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# Lower crustal influence on CVZ magmas: Insights from chemical and isotopic zoning in plagioclase at Parinacota volcano, North Chile

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## INTRODUCTION

The influence of the various components (mantle wedge, lithospheric mantle, slab melt/fluids and continental crust) in the sources of arc magmatism clearly varies among arcs and is a subject of debate. The important role of lower continental crust has been shown (Hildreth and Moorbath, 1988) in the southern Andean volcanic arc. The Andean Central Volcanic Zone (CVZ) represents a portion of continental arc where the crust is the thickest, therefore the chemical and isotopic characteristics of the magmas are expected to be strongly influenced by the nature of the crust underneath the volcanic front. Several studies document this influence (Davidson et al. 1991; Wörner et al., 1994) including the existence of two different domains in the lower crust (north and south from the Pica Gap) as well as the time-relationship between a strong crustal signature and the crustal thickening (McMillan et al., 1994).

The specific lower crust signature is particularly clear in the Nevados de Payachata volcanic region, (18°S), which has been studied in detail (in particular the Holocene lavas of Parinacota Volcano). Parinacota stratigraphy includes the homogeneous Chungara Andesite, followed by Rhyolite Domes at the base of the edifice, a main Stratocone (Old cone) partially destroyed by a cone collapse and reconstructed to its' original size by the so called "Healing Flows". Whole rock compositions at Parinacota range from basaltic andesites to rhyodacites and exhibit enrichment of incompatible elements and small $^{87}Sr/^{86}Sr$ variations (0.70613±4 to 0.70702±4). Fig 1 shows variations in Sr concentrations and isotopes in the various stages.

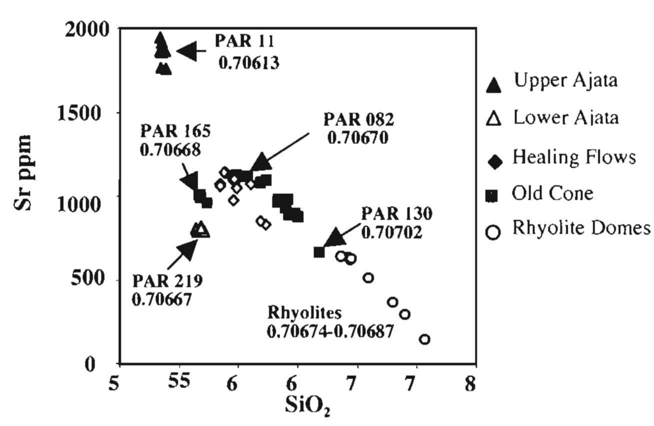


Fig. 1: Whole Rock compositions of most Parinacota samples. Samples number are representative samples used in the present study. Their $^{87}Sr/^{86}Sr$ ratios are also shown.
Modified after Wörner et al. (1988)

Although most samples show only moderately elevated Sr concentrations (900-1200ppm) similar to other volcanic centers of the northern CVZ, one unit of lava flows (Upper Ajata flow), from a recent flank eruption, have Sr content as high as 1800 ppm with a relatively low $^{87}Sr/^{86}Sr$ (0.70613), while Lower Ajata flows, erupted from the same fissure, have Sr contents similar to the other CVZ volcanic centers (800 ppm) and higher $^{87}Sr/^{86}Sr$

ratios (0.70667±4). On the basis of U-Th data Bourdon et al. (2000) suggested that magmas similar to Lower Ajata and Upper Ajata lavas mixed to form the parent magma of most Parinacota samples and they also emphasize the important role of lower crust assimilation. Magmatic processes such as magma mixing, differentiation, and assimilation of crust are recorded in chemical and isotopic zoning in phenocrysts (e.g. Davidson et al., 2005). In order to determine better the link between these two possible mafic end-members and the other Parinacota lavas, we compare chemical and isotopic zoning patterns in plagioclase phenocrysts. We then discuss the implications for other CVZ volcanic centers

