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叶海敏 叶现韬 张传林
YE HaiMin, YE XianTao and ZHANG ChuanLin

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Ye HM Ye XT and Zhang CL. 2013. Geochemistry and geodynamic implications of Nileke Permian volcanic rocks in Western Tianshan NW China. ***Acta Petrologica Sinica*** **29 10 3389 – 3401**

Abstract The terrestrial Nileke Permian volcanic rocks outcrop at the most western section of the Awulale Late Paleozoic volcanic belt. In this contribution we reported petrography elemental and Sr-Nd isotope compositions of the Nileke Permian basaltic rocks in aiming to have a better understanding its geodynamic implications. The Nileke volcanic strata could be divided into two series i. e. the Wulang series lower and the Hamisite seires upper and the diverse rock types include basalts andesites trachytes and rhyolites. In geochemistry the upper Hamisite seires exhibit shoshonitic signatures such as having high K_2O 2.81% ~ 3.91% Sr $> 1000 \times 10^{-6}$ total REE $> 200 \times 10^{-6}$ contents high La/Yb_N 9.7 ~ 11.7 but low Nb/La ratios most < 0.2 and shows. The lower Wulang series could be divided into two sub-groups sub-group one contains the lowest SiO_2 low Sr $< 500 \times 10^{-6}$ total REE $50 \times 10^{-6} < \Sigma REE < 80 \times 10^{-6}$ and low La/Yb_N 1.6 ~ 2.2 but the highest MgO and relatively higher Nb/La ratios > 0.35 . These features are comparable with those of E-MORB suggesting that they could be derived from high-degree partial melting in a decompressing process. Sub-group two has a wide range of geochemical compositions straddling between the Hamisite seires and the sub-group one. The Nileke Permian volcanic rocks have intensive depleted Sr-Nd isotopic compositions similar with those of MORB indicating that they were derived from the time-integrated depleted mantle sources. However their significant depletion in Nb-Ta intensive differentiation and enrichment in LILE argue that the Permian basaltic rocks in Nileke area were derived from a recently metasomatized depleted lithospheric mantle sources. Additionally our study reveals that their chemical signatures were constrained by partial melting degree and crystal fractionation process. In combination with regional geology and previous studies the Nileke Permian volcanic rocks could be genetically related to the Permian Tarim mantle plume.

Key words Nileke Western Tianshan Permian volcanic rocks Geochemistry Tectonic implications

Sr-Nd

K_2O

2.81% ~3.91% Sr $> 1000 \times 10^{-6}$ $\Sigma REE > 200 \times 10^{-6}$ La/Yb_N 9.7 ~ 11.7 Nb/La <

0.2 郎 SiO_2 MgO Sr $< 500 \times 10^{-6}$ $50 \times 10^{-6} < \Sigma REE < 80 \times 10^{-6}$

La/Yb_N 1.6 ~2.2 Nb/La > 0.35 E-MORB

Sr-Nd MORB Nb-Ta

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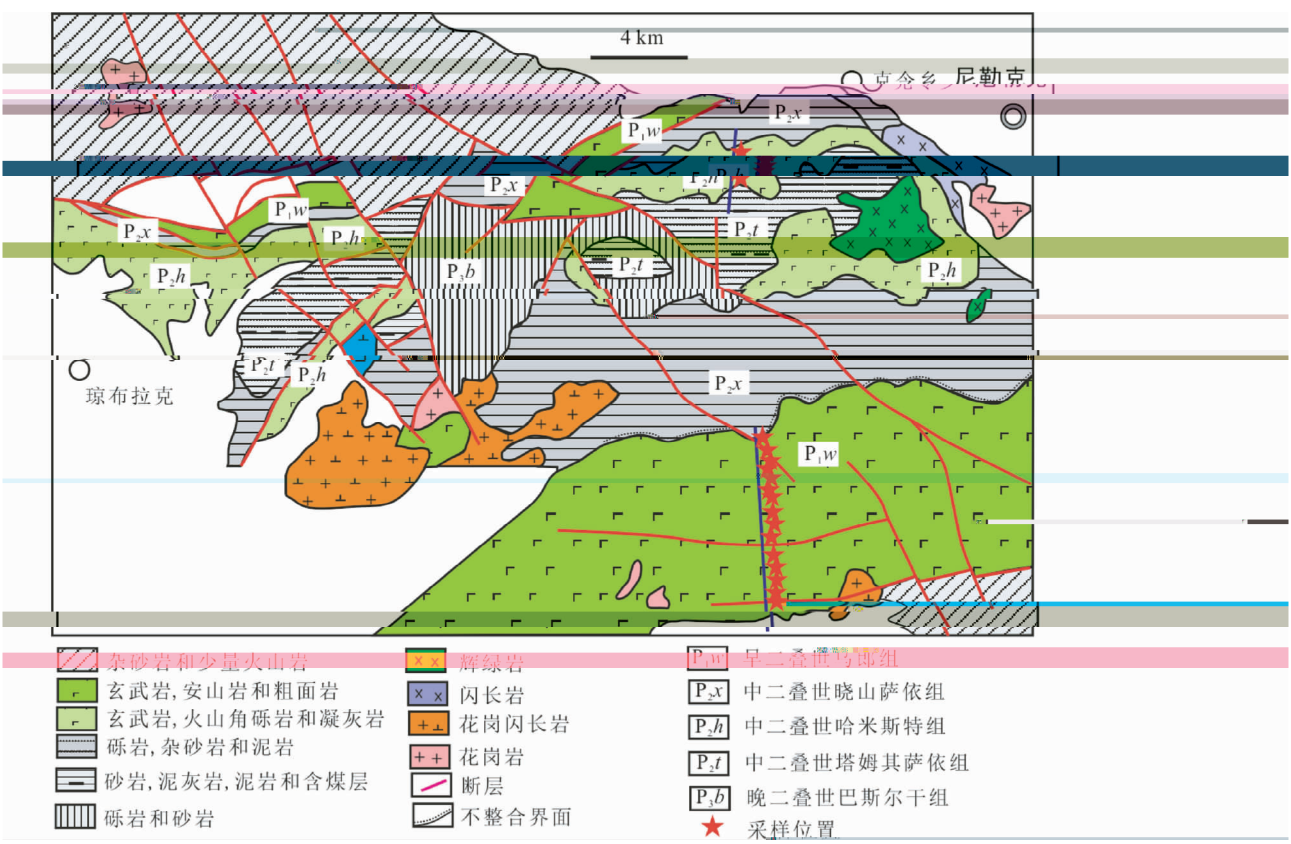

