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Evolution of Taapaca Volcano, N. Chile: Evidence from major and trace elements, Sr-, Nd-, Pb-isotopes, age dating and chemical zoning in sanidine megacrysts

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INTRODUCTION

The Taapaca volcano in N. Chile (18°06'S, 69°30'W) forms a dacitic dome cluster with rare lava flows (Fig. 1 a-c). The basement is formed by folded Tertiary volcanic and volcaniclastic deposits and the 2,72 Ma Lauca Ignimbrite. The volcano is associated with an apron (W and N) and valley-filling (SW) black-and-ash flows resulting from frequent dome collapse. Ar-Ar ages for Taapaca rocks range from 1,27 Ma at the base to 32 ka for one of the youngest domes. Late Quaternary (<20 ka) activity is indicated by isolated deposits block-and-ash flows in a distal transverse valley, suggesting descent from the summit over glacier filled valleys.

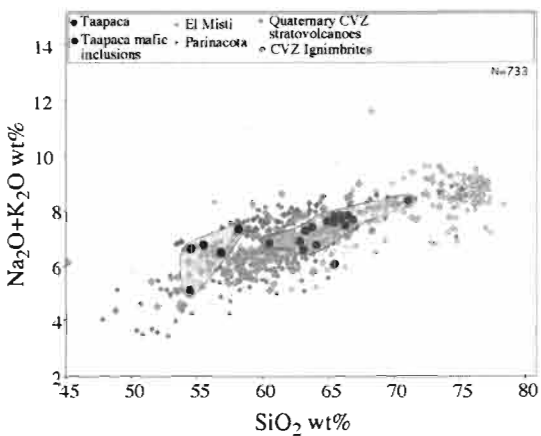

Fig. 1: Alkali-Silica - diagram showing the small range for Taapaca compositions (main cone) compared to other stratovolcanoes Parinacota and El Misti. N=733 largely unpublished data

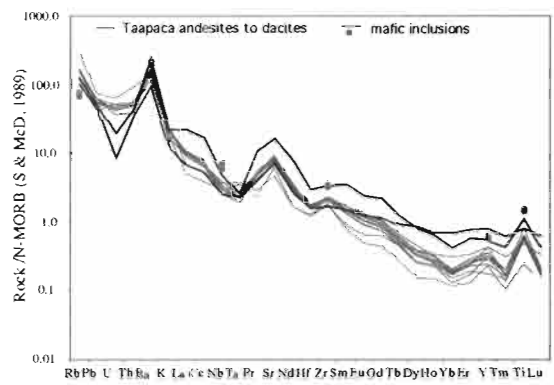

Fig. 2: Trace element distribution diagram with a weak Nb-Ta trough and strong enrichments in Ba. Mafic inclusions have less enriched patterns

Magma compositions are surprisingly uniform throughout the volcano's history (Fig. 1, 2), except one rhyolite and abundant mafic inclusions. This argues for a steady-state thermally buffered magma system at 15-20km depth (Al-in-hbl barometry, see below). Sanidine megacrysts (up to 15 cm) are frequent in some domes, their included amphiboles indicate shallower depths (5-12km) of formation compared to the host.

PROCESS AND PRESSURE OF MAGMA EVOLUTION

We used the Al-in-Hornblende barometer (Schmidt (1992) and we are well aware of the limitations and the large errors involved. Nevertheless, we found significant differences in composition between amphibole inclusions in the sanidine megacrysts and those of the host dacite magma (Fig. 3). Using O-, Sr-, Nd-, and Pb-isotope data, we modeled Recharge+Assimilation+Fractionation+ Tapping (Aitcheson & Forrest, 1994; J Pet 35:461-488) for a Taapaca dacite using a primitive island arc basalt (Nye and Reid, 1986, JGR 91 B10:10271-

10287) and average nearby Belen basement (Wörner et al., 2000, JSAES 13:717-737). The model is solved to satisfy all dacite isotope compositions for a RAFT process based on an input and assimilant compositions. The solution then allows comparison between observed and calculated trace element patterns. The successful solution predicts c.18 % crustal assimilation (=0.18) at an assimilation/fractionation rate of r=0.15. The recharge rate is rather low compared to the assimilation rate (=0,6). This is consistent with a restricted range of compositions and a long storage and evolution in a thermally buffered magma system. Note, however, that the residence times of the crystals are relatively short (see below).

