198551: quartzofeldspathic gneiss, Donnelly River

(South West Terrane, Yilgarn Craton)

Blereau, ER, Kelsey, DE and Korhonen, FJ

Location and sampling

PEMBERTON (SI 50-10), DONNELLY (2029)

MGA Zone 50, 389800E 6200700N

Warox Site FJKBGD198551

Sampled on 2 November 2010

This sample was a river cobble collected from the Donnelly River, about 39 km south of Nannup, 25 km northwest of Pemberton, and 2.4 km east of the Vasse Highway–Spencer Road intersection. The sample was collected as part of the Yilgarn Craton Metamorphic Project (2003–14) undertaken by Ben Goscombe for the Geological Survey of Western Australia (GSWA), and referred to in that study as sample BG10-28a. The results from this project have not been released by GSWA, although select data have been published in Goscombe et al. (2019).

Tectonic unit

The unit sampled is a quartzofeldspathic gneiss from the southwestern corner of the South West Terrane, within a belt of Archean metasedimentary and gneissic rocks referred to by Wilde (2001) as the informally named 'Balingup Terrane'. The sample locality is about 3 km east of the inferred position of the Darling Fault. A pelitic gneiss, sampled about 120 km to the north, and about 4 km east of the Darling Fault, yielded detrital zircon ages between c. 3296 and 1402 Ma, a conservative maximum depositional age of 1654 ± 35 Ma, and ages of metamorphism of c. 891 and 707 Ma (GSWA 198532; Wingate et al., 2014). Zircon dating of the sample reported here yielded inherited ages along a discordia up to 2.6 Ga, with four metamorphic zircon rims scattered along concordia between 1071–643 Ma and a second metamorphic population of zircon rims with a concordia age at 620 ± 6 Ma (GSWA 198551; Lu et al., 2015). Monazite dating of four samples 25 to 26 km to the northeast yielded metamorphic ages of 1144 ± 11 Ma (1σ), 1148 ± 5 Ma, 1148 ± 13 Ma, 1189 ± 5 Ma (GSWA 224767, GSWA 224771, GSWA 224777, GSWA 224779, preliminary data), and one of those samples also yielded an older metamorphic age of 1841 ± 5 Ma (GSWA 224777, preliminary data).

Petrographic description

The sample is a mylonitic quartzofeldspathic gneiss containing 55% plagioclase, 25% quartz, 6% hornblende, 3% K-feldspar, 3% biotite and trace amounts of apatite, zircon and an unidentified rare earth element silicate mineral (?chevkinite) (Table 1). Porphyroclasts of dark green hornblende, feldspar and strained quartz are 1–2 mm in diameter, surrounded by fine-grained, quartzofeldspathic matrix (Figs 1, 2). Hornblende porphyroclasts are elongate in the fabric (Figs 1, 2). Hornblende contains rare inclusions of quartz, plagioclase, apatite, biotite and, within fractures, the unidentified rare earth element mineral. Porphyroclasts and the matrix together define a seriate–interlobate texture (Fig. 1). The matrix consists of interlobate–polygonal-textured, fine-grained, anhedral quartz, plagioclase, K-feldspar and hornblende with interstitial brown biotite that defines a mylonitic fabric (Figs 1, 2). Coarser grained biotite occurs partially mantling the coarsest grained hornblende porphyroclasts (Fig. 1). Rounded and elongate grains of zircon and an unidentified rare earth element mineral occur throughout the rock.

