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Supplemental Material

Appendix. Analytical techniques

Table S1. Major and trace element contents of late Mesozoic volcanic rocks from the southern Xiong'er Mountains

Table S2. U-Pb isotopic data and trace element contents of zircon grains in late Mesozoic volcanic rocks from the southern Xiong'er Mountains

Table S3. Whole-rock Sr-Nd-Pb isotopic compositions of late Mesozoic volcanic rocks from the southern Xiong'er Mountains.

ANALYTICAL TECHNIQUES

Zircon U-Pb dating

Zircon grains were handpicked under a binocular microscope and were mounted in epoxy resin; then, they were polished to approximately half their original thickness for cathodoluminescence (CL) imaging. Zircon U-Pb dating was performed using laser-ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) at the Key Laboratory of Crust-Mantle Materials and Environments, University of Science and Technology of China (USTC). The diameter of the laser ablation pit was 24 or 32 μm , and the laser frequency was 10 Hz. National Institute of Standards and Technology (NIST) Standard Reference Material (SRM) 610 and 612 and International Association of Geoanalysts (IAG) standard zircon 91500 were used as external calibration standards, and ^{29}Si (32.7% SiO_2 in zircon) was used as an internal standard to calculate elemental concentrations and age. Details of the analytical technique and process are available elsewhere (Liu et al., 2008). Age calculation was performed and concordia diagrams were plotted using the ISOPLOT software (Ludwig, 2003).

Whole-rock geochemistry

Whole-rock powder was obtained by grinding fresh rock samples. Major element contents were measured using a PANalytical AXIOS X-ray fluorescence (XRF) spectrometer at Australian Laboratory Services (ALS) in Guangzhou, China [analytical conditions: 50 kV (voltage), 50 mA (current)]. Loss on ignition (LOI) was determined by gravimetric analysis (weighing 1 g sample powder heated to 1100 $^{\circ}\text{C}$ for 1 h). Analytical uncertainties of major elements were better than 1%. Trace element contents were measured using a Perkin-Elmer ELAN 6100 DRC II ICP-MS at the USTC. According on the analyses of Chinese and United States Geological Survey (USGS) geochemical reference standard GSR-1, AGV-2, and BHVO-2, the relative deviation of accuracy is better than 5% for most elements and $\sim 10\%$ for Rb, Zr, and Hf. Details of the analytical technique are available elsewhere (Hou and Wang, 2007).

Whole-rock Sr-Nd isotope

Whole-rock Sr-Nd isotopic composition was measured on a Finnigan MAT 262 thermal ionization mass spectrometer (TIMS) in the Laboratory for Radiogenic Isotope Geochemistry, USTC. Approximately 100 mg of rock powder was dissolved in acid solution (HF-HNO₃-HClO₄) for more than 5 days. Rb-Sr and Sm-Nd were separated on quartz columns by ion-exchange chromatography. NIST SRM 987 and La Jolla standard solution were used as standards for Sr and Nd analyses, respectively. The repeated analyses for NIST SRM 987 Sr standard and La Jolla Nd standard gave mean values of 0.710241 ± 0.000012 (2σ) and 0.511869 ± 0.000006 (2σ), respectively. The analytical techniques have been described elsewhere (Chen et al., 2007). The NIST common lead isotopic standard reference material (SRM 981) solution was repeatedly measured for mass fractionation correction of Pb isotopic ratios of the samples.

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Analytical results of major element contents (wt. %) for standard materials

Element (%)	GBW07211		GBW07241		Blank
	Measured	Ref.	Measured	Ref.	
Al ₂ O ₃	2.64	2.58	10.96	11.15	<0.01
As ₂ O ₃	<0.01	0.00	0.01	0.00	<0.01
BaO	0.01	0.00	0.01	0.01	<0.01
CaO	40.80	40.60	4.15	4.17	<0.01
CoO	<0.01	0.00	<0.01	0.00	<0.01
Cr ₂ O ₃	0.02	0.00	0.01	0.00	0.01
CuO	0.02	0.00	0.12	0.12	<0.01
^T Fe ₂ O ₃	1.04	1.08	5.49	5.60	<0.01
K ₂ O	0.27	0.28	1.56	1.58	<0.01
MgO	8.18	8.19	0.14	0.14	<0.01
MnO	0.01	0.02	0.09	0.09	<0.01
Na ₂ O	0.08	0.06	0.10	0.12	<0.01
P ₂ O ₅	20.3	20.9	0.02	0.08	<0.01
PbO	<0.01	0.00	0.01	0.01	<0.01
SiO ₂	3.77	3.61	71.75	71.27	99.31
SnO ₂	<0.01	0.00	0.23	0.22	<0.01
SrO	0.15	0.16	<0.01	0.00	<0.01
TiO ₂	0.13	0.14	0.04	0.04	<0.01
V ₂ O ₅	0.01	0.00	<0.01	0.00	<0.01
ZnO	0.02	0.00	<0.01	0.01	<0.01
ZrO ₂	0.01	0.00	0.01	0.00	<0.01

