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Research Advances

Discovery of Early Paleozoic Garnet Amphibolite in the Wenquan Complex, Northern Margin of the Yili Block, NW China

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Objective

High-pressure (HP) and ultrahigh-pressure (UHP) minerals tend to be preserved in mafic and ultramafic metamorphic rocks (e.g. eclogites and garnet amphibolite) rather than felsic rocks. Generally, HP and UHP rocks are thought to be formed as a result of the tectonic burial or subduction of oceanic crust or thicked continental lithosphere to depths corresponding to the eclogite facies metamorphism, followed by fast uplift (Ernst et al., 2007). Therefore, identification of HP-UHP rocks might indicate that subduction and/or collision processes are likely to have occurred, providing important information regarding regional tectonic evolution. The northern margin of the Yili Block (YB) is characterized by the presence of Precambrian metamorphic rocks, represented by the Wenquan Complex (WQC), but detailed information on the metamorphic evolution of the WQC still requires further study. Recently, we identified garnet amphibolite from the WQC and further constrained its high-pressure amphibolite facies metamorphism (700°C/9.6 kbar, Wang et al., 2018). However, the metamorphic age, protolith composition and provenance of the garnet amphibolite are unknown, which limits our understanding of the earlier stages of the tectonic evolution of the Western Tianshan Orogen. In this study, ages of the garnet amphibolite from the Wenquan area (Western Tianshan Orogen) are reported for the first time. In addition, whole rock geochemistry of the garnet amphibolite was analyzed in order to constrain both the protolith and the provenance.

Methods

Samples for zircon U-Pb dating in this paper were collected from the garnet amphibolite lens in the WQC, Wenquan area of Xinjiang, China. Zircon grains were separated at the Xi'an Ruishi Geological Technology Limited Company, Xi'an, China. The cathodoluminescence (CL) images of zircons were taken at Northwest University, Xi'an, China. Zircon U-Pb and whole rock geochemistry analyses were conducted at the State Key Laboratory of Continental Dynamics, Northwest University, Xi'an, China. The LA-ICP-MS zircon U-Pb isotopic ratios were analyzed on an Agilent 7500a. Major elements were determined using the XRF method on a Rigku RIX 2100, the trace elements being analyzed using ICP-MS on a PE 6100 DRC.

Results

The garnet amphibolite from the Wenquan Complex displays a fine-grained, porphyroblastic texture, consisting mainly of garnet, hornblende, plagioclase and quartz, with minor epidote, chlorite, sphene and magnetite. Garnet sizes range from 3 to 5 mm and occur as porphyroblasts with inclusions of quartz, hornblende and epidote. Some of the garnet porphyroblasts have been partly replaced by the symplectite of fine-grained plagioclase, hornblende and quartz, forming coronas around garnet grains.

The zircons from the garnet amphibolite are composed mainly of subhedral, transparent, or colorless prismatic grains. The grain sizes range from 60 to 100 μm, with a length/width ratio of 1.0–2.0. Twenty zircon grains were dated by LA-ICP-MS and eighteen concordant analyses yielded ages of 1933 Ma and 434 Ma. The upper intercept age of 1877 ± 15 Ma (Fig. 2e) is considered to be the crystallization age of the protolith of the amphibolite, the lower intercept age of 433 ± 33 Ma (Fig. 2e) being interpreted as the peak metamorphic age. Additionally, sixty analyses were conducted for the surrounding paragneiss (Fig. 2c, f). The complex internal textures showed in the CL images indicate multi-phased thermo-tectonic events. The zircon cores display prominent magmatic oscillatory ring zones, while the rim could be related to subsequent metamorphic growth. The analytical data are well aligned on the concordia diagram and define a discordia line with intercept ages of 1777 ± 35 Ma and 442 ± 45 Ma, respectively (Fig. 2f, unpublished data). The lower intercept age of 442 Ma is considered to be the metamorphic age of the paragneiss, which is consistent with the ages of the rims. The metamorphic ages of the samples are also consistent with the ^{40}Ar-^{39}Ar ages of

