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How late are K-feldspar megacrysts in granites?

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Abstract

Various petrologists have suggested that K-feldspar megacrysts grow in granites that are extensively crystallized, even at subsolidus conditions. However, experimental evidence indicates that, though K-feldspar nucleates relatively late in the crystallization history, abundant liquid is available for development of large crystals. A great deal of evidence, involving many different factors, favours a magmatic/phenocrystic origin for K-feldspar megacrysts in granites, namely simple twinning, oscillatory zoning, euhedral plagioclase inclusions, and concentric, crystallographically controlled arrangements of inclusions. In addition, abundant evidence has been presented of (1) mechanical accumulation of K-feldspar megacrysts in granites, (2) alignment of megacrysts and megacryst concentrations in magmatic flow foliations, (3) involvement of megacrysts in zones of magma mixing in granite plutons, and (4) occurrence of megacrysts in some volcanic rocks, implying that the megacrysts were suspended in enough liquid to be moved without fracturing or plastic deformation. Detailed trace element and isotopic data also indicate that megacrysts can move between coexisting felsic and more mafic magmas. Irregular overgrowths on megacrysts are consistent with continued magmatic growth after euhedral megacrystic growth ceased, the overgrowths being impeded by simultaneously crystallizing quartz and feldspar grains.

Keywords: Crystal accumulation; Granites; K-feldspar megacrysts; Grain shapes; Pluton; Mineral zoning

1. Introduction

This paper concerns the growth of K-feldspar megacrysts (Figs. 1 and 2) during the cooling of granite magma. Over many years, various petrologists have suggested that K-feldspar megacrysts in granites grow late in the cooling history, even at subsolidus conditions, as reviewed by Vernon (1986). More recently, Coleman et al. (2005), Johnson et al. (2006a,b) and Glazner et al. (2007) have inferred that K-feldspar megacrysts in the Cathedral Peak Granodiorite of the Tuolumne intrusive complex, Sierra Nevada batholith, California, USA, were formed very late by "textural coarsening"—later than the crystallization of the groundmass and even at subsolidus temperatures. For example, Coleman et al. (2005, p. 18) stated that the structures shown by K-feldspar in the Tuolumne Batholith "are not clearly igneous (and certainly not clearly sedimentary) and have been significantly modified by late-stage processes", and Glazner et al. (2007) asserted that physical accumulation of K-feldspar megacrysts "is precluded by crystallization of most K-feldspar after rheologic lock-up occurs." In addition, Johnson et al. (2006b) inferred that K-feldspar megacrysts are younger than the groundmass, and that they grew during prolonged cooling at subsolidus temperatures. These interpretations have prompted us to re-evaluate the evidence of K-feldspar growth timing in granitic rocks, emphasizing as many factors as possible.

2. Whole-rock chemical argument

Confirming an earlier observation made by Bateman and Chappell (1979), Coleman et al. (2005, p. 20) stated that "there is no significant change in the bulk K_2O content of the rock… going from non-phenocrystic Half Dome to porphyritic Half Dome and thence to megacrystic Cathedral Peak granodiorite; the available K_2O is concentrated in the megacrysts." They also stated that "the large K-feldspar megacrysts appear to grow at the expense of smaller crystals", referring to the process as "textural ripening."

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Fig. 1. Dispersed euhedral K-feldspar megacrysts aligned in a magmatic flow foliation in the northern Cathedral Peak pluton, Tuolumne intrusive complex, Thompson Canyon, south of Peeler Lake, Sierra Nevada, California, USA. Scale 15 cm long.

They added that "Higgins (1999) performed a crystal-size distribution study of megacrysts in the Cathedral Peak and reached similar conclusions."

However, this whole-rock chemical evidence can be explained equally well by differences in the ratios of nucleation rate to growth rate, as explained by Vernon (2004, pp. 61–63) and Paterson et al. (2005). Despite an assertion to the contrary by Higgins (1999), nucleation of K-feldspar is difficult in melts, especially for hydrous magmas, as indicated by the experiments in the system Ab–Or–H_2O of Fenn (1977). This is supported by the extremely common occurrence of simple twinning in igneous K-feldspar (e.g., Eggleton, 1979; Vernon, 1986, 1999, 2004), which evidently develops at the viable nucleation stage, owing to the very similar or identical size of both twin individuals. Twinned nuclei appear to assist growth (e.g., Baronnet, 1984), and twinned feldspar crystals have been observed experimentally to grow faster than untwined crystals (Dowty, 1980, p. 434). The formation of viable nuclei may involve "Ostwald ripening", while the particle size and diffusion distances are small enough for particle size to be controlled by surface free energy (e.g., Jackson, 1967; Martin and Doherty, 1976; Vernon, 2004, p. 52).

3. Evidence against subsolidus growth of megacrysts

The evidence against the solid-state growth hypothesis and in favour of a magmatic/phenocrystic origin for K-feldspar megacrysts in granites was evaluated in detail by Vernon (1986), and microstructural criteria for distinguishing between magmatic and solid-state growth of megacrysts have been discussed by Vernon (1986, 1990a, 1999, 2004) and Vernon and Paterson (2002). The

Fig. 2. Concentrated euhedral K-feldspar megacrysts, many of which show zonal crystallographic arrangement of inclusions, in the northern Cathedral Peak pluton, Tuolumne intrusive complex, Thompson Canyon, south of Peeler Lake, Sierra Nevada, California, USA. Scale 15 cm long.