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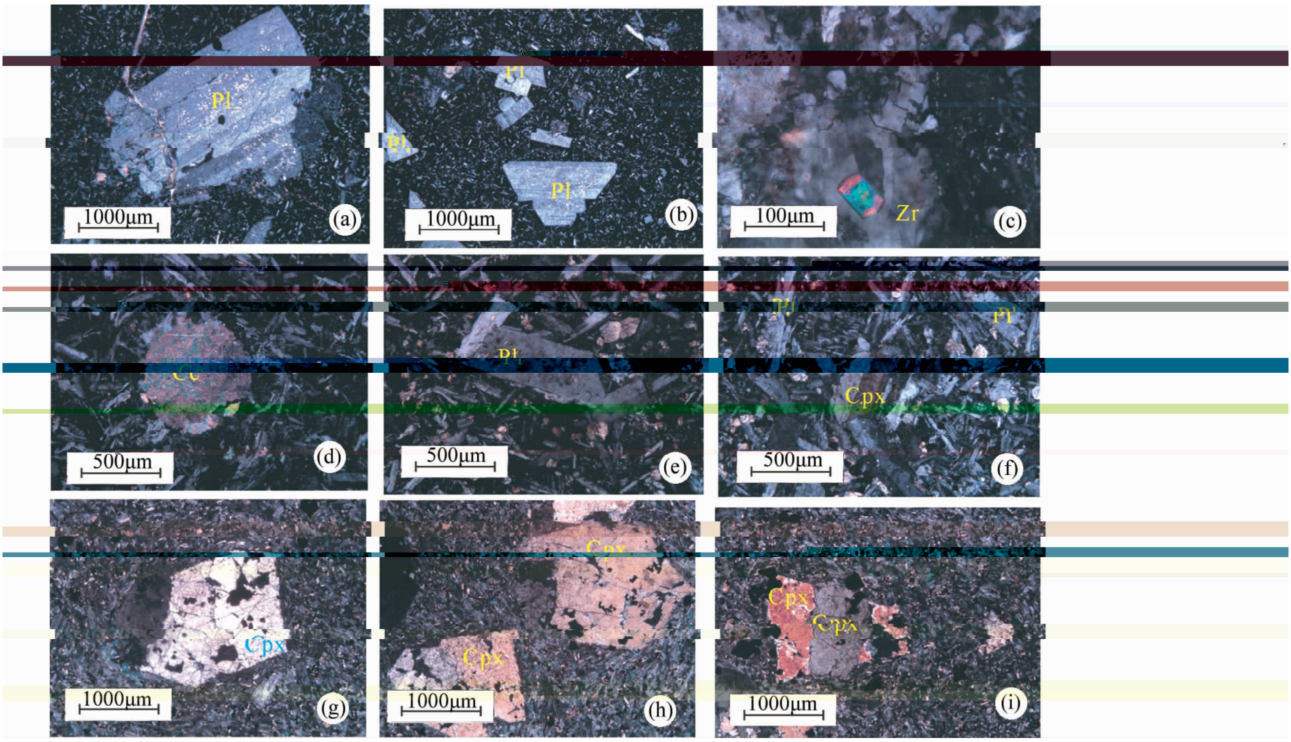
Fig. 1 Geological map of Nileke Xinjiang



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a b e - Pl c - Zr d - Cc f -
Cpx g-i -

Fig. 2 Microphotographs showing petrologic characteristics of the Nileke Permian volcanic rocks

a b e -tabular plagioclase phenocrysts of basalt c -zircon of basalt d -blowhole filled with calcites of basalt f -clinopyroxenes together with plagiocalses of basalt g-i -euhedral/semi-euhedral clinopyroxene phenocrysts of basalt

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1 wt% $\times 10^{-6}$

Table 1 Major element (wt%) and trace element ($\times 10^{-6}$) compositions of the Permian Nileke volcanic rocks