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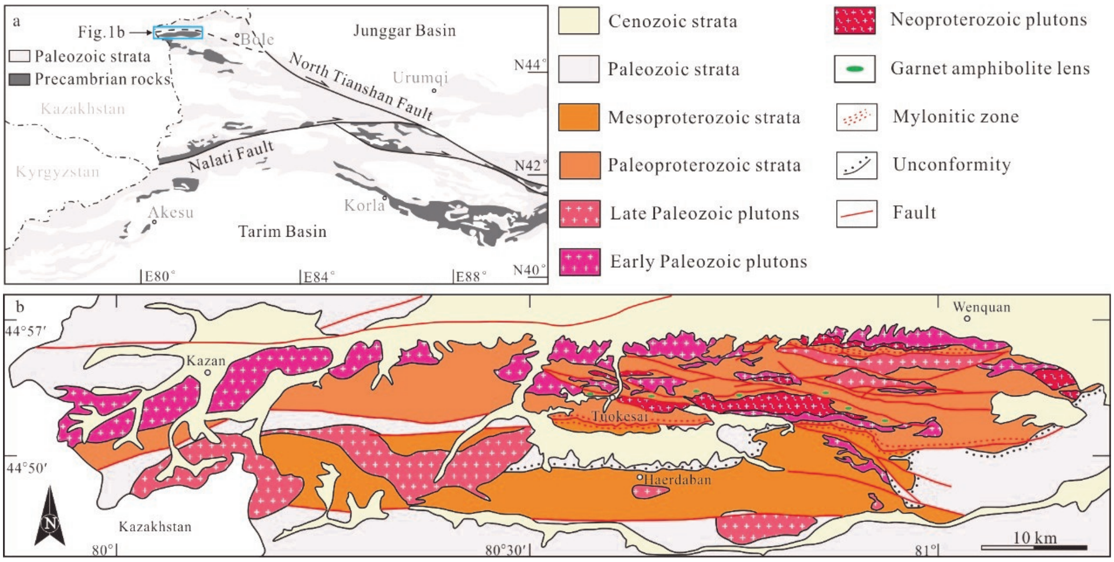

Fig. 1. (a) Distribution of Precambrian rocks in the Chinese Tianshan belt (modified from Wang et al., 2011) and location of the study area; (b) Simplified geological map of the Wenquan area (modified from XBGMR, 1988).

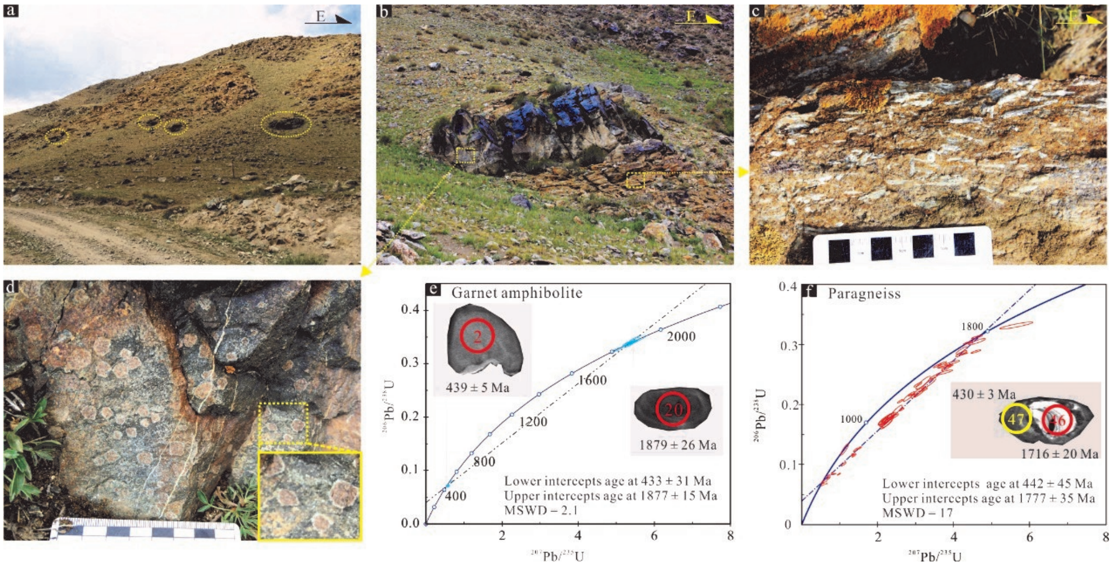

Fig. 2. The outcrop of the garnet amphibolite (a, b) and surrounding rocks (c), the ‘white eye’ texture preserved in garnet amphibolite (d), zircon U-Pb concordia diagram of garnet amphibolite (e) and surrounding rock (f) from the Wenquan area, northern margin of the YB.

amphibolite in the WQC (Wang et al., 2011).

