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Supporting information for

Lithium, Oxygen and Magnesium Isotope Systematics of Volcanic Rocks in the Okinawa Trough: Implications for Plate Subduction Studies

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Contents of this file

Text S1
Figures S1 to S4
Tables S1 to S9

Text S1

Sample processing, electron microprobe, and major and trace element analytic methods

Sample processing

The fresh volcanic lava samples obtained from the middle Okinawa Trough (MOT) and southern Okinawa Trough (SOT) were divided into two subsamples. The T9-1, T2, R2, T6-1, and T6-2 samples were processed using a cutter bar. These samples were then polished to a thickness of ~80 μm using 0.25 μm alumina powder in preparation for in situ electron microprobe analyses. The R2, T5-2, T2, T6-1, T6-2, and T9-1 samples were cleaned and cut into thin slices that were placed in an ultrasonic cleaning machine and cleaned for 15 min to remove any sediments trapped within the vesicles. The cleaned slices were immersed in anhydrous ethanol to remove any organic matter present and then soaked in dilute hydrochloric acid (HCl^-) in a water bath heated to 60°C for 1 h to eliminate any secondary carbonates. Finally, the slices were broken into 2- to 3-mm rock chips and soaked in hot ultrapure water for 7 d. The water was repeatedly changed until no precipitation occurred after silver nitrate ($AgNO_3$) was added to the supernatant, which indicated that the HCl had been completely washed away (Huang et al., 2006). The rock chips were powdered (200 mesh) using an agate mortar in preparation for whole-rock major element, trace element and isotopic analyses. The minerals (olivine, clinopyroxene, orthopyroxene, and plagioclase) and glasses were separated by integrated mechanical separation using a high-frequency dielectric splitter and magnetic and electromagnetic separators. All the minerals were carefully selected by hand under a light microscope to avoid grains showing discernible mineral inclusions or alterations, and the handpicked minerals were washed with Milli-Q® water (18.2 MΩ·cm) prior to the isotopic analyses.

Electron microprobe analyses

The major element compositions of minerals in the MOT and SOT volcanic lavas were analyzed using a JEOL JXA-8230 electron microprobe (EMP) at the Key Laboratory

of Submarine Geosciences and Prospecting Techniques, Ministry of Education, Ocean University of China, Qingdao (Tables S2–S6). The quantitative analyses were performed using a 15 kV acceleration voltage, a 20 nA beam current, and an ~10 μm beam diameter. The standards used in the analyses included albite for Na, Al, and Si, diopside for Mg and Ca, sanidine for K, rutile for Ti, almandine for Fe, bustamite for Mn, and chlorite for Cr. The precision of the major element data was better than 1%.

Major element analyses

The major element compositions of the whole-rock samples obtained from the MOT and SOT were determined using an X-ray fluorescence (XRF) spectrometer at the China National Nuclear Corporation (CNNC), Beijing Research Institute of Uranium Geology (Table S7). The sample powders (~0.9 g) were mixed with 9.0 g of lithium tetraborate ($Li_2B_4O_7$) to produce glass disks at 1050–1100°C in an automatic melting instrument. The loss on ignition (LOI) values were determined from the weight differences after ignition at 1000°C. The samples were analyzed following the methods reported by Goto and Tatsumi (1996). The analytical accuracy was assessed using the certified reference materials SARM-5, NCSDC47009, and GBW07295. The analytical precision was better than ± 5%. The accuracy of the analyses was better than 5% for SiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, Na_2O, and K_2O, and it was better than 9% for TiO_2, MnO, and P_2O_5.

Trace element analyses

The whole-rock powder samples (~40 mg) were dissolved in a mixture consisting of 0.5 mL concentrated nitric acid (HNO_3) and 1.5 mL hydrofluoric acid (HF) in a Teflon® beaker and heated at 150°C for 24 h. Then, 0.2 mL of perchloric acid ($HClO_4$) was added, and the temperature was maintained at 120°C. When no more $HClO_4$ was observed to volatilize from the beaker, 1 mL of HNO_3 and 1 mL of Milli-Q® water (18.2 MΩ·cm) were added to redissolve the residue. Then, the solutions were cooled and diluted 1,000 times with 2% pure HNO_3 and analyzed for trace elements using inductively coupled plasma mass spectrometry (ICP-MS) (ELAN DRC II) at the Institute of Oceanology, Chinese Academy of Sciences (CAS). The international standards used for the whole-rock trace element analyses were a basalt from the Columbia River (BCR-2) and a basalt from the Hawaiian Volcanic Observatory (BHVO-2). The analytical results for the reference materials (BCR-2 and BHVO-2) agreed well with the certified values (Table S8). The ICP-MS detection limits for rare earth elements (REEs) and the other trace elements were 10^{-12} to 10^{-9} g/g, and the analytical accuracy of each measured element was better than 5%.

Sr-Nd isotope analyses

Sr-Nd isotope compositions were analyzed at the Key Laboratory of the Chinese Academy of Sciences (CAS) for Crust-Mantle Materials and Environments at the University of Science and Technology of China, Anhui. The measurements of Rb-Sr and Sm-Nd isotopes were performed using a Finnigan MAT262 thermal ionization mass spectrometer (TIMS). Standard values of $^{86}Sr/^{88}Sr$=0.1194 and $^{146}Nd/^{144}Nd$=0.7219 were used to correct the measured $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios. Repeated measurements of the NBS987 and La Jolla standards were used to correct the mass fractionation of Sr and Nd. The analytical precisions of the ratios of $^{87}Rb/^{86}Sr$ and $^{147}Sm/^{144}Nd$ were better than 0.5% and 0.003%, respectively (Li et al., 2018).

