Carbon-isotope composition of graphite associated with V-bearing grossular and origin of C-O-H fluid from Menipa, Sør Rondane Mountains, East Antarctica

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The lower crustal rocks of the ca. 650-500 Ma continental collision zone are widely exposed in the Sør Rondane Mountains (SRM), East Antarctica. The SRM is divided into the NE and SW terranes by the Main Tectonic Boundary, which is considered to be the collision boundary. The granulite-facies gneisses in the NE terrane record clockwise pressure-temperature-time (*P-T-t*) path whereas those in the SW terrane record counter-clockwise *P-T-t* path (Osanai et al., 2013). Recently, ultrahigh-temperature (UHT) metamorphic rock is newly found from the Balchenfjella area in the NE terrane (Higashino & Kawakami, 2022). Timing of metamorphism in both terranes are petrochronologically examined in detail and found that timing of granet-forming metamorphism varies in the entire SRM irrespective of which terrane the region belongs to (Higashino et al., 2023a). As one example of such study, Kawakami et al. (2022a) used a Sil-Bt-Grt gneiss and graphitic Sil-Bt gneiss containing green V-bearing grossular from Menipa in the SW terrane (Osanai et al., 1990) to construct a *P-T-t* path. They concluded that Menipa experienced a clockwise *P-T-t* path and ca. 600-560 Ma was the timing of prograde metamorphism and the peak metamorphic conditions of ~1.0 GPa, ~800 ºC were attained at ca. 560 Ma. Saline fluid infiltrations in the SRM have been proposed based on the detailed studies on black selvages mainly composed of Cl-rich biotite and/or hornblende developed along the cracks (Higashino et al., 2013; 2015; 2019a; 2019b; 2023a; 2023b; Kawakami et al., 2017; Mindaleva et al., 2020). Based on the whole-rock S-isotope study, fluid source to form such selvages is considered as fluids released from granitoids (Kawakami et al., 2022b).

This study aims to constrain the origin of metamorphic fluid that was related to the formation of rare V-bearing green grossular. The green grossular is surrounded by symplectite that consists of An+V-Cpx+V-Grt+V-Ttn+V-Zoi+Qz+Ap+V-Ti-Fe oxide+Pyh+Py+Cal, and the symplectite formation was dated to be ca. 550 Ma by U-Pb dating of titanite in the symplectite (Niki et al., 2022). The graphitic Sil-Bt gneiss rarely contains green grossular of ~10 cm in diameter, which is associated with a crust of quartz aggregate. The quartz includes fluid inclusions containing CO_2+CH_4. This suggests that C-O-H fluid played an important role in coarsening the green grossular. Outline of some symplectites replacing the rim of green grossular follows that of pressure shadows, suggesting that the symplectite formation was contemporaneous with or postdated the formation of the matrix foliation defined by the arrangement of Sil+Bt. The outermost part of the symplectite is coarser-grained than the inner part of the symplectite and accompanies graphite. We determined the C-isotope composition of such graphite to be $\delta^{13}C$ = -24.74 ±0.01, which is a typical biogenic value based on Luque et al. (2012).

The symplectite is also developed along the cracks in the green grossular. Healed cracks recognized as narrow linear domain of higher-V grossular are developed along the extension of the cracks. Calcite inclusions are locally found along such cracks and healed cracks. Therefore, C-O-H fluid infiltration probably played an important role in forming the symplectite along the cracks. Graphite is also found in the symplectite developed along the cracks, indicating that some graphite crystals recrystallized from the C-O-H fluid. However, since precipitation of V in the gneiss requires a reducing environment, the graphite was probably already present in the protolith of the graphitic Sil-Bt gneiss. Therefore, the C-O-H fluid is likely a reaction product of graphite in the gneiss and the aqueous fluid that infiltrated from the external source.

Since sulfide is also found in the symplectite developed along the cracks in the green garnet, the fluid responsible for the symplectite formation was also S-bearing. This implies that the external fluid was sourced from ~500 Ma granitoid intruded nearby (Adachi et al. 2022), similar to the case of saline fluids that formed black selvages mainly composed of Cl-rich biotite and hornblende observed throughout the SRM (Kawakami et al., 2022b).

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