indicate the importance of both fractional crystallization and magma mixing processes in the evolution of Curacautín ignimbrite. As an example, only the basic group contains plagioclase phenocrysts with An>75 while in the acid group plagioclase is more sodic (An≤61) (Figure 3a). The zoning is mainly



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normal or absent (Figure 3b). However, conspicuous inverse zoning occurs in some plagioclase phenocrysts with Na-rich cores (even more sodic than the coexisting microlites), overgrown by more calcic rims (Figure 3b), suggesting magma mixing. Similar disequilibrium features have been observed in other mineral phases (olivine, pyroxenes), but are not presented here.

The comparison of Ti and Al contents in Curacautín clinopyroxenes with experimental data from the literature ^[3-7] shows that the disequilibrium features were developed under low and isobaric conditions (Figure 4).

Simple modelling of processes

First we modelled fractional crystallization in closed system ^[8] considering a range of partition coefficients (<http://earthref.org/GERM>). Grey shaded areas in Figure 5 represent the calculated liquid compositions. The whole compositional range of Curacautín ignimbrite can be reproduced by a 2-step model. Only the Ti contents of the real daughters are higher than the predicted values.

Simple mixing tests ^[9] (Figure 6) show that mixing of a basic group component and rhyodacitic pumice from Llaima volcano describes pretty well the composition of the acid group of Curacautín ignimbrite.

Assimilation

Sr-isotopic ratios of Curacautín ignimbrite are relatively low ($^{87}\text{Sr}/^{86}\text{Sr}$: 0.703976-0.704001; $2\sigma = 1 \times 10^{-5}$) while Nd isotopic ratios are relatively high ($^{143}\text{Nd}/^{144}\text{Nd}$: 0.512868-0.512881; $2\sigma = 1 \times 10^{-5}$) and do not correlate with silica content. These radiogenic isotope ratios suggest either no assimilation of crustal rocks, or the lack of isotopic contrast between the magma and surrounding crustal rocks. $\delta^{18}\text{O}$ values of the juvenile component span a large range from 3.7 to 5.9‰ VSMOW (Figure 7a), which indicate an open-system evolution of the magma batch. Indeed, $\delta^{18}\text{O}$ values < 5.5‰ cannot reflect a pristine high-temperature magmatic signature for basaltic andesites and andesites. Both low δD and $\delta^{18}\text{O}$ could be explained by assimilation of depleted plutonic rocks (tonalite and diorite) or the selective digestion of hydrated minerals from these rocks (Figure 7b).

Conclusions

Mineral and whole-rock chemical compositions as well as modelling of fractional crystallization and magma mixing show that both processes seem to be superimposed in Curacautín ignimbrite. Fractionating magma interrupted by new basic magma input, mixed magmas which start fractionation or convective self-mixing are possible scenarios, but our tools do not allow to distinguish the specific mechanism. Assimilation of hydrothermally altered plutonic rocks (low δD and $\delta^{18}\text{O}$) would have played a minor role.



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Acknowledgement

Funding has been provided by ECOS-CONICYT Grant C01U03 and the IRD. Silke Lohmar acknowledges the support given by a MECESUP grant.

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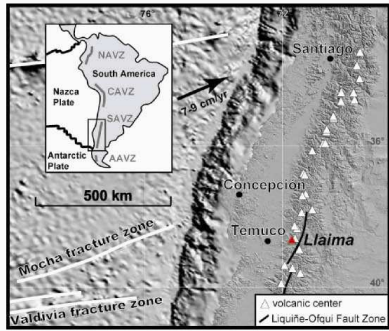


Figure 1: Location of Llaima volcano in the Southern Andean Volcanic Zone (SAVZ). Base images are shaded DEM (SRTM) and bathymetry (Etopo 2). The inset map shows the position of the SAVZ relative to the Northern, Central and Austral Andean volcanic zones (NAVZ, CAVZ and AAVZ, respectively).

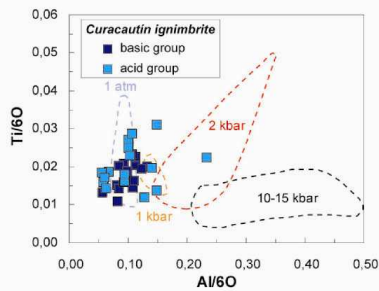


Figure 4: Ti versus Al in clinopyroxene phenocrysts of Curacautín ignimbrite. Pressure fields come from experimental data [3-7].