	WT03-1	WT03-2	WT03-3	WT03-4	WT03-5	WT03-6	WT03-7	WT04-2	WT04-5	WT04-7
SiO_2	47.72	51.58	51.71	49.87	51.36	51.56	51.79	62.91	51.11	51.18
TiO_2	1.48	1.50	1.56	1.51	1.55	1.55	1.55	0.77	1.57	1.53
Al_2O_3	15.56	15.20	15.85	15.63	15.76	15.95	15.72	16.87	15.81	15.66
Fe_2O_3	9.71	10.49	10.41	10.21	10.62	10.75	10.58	5.45	10.70	10.35
MnO	0.21	0.12	0.23	0.22	0.19	0.18	0.15	0.02	0.14	0.14
CaO	9.30	6.89	7.77	8.23	7.61	8.05	7.18	5.25	6.99	7.95
MgO	3.97	4.23	4.05	3.99	4.17	3.88	4.11	1.94	3.91	3.92
K_2O	3.21	3.91	3.10	3.11	2.94	2.81	3.39	1.41	3.73	3.48
Na_2O	2.97	3.20	3.36	3.49	3.60	3.45	3.45	4.24	3.35	3.22
P_2O_5	0.53	0.60	0.66	0.63	0.65	0.64	0.64	0.33	0.65	0.65
LOI	5.47	2.18	1.15	3.02	1.38	1.02	1.30	0.69	1.88	1.78
Total	100.12	99.90	99.84	99.92	99.83	99.84	99.85	99.87	99.85	99.84
$Mg^{\#}$	57	57	56	56	56	54	56	54	55	55
La	30.92	33.71	40.09	39.88	41.09	40.44	40.66	12.97	41.80	40.90
Ce	73.21	80.18	97.81	97.21	99.83	99.24	98.68	31.20	101.2	99.66
Pr	9.93	11.03	13.61	13.53	13.90	13.71	13.75	4.40	14.50	14.24
Nd	41.94	46.49	58.26	57.42	59.07	58.48	58.30	20.06	61.81	61.09
Sm	7.85	8.62	10.57	10.36	10.66	10.58	10.49	4.95	10.92	10.70
Eu	2.35	2.48	3.00	2.87	2.93	2.95	2.95	1.55	3.01	2.95
Gd	6.56	7.09	8.33	8.07	8.45	8.35	8.44	5.08	8.60	8.44
Tb	0.91	0.93	1.13	1.10	1.13	1.11	1.13	0.89	1.13	1.11
Dy	4.75	4.62	5.78	5.44	5.60	5.49	5.60	5.75	5.69	5.47
Ho	0.91	0.85	1.09	1.02	1.04	1.03	1.06	1.25	1.08	1.04
Er	2.50	2.29	3.00	2.81	2.82	2.81	2.90	3.56	2.91	2.80
Tm	0.37	0.34	0.45	0.42	0.43	0.42	0.44	0.53	0.42	0.40
Yb	2.28	2.06	2.79	2.56	2.59	2.56	2.64	3.39	2.69	2.59
Lu	0.34	0.31	0.42	0.38	0.40	0.40	0.39	0.54	0.40	0.39
Rb	116.5	170.6	81.14	58.96	63.49	61.55	89.53	50.35	85.79	79.55
Ga	20.43	20.89	20.72	19.52	20.70	20.12	19.90	17.84	20.27	21.26
V	227.5	230.1	227.0	222.7	222.6	219.1	219.9	28.52	225.9	223.5
Cr	116.2	127.0	78.84	77.63	75.56	62.97	67.76	28.86	69.99	71.20
Ni	66.32	58.77	38.96	33.88	35.99	35.80	37.09	2.62	37.25	36.84
Sc	23.14	22.56	23.06	21.99	22.52	21.69	22.17	17.54	22.15	21.94
Sr	1157	1627	1915	1992	1979	1904	1892	472	2330	1974
Ba	1153	937	1037	1077	977	1010	1115	286	1166	1099
Th	3.29	3.41	4.18	3.96	4.14	3.95	3.99	2.13	4.17	4.19
U	0.76	0.79	0.94	1.01	0.93	0.89	0.93	0.84	0.97	1.08
Ta	0.33	0.31	0.31	0.30	0.30	0.29	0.30	0.27	0.30	0.31
Nb	5.86	5.60	5.32	5.21	5.35	5.18	5.27	3.71	5.40	5.46
Zr	149.4	151.4	183.2	180.2	186.5	177.4	178.7	99.79	184.2	184.1
Hf	3.77	3.87	4.66	4.60	4.77	4.49	4.59	2.94	4.68	4.70
Y	23.73	23.61	29.52	27.46	27.96	27.41	28.07	31.71	27.64	26.58

	WT04-21	WT09-1	WT09-2	WT09-3	WT09-5	WT09-6	WT09-7	WT010-1	WT010-2	WT010-3
					郎					
SiO_2	51.04	50.89	50.91	49.73	52.48	50.95	53.16	48.09	47.79	48.84
TiO_2	1.53	1.31	1.29	1.40	1.35	1.25	1.25	1.24	1.27	1.62
Al_2O_3	15.83	16.22	15.95	16.92	15.65	16.53	15.64	17.59	17.99	14.60
Fe_2O_3	10.50	10.38	10.30	12.22	9.97	9.99	10.87	10.21	10.34	10.29
MnO	0.23	0.42	0.39	0.66	0.16	0.16	0.18	0.32	0.50	0.51
CaO	7.40	5.03	5.43	2.83	5.92	9.05	4.62	8.40	6.03	6.60
MgO	4.30	5.70	5.62	5.01	4.88	5.65	4.49	6.63	6.89	4.68
K_2O	3.59	1.92	1.70	1.47	0.90	1.26	0.89	1.59	2.43	1.49

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Continued Table 1

	WT04-21	WT09-1	WT09-2	WT09-3	WT09-5	WT09-6	WT09-7	WT010-1	WT010-2	WT010-3
	郎									
Na_2O	3.14	4.42	4.66	5.43	5.44	2.60	5.90	2.67	3.00	3.39
P_2O_5	0.65	0.56	0.56	0.60	0.60	0.22	0.54	0.21	0.22	0.64
LOI	1.63	3.09	3.11	3.66	2.57	2.21	2.34	2.96	3.48	7.72
Total	99.85	99.92	99.92	99.94	99.90	99.88	99.88	99.91	99.93	100.38
$Mg^{\#}$	57	64	64	57	62	65	58	68	69	60
La	41.59	29.80	27.71	27.88	30.58	14.51	31.90	6.94	5.51	32.45
Ce	101.5	65.12	63.25	65.56	69.31	33.35	68.31	17.75	14.24	71.23
Pr	14.48	8.51	8.31	8.65	9.04	4.76	8.77	2.70	2.26	9.45
Nd	61.81	34.04	34.00	35.01	37.26	21.04	34.38	12.94	11.38	38.52
Sm	10.86	6.55	6.52	6.92	7.47	4.98	6.41	3.52	3.36	7.26
Eu	3.02	1.73	1.78	1.72	2.11	1.70	1.78	1.24	1.25	1.99
Gd	8.42	5.94	5.89	6.18	6.74	5.05	5.84	3.66	3.60	6.60
Tb	1.13	0.88	0.88	0.92	0.97	0.88	0.88	0.68	0.68	0.99
Dy	5.65	5.02	4.92	5.25	5.51	5.53	4.94	4.31	4.38	5.54
Ho	1.05	0.99	0.99	1.05	1.10	1.19	0.99	0.91	0.92	1.13
Er	2.86	2.78	2.70	2.86	3.00	3.27	2.74	2.44	2.55	3.06
Tm	0.42	0.40	0.40	0.42	0.44	0.50	0.39	0.38	0.39	0.43
Yb	2.69	2.52	2.47	2.62	2.78	3.17	2.52	2.31	2.42	2.82
Lu	0.39	0.40	0.38	0.40	0.43	0.49	0.37	0.36	0.37	0.42
Rb	75.06	70.66	62.85	53.85	30.22	40.00	28.35	86.44	197.1	72.51
Ga	20.86	18.08	19.20	28.40	18.65	17.53	18.40	17.32	17.11	17.67
V	213.4	221.9	217.5	225.9	228.1	201.3	209.3	253.9	249.2	219.6
Cr	68.33	96.69	91.10	104.3	68.20	110.5	54.85	164.1	169.6	70.99
Ni	34.40	42.38	38.80	43.13	26.22	86.40	31.79	71.56	70.06	18.66
Sc	21.64	27.73	27.23	28.32	27.93	29.30	25.53	34.32	34.30	26.14
Sr	2131	451.7	351.8	252.1	311.3	292.6	232.7	394.4	462.1	96.50
Ba	1173	492.6	496.8	507.9	297.9	271.4	183.1	388.8	599.5	184.7
Th	4.22	2.63	2.57	2.77	3.25	2.75	2.93	0.70	0.70	3.70
U	0.93	0.81	0.78	0.92	1.03	0.85	1.00	0.24	0.27	0.99
Ta	0.31	0.56	0.54	0.59	0.60	0.34	0.55	0.19	0.19	0.58
Nb	5.34	9.40	9.24	10.00	10.13	4.58	9.15	2.44	2.51	9.44
Zr	181.8	211.6	209.2	225.7	231.9	198.2	204.7	96.71	98.82	220.4
Hf	4.65	4.78	4.63	5.05	5.17	4.54	4.52	2.47	2.51	5.15
Y	27.19	25.32	25.01	26.43	28.32	28.90	25.27	23.42	23.87	28.18