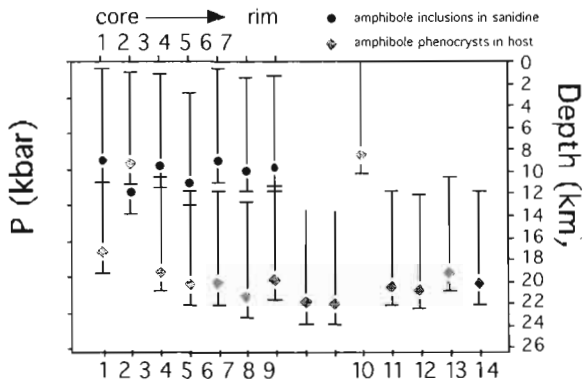

Fig. 3: Al-in-hbl barometer for amphibole inclusions in sanidine megacryst (diamonds) and host dacite (triangles) after Schmidt (1992, CMP 110:304-31)

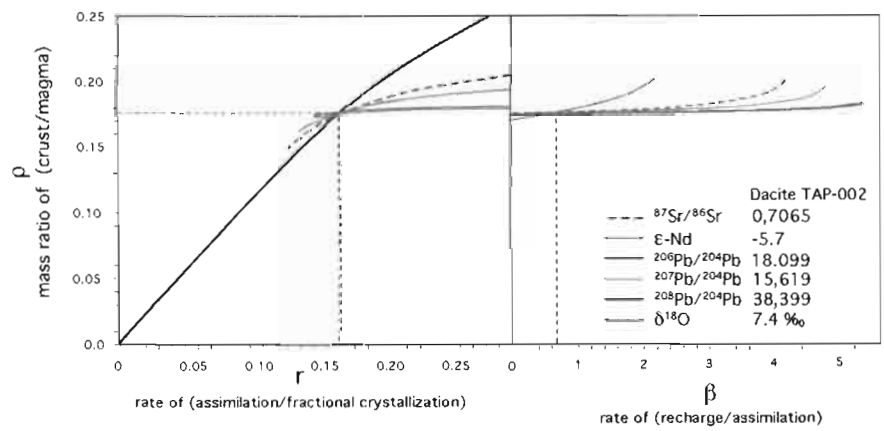

Fig. 4: Results of the RAFT model showing the convergence of parameters for a particular set of parameters. According to this solution, the amount of crustal assimilation is about 18% and the relative rate of assimilation to crystallisation is 0.16.

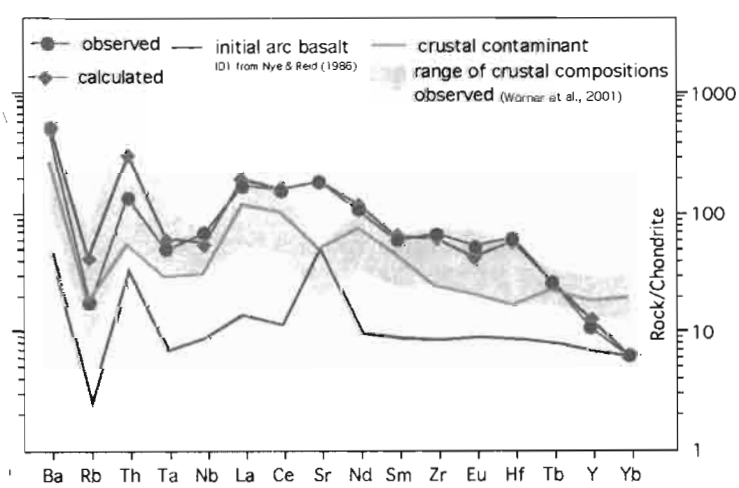

Fig. 5: The RAFT model (Fig. 4) gave good solutions in the trace element modeling for the following fractionating assemblages:
Olivine 8%, Opx 10%, Cpx18 %, garnet 30 %.

