

224777: kyanite–garnet–staurolite schist, Kingsley prospect

(South West Terrane, Yilgarn Craton)

Location and sampling

PEMBERTON (SI 50-10), DONNELLY (2029)
MGA Zone 50, 406593E 6219459N

Sampled on 13 April 2017

This sample was collected from the 117.8 – 118.2 m depth interval of diamond drillcore WPD04, drilled in 2004 by Teck Cominco Australia Pty Ltd at their Kingsley prospect (Griggs, 2004; Hassan, 2017). The drillhole is located about 25 km south-southwest of Bridgetown, 17.3 km west-northwest of Manjimup, and 7.3 km southeast of Mount Mack.

Geological context

The unit sampled is a kyanite–garnet–staurolite schist in the southwestern corner of the South West Terrane of the Yilgarn Craton (Quentin de Gromard et al., 2021), within a belt of Archean metasedimentary and gneissic rocks referred to by Wilde et al. (2001) as the Balingup Metamorphic Belt. This sample was collected to constrain the timing of metamorphism. Monazites from garnet–kyanite schist at about 174 m depth in this drillcore yielded an age for metamorphism of 1189 ± 5 Ma (GSWA 224779, Fielding et al., 2022c). Zircons from amphibolite in drillcore WPD01, about 0.3 km to the southwest, yielded a zircon $^{207}\text{Pb}^*/^{206}\text{Pb}^*$ date of 1179 ± 6 Ma, interpreted as either the crystallization age of an igneous protolith, or the age of metamorphism (GSWA 229286, Wingate et al., 2021). Disseminated sulfide mineralization in drillcores WPD01 and WPD02 indicated Pb isotope model ages of c. 2710 and 2690 Ma, respectively (Denton et al., 2003 in Hassan, 2017), and detrital zircons from a strongly deformed metasandstone in drillcore WPD02 yielded a maximum depositional age of c. 2646 Ma (GA 2004968001A, Sircombe et al., 2007). Monazites from a kyanite–garnet schist, about 0.3 km to the southwest in drillcore WPD01, yielded ages for metamorphism of c. 1144 and 1041 Ma (GSWA 224767, Fielding et al., 2022a). Monazites from garnet–kyanite schist, about 1.2 km to the east-northeast in drillcore WPD02, yielded ages for metamorphism of c. 1147 and 1037 Ma (GSWA 224771, Fielding et al., 2022b).

Petrographic description

The sample is a kyanite–garnet–staurolite schist (Fig. 1), consisting of about 55–60% quartz, 25–30% biotite, 8% kyanite, 2% garnet, 2% staurolite and trace albite, muscovite, apatite, magnetite, monazite and zircon.

Quartz makes up most of the matrix but also forms inclusions within garnet porphyroblasts. Biotite forms laths up to 2 mm long associated with quartz and kyanite in the matrix, where they define a weak, anastomosing foliation, as well as rare inclusions within garnet. Kyanite is anhedral to subhedral, up to 4 mm in size, and occurs in aggregates up to 6 mm in size. Anhedral and elongate garnet porphyroblasts up to 8 mm in diameter are weakly wrapped by biotite with small pressure shadows. Garnet is not in contact with staurolite and is only rarely in contact with kyanite. Staurolite in the matrix is associated with kyanite, and up to 2 mm in size, and also forms anhedral inclusions up to 3 mm across within garnet. Garnet appears to have grown at the same time or later than kyanite and staurolite, and staurolite, kyanite and garnet were in stable coexistence at the peak of metamorphism. Magnetite is associated with biotite, and muscovite forms prismatic to acicular grains with no preferred orientation. Albite forms very fine-grained inclusions in kyanite. The interpreted peak metamorphic assemblage is garnet–kyanite–staurolite–biotite–quartz–magnetite.

