

**Recycled carbonates in the mantle sources of natural kamafugites:
A zinc isotope perspective**

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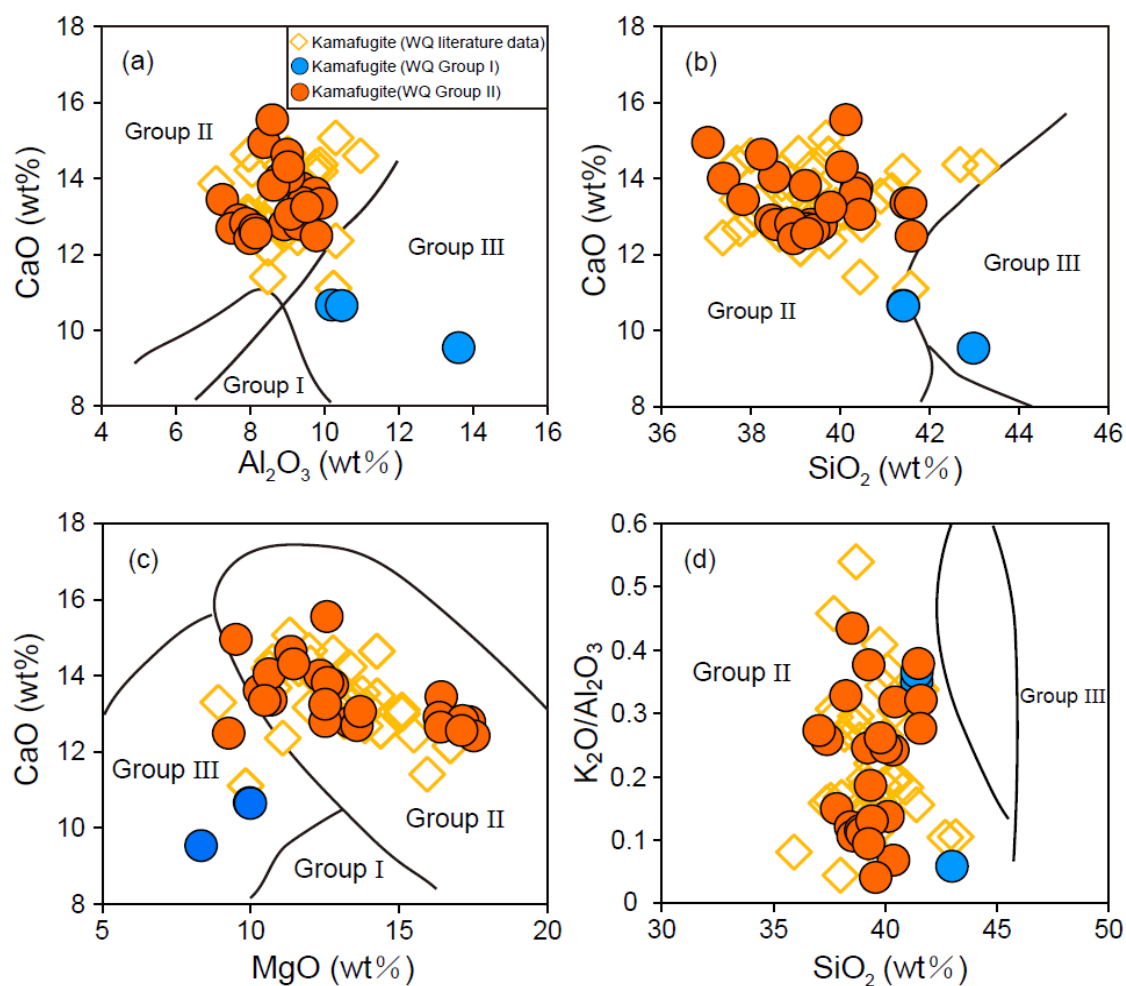


FIGURE S1. The (a) Al_2O_3 vs CaO (b) SiO_2 vs CaO (c) MgO vs CaO (d) SiO_2 vs $\text{K}_2\text{O}/\text{Al}_2\text{O}_3$ diagrams for Cenozoic kamafugites from the West Qinling orogen, China. Literature data are from Yu et al. (1998, 2001, 2009), Dong et al. (2008) and Guo et al. (2014). The Group classification is after Foley (1987).