	WT010-6	WT010-7	WT011-1	WT011-2	WT011-3	ZK03	WT012-1	WT012-2-1	WT012-2-2
	郎								
SiO_2	67.42	67.92	54.93	57.67	50.74	54.91	47.45	54.14	56.47
TiO_2	0.44	0.43	1.06	1.16	1.18	1.06	1.98	1.20	2.04
Al_2O_3	15.77	15.55	14.43	14.58	15.83	15.28	18.15	16.63	14.66
Fe_2O_3	3.75	3.86	10.74	9.87	10.99	9.79	12.17	9.81	8.89
MnO	0.11	0.09	0.54	0.30	0.63	0.48	1.32	0.70	0.35
CaO	2.84	1.58	3.63	5.34	4.79	5.32	2.75	3.08	5.89
MgO	1.02	1.06	4.74	2.81	5.34	3.44	5.97	2.45	3.04
K_2O	3.37	3.45	3.75	3.63	3.57	3.93	0.32	4.93	3.27
Na_2O	3.91	4.67	2.93	2.69	3.25	2.51	5.20	3.57	2.54
P_2O_5	0.18	0.18	0.37	0.48	0.42	0.37	0.31	0.50	0.92
LOI	1.08	1.09	2.79	1.33	3.15	2.85	4.32	2.90	1.82
Total	99.88	99.88	99.91	99.86	99.91	99.95	99.94	99.90	99.89
$Mg^{\#}$	47	47	59	48	62	54	62	45	53
La	24.72	17.64	12.17	20.79	15.57	16.21	6.96	18.72	21.60
Ce	49.61	37.15	30.21	49.02	37.79	36.77	20.67	44.21	52.62
Pr	5.98	4.78	4.31	6.65	5.27	5.01	3.48	5.91	7.67

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Continued Table 1

	WT010-6	WT010-7	WT011-1	WT011-2	WT011-3	ZK03	WT012-1	WT012-2-1	WT012-2-2
					郎				
Nd	22.66	19.03	19.26	28.94	23.60	21.73	17.22	25.41	35.25
Sm	4.08	3.85	4.82	6.78	5.77	5.10	5.05	6.11	8.27
Eu	1.17	1.01	1.02	1.55	1.25	1.24	1.33	1.24	4.91
Gd	3.81	3.56	4.83	6.58	5.67	5.01	5.19	6.12	8.31
Tb	0.57	0.56	0.85	1.13	0.98	0.86	1.00	1.10	1.36
Dy	3.30	3.41	5.43	7.07	6.23	5.25	6.39	6.99	8.17
Ho	0.71	0.74	1.17	1.48	1.32	1.12	1.35	1.52	1.72
Er	2.08	2.14	3.35	4.15	3.70	3.09	3.62	4.22	4.65
Tm	0.33	0.34	0.51	0.65	0.59	0.48	0.52	0.67	0.67
Yb	2.25	2.33	3.28	4.07	3.68	3.01	3.22	4.13	4.21
Lu	0.38	0.37	0.50	0.61	0.56	0.47	0.49	0.62	0.64
Rb	103.4	108.4	188.2	188.7	191.4	186.0	13.70	232.8	85.68
Ga	15.24	14.54	14.51	16.68	16.34	16.18	25.28	19.53	17.45
V	42.48	45.59	244.0	203.9	268.1	267.2	234.5	214.8	99.53
Cr	28.37	36.90	74.77	48.06	81.26	86.08	315.70	51.42	24.52
Ni	2.25	2.59	22.00	13.64	25.22	21.60	211.7	12.65	5.09
Sc	10.34	9.97	30.77	29.55	32.97	32.54	36.02	30.07	27.71
Sr	302.6	147.5	234.9	289.4	310.4	285.1	337.7	294.7	365.8
Ba	513.9	498.6	500.8	428.8	499.8	506.8	143.6	1177	1831
Th	6.35	4.74	8.47	11.00	9.66	8.45	0.47	11.51	5.91
U	1.18	1.21	2.47	3.30	3.08	2.66	0.34	3.36	1.80
Ta	0.45	0.42	0.44	0.57	0.49	0.45	0.33	0.60	0.52
Nb	5.35	5.22	6.16	8.06	6.94	6.26	4.32	8.28	6.55
Zr	128.1	127.9	176.0	229.9	200.3	177.4	149.1	242.4	207.5
Hf	3.47	3.48	4.84	6.28	5.41	4.82	3.49	6.47	5.21
Y	19.14	20.05	31.82	39.12	35.30	29.94	36.48	42.73	41.72

