218321: biotite–garnet semipelitic gneiss, Winnama Yard

(Tickalara Metamorphics, Central Zone, Lamboo Province)

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Location and sampling

DIXON RANGE (SE 52-6), TURKEY CREEK (4563)

MGA Zone 52, 419906E 8100526N

WAROX site JBHLEN000217

Sampled on 3 June 2015

This sample was collected from an outcrop on a north-northeast-trending track on Mabel Downs Station, about 10.2 km south-southeast of Six Mile Bore, 5.9 km west of Mount Parker and 0.9 km north of Winnama Yard.

Geological context

The unit sampled is a biotite–garnet semipelitic gneiss (Fig. 1) assigned to the 1865–1850 Ma Tickalara Metamorphics of the Central Zone of the Lamboo Province. The Tickalara Metamorphics is the oldest rock unit recognized in the Central Zone of the Lamboo Province, and consists of low- to high-grade mafic metavolcanic rocks, interbedded turbiditic and calcareous metasedimentary rocks, minor metamorphosed banded iron-formation and chert, and minor metagranitic rocks (Sheppard et al., 1999). Zircons from this sample indicate a maximum depositional age of 1879 ± 15 Ma and an age for high-grade metamorphism of 1820 ± 9 Ma (GSWA 218321, Lu et al., 2017). Monazite yields a similar age for high-grade metamorphism of 1820 ± 8 Ma (GSWA 218321, Fielding et al., 2021).

Petrographic description

The sample is a semipelitic gneiss (Fig. 1), consisting of about 37% plagioclase, 29% quartz, 18% garnet, 10% biotite, 5% magnetite, 1% ilmenite, trace aluminosilicate, and accessory zircon and monazite (Table 1; Fig. 2). In outcrop, quartzofeldspathic layers containing garnet form elongate, layer-parallel domains a few centimetres in size (Fig. 1), which are interpreted as leucosomes. Layering in the gneiss is defined partly by variation in grain size of the quartz–plagioclase-rich matrix and partly by garnet abundance in leucosome layers. The coarser grained layers are more massive (poorer in biotite) and the finer grained layers contain more biotite and are foliated (Fig. 2). Quartz occurs as anhedral, irregularly shaped grains up to 3 mm in size in the coarser grained layer and 0.5 – 0.7 mm in the finer grained layers (Fig. 3). Plagioclase has a similar size range and grain shape and forms an interlobate to polygonal aggregate texture with quartz (Fig. 3). Garnet occurs as anhedral, approximately equant, poikiloblasts up to 6 mm in diameter. Garnet contains abundant rounded to elongate inclusions of mostly quartz and magnetite with minor biotite, ilmenite and plagioclase (Fig. 3). Brown biotite occurs as aligned, subhedral laths up to 1 mm long, and is more abundant in the finer grained, quartz–plagioclase layers, in which it defines the foliation. Magnetite is up to 1.5 mm in size, has irregular to subhedral shape, and is disseminated throughout the sample, although it is slightly more abundant in the biotite-rich layers and as inclusions in garnet. Ilmenite forms elongate grains up to 1 mm in length and is disseminated throughout the sample and as inclusions in garnet. A trace amount of fine-grained aluminosilicate is present as very small inclusions less than 100 µm in size within biotite, garnet and plagioclase. Although these are too small to optically identify, fibrolitic sillimanite inclusions in garnet porphyroblasts have been described in other studies (Bodorkos et al., 1999).