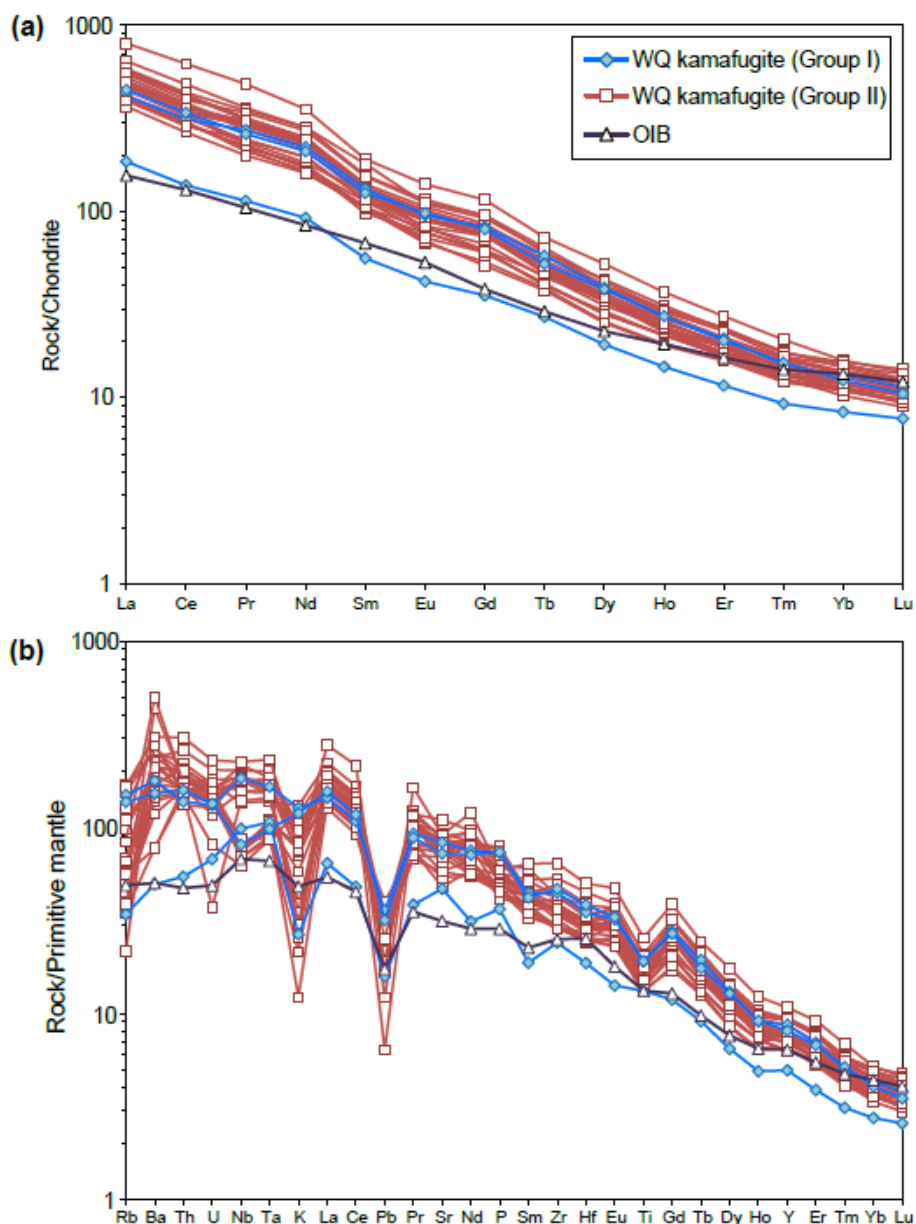


FIGURE S2 (a) Chondrite-normalized REE patterns and (b) primitive mantle-normalized trace element patterns for two groups of kamaufugites from West Qinling. The chondrite and primitive mantle data are from McDonough and Sun (1995). OIB compositions are after Sun and McDonough (1989).