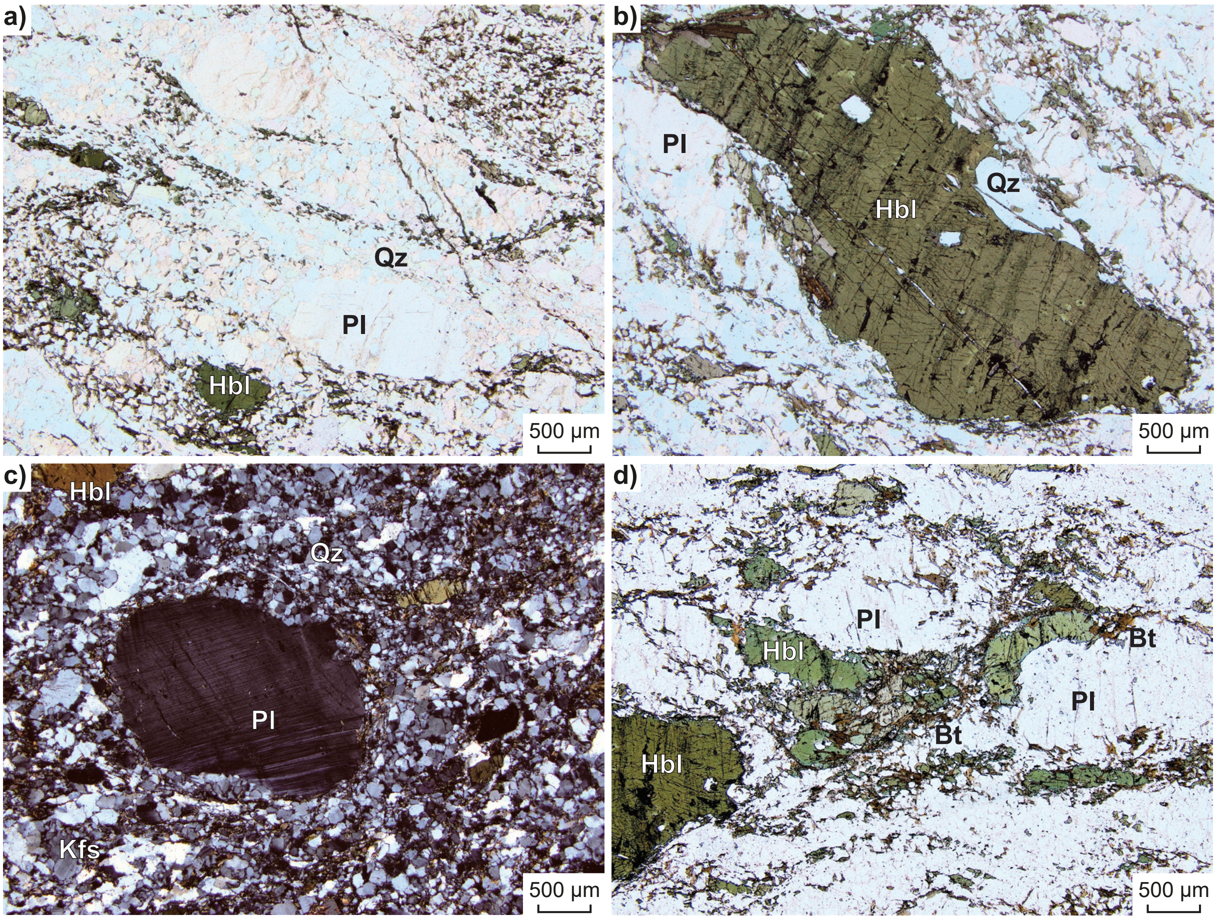

Figure 1. Photomicrographs, in plane-polarized (a, b, d) and cross-polarised (c) light, of sample 198551: quartzofeldspathic gneiss, Donnelly River. Mineral abbreviations are explained in the caption to Figure 3