Recommended values from National Sharing Platform for Reference Materials

ICP-MS analytical results of trace elements for standard materials

Element (ppm)	BHVO-2				AGV-2				BCR-2				Blank
	Measured			Ref.	Measured			Ref.	Measured			Ref.	
Li	4.69	4.93	5.43	4.80	11.8	10.4	10.0	11.0	10.1	8.48	10.3	9.00	0.52
Be	1.76	1.84	1.57	1.00	2.75	2.58	2.34	2.30	2.32	2.31	2.48	2.12	0.97
Sc	31.0	32.3	32.9	32.0	14.6	14.2	13.8	13.0	34.6	31.3	33.5	33.0	2.45
V	279	285	303	317	128	123	119	122	397	328	361	416	2.16
Cr	274	278	292	280	20.3	19.9	19.6	16.0	21.1	19.6	20.6	18.0	1.68
Ni	122	123	126	119	19.5	19.3	19.4	20.0	14.0	13.0	13.4	18.0	0.57
Cu	134	133	138	127	53.3	51.2	52.2	53.0	24.2	24.0	24.6	21.0	0.28
Zn	198	171	176	103	88.1	87.0	85.9	86.0	137	129	135	127	3.43
Ga	22.8	23.1	23.0	22.0	22.1	21.7	21.5	20.0	23.5	22.8	23.5	23.0	0.10
Rb	9.55	9.46	9.43	9.11	65.3	63.4	64.1	66.3	47.5	45.5	46.5	46.9	0.07
Sr	408	404	413	396	653	630	632	661	359	344	353	340	0.58
Y	25.2	24.8	25.5	26.0	19.2	18.7	19.0	19.0	35.0	33.3	34.4	37.0	0.02
Zr	172	174	180	172	228	218	217	230	202	180	190	184	0.06
Nb	19.1	18.9	19.3	18.1	14.6	14.4	14.5	14.5	14.6	13.1	13.2	12.6	0.02
Cs	0.12	0.13	0.13	0.10	1.25	1.23	1.25	1.20	1.25	1.26	1.21	1.10	0.01
Ba	142	139	139	131	1093	1055	1061	1130	699	675	685	677	0.41
La	15.5	15.3	15.4	15.2	37.0	36.3	36.3	37.9	25.0	24.7	24.7	24.9	0.02
Ce	37.2	36.7	37.2	37.5	65.6	63.3	63.7	68.6	52.3	50.1	50.9	52.9	0.02
Pr	5.39	5.20	5.27	5.35	8.08	7.98	8.04	7.84	6.71	6.73	6.63	6.70	0.01
Nd	26.4	25.8	25.7	24.5	31.8	31.3	31.9	30.5	29.8	29.7	29.9	28.7	0.09
Sm	6.44	6.23	6.28	6.07	5.72	5.71	5.70	5.49	6.72	6.94	6.77	6.58	0.06
Eu	2.14	2.14	2.13	2.07	1.66	1.67	1.67	1.53	2.03	2.11	2.10	1.96	0.02
Gd	6.10	5.86	5.95	6.24	5.03	4.97	5.14	4.52	6.57	6.67	6.72	6.75	0.06
Tb	0.96	0.95	0.94	0.92	0.67	0.64	0.67	0.64	1.07	1.06	1.05	1.07	0.01
Dy	5.18	5.12	5.25	5.31	3.52	3.44	3.52	3.47	6.27	6.12	6.24	6.41	0.05
Ho	0.97	0.97	0.97	0.98	0.65	0.65	0.66	0.65	1.28	1.23	1.25	1.28	0.01
Er	2.53	2.52	2.47	2.54	1.83	1.85	1.84	1.81	3.54	3.44	3.48	3.66	0.02
Tm	0.35	0.35	0.33	0.33	0.27	0.26	0.26	0.26	0.54	0.52	0.54	0.54	0.01
Yb	1.95	1.97	2.01	2.00	1.62	1.56	1.63	1.62	3.27	3.21	3.24	3.38	0.04
Lu	0.30	0.28	0.28	0.27	0.25	0.25	0.25	0.25	0.53	0.51	0.50	0.50	0.01
Hf	4.62	4.52	4.56	4.36	5.27	5.12	5.22	5.00	5.71	5.12	5.14	4.90	0.03
Ta	1.19	1.22	1.43	1.14	0.98	0.87	0.88	0.87	4.08	1.43	1.20	0.74	0.01
Pb	2.00	1.99	1.97	1.60	13.3	13.3	13.5	13.2	10.4	10.2	10.4	11.0	0.16
Th	1.23	1.22	1.26	1.22	6.17	5.98	6.13	6.10	6.19	5.86	5.98	5.70	0.01
U	0.43	0.44	0.42	0.40	1.91	1.90	1.89	1.86	1.67	1.66	1.70	1.69	0.01

Recommended values from http://minerals.cr.usgs.gov/geo_chem_stand/; <http://georem.mpch-mainz.gwdg.de/>