The pressure-temperature conditions of high-grade pelitic gneisses in the Dai Loc Complex, Truong Son Belt, central Vietnam

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The Dai Loc Complex is a Devonian–Silurian granitoid complex located at the southmost Truong Son Belt in central Vietnam along the Tam Ky–Phuoc Son suture zone. The suture zone corresponds to the boundary between the Truong Son Belt and Kontum Massif which is a Ordovician–Silurian and Permo–Triassic plutono–metamorphic complex (e.g., Nakano et al., 2013). The Dai Loc Complex is composed of granodiorite, granite and aplite with I- and S-type affinities (e.g., Hieu et al., 2016; Jiang et al., 2020). The gneissose or augen structures are well developed in most of the Dai Loc granitoids (e.g., Jiang et al., 2020). These granitoids intrudes into the Cambrian–Ordovician A Vuong Formation which consists of weakly metamorphosed sandstone, schist, and quartzite (Faure et al., 2018). Recently, the occurrences of high-grade pelitic gneisses in the Dai Loc Complex have been reported (Osanai et al., 2018; Bui et al., 2022). The pelitic gneisses are characterized by migmatitic structure associated with euhedral Crd-bearing leucosome, and mineral assemblages of Grt porphyroblast with textural zoning (inclusion-rich core, inclusion-free mantle, and dusty rim), Crd, and Bt with/without minor Spl, Sil, Ky, and St (Osanai et al., 2018; Bui et al., 2022). Bui et al. (2022) reported Zrn U–Pb ages of *ca.* 440–430 Ma obtained from metamorphic Zrn domain including rare Sil and *ca.* 2500–500 Ma as detrital Zrn ages. They suggested a low pressure (LP) / high temperature (HT) stage with the coexistence of Grt (core and mantle) + Crd + Bt ± Spl ± Sil at *ca.* 440–430 Ma and subsequent isobaric cooling which produced Grt dusty rim and Ky + Bt ± St aggregate after Crd. However, the metamorphic conditions of pelitic gneisses in the Dai Loc Complex, which give a critical clue to reveal the tectonic evolution of the southern part of the Truong Son Belt, haven't been constrained yet. Therefore, this study reports the pressure (*P*)–temperature (*T*) conditions of two Grt–Crd–Bt gneisses dated by Bui et al. (2022) (samples 73102I and 73103F) and an Opx-bearing Grt–Crd–Bt gneiss (sample 73102B) we newly identified (Fig. 1), and discuss the tectonic implication.

The Grt in these samples chemically can be divided into high-Ca core and low-Ca rim (Fig. 2) that correspond to the core and/or mantle, and rim described by Bui et al. (2022), respectively. The high-Ca core (X_{grs} = 0.022–0.041) shows the normal zoning with decrease in Mn, slight increase or almost homogenity of Mg toward its margin in 73102I (Fig. 2) and 73102B, while that of Grt in 73103F shows opposite zoning pattern. The low-Ca rim (X_{grs} = 0.001–0.015) has lower Mn and higher Mg contents than the core or Mg contents similar to the core (Fig. 2). The Grt core includes Bt, Als (Sil?), Pl, Qz, Ilm, Rt, and Ap. Inclusions in Grt rim are too tiny to be identified. Opx (X_{Mg} = 0.376–0.387, Al_2O_3 = 2.90–3.17 wt%) in 73102B occurs in the leucosome as a subhedral porphyroblast surrounded by Cum and Bt + Qz (Fig. 1). Bt is present in the matrix (X_{Mg} = 0.424–0.654, TiO_2 = 0.00–5.97 wt%) or inside Grt and Crd (X_{Mg} = 0.423–0.642, TiO_2 = 0.29–6.40 wt%). The Bt in the matrix is overgrown by fine-grained Bt ± Qz or partly replaced by low-Ca dusty Grt. Anhedral and euhedral Crd can be recognized in the melanosome (X_{Mg} = 0.602–0.761) and leucosome (X_{Mg} = 0.671–0.753 (73103F)), respectively. The former includes anhedral to subhedral green Spl (X_{Mg} = 0.137–0.164 (73102B), 0.189–0.254 (73102I), 0.255–0.270 (73103F)) in association with Crn and/or Dsp. The Crd grains are replaced by Ky + Bt ± St (X_{Mg} = 0.149–0.164 (73102B), 0.220–0.260 (73103F)) ± Ged (X_{Mg} = 0.363–0.378 (73102B), 0.427–0.485 (73102I, 73103F)) ± low-Ca dusty Grt ± Qz. Pl lamellae of the mesoperthite in the matrix are enriched in Na (X_{An} = 0.005–0.047), while the Pl inclusions in the Grt (X_{An} = 0.089, 0.207) of 73102I and Pl in the leucosome of 73103F (X_{An} = 0.192–0.264) represent relatively higher anorthite contents. Opaque phases are Ilm in 73102B and 73102I, and Py in 73103F.

