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Research Advances

SHRIMP Zircon U-Pb Ages of the Wajilitag Igneous Complex: Constraints on the Origin of A-type Granitoids in the Tarim Large Igneous Province, NW China

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Objective

Large igneous provinces (LIPs) are sites of spatially contiguous, rapidly emplaced magmatic rocks, which represent the physical and chemical transfer of material from the mantle to the crust. Exposed within some continental LIPs are felsic and mafic plutonic and volcanic rocks. Although their volumes are minor compared to the flood basalts, the plutonic rocks of continental LIPs are often associated with economic deposits of precious metals. Within the Permian Tarim LIP of NW China, there are at least two layered ultramafic-mafic intrusions (e.g. Wajilitag and Piqiang) contain economically important Fe-Ti-V oxide deposits. Spatially associated with these layered ultramafic-mafic intrusions are syenitic and granitic plutons, which have chemical characteristics of A-type granitoids. The formation of a bimodal distribution of felsic and mafic igneous suites within continental settings is a long-standing problem and has multiple petrogenetic interpretations. In this sense, the Tarim LIP offers an opportunity to investigate this issue. In this paper, we present precise zircon U-Pb and Hf isotopic data in combination with mineral chemistry of clinopyroxene for syenitic and gabbroic units of the Wajilitag igneous complex (Fig. 1a) in the Tarim LIP to elucidate the genetic relationship between the neighboring A-type syenitic pluton and gabbroic rocks.

Methods

Zircon U-Pb age determination was performed using the SHRIMP II instrument at the Beijing SHRIMP Center, Chinese Academy of Geological Sciences. Zircon Lu-Hf isotopes were measured using a Neptune Plus multiple-collector inductively coupled plasma mass spectrometer (ICP-MS) equipped with a 193 nm laser at the Guangzhou Institute of Geochemistry, Chinese Academy of Sciences (GIG-CAS). Major element analyses of clinopyroxene were obtained by electron microprobe analysis (EMPA) using a JEOL JXA-8100 Superprobe electron microprobe at GIG-CAS. Trace elements of clinopyroxene were analyzed on an Agilent 7500a ICP-MS at GIG-CAS.

Results

Zircon crystals of sample BC1112, collected from the upper gabbro zone at 39°33′4.4″N, 78°55′12.9″E, show typical igneous zonation and have fragmented, euhedral-subhedral textures (Fig. 1b). The zircons from BC1112 have low U and Th contents of 68–201 ppm and 110–440 ppm, respectively, with Th/U ratios of 1.16−3.07 (Appendix Table 1). Analyses of twelve individual zircon crystals form a single age group and yield a mean $^{206}Pb/^{238}U$ age of 282 ± 4 Ma with a mean square of weighted deviates (MSWD) of 0.47 (Fig. 1b). Two syenitic samples, BC1218 and BC1222, were selected for zircon U-Pb dating. Samples BC1218 and BC1222 were collected at 39°32′44.2″N, 78°56′6″E. Compared to BC1112, the zircons from BC1218 have relatively higher and scattered U and Th contents of 87–978 ppm and 47–598 ppm, respectively, with Th/U ratios of 0.41−1.03 (Appendix Table 1). Analyses from sixteen individual zircon crystals from sample BC1218 yield a mean $^{206}Pb/^{238}U$ age of 278 ± 3 Ma (Fig. 1c). Sample BC1222 has euhedral to anhedral zircon crystals. Their Th/U ratios vary from 0.56 to 1.32. Analyses on eleven zircon crystals yield a mean $^{206}Pb/^{238}U$ age of 278 ± 3 Ma with a MSWD of 0.61 (Fig. 1d).

