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# Hornblende as a tool for assessing mineral-melt equilibrium and recognition of crystal accumulation

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## ABSTRACT

Bulk-rock compositions are commonly used as proxies for melt compositions, particularly in silicic plutonic systems. However, crystal accumulation and/or melt loss may play an important role in bulk-rock compositional variability (McCarthy and Hasty 1976; McCarthy and Groves 1979; Wiebe 1993; Wiebe et al. 2002; Collins et al. 2006; Deering and Bachmann 2010; Miller et al. 2011; Vernon and Collins 2011; Lee and Morton 2015; Lee et al. 2015; Barnes et al. 2016a; Schaen et al. 2018). Recognizing and quantifying the effects of crystal accumulation and melt loss in these silicic systems is challenging. Hornblende-melt Fe/Mg partitioning relationships and hornblende (Hbl) chemometry are used here to test for equilibrium with encompassing bulk-rock and/or glass compositions from several plutonic and volcanic systems. Furthermore, we assess the extent to which these tests can be appropriately applied to Hbl from plutonic systems by investigating whether Hbl from the long-lived (~10 Ma) Tuolumne Intrusive Complex preserves magmatic crystallization histories. On the basis of regular zoning patterns, co-variation of both fast- and slow-diffusing trace elements, Hbl thermometry, and compositional overlap with volcanic Hbl we conclude that Hbl from plutons largely preserve records supporting the preservation of a magmatic crystallization history, although many compositional analyses yield calculated temperatures <750 °C, which is unusual in volcanic Hbl.

Hornblende is only rarely in equilibrium with host plutonic bulk-rock compositions over a wide range of $SiO_2$ contents (42–78 wt%). Hornblende chemometry indicates that the majority of Hbl from the plutonic systems investigated here is in equilibrium with melts that are typically more silicic (dacitic to rhyolitic in composition) than bulk-rock compositions. These results are consistent with crystal accumulation and/or loss of silicic melts within middle- to upper-crustal plutons. Although the processes by which melts are removed from these plutonic systems is uncertain, it is evident that these melts are either redistributed in the crust (e.g., leucogranite dikes, plutonic roofs, etc.) or are instead erupted. In contrast, Hbl from volcanic rocks is more commonly in equilibrium with bulk-rock and glass compositions. In most cases, where Hbl is out of equilibrium with its host glass, the glasses are more evolved than the calculated melts indicating crystallization from a less fractionated melt and/or mixed crystal populations. Where Hbl is not in equilibrium with volcanic bulk-rocks, the bulk-rock compositions are typically more mafic than the calculated melts. In some intermediate volcanic samples, the occurrence of wide-ranges of calculated melt compositions is indicative of magma mixing. The general absence of Hbl with temperatures <750 °C from volcanic systems suggests that magmatic mushes below this temperature are unlikely to erupt. Our results indicate that bulk-rock compositions of granitic plutonic rocks only rarely approximate melt compositions and that the possibility of crystal accumulation and/or melt loss cannot be ignored. We suggest that detailed assessments of crystal accumulation and melt loss processes in magmatic systems are crucial to evaluating magma differentiation processes and discerning petrogenetic links between plutonic and volcanic systems.

**Keywords:** Hornblende, crystal accumulation, granite, rhyolite, volcano–plutonic connection