Differentiation processes in subvolcanic magma reservoirs: insights from SIMS studies of plagioclase, hornblende and glass

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In order to constrain the physico-chemical processes responsible for magma differentiation in subvolcanic calc-alkaline magma reservoirs, we have studied a suite of glass-bearing noritic xenoliths. The presence of interstitial glass and the lack of subsolidus features indicate that these are samples from a partially crystallized magma chamber. We have undertaken a detailed textural, major and trace element study of plagioclase (and hornblende) with the following goals: (1) establish the liquid-line of descent recorded by a hydrous calc-alkaline magma chamber typical of volcanic arcs; and (2) determine the physical processes that occur in partially solidified zones of magma chambers. The xenoliths were collected from a dacitic lava flow of Volcán San Pedro. This volcano is the youngest edifice of the Tatara-San Pedro Volcanic Complex, a ~55 km^3 Quaternary volcanic system located at the Southern Volcanic Zone of the Andes (36°S). This abstract presents the results of geochemical modelling based on electron and ion microprobe analyses obtained from plagioclase, hornblende and glass in two of these Ol-Hbl norite xenoliths.

Petrography, textures and mineral chemistry

The Ol-Hbl norites have ~20 MgO wt.%, and Cr and Ni contents between 1300–700 ppm and 620–450 ppm (respectively) which indicate that they are olivine+Cr-spinel cumulates. The xenoliths are characterized by minor interstitial (residual) glass and large proportions of olivine (~ 25%) and poikilitic hornblende (~25%). Olivine (Ol), orthopyroxene (Opx), hornblende (Hbl), plagioclase (Pl) and phlogopite (Phl), form a coarse-grained crystal network with high SiO_2 (~72 wt.%) vesiculated glass filling the interstices. Euhedral Pl crystals are found inside Hbl, Opx, Phl and in the matrix glass. Anhedral, resorbed, Ol and rare clinopyroxene (Cpx) are found inside Hbl, and resorbed Ol is found inside Opx. Opx, Hbl, Pl and Phl are euhedral and in contact with the interstitial glass. Moreover, skeletal crystals of Pl, biotite (Bt) and apatite (Ap) are found in the glass. From textural observations we suggest that Ol+Cpx reacted with the liquid to produce Hbl and that Ol reacted with the liquid to produce Opx.

The Ol composition ranges from Fo_{85} cores to Fo_{77} rims. The Mg# (Mg #= molar Mg/(Mg+ Fe^t as Fe^{2+}) of Cpx ranges from 84–81 and from 82–78 in Opx. The Hbl and Phl are zoned in TiO_2 and have Mg# ranging 80–72 and 81–77, respectively.

Plagioclase crystals inside Hbn and Opx are An_{85-70} and those surrounded by glass range from An_{45-20}. Some Pl crystals show a wide compositional range, with a euhedral core of An_{85-78} and a rim An_{45-26} (see Fig. 1a).

Interstitial glass has a rhyolitic composition: ~72 wt.% SiO_2, 0.15 wt.% TiO_2, 0.25 wt.% MgO, 0.3 wt.% CaO, 5 wt.% K_2O and 4 wt.% Na_2O.

Combining textural and mineralogical data the following crystallization-reaction sequence is proposed: (1) Ol+Cr-spinel+Cpx+(Pl?) (2) Hbl+ Opx+Pl+Phl+Cr-spinel+sulphides and (3) Pl+Bt +Ap. This crystallization-reaction sequence is very similar to the proposed by Grove and Donnelly-Nolan (1986) for the Hbl-gabbro inclusions of Medicine Lake volcano. Comparison with experimental data on calc-alkaline hydrous systems (e.g. Sisson and Grove, 1993) suggest H_2O contents between 3–5 wt.% and pressures <3 kbar.

Trace element concentrations in plagioclase, hornblende and glass

Core to rim electron microprobe traverses were done on more than 25 plagioclase crystals, from which eight were selected for SIMS analyses. Additionally, six SIMS analyses of Hbl and interstitial glass were also performed. Concentrations of Ti, Fe, Mg, K, Li, Rb, Ba, Sr, Y, La, Ce and Sm were calculated by normalization to the silica values obtained by electron microprobe. Plagioclase trace element concentrations from the inner to the outer part of the core, increase more or less regularly for Ti, Sr, Ba, Y, La, and Ce, with the highest relative