Monazite characteristics

Monazites from this sample are colourless to pale yellow, anhedral, and up to 100 μm long. In high-contrast backscattered electron (BSE) images, some monazites exhibit non-concentric complex internal structures. BSE images of representative monazites are shown in Figure 2. Monazites occur in two groups (Groups M and M2) based on their U–Pb ages (described below) and rare earth element (REE) characteristics. Monazites from Groups M and M2 show no distinctive textural setting and are associated with biotite, kyanite, quartz and staurolite in the matrix of the sample. REE data were collected at the same time, and from the same volume, as the U–Pb data (Fig. 3). Group M monazite has chondrite-normalized Eu/Eu^* ($\text{Eu}/[\text{Sm} \times \text{Gd}]$) of 0.99 – 1.05, and chondrite-normalized La/Sm of 6.56 – 7.11 and Gd/Yb of 233–579. Group M2 monazites have chondrite-normalized Eu/Eu^* of 1.08, and steeper heavy-REE profiles with chondrite-normalized La/Sm of 7.03 – 7.97 and Gd/Yb of 227–870.

Analytical details

This sample was analysed in polished thin section on 26 September 2018, using the laser ablation split stream inductively coupled plasma mass spectrometry (LA-SS-ICP-MS) system at the GeoHistory Facility in the John de Laeter Centre, Curtin University. Monazites were ablated using a Resonetics RESolution M-50A-LR sampling system, incorporating a 193 nm Compex 102 excimer laser.

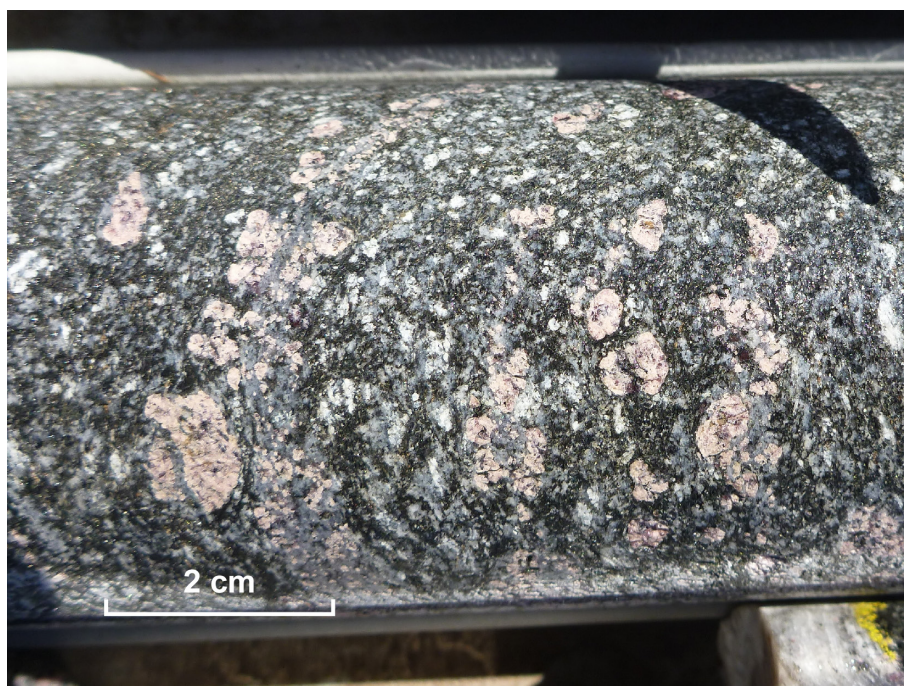


Figure 1. Drillcore image (wet surface) of sample 224777: kyanite–garnet–staurolite schist, Kingsley prospect

