

Duration of low-P/T type metamorphism and zircon/garnet REE partitioning in migmatites, Ryoke metamorphic belt, Japan

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Duration of low-pressure/high-temperature type, upper amphibolite to granulite facies Ryoke metamorphism is estimated by SHRIMP zircon U-Pb dating. Zircon in migmatites (up to ca. 800°C, ca. 0.5 GPa) has inherited core and metamorphic rim, and between them is a dark-cathodoluminescence (dark-CL) annulus with melt (glass) inclusions (Kawakami et al., 2013). The rim shows variation in age from ca. 95.5 Ma to 88.7 Ma, suggesting the duration of hypersolidus high-temperature condition for ca. 7 Myr. Zircon rims with old ages tend to show steeply positive HREE patterns whereas the young zircon rims tend to show less steeply positive HREE patterns. Ti content in zircon rims are low, ranging from 1.23 to 2.25 ppm. This small variation in Ti content may imply narrow temperature range of zircon rim formation.

Garnet in the same sample has zoning in trace elements, and REE and Y contents are high in the core and lower towards the rim, suggesting prograde growth of this garnet. Garnet shows steeply positive HREE patterns at the core whereas it becomes less steep at the rim. Zircon grains with dark-CL annulus with um-sized inclusions are also included in the garnet, and judging from the mixed analysis of thin zircon rim and core, these inclusion zircon also has rims with steeply positive HREE patterns. This suggests that the inclusion zircons also have the rim that grew during the prograde, melt-present stage of the Ryoke metamorphism, but has the steeply positive HREE patterns even though they likely grew simultaneously with garnet in the presence of melt.

Systematic change of REE patterns in garnet and in zircon rim described above suggests that availability of HREE decreased as zircon grew, because of the simultaneous growth of garnet. In spite of this, $D_{REE}(\text{garnet/zircon})$ does not show flat pattern nor approach unity for HREE (e.g., Rubatto, 2002), showing different trend from the cases in the UHT rocks. Possible controlling factors of $D_{REE}(\text{garnet/zircon})$ include (i) difference in pressure and temperature conditions, (ii) difference in garnet composition, especially in grossular content (Taylor et al., 2014), (iii) effect of self-diffusion of garnet trace element compositional profiles under UHT conditions (Buick et al. 2006), and (iv) different timing of zircon and garnet growth (Buick et al. 2006). Among the possible controlling factors of the difference of $D_{REE}(\text{zircon/garnet})$ from UHT examples discussed above, (ii) can be neglected because garnet in this study has low grossular content (0.02-0.03) but showing the steep HREE pattern. Factor (iii) is not likely because our garnet preserves zoning in trace elements and even the high-Y annulus is preserved. Factor (iv) is also not likely from the above-mentioned observations that support simultaneous growth of zircon and garnet. Therefore, the temperature condition could be the most likely factor to control $D_{REE}(\text{garnet/zircon})$, although an example of Whitehouse and Platt (2003) who reported the flat $D_{REE}(\text{garnet/zircon})$ pattern near unity does not fit this interpretation. Our example suggests that it can be misleading to judge timing of 'normal' granulite facies metamorphism solely from the $D_{REE}(\text{garnet/zircon})$ pattern on the assumption that $D_{REE}(\text{garnet/zircon})$ becomes unity when garnet and zircon coexisted.

Keywords: high temperature metamorphism, partial melting, zircon, garnet, rare earth elements