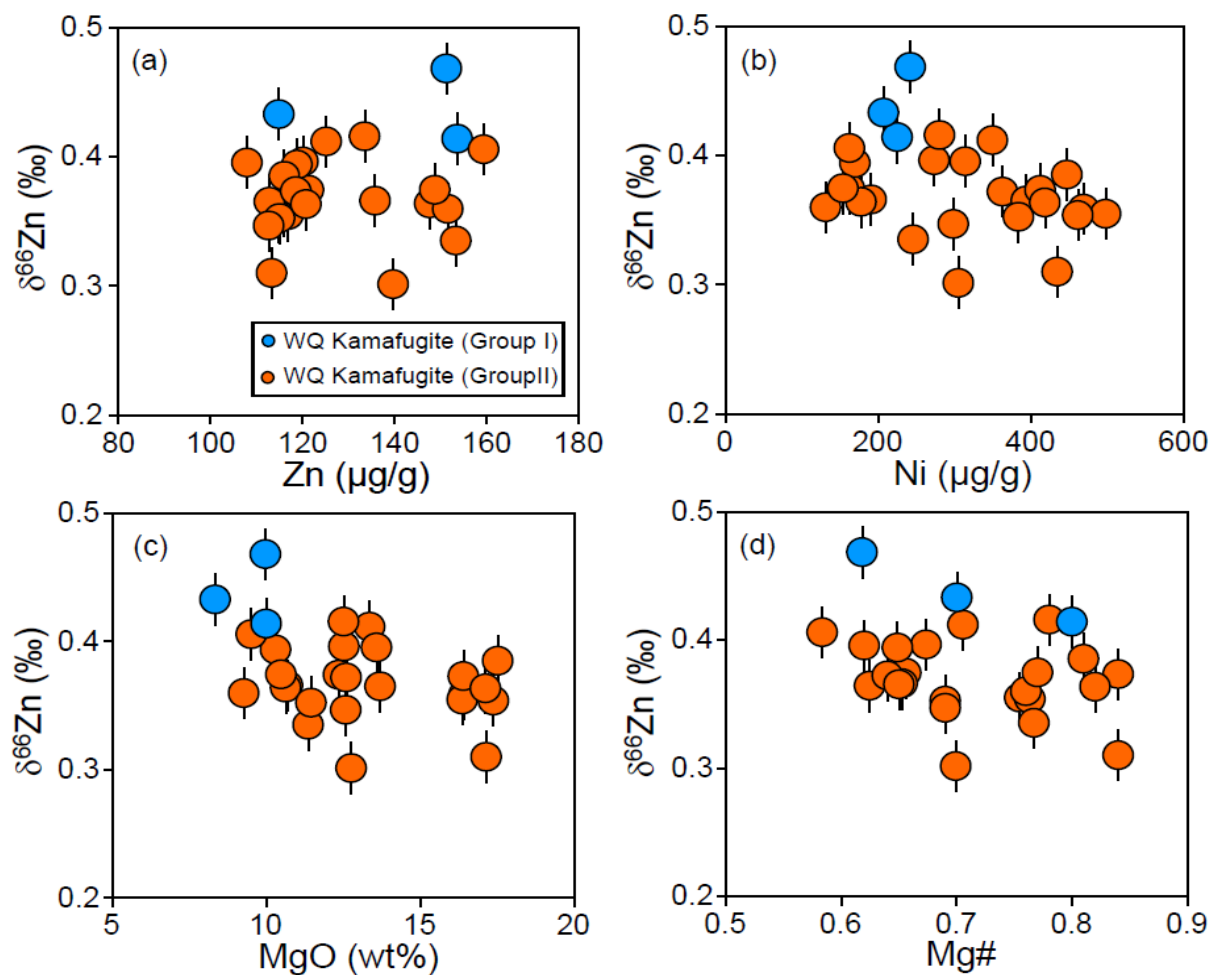


FIGURE S3. The (a) Zn vs $\delta^{66}\text{Zn}$ (b) Ni vs $\delta^{66}\text{Zn}$ (c) MgO vs $\delta^{66}\text{Zn}$ (d) Mg# vs $\delta^{66}\text{Zn}$ diagrams for Cenozoic kamafugites from the West Qinling orogen, China.