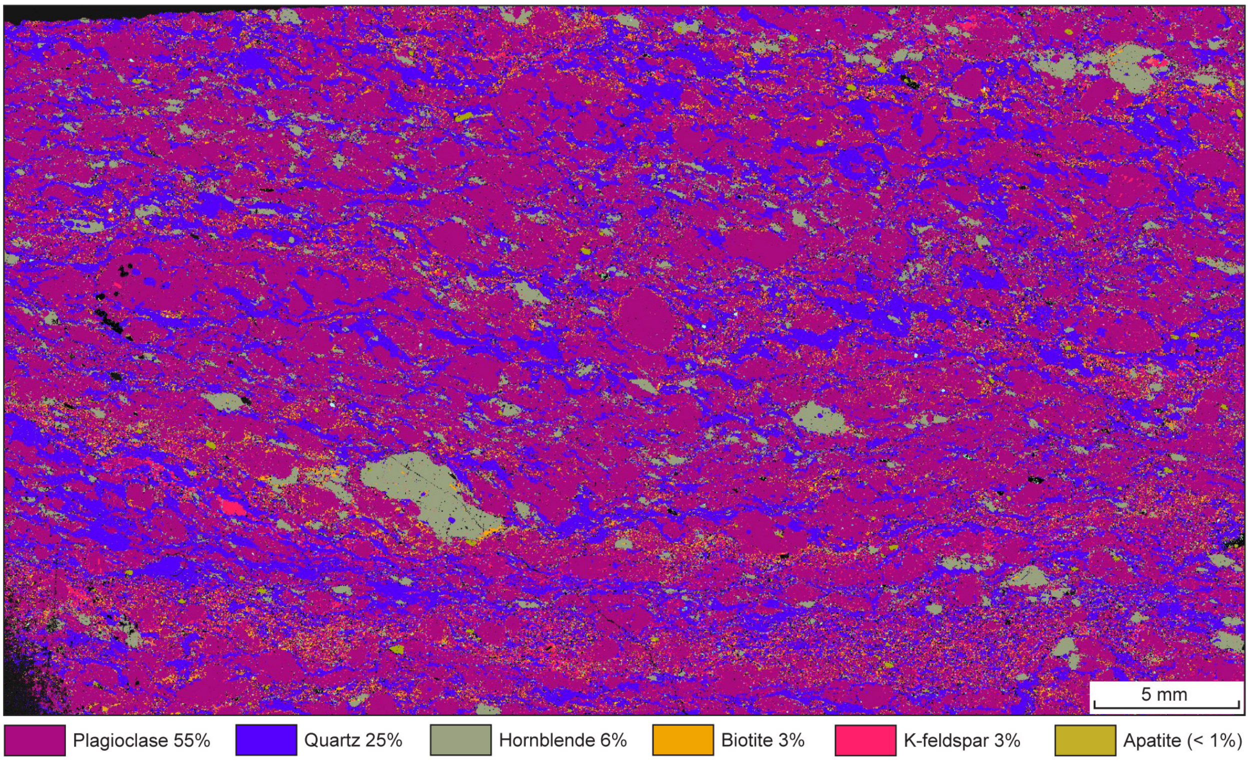

Figure 2. TESCAN Integrated Mineral Analyser (TIMA) image of an entire thin section from sample 198551: quartzofeldspathic gneiss, Donnelly River. Volume percent proportion of major rock-forming minerals are calculated by the TIMA software

Table 1. Mineral modes for sample 198551: quartzofeldspathic gneiss, Donnelly River

Mineral modes	Pl	Qz	Hbl	Bt	Kfs	Ap	Ttn	Mag	Liq
Observed (vol%)[(a)]	55	25	6	3	3	<1	–	–	–
Predicted (mol%)									
@ 890 °C, 4.1 kbar	55	24	8	5	7	–	0.4	0.5	9
@ 890 °C, 6.2 kbar	53	24	11	4	8	–	0.4	trace	11

NOTES: (a) trace zircon and ?chevkinite also present in thin section
– not present

Methodology and analytical details

Preliminary *P–T* estimates were obtained using multiple-reaction thermobarometry calculated from the mineral compositions (Table 2; Goscombe et al., 2015). These estimates were derived from the 'averagePT' module (avPT) in the program THERMOCALC version tc325 (Powell and Holland, 1988), using the internally consistent Holland and Powell (1998) dataset.