Figures S1 to S4

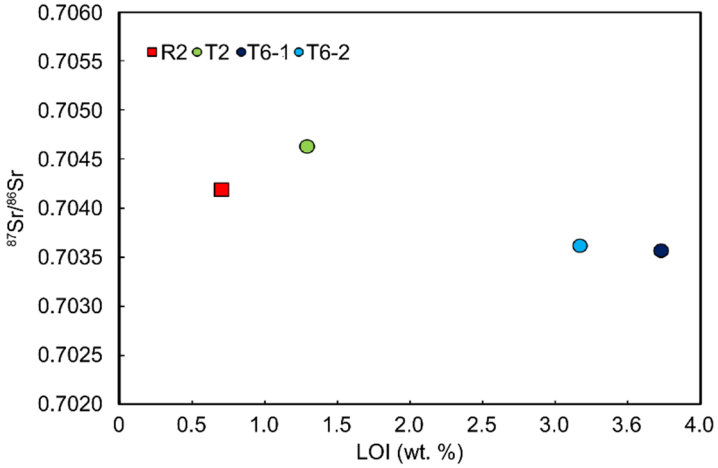

Figure S1. Plot of $^{87}Sr/^{86}Sr$ vs. LOI for the middle Okinawa Trough (MOT) and the southern Okinawa Trough (SOT) volcanic lavas. Sr isotope data are from Li et al. (2018) and this study.

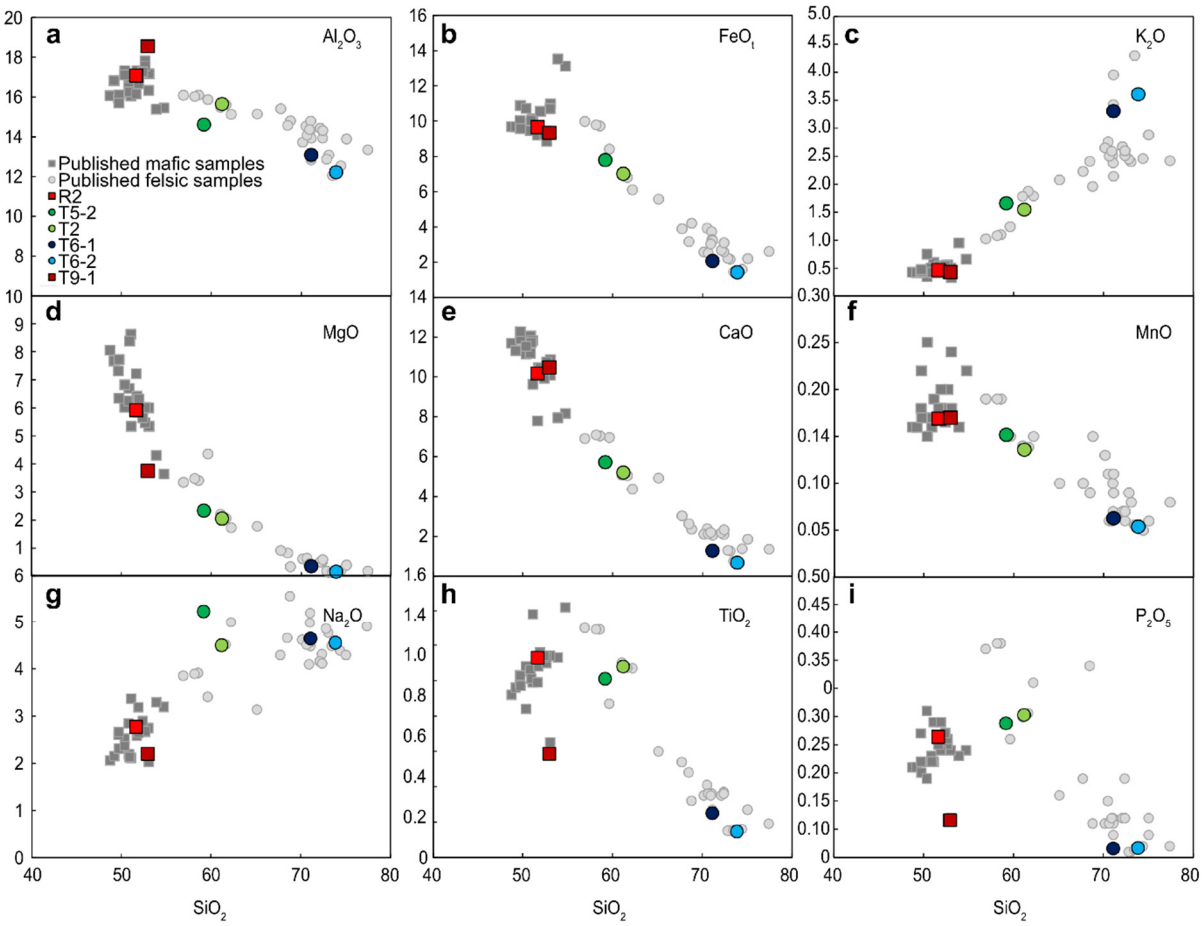

Figure S2. Harker diagrams of the MOT and SOT volcanic lavas. Data for published mafic and felsic samples are from Honma et al. (1991), Li et al. (2018), Shinjo (1999), Shinjo et al. (1999), and Shinjo and Kato (2000). Data for samples R2, T5-2, T6-1, T2, T6-2, and T9-1 are from this study.

