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Research Advances

$^{40}Ar/^{39}Ar$ Geochronology of the Late Paleozoic Woniusi Basalts from the Baoshan Terrane, SW China: Implications for the Rifting of the Northern Margin of Gondwana

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Objective

Although the occurrence of Late Paleozoic rifting on the northern margin of Gondwana is widely accepted, the precise reason for the rifting is not constrained. The Woniusi basalts in the Baoshan terrane cover an area of ~1.2×10^4 km^2 and have been considered to be likely part of Late Paleozoic Himalayan volcanic groups (Zhou Xiaoyao et al., 2016). Therefore, precise dating of the Woniusi basalts is not only the basis of correlation with the Late Paleozoic magmatism occurred within the Himalaya, but also is significant for constraining the rifting history of the northern margin of Gondwana. Herein, we report precise $^{40}Ar/^{39}Ar$ dating of the Woniusi basalts from the Dongshanpo section in order to better understand the timing of this magmatism. Additionally we present new whole-rock elemental and isotope data of the Woniusi basalts in order to determine their petrogenetic origin and geodynamic implications.

Methods

One basalt sample (DSP-10; 24°53'27.5" N and 99°07'06.0" E) from the Woniusi Formation at Dongshanpo section, Shidian area (Fig. 1a) was selected for dating. $^{40}Ar/^{39}Ar$ dating was carried out using a GVI5400 mass spectrometer at the Key Laboratory of Tectonics and Petroleum Resources, Ministry of Education, China University of Geosciences (Wuhan). The ArArCALC software was used for data reduction and age calculation. Whole-rock major and trace element analyses were analyzed using Rigaku ZSX-100e X-ray fluorescence spectrometry and PerkinElmer Sciex ElAN 6000 inductively coupled plasma mass spectrometry (ICP-MS) at Guangzhou Institute of Geochemistry, Chinese Academy of Sciences (GIG-CAS), respectively. Whole-rock Sr–Nd isotopic analyses were carried out using a Neptune Plus multi-collector ICP-MS at GIG-CAS.

Results

The $^{40}Ar/^{39}Ar$ dating results for the sample DSP-10 are presented in Appendix 1 and plotted in Fig. 1b-c. Initial argon compositions have $^{40}Ar/^{36}Ar$ ratios approximate to atmospheric $^{40}Ar/^{36}Ar$ ratios (295.5±0.5), indicating that excess argon is insignificant in the sample (Fig. 1c). Plateau age of the sample (279.5±1.4 Ma) is identical to its isochron age (and reverse isochron age, not shown) within error (Fig. 1b-c). Since this sample is collected from the uppermost part of the Dongshanpo section, we interpret this age as the approximate estimate of the termination age of the Woniusi basalts. However, we will not utilize the $^{40}Ar/^{39}Ar$ dates to constrain the initial eruption age of the Woniusi basalts because of the severe alterations of the lowermost part of the Woniusi Formation. Instead, the observation that the Woniusi basalts erupted on top of the Dingjiazhai Formation (containing *Sweetognathus bucaramangus* fauna in the in limestone units within the upper part of the formation) was interpreted to constrain their emplacement to post-middle Artinskian (~287 Ma; Ueno et al., 2002). Thus, the eruption of the Woniusi volcanism can be constrained at ~287 to ~280 Ma, which is synchronous with the basaltic rocks from the Panjal Traps, Tethyan Himalaya (Abor, Bhote Kosi, Selong), Oman and South Qiangtang (302−273 Ma).

The Woniusi basalts from the Dongshanpo section are weakly alkalic to tholeiitic in composition and have $Mg^{\#}$ values of 36 to 58. The basalts are characterized by low TiO_2 contents (1.19wt%−2.19wt%) and low Ti/Y ratios of 257 to 469 with one exception; these values are comparable to those of the low-Ti basalts from the ~260 Ma Emeishan large igneous province in Southwest China. All samples from the Dongshanpo section have very