Totally fifteen spot analyses for BC1112 yield relatively uniform $^{176}Hf/^{177}Hf$ values from 0.282632 to 0.282740, with initial ε_{Hf} (t = 282 Ma) range of +1.1 to +4.9. Calculated zircon Hf model ages (T_{DM}) are between 727 and 869 Ma. Zircons from the syenite (BC1218) and quartz syenite (BC1222) show similar $^{176}Hf/^{177}Hf$ values

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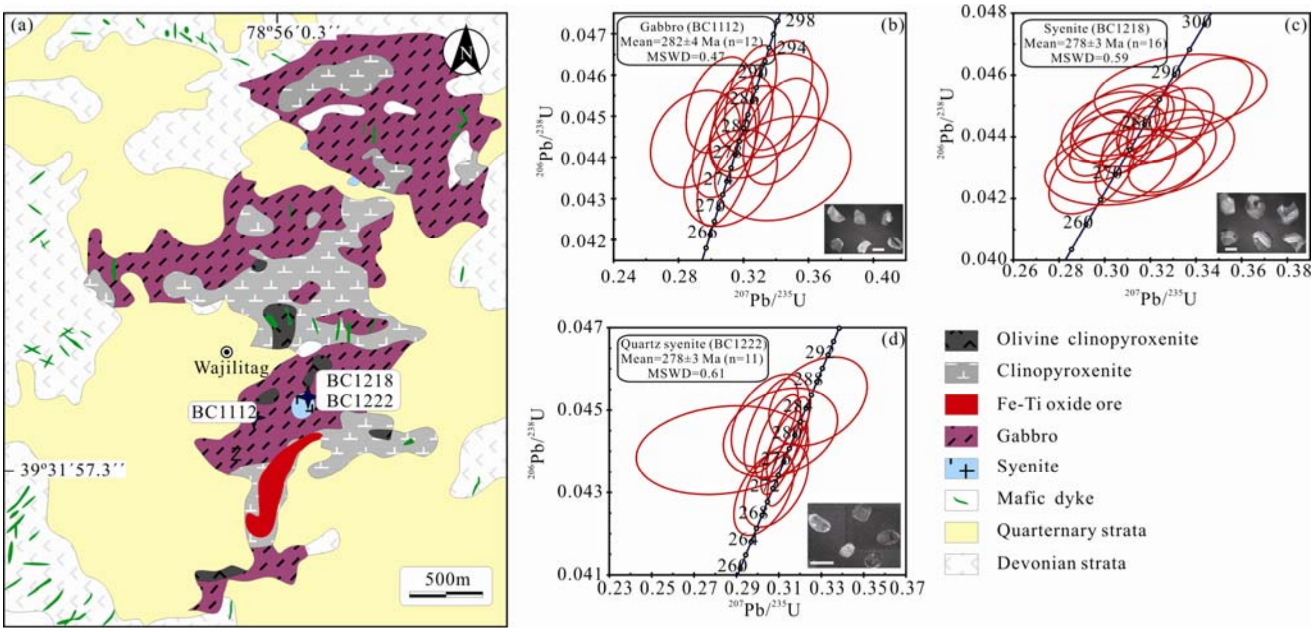

Fig. 1. (a), Geological map of the Wajilitag igneous complex, Bachu county, with sample locations for U-Pb dating; (b, c, d), U-Pb concordia diagrams and CL images of zircons from the Wajilitag igneous complex. The length of white line in CL image denotes 100 μm; (b), Sample BC1112; (c), Sample BC1218; (d), Sample BC1222.

that range from 0.282696 to 0.282863. Their initial ε_{Hf}(t = 278 Ma) values are +3.6 to +7.1 for BC1218 and +2.5 to +8.5 for BC1222, respectively. The T_{DM} of syenite range between 629 and 777 Ma, also overlapping with those of quartz syenite (610 to 883 Ma).

The clinopyroxenes of gabbroic samples display high $Mg^{\#}$ (68–80.4) and fall within the diopside field of the pyroxene quadrilateral with $Wo_{44.5-48.1}En_{35.4-43.7}Fs_{10.9-17}$. TiO_2 and Al_2O_3 contents are relatively high and vary from 0.51wt% to 2.37wt% and 1.88wt% to 5.11wt% respectively. Na_2O contents vary from 0 to 0.80wt%. The clinopyroxenes show similar upward-convex REE patterns with negligible Eu anomalies (0.9–1.2). In the primitive mantle-normalized trace element diagram, they show enrichment in Sm and depletions in Nb, Ta, Zr and Hf. The clinopyroxenes of syenites have lower $Mg^{\#}$ (38.4–75.1), TiO_2 (0–0.93wt%), Al_2O_3 (0.14wt%–2.86wt%) and higher Na_2O (0.27wt%–1.16wt%) contents compared with those in the gabbros. Despite the differences in the absolute abundances, they have parallel REE and primitive mantle-normalized trace element patterns to the clinopyroxenes from the gabbros and Bachu mafic dykes.