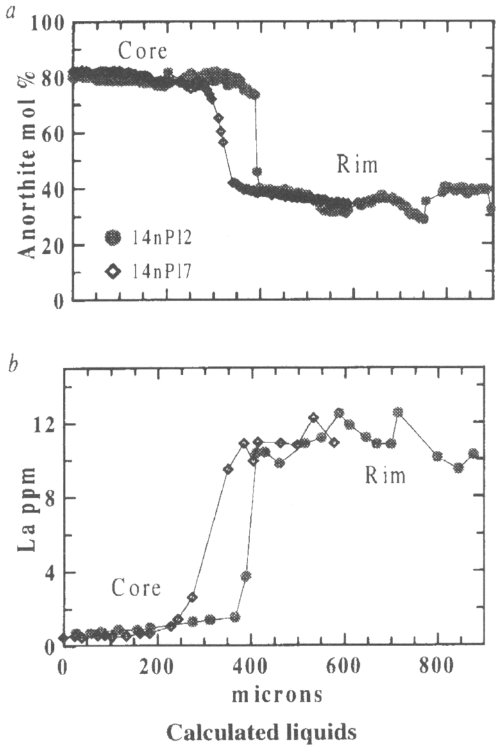

FIG. 1. Calculated liquids.

enrichments in La and Ce. Fe remains nearly constant, whereas Mg decreases. K in some crystals increases and in others decreases. Rims have higher concentrations (than cores) of K, Sr, Ba, La, Ce, and higher La/Ce and La/Y, lower Mg, Ti, Fe and Y concentrations, (see Fig. 1b).

Trace element analyses of Hbl record relatively high Y contents (up to 45 ppm) and low Ce/Y and La/Y ratios (~0.23 and ~0.12, respectively).

Glass trace element compositions are characterized by 100–140 ppm Rb, 300–450 ppm Ba, 6–10 ppm Sr, 8–9 ppm Y and very high La/Y (2–3) and Ce/Y (5) values.

Liquids in equilibrium with plagioclase were calculated using the partition coefficients of Blundy and Wood (1991) for Sr and Ba; Sato (1984) for K; and Bindeman *et al.* (in press) for Ti, Mg, La, Ce and Y. The 1-sigma precision of the partition coefficients ranges from 10 to 25 %. Plagioclase cores crystallized from a liquid with 6–2 wt.% MgO, 0.5–1 wt.% K_2O, 0.9–0.8wt.% TiO_2, 600–400 ppm Sr, 160–200 ppm Ba, 4–9 ppm La, 10–25 ppm Ce and 4–6 ppm Y. The trace element zoning recorded from the inner to the outer part of the core suggests an evolution from a basaltic andesitic to an andesitic liquid, and can be explained by 60–70 % fractional crystallization of Opx+Hbl+Pl+Phl+ Cr-spinel.

Calculated liquids in equilibrium with rims had 1–0.6 wt.% MgO, 1.5–5 wt.% K_2O, 0.1 wt.% TiO_2, 400–150 ppm Sr, 30–150 ppm Ba, ~50 ppm La, ~70–80 ppm Ce, Y <1 ppm, and very high La/Y and Ce/Y values. The trace element zoning recorded by the rims is complex, but suggests they crystallized from a dacite-rhyolite liquid and involved ~30 % fractional crystallization of Pl+Bt.

The extremely different elemental concentrations and ratios between plagioclase cores and rims precludes closed system evolution. We suggest that an event of melt migration and replacement of the interstitial liquid occurred between core and rim crystallization. According to the calculated liquid composition in equilibrium with plagioclase rims, the replacing liquid was more evolved, and probably had a composition similar to the analysed interstitial glass. In particular, the low TiO_2 concentrations and high La/Y and Ce/Y values of the glass can be readily explained as the result of large amounts the crystallization of Hbl with compositions similar to the analysed (very low Ce/Y and La/Y values).

Discussion and implications

Combining textural, major and trace element data of Pl, Hbl and glass we suggest that these partially crystallized xenoliths have recorded a complex differentiation history involving:

(1) crystallization and accumulation of Ol+Cr-spinel+Cpx from a basaltic magma

(2) extensive crystallization (60–70 %) of Hbl+Opx+Cr-spinel+Pl(cores)+Phl, from a basaltic andesite-(andesite?) magma

(3) replacement of the interstitial melt by a more evolved one. The low TiO_2 and high La/Y, Ce/Y values recorded in Pl rims and interstitial glass indicate that this melt had previously crystallized significant amounts of Hbl, and

(4) crystallization (~30 %) of Pl(rims)+Bt+Ap from a rhyolitic-(dacitic?) melt

Comparison of the proposed crystallization sequence with experimental data suggest H_2O contents between 3–5 wt.% and pressures <3 kbar, and points out the importance of Hbl crystallization for the evolution of hydrous calc-alkaline magmas. Furthermore the proposed event of melt migration through a crystal-mush system could be an important process for the differentiation of plutonic and volcanic rocks.