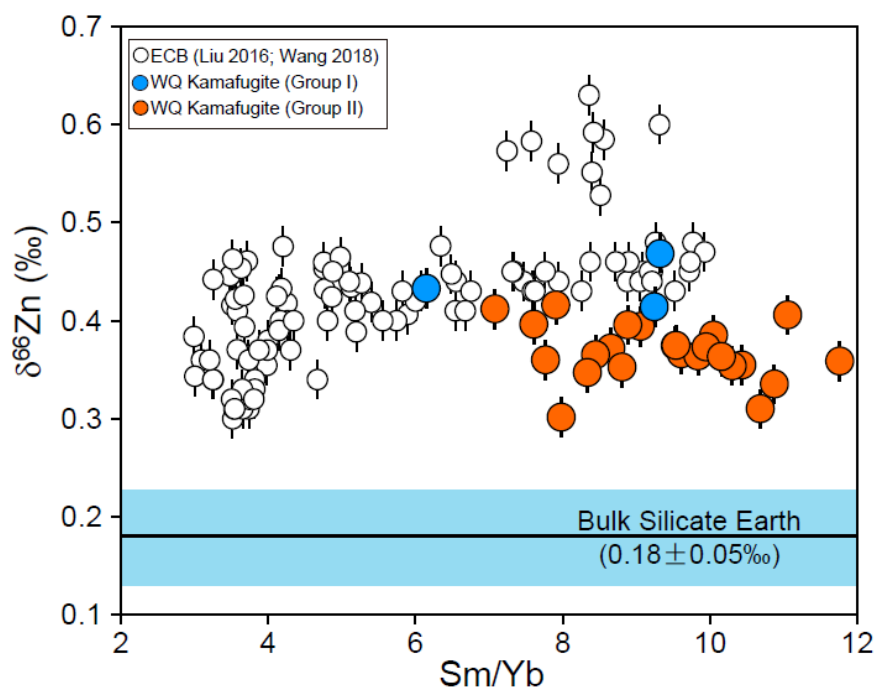


FIGURE S4. The Sm/Yb vs $\delta^{66}\text{Zn}$ diagram for Kamaufugites from the West Qinling orogen. Data for Cenozoic basalts in Eastern China (ECB) are shown for comparison. Zinc isotopic composition of the bulk silicate Earth is from Wang et al. (2017), Sossi et al. (2018), McCoy-West et al. (2018), and Liu et al. (2019).

Table S1. Whole-rock major (wt%) elements and trace element (ppm) contents of kamafugites from the West Qinling orogen.

