Timescales and rates of intrusive and metamorphic processes determined from zircon and garnet in migmatitic granulite, Fiordland, New Zealand

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ABSTRACT

Zircon U-Pb, and garnet Sm-Nd and Lu-Hf dates provide important constraints on local and orogenic scale processes in lower-crustal rocks. However, in high-temperature metamorphic rocks these isotopic systems typically yield significant ranges reflecting both igneous and metamorphic processes. Therefore, linking dates to specific aspects of rock history can be problematic. In Fiordland, New Zealand, granulite-facies orthogneiss is cut by leucosomes that are bordered by garnet clinopyroxene reaction zones (garnet reaction zones). In both host orthogneiss and garnet reaction zones, zircon are typically anhedral with U-Pb dates ranging from 118.30 ± 0.13 to 115.70 ± 0.18 Ma (CA-ID-TIMS) and 121.4 ± 2.0 to 109.8 ± 1.8 Ma (SHRIMP-RG). Zircon dates in host and garnet reaction zone do not define distinct populations. In addition, the dates cannot be readily grouped based on external morphology or internal CL zoning. Zircon trace-element concentrations indicate two distinct crystallization trends, clearly seen in Th and U. Garnet occurs in selvages to the leucosome veins and in the adjacent garnet reaction zones. In selvages and host orthogneiss, garnet is generally 0.5 to 1 cm diameter and euhedral and is 0.1 to 0.5 cm diameter and subhedral in garnet reaction zones. Garnet Sm-Nd and Lu-Hf dates range from ca. 115 to 101 Ma (including uncertainties) and correlate with grain size. We interpret the CA-ID-TIMS zircon dates to record the age of magma emplacement and the SHRIMP-RG dates to record a range from igneous crystallization to metamorphic dissolution and reprecipitation and/or local Pb loss. Zircon compositional trends within the garnet reaction zone and host are compatible with locally isolated melt and/or separate intrusive magma batches for the two samples described here. Dates for the largest, ~1 cm, garnet of ~113 Ma record growth during metamorphism, while the smaller grains with younger dates reflect high-temperature intracrystalline diffusion and isotopic closure during cooling. The comprehensive geochronological data set for a single location in the Malaspina Pluton illustrates a complex and protracted geologic history common in granulite facies rocks, estimates lower crustal cooling rates of ~20 °C/m.y., and underlines the importance of multiple chronometers and careful textural characterization for assigning meaningful ages to lower-crustal rocks. Numerous data sets from single locations, like the one described here, are needed to evaluate the spatial extent and variation of cooling rates for Fiordland and other lower crustal exposures.

Keywords: Zircon U-Pb, garnet Sm-Nd, migmatite, lower crust, rates of intrusion, duration of metamorphism

INTRODUCTION AND GEOLOGIC SETTING

Zircon and garnet isotopic dates are widely used for understanding local and orogenic scale processes in magmatic arcs, lower-crustal rocks, and high-grade metamorphic terrains. For example, ages and associated trace-element compositions in zircon are critical components of studies that address magma sources, mixing, and assimilation (e.g., Hammerli et al. 2018). Garnet stability is important for characterizing arc roots because it exerts controls on partial melting processes, the composition of intermediate- to high-silica magmas found in magmatic arcs (e.g., Lee et al. 2006; Ducea et al. 2015), and the density of lower crust and mantle lithosphere (e.g., Kay and Mahlburg Kay 1993). Garnet ages provide a means of understanding processes in magmatic arc roots because they can be directly linked to pressure and temperature estimates for constructing quantitative P-T-t paths and calculating rates of tectonic processes (e.g., Stowell et al. 2001, 2007; Lapen et al. 2003; Gatewood et al. 2015). In granulite facies metamorphic rocks, the zircon U-Pb, and garnet Sm-Nd and Lu-Hf ages generally yield significant differences that may reflect igneous, peak metamorphic, and post-peak metamorphic processes (e.g., Mezger et al. 1992; Hoskin and Schaltegger 2003; Harley et al. 2007; Baxter and Scherer 2013; Smit et al. 2013, 2015).

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