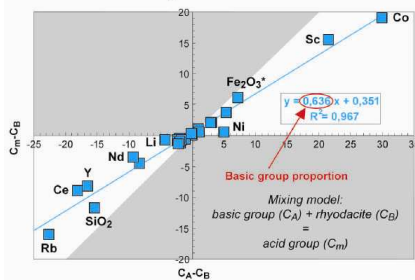


Figure 6: Simple magma mixing test [9] between the basic group of Curacautín ignimbrite and a rhyodacite to produce the acid group. The shaded area corresponds to domains where the mixing model is not verified.

Figure 7: a) $\delta^{18}O_{WR}$ versus silica content for Curacautín ignimbrite. b) δD (‰ VSMOW) versus $\delta^{18}O$ (‰ VSMOW). The compositional ranges of magmatic water and mantle rocks as well as the Meteoric Water Line (MWL) [13] and some thermal spring data from the area [14] are reported on the diagram. Biotite (bt) comes from a granite fragment and amphibole (amph) from a tonalite fragment.

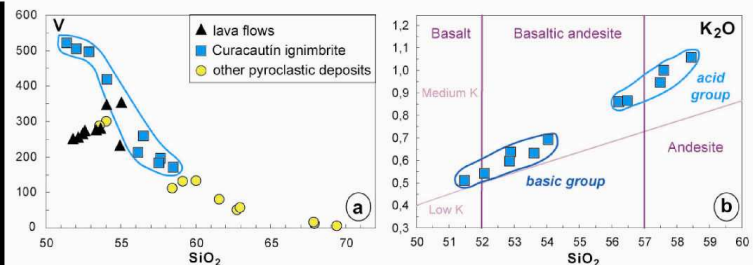


Figure 2: Selected variation diagrams (values in weight %; ppm in case of V) for Curacautín ignimbrite and other Llaima deposits. Limits in b) from [10].

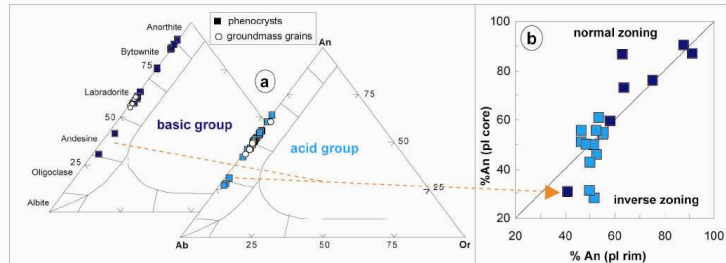


Figure 3: Plagioclase of Curacautín ignimbrite. a) compositional ranges of the basic and acid group, b) zoning of phenocrysts.

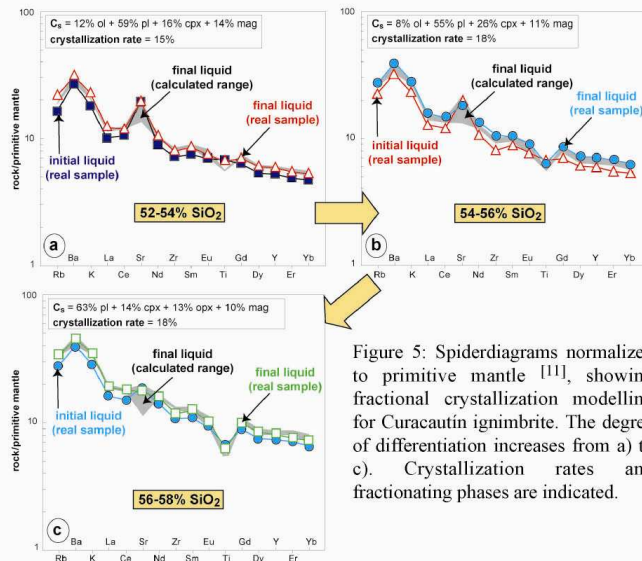


Figure 5: Spiderdiagrams normalized to primitive mantle [11], showing fractional crystallization modelling for Curacautín ignimbrite. The degree of differentiation increases from a) to c). Crystallization rates and fractionating phases are indicated.