## CHEMICAL AND ISOTOPIC ZONING IN PLAGIOCLASE PHENOCRYSTS

Chemical zoning of major, minor and trace elements (including Fe, Mg, Ba, Sr, Ti) was determined by electron microprobe. Whereas An content in plagioclase depends on several factors (T, water content, melt composition) minor elements depend mainly on the melt chemical composition and partition coefficient. Fe and Mg are linearly correlated with whole rock $SiO_2$ and thus reflect mainly the differentiation of the liquid by fractional crystallization. Sr (and Ba) depend not only on fractional crystallization (with distribution coefficient depending on plagioclase composition) but also on the parent magma, one of the mafic end-members having moderate Sr content (700ppm), the other one extremely high (1800 ppm). Therefore, the comparison of Fe (or Mg) with Sr gives information on the parent magma. Similarly Sr isotope ratios vary between the Ajata end-members, and also with upper crustal contamination. We analyzed $^{87}Sr/^{86}Sr$ in individual zones of these plagioclases using microdrilling and Thermal Ionisation Mass Spectrometry analysis. The chemical and isotopic zoning data show that recharge events occurred involving two distinct mafic magmas types, respectively with high and low Sr concentrations, alternating throughout the whole of the history of the volcano, with increasing frequency and accompanied by various amounts of crustal contamination.

### Ajata flows (recent flank eruptions)

The high-Sr mafic Upper Ajata lavas are aphyric and therefore regarded here as a possible mafic end-member. The Low-Sr Lower Ajata magma is almost aphyric, but contains few resorbed plagioclase xenocrysts with high Sr content (>3000 ppm). The true mafic end-member of the Lower Ajata magma is therefore more likely to be represented by the groundmass of those magmas. Microdrilling of groundmass from a Lower Ajata sample yields an $^{87}Sr/^{86}Sr$ ratio of 0.706822±24 and is thus more radiogenic than most Parinacota samples. The two likely mafic end-members for Parinacota magmas are therefore an Upper Ajata-like, high-Sr (1800 ppm), relatively unradiogenic ($^{87}Sr/^{86}Sr$ =0.7061) basaltic andesite, and a lower-Sr (700 ppm), more radiogenic (0.7068) basaltic andesite, similar to Lower Ajata groundmass.

### Old cone (pre-collapse)

Three groups of samples contrasting in terms of mineralogical assemblage, textures and zoning patterns are recognized in Old Cone samples. Two of them are shown in Fig 2.

The main group consists of andesites to dacites (e.g. PAR082). Feldspars are resorbed xenocrysts of plagioclase ($An_{20}$- $An_{45}$) or sanidine, with low Sr and and $^{87}Sr/^{86}Sr$ similar to the rhyolite dome samples. They all show extensive resorption at the rim, with a more calcic plagioclase overgrowth ($An_{50}$- $An_{60}$) with high Fe and Sr and slightly lower $^{87}Sr/^{86}Sr$ ratios. They are interpreted as the mixing of crystal-rich magmas from the Rhyolite Domes with a basaltic andesite similar in chemical composition to Upper Ajata magma but with only slightly lower $^{87}Sr/^{86}Sr$.

The second group is more homogeneous and consists of pyroxene-bearing basaltic andesites with relatively low whole rock Sr content (e.g. PAR165). Plagioclase crystals have a $An_{45}$ to $An_{58}$ core with relatively high Sr content and Fe and, after a resoption zone, a slightly An-richer rim ($An_{55}$ – $An_{68}$) with lower Sr content and higher Fe. The cores have $^{87}Sr/^{86}Sr$ as low as 0.706588 while the rims have higher $^{87}Sr/^{86}Sr$. This is interpreted as the mafic recharge of a Lower Ajata-type magma into a magma differentiated from a high-Sr magma and partly contaminated.

The third group consists of dacites with little evidence for mixing. Plagioclase crystals are oscillatory/normally zoned with decreasing Sr and Fe towards the rim. Increasing $^{87}Sr/^{86}Sr$ from 0.706682±08 to 0.706909±11 in the last 300 $\mu$m indicates concomitant fractional crystallization and crustal assimilation. However both chemical and isotopic signals at a major resorption surface indicate the influence of a slightly more mafic and less contaminated magma recharge. This sample also contains plagioclase crystals with Sr-rich cores (3000 ppm) and $^{87}Sr/^{86}Sr$ of 0.70645 probably remnant from an earlier stage.