Garnet amphibolite is characterized by low content of SiO_2 (40.25–46.06 wt%) and Na_2O + K_2O (0.30–1.63 wt%) with high concentrations of FeO (12.28–14.89 wt%) and TiO_2 (3.36–5.07 wt%). The low K_2O and Na_2O content, $K_2O/Na_2O < 1$, $Na_2O/CaO < 1$ and CaO > MgO indicate the geochemical characteristics of ortho-metamorphic rocks. These geochemical characteristics indicate that the protoliths were tholeiitic mafic rocks and all samples fall in the field of tholeiites in an AFM plot.

The studied garnet amphibolite rocks are generally characterized by relatively high total concentrations of REE (∑REE = 139–347 ppm). The samples demonstrate enrichment in LREE relative to HREE, with La_N/Yb_N values of 1.82 to 3.87. Trace element patterns show depletion in Sr, K, Hf and enrichment in LILE, which are different from the characteristics of oceanic ridge basalt (MORB) and island arc basalt (IAB), being similar to intra-plate basalt. Furthermore, the Th/Ta ratios of the samples are 0.94 to 1.98 (average = 1.47), similar to that of the typical continental rift basalt (Th/Ta = 1.6–4), indicating that the protolith of the garnet amphibolite may have formed in an intra-plate setting during the initial rifting, or at a slightly later stage related to mantle plume activities.

Conclusions

A suite of the garnet amphibolite was identified in the

WQC, northern margin of the YB. LA-ICP-MS zircon U-Pb dating showed that the protolith age of the garnet amphibolite is 1.8 Ga and the peak metamorphism age is 433 Ma. In addition, the surrounding paragneiss of the garnet amphibolite also recorded a coeval metamorphic event. Geochemical data indicate that the protoliths of the garnet amphibolite were tholeiitic mafic rocks, which may have formed in an intra-plate environment. The garnet amphibolite may have been introduced into the continental crust prior to HP metamorphism, undergoing HP metamorphism in the Early Paleozoic. The identification of the early Paleozoic garnet amphibolite provides metamorphic evidence for the southward subduction of the Junggar Ocean beneath the YB during the Early Paleozoic.

Acknowledgments

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Appendix 1 LA-ICP-MS U-Pb data of zircons from the garnet amphibolite in the Wenquan area

Analysis spots	Content (ppm)			Th/U	$^{207}Pb/^{206}Pb$		$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$		$^{207}Pb/^{206}Pb$		$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$	
	Pb	Th	U		Ratio	1σ	Ratio	1σ	Ratio	1σ	Age (Ma)	1σ	Age (Ma)	1σ	Age (Ma)	1σ
133-1-01	10	12	150	0.08	0.0565	0.0031	0.5617	0.0319	0.0728	0.0011	472	120	453	21	453	6
133-1-02	14	13	213	0.06	0.0614	0.0029	0.5948	0.0296	0.0706	0.0009	654	103	474	19	440	6
133-1-04	15	16	200	0.08	0.0640	0.0027	0.6198	0.0298	0.0699	0.0011	743	89	490	19	436	7
133-1-06	407	355	736	0.48	0.1111	0.0010	5.0137	0.0996	0.3261	0.0032	1818	16	1822	17	1820	15
133-1-07	13	18	195	0.09	0.0570	0.0025	0.5642	0.0265	0.0723	0.0010	500	94	454	17	450	6
133-1-08	23	6	400	0.02	0.0603	0.0023	0.5988	0.0236	0.0726	0.0010	613	81	476	15	452	6
133-1-09	107	4	372	0.01	0.1147	0.0014	5.2809	0.0973	0.3337	0.0031	1876	22	1866	16	1856	15
133-1-10	99	8	323	0.02	0.1158	0.0014	5.4959	0.1007	0.3444	0.0035	1892	22	1900	16	1908	17
133-1-11	15	10	244	0.04	0.0616	0.0027	0.5840	0.0261	0.0697	0.0009	657	94	467	17	434	6
133-1-12	332	2891	2979	0.97	0.0643	0.0009	0.4560	0.0146	0.0518	0.0015	750	31	381	10	326	9
133-1-14	411	336	3144	0.11	0.0753	0.0046	9.8811	4.2862	0.5511	0.1339	1076	124	2424	423	2830	558
133-1-15	125	11	396	0.03	0.1156	0.0013	5.4440	0.1068	0.3409	0.0024	1900	20	1892	17	1891	11
133-1-16	1127	579	1881	0.31	0.1365	0.0019	7.2330	0.2503	0.3746	0.0069	2183	24	2141	31	2051	32
133-1-17	46	27	95	0.28	0.1180	0.0032	5.5672	0.1785	0.3468	0.0053	1928	49	1911	28	1919	25
133-1-18	22	21	226	0.09	0.0609	0.0030	0.6672	0.0360	0.0795	0.0011	639	106	519	22	493	6
133-1-19	12	16	134	0.12	0.0696	0.0053	0.7048	0.0620	0.0734	0.0014	917	192	542	37	457	9
133-1-20	102	10	326	0.03	0.1150	0.0017	5.3894	0.1327	0.3398	0.0024	1880	26	1883	21	1886	12
133-1-21	464	426	1404	0.30	0.0862	0.0008	2.6259	0.0603	0.2204	0.0028	1344	17	1308	17	1284	15
133-1-22	348	248	657	0.38	0.1139	0.0010	5.2764	0.1012	0.3359	0.0028	1863	16	1865	16	1867	14
133-1-24	132	44	391	0.11	0.1142	0.0013	5.3413	0.1279	0.3375	0.0037	1933	21	1876	20	1875	18

