Origin of K-feldspar Megacrysts in Dacites from Taapaca Volcano, Chile: Cathodoluminescence Imaging and Quantitative Petrological Evidence

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Summary

K-feldspar megacrysts are common in granitoids, but rare in chemically equivalent volcanic rocks, of which the Taapaca dacites are the best known. Sanidine megacrysts up to 10 cm long occur in some of the lavas, and contain abundant chadocrysts of plagioclase, sanidine, amphibole and oxides, as well as glassy magmatic inclusion and voids. Chadocrysts are generally isolated from the host by a thin film of glass. The matrix contains abundant plagioclase crystals, as well as amphiboles and oxides. Both megacrysts and host lavas were imaged using cold-cathode cathodoluminescence. Growth of the megacrysts engulfed plagioclase, sanidine and amphibole crystals. Crystal size distributions (CSD) of sanidine megacrysts are hump-shaped. Large crystals are euhedral and small crystals are rounded. These data show that megacrysts developed from the host magma by coarsening: this was enabled by cycling of the temperature of the magma around the sanidine liquidus temperature in response to injections of more mafic magmas and subsequent magmatic overturns. Chemical zonation of the megacrysts reflects heterogeneity of the host magma and not transfer of crystals from other magmas. Plagioclase crystals enclosed in the megacrysts are small and have straight CSDs, which contrasts with the hump-shaped CSDs of plagioclase in the matrix. This shows that plagioclase was also coarsened, starting at the same time as the growth of the sanidine crystals and continuing afterwards.

Introduction

K-feldspar megacrysts occur in many granitoids and have provoked considerable interest by petrologists (Vernon, 1986, Vernon & Paterson, 2008). The mechanism by which megacrysts form would be easier to determine if they were also found in chemically equivalent volcanic rocks, but this is rarely the case. However, one well-known example of volcanic K-feldspar megacrysts is in some of the dacite lavas of Taapaca volcano, Chile (Clavero *et al.*, 2004, Zellmer & Clavero, 2006).

Taapaca volcano (also known as Nevados de Putre) is situated in the Andes of northern Chile. It has produced 35 km^3 of volcanic rocks during the last 1.5 Ma. The volcano is potentially active and last erupted about 2300 years ago (Clavero *et al.*, 2004). Taapaca has been mapped in detail (Clavero & Sparks, 2005) and the volcanology clearly described (Clavero *et al.*, 2004). A single megacryst has been described in detail and used to determine the crystallisation time of the megacrysts (Zellmer & Clavero, 2006).

The earliest rocks (T1) are silicic andesites, but the later cycles of the volcano are dominated by dacites (T2, T3, T4). All have substantial amounts of plagioclase phenocrysts, together with minor biotite and hornblende. Sanidine is generally only present as megacrysts and only in some of the volcanic products. Mafic enclaves are ubiquitous.

Petrographic data

Sanidine petrographic data

Samples were taken from unaltered parts of flows or domes, where possible. Some of the youngest domes were so high that they could not be easily sampled. In these cases the block and ash flows that issued from these domes was sampled instead, using the map of Clavero and Sparks (2005). Petrologic information was determined from scans of stained slabs and large thin sections, as well as cathodoluminescence (CL) images of polished thin sections. The modal abundance of plagioclase does not have a large range, 15-20%, as compared to that of sanidine, 0-6%. The chemical composition of the dacite samples cannot account for the range in sanidine abundance; hence it must be a feature of the crystallisation process.

The largest sanidine megacrysts are euhedral, with equal populations of simple and interpenetrating Carlsbad twinned crystals. The smallest are rounded, suggesting that they are being dissolved. However, CL images show that all crystals have complex histories of growth and solution. The only abundant phases included in the megacrysts are plagioclase and amphibole. The edges of the megacrysts are generally straight, without any extensions into the matrix, as is found in some megacrystic granites [6]. At some points there are areas where the crystal has not grown and these extend into the crystal as glass-filled patches. Such patches occur throughout the crystal, showing that the process has happened many times. In some cases this process originated when the megacryst engulfed a plagioclase crystal, or another smaller sanidine crystal (fig 1).