2 Sm-Nd

Table 2 Sm-Nd isotopic compositions of the Permian Nileke volcanic rocks

	Rb $\times10^{-6}$	Sr $\times10^{-6}$	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	2σ	$(^{87}Sr/^{86}Sr)_i$	Sm $\times10^{-6}$	Nd $\times10^{-6}$	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	2σ	$(^{143}Nd/^{144}Nd)_i$	ε_{Nd}
wt03-2	170.6	1627	0.3033	0.70560	5	0.70439	8.62	46.49	0.112097	0.512692	9	0.512487	4.08
wt09-6	40	292.6	0.3954	0.70543	3	0.70385	4.98	21.04	0.142965	0.512846	3	0.512584	5.98
wt10-1	86.44	394.4	0.6341	0.70680	4	0.70427	3.52	12.94	0.164465	0.512893	4	0.512592	6.13
wt10-2	197.1	462.1	1.2343	0.70944	2	0.70452	3.36	11.38	0.17851	0.512888	4	0.512561	5.53
wt10-3	72.51	96.5	2.1751	0.71307	5	0.70440	7.26	38.52	0.113945	0.512681	9	0.512472	3.80
wt10-6	103.4	302.6	0.9887	0.70794	8	0.70400	4.08	22.66	0.108855	0.512725	8	0.512525	4.84
wt11-2	188.7	289.4	1.8873	0.71184	6	0.70432	6.78	28.94	0.141641	0.512805	4	0.512545	5.23
wt11-3	191.4	310.4	1.7834	0.70429	5	0.69718	5.77	23.60	0.147816	0.512813	6	0.512542	5.17
wt12-1	13.7	337.7	0.1173	0.70524	8	0.70477	5.05	17.22	0.177308	0.512951	5	0.512626	6.80

Note Isotopic results normalized to $^{86}Sr/^{86}Sr = 0.1194$ and $^{146}Nd/^{144}Nd = 0.7219$. NBS 987 average Sr standard = 0.71025 ± 1 and Jndi-1 Nd standard = 0.51212 ± 1.1 in this study. Initial isotope ratios and epsilon values calculated at 280Ma using present day bulk Earth-CHUR values of $^{87}Rb/^{86}Sr$ = 0.07809 $^{87}Sr/^{86}Sr$ = 0.7045 $^{147}Sm/^{144}Nd$ = 0.19667 and $^{143}Nd/^{144}Nd$ = 0.512638

Perkin-Elmer Sciex Elan 6000

1 ~ 5mm ICP-MS 40mg bomb

5% 5% HNO_3 HF Rh

200 USGS W-2 G-2 GSR-I

GSR-2 GSR-3

Rigaku 100e X XRF 2% ~ 5% 1996

1% ~ 5% Li 2009

MC-ICPMS Sr NBS987
Sr-GIG $^{87}Sr/^{86}Sr$ $^{86}Sr/^{88}Sr = 0.1194$
2002 Nd
JNdi-1 Nd-GIG $^{143}Nd/^{144}Nd$
$^{146}Nd/^{144}Nd = 0.7219$ 2003
Sr Nd 0.002%

4

4.1

11 18
1 Sm-Nd
2

-SiO_2 TAS 3a
WT04-2

K Na
TAS
Ti Zr Y Nb
Zr/TiO_2-Nb/Y 3b

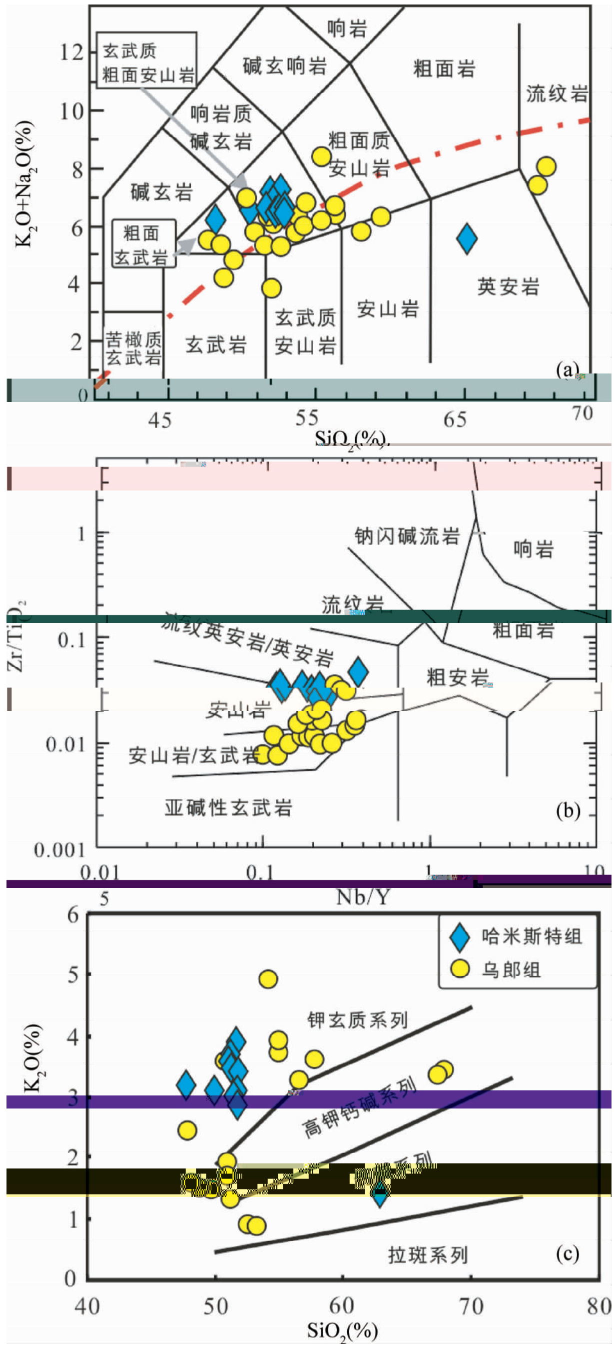
SiO_2 47.72% ~
51.71% TiO_2 1.48% ~ 1.57% K_2O 2.81% ~
3.91% K_2O/Na_2O 0.81 ~ 1.22 Al_2O_3 15.20% ~
15.95% 3a 4 1 K_2O-SiO_2
3c
WT04-2
4 WT04-2
SiO_2 CaO

