Magmatic relations in the La Pacana Caldera System, Andean CVZ, North Chile

SFB 267

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Altiplano-Puna Volcanic Complex

The Altiplano-Puna Volcanic Complex (APVC, Fig. 1) is one of the largest Neogene ignimbrite provinces on Earth, and represents an episode of large-scale crustal melting in the Andean magmatic arc. The La Pacana Caldera, one of the largest and best-exposed resurgent calderas in the world, is representative of the large-volume, homogeneous magma systems typical of the APVC. The main units associated with this caldera are the Toconao Ignimbrite (500 km^3) and the Atana Ignimbrite (1,200 km^3), which have both been dated at 4 Ma. Post-eruption resurgence formed an elongate block of intracaldera tuff, along the margins of which several dacite domes were extruded (Fig. 2).

Fig. 1. Map showing the location of the APVC and the extent of ignimbrites in the CVZ.

Project goals

Previous geologic and stratigraphic studies (Gardeweg and Ramirez, 1987; deSilva, 1989a) of the La Pacana caldera provide a solid basis for our work - the first detailed petrologic and geochemical study of the ignimbrite-producing magmas. Our specific goals are to investigate:

1. the genetic relationship between eruptive units to determine the importance of fractionation, assimilation, recharge and zoning in large-volume magma chambers, and

2. magmatic pressures, temperatures and volatile contents to constrain conditions of melt generation and evolution.

La Pacana caldera-forming ignimbrites

Toconao Ignimbrite

The rhyolitic Toconao Ignimbrite is crystal poor (<10% crystals), and contains abundant glassy, crystal-poor, tubular pumices (Fig. 3) bearing plagioclase, sanidine, quartz and biotite which range in composition from 76-77 wt% SiO_2. It comprises two main facies: a lower, non-indurated facies, and an upper, vapour-phase altered indurated sillar facies (Fig. 2). In places, a thin plinian deposit is preserved at its base.

Atana Ignimbrite

The dacitic Atana Ignimbrite is crystal rich (45% crystals) and contains variable amounts of crystal-rich pumices bearing plagioclase, quartz, biotite, hornblende, magnetite and accessory ilmenite, zircon and titanite. These pumices range from 67-70 wt% SiO_2. The Atana Ignimbrite also contains rare crystal-poor pumices (76 wt% SiO_2) that lack the tubular texture of the Toconao pumices. In contrast to the Toconao Ignimbrite, the Atana Ignimbrite is relatively homogeneous, and lacks a basal plinian unit. In some localities the Atana Ignimbrite contains significant amounts of grey, crystal-rich (70% crystals), andesitic inclusions in the pumices and as individual clasts (Fig. 3). These have a similar mineral assemblage as the host pumice (but lack quartz), and range from 59-61 wt% SiO_2.

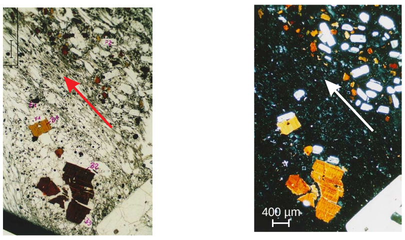

Fig. 3. Photomicrograph of a crystal rich inclusion (right of arrow) in an Atana pumice (left of arrow). Left = plane-polarized light; right = crossed nicols.

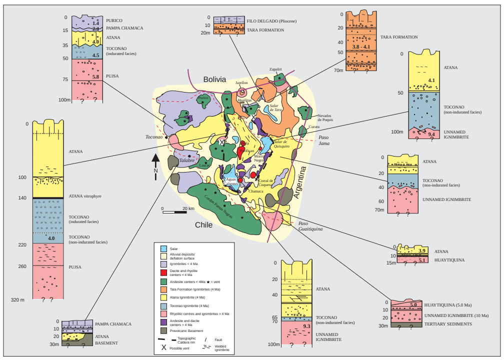

Fig. 2. Geological map and representative stratigraphic sections of ignimbrites in the La Pacana region. Where samples from particular sections have been dated, their ages are given in Ma in the section.

Pressure, temperature and magmatic water contents

Magnetite-ilmenite and hornblende-plagioclase geothermometers (Fig. 4) yield temperatures of 730°-810°C for Atana pumices. A greater range was obtained for the grey inclusions (720-870°C). Zircon-saturation thermometry yields minimum temperatures of 750°C and 770°C for the grey inclusions and Atana pumices respectively, and 720°C for Toconao pumices. Preliminary results from Al in hornblende barometry yield a range of pressures for the Atana pumices and grey inclusions of 3-5 kbar, corresponding to 10-17 km depth. SIMS analyses of melt inclusions yield water contents ranging from 3.2 to 4.6 wt%.

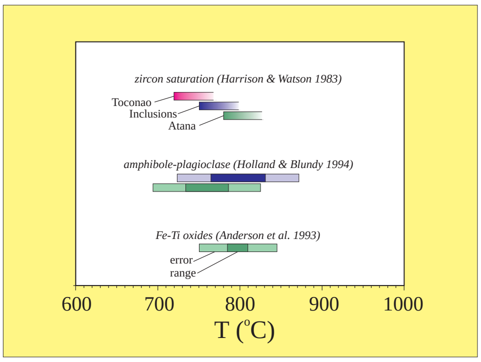

Fig. 4. Temperatures of the Atana and Toconao ignimbrites and grey inclusions derived by different geothermometers.

