Supplementary Material

An experimental study on the role of F^-, PO_4^{3-}, Cl^- and SO_4^{2-} ligands in the natrocarbonatite-nephelinite system at 850 °C and 0.1 GPa

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Supplementary Figure

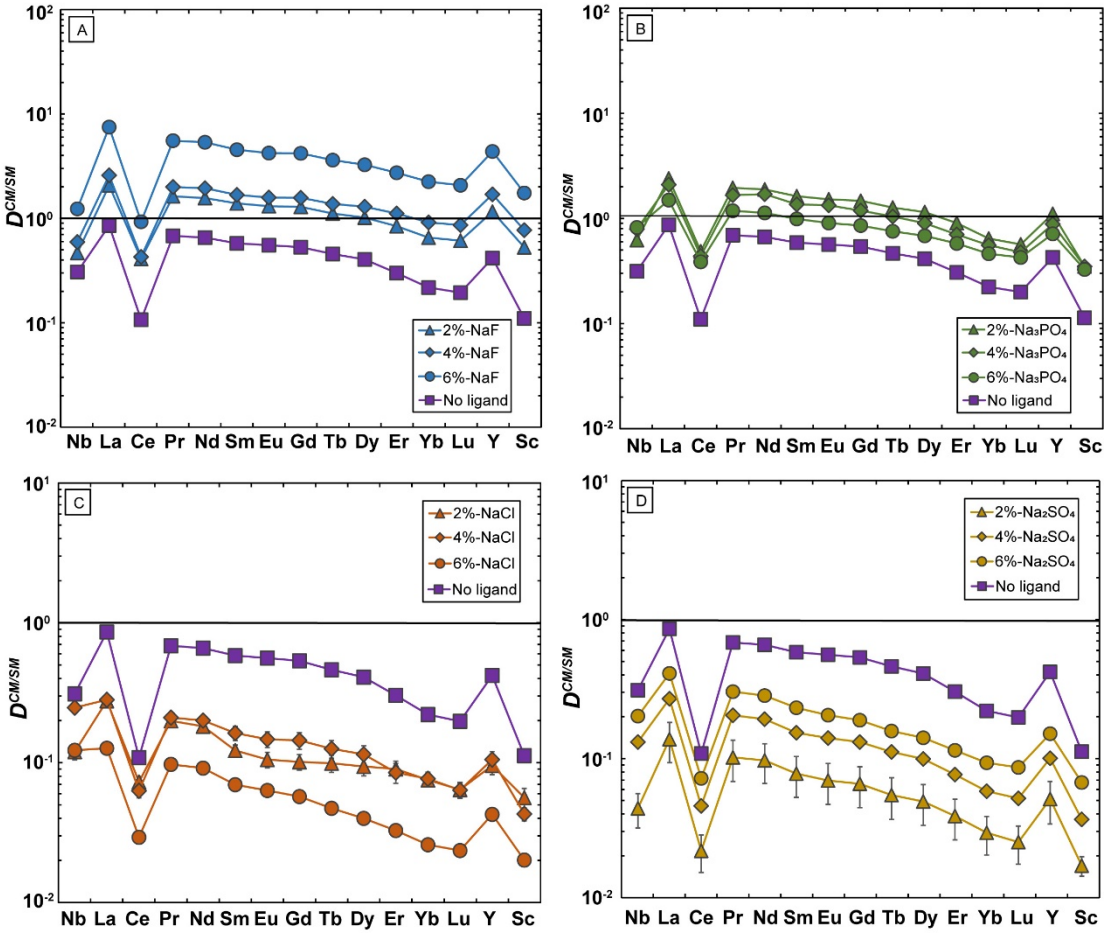

Fig. S1. Liquid-liquid partition coefficients (*D*) with the standard deviation as error bars. (A) REE and Nb partition coefficients measured between carbonate and silicate melts in the doping 2 wt.% NaF (blue triangle), 4 wt.% NaF (blue rhombus), 6 wt.% NaF (blue circle) and no ligand (purple square) experiments. (B) Partition coefficients of REE and Nb between carbonate and silicate melts in the doping 2 wt.% Na_3PO_4 (green triangle), 4 wt.% Na_3PO_4 (green rhombus), 6 wt.% Na_3PO_4 (green circle) and no ligand (purple square) experiments. (C) Carbonate and silicate melts partition coefficients (*D*) in the doping 2 wt.% NaCl (orange triangle), 4 wt.% NaCl (orange rhombus), 6 wt.