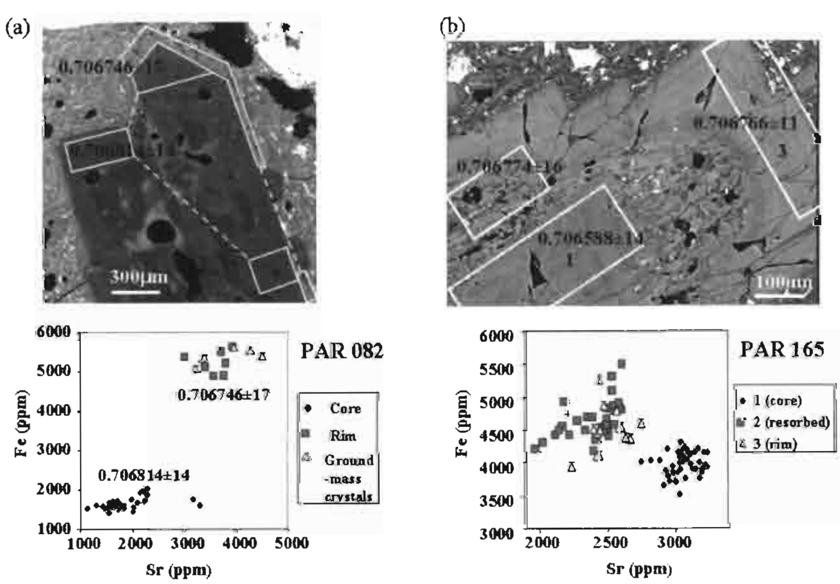


Fig. 2 : Chemical and isotopic zoning in plagioclase from two Old cone samples. Boxes indicate the location of drilled zones, and corresponding isotopic ratios are indicated. a) PAR082 shows the mixing of rhyolites with a high Sr more mafic magma.
b) In PAR165 the recharge event causing the resorption involves a magma with relatively low-Sr concentrations.

**Healing flows (postcollapse)**

The post-collapse lavas show much more evidence for mixing such as resorption surfaces or sieve textures within the crystals. Fe and Sr systematics show alternating mafic recharge with both low- and high-Sr magma within the same crystal, indicating more extensive interaction between the two end-members after the cone collapse.

## CONCLUSIONS

**Interaction between magmas and crust at Parinacota volcano.**

The influence of two distinct mafic magmas with respectively moderate and high Sr concentrations is recognized in the plagioclase zoning throughout the history of the Parinacota volcano. At the resorption surfaces where minor elements indicate a mafic magma recharge event, the $^{87}Sr/^{86}Sr$ is inversely correlated with the Sr content.

This implies that the mafic magmas interacting in the plumbing system of the volcano are distinct not only in trace elements, but also in isotopic signature, similar to the two Ajata end-members identified above. However, quantitatively, the isotopic ratios observed in high-Sr recharge events are higher that would be expected from direct mixing with the unradiogenic high-Sr mafic end-member, based on the Sr contents. This suggests some additional crustal contamination of this mafic magma before interaction with the resident magmas. No plagioclase crystal are found with $^{87}Sr/^{86}Sr$ lower than 0.7064, which suggests that the high Sr magma has undergone further crustal contamination *before* the onset of plagioclase crystallization (when the magma existed in conditions outside of plagioclase stability)

The recharge frequency increases with time, which is probably related to the dynamics of that particular volcano (including cone collapse). This leads to the recent eruption of the mafic end-members without much interaction with the upper crust associated with plagioclase crystallisation. On the other hand the Upper Ajata magma with extremely high Sr, is probably only seen because of the particular dynamics of the volcano.

**Regional implications**

The present study shows the influence of extremely high-Sr magmas in lavas with only moderately high bulk rock Sr. It is interesting to note that except the Ajatas flows, Parinacota samples lie within the highest Sr in the CVZ but are not unusual, and that the highest Sr concentrations in the CVZ are often found in relatively simple volcanic edifices and flank eruptions. A large proportion of volcanic centers in the northern CVZ (North of the Pica Gap) have Sr contents >800-900 ppm. We suggest that these volcanic centers might have also seen the influence of the extremely high Sr magma-type, presumably originated in the deep crust (where garnet rather than plagioclase is the stable aluminous phase – resulting in bulk $K_{DSr}$ ~0). These magmas were only exceptionally erupted, however their influence is recorded in plagioclase zoning.

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