The metamorphic evolution of this sample has been subsequently re-evaluated using phase equilibria modelling, based on the bulk-rock composition (Table 3). The bulk-rock composition was determined by X-ray fluorescence spectroscopy, together with loss on ignition (LOI). The modelled O content (for Fe^{3+}) was set to be 20% of measured total Fe. The modelled H_2O content is the measured LOI. The bulk composition was corrected for the presence of apatite by applying a correction to calcium (Table 1). Thermodynamic calculations were performed in the NCKFMASHTO (Na_2O–CaO–K_2O–FeO–MgO–Al_2O_3–SiO_2–H_2O–TiO_2–O) system using THERMOCALC version tc340 (Powell and Holland, 1988; updated October 2013) and the internally consistent thermodynamic dataset of Green et al. (2016; version dataset tc-ds63, created January 2015). The activity–composition relations used in the modelling are detailed in Green et al. (2016), with the augite model used for clinopyroxene. Additional information on the workflow with relevant background and methodology are provided in Korhonen et al. (2020).

Table 2. Mineral compositions for sample 198551: quartzofeldspathic gneiss, Donnelly River

Mineral[(a)]	Hbl	Hbl	Hbl	Hbl	Pl	Pl	Pl	Pl	Kfs	Kfs	Bt
Setting	Core	Rim	Core	Rim	Core	Core	Rim	Core	Core	Core	Core
wt%											
SiO_2	40.89	40.11	40.70	40.76	60.74	62.08	62.20	61.42	64.39	63.79	35.57
TiO_2	1.81	1.51	1.54	1.30	0.00	0.01	0.00	0.02	0.03	0.05	3.56
Al_2O_3	11.36	12.33	12.42	12.36	24.36	24.09	23.92	24.95	18.42	18.25	14.84
Cr_2O_3	0.05	0.02	0.00	0.02	0.01	0.04	0.01	0.03	0.00	0.00	0.06
FeO	20.77	21.18	20.66	20.81	0.19	0.03	0.07	0.17	0.03	0.15	22.32
MnO	0.35	0.33	0.34	0.37	0.00	0.00	0.01	0.00	0.00	0.00	0.20
MgO	6.87	6.54	6.94	6.93	0.03	0.00	0.00	0.01	0.00	0.00	9.26
ZnO	0.02	0.05	0.00	0.03	0.02	0.00	0.06	0.11	0.06	0.09	0.11
CaO	11.47	11.50	11.60	11.63	6.58	5.68	5.35	6.23	0.00	0.00	0.00
Na_2O	1.47	1.27	1.24	1.21	8.03	8.29	8.41	8.22	0.94	0.83	0.07
K_2O	1.62	1.76	1.68	1.69	0.20	0.33	0.31	0.16	15.24	15.28	9.70
Total[(b)]	96.67	96.59	97.12	97.12	100.17	100.54	100.33	101.32	99.11	98.44	95.70
Oxygen	23	23	23	23	8	8	8	8	8	8	11
Si	6.30	6.20	6.23	6.24	2.70	2.74	2.75	2.70	3.00	2.99	2.75
Ti	0.21	0.18	0.18	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.21
Al	2.06	2.25	2.24	2.23	1.28	1.25	1.25	1.29	1.01	1.01	1.35
Cr	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe^{3+}[(c)]	0.62	0.66	0.62	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.07
Fe^{2+}	2.05	2.08	2.03	2.00	0.01	0.00	0.00	0.01	0.00	0.01	1.37
Mn^{2+}	0.05	0.04	0.04	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Mg	1.58	1.51	1.58	1.58	0.00	0.00	0.00	0.00	0.00	0.00	1.07
Zn	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Ca	1.89	1.90	1.90	1.91	0.31	0.27	0.25	0.29	0.00	0.00	0.00
Na	0.44	0.38	0.37	0.36	0.69	0.71	0.72	0.70	0.09	0.08	0.01
K	0.32	0.35	0.33	0.33	0.01	0.02	0.02	0.01	0.90	0.91	0.96
Total	15.53	15.54	15.51	15.51	5.00	5.00	5.00	5.00	5.00	5.00	7.81
Compositional variables											
XFe[(d)]	0.57	0.58	0.56	0.56	–	–	–	–	–	–	0.56

