Igneous or metamorphic? Hornblende phenocrysts as greenschist facies reaction cells in the Half Dome Granodiorite, California

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ABSTRACT

The Half Dome Granodiorite, Yosemite National Park, California, is recognized in the field by euhedral, fresh-looking, black hornblende phenocrysts up to 2 cm in length. This variety of granodiorite typifies intermediate-age hornblende-phyric units of Cretaceous nested plutonic suites in the Sierra Nevada batholith. Although only inclusions of feldspar are evident in hand samples, the phenocrysts are riddled with up to 50% inclusions of every major mineral found in the host granodiorite plus metamorphic minerals formed during cooling. Amphibole compositions within single phenocrysts vary from actinolite with less than 1 wt% $\text{Al}_2\text{O}_3$ to magnesiohornblende with over 8 wt%. Elemental zoning within the amphibole is highly irregular on the micrometer scale, showing patches and polygonal zones with dramatically different compositions separated by sharp to gradual transitions. The chemical compositions of entire phenocrysts are equivalent to hornblende plus a small proportion of biotite, suggesting that the non-biotite inclusions are the result of metamorphism of the phenocrysts. Backscattered electron imaging shows evidence of brecciation that may have been the result of volume changes as hornblende was converted to actinolite. Pressure calculations using the Al-in-hornblende geobarometer show unreasonably wide variations on the micrometer scale that cannot have been produced by temperature or pressure variations during crystallization. These hornblende phenocrysts would thus be unsuitable for geobarometry, and caution must be used to avoid similarly zoned phenocrysts in the application of the Al-in-hornblende geobarometer.

Keywords: Igneous petrology, amphibole, mineralogy, metamorphic petrology, incremental emplacement, barometry, hornblende, thermal cycling

INTRODUCTION

What are phenocrysts, and what do they signify? In both plutonic and volcanic rocks, crystals that are much larger than their surrounding matrix are generally interpreted as having grown early in a magma’s crystallization history (e.g., Harker and Marr 1891; Crosby 1900; Kelley and Branson 1947; Vernon 1986; Straub and Martin-Del Pozzo 2001). In volcanic rocks this interpretation is generally unambiguous, because volcanic rocks are cooled rapidly from the magmatic state and thus freeze in magmatic texture, and experiments can duplicate observed volcanic phase assemblages and textures (e.g., Lofgren 1980; Johnson and Rutherford 1989).

However, textural interpretation is more challenging in plutonic rocks because such rocks are not quenched but rather cool over periods of up to millions of years (Coleman et al. 2004), allowing ample time for chemical and textural modification. For example, Davis et al. (2012) found that some plutons emplaced at shallow levels in the Sierra Nevada of California took up to 10 m.y. to cool below 300 °C. This means that they could have spent millions of years at temperatures corresponding to the greenschist and amphibolite facies, and that temperature may have oscillated during cooling owing to emplacement of new increments of magma. In addition, phase equilibria studies show that some common phenocrystic phases, such as K-feldspar megacrysts that reach sizes over 10 cm (Gilbert 1906; Bateman 1961; Booth 1968), cannot be early crystallization products (Johnson and Glazner 2010; Glazner and Johnson 2013). Thus, interpretation of phenocrysts in plutonic rocks can be ambiguous.

Hornblende and biotite commonly form large (centimeter-scale), euhedral phenocrysts in granodiorites. In contrast to K-feldspar, both experimental studies and the petrography of volcanic rocks show that they can be near-liquidus phases in intermediate magmas (Pwinskii 1968; Naney and Swanson 1980; Devine et al. 1998). For such phenocrysts, unlike K-feldspar megacrysts, large size and euhedral habit are not surprising, and their textural origin has remained unquestioned.

The Half Dome Granodiorite is the middle unit of the nested Late Cretaceous Tuolumne Intrusive Suite of Yosemite National Park, California (Fig. 1; Bateman and Chappell 1979; Bateman 1992). As with most plutons, this unit was defined and mapped on the basis of its texture—primarily the presence of large, euhedral hornblende phenocrysts that can reach up to 2 cm in length (Fig. 2; Dodge et al. 1968; Coleman et al. 2005). Hornblende is a particularly important phase in plutonic rocks because it offers one of the only barometers available for igneous rocks—the Al-in-hornblende geobarometer (Hammarstrom and Zen 1986; Anderson and Smith 1995). In a plutonic rock emplaced at a given depth and then cooled, core-to-rim Al zoning should be...