Conclusions

The Wajilitag syenites of A-type affinity are spatially and temporally associated with Fe-Ti-V oxide ore bearing layered ultramafic-mafic intrusions and both were emplaced at ~280 Ma. The clinopyroxenes in the syenitic units of the Wajilitag igneous complex display REE and trace element patterns parallel to those from the gabbroic units and coherent compositional variations exist between them. They are thus interpreted to be derived by fractional crystallization of a common parental magma resembling Bachu mafic dyke. The zircon Hf isotopic data suggest the parental magma of the Wajilitag rocks was likely derived by partial melting of the Tarim mantle plume.

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Appendix 1 SHRIMP zircon U-Pb data for the Wajilitag igneous complex

Samples	Spot	$^{206}Pb^{a}$ ppm	$^{206}Pb^{b}$ %	U ppm	Th ppm	$^{232}Th/^{238}U$	$^{207}Pb/^{206}Pb$	±1σ %	$^{207}Pb/^{235}U$	±1σ %	$^{206}Pb/^{238}U$	±1σ %	$t_{206/238}$ Ma	±1σ	$t_{207/206}$ Ma	±1σ	$t_{208/232}$ Ma	±1σ
BC1112	1	3.07	0.00	79	141	1.85	0.0543	4.6	0.341	5.2	0.0455	2.4	286.9	6.7	385	100	288.7	9.4
	2	5.53	0.23	143	440	3.17	0.0516	4.5	0.319	4.9	0.04482	2.1	282.7	5.9	267	100	273.9	7
	3	5.53	0.28	142	264	1.93	0.0489	5.1	0.305	5.5	0.04528	2.1	285.5	5.9	142	120	269.6	7.4
	4	3.79	0.22	101	258	2.64	0.0520	7.2	0.312	7.5	0.04350	2.2	274.5	5.9	287	160	288.3	8.3
	5	5.02	0.42	131	334	2.63	0.0505	4.8	0.309	5.4	0.0444	2.4	279.8	6.7	220	110	276.5	9
	6	3.74	0.63	99	206	2.15	0.0571	9.7	0.344	9.9	0.0437	2.4	275.9	6.4	495	210	287	16
	7	4.71	0.00	125	229	1.89	0.0512	3.9	0.310	4.8	0.0438	2.8	276.6	7.6	251	89	278.9	9.3
	8	2.61	0.00	68	110	1.67	0.0558	5.0	0.343	5.6	0.0446	2.4	281.5	6.5	443	110	294	10
	9	6.02	0.00	154	293	1.97	0.0517	3.4	0.324	4.0	0.04555	2.1	287.2	5.9	270	78	287.9	7.5
	10	7.73	0.27	201	234	1.20	0.0528	6.2	0.325	6.5	0.04462	2.0	281.4	5.6	319	140	285.4	8
	11	3.68	0.06	95	135	1.47	0.0540	8.1	0.337	8.4	0.0453	2.3	285.4	6.3	372	180	278	11
	12	5.00	0.75	130	258	2.05	0.0474	7.5	0.290	7.8	0.04445	2.2	280.4	5.9	69	180	269.3	8.1
BC1218	1	6.08	0.40	158	126	0.82	0.0502	5.5	0.308	5.9	0.04453	2.1	280.8	5.8	204	130	271	10
	2	5.33	0.30	142	91	0.66	0.0498	5.3	0.300	5.7	0.04366	2.1	275.5	5.7	186	120	271	11