NOTES: – not applicable
(a) Mineral abbreviations explained in the caption to Figure 2
(b) Totals on anhydrous basis
(c) Hornblende cations calculated following Holland and Blundy (1994); biotite Fe^{3+} assumed to be 10% of total Fe
(d) $XFe = Fe^{2+}/(Fe^{2+} + Mg)$

Table 3. Measured whole-rock and modelled compositions for sample 198551: quartzofeldspathic gneiss, Donnelly River

XRF whole-rock composition (wt%)[(a)]												
SiO_2	**TiO_2**	**Al_2O_3**	**Fe_2O_3**	**FeO[(b)]**	**MnO**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**P_2O_5**	**LOI**	**Total**
66.20	0.44	17.30	–	3.64	0.04	1.17	4.98	4.47	1.86	0.11	0.35	100.56
Normalized composition used for phase equilibria modelling (mol%)												
SiO_2	**TiO_2**	**Al_2O_3**	**O[(c)]**	**FeO^{T}[(d)]**	**MnO**	**MgO**	**CaO[(e)]**	**Na_2O**	**K_2O**	--	**H_2O[(f)]**	**Total**
70.93	0.35	10.92	0.29	2.93	–	1.87	5.55	4.54	1.27		1.25	99.9

NOTES: (a) Data from Goscombe unpublished metamorphic study
(b) FeO content is total Fe
(c) O content (for Fe_2O_3) set to be 20% of FeO (b)
(d) CaO modified to remove apatite: CaO(Mod) = CaO(Total) - (moles CaO(in Ap) = 3.33 * moles P_2O_5)
(e) H_2O content is LOI
– not applicable

Results

Metamorphic *P–T* estimates have been derived based on detailed examination of one thin section and the bulk-rock composition (Table 3); 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 (Table 1), to minimize any potential compositional differences. At the scale of the thin section the sample is homogeneous. The *P–T* pseudosection was calculated over a pressure–temperature range of 3–10 kbar and 500–850 °C (Fig. 3). The solidus is located at 590–685 °C across the modelled pressure window. Rutile is stable above 6.4 kbar at 500 °C and 10 kbar at 670 °C. Garnet is stable above 5.0 kbar at 500 °C and 8.2 kbar at 825 °C. Titanite is stable to lower temperatures than 650 °C at 4 kbar and 800 °C at 10 kbar. Above the solidus titanite stability is limited and ilmenite stability is more widespread. Biotite stability occurs to 830 °C. Magnetite is stable below 7 kbar across the modelled temperature window. Clinopyroxene (augite) is not stable in the low-temperature–high-pressure part of the modelled *P–T* range (Fig. 3).

Metamorphic *P–T* estimates (± 2σ uncertainty) calculated using multiple-reaction thermobarometry are 5.5 ± 0.5 kbar and 587 ± 9 °C (Goscombe et al., 2015). These calculations used the mineral core compositions (Table 2) to estimate peak conditions. Conventional thermobarometry using hornblende–plagioclase and Al-in-hornblende yielded results of 650 °C and 6.5 kbar (Goscombe et al., 2015).