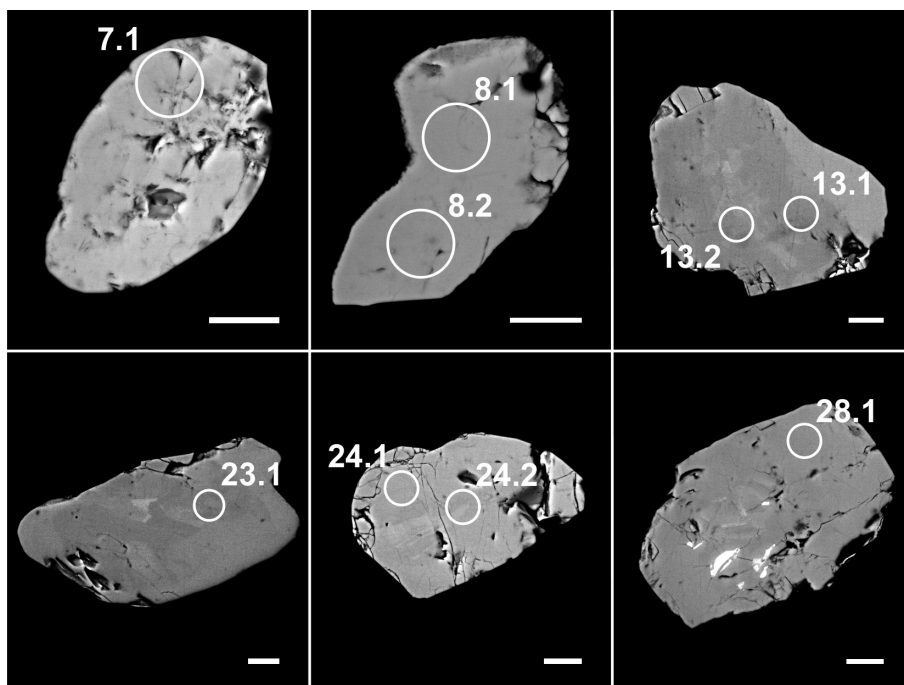


Figure 2. BSE images of representative monazites from sample 224777: kyanite–garnet–staurolite schist, Kingsley prospect. Numbered circles indicate the approximate locations of analysis sites; scale bars are 10 μm

Table 1. LA-SS-ICP-MS analytical results for monazites from sample 224777: kyanite–garnet–staurolite schist, Kingsley prospect

Group ID	Spot no.	Grain. spot	²³⁸ U (ppm)	²³² Th (ppm)	²³² Th / ²³⁸ U	²³⁸ U/ ²⁰⁶ Pb ± 1σ	²⁰⁷ Pb/ ²⁰⁶ Pb ± 1σ	²³⁸ U/ ²⁰⁶ Pb date (Ma) ± 1σ	²⁰⁷ Pb/ ²⁰⁶ Pb date (Ma) ± 1σ	Disc. (%)				
M	62	14.2	6150	41100	6.68	3.041	0.046	0.11050	0.00085	1833	24	1808	14	-1.4
M	93	23.1	5000	33200	6.64	3.006	0.037	0.11134	0.00060	1851	20	1821	10	-1.6
M	22	4.1	11000	34200	3.11	3.002	0.037	0.11156	0.00065	1853	20	1825	11	-1.6
M	59	13.2	7100	31100	4.38	3.103	0.042	0.11180	0.00060	1801	21	1829	10	1.5
M	2	1.1	4830	92100	19.07	3.111	0.035	0.11191	0.00065	1797	18	1831	11	1.9
M	68	15.3	7100	23100	3.25	3.013	0.045	0.11222	0.00060	1848	24	1836	10	-0.6
M	98	26.1	3790	51400	13.56	3.092	0.041	0.11240	0.00060	1806	21	1839	10	1.8
M	85	21.1	3760	23600	6.28	2.989	0.034	0.11241	0.00060	1861	19	1839	10	-1.2
M	45	9.1	13600	80000	5.88	3.135	0.049	0.11246	0.00070	1785	24	1840	11	3.0
M	70	16.1	10290	23500	2.28	3.037	0.039	0.11263	0.00060	1835	21	1842	10	0.4
M	36	5.3	8930	20600	2.31	3.053	0.039	0.11265	0.00065	1826	20	1843	10	0.9
M	79	19.1	5600	42500	7.59	3.085	0.040	0.11266	0.00060	1810	20	1843	10	1.8
M	83	20.1	6940	39700	5.72	3.070	0.036	0.11274	0.00060	1818	18	1844	10	1.4
M	100	27.1	6630	43400	6.55	3.096	0.041	0.11286	0.00060	1804	21	1846	10	2.3
M	40	7.1	9370	44000	4.70	3.100	0.038	0.11301	0.00065	1802	19	1848	10	2.5
M	54	11.1	15400	31000	2.01	3.087	0.037	0.11323	0.00065	1809	19	1852	10	2.3
M	58	13.1	13160	20600	1.57	3.165	0.041	0.11325	0.00060	1770	20	1852	10	4.4
M	71	16.2	10200	18840	1.85	3.036	0.042	0.11335	0.00065	1835	22	1854	10	1.0
M	73	17.1	13200	38300	2.90	2.938	0.043	0.11392	0.00075	1889	24	1863	12	-1.4
M2	61	14.1	25400	44200	1.74	5.456	0.071	0.07716	0.00060	1085	13	1125	15	3.6
M2	39	6.3	18700	51400	2.75	5.271	0.061	0.07764	0.00044	1120	12	1138	11	1.6
M2	33	5.1	20400	65500	3.21	5.225	0.059	0.07773	0.00045	1129	12	1140	11	1.0
M2	34	5.2	19800	60200	3.04	5.040	0.074	0.07798	0.00046	1167	16	1146	12	-1.8
M2	55	12.1	26100	46000	1.76	5.187	0.069	0.07818	0.00046	1137	14	1151	12	1.3
M2	43	8.2	23000	62600	2.72	5.371	0.062	0.07826	0.00046	1101	12	1153	12	4.6
M2	94	24.1	13820	50000	3.62	5.136	0.061	0.07898	0.00044	1147	12	1172	11	2.1
M2	75	18.1	28500	48400	1.70	5.233	0.064	0.07937	0.00047	1127	13	1181	12	4.6