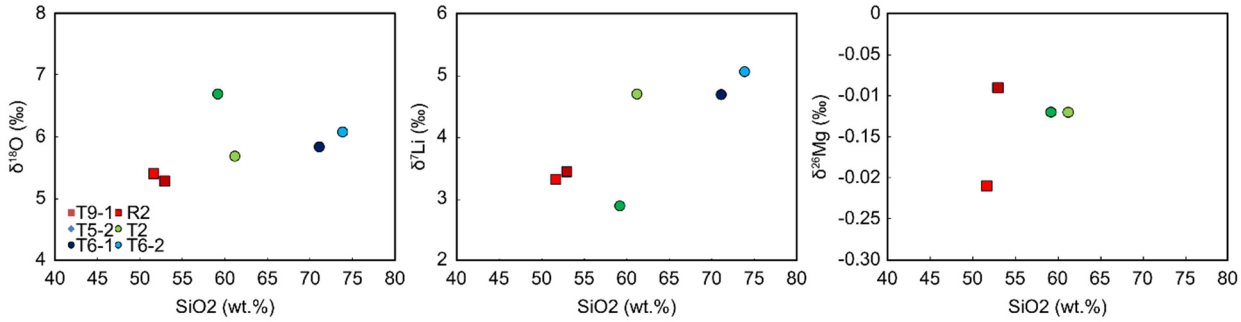

Figure S3. Plots of $\delta^{18}O$ vs. SiO_2 (a), $\delta^{7}Li$ vs. SiO_2 (b), and $\delta^{26}Mg$ vs. SiO_2 (c) for the MOT and SOT volcanic lavas.

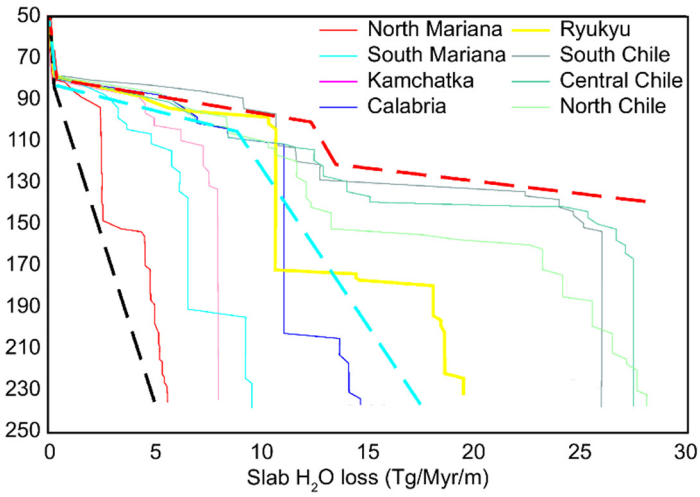

Figure S4. The relationship between the amount of dehydration and the subduction zone depth (modified from van Keken et al., 2011). Dashed red, blue, and black lines indicate the dehydration of warm, cold, and very cold slabs, respectively (Leng & Mao, 2015), and the solid lines represent specific dehydration processes in several representative subduction zones.

Tables S1 to S9

Table S1. Sampling Locations of the Volcanic Lavas Collected from the Middle Okinawa Trough (MOT) and the Southern Okinawa Trough (SOT).

Location	Sample	Latitude	Longitude	Depth, m
MOT	R2	27°32.47′N	126°58.62′E	1309.7
MOT	T5-2	27°32.86′N	126°59.36′E	1283
MOT	T2	27°32.76′N	126°58.52′E	1240
MOT	T6-1	27°48.79′N	126°54.53′E	1190
MOT	T6-2	27°48.79′N	126°54.53′E	1190
SOT	T9-1	25°13.69′N	124°52.26′E	1704

Table S2. Major element compositions of representative orthopyroxene phenocrysts (wt.%) from the T9-1 basaltic andesite in the SOT and corresponding temperature (ºC) and pressure (GPa) calculated using geothermometers and barometers based on orthopyroxene-liquid equilibria.

T9-1	SiO_2	TiO_2	Al_2O_3	FeOt	MnO	MgO	CaO	Na_2O	K_2O	NiO	Cr_2O_3	P_2O_5	Orthopyroxene components						Mg#	T (℃)	P (GPa)	d (km)
													$NaAlSiO_6$	$FmTiAlSiO_6$	$CrAl_2SiO_6$	$FmAl_2SiO_6$	$CaFmSi_2O_6$	$Fm_2Si_2O_6$				
1	53.68	0.23	1.22	19.40	0.44	22.68	1.82	0.00	0.00	0.02	0.01	0.01	0.000	0.007	0.000	0.038	0.072	0.874	67.8	1095.4		

