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Second boiling effects on the Al-content of hornblende rims from an exhumed Cretaceous arc pluton, Stewart Island, New Zealand

Rose E. Turnbull,[1,2,*] Chad D. Deering,[3] Andy J. Tulloch,[1] and Steve D. Weaver[2]

[1]GNS Science, Private Bag 9130, Dunedin, New Zealand
[2]Department of Geological Sciences, University of Canterbury, Private Bag 4800, New Zealand
[3]Department of Geology, University of Wisconsin Oshkosh, 800 Algoma Boulevard, 54901-8649, U.S.A.

Abstract

High-resolution transects across amphiboles from the layered mafic-felsic Halfmoon Pluton suggest that amphibole compositions in the outermost ~40 μm of grains analyzed fluctuate in response to P-T-P_{H_2O} conditions during the final stages of pluton emplacement and crystallization. Detailed transects (~10–15 μm point spacing) across 15 crystals from six representative rock types within the compositionally stratified Halfmoon Pluton revealed that in almost all crystals Al_{tot} increased over at least the outer 40 μm, coupled with a decrease in temperature and Ti-content. P-T estimates for Halfmoon Pluton amphiboles using the Al-in-hornblende geobarometer and the hornblende-plagioclase geothermometer are consistent with upper crustal emplacement depths. Amphibole Al_{tot} within the core and midsections is controlled by the temperature-dependent edenite and Ti-Tschermak exchanges, and is interpreted to reflect the influence of repeated injections of hot mafic magma into the magma reservoir during crystallization. Increases in Al_{tot} at all amphibole rims arise from a notable increase in ^{VI}Al and small increases in ^{IV}Al, indicating that, unlike the core and midsections that exhibit a strong temperature dependence, rim-Al_{tot} is a function of the pressure-dependent Al-Tschermak exchange. Pressure estimates calculated for amphibole rims record a rim-ward increase in P equivalent to between 0.2 and 1.9 kbar, which corresponds to increases in depth of crystallization of 0.7 and 6.7 km, respectively. This observed increase in pressure at the rims of all amphibole grains analyzed is not consistent with increasing lithostatic pressure as a result of pluton burial, but to an increase in P_{H_2O} in response to second boiling, a common process during late-stage crystallization of H_2O-rich intermediate-silicic magmas. The presence of water escape structures throughout the pluton, and the predominance of biotite-rich mafic enclaves that commonly contain amygdules toward the inferred top of the magmatic "stratigraphy" provide further evidence to support the process of second boiling. These results indicate that caution is required in choosing suitable analytical sites when applying the Al-in-hornblende geobarometer, particularly within plutonic bodies where there is evidence for vesiculation and water escape structures, as the outer rim compositions of amphiboles may not be a function of lithostatic pressure alone.

Keywords: Amphibole, granite, Al-in-hornblende, geobarometry, geothermometry, second boiling