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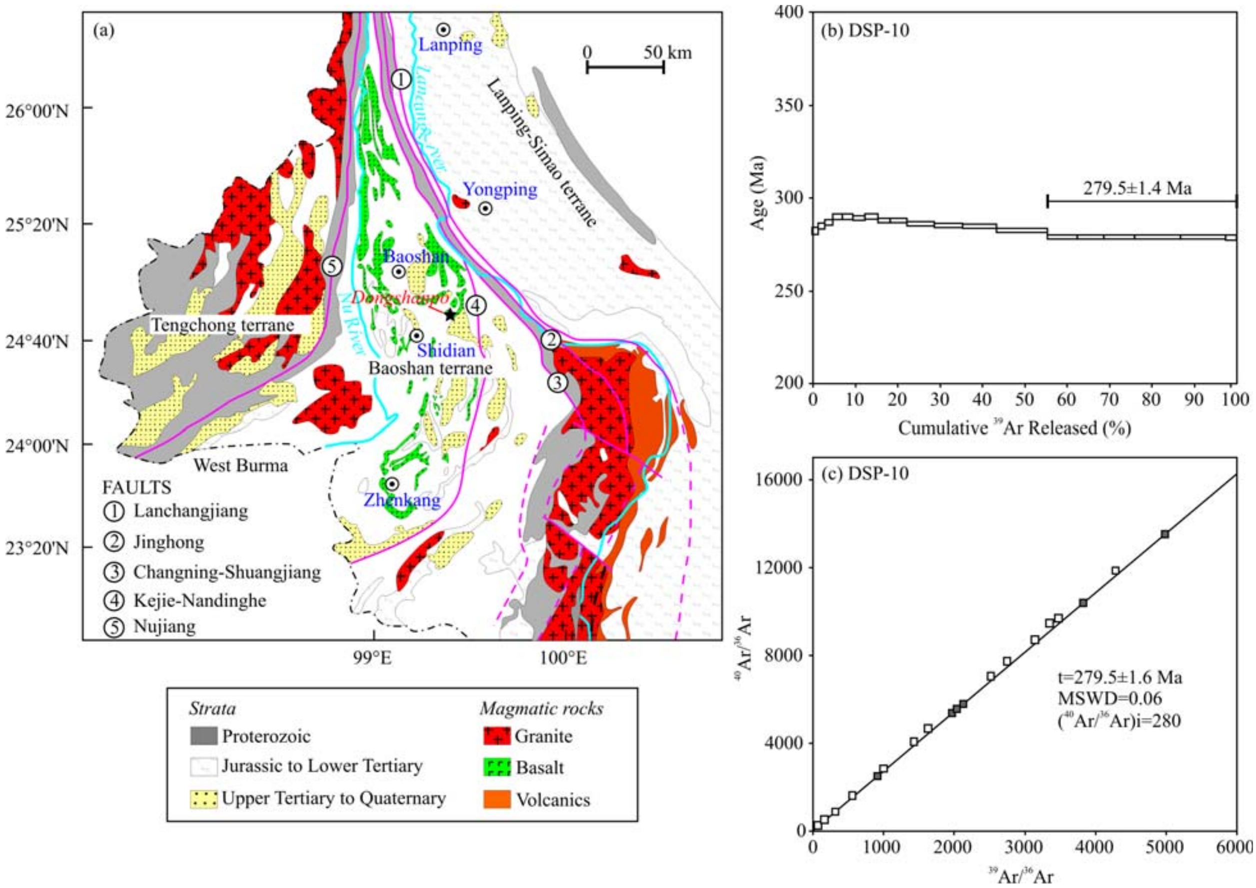

Fig. 1. (a), Simplified geological map of Baoshan terrane and adjacent areas, showing the distribution of the Woniusi basalts and sampling locality of the Dongshanpo section; (b), $^{40}Ar/^{39}Ar$ plateau age spectra of the groundmass for the Woniusi basalts (Sample DSP-10); (c), $^{40}Ar/^{36}Ar$ versus $^{39}Ar/^{36}Ar$ correlation of the groundmass for the Woniusi basalts (Sample DSP-10). On isochron plots, grey squares are data used to determine isochrones.

uniform chondrite-normalized rare earth element (REE) patterns with enrichment of light REE over heavy REE ($(La/Yb)_N$ = 2.86–5.58) and neutral to slightly negative Eu anomalies (Eu/Eu^*=0.83–1.15). On primitive mantle-normalized trace element spidergram, they show moderate enrichment in highly incompatible elements (e.g., Ba, Ba, Th, U) and weak depletion in Nb, Ta and Ti. The samples from the Dongshanpo section show relatively large variations in isotope composition with initial $^{87}Sr/^{86}Sr$ ratios ranging from 0.7045 to 0.7072 and $\varepsilon_{Nd}(t$=280 Ma) values from −1.4 to +0.9. On the $\varepsilon_{Nd}(t)$ versus $(^{87}Sr/^{86}Sr)_i$ diagram, most of them plot close to the field defined by the low-Ti basalts from the Emeishan large igneous province and ~289 Ma Panjal Traps but are displaced from the range for South Qiangtang mafic dykes.