2	53.41	0.16	1.52	16.43	0.37	25.13	2.57	0.06	0.00	0.00	0.00	0.01	0.004	0.004	0.000	0.015	0.101	0.882	73.4	1125.6	0.29	12.6
3	54.01	0.13	0.84	16.55	0.46	23.77	3.61	0.04	0.00	0.00	0.00	0.00	0.003	0.004	0.000	0.018	0.142	0.831	72.1	1127.9	0.26	11.7
4	54.12	0.18	1.23	16.40	0.25	25.54	1.82	0.04	0.00	0.03	0.14	0.00	0.003	0.005	0.004	0.016	0.071	0.901	73.7	1125.1	0.22	10.5
5	54.48	0.14	1.30	15.23	0.29	26.24	1.79	0.00	0.00	0.06	0.06	0.03	0.000	0.004	0.002	0.027	0.070	0.893	75.6	1138.2		
6	54.64	0.16	1.59	15.97	0.53	25.63	2.03	0.02	0.01	0.02	0.04	0.02	0.001	0.004	0.001	0.033	0.078	0.879	74.3	1132.9	0.16	8.4
7	54.26	0.13	1.41	15.79	0.27	26.17	1.95	0.05	0.01	0.01	0.00	0.02	0.004	0.003	0.000	0.020	0.075	0.900	74.9	1132.2	0.29	12.5
8	54.54	0.13	1.24	15.88	0.38	26.13	1.86	0.06	0.00	0.00	0.01	0.02	0.004	0.003	0.000	0.019	0.072	0.902	74.8	1131.4	0.30	13.0
9	54.22	0.20	1.41	16.42	0.47	24.50	2.08	0.06	0.00	0.00	0.00	0.00	0.004	0.006	0.000	0.038	0.082	0.863	72.9	1127.4	0.38	15.4
10	54.01	0.11	1.26	16.19	0.53	25.80	1.98	0.00	0.00	0.01	0.00	0.00	0.000	0.003	0.000	0.018	0.077	0.905	74.2	1127.1		
11	53.91	0.20	1.58	16.91	0.50	24.75	2.47	0.09	0.00	0.10	0.06	0.00	0.006	0.006	0.002	0.017	0.096	0.875	72.5	1122.6	0.36	15.0
12	54.17	0.19	1.53	15.62	0.41	25.82	2.17	0.05	0.00	0.00	0.09	0.00	0.003	0.005	0.002	0.021	0.084	0.885	74.8	1135.0	0.27	12.1
13	54.68	0.19	1.35	16.15	0.38	25.57	2.04	0.00	0.01	0.00	0.06	0.02	0.000	0.005	0.002	0.029	0.079	0.881	74.0	1130.6		
14	53.87	0.19	1.69	16.59	0.39	25.16	2.29	0.00	0.00	0.00	0.01	0.03	0.000	0.005	0.000	0.029	0.089	0.877	73.2	1125.5		
15	54.23	0.17	1.41	15.61	0.39	25.94	1.91	0.02	0.00	0.01	0.00	0.00	0.001	0.005	0.000	0.027	0.074	0.892	74.9	1134.3	0.16	8.5
16	54.12	0.19	1.51	15.98	0.40	25.24	2.00	0.05	0.01	0.02	0.00	0.01	0.003	0.005	0.000	0.033	0.078	0.877	74.0	1131.1	0.32	13.5
17	52.82	0.21	1.40	18.64	0.46	20.90	5.69	0.10	0.01	0.00	0.04	0.00	0.007	0.006	0.001	0.012	0.226	0.752	66.9	1112.6	0.40	16.1
18	53.62	0.19	1.61	15.74	0.29	25.80	2.10	0.08	0.00	0.00	0.10	0.02	0.006	0.005	0.003	0.014	0.082	0.894	74.7	1132.1	0.33	13.9

The equations of geothermometers and barometers based on orthopyroxene-liquid equilibria are:

$$\frac{10^4}{T\ (°\mathrm{C})} = 4.07 - 0.329[\mathrm{P(GPa)}] + 0.12\left(H_2O^{liq}\right) + 0.567ln\left[\frac{X^{Opx}_{Fm_2Si_2O_6}}{\left(X^{liq}_{SiO_2}\right)^2\left(X^{liq}_{FeO} + X^{liq}_{MnO} + X^{liq}_{MgO}\right)^2}\right]$$
$$- 3.06\left(X^{liq}_{MgO}\right) - 6.17\left(X^{liq}_{KO_{0.5}}\right) + 1.89\left(Mg^{\#liq}\right) + 2.57\left(X^{Opx}_{Fe}\right)$$

(Eqn. (28a); Putirka, 2008)

$$\mathrm{P\ (kbar)} = -13.97 + 0.0129T(°\mathrm{C}) + 0.001416T(°\mathrm{C})ln\left[\frac{X^{Opx}_{NaAlSi_2O_6}}{X^{liq}_{NaO_{0.5}}X^{liq}_{AlO_{1.5}}\left(X^{liq}_{SiO_2}\right)^2}\right] - 19.64\left(X^{liq}_{SiO_2}\right)$$
$$+ 47.49\left(X^{liq}_{MgO}\right) + 6.99\left(X^{Opx}_{Fe}\right)$$
$$+37.37\left(X^{Opx}_{FmAl_2SiO_6}\right) + 0.748\left(H_2O^{liq}\right) + 79.67\left(X^{liq}_{NaO_{0.5}} + X^{liq}_{KO_{0.5}}\right)$$

(Equation (29a); Putirka, 2008)

d (km) =14.6 + 29P (GPa) - 0.157[P (GPa) - 8.4]^2 (Anderson, 1989)

Table S3. Major element compositions of representative orthopyroxene phenocrysts (wt.%) from the T2 andesite in the MOT and corresponding temperature (ºC) and pressure (GPa) calculated using geothermometers and barometers based on orthopyroxene-liquid equilibria.

T2	SiO_2	TiO_2	Al_2O_3	FeOt	MnO	MgO	CaO	Na_2O	K_2O	Cr_2O_3	Orthopyroxene components						Mg#	T (℃)	P (GPa)	d (km)
											$NaAlSi_2O_6$	$FmTiAlSiO_6$	$CrAl_2SiO_6$	$FmAl_2SiO_6$	$CaFmSi_2O_6$	$Fm_2Si_2O_6$				
1	51.99	0.28	0.86	22.69	0.78	21.50	1.52	0.05	0.00	0.00	0.003	0.008	0.000	0.000	0.061	0.939	63.0	1040.0	0.29	12.5
2	50.94	0.32	0.91	23.20	0.77	20.40	1.77	0.07	0.02	0.08	0.005	0.009	0.002	0.000	0.073	0.926	61.3	1032.8	0.37	15.3
3	52.05	0.22	0.90	23.42	0.72	21.14	1.52	0.03	0.00	0.00	0.002	0.006	0.000	0.000	0.061	0.939	61.9	1033.8	0.21	10.1
4	51.87	0.24	0.65	22.22	0.75	21.46	1.56	0.03	0.00	0.01	0.002	0.007	0.000	0.000	0.063	0.936	63.5	1042.9	0.23	10.7
5	52.42	0.33	1.01	21.57	0.66	22.12	1.66	0.01	0.02	0.02	0.001	0.009	0.001	0.002	0.066	0.925	64.9	1052.3	0.08	6.1
6	52.72	0.33	1.03	20.53	0.63	22.87	1.46	0.04	0.00	0.05	0.003	0.009	0.002	0.003	0.058	0.929	66.7	1062.2	0.24	11.0
7	52.68	0.21	0.74	25.09	0.74	20.05	1.45	0.06	0.01	0.00	0.004	0.006	0.000	0.003	0.058	0.932	59.0	1020.9	0.36	15.0
8	53.17	0.34	0.88	19.75	0.58	23.76	1.75	0.02	0.00	0.02	0.001	0.009	0.001	0.000	0.069	0.927	68.4	1071.2	0.08	6.0
9	53.77	0.25	0.72	19.49	0.56	24.09	1.70	0.06	0.01	0.00	0.004	0.007	0.000	0.000	0.067	0.928	69.0	1074.5	0.27	12.1
10	53.33	0.27	0.93	20.20	0.73	22.97	1.67	0.03	0.00	0.01	0.002	0.007	0.000	0.009	0.066	0.915	67.2	1067.4	0.25	11.3
11	53.18	0.30	1.03	19.18	0.53	23.85	1.59	0.05	0.01	0.00	0.004	0.008	0.000	0.006	0.063	0.923	69.1	1076.3	0.28	12.5
12	53.98	0.29	1.09	18.20	0.57	25.08	1.66	0.06	0.00	0.05	0.004	0.008	0.001	0.001	0.064	0.927	71.3	1088.0	0.27	12.0
13	53.70	0.31	1.27	17.54	0.53	24.60	1.82	0.01	0.03	0.04	0.001	0.009	0.001	0.019	0.071	0.898	71.6	1095.0	0.03	4.3
14	52.88	0.22	0.87	24.76	0.83	20.49	1.55	0.05	0.02	0.06	0.004	0.006	0.002	0.000	0.062	0.932	59.8	1025.4	0.32	13.7