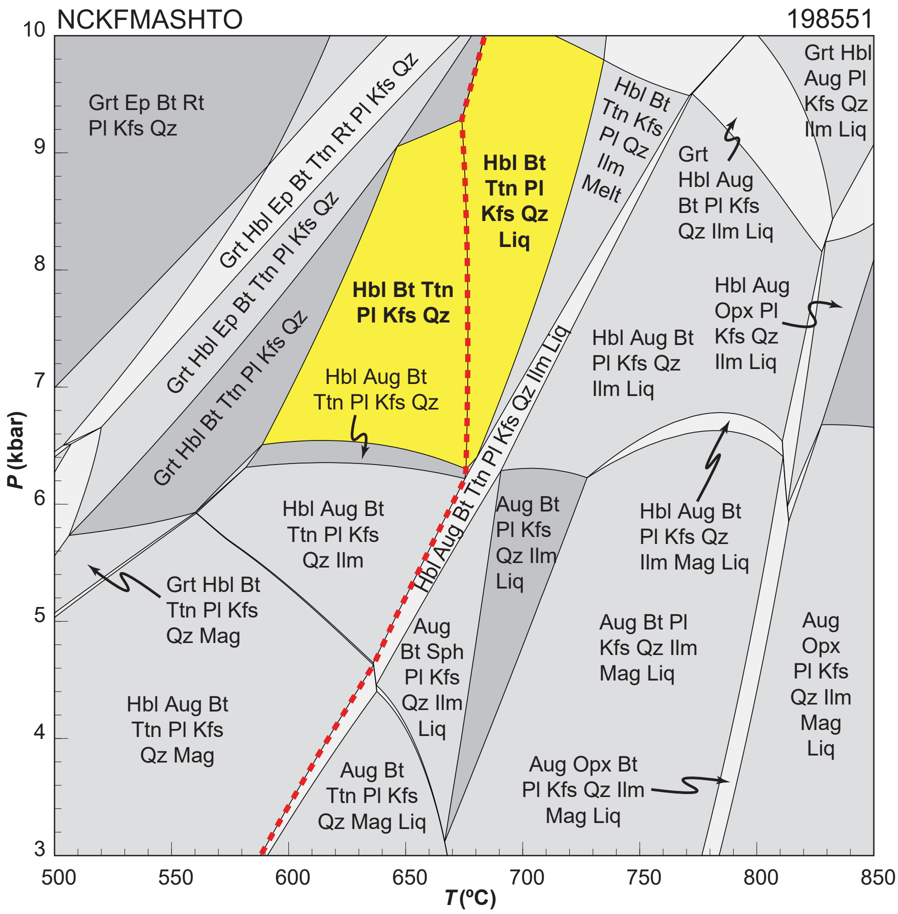

Figure 3. ***P–T*** **pseudosection calculated for sample 198551: quartzofeldspathic gneiss, Donnelly River. Assemblage fields corresponding to peak metamorphic conditions are shown in bold text and yellow shading. Red dashed line represents the solidus. Abbreviations: Aug, augite; Bt, biotite; Ep, epidote; Grt, garnet, Hbl, hornblende; Ilm, ilmenite; Kfs, K-feldspar; Liq, silicate melt; Mag, magnetite; Opx, orthopyroxene; Pl, plagioclase; Qz, quartz; Rt, rutile; Ttn, titanite**

Interpretation

The interpreted peak assemblage is hornblende–biotite–plagioclase–K-feldspar–quartz(–partial melt). The absence of pyroxene from the sample suggests *P–T* conditions were >6.6 kbar and <770 °C. Titanite stability is predicted as part of such assemblages but it does not occur in the sample. The calculated mode of titanite in these fields is very low, at 0.3 – 0.45 vol%, and could reflect the inability of the biotite and hornblende activity–composition models to accommodate sufficient TiO_2. The peak assemblage is conservatively interpreted to constrain *P–T* conditions of 6.3 to >10 kbar and 590–740 °C, straddling the solidus, and is shown as yellow-shaded fields in Figure 2.

The complex geochronology from this sample suggests a strong likelihood of a polymetamorphic mineral assemblage. Coarser grained biotite partially mantling hornblende may reflect later growth of some or all biotite, potentially contemporaneous with mylonitisation. Conventional thermobarometry estimates occur to lower pressure and temperature than the yellow-shaded fields in Figure 2 and may highlight a cooling and decreasing pressure path followed during mylonitisation. However, there is very limited petrologic information on the *P–T* path shape and trajectory.

Peak metamorphic conditions are conservatively estimated at 590–740 °C and a minimum pressure of 6.3 kbar, with an apparent thermal gradient between 70 and 110 °C/kbar.

References

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Links

Metamorphic history introduction document: Intro_2020.pdf

Recommended reference for this publication

Blereau, ER, Kelsey, DE, Korhonen, FJ 2021, 198551: quartzofeldspathic gneiss, Donnelly River; Metamorphic History Record 8: Geological Survey of Western Australia, 7p.

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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 at UWA, and at Adelaide Microscopy, University of Adelaide.

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