% NaCl (orange circle) and no ligand (purple square) experiments. (D) Partition coefficients between carbonate melts and silicate melts in the doping 2 wt.% Na_2SO_4 (yellow triangle), 4 wt.% Na_2SO_4 (yellow rhombus), 6 wt.% Na_2SO_4 (yellow circle) and no ligand (purple square) experiments. Abbreviation: CM, carbonate melt; SM, silicate melt.

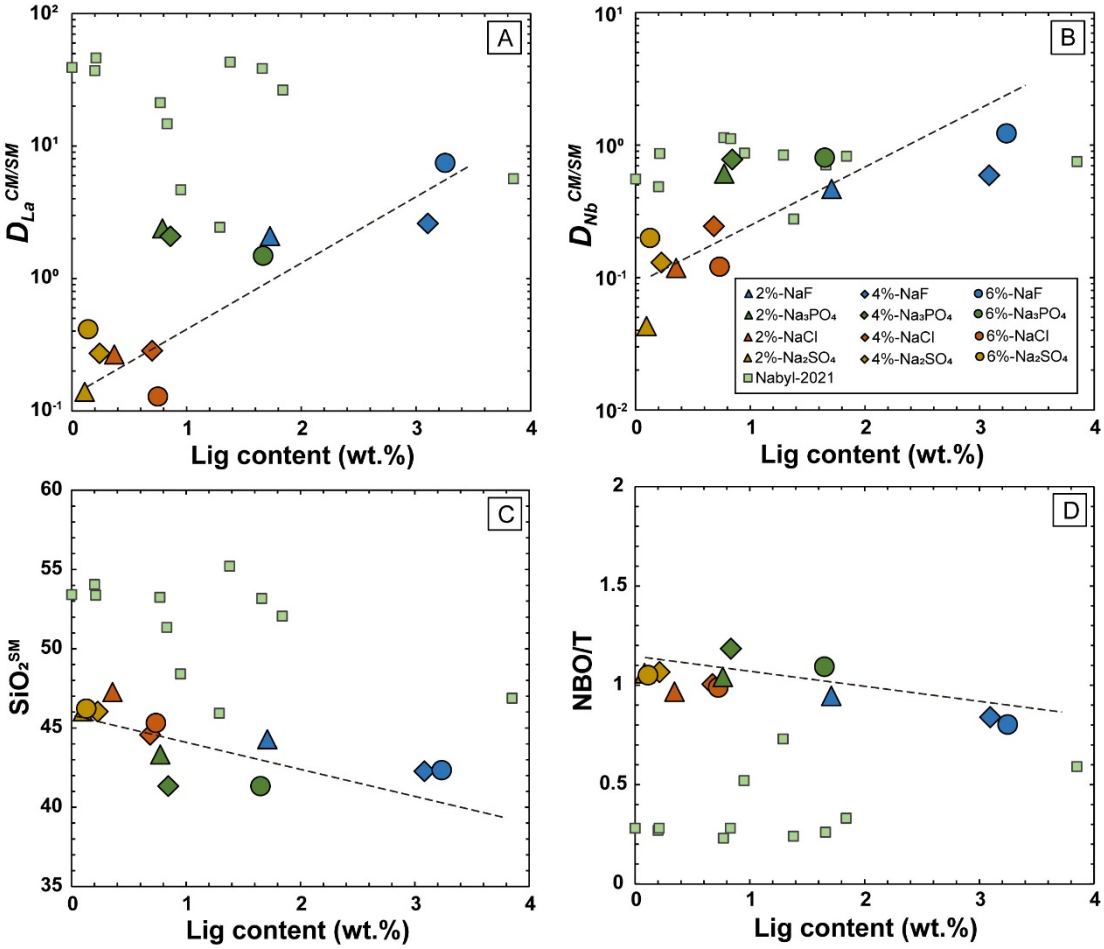

Fig. S2. La (A) and Nb (B) partition coefficients between carbonate and silicate melts ($D_{La}^{CM/SM}$ and $D_{Nb}^{CM/SM}$ respectively) plotted against ligand content (e.g., F, P_2O_5, Cl, SO_3) of the silicate melt. Silica content (C) and the degree of polymerization (D) of the silicate melt versus ligand contents (e.g., F, P_2O_5, Cl, SO_3) of the silicate melt. Data source: Experimental melt data from immiscibility experiments (Nabyl et al., 2021). Samples synthesized in the systems doped in F^- (blue), PO_4^{3-} (green), Cl^- (orange), SO_4^{2-} (yellow) and no ligand (purple) are represented in this study.