Table S4. Major element compositions of representative clinopyroxene phenocrysts (wt.%) from the R2 basalt in the MOT and corresponding temperature (ºC) and pressure (GPa) calculated using geothermometers and barometers based on clinopyroxene-liquid equilibria.

R2	SiO_2	TiO_2	Al_2O_3	FeOt	MnO	MgO	CaO	Na_2O	K_2O	Cr_2O_3	Clinopyroxene components						Mg#	T (℃)	P (GPa)	d (km)
											Jd	CaTs	CaTi	CrCaTs	DiHd	EnFs				
1	52.34	0.55	2.45	7.02	0.25	17.35	18.77	0.23	0.01	0.53	0.017	0.020	0.025	0.008	0.689	0.241	81.6	1135.8	0.24	11.1
2	52.64	0.43	2.28	5.83	0.14	17.01	20.99	0.23	0.00	0.46	0.016	0.013	0.028	0.007	0.777	0.166	84.0	1114.8	0.16	8.6
3	52.22	0.35	2.02	6.86	0.21	16.77	19.73	0.23	0.01	0.33	0.016	0.016	0.020	0.005	0.746	0.199	81.5	1123.6	0.19	9.4
4	50.25	0.67	3.83	6.64	0.20	15.20	20.98	0.34	0.05	0.76	0.025	0.024	0.048	0.011	0.758	0.149	80.5	1137.1	0.42	16.9
5	50.58	0.76	3.54	7.11	0.27	15.74	20.47	0.29	0.03	0.53	0.021	0.019	0.048	0.008	0.742	0.177	79.9	1133.5	0.33	13.9
6	52.35	0.44	2.38	5.88	0.18	16.58	21.01	0.26	0.00	0.43	0.018	0.017	0.026	0.006	0.782	0.156	83.5	1119.2	0.23	10.8
7	51.67	0.43	2.11	6.20	0.18	16.58	20.89	0.22	0.00	0.38	0.016	0.005	0.034	0.006	0.791	0.162	82.8	1112.0	0.14	8.0
8	51.60	0.51	2.83	6.03	0.19	16.13	21.35	0.24	0.00	0.25	0.017	0.022	0.031	0.004	0.792	0.144	82.8	1112.2	0.19	9.4
9	51.90	0.48	2.61	6.46	0.22	16.74	20.28	0.30	0.00	0.52	0.021	0.011	0.035	0.008	0.749	0.186	82.4	1137.0	0.34	14.4
10	52.73	0.44	1.93	6.79	0.18	17.00	19.95	0.23	0.00	0.25	0.016	0.014	0.020	0.004	0.751	0.197	81.8	1122.8	0.18	9.3

11	50.51	0.80	3.38	6.95	0.19	15.38	20.73	0.27	0.00	0.39	0.020	0.023	0.042	0.006	0.762	0.158	79.9	1125.5	0.29	12.6

The equations of geothermometers and barometers based on clinopyroxene-liquid equilibria are:

$$\frac{10^4}{T\ (K)} = 7.53 - 0.14\ln\left(\frac{X_{Jd}^{Cpx}X_{CaO}^{liq}X_{Fm}^{liq}}{X_{DiHd}^{Cpx}X_{Na}^{liq}X_{Al}^{liq}}\right) + 0.07\left(H_2O^{liq}\right) - 14.9\left(X_{CaO}^{liq}X_{SiO_2}^{liq}\right) - 0.08\ln\left(X_{TiO_2}^{liq}\right) - 3.62\left(X_{NaO_{0.5}}^{liq} + X_{KO_{0.5}}^{liq}\right) - 1.1\left(Mg^{\#liq}\right) - 0.18\ln\left(X_{EnFs}^{Cpx}\right) - 0.027P(kbar)$$

(Equation (33); Putirka, 2008)

$$\text{P (kbar)} = -26.27 + 39.16\frac{T(K)}{10^4}ln\left[\frac{X_{Jd}^{Cpx}}{X_{NaO_{0.5}}^{liq}X_{AlO_{1.5}}^{liq}\left(X_{SiO_2}^{liq}\right)^2}\right] - 4.22\ln\left(X_{DiHd}^{Cpx}\right) + 78.43X_{AlO_{1.5}}^{liq} + 393.81(X_{NaO_{0.5}}^{liq}X_{KO_{0.5}}^{liq})^2$$

(Neave & Putirka, 2017)

Table S5. Major element compositions of representative orthopyroxene phenocrysts (wt.%) from the T6-1 rhyolite in the MOT and corresponding temperature (ºC) and pressure (GPa) calculated using geothermometers and barometers based on orthopyroxene-liquid equilibria.