Figure 1. Outcrop image for sample 218321: biotite–garnet semipelitic gneiss, Winnama Yard

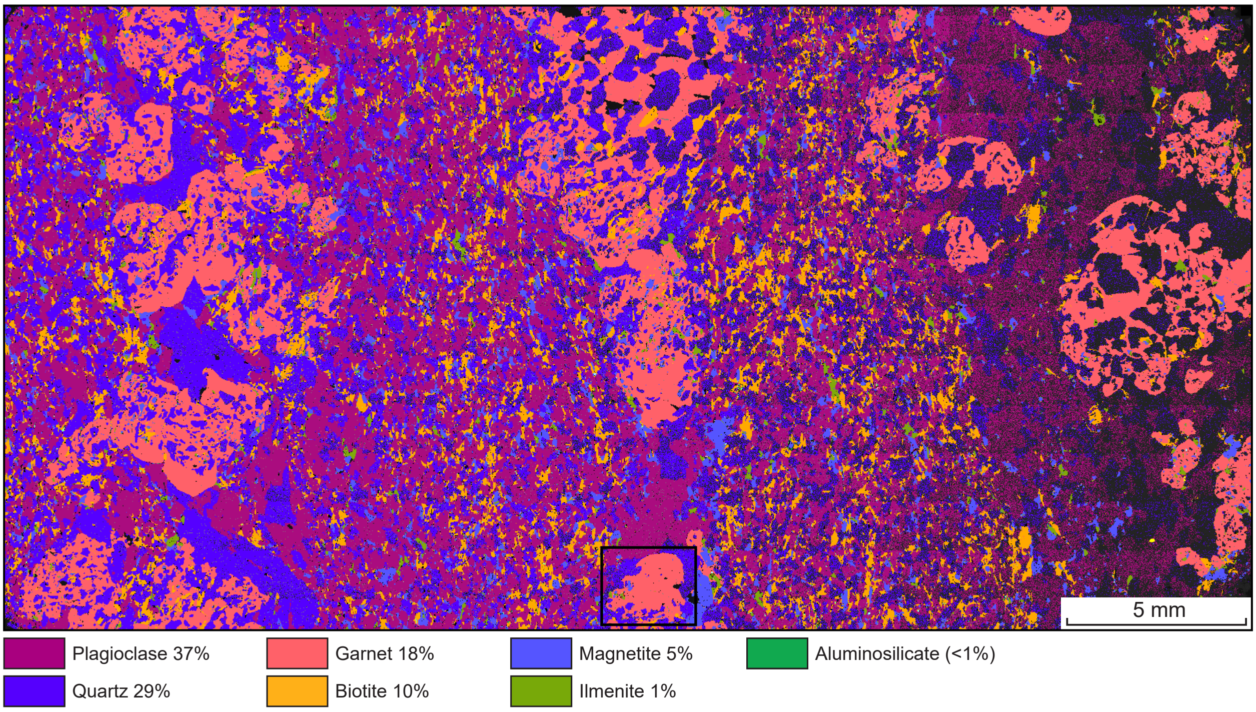

Figure 2. TESCAN Integrated Mineral Analyser (TIMA) image of an entire thin section from sample 218321: biotite–garnet semipelitic gneiss, Winnama Yard. Volume percent proportions of major rock-forming minerals are calculated by the TIMA software. Black outline shows measured garnet grain (Appendix 2). Increase in dark shading on right side is a result of poor signal during analysis

Table 1. Mineral modes for sample 218321: bioitite–garnet semipelitic gneiss, Winnama Yard

Mineral modes	Grt	Bt	Sil	Pl	Mag	Ilm	Qz	Liq
Observed (vol%)	18	10	trace	37	5	1	29	–
Predicted (mol%)								
@ 3.5 kbar, 700 °C	11.7	7.5	2.8	39.9	5.2	3.6	29.3	1.0
@ 3.5 kbar, 730 °C	15.2	6.6	2.2	39.7	2.4	5.3	28.1	0.5
@ 2.9 kbar, 700 °C	12.3	7.5	2.7	39.8	4.6	4.0	29.1	0.04
@ 3.3 kbar, 700 °C	17.0	1.3	1.6	41.0	4.3	4.4	26.3	4.2