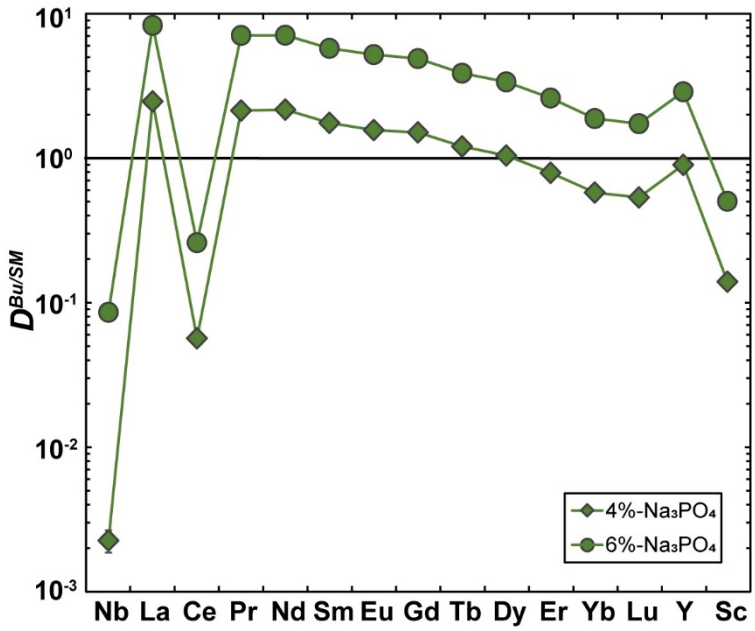

Fig. S3. The REE and Nb partition coefficients measured between buchwaldite and silicate melts in the doping 4 wt.% Na_3PO_4 (green rhombus), 6 wt.% Na_3PO_4 (green circle). Abbreviation: Bu, Buchwaldite; CM, carbonate melt; SM, silicate melt.

Supplementary Table

Table S1. Major element compositions of experimental silicate liquids (weight %) analysed by EPMA. Abbreviation: s.d. standard deviation, statistical uncertainty calculated on the mean value; Lig ligand; SM silicate melt.

Experiment	0-0-SM		1-1-SM		1-2-SM		1-3-SM		2-1-SM		2-2-SM		2-3-SM	
Lig	-		NaF		NaF		NaF		NaCl		NaCl		NaCl	
Analysis	7		5		8		5		5		10		7	
		s.d.		s.d.		s.d.		s.d.		s.d.		s.d.		s.d.
SiO_2	43.39	1.95	42.01	0.22	42.77	0.43	38.24	0.92	45.95	0.14	47.38	0.20	46.65	0.23
TiO_2	0.70	0.21	0.92	0.09	1.42	0.05	1.37	0.23	1.06	0.08	0.94	0.06	1.01	0.06
Al_2O_3	10.20	0.53	7.30	0.04	8.31	0.09	8.17	0.53	7.66	0.34	8.98	0.08	8.23	0.17
FeO	6.29	1.50	13.47	0.15	13.97	0.22	12.33	0.67	13.18	0.38	14.07	0.17	14.03	0.13
MnO	0.02	0.02	0.04	0.04	0.05	0.04	0.05	0.04	0.06	0.02	0.04	0.04	0.07	0.04
MgO	0.30	0.07	1.07	0.03	0.87	0.02	0.63	0.05	1.22	0.13	1.43	0.06	1.45	0.04
CaO	4.18	0.33	3.50	0.05	3.96	0.06	2.65	0.12	2.50	0.23	2.88	0.05	2.56	0.04
Na_2O	17.25	0.26	13.40	0.17	15.98	0.28	16.84	0.29	13.35	0.30	16.23	0.20	15.62	0.18
K_2O	4.05	1.60	6.85	0.09	6.95	0.07	6.71	0.15	6.46	0.40	6.61	0.08	5.66	0.07
P_2O_5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F	-	-	1.71	0.14	3.09	0.15	3.24	0.18	-	-	-	-	-	-
Cl	-	-	-	-	-	-	-	-	0.35	0.04	0.68	0.07	0.73	0.06
SO_3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CO_2	18.54	1.95	6.13	0.13	6.69	0.41	7.80	0.27	5.59	0.15	7.52	0.41	7.47	0.70
Total	104.92		96.39		104.05		98.03		97.39		106.76		103.47	
Na_2O+K_2O	13.73		21.38		22.70		26.11		20.41		21.52		20.70	
(Na+K)/Al	1.99		4.04		4.07		4.28		3.78		3.77		3.87	
ASI[Al_2O_3/(CaO+Na_2O+K_2O)]	0.42		0.22		0.22		0.22		0.25		0.25		0.24	
(Na_2O+K_2O)/(CaO+MgO)	4.85		6.50		7.20		10.90		7.59		7.64		7.65	
AI[Al_2O_3-(Na_2O+K_2O)]	-0.20		-0.46		-0.50		-0.58		-0.43		-0.46		-0.45	
NBO/T	0.84		0.95		0.84		0.80		0.97		1.01		0.99	