郎
3a 4 K_2O-SiO_2
3c

SiO_2 MgO TiO_2
CaO Al_2O_3 FeO MnO P_2O_5

>10% SiO_2 3a
Al_2O_3 K_2O Na_2O Sr SiO_2
4

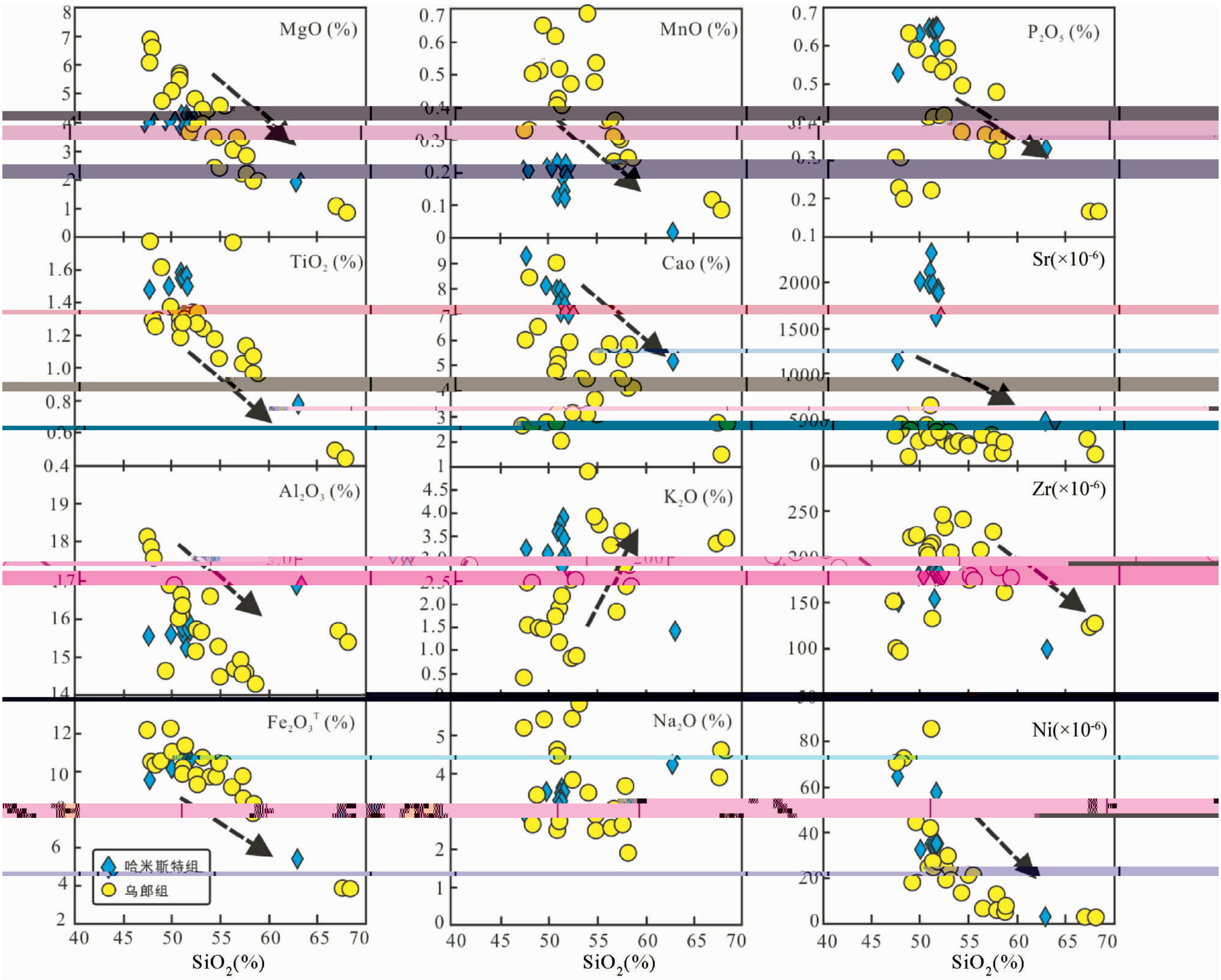
4.2



3

Fig. 3 Classification of types and series of the Nileke Permian volcanic rocks

5a b
184.8×10^{-6} ~ 256.2×10^{-6} $(La/Yb)_N$
= 9.7 ~ 11.7 WT04-2
96.1×10^{-6} $(La/Yb)_N$ 2.7 5a Eu
$Eu/Eu^* = 0.91 \sim 0.97$ $\Sigma REE = 53.1 \times 10^{-6}$ ~
181.9×10^{-6} $(La/Yb)_N = 1.6 \sim 9.1$ Eu Eu



4

Fig. 4 Harker diagram o f the Nileke Permian volcanic rocks

$Eu/Eu^* = 0.61 \sim 1.79$

5a 5b WT010-1 WT010-2

WT012-1

5b $\Sigma REE = 53.3 \times 10^{-6} \sim 76.5 \times 10^{-6}$ $(La/Yb)_N = 1.6 \sim 2.2$ $Eu/Eu^* = 0.79 \sim 1.09$ E-MORB

5c d

Rb Ba Th K Sr $1157 \times 10^{-6} \sim 2330 \times 10^{-6}$ WT04-2 $= 472 \times 10^{-6}$ Nb Ta Zr Hf Ti Nb-Ta La