NOTES: – not present

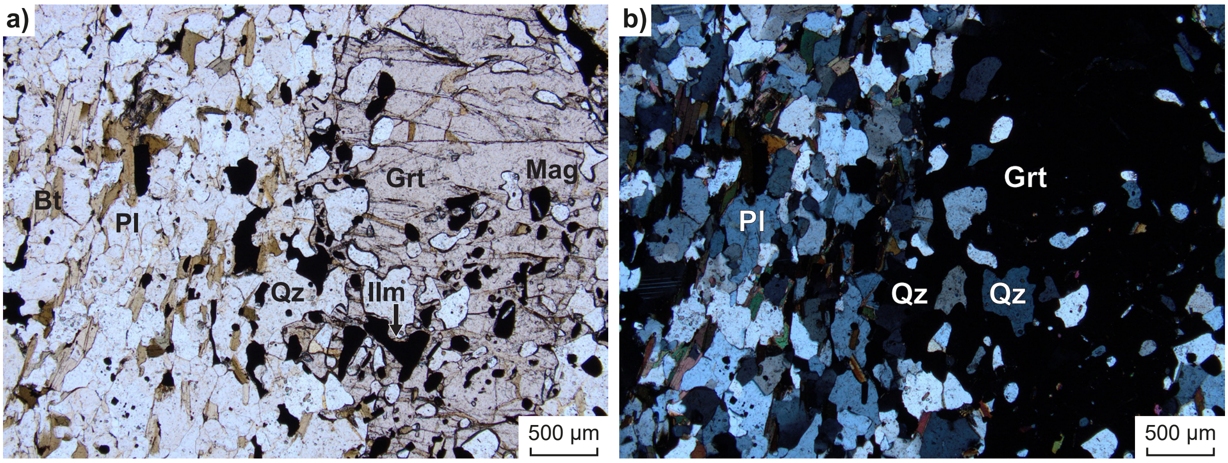

Figure 3. **Photomicrographs of sample 218321: biotite–garnet semipelitic gneiss, Winnama Yard: a) plane-polarized light; b) cross-polarized light. Abbreviations: Bt, biotite; Grt, garnet; Ilm, ilmenite; Mag, magnetite; Pl, plagioclase; Qz, quartz**

Analytical details

The metamorphic evolution of this sample was investigated using phase equilibria, based on the bulk-rock composition (Table 2). The composition was determined by X-ray fluorescence spectroscopy, together with loss on ignition (LOI). All iron was measured as Fe_2O_3. The modelled H_2O was increased slightly from the measured LOI (<0.01 wt%; Table 2) in order to better approximate the modal abundance of biotite observed in thin section at the conditions of the solidus (Table 1). In a similar way, the O content (for Fe^{3+}) was estimated based on reproducing the modal abundance of magnetite (~ 5 vol%) observed in thin section, resulting in 45% of total Fe as Fe_2O_3. Thermodynamic calculations were performed in the MnNCKFMASHTO ($MnO–Na_2O–CaO–K_2O–FeO–MgO–Al_2O_3–SiO_2–H_2O–TiO_2–O$) system using THERMOCALC version tc340 (updated October 2013; Powell and Holland, 1988) and the internally consistent thermodynamic dataset of Holland and Powell (2011; dataset tc-ds62, created in February 2012). The activity–composition relations used in the modelling are detailed in White et al. (2014a,b). Compositional and mode isopleths for all phases were calculated using the software TCInvestigator (Pearce et al., 2015). Additional information on the workflow with relevant background and methodology are provided in Korhonen et al. (2020).

Table 2. Measured whole-rock and modelled compositions for sample 218321: bioitite–garnet semipelitic gneiss, Winnama Yard

XRF whole-rock composition (wt%)[(a)]											
SiO_2	**TiO_2**	**Al_2O_3**	**Fe_2O_3[(b)]**	**FeO[(b)]**	**MnO**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**LOI**	**Total**
59.06	1.67	13.97	16.66	–	0.11	2.20	1.22	3.55	0.99	<0.01	99.43
Normalized composition used for phase equilibria modelling (mol%)											
SiO_2	**TiO_2**	**Al_2O_3**	**O[(c)]**	**FeO^T[(d)]**	**MnO**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**H_2O[(e)]**	**Total**
63.15	1.35	8.80	3.04	13.40	0.10	3.51	1.40	3.68	0.67	0.90	100