	3	5.74	0.63	150	62	0.43	0.0495	5.4	0.302	5.8	0.04432	2.1	279.5	5.8	172	130	241	11
	4	5.72	0.39	150	99	0.68	0.0516	7.3	0.314	7.6	0.04418	2.1	278.7	5.8	267	170	259	11
	5	4.09	0.00	110	54	0.51	0.0551	4.2	0.330	4.8	0.04341	2.3	274.0	6.1	415	93	285	16
	6	5.98	0.02	160	80	0.52	0.0546	6.9	0.327	7.4	0.0435	2.6	274.4	7	395	150	266	18
	7	4.83	0.00	124	71	0.59	0.0551	4.5	0.343	5.1	0.0452	2.4	285.2	6.6	414	100	277	12
	8	4.16	0.00	109	73	0.69	0.0537	4.2	0.329	4.7	0.04437	2.2	279.9	6.1	360	94	268	10
	9	10.4	0.22	276	121	0.45	0.0517	3.1	0.313	3.7	0.04390	2.0	276.9	5.4	271	70	257.9	8.8
	10	4.97	0.55	134	114	0.88	0.0499	4.5	0.294	5.2	0.0428	2.5	270.2	6.6	189	110	262.5	9.5
	11	37.3	0.08	978	598	0.63	0.0518	2.0	0.3170	2.8	0.04441	1.9	280.1	5.3	275	46	275.2	6.2
	12	12.7	0.25	338	335	1.02	0.0495	3.3	0.299	3.8	0.04379	2.0	276.3	5.4	170	77	274.9	7.1
	13	7.70	0.00	201	208	1.06	0.0522	3.2	0.320	3.8	0.04449	2.1	280.6	5.8	295	73	275.4	7.9
	14	7.91	0.15	214	155	0.75	0.0529	4.1	0.314	4.6	0.04298	2.0	271.3	5.4	326	93	275.8	8.8
	15	5.42	0.17	138	64	0.47	0.0532	9.0	0.333	9.3	0.04545	2.2	286.5	6.2	337	200	296	24
	16	3.24	0.18	87	47	0.55	0.0520	8.9	0.309	9.2	0.0430	2.3	271.5	6.2	287	200	256	20
BC1222	1	18.8	0.79	488	415	0.88	0.0507	6.8	0.311	7.1	0.04445	2.0	280.4	5.5	227	160	255	11
	2	56.3	1.75	1438	933	0.67	0.0496	4.6	0.306	5.0	0.04475	2.0	282.2	5.6	178	110	262.1	10
	3	45.2	0.08	1203	830	0.71	0.0521	1.6	0.3141	2.5	0.04370	1.9	275.7	5.2	291	36	253.4	5.8
	4	49.3	0.38	1289	856	0.69	0.0506	2.1	0.3095	2.9	0.04435	1.9	279.7	5.2	224	49	271.8	6.4
	5	45.4	1.02	1213	742	0.63	0.0519	3.5	0.309	4.0	0.04317	1.9	272.5	5.1	279	81	254.9	8.8
	6	62.0	0.16	1638	1141	0.72	0.0514	1.7	0.3113	2.5	0.04396	1.9	277.4	5.1	257	39	266.2	5.6
	7	33.6	0.66	905	505	0.58	0.0511	3.3	0.303	3.8	0.04297	1.9	271.2	5.1	247	76	255.1	8.4
	8	15.0	0.28	391	516	1.36	0.0498	2.7	0.306	3.4	0.04462	2.1	281.4	5.8	185	62	273.5	6.7
	9	28.4	0.57	726	515	0.73	0.0527	5.4	0.328	5.8	0.04521	1.9	285.1	5.4	316	120	278	11
	10	53.9	7.97	1310	1069	0.84	0.0467	12	0.283	12	0.04403	2.0	277.7	5.4	33	280	251	22
	11	79.7	0.30	2087	1650	0.82	0.0515	1.8	0.3143	2.6	0.04430	1.9	279.4	5.2	261	41	269.0	5.7

Pb^{a} and Pb^{b} indicate the radiogenic and common portions, respectively.