Appendix 2 Whole rock geochemistry for the garnet amphibolite from the Wenquan Complex

Sample	101/2	101/3	101/4	101/5	109/1	109/2	Sample	101/2	101/3	101/4	101/5	109/1	109/2
SiO_2	46.06	44.19	44.86	44.38	40.51	40.25	Sb	0.35	0.32	0.53	0.44	0.43	0.31
Al_2O_3	15.93	14.86	16.42	15.76	16.57	16.94	Cs	0.73	4.70	2.85	4.04	0.46	0.30
Fe_2O_3	4.11	5.02	3.1	2.41	4.66	5.36	Ba	117	260	222	246	162	114
FeO	13.68	14.49	12.28	13.01	14.89	14.81	Hf	2.86	2.13	2.96	2.45	3.32	3.23
MgO	6.59	5.97	7.00	6.57	7.53	7.33	Ta	1.55	3.34	2.56	2.59	1.58	1.77
CaO	8.49	8.29	9.98	9.11	9.46	9.31	W	0.50	0.43	1.12	0.77	1.08	1.10
Na_2O	1.46	0.82	0.77	3.07	1.63	1.58	Tl	0.25	0.28	0.58	0.74	0.32	0.19
K_2O	0.43	0.60	1.25	1.53	0.86	0.56	Pb	5.44	6.91	8.87	8.81	4.52	4.51
MnO	0.25	0.30	0.29	0.28	0.25	0.31	Bi	0.74	0.32	0.23	0.21	0.55	0.58
TiO_2	3.36	5.07	3.55	3.49	3.98	3.97	Th	3.07	4.59	2.49	2.43	2.87	2.93
P_2O_5	0.31	0.94	0.48	0.47	0.33	0.34	U	0.99	2.18	0.67	0.63	1.30	1.23
LOI	0.74	0.94	1.26	1.26	0.86	0.77	Y	48.7	77.1	50.9	53.2	57.9	68.9
Be	2.27	3.20	1.94	1.60	1.89	1.76	La	22.6	54.2	29.6	29.7	20.3	24.7
Sc	47.8	43.8	47.1	44.7	48.4	48.6	Ce	39.2	141	50.2	50.7	35.4	43.7
V	339	239	290	274	342	342	Pr	7.32	15.8	9.03	9.21	6.71	8.13
Cr	116	136	171	157	155	156	Nd	32.0	65.9	38.4	39.3	29.8	35.6
Co	59.9	42.6	41.9	45.4	40.4	41.7	Sm	7.87	14.0	8.54	8.88	7.80	9.12
Ni	51.2	30.2	32.5	33.4	25.7	29.8	Eu	2.24	3.33	2.54	2.57	2.11	2.39
Cu	57.4	36.7	28.0	30.8	23.2	20.9	Gd	7.40	12.9	7.67	8.10	7.37	8.36
Zn	167	213	209	194	160	161	Tb	1.40	2.26	1.42	1.49	1.49	1.69
Ga	28.2	28.7	25.4	23.7	26.9	26.3	Dy	9.16	14.2	9.01	9.67	10.2	11.8
Rb	11.1	25.6	45.4	60.2	34.6	15.4	Ho	1.98	3.12	2.02	2.14	2.31	2.69
Sr	73.8	69.1	165	164	129	119	Er	5.28	8.49	5.4	5.79	6.38	7.49
Zr	248	439	250	245	269	252	Tm	0.96	1.56	1.01	1.07	1.20	1.42
Nb	15.7	39.3	28.8	29.5	15.3	15.8	Yb	5.80	9.45	6.15	6.49	7.54	8.77
Mo	1.64	1.04	1.60	1.62	0.23	0.16	Lu	0.99	1.62	1.07	1.12	1.29	1.52