T6-1	SiO_2	TiO_2	Al_2O_3	FeOt	MnO	MgO	CaO	Na_2O	K_2O	Cr_2O_3	Orthopyroxene components						Mg#	T (℃)	P (GPa)	d (km)
											$NaAlSi_2O_6$	$FmTiAlSiO_6$	$CrAl_2SiO_6$	$FmAl_2SiO_6$	$CaFmSi_2O_6$	$Fm_2Si_2O_6$				
1	52.07	0.21	1.16	30.07	1.62	10.54	6.18	0.30	0.15	0.00	0.022	0.006	0.000	0.031	0.255	0.668	38.7	884.2	0.59	22.2
2	49.41	0.16	0.20	36.35	1.95	10.56	1.50	0.05	0.01	0.01	0.004	0.005	0.000	0.000	0.065	0.928	34.3	822.7	0.36	14.9
3	49.66	0.13	0.23	36.22	2.06	11.12	1.47	0.04	0.01	0.00	0.003	0.004	0.000	0.000	0.063	0.938	35.6	824.9	0.33	14.1
4	49.67	0.12	0.18	36.73	1.98	10.84	1.48	0.08	0.02	0.02	0.006	0.004	0.001	0.000	0.063	0.937	34.7	821.9	0.41	16.5
5	48.95	0.13	0.19	36.03	1.97	10.73	1.51	0.06	0.02	0.04	0.004	0.004	0.001	0.000	0.066	0.934	34.9	823.1	0.37	15.3
6	49.31	0.12	0.17	36.02	1.82	10.99	1.45	0.02	0.02	0.00	0.002	0.004	0.000	0.000	0.063	0.936	35.4	824.2	0.27	12.0
7	49.19	0.20	0.21	36.25	2.04	10.72	1.42	0.01	0.02	0.03	0.000	0.006	0.001	0.000	0.061	0.936	34.7	822.7	0.12	7.2
8	49.05	0.16	0.22	36.47	1.87	11.08	1.30	0.04	0.01	0.01	0.003	0.005	0.000	0.000	0.056	0.949	35.4	821.0	0.32	13.7
9	49.59	0.15	0.17	36.63	1.96	11.01	1.42	0.07	0.02	0.00	0.006	0.004	0.000	0.000	0.061	0.941	35.1	822.2	0.41	16.4
10	49.26	0.11	0.17	36.04	2.05	11.00	1.46	0.02	0.00	0.00	0.002	0.003	0.000	0.000	0.063	0.940	35.5	824.0	0.27	12.0
11	48.24	0.13	0.23	34.57	1.91	11.04	1.51	0.11	0.05	0.07	0.009	0.004	0.002	0.000	0.066	0.931	36.5	828.9	0.44	17.4
12	49.99	0.09	0.17	31.11	1.49	14.85	1.28	0.01	0.00	0.00	0.001	0.003	0.000	0.000	0.054	0.952	46.2	856.6	0.11	7.1
13	50.77	0.09	0.13	32.64	1.60	14.47	1.10	0.01	0.00	0.01	0.001	0.003	0.000	0.000	0.046	0.958	44.4	849.6	0.13	7.6
14	51.07	0.13	0.23	32.06	1.61	14.24	1.25	0.04	0.01	0.02	0.003	0.004	0.001	0.003	0.052	0.936	44.4	854.4	0.24	11.2

15	50.97	0.16	0.17	32.68	1.63	14.08	1.20	0.11	0.01	0.02	0.008	0.005	0.000	0.000	0.050	0.943	43.7	850.4	0.37	15.3
16	50.36	0.10	0.09	31.60	1.69	15.05	0.98	0.02	0.00	0.03	0.002	0.003	0.001	0.000	0.041	0.968	46.2	854.5	0.17	8.9
17	52.42	0.14	0.86	28.69	1.55	14.24	1.59	0.32	0.21	0.03	0.024	0.004	0.001	0.014	0.066	0.857	47.2	881.6	0.51	19.5
18	48.54	0.10	0.15	30.48	1.52	14.22	1.10	0.00	0.02	0.64	0.000	0.003	0.020	0.000	0.048	0.951	45.6	855.7		
19	49.40	0.07	0.17	31.54	1.66	14.71	1.23	0.01	0.04	0.03	0.001	0.002	0.001	0.000	0.053	0.965	45.6	852.2	0.12	7.5
20	51.45	0.02	0.19	31.24	1.68	15.36	1.11	0.03	0.00	0.03	0.002	0.001	0.001	0.000	0.046	0.953	47.0	860.5	0.19	9.6
21	51.34	0.14	0.19	30.65	1.60	15.30	1.09	0.02	0.01	0.06	0.001	0.004	0.002	0.002	0.045	0.943	47.3	863.8	0.12	7.5
22	45.55	0.08	0.32	30.85	1.58	12.29	1.12	0.12	0.06	0.63	0.010	0.003	0.022	0.000	0.052	0.952	41.8	842.1	0.42	16.6
23	52.89	0.16	0.81	29.69	1.45	14.29	1.72	0.37	0.19	0.00	0.027	0.005	0.000	0.009	0.070	0.862	46.4	877.2	0.51	19.7
24	52.48	0.12	0.13	31.13	1.57	16.21	1.09	0.02	0.00	0.05	0.002	0.003	0.001	0.000	0.044	0.954	48.4	865.1	0.14	8.0
25	51.01	0.08	0.18	30.95	1.62	15.39	1.27	0.03	0.03	0.05	0.002	0.002	0.001	0.000	0.053	0.949	47.2	861.5	0.20	10.0
26	51.06	0.11	0.45	31.00	1.58	14.24	1.20	0.12	0.12	0.01	0.009	0.003	0.000	0.012	0.050	0.918	45.3	861.2	0.41	16.5
27	48.26	0.09	0.25	30.55	1.53	13.93	1.06	0.03	0.10	0.04	0.002	0.003	0.001	0.000	0.047	0.953	45.1	853.3	0.21	10.2
28	51.26	0.11	0.24	30.29	1.55	15.16	1.63	0.04	0.05	0.01	0.003	0.003	0.000	0.003	0.068	0.921	47.4	866.9	0.22	10.4
29	51.09	0.09	0.18	30.85	1.58	14.96	1.39	0.02	0.01	0.00	0.001	0.003	0.000	0.003	0.058	0.934	46.6	862.1	0.14	8.0