The fractionating assemblage included amphibole and garnet but little plagioclase to satisfy the strong LREE/HREE fractionation in the RAFT-process. The host dacite thus evolved during deep (>40 km) crustal assimilation (Fig. 5). Compositional and isotope data thus suggest 18% of crustal melt in the formation of the dacites (Fig. 4). Subsequent evolution took place at shallower levels (15-20 km), based on Al in Hbl barometry of host dacite amphibole phenocrysts. The sanidine megacrysts formed at still shallower depths and were taken up as xenocrysts during ascent of the dacite.

ZONATION IN SANIDINE MEGACRYSTS

20 sanidines were mapped and profiled by microprobe analysis for zonations in Ba, Ca, K, and other trace elements. Both, small and large crystals show large Ba variations with Ba-poor cores, saw-tooth-type oscillations (0.2-3.1%BaO) and high-frequency alternating zonations in the outer rim (Fig. 6, 7).

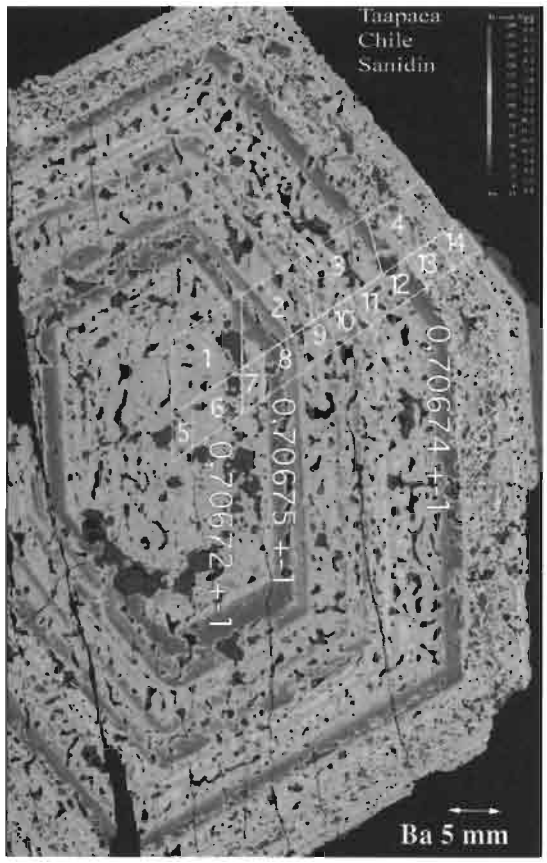

Fig. 6: Largest megacryst mapped with 87Sr/86Sr ratios in individual growth zones.

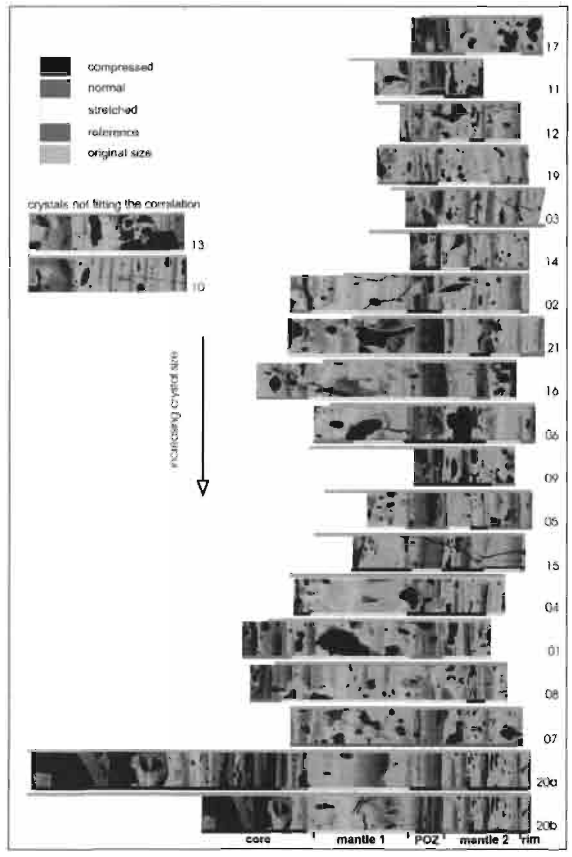

Fig. 7: Correlations of growth zones using slight manual stretching and compression to improve fit.