NOTES: (a) Data and analytical details are available from the WACHEM database <http://geochem.dmp.wa.gov.au/geochem/>
(b) Fe_2O_3 content is total Fe
(c) O content (for Fe^{3+}) based on modal abundance of magnetite; see text
(d) FeO^T = moles FeO + 2 * moles O
(e) H_2O content based on modal abundance of biotite; see text

Results

Metamorphic *P–T* estimates have been derived based on detailed examination of the thin section and the bulk-rock composition. Care was taken to ensure that the thin section and the sample volume selected for whole-rock chemistry were similar in terms of featuring the same minerals in approximately the same abundances, to minimize any potential compositional differences. The *P–T* pseudosection for this sample was calculated over a *P–T* range of 5–10 kbar and 700–850 °C (Fig. 4). The solidus is located between 730 and 795 °C across the range of modelled pressures. Garnet is stable across the entire modelled *P–T* range. Cordierite has a maximum pressure stability of 6.6 kbar, and sillimanite is stable at pressures above 5 kbar at 730 °C and above 6.3 kbar at 850 °C. Biotite has a maximum temperature stability of about 825 °C at 5 kbar.

Mineral compositions are provided in Appendix 1 as an accompanying electonic file. Plagioclase compositions have Ca(Pl) [= Ca/(Ca + Na + K)] values between 0.122 – 0.145, with most values between 0.13 and 0.14. Garnets are almandine-rich, with Fe–Mg zoning ranging from XFe [= $Fe^{2+}/(Fe^{2+} + Mg)$] contents of 0.69 in the cores to 0.78 in the rims (Appendix 2). There is little zoning in p(Grs) [= $Ca/(Fe^{2+} + Mg + Ca + Mn)$] or p(Sps) [= $Mn/(Fe^{2+} + Mg + Ca + Mn)$] contents, with values of 0.015 and 0.01, respectively. Biotite compositions have XFe contents of 0.28 – 0.44 and Ti contents of 0.11 – 0.16 per formula unit (pfu).

Interpretation

Based on the coarse grain size and mineral associations that support textural equilibrium, the peak metamorphic assemblage is interpreted to include garnet, biotite, quartz, plagioclase, magnetite, ilmenite and melt. A small amount of sillimanite (1 – 2.5 mol%) is predicted with this assemblage, although the predicted modes are higher than the trace amount of Al_2SiO_5 observed in thin section. The predicted modes (molar proportions approximately equivalent to vol%) of the other minerals within the peak field are broadly similar to the modes observed in the thin section (Table 1). The inferred peak assemblage of garnet–biotite–sillimanite–plagioclase–magnetite–ilmenite–quartz–melt has a broad stability field between 740 and 820 °C at 6.3 – 9.7 kbar (Fig. 4). The peak field is delimited by the absence of biotite at higher temperatures, the stability of cordierite at lower pressure, and kyanite at higher pressure limits. At pressures > 10 kbar, magnetite is no longer stable.

Predicted mineral compositions within the garnet–biotite–sillimanite–plagioclase–magnetite–ilmenite–quartz–melt peak field are broadly similar to measured compositions (Appendices 1–3). Plagioclase has Ca(Pl) values mostly between 0.13 and 0.14, which are the same as the predicted values in the peak field. Garnet shows an increase in p(Alm) from core to rim that is consistent with a cooling path, although the measured compositions (= 0.69 – 0.78) in the rims to not match the predicted compositions, likely due to late Fe–Mg exchange. However, the measured p(Grs) content of 0.015 is similar to the predicted values at the lower pressure limit (< 7 kbar) of the peak assemblage field. The Ti content in biotite is sensitive to temperature, with decreasing values with a decrease in temperature. The predicted Ti values of biotite in the peak field are the same as the measured Ti contents (= 0.11 – 0.16). Although there is some uncertainty in the identification of the trace Al_2SiO_5 in thin section, these mineral compositions (and modes) are most consistent with equilibration in the sillimanite field.