Sample No.	ND20-20	SW5 ¹	JK6 ¹	F17	F21	FSL	BGL	HT-0309	GJS-0310	CZ-0303
Rock type:	Kamafugites (Group I)			Kamafugites (Group II)						
Major elements (wt%)										
SiO ₂	41.4	43.0	41.4	38.4	38.6	37.8	40.4	39.6	39.3	40.3
TiO ₂	4.1	2.9	4.1	3.1	3.1	3.1	3.1	3.2	4.0	4.0
Al ₂ O ₃	10.2	13.6	10.5	7.7	7.9	7.3	9.4	8.9	9.3	9.7
TFe ₂ O ₃	12.3	13.5	12.6	10.6	10.8	10.4	11.0	11.2	12.1	11.2
MnO	0.2	0.2	0.2	0.1	0.2	0.1	0.2	0.2	0.2	0.1
MgO	10.0	8.3	10.0	16.4	17.4	16.4	12.8	13.4	12.5	10.3
CaO	10.7	9.5	10.7	12.9	12.8	13.5	13.8	12.8	12.8	13.6
Na ₂ O	3.9	4.5	3.8	1.5	1.3	1.8	1.1	2.2	2.8	2.1
K ₂ O	3.6	0.8	3.8	0.9	0.9	1.1	0.6	0.4	1.7	2.4
P ₂ O ₅	1.6	0.8	1.6	1.4	1.5	1.6	1.0	1.2	0.9	1.2
LOI	1.4	2.9	1.1	5.9	5.8	6.2	6.5	7.0	3.5	4.4
Total	99.4	100	99.8	98.9	100.3	99.3	99.9	100.1	99.1	99.3
Mg#	62	70	80	75	76	76	70	71	67	65
Trace elements (ppm)										
Zn	151	115	154	117	115	116	139	125	120	119
La	107	96.2	98.9	136	125	130	96.5	93.7	98.9	119
Ce	207	185	191	259	233	257	181	180	194	229
Pr	24.2	19.5	25.4	29.5	26.6	29.2	20.6	20.7	22.5	25.5
Nd	96.1	75.6	101	113	102	112	79.6	81.2	89.7	98.0
Sm	18.6	15.3	19.6	20.1	18.1	19.4	14.5	15.5	17.0	17.7
Eu	5.51	3.81	5.37	5.71	5.21	5.49	4.32	4.58	5.04	5.09
Gd	16.0	10.7	16.4	16.3	14.8	15.5	12.3	13.3	14.7	14.8
Tb	1.89	1.40	2.09	1.85	1.68	1.71	1.44	1.60	1.75	1.73
Dy	9.41	6.31	9.60	8.91	8.14	8.11	7.17	8.19	8.84	8.56
Ho	1.50	1.06	1.48	1.41	1.29	1.26	1.18	1.37	1.45	1.39
Er	3.24	2.58	3.33	3.06	2.81	2.71	2.68	3.15	3.30	3.06
Tm	0.38	0.31	0.37	0.36	0.33	0.31	0.33	0.39	0.41	0.36
Yb	1.99	1.81	2.12	1.92	1.75	1.65	1.82	2.19	2.24	1.96
Lu	0.26	0.24	0.28	0.25	0.23	0.22	0.25	0.30	0.31	0.27
Rb	86.6	41.8	94.5	27.4	22.4	36.4	13.6	35.4	24.6	61.7
Ba	1059	1004	1242	1185	1659	1468	1950	1556	959	1435
Th	13.4	13.2	11.6	17.5	15.8	17.1	12.7	12.8	13.0	15.0
U	2.80	3.64	2.75	3.39	3.13	2.92	1.69	2.96	2.86	3.14
Nb	57.42	69.90	130	53.42	49.29	49.21	44.32	52.60	53.71	52.20
Ta	4.00	6.36	6.76	3.94	3.65	3.51	3.50	4.04	4.28	4.46
K	29662	23989	31698	7717	7015	9006	5324	3046	14407	19564
Pb	5.86	5.03	6.61	5.46	5.21	5.01	4.44	7.37	6.28	3.79
Sr	1523	1447	1742	1757	1845	1343	1007	1627	1223	1762
P	6965	4454	6899	6279	6687	7092	4327	5303	3940	5296
Zr	521	317	497	427	394	375	329	436	463	401
Hf	11.8	7.68	10.79	9.72	8.95	8.54	7.4	9.6	10.9	9.5
Ti	24756	16920	24720	18332	18731	18338	18417	19419	23674	23746
Y	36.7	29.9	39.5	34.1	31.5	31.4	28.3	33.6	34.3	33.4

(continued)