Table S6. Major element compositions of representative orthopyroxene phenocrysts (wt.%) from the T6-2 rhyolite in the MOT and the temperature (ºC) and pressure (GPa) calculated using geothermometers and barometers based on orthopyroxene-liquid equilibria.

T6-2	SiO_2	TiO_2	Al_2O_3	FeOt	MnO	MgO	CaO	Na_2O	K_2O	Cr_2O_3	Orthopyroxene components						Mg#	T (℃)	P (GPa)	d (km)
											$NaAlSi_2O_6$	$FmTiAlSiO_6$	$CrAl_2SiO_6$	$FmAl_2SiO_6$	$CaFmSi_2O_6$	$Fm_2Si_2O_6$				
1	52.47	0.14	0.20	29.57	1.93	16.85	1.04	0.01	0.01	0.00	0.001	0.004	0.000	0.000	0.042	0.954	50.6	853.8		
2	51.60	0.10	0.18	29.13	1.92	16.30	1.08	0.03	0.01	0.00	0.002	0.003	0.000	0.001	0.045	0.948	50.2	853.3	0.07	5.7
3	51.93	0.10	0.30	28.61	1.74	17.43	0.82	0.05	0.00	0.03	0.004	0.003	0.001	0.000	0.034	0.964	52.3	857.7	0.11	7.0
4	52.05	0.16	0.20	28.92	1.96	16.54	1.08	0.02	0.02	0.00	0.001	0.005	0.000	0.005	0.044	0.942	50.7	856.2		
5	50.08	0.04	0.18	29.72	1.88	14.79	1.13	0.00	0.01	0.00	0.000	0.001	0.000	0.008	0.048	0.939	47.2	844.3		
6	51.13	0.13	0.15	29.46	1.89	16.08	1.12	0.02	0.01	0.05	0.001	0.004	0.002	0.000	0.047	0.951	49.6	850.1	0.01	3.7

Table S7. Major element and Sr-Nd isotope compositions of the MOT and SOT volcanic lavas. Scheme 2018. and this study.

Sample	SiO_2	TiO_2	Al_2O_3	FeOt	MnO	MgO	CaO	Na_2O	K_2O	Cr_2O_3	P_2O_5	H_2O	LOI	Total	$^{87}Sr/^{86}Sr$ (2σ)	$^{3}Nd/^{144}Nd$ (2σ)
R2	51.62	1.13	17.08	9.66	0.17	5.92	10.19	2.77	0.46	0.00	0.21	0.80	0.70	99.916	0.704188±14	0.512763±9
T5-2	59.16	1.01	14.62	7.80	0.15	2.34	5.73	5.23	1.66	0.00	0.24	1.19	1.74	99.68		
T2	61.17	1.08	15.66	7.02	0.14	2.06	5.21	4.50	1.55	0.00	0.25	1.18	1.29	99.929	0.704628±12	0.512811±9
T6-1	71.09	0.25	13.10	2.08	0.06	0.36	1.30	4.64	3.31	0.00	0.02	2.68	3.73	99.939	0.703568±10	0.512934±11
T6-2	73.85	0.15	12.23	1.44	0.05	0.17	0.69	4.55	3.61	0.00	0.02	2.26	3.17	99.927	0.703617±13	0.51297±12
T9-1	52.94	0.59	18.55	9.34	0.17	3.76	10.49	2.20	0.43	0.00	0.07	1.32	1.37	99.904		

Table S8. Trace element compositions of the MOT and SOT volcanic lavas.