The sharpest compositional contrasts (Fig. 8) were selected from core to rim for high-resolution chemical profiling using quantitative microprobe measurements and X-ray profiling. These compositional steps were then modeled for diffusional smoothing to derive minimum residence times for the crystals.

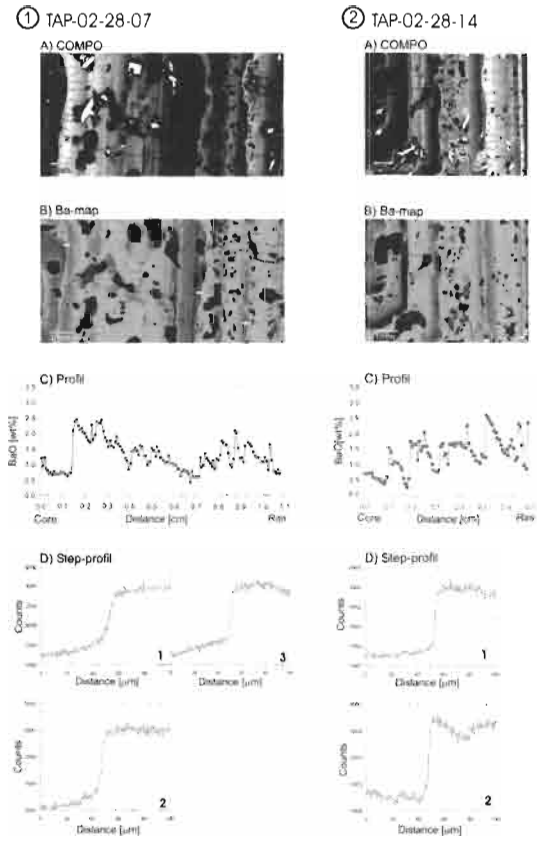

Fig. 8: Two examples of measured step-profiles. The top two images are "COMPO"_mode images of the zoned crystals. Grayscales represent Ba contents (light: high Ba, dark. low Ba). The second two samples are colored (see our poster !!) images of Ba zonation. The profiles below are based on fully quantitative electron microprobe measurements. These profiles show a "saw-tooth" zonation pattern with steep increases of Ba at resorption interfaces. The lower profiles are X-ray - scans at high spatial resolution across steep Ba compositions steps. These steps were modeled for diffusional smoothing to obtain crystal residence times.

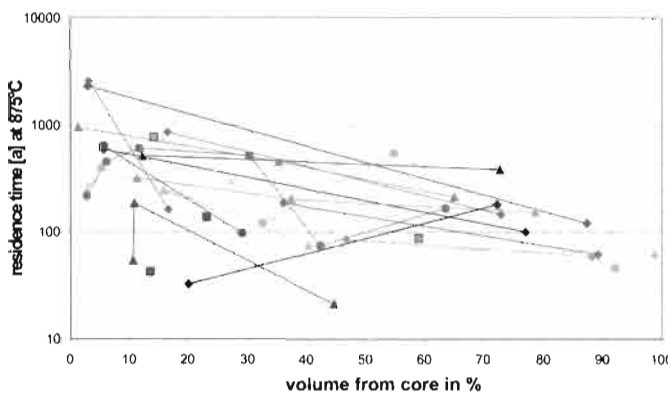

Fig. 9: Residence times derived from several compositional steps in each crystal (calculations after Morgan et al, 2004, EPSL 222: 933-946). Position is represented as calculated volume % from core. Note the generally negative correlation suggesting - as expected - shorter residence times for younger growth zones.

CONCLUSIONS

1. Isotopic and trace element compositions indicate a RAFT process at high pressures (garnet involved, > 40 km). Al-Hbl barometry indicates further storage and crystallization at shallower levels (host: 15-20 km, sanidines 5-12 km).
2. Barium element maps of sanidine megacryst allow correlation of zonation patterns. Small and large crystals have the same growth zones, indicating that large crystals grew faster than small crystals.
3. Scans across steep Ba contrasts give residence times between some thousand (core) and some few tens of years (rim) for a temperature of 845°C. Residence times are independent of crystal size.
4. Linear growth rates derived from residence time and lateral distance to the rim range between 10-9 and 10-13 cm/s for temperatures between 845°C and 915°C.