Nb/La = 0.13 ~ 0.19 WT04-2 = 0.28

郎

Sr $96 \times 10^{-6} \sim 462 \times 10^{-6}$

Nb-Ta Nb/La = 0.22 ~ 0.62

4.3 Sr-Nd

Sr-Nd 6

郎

Sr-Nd Nd

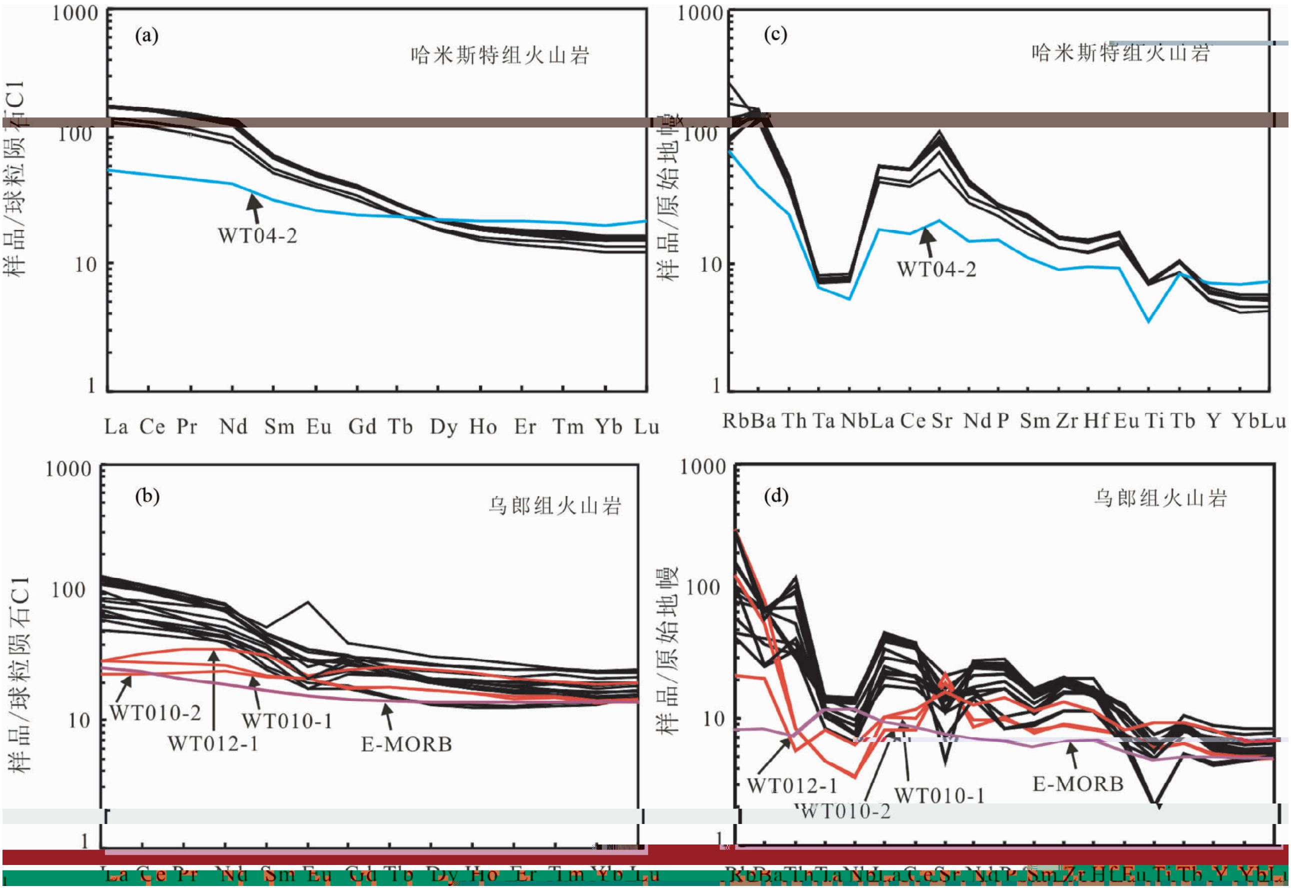
Sr $\varepsilon_{Nd} = 3.8 \sim 6.8$ $(^{87}Sr/^{86}Sr)_i = 0.69718 \sim 0.70477$ OIB

MORB Sr-Nd

5

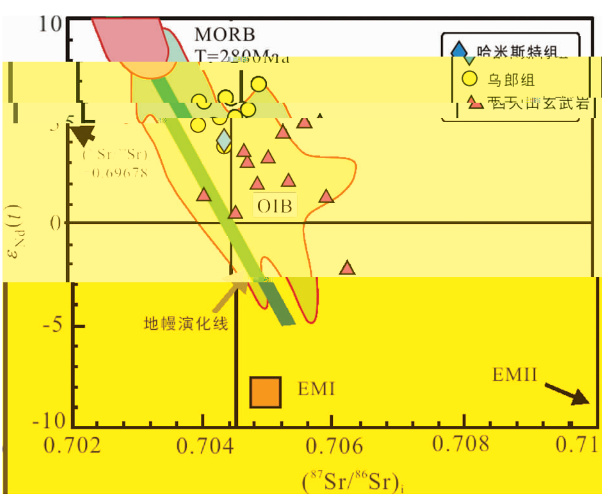
5.1

郎



5

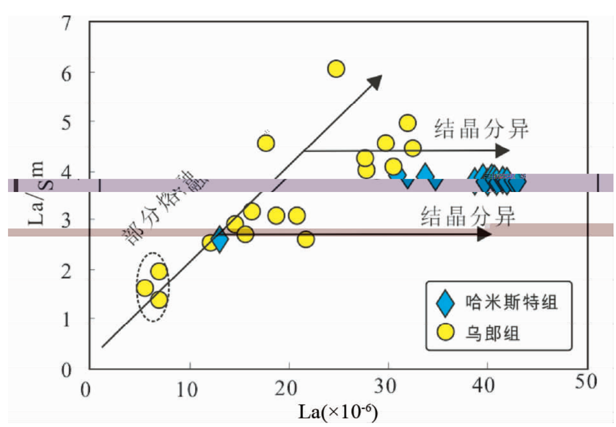
Fig. 5 REE distribution patterns and trace element spider diagrams of the Nileke Permian volcanic rocks