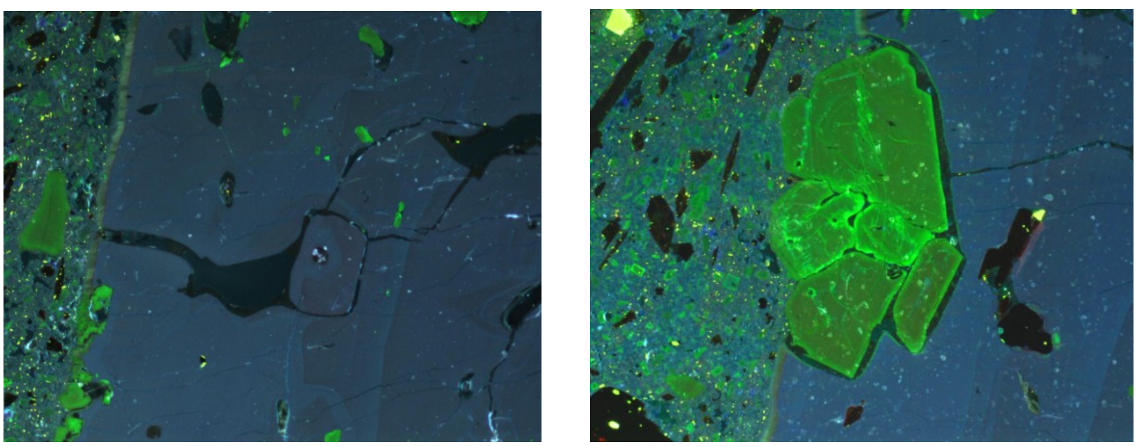

Figure 1: Cathodoluminescence images obtained with a CITL CL8200 cold cathode machine. Sanidine is blue-grey and plagioclase is green. Left: A sanidine crystal (centre) has been engulfed by the growing megacryst. A thin film of magma (glass) isolates the two. Right: A cluster of existing plagioclase crystals have been also engulfed by the growth of a megacryst. Again a thin film of magma separates the two.

The textures of the sanidine megacrysts were mostly quantified in the field, supplemented by examination of blocks and thin sections. In the field clean rock surfaces were selected with an area of at least 1 square metre. The apparent length and width of sanidine crystal intersections were measured with a ruler. All crystals larger than 10 mm long could be quantified. Large thin sections were also examined to complement field measurements. In all cases there were too few crystals (0-10) to significantly change the CSD.

All sanidine megacryst have hump-shaped CSDs (concave-down), with an absence, or low abundance, of crystals smaller than 15 mm (fig 2A). The maximum population density and largest sizes are very variable with no clear progression with time. Such CSDs are characteristic of textural coarsening (Higgins, 1999). The complex internal structure of the megacrysts shows that this happened by repeated cycles of solution and growth (Simakin & Bindeman, 2008). The presence or absence of sanidine in compositionally similar rocks is related to the minimum temperature reached during the temperature cycle. If it went below the liquidus temperature of sanidine, then sanidine would have nucleated and grown. Subsequent cycles may enlarge the size of these primocrysts or remove them.

Plagioclase petrographic data

Plagioclase is present in the megacrysts and the matrix. The presence of partly included plagioclase crystals at the edges of the megacrysts shows that these crystals were present when the megacryst formed and were not pushed aside by the growing megacryst. The crystals in the interior of the megacrysts are mostly single, but some of those towards the exterior are clusters. Hence, plagioclase crystal clustering must have started towards the end of the period of megacryst growth. In the matrix most crystal are present in clusters. Plagioclase CSDs were determined in the megacrysts and matrix (fig 2B).