Peak metamorphic conditions are estimated at 750–815 °C and 6.3 – 7.0 kbar, with an apparent thermal gradient between 80 and 125 °C/kbar. There is no information on the prograde and retrograde segments of the *P–T* path, and therefore the overall shape of the *P–T* path is not defined.

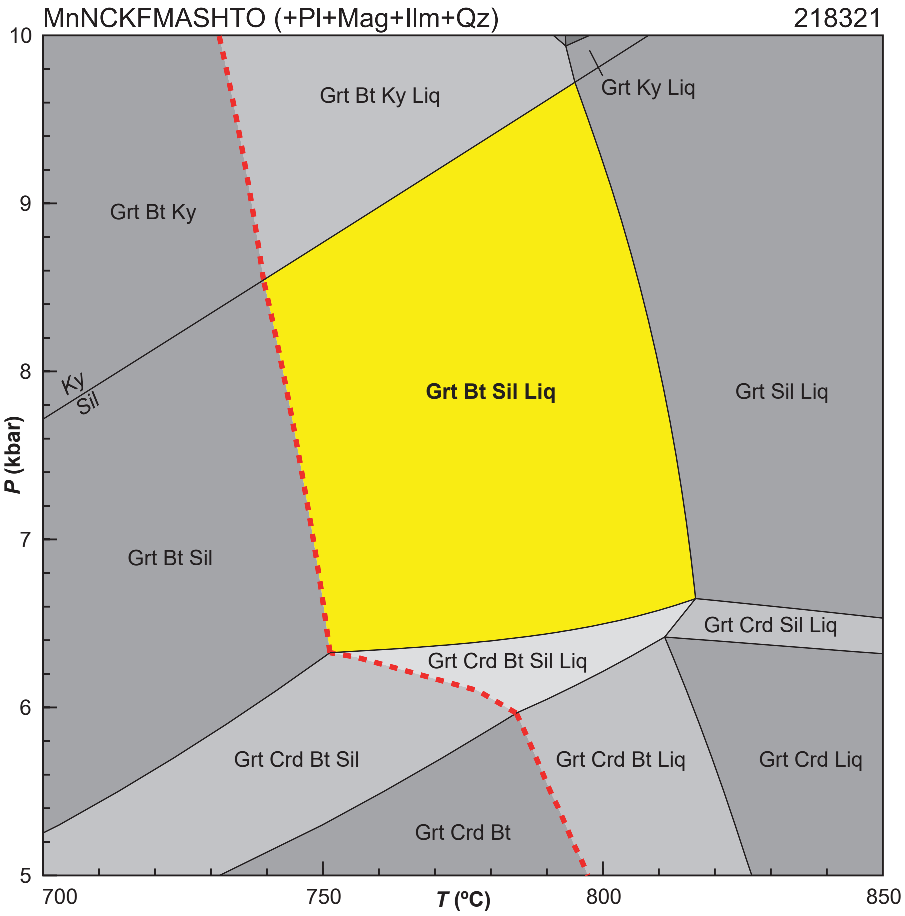

Figure 4. *P–T* pseudosection calculated for sample 218321: biotite–garnet semipelitic gneiss, Winnama Yard. Assemblage field corresponding to peak metamorphic conditions is shown in bold text and yellow shading. Red dashed line represents the solidus. Abbreviations: Bt, biotite; Crd, cordierite; Grt, garnet; Ilm, ilmenite; Ky, kyanite; Liq, silicate melt; Mag, magnetite; Pl, plagioclase; Qz, quartz; Sil, sillimanite

