

Methods

Garnet trace elements measurement

The trace element content of garnet in samples 10DP01a and of one garnet grain in sample 10DP01b were measured by laser ablation inductively coupled plasma mass spectrometry (LA–ICP–MS) at the Institute of Geology and Geophysics, Chinese Academy of Sciences (IGGCAS). An Agilent 7500a quadrupole ICP–MS was coupled to a COMPEX Pro 193 nm excimer laser ablation system, with He as the carrier gas and Ar as the plasma gas. During the analysis, the laser spot size was 50 μm and repetition rate was 8 Hz, and on-sample energy was $\sim 4.0 \text{ J/cm}^2$. Three cleaning pulses were followed by 15 s of baseline acquisition. NIST 610 glass was used as the primary standard with recommended values from Jochum et al. (2011), and was measured once between every ten unknowns. During the analysis, signals of Ce/Th, Ti and Zr were monitored to determine whether monazite, rutile/ilmenite or zircon inclusions were encountered. Element concentrations were processed with the “GLITTER” software, with ^{43}Ca as the internal reference isotope, and calibrated to the Ca content in the target as determined by electron microprobe (Jiao et al. 2017). The final results are listed in Table A1.

The trace element contents in all other garnet were measured using an Agilent 7700x quadrupole ICP–MS coupled to a Resonetics S-155-LR 193 nm excimer laser ablation system at the GeoHistory Facility, John de Laeter Centre, Curtin University. The sample cell was flushed with ultrahigh purity He (350 mL min^{-1}) and N_2 (3.6 mL min^{-1}) and high purity Ar was used as the plasma gas. A laser spot size of 50 μm , repetition rate of 7 Hz, and on-sample energy of 2.7 J cm^{-2} were used during garnet analysis. Following two cleaning pulses, material was ablated for 40 s with 35s of baseline acquisition.

However, some grains were ablated through in less than the available 40s, and some ablated into monazite or other inclusions. In these cases, the integration time was cropped based on the time resolved traces for Si, Ce and Th, or data were excluded from interpretations if the trace element concentrations were spurious relative to neighboring analyses. The trace element abundances were determined using the Trace_Elements DRS in Iolite3.5 (Paton et al. 2011) using NIST 610 as the primary standard and ^{29}Si as the internal reference isotope, taking the average SiO_2 content (38.99 wt% Si) for garnet (Guo et al. 2012). Secondary standard NIST 612 yielded recommended values within 4%. The uncertainty is better than 8%. The final results are listed in Table A1.

In sample 08JDP11, one traverse through a biotite-bearing large garnet (> 6 mm; Fig. 3a) and one through an inclusion-rare, small garnet grain (ca. 3 mm; Fig. 3c), were conducted. A traverse through a large garnet (ca. 4 mm; Fig. 3b) with no inclusions in the core and abundant fibrous sillimanite and biotite in the rim, was also performed. In sample 10DP01b, one traverse through a large garnet grain (ca. 8 mm; Fig. 4a), with an inclusion-rare core and biotite- and sillimanite-bearing rim was conducted. This is the same grain analyzed for major element composition by Jiao et al. (2017). In sample 08JDP08, two perpendicular traverses through a large garnet (> 4 mm) were conducted (Fig. 5a). In sample 10DP01c, four traverses across three small garnet grains (Fig. 6a) were completed. In sample 10DP01a, two parallel traverses through a large garnet (ca. 8 mm), and several spots on small garnet (< 1 mm) were conducted as shown in the Appendix material (Fig. A3).

***P–T* pseudosection calculations**

Mineral phase scanning of polished thin section of each sample was conducted by TIMA with a beam current of 5.8 nA, beam energy of 25 kV, and working distance of

15 mm at the John de Laeter Centre, Curtin University. The mass fractions of minerals were estimated by off-line TIMA software. Mineral compositions in sample 10DP01b were from Jiao et al. (2017), and those in sample 10DP01c were from Jiao and Guo (2020). The bulk compositions were calculated by summing up average of each mineral composition and its mineral mass. Fe_2O_3 content using for modeling was calculated based on stoichiometry. Sapphirine is the main phase containing Fe_2O_3 , so that the calculated bulk Fe_2O_3 largely depends on the estimated modes of sapphirine. H_2O content was determined by Bt mass and its H_2O content that is assumed to be 3 wt% (Cesare et al. 2003).

THERMOCALC (version 3.33) was used for the calculation, with the internally consistent thermodynamic dataset (ds55) of Holland and Powell (1998). The calculations were performed in the NCKFMASHTO (Na_2O - CaO - K_2O - FeO - MgO - Al_2O_3 - SiO_2 - H_2O - TiO_2 - Fe_2O_3) system. The activity-composition models were used as below: sapphirine (Taylor-Jones and Powell 2010); garnet, biotite and silicate melt (White et al. 2007); orthopyroxene, spinel and magnetite (White et al. 2002); ilmenite (White et al. 2000); cordierite (Holland and Powell 1998); and feldspar (Holland and Powell 2003). Isopleths of mineral modes in Fig. A4 were automatically calculated by TCInvestigator software (Pearce et al. 2015), and the others were calculated manually by THERMOCALC.

The P - T pseudosection was calculated in a P - T range of 6–14 kbar and 750–1100 °C. For sample 10DP01b, rutile and plagioclase are stable in the whole P - T range, and garnet and sapphirine are stable over most of the range. Orthopyroxene and spinel are stable in the low- P and high- T parts, and corundum is stable in the high- P and low- T parts. Aluminosilicate is stable in the low- T parts and cordierite is stable in low- T and low- P parts, and biotite is stable until 1040 °C due to TiO_2 enrichment (Jiao and Guo

2020). The fluid-absent solidus is 790-820 °C in cordierite-absent fields but elevates to 890 °C in cordierite-stable fields (Fig. A4).

The general topology for sample 10DP01c is similar to that of sample 10DP01b, but spinel is stable at higher P up to ~11 kbar and biotite is stable to much higher T than that of sample 10DP01b, outside the scope of the P – T range (Fig. 8). It might be related to much more biotite abundance in this sample (24 vs. 15 mass%).

Additional calculations using THERMOCALC (version 3.40) and the updated dataset (ds62; Holland and Powell 2011) were also applied to thin section 10DP01b here, with sapphirine a-x model from Wheller and Powell (2014) and the others from White et al. (2014). Isopleths of mineral modes were also automatically calculated by TCInvestigator software (Pearce et al. 2015). However, mineral assemblages in the resultant P – T pseudosections are inconsistent with the observed ones, and spinel-stable fields are in the whole P – T range and no sapphirine-stable fields can be calculated (Fig. A5), and similar cases were encountered by Jiao et al. (2017) when using the whole-rock composition for modeling, although the calculated and observed mineral assemblages can march well if using effective bulk composition from microdomains (Jiao and Guo 2020). Change of plagioclase modes in pseudosections calculated with ds62 (Fig. A5) is similar to that based on ds55 (Figs. 8, A4), but the sillimanite- and biotite-stable fields are quite different, and changes of Ca-in-Grt and garnet mode isopleths are mostly consistent but are opposite in some fields. Considered the consistency of observed and modeled mineral assemblages and their modes, we think the pseudosections using ds55 presented here better represent the metamorphic evolution of these granulites.

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