Continued Table S1

Experiment	3-1-SM		3-2-SM		3-3-SM		4-1-SM		4-2-SM		4-3-SM	
Lig	Na_2SO_4		Na_2SO_4		Na_2SO_4		Na_3PO_4		Na_3PO_4		Na_3PO_4	
Analysis	6		8		5		5		10		6	
		s.d.		s.d.		s.d.		s.d.		s.d.		s.d.
SiO_2	44.15	0.17	46.58	0.26	44.36	0.10	41.62	0.17	42.85	0.18	38.82	0.41
TiO_2	0.91	0.04	0.91	0.05	0.87	0.06	0.96	0.09	1.45	0.03	1.28	0.05
Al_2O_3	6.92	0.07	7.72	0.07	7.13	0.07	7.24	0.11	7.37	0.09	6.88	0.07
FeO	13.27	0.19	14.09	0.18	13.61	0.14	13.87	0.06	15.05	0.12	14.05	0.18
MnO	0.03	0.03	0.07	0.04	0.06	0.03	0.06	0.04	0.05	0.01	0.06	0.04
MgO	1.23	0.03	1.39	0.06	1.29	0.04	1.11	0.04	1.18	0.03	1.00	0.03
CaO	2.43	0.02	2.59	0.06	2.25	0.07	3.24	0.07	3.06	0.09	2.68	0.04
Na_2O	12.86	0.14	14.51	0.16	13.31	0.08	13.94	0.07	16.48	0.15	14.89	0.10
K_2O	6.99	0.08	7.19	0.07	6.31	0.03	7.96	0.11	8.22	0.07	7.20	0.06
P_2O_5	-	-	-	-	-	-	0.77	0.12	0.84	0.20	1.65	0.17
F	-	-	-	-	-	-	-	-	-	-	-	-
Cl	-	-	-	-	-	-	-	-	-	-	-	-
SO_3	0.09	0.06	0.22	0.07	0.12	0.07	-	-	-	-	-	-
CO_2	6.89	0.28	5.92	0.32	6.58	0.21	5.81	0.09	6.71	0.16	6.85	0.12
Total	95.75		101.19		95.89		96.58		103.26		95.36	
Na_2O+K_2O	20.73		21.48		20.47		22.83		23.87		23.56	
(Na+K)/Al	4.15		4.10		4.03		4.35		4.89		4.69	
ASI[Al_2O_3/(CaO+Na_2O+K_2O)]	0.22		0.23		0.23		0.21		0.19		0.20	
(Na_2O+K_2O)/(CaO+MgO)	7.63		7.70		7.81		7.25		6.95		8.72	
AI[Al_2O_3-(Na_2O+K_2O)]	-0.45		-0.46		-0.44		-0.50		-0.54		-0.53	
NBO/T	1.06		1.07		1.05		1.04		1.19		1.09	

NBO/T calculated following Mysen and Richet (2019; Chapter 4). NBO/T = $(4 \cdot X_T - 2 \cdot X_O)/X_T$, where X_T and X_O are the atomic proportions of tetrahedrally coordinated cations (Si and Al) and oxygen, respectively. NBO/T calculated with all Fe as Fe^{2+} on a volatile-free basis.