The application of the Grt–Bt, Grt–Crd, and Grt–Opx geothermometers, and Grt–Bt–Pl–Qz, Grt–Rt–Als–Ilm–Qz, and Grt–Bt–Als–Qz geobarometers indicates the *P*–*T* conditions on prograde, peak and retrograde stages as follows:

- Prograde stage (Grt + Bt + Pl + Qz ± Ilm ± Als(Sil?) ± Rt):
  T = 560–600 ℃ (73102B), *P* = 4.1–5.6 kbar and *T* = 600–670 ℃ (73102I)
- Peak stage (Grt + Crd + Spl + Bt + Pl + Afs + Qz ± Ilm ± Opx ± Als(Sil?) ± Rt ± Py):
  T = 800–950 ℃ (73102B), *P* = 6.0–8.5 kbar and *T* = 730–800 ℃ (73102I), *P* = 6.0–7.7 kbar and *T* = 730–840 ℃ (73103F)
- Retrograde stage (Grt + Ky + Ged + Bt ± St + Pl + Afs + Qz ± Ilm ± Py):

P = 7.5–9.2 kbar and T = 670–700 ℃ (73102B), P = 6.5–7.8 kbar and T = 580–630 ℃ (73102I), P = 6.5–7.5 kbar and T = 580–620 ℃ (73103F)

Additionally, the Ti-in-Grt geothermometer for Ilm-bearing samples yields T = 900–950 ℃ (73102B) and 850–900 ℃ (73102I).

The results suggest the counter-clockwise P–T paths with peak granulite-facies condition and subsequent isobaric cooling upto epidote amphibolite- to amphibolite-facies condition for pelitic gneisses in the Dai Loc Complex. Their peak P–T conditions are well comparable with those of the Ordovician–Silurian metamorphic rocks in the eastern Kannack Complex and western Ngoc Linh Complex of the Kontum Massif. The results of this study support Bui et al. (2022) who inferred the isobaric cooling process for the Dai Loc pelitic gneisses and the Ordovician–Silurian LP/HT metamorphism triggered by subduction-related arc magmatism between the Kontum Massif and Dai Loc Complex. The core of Grt in the 73102B and 73102I preserves the prograde zoning of Mn without homogenization by the diffusion under the granulite-facies HT condition. It may represent that the Dai Loc pelitic gneisses experienced the rapid burying and heating followed by quick cooling process. The post-peak isobaric cooling may be explained by the horizontal movement of pelitic gneisses together with the Dai Loc granitoids in the arc crust to get away from the heat source. Thus, the metamorphic evolution of pelitic gneisses in the Dai Loc Complex possibly indicates the development of the arc-trench system involving the arc magmatism and LP/HT metamorphism during Ordovician–Silurian in the southern Truong Son Belt.

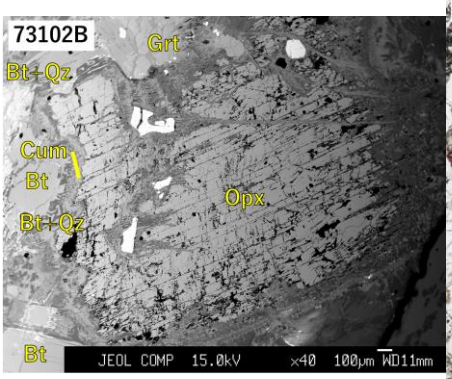

Fig. 1. The occurrence of Opx in sample 73102B.

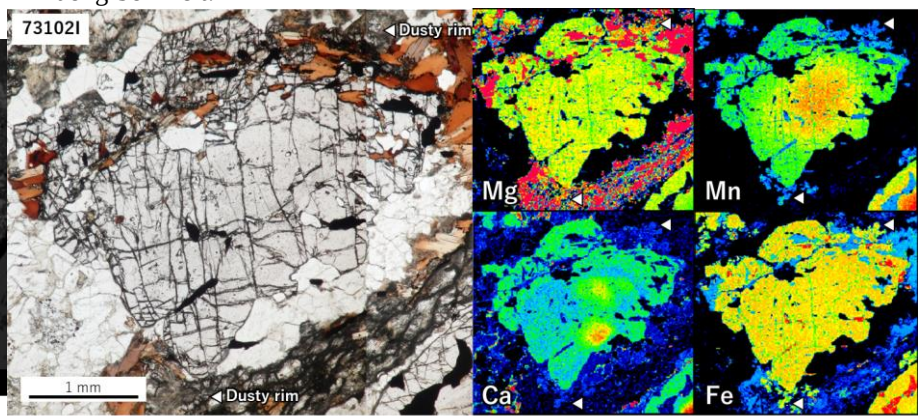

Fig. 2. The occurrence and X-ray mapping of Grt in sample 73102I. The white triangle marks indicate the locations of representative dusty rim of Grt.

Abbreviation: Afs, alkali feldspar; Als, aluminosilicate; Ap, apatite; Bt, biotite; Crd, cordierite; Crn, corundum; Cum, cummingtonite; Dsp, diaspore; Ged, gedrite; Grt, garnet; Ilm, ilmenite; Ky, kyanite; Opx, orthopyroxene; Pl, plagioclase; Py, pyrite; Qz, quartz; Rt, rutile; Spl, spinel; Sil, sillimanite; St, staurolite; Zrn, zircon

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