Table 1. continued

Group ID	Spot no.	Grain. spot	²³⁸ U (ppm)	²³² Th (ppm)	²³² Th / ²³⁸ U	²³⁸ U/ ²⁰⁶ Pb ± 1σ		²⁰⁷ Pb/ ²⁰⁶ Pb ± 1σ		²³⁸ U/ ²⁰⁶ Pb date (Ma) ± 1σ		²⁰⁷ Pb/ ²⁰⁶ Pb date (Ma) ± 1σ		Disc. (%)
P	88	22.1	16100	48000	2.98	6.158	0.076	0.07279	0.00044	970	11	1008	12	3.8
P	14	3.1	9830	25200	2.56	3.362	0.040	0.10510	0.00085	1678	18	1716	15	2.2
P	24	4.3	7580	23100	3.05	3.145	0.039	0.10778	0.00060	1780	19	1762	10	-1.0
P	10	2.1	7590	30200	3.98	3.096	0.044	0.10780	0.00080	1804	22	1763	14	-2.4
P	23	4.2	11000	29300	2.66	3.246	0.045	0.10845	0.00065	1731	21	1774	11	2.4
P	53	10.3	4900	59000	12.04	3.077	0.066	0.10890	0.00085	1814	34	1781	14	-1.9
P	96	25.1	4000	47400	11.85	3.215	0.043	0.10901	0.00065	1746	20	1783	11	2.1
P	38	6.2	9430	21900	2.32	3.139	0.054	0.10990	0.00100	1783	27	1798	17	0.8
P	3	1.2	4480	63000	14.06	3.071	0.040	0.11025	0.00060	1817	20	1804	10	-0.7
P	46	9.2	10300	47400	4.60	3.269	0.049	0.11045	0.00060	1720	23	1807	10	4.8
P	67	15.2	12100	44100	3.64	3.151	0.048	0.11052	0.00075	1777	23	1808	12	1.7
P	49	9.4	11500	55000	4.78	3.220	0.047	0.11072	0.00060	1744	22	1811	10	3.7
D	51	10.2	19000	46700	2.46	4.926	0.069	0.08110	0.00065	1191	15	1224	16	2.7
D	86	21.2	7270	29000	3.99	7.032	0.101	0.06922	0.00040	857	12	905	12	5.3
D	42	8.1	24640	65300	2.65	5.362	0.068	0.07888	0.00046	1102	13	1169	11	5.7
D	56	12.2	22500	73100	3.25	5.274	0.063	0.08071	0.00047	1119	12	1214	11	7.8
D	37	6.1	13140	41700	3.17	4.885	0.073	0.08443	0.00065	1201	16	1302	15	7.8
D	50	10.1	25900	70400	2.72	4.427	0.060	0.09126	0.00050	1313	16	1452	10	9.6
D	102	28.1	9570	49500	5.17	3.584	0.044	0.10480	0.00060	1586	17	1711	11	7.3
D	95	24.2	5730	52000	9.08	3.350	0.056	0.10863	0.00065	1684	25	1777	11	5.2
D	4	1.3	4470	84000	18.79	2.843	0.044	0.11110	0.00060	1943	26	1817	10	-6.9
D	48	9.3	16600	63400	3.82	3.262	0.048	0.11254	0.00075	1724	22	1841	12	6.3
D	64	14.3	13600	47200	3.47	3.208	0.041	0.11342	0.00070	1749	19	1855	11	5.7
D	66	15.1	24200	44500	1.84	3.224	0.036	0.11420	0.00065	1742	17	1867	10	6.7