Samples	MOT				SOT		BHVO-2		BCR-2	
	R2	T5-2	T2	T6-1	T6-2	T9-1	Measured	Recommended	Measured	Recommended
Li	6.11	14.9	11.6	23.9	23.2	6.25	4.77	5	9.48	9±2
Be	0.74	1.58	1.58	3.43	3.1	0.448	1.24		2.85	
Sc	13	20.7	20.4	6.72	5.18	32.8	29.2	32±1	31.9	33±2
V	273	140	134	10.7	3.27	274	339	317±11	452	416±14
Cr	158	12.5	11.5	5.56	3.02	8.33	280	280±19	17.9	18±2
Co	32.7	14.2	13.3	1.74	0.768	31.9	44.0	45±3	38.4	37±3
Ni	51.4	5.15	4.68	2.47	2.04	8.08	120	119±7	13.4	
Ga	19.4	21.1	21.2	18.8	19.4	18.5	23.2	21.7±0.9	24.6	32±2
Rb	6.98	46	44.8	92.7	97.7	12.6	9.33	9.8±1.0	48.5	48±2
Sr	261	202	208	67.7	27	172	383	389±23	340	346±14
Y	20.6	39.7	40.4	34.9	46.1	17.1	25.6	26±2	36.2	37±2
Zr	87.6	258	219	149	183	47.4	185	172±11	206	188±16
Nb	3.66	8.36	8.37	11.9	14.8	1.27	19.1	18±2	13.4	
Cd	0.191	0.246	0.268	0.267	0.249	0.155	0.209		1.06	
Cs	0.235	2.14	2.01	3.39	3.53	1.02	0.099		1.18	1.1±0.1
Ba	94.1	266	267	324	312	87.3	129	130±13	689	683±28
La	7.21	19.3	18.6	21.9	26.5	4.3	16.0	15±1	27.0	25±1
Ce	18	42.6	41.6	43.7	54.7	9.87	38.3	38±2	56.2	53±2
Pr	2.58	5.48	5.4	4.99	6.47	1.33	5.36		7.17	6.8±0.3
Nd	12.3	23.4	23.3	18.8	24.5	6.24	25.0	25.0±1.8	30.5	28±2
Sm	3.36	5.7	5.82	4.14	5.57	1.97	6.38	6.2±0.4	6.90	6.7±0.3
Eu	1.13	1.64	1.67	0.767	0.662	0.72	2.28		2.03	2.0±0.1
Gd	3.51	6.12	6.01	4.26	5.67	2.19	5.93	6.3±0.2	6.88	6.8±0.3
Tb	0.676	1.1	1.08	0.823	1.11	0.465	0.946	0.9	1.11	1.07±0.04
Dy	3.82	6.32	6.39	5.03	6.75	2.77	5.07		6.34	
Ho	0.899	1.48	1.49	1.22	1.6	0.685	1.01	1.04±0.04	1.39	1.33±0.06
Er	2.35	4.06	4.13	3.66	4.75	1.82	2.44		3.65	
Tm	0.375	0.667	0.667	0.639	0.846	0.297	0.345		0.568	0.540
Yb	2.32	4.29	4.24	4.28	5.46	1.86	1.97	2.0±0.2	3.45	3.5±0.2
Lu	0.342	0.656	0.656	0.661	0.838	0.29	0.285	0.28±0.01	0.537	0.51±0.02
Hf	2.14	5.48	5.3	4.41	5.57	1.36	4.45	4.1±0.3	5.10	4.8±0.2
Ta	0.186	0.475	0.484	0.822	0.936	0.079	1.07	1.4	0.729	
W	0.169	0.637	0.572	1.07	1.15	0.355	0.269		0.603	
Pb	2.63	6.18	6.14	8.76	7.75	4.68	1.76		11.8	11±2
Bi	0.001	0.043	0.043	0.086	0.103	0.041	0.003		0.051	

Th	0.733	5.14	5.18	11.2	11.4	1.22	1.23	1.2±0.3	6.26	6.2±0.7
U	0.323	1.24	1.32	2.63	2.74	0.345	0.433		1.81	1.69±0.19

Table S9. Li–O–Mg isotope compositions of the MOT and SOT volcanic lavas.

Δ is the difference between two values for the same sample.

	Sample	$\delta^{18}O$ (‰)	Δ (n=2) (‰)	Li (ppm)	$\delta^{7}Li$ (‰)	2σ/2sd (‰)	$\delta^{26}Mg$ (‰)	2sd (‰)	$\delta^{25}Mg$ (‰)	2sd (‰)	n
R2-1	Whole rock	5.41	0.22	4.68	3.33	0.30	-0.21	0.02	-0.10	0.01	3
	Ol	5.50	0.01	2.27	3.06	0.30	-0.25	0.02	-0.12	0.03	3
	Cpx	5.49	0.07				-0.26	0.05	-0.13	0.03	3
	Pl	5.72	0.18	0.89	-0.71	0.30					
	Glass	5.79	0.11	7.82	4.09	0.30	-0.28	0.05	-0.14	0.04	3
R2-2	Ol	5.38	0.05	2.51	5.61	0.30	-0.31	0.04	-0.15	0.02	3
	Cpx	5.46		3.03	1.85	0.30	-0.24	0.02	-0.12	0.02	3
	Glass	5.78	0.18	7.74	3.81	0.30	-0.20	0.06	-0.10	0.04	3
T5-2	Whole rock	6.69	0.01	11.96	2.90	0.30	-0.12	0.02	-0.07	0.01	3
	Ol	5.24	0.06	2.63	2.41	0.30	-0.21	0.06	-0.12	0.02	3
	Cpx	5.15	0.03	3.13	-0.83	0.30	-0.22	0.02	-0.12	0.01	3
	Opx	5.65	0.23	5.84	2.34	0.30	-0.23	0.01	-0.12	0.02	3
	Pl	5.99	0.08	4.63	1.59	0.30					
	Glass	6.31	0.01	14.64	1.86	0.30	-0.16	0.01	-0.08	0.03	3
T2	Whole rock	5.69	0.08	4.89	4.71	0.30	-0.12	0.05	-0.06	0.01	3
	Cpx						-0.17	0.02	-0.09	0.03	3
	Opx	5.86					-0.20	0.04	-0.09	0.04	3
	Glass	6.21	0.01	9.24	5.12	0.30	-0.17	0.02	-0.09	0.04	3
T6-1	Whole rock	5.84	0.08	18.69	4.70	0.30					
T6-2	Whole rock	6.08	0.16	17.15	5.07	0.30					
T9-1	Whole rock	5.29	0.06	5.69	3.45	0.30	-0.09	0.02	-0.06	0.03	3
	Ol	4.83	0.16	2.20	2.84	0.30	-0.16	0.04	-0.10	0.02	3
	Cpx	4.99	0.01	1.24	0.49	0.30	-0.15	0.04	-0.08	0.02	3
	Opx	5.50	0.10	1.05	1.04	0.30	-0.15	0.04	-0.08	0.03	3
	Pl	5.49	0.13	2.22	-5.05	0.30					
	Glass	5.80	0.01	6.36	4.98	0.30	-0.11	0.03	-0.06	0.01	3