6 Sr-Nd MORB

OIB EMI EMII Zindler and Hart 1986

Fig. 6 Sr-Nd isotopic composition diagram of the Nileke Permian volcanic rocks after Zindler and Hart 1986



7 La La/Sm

E-MORB WT010-1 WT010-2

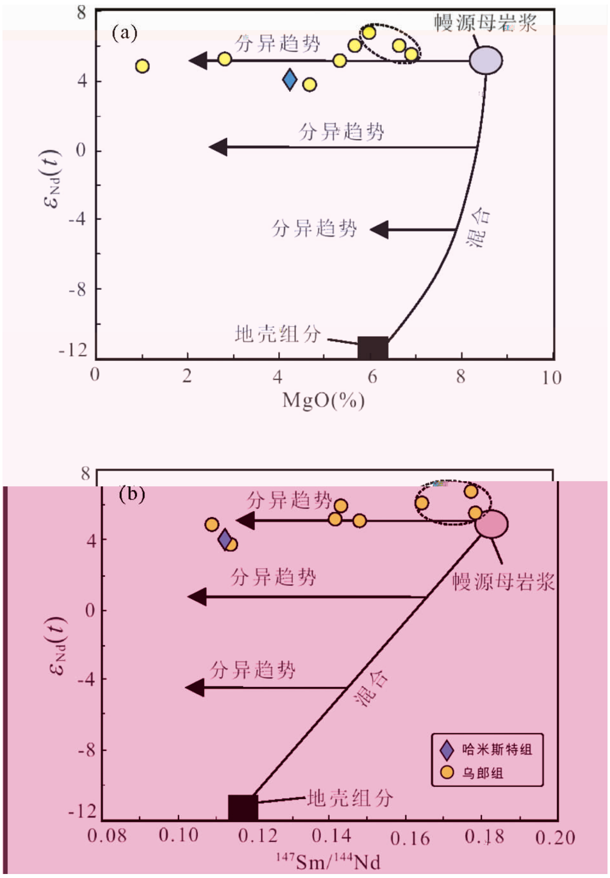
WT012-1

Fig. 7 La vs. La/Sm of the Nileke Permian volcanic rocks

OIB Sr-Nd

3a b Eu 5a La/Sm

La 7 WT010-1 WT010-2



8 MgO $^{147}Sm/^{144}Nd$

ε_{Nd}

E-MORB WT010-1 WT010-2

WT012-1

Fig. 8 MgO and $^{147}Sm/^{144}Nd$ vs. ε_{Nd} diagram of the Nileke Permian volcanic rocks

WT012-1 SiO_2 47.5% ~ 48.1% MgO 5.97% ~ 6.89% Sr < 500 × 10^{-6} 50 × 10^{-6} < ΣREE < 80 × 10^{-6} La/Yb_N 1.6 ~ 2.2 Nb/La > 0.35 E-MORB Cr Ni 164.1 × 10^{-6} ~ 315.7 × 10^{-6} 70.1 × 10^{-6} ~ 211.7 × 10^{-6} $^{147}Sm/^{144}Nd$ Eu Eu/Eu^* = 0.79 ~ 1.09

8

K_2O 2.81% ~ 3.91% Sr > 1000 × 10^{-6} ΣREE > 200 × 10^{-6} La/Yb_N 9.7 ~ 11.7

9 Arth 1976

Zr/Sm Hf/Sm Nb/

Y Nu9607

1% 5% 10% Zr/Sm

Hf/Sm Nb/Y

E-MORB

> 10%

E-MORB

Dy/Yb

Dy/Yb > 2.5

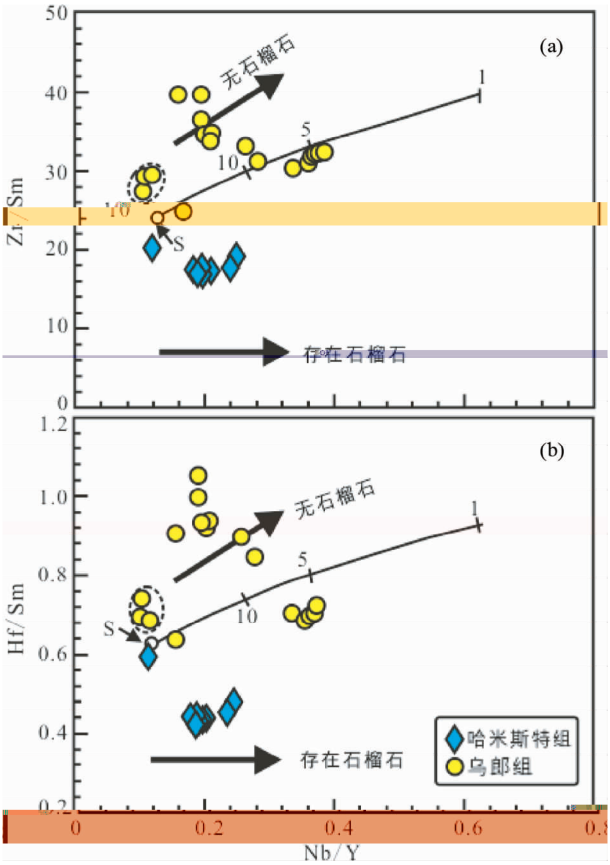
Dy/Yb < 1.5 Jiang 2009 Dy/Yb 2.07 ~ 2.24 WT04-2 = 1.7 1.46 ~ 2.0

Nb-Ta 郎

Nb/La 0.22 ~ 0.62 Nb/La < 0.2 Nb-Ta

MgO $^{147}Sm/^{144}Nd$

ε



9 Nb/Y-Zr/Sm a Nb/Y-Hf/Sm b

Arth 1976

Nu9607

S

Nb/La >0.35 E-MORB

3 Sr-Nd

MORB

Nb-Ta

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