Sample No.	DS-STB -0305B	F1 ¹	F4 ¹	F8 ¹	BGL-0315S ²	JK7 ¹	BGL-0315N ²	HT-11 ¹	DS-1 ¹	XD20 ¹
Rock type:		Kamafugites (Group II)								
Major elements (wt%)										
SiO ₂	38.5	39.0	39.4	39.3	40.4	38.9	39.2	39.8	41.6	41.6
TiO ₂	4.5	3.4	3.4	3.4	2.8	3.3	3.5	3.8	4.4	3.9
Al ₂ O ₃	9.0	8.0	8.1	8.2	9.1	7.9	8.6	9.5	9.8	9.9
TFe ₂ O ₃	12.8	11.2	11.2	11.2	12.2	10.9	11.9	12.3	12.9	11.5
MnO	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
MgO	10.6	17.5	16.4	17.1	13.7	17.1	12.6	12.5	9.3	10.5
CaO	14.1	12.4	12.7	12.6	13.1	12.8	13.8	13.3	12.5	13.4
Na ₂ O	2.5	1.3	1.6	1.2	2.9	1.4	2.8	2.7	3.0	3.6
K ₂ O	3.9	0.9	1.1	0.8	2.9	0.9	2.1	2.5	3.1	2.7
P ₂ O ₅	1.2	1.2	1.2	1.3	1.0	1.3	1.1	1.0	1.0	1.1
LOI	1.9	4.5	4.6	4.9	1.8	4.9	3.9	2.0	2.0	1.5
Total	99.2	99.6	99.9	100.2	100.1	99.6	99.7	99.6	99.8	99.9
Mg#	62	81	84	82	65	84	64	78	76	77
Trace elements (ppm)										
Zn	148	116	119	121	113	113	119	134	152	149
La	152	116	116	117	96.2	112	106	93.2	111	130
Ce	295	220	220	222	185	212	200	176	207	243
Pr	33.5	28.1	28.3	28.4	19.5	27.5	21.3	22.5	26.9	31.4
Nd	129	109	109	110	75.6	107	77.9	89.4	106	124
Sm	23.1	19.4	19.3	19.4	15.3	18.7	16.8	17.0	19.5	22.8
Eu	6.51	5.09	5.04	5.11	3.81	5.02	4.36	4.67	5.33	6.29
Gd	18.9	15.9	15.8	16.0	10.7	15.2	12.0	14.7	16.8	19.0
Tb	2.18	1.91	1.90	1.92	1.40	1.84	1.48	1.84	2.11	2.30
Dy	10.62	8.51	8.50	8.52	6.31	8.12	6.92	8.40	9.80	10.40
Ho	1.70	1.28	1.29	1.30	1.06	1.23	1.18	1.36	1.58	1.60
Er	3.73	3.00	2.98	2.96	2.58	2.78	2.83	3.15	3.68	3.64
Tm	0.44	0.33	0.33	0.33	0.31	0.30	0.34	0.36	0.43	0.41
Yb	2.34	1.93	1.94	1.91	1.81	1.75	1.94	2.15	2.51	2.39
Lu	0.31	0.26	0.26	0.26	0.24	0.24	0.27	0.30	0.35	0.33
Rb	107	23.9	28.5	22.0	41.8	24.5	31.2	69.2	80.9	53.0
Ba	1786	1073	823	1189	1004	1914	3036	1243	1934	3478
Th	18.7	13.6	13.6	13.8	13.2	13.2	14.7	11.2	13.4	14.8
U	3.58	2.96	2.93	3.01	3.64	2.80	3.77	2.67	3.23	3.37
Nb	96.71	133	132	133	111.15	128	129.97	132	154	136
Ta	5.63	6.38	6.33	6.40	6.36	6.06	7.26	6.90	7.55	6.44
K	32549	7385	8796	6389	23989	7551	17595	20662	26055	22736
Pb	2.24	5.82	5.91	5.23	5.03	4.66	5.76	5.30	3.54	5.43
Sr	1833	1728	1546	1811	1447	1602	1544	1601	1682	1900
P	53712	5370	5152	5458	4454	5589	4716	4279	4279	4672
Zr	595	395	400	390	317	357	327	408	546	477
Hf	13.81	8.71	8.63	8.39	7.68	7.77	8.39	8.74	12.0	10.2
Ti	27057	20100	20340	20580	16920	19680	20760	22920	26400	23580
Y	42.6	33.5	33.9	34.0	29.9	31.7	32.7	35.4	41.7	42.0

(continued)

