Multiple timings of garnet formation in granulites constrained from *in situ* U-Pb zircon dating and REE compositions of garnet and zircon (Sør Rondane Mountains, East Antarctica)

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In high-grade metamorphic rocks, U-Pb geochronology of zircon is a powerful tool to understand metamorphic events. This is because zircon represents relatively high closure temperature of U-Pb system and its atomic structure remains stable over long periods of geological time. Since zircon could record various metamorphic ages in high-grade metamorphic terranes (e.g., Harley et al., 2007), the appropriate interpretation of their ages is significant. The REE pattern of zircon and distribution coefficient of REE (D_{REE}) between zircon and garnet has been used as useful tools to establish the link between zircon geochronology and timing of garnet formation. A considerable issue is that the equilibrium D_{REE} values between zircon and garnet could change depending on temperature, pressure and grossular content in garnet; the REE patterns of D_{HREE} tend to become positive with decreasing temperature, increasing pressure, and increasing X_{Ca} [= Ca/(Fe+Mn+Mg+Ca)] in garnet (e.g., Harley et al., 2001; Rubatto, 2002; Hokada and Harley, 2004; Buick et al., 2006; Rubatto and Hermann, 2007). In spite of these uncertainties, the flat pattern of D_{HREE} between zircon and garnet is interpreted to represent equilibrium between these two phases. This criterion is even more powerful when combined with microstructural criteria. For example, if the REE pattern of D_{HREE} between zircon included in garnet and the host garnet was not flat, the zircon might have been formed prior to the host garnet or might have been formed in disequilibrium with garnet during the garnet-forming metamorphism. Therefore, in addition to their microstructure, the REE pattern of D_{HREE} is an important method to assess whether the two minerals were chemically in equilibrium or not.

In the Sør Rondane Mountains (SRM), East Antarctica, Late Proterozoic to Cambrian granulites are widely exposed (e.g., Jacobs and Thomas, 2004; Shiraishi et al., 2008; Osanai et al., 2013; Elburg et al., 2016). In the SRM, each metamorphic event has been related to the different zircon age groups, mainly using Th/U ratio of zircon domains (e.g., Shiraishi et al., 2008; Hokada et al., 2013). These studies used separated zircon grains, and *in situ* U-Pb dating of zircon that takes microstructural context into account (Higashino et al., 2013; Kawakami et al., 2017) is rare. Furthermore, limited number of previous studies have investigated REE patterns of zircon and garnet in the SRM (e.g., Hokada et al., 2013). Therefore, in this study, the D_{HREE} values between garnet and zircon and *in situ* U-Pb dating of zircon included in other metamorphic minerals are examined in detail in order to determine the timing(s) of garnet-forming metamorphism in selected regions of the SRM.

Using LA-ICPMS, *in situ* U-Pb dating of zircon and quantitative analysis of REE in garnet and zircon have been performed on seven mafic and pelitic gneisses collected from Perlebandet (one pelitic gneiss), Brattnipene (one pelitic gneiss and one mafic gneiss), Pilten (one pelitic gneiss), Mefjell (one pelitic gneiss), and Balchenfjella (two pelitic gneisses). The rims of zircon inclusions in garnet from seven samples gave U-Pb ages of ca. 560 Ma (Pilten and Balchenfjella), ca. 580 Ma (Perlebandet and Mefjell) and ca. 610-620 Ma (Balchenfjella and Brattnipene). Each sample gave a single peak age distribution for the zircon rim dating. Among the seven samples, a mafic gneiss from Brattnipene and a pelitic gneiss from Pilten have a positive-sloping REE pattern of D_{HREE} between zircon included in garnet and the host garnet, whereas other five samples show flat REE pattern of D_{HREE} indicative of chemical equiliburium. Therefore, the five equilibrium samples could reveal the multiple timing of garnet-forming metamorphism in different regions of the SRM; Perlebandet (ca. 580 Ma), Brattnipene (ca. 610-620 Ma), Mefjell (ca. 580 Ma), and Balchenfjella (ca. 560 Ma and ca. 610-620 Ma). On the other hand, X_{Ca} in garnet in the two samples representing the positive-sloping D_{HREE} pattern is ~ 15-18 for a mafic gneiss from Brattnipene and ~ 6 for a pelitic gneiss from Pilten, respectively. The X_{Ca} value of garnet in the mafic gneiss from Brattnipene is similar to the value showing equilibrium positive-sloping REE pattern of D_{HREE} between zircon and garnet with similar X_{Ca} (Rubatto, 2002; Rubatto and Hermann, 2007). Therefore, this zircon in the mafic gneiss might be in equilibrium with garnet. In the pelitic gneiss from Pilten, however, positive-sloping REE pattern of D_{HREE} is not explained by the X_{Ca} value in garnet due to its low value. This either implies that the garnet was formed after ca. 560 Ma or the zircon was formed during ca. 560 Ma metamorphic event not in equilibrium with garnet.

In the SRM, Cl-rich fluid/melt infiltration event is widely observed along the Main Tectonic Boundary, Balchen Detachment Fault, and the dextral shear zone in Balchenfjella (Higashino et al., 2013; 2015; Kawakami et al., 2017). The timing of Cl-rich fluid/melt infiltration is considered to be multiple (Higashino et al., 2013; Kawakami et al., 2017). In addition, the multiple timing of garnet formation revealed in this study further enables to understand the timings of Cl-rich fluid/melt infiltration. The fluid-related metamorphic processes during the collision in the SRM will be discussed.

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