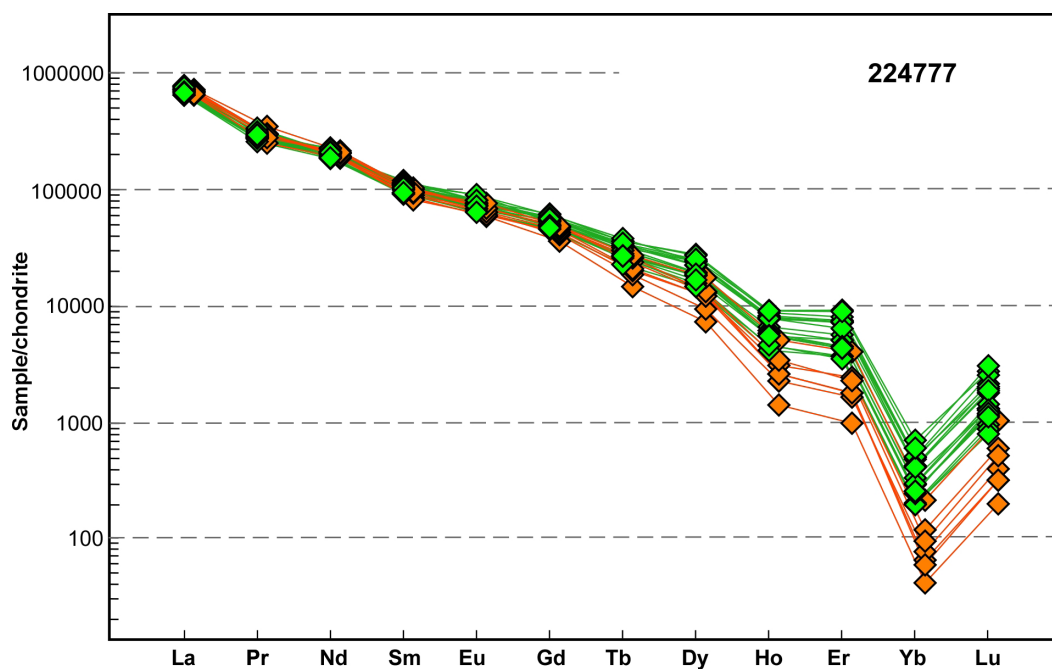


Figure 3. Chondrite-normalized REE diagram for monazites from sample 224777: kyanite–garnet–staurolite schist, Kingsley prospect. Green diamonds indicate Group M (metamorphic monazite); orange diamonds indicate Group M2 (younger metamorphic monazites). Normalization values are from Sun and McDonough (1989)