Sample No.	GJS-0320 ²	WZB-0306A ²	WJP-0307	PJS-0310 ²	DS-SYB-0305	XQL	HYS-0316 ²
Rock type: Kamafugites (Group II)							
Major elements (wt%)							
SiO ₂	40.1	38.2	37.4	39.3	37.0	41.5	40.0
TiO ₂	3.0	4.0	4.1	3.7	5.5	4.0	2.9
Al ₂ O ₃	8.6	9.0	8.8	7.5	8.4	9.4	9.0
TFe ₂ O ₃	11.0	11.2	13.0	12.5	13.6	11.4	11.3
MnO	0.2	0.2	0.2	0.2	0.2	0.2	0.2
MgO	12.6	11.4	12.3	13.6	9.5	10.7	11.5
CaO	15.6	14.6	14.0	12.7	15.0	13.4	14.3
Na ₂ O	2.0	2.2	3.5	2.5	1.7	3.1	1.6
K ₂ O	1.2	3.0	2.3	2.8	2.3	3.6	2.2
P ₂ O ₅	1.0	1.4	1.7	1.1	1.3	1.2	1.0
LOI	4.3	4.9	2.6	3.8	4.7	1.4	5.5
Total	99.6	100.1	99.9	99.7	99.2	99.9	99.5
Mg#	69	69	66	62	58	65	69
Trace elements (ppm)							
Zn	113	153	121	108	159	136	115
La	86.8	138	134	116	189	135	98.5
Ce	163	266	255	205	381	257	184
Pr	18.6	32.3	28.8	21.9	44.8	29.3	20.2
Nd	73.4	129	110	83.3	162	114	73.7
Sm	15.7	26.7	19.6	18.5	28.3	20.8	15.9
Eu	4.06	6.19	5.62	4.64	7.88	5.95	3.91
Gd	12.0	18.3	16.3	12.4	23.0	17.1	10.2
Tb	1.47	2.21	1.88	1.64	2.62	1.96	1.36
Dy	6.93	9.87	9.28	7.68	12.87	9.63	6.21
Ho	1.19	1.64	1.50	1.31	2.01	1.53	1.04
Er	2.67	3.80	3.27	3.03	4.39	3.37	2.53
Tm	0.33	0.43	0.39	0.35	0.51	0.40	0.30
Yb	1.88	2.45	2.05	2.08	2.56	2.16	1.80
Lu	0.26	0.31	0.28	0.27	0.34	0.29	0.23
Rb	22.6	43.6	61.8	36.9	105	97.9	35.6
Ba	540	1645	1406	1326	2134	1818	535
Th	12.7	21.9	17.6	13.6	25.7	16.5	13.8
U	0.78	4.27	3.43	3.28	4.80	3.29	2.46
Nb	98.79	143.49	55.37	123.44	159.74	61.31	110.09
Ta	5.89	8.16	4.37	7.52	9.45	3.57	6.27
K	9792	24479	18934	23483	18951	29624	18421
Pb	5.12	6.07	1.17	4.87	3.06	4.03	4.75
Sr	1213	2313	1420	1718	1915	1940	1135
P	4323	5894	7447	4672	5565	5150	4279
Zr	326	477	397	409	715	469	335
Hf	7.92	11.8	9.4	9.94	15.4	10.6	7.60
Ti	17940	23940	24360	22320	33060	23672	17580
Y	28.8	43.1	35.4	35.7	48.8	39.2	29.7

LOI = loss on ignition. Major elements are recalculated on anhydrous basis.

$$\text{Mg\#} = 100 \times \text{Mg}^{2+} / (\text{Mg}^{2+} + \text{Fe}^{2+}).$$

Major elements are in wt% and trace elements are in ppm ($\mu\text{g/g}$).

Reference:

1. Dong, X., Zhao, Z.D., Mo, X.X., Yu, X.H., Zhang, H.F., Li, B., DePaolo, D. J. (2008). Geochemistry of the Cenozoic Kamaflutites from West Qinling and constraint for the nature of magma source region. *Acta Petrologica Sinica*, 24, 238-248 (in Chinese).
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Table S2. Parameters for modeling used in Figure 5.

A non-modal incremental batch melting model is used to assess the magnitude of Zn isotope fractionation during mantle melting. Method is from Wang and Liu, 2021.

	Olivine	Opx	Cpx	Garnet	Initial composition	
Initial modal abundance ^a	0.52	0.22	0.16	0.10	Zn (ppm) ^e	55
Melting mode ^a	0.08	-0.19	0.81	0.30	Dy (ppm) ^e	674
K _D (Zn) ^b	0.960	0.451	0.333	0.213	Yb (ppm) ^e	441
K _D (Dy) ^c	0.002	0.07	0.17	2.2	$\delta^{66}\text{Zn}$ (‰) ^f	0.18
K _D (Yb) ^d	0.02	0.08	0.25	5.5		

a-Walter, 1998; b-Le Roux et al., 2015; c- Nielsen et al., (1992); Green et al. (2000); Tuff & Gibson (2007); Johnson (1994); d- Adam and Green, 2006; e-McDonough & Sun, 1995; f-Wang et al., 2017.

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