References

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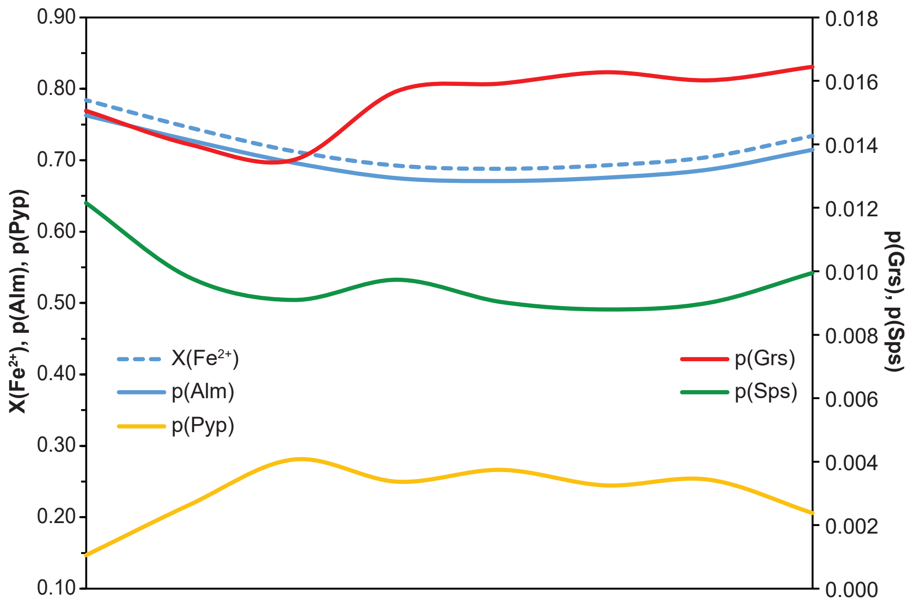
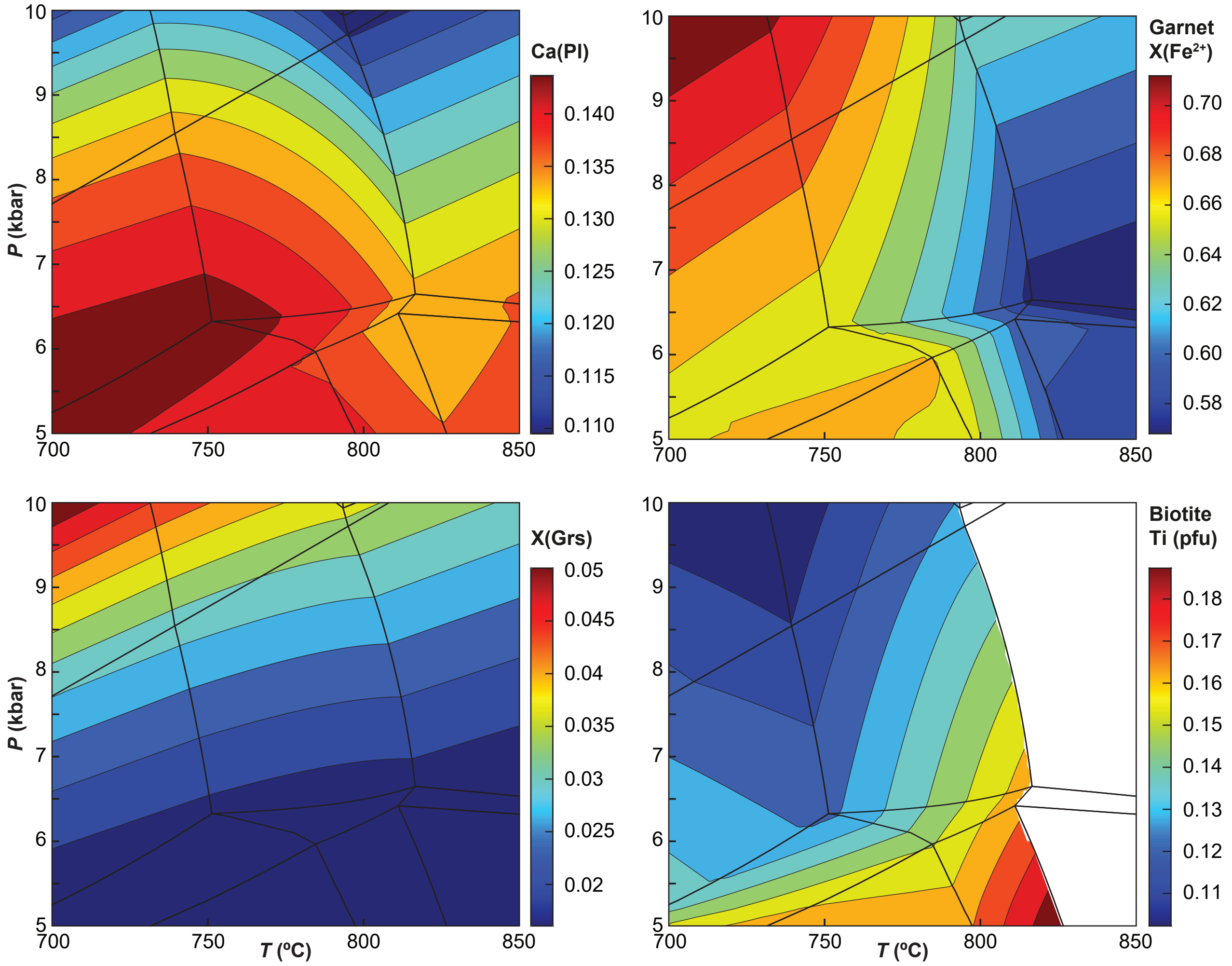
Appendix 2