Toconao - Atana relationship

Age and stratigraphic relationships (Fig. 2) and whole rock compositions suggest that the Toconao Ignimbrite represents the evolved cap of the Atana magma chamber. Confirming whether these two ignimbrites are cogenetic has implications for size, shape and zonation of the magma chamber, and the nature of the eruption.

The isotopic values for Atana and Toconao pumices are indistinguishable, consistent with the hypothesis that they are cogenetic. These isotopic values are typical of crustal melts in the CVZ: εNd ranges from -8.14 to -6.56; and $^{87}Sr/^{86}Sr$ from 0.7091 to 0.7132 (Fig. 5).

Toconao pumices fail to plot on an extrapolation of the Atana pumice array on most major and trace element variation diagrams (Fig. 6). However, the fields for Atana pumice glasses and crystal-poor pumices overlap the Toconao pumice field (Fig. 6), showing that the compositional gap between the Atana and Toconao pumices may be primarily due to differences in crystal content.

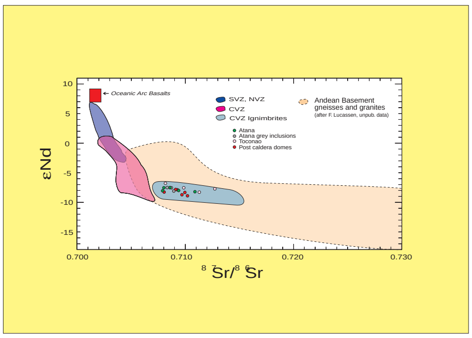

Fig. 5. Nd and Sr isotope data from the Andes. Symbols denote new data. The fields for the CVZ and SVZ+NVZ are based on literature data, and mainly represent data from stratovolcanoes.

A fractionation model

The grey, crystal-rich inclusions found in the Atana Ignimbrite have mineral compositions similar to the host pumice (e.g. pumice plagioclase cores: An_{30-60}; rims: An_{30-50}, inclusion cores: An_{35-60}, rims: An_{36-40}). Bulk compositions plot at the mafic end of the fractional crystallisation trend defined by the Atana pumice (Fig. 6), but matrix glass compositions are the same (inclusions and pumice: 76-77 wt% SiO_2). We interpret these inclusions as accumulations of early-formed crystals resulting from fractionation of magmas now represented by the host pumice, and note that similar inclusions have been recognised in other APVC ignimbrites (deSilva 1989b), where they have been interpreted in a similar way. These inclusions provide evidence for side-wall fractional crystallisation in the Atana magma chamber, and can be considered representative of an early Atana magma.

The compositional variations within and between the Toconao and Atana ignimbrites can be explained by fractional crystallisation of the observed mineral assemblages, with accessory minerals playing a greater role above about 70 wt% SiO_2. In particular, variations in REE, Zr, TiO_2 and P_2O_5 can be explained by fractionation of allanite, zircon and titanite respectively (Figs. 6 and 7).

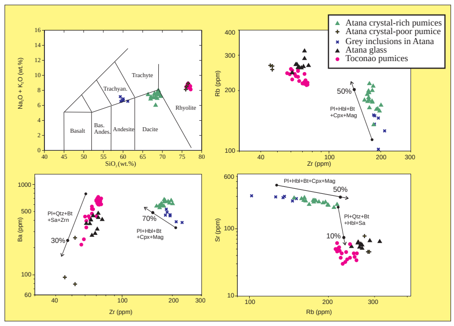

Fig. 6. TAS classification diagram and trace element variation diagrams. Arrows represent model fractionation paths of observed mineral assemblages. The gap in Zr can be explained by zircon fractionation above 70 wt% SiO_2.

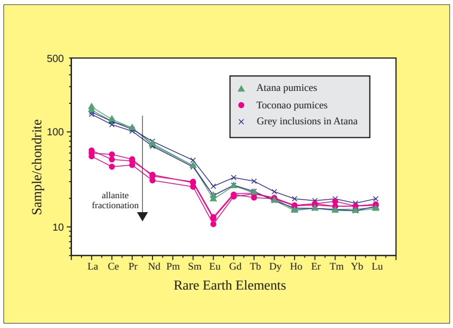

Fig. 7. REE patterns of the Toconao and Atana ignimbrites. The lower LREE concentrations in the Toconao relative to Atana pumices can be explained by allanite fractionation. Normalising values are from Anders and Grevesse (1989).

Synthesis

We propose that side-wall crystallisation in the Atana magma chamber led to the development of crystal accumulations (represented by the grey inclusions) and released a buoyant residual melt which collected at the top of the magma chamber. This was efficiently separated from the bulk of the convecting magma chamber prior to its eruption as the rhyolitic Toconao ignimbrite. This eruption was followed closely by that of the homogeneous, crystal-rich Atana ignimbrite, which formed the current caldera.

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