American Mineralogist, Volume 101, pages 328–342, 2016

SPECIAL COLLECTION: PERSPECTIVES ON ORIGINS AND EVOLUTION OF CRUSTAL MAGMAS

Deciphering magmatic processes in calc-alkaline plutons using trace element zoning in hornblende

Calvin G. Barnes[1,*], Valbone Memeti[2], and Nolwenn Coint[3]

[1]Department of Geosciences, Texas Tech University, Lubbock, Texas 07409-1053, U.S.A.
[2]Department of Geological Sciences, California State University, Fullerton, Fullerton, California 92834, U.S.A.
[3]Geological Survey of Norway, PO Box 6315 Sluppen, 7491 Trondheim, Norway

Abstract

Hornblende in the Kuna Crest lobe (KCL) of the Tuolumne Intrusive Complex (TIC) and the upper zone of the Wooley Creek batholith (WCB) precipitated over a temperature range of ~835 to 700 °C, and thus has the potential to record magmatic processes. We measured trace element concentrations in hornblende from the WCB, from the KCL of the TIC, and from one sample from an adjacent interior unit of the TIC to compare and contrast magmatic processes in these two mid-crustal intrusions. In both systems the magmatic amphibole is magnesiohornblende in which Ti, Zr, Hf, Nb, Sr, Ba, and rare earth elements (REE) typically decrease from crystal interiors to rims, an indication of compatible behavior of these elements, and the size of the negative Eu anomaly decreases. In the Kuna Crest lobe, hornblende from individual mapped units differs in trace element abundances and zoning trends. Some samples contain at least two distinct hornblende populations, which is particularly evident in the shapes of REE patterns. In contrast, compositions of hornblende from all structural levels of the upper WCB and related dacitic roof-zone dikes form a single broad array and the REE patterns are essentially indistinguishable, regardless of rock type, from quartz diorite to granite. In the WCB, Zr/Hf ratios in hornblende are consistent with crystallization from a melt with chondritic Zr/Hf values. In contrast, most hornblende in the KCL has Zr/Hf values lower than expected from crystallization from a melt with chondritic values, suggesting that zircon fractionation occurred before and during crystallization of the hornblende. Simple fractional crystallization models indicate that REE, high field strength elements, Sr, and Ba were compatible in KCL and WCB magmas as hornblende grew; these trends require removal of hornblende + plagioclase + zircon ± ilmenite ± biotite.

The uniform variations of trace element concentrations and patterns in the upper WCB and roof-zone dikes indicates crystallization from a large magma body that was compositionally uniform; probably stirred by convection caused by influx of mafic magmas at the base of the zone (Coint et al. 2013a, 2013b; cf. Burgisser and Bergantz 2011). In contrast, in the KCL, each analyzed sample displays distinct hornblende compositions and zoning patterns, some of which are bimodal. These features indicate that each analyzed sample represents a distinct magma and that individual magmas were variably modified by fractionation and mixing. Hornblende trace element contents and zoning patterns prove to be powerful tools for identification of magma batches and for assessing magmatic processes, and thereby relating plutonic rocks to hypabyssal and volcanic equivalents.

Keywords: Hornblende, trace element, sphene, calc-alkaline, magmatic processes