Table S2. Major element compositions of experimental carbonate liquids (weight %) analysed by EPMA. Abbreviation: s.d. standard deviation, statistical uncertainty calculated on the mean value; Lig ligand; CM carbonate melt.

Experiment	0-0-CM		1-1-CM		1-2-CM		1-3-CM		2-1-CM		2-2-CM		2-3-CM	
Lig	-		NaF		NaF		NaF		NaCl		NaCl		NaCl	
Analysis	7		5		3		8		3		5		4	
		s.d.		s.d.		s.d.		s.d.		s.d.		s.d.		s.d.
SiO_2	1.39	0.28	1.94	0.49	3.78	0.07	3.80	0.94	0.36	0.28	0.07	0.05	1.95	0.65
TiO_2	0.03	0.01	0.14	0.04	0.31	0.04	0.31	0.05	0.05	0.01	0.00	0.01	0.03	0.02
Al_2O_3	0.21	0.03	0.22	0.09	0.49	0.03	0.50	0.11	0.03	0.03	0.01	0.01	0.07	0.02
FeO	0.24	0.20	0.47	0.12	0.69	0.06	0.55	0.11	0.11	0.10	0.10	0.03	0.14	0.07
MnO	0.02	0.01	0.04	0.02	0.05	0.05	0.04	0.03	0.04	0.03	0.02	0.02	0.07	0.05
MgO	0.19	0.10	1.74	0.31	1.86	0.05	1.84	0.19	0.21	0.15	0.01	0.01	0.25	0.00
CaO	2.76	0.86	15.04	1.71	19.20	0.34	16.80	1.63	1.94	1.52	0.11	0.05	1.83	0.33
Na_2O	16.65	0.61	33.24	2.50	35.59	0.19	33.43	3.04	39.56	4.61	45.86	2.08	36.91	0.94
K_2O	17.87	4.33	2.53	0.69	3.76	0.03	2.57	0.69	0.46	0.20	0.06	0.02	1.20	0.25
P_2O_5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F	-	-	10.82	2.57	12.84	0.88	18.84	0.54	-	-	-	-	-	-
Cl	-	-	-	-	-	-	-	-	0.24	0.16	0.04	0.02	0.41	0.27
SO_3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CO_2	62.98	3.26	33.01	3.01	22.51	0.79	22.28	3.60	45.21	2.48	53.12	1.98	50.24	2.04
Total	102.94		99.20		101.07		100.96		88.22		99.38		93.11	
Na_2O+K_2O	35.11		35.77		39.35		36.00		40.02		45.91		38.12	

Continued Table S2

Experiment	3-1-CM		3-2-CM		3-3-CM		4-1-CM		4-2-CM		4-3-CM	
Lig	Na_2SO_4		Na_2SO_4		Na_2SO_4		Na_3PO_4		Na_3PO_4		Na_3PO_4	
Analysis	5		4		2		4		6		4	
		s.d.		s.d.		s.d.		s.d.		s.d.		s.d.
SiO_2	0.58	0.36	0.65	0.35	0.38	0.10	0.86	0.41	0.03	0.02	0.32	0.37
TiO_2	0.60	0.24	0.05	0.04	0.27	0.13	0.85	0.41	0.01	0.01	0.01	0.02
Al_2O_3	0.71	0.44	0.04	0.03	0.02	0.02	0.03	0.01	0.01	0.01	0.05	0.03
FeO	0.10	0.06	0.13	0.09	0.10	0.05	0.10	0.04	0.04	0.04	0.11	0.12
MnO	0.16	0.03	0.06	0.03	0.27	0.06	0.13	0.03	0.03	0.01	0.02	0.03
MgO	0.53	0.22	0.40	0.21	0.22	0.08	0.34	0.18	0.01	0.01	0.06	0.04
CaO	0.25	0.18	2.80	1.51	0.52	0.31	2.19	0.54	0.54	0.06	0.36	0.07
Na_2O	45.71	0.47	38.25	4.01	43.13	1.51	41.73	2.46	41.68	0.59	42.09	5.65
K_2O	0.44	0.17	1.12	0.71	1.02	0.65	0.51	0.17	0.16	0.08	0.69	0.10
P_2O_5	-	-	-	-	-	-	0.75	0.16	0.34	0.17	1.44	0.47
F	-	-	-	-	-	-	-	-	-	-	-	-
Cl	-	-	-	-	-	-	-	-	-	-	-	-
SO_3	0.31	0.21	6.12	1.45	3.46	1.06	-	-	-	-	-	-
CO_2	45.35	1.28	44.99	1.08	44.11	1.68	48.95	1.88	51.57	0.78	53.32	3.18
Total	94.76		94.61		93.50		96.45		94.41		98.48	
Na_2O+K_2O	46.15		39.37		44.16		42.25		41.84		42.78	