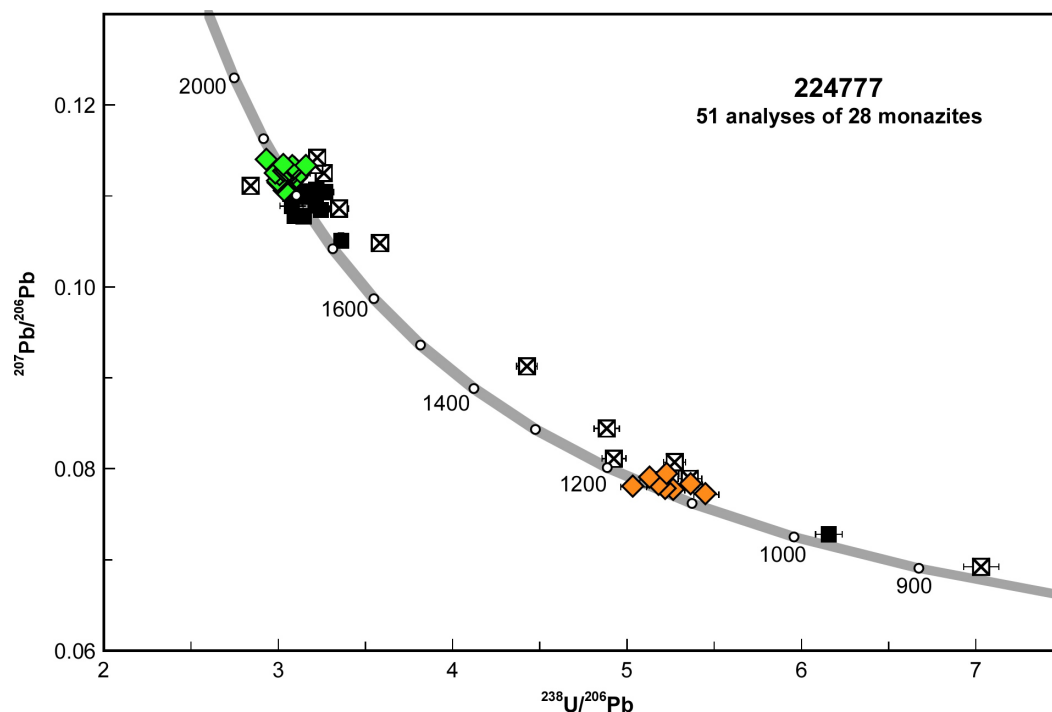


Figure 4. U–Pb analytical data, not corrected for common Pb, for monazites from sample 224777: kyanite–garnet–staurolite schist, Kingsley prospect. Green diamonds indicate Group M (metamorphic monazites); orange diamonds indicate Group M2 (younger metamorphic monazites); black square indicates Group P (radiogenic Pb-loss); crossed squares indicate Group D (discordance >5%, or mixtures of Group M and M2 monazite)

The ablated product was split evenly between a Nu Plasma II multi-collector ICP-MS, to measure ion signal intensities, and an Agilent 7700x quadrupole MS to measure trace element abundances. Samples were ablated for 20 s at a 4 Hz repetition rate, using a 7 µm beam diameter and laser energy of 0.8 J/cm². Monazite standard 44069 was used as the primary reference material, and secondary standards included Stern and a suite of well-characterized in-house monazite standards. Additional analytical details are provided in Wingate et al. (2022). Data for this sample are not corrected for common Pb. All propagated uncertainties are included in the errors of isotope ratios and dates listed in Table 1.

Results

Fifty-one analyses were obtained from 28 monazites. Results are listed in Table 1, and shown in a concordia diagram (Fig. 4).

Interpretation

The analyses are concordant to moderately discordant (Fig. 4). Eleven analyses are >5% discordant and one is interpreted to reflect a mixture of Group M and M2 monazite or possibly loss of radiogenic Pb. The dates obtained from these 12 analyses (Group D; Table 1) are unreliable, and are considered not to be geologically significant. The remaining 39 analyses can be divided into three groups, based on their ²⁰⁷Pb/²⁰⁶Pb ratios and REE characteristics (described above).

Group M comprises 19 analyses of 17 monazites (Table 1), which yield a weighted mean ²⁰⁷Pb/²⁰⁶Pb date of 1840 ± 6 Ma (MSWD = 1.3).

Group M2 comprises eight analyses of seven monazites (Table 1), which yield a weighted mean ²⁰⁷Pb/²⁰⁶Pb date of 1153 ± 15 Ma (MSWD = 2.2).

Group P comprises 12 analyses of 10 monazites (Table 1) which yield ²⁰⁷Pb/²⁰⁶Pb dates of 1811–1008 Ma.

The date of 1840 ± 6 Ma for the 19 analyses in Group M is interpreted as the age of metamorphism. The date of 1153 ± 15 Ma for the seven analyses in Group M2 is interpreted as the age of a younger metamorphic event. The dates of 1811–1008 Ma for the 12 analyses in Group P (Table 1) are interpreted to reflect mainly loss of radiogenic Pb, although some could represent mixtures between Group M and M2 monazite.

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Recommended reference for this publication

Fielding, IOH, Wingate, MTD, Kelsey, DE, Korhonen, FJ, De Paoli, M and Rankenburg, K 2022, 224777: kyanite–garnet–staurolite schist, Kingsley prospect; Geochronology Record 1876: Geological Survey of Western Australia, 6p.

Data obtained: 26 September 2018

Data released: 14 April 2022