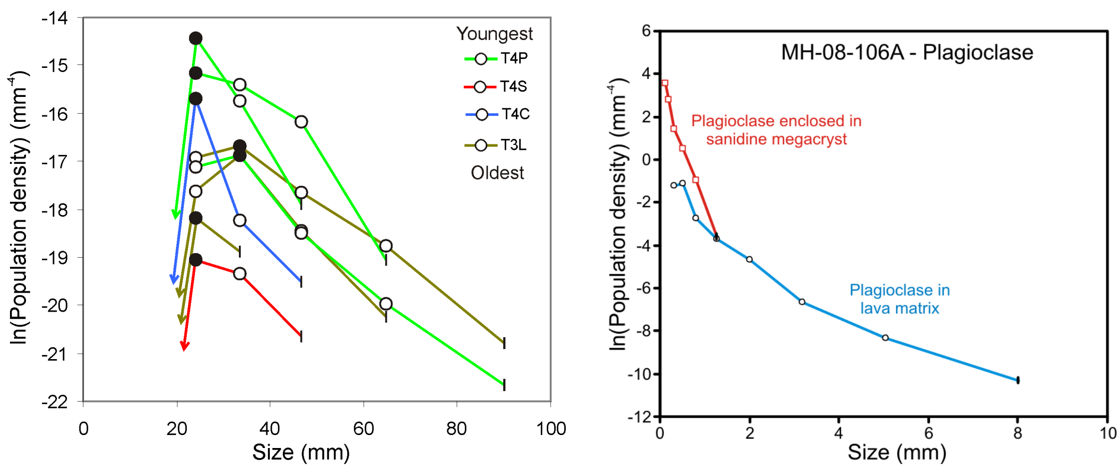

Figure 2: A) Sanidine megacryst CSDs. All crystals were measured; hence the left CSD termination is not an artefact. There is no clear progression with temporal units: T2, T3L, T4C, T4T, T4S, T4P. B) Plagioclase CSDs of chadocrysts in a sanidine megacryst and in the matrix of the rock.

The CSD of plagioclase enclosed in the sanidine megacrysts and those in the matrix of the rock are very different. The chadocrysts have a steep, straight CSD and extend out to ~1 mm. The CSDs of the matrix plagioclase are concave up to the left and extend to 8 mm. They appear to have a down-turn for small crystals. It should be noted that the larger crystals are commonly in clusters, which were counted as one crystal. If they were separated then the CSD would be greater for large crystals.

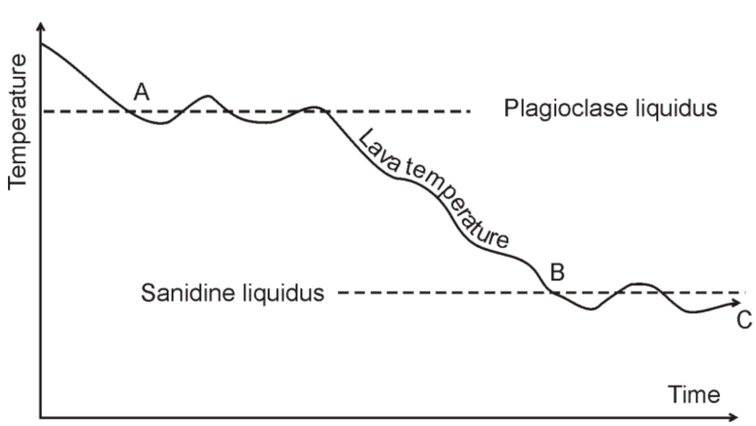

Figure 3: Cooling and crystallisation model.

The megacryst plagioclase CSD can be considered as a record of an early texture, which finally evolves into the matrix CSD. This evolution resembles that seen in plagioclase from Montserrat andesites and other rocks (Higgins & Roberge, 2003). It is clearly also produced by coarsening.

The solidification model for these laves involves overall cooling with superimposed temperature cycling (figure 3). Initially plagioclase nucleates and grows. Cooling and cycling of the temperature coarsens the plagioclase crystals. As they grow plagioclase crystals may stick together, so that subsequent growth is of the cluster as a whole. In the sanidine-free lavas the process of cooling and cycling was stopped by eruption before sanidine could nucleate. Some magma batches continued to cool until sanidine started to nucleate. Continued cooling and cycling coarsened the sanidine crystals into megacrysts.

Conclusions

The textures of the Taapaca dacites were produced by textural coarsening, probably related to reheating by injections of mafic magma into a magma chamber. Sanidine nucleated during a deeper thermal cycle and may have been preserved and grown during subsequent cycles.

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