Garnet compositional data from sample 218321: biotite–garnet semipelitic gneiss, Winnama Yard, obtained by electron probe microanalyser (EPMA). Full compositional data provided in Table 1. XFe = $Fe^{2+}/(Fe^{2+} + Mg)$; p(Alm) = $Fe^{2+}/(Fe^{2+} + Mg + Ca + Mn)$; p(Pyp) = $Mg/(Fe^{2+} + Mg + Ca + Mn)$; p(Grs) = $Ca/(Fe^{2+} + Mg + Ca + Mn)$; p(Sps) = $Mn/(Fe^{2+} + Mg + Ca + Mn)$



Appendix 3

Predicted mineral compositional data from sample 218321: biotite–garnet semipelitic gneiss, Winnama Yard. Labelled *P–T* pseudosection shown on Figure 4. Garnet compositional data defined in Appendix 1; Ca(Pl) = Ca/(Ca + Na + K)] in plagioclase; pfu, cations per formula unit based on 11 oxygens (biotite)



Links

Record 2020/14 The utility of the metamorphic rock record: constraining the pressure–temperature–time conditions of metamorphism

Appendix 1 (an accompanying electonic file on eBookshop)

Recommended reference for this publication

Korhonen, FJ, Romano, SS, Fielding, IOH, Kelsey, DE and Hollis, JA 2022, 218321: biotite–garnet semipelitic gneiss, Winnama Yard; Metamorphic History Record 21: Geological Survey of Western Australia, 8p.

Data obtained: 28 August 2019

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This Metamorphic History Record was last modified on 5 October 2022

Grid references in this publication refer to the Geocentric Datum of Australia 1994 (GDA94). All locations are quoted to at least the nearest 100 m.

WAROX is GSWA's field observation and sample database. WAROX site IDs have the format 'ABCXXXnnnnnnSS', where ABC = geologist username, XXX = project or map code, nnnnnn = 6 digit site number, and SS = optional alphabetic suffix (maximum 2 characters).

Isotope and element analyses are routinely conducted using the GeoHistory laser ablation ICP-MS and Sensitive High-Resolution Ion Microprobe (SHRIMP) ion microprobe facilities at the John de Laeter Centre (JdLC), Curtin University, with the financial support of the Australian Research Council and AuScope National Collaborative Research Infrastructure Strategy (NCRIS). The TESCAN Integrated Mineral Analyser (TIMA) instrument was funded by a grant from the Australian Research Council (LE140100150) and is operated by the JdLC with the support of the Geological Survey of Western Australia, The University of Western Australia (UWA) and Murdoch University. Mineral analyses are routinely obtained using the electron probe microanalyser (EPMA) facilities at the Centre for Microscopy, Characterisation and Analysis, UWA, at Adelaide Microscopy, University of Adelaide, and at the Electron Microscopy and X-ray Microanalysis Facility, University of Tasmania.

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