Conclusions

Regionally, the Woniusi basalts are contemporaneous with many occurrences of Latest Carboniferous to Early Permian basaltic rocks within the Himalaya that are attributed to the rifting of Cimmera from Gondwana. The Woniusi basalts have Sr–Nd isotopic signatures similar to the basaltic rocks in the Panjal Traps and Tethyan Himalaya but distinct from those of the Qiangtang mafic dykes. They were likely derived from an enriched sub-continental lithospheric mantle source and possibly formed as a result of plume-lithosphere interaction. It is suggested that a mantle plume probably triggered the Late Paleozoic rifting on the northern margin of Gondwana.

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Appendix 1 $^{40}Ar/^{39}Ar$ dating results of the Woniusi basalts

Incremental Heating		^{36}Ar (a)	^{38}Ar (cl)	^{39}Ar (k)	^{40}Ar (r)	Age	± 2σ	^{40}Ar (r)	^{39}Ar (k)
Steps	Laser (%)	(V)	(V)	(V)	(V)	(Ma)		(%)	(%)
Sample DSP-10 (Groundmass)			*T*1=279.5±1.4 Ma; *T*2=283.3±1.4 Ma; *T*3=279.5±1.6 Ma; *T*4=279.6±1.6 Ma						
16WHA0501A-003	3.2	0.509	0.004	40.557	1109.879	282.9	± 1.9	88.06	1.18
16WHA0501A-004	3.6	0.310	0.039	52.894	1459.895	285.2	± 1.5	94.09	1.54
16WHA0501A-005	4.0	0.218	0.000	68.402	1903.050	287.3	± 1.3	96.72	1.99
16WHA0501A-006	4.5	0.138	0.099	76.202	2145.134	290.4	± 1.5	98.13	2.22
16WHA0501A-007	5.0	0.085	0.084	85.479	2405.603	290.4	± 1.2	98.96	2.49
16WHA0501A-008	5.5	0.068	0.120	97.691	2742.287	289.7	± 1.2	99.26	2.85
16WHA0501B-001	6.0	0.065	0.109	107.126	3015.399	290.4	± 1.3	99.36	3.12
16WHA0501B-002	6.6	0.035	0.059	95.811	2676.127	288.3	± 1.2	99.61	2.79
16WHA0501B-003	7.2	0.042	0.127	140.940	3936.572	288.3	± 1.2	99.68	4.11
16WHA0501B-004	8.0	0.088	0.214	220.624	6126.556	286.8	± 1.1	99.57	6.43
16WHA0501B-005	9.0	0.066	0.186	230.055	6364.702	285.8	± 1.1	99.69	6.70
16WHA0501B-006	10.0	0.064	0.237	273.852	7561.346	285.3	± 1.1	99.74	7.98
16WHA0501B-007	12.0	0.131	0.402	412.087	11286.418	283.1	± 1.1	99.65	12.01
16WHA0501D-001	15.0	0.063	0.276	241.388	6523.299	279.7	± 1.1	99.71	7.03
16WHA0501D-002	18.0	0.105	0.226	214.149	5783.122	279.5	± 1.1	99.46	6.24
16WHA0501D-003	23.0	0.050	0.369	249.751	6743.117	279.4	± 1.1	99.77	7.28
16WHA0501D-004	28.0	0.175	0.677	374.476	10107.623	279.3	± 1.1	99.48	10.91
16WHA0501D-005	34.0	0.186	0.885	366.253	9894.835	279.6	± 1.2	99.44	10.67
16WHA0501D-006	40.0	0.093	0.175	84.440	2278.709	279.3	± 1.3	98.81	2.46

*T*1, Weighted plateau age; *T*2, Total fusion age; *T*3, Isochron age; *T*4, Inverse isochron age. All ages are given at 2σ.