Table S3. Major element compositions of experimental mineral (weight %) analysed by EPMA. Abbreviation: s.d. standard deviation, statistical uncertainty calculated on the mean value; Lig ligand; Bu Buchwaldite; Ne nepheline; Men melanite; Ap apatite.

Experiment	0-0-Men		1-1-Men		2-1-Men		2-2-Men		2-3-Men		3-1-Men		3-2-Men	
Lig	-		NaF		NaCl		NaCl		NaCl		Na_2SO_4		Na_2SO_4	
Mineral	Men		Men		Men		Men		Men		Men		Men	
Analysis	5		5		3		10		4		3		5	
		s.d.		s.d.		s.d.		s.d.		s.d.		s.d.		s.d.
SiO_2	29.89	0.53	28.85	0.48	32.49	0.75	32.42	0.32	31.48	0.54	32.82	0.33	32.39	0.27
TiO_2	10.12	0.72	7.52	0.46	3.56	0.91	4.51	0.51	3.76	0.23	3.69	0.11	4.76	0.68
Al_2O_3	0.33	0.02	0.38	0.18	1.61	0.24	0.91	0.21	1.20	0.13	1.25	0.13	0.75	0.16
FeO	22.85	0.56	24.21	0.48	23.62	0.53	24.37	0.73	23.74	0.41	24.35	0.42	24.84	1.62
MnO	0.06	0.03	0.14	0.08	0.03	0.03	0.06	0.03	0.07	0.03	0.07	0.04	0.07	0.03
MgO	0.25	0.02	0.24	0.02	0.17	0.04	0.17	0.06	0.15	0.03	0.21	0.06	0.16	0.09
CaO	31.63	0.42	31.07	0.19	31.94	0.07	30.68	0.70	30.47	0.50	31.67	0.31	30.68	1.38
Na_2O	0.94	0.12	0.89	0.07	0.62	0.12	0.78	0.20	1.11	0.25	0.66	0.08	0.92	0.18
K_2O	0.07	0.04	0.05	0.03	0.10	0.02	0.19	0.11	0.18	0.07	0.09	0.04	0.12	0.03
P_2O_5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cl	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SO_3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	96.13		93.32		94.13		94.11		92.15		94.80		94.69	

Continued Table S3

Experiment	3-3-Men		4-1-Men		0-0-Ne		1-1-Ne		1-2-Ne		2-1-Ne		2-2-Ne	
Lig	Na_2SO_4		Na_3PO_4		-		NaF		NaF		NaCl		NaCl	
Mineral	Men		Men		Ne		Ne		Ne		Ne		Ne	
Analysis	3		3		4		5		1		3		10	
		s.d.		s.d.		s.d.		s.d.		s.d.		s.d.		s.d.
SiO_2	32.12	0.62	27.68	0.70	36.51	0.68	48.86	0.51	37.80	-	48.60	2.64	37.63	0.26
TiO_2	3.04	0.64	10.42	0.90	-	-	0.08	0.09	0.09	-	0.07	0.05	0.04	0.04
Al_2O_3	1.16	0.12	0.05	0.07	33.86	0.25	35.11	0.63	28.34	-	34.06	0.67	28.01	0.62
FeO	24.05	0.52	22.80	0.28	4.02	0.38	5.26	0.32	4.88	-	3.67	0.13	4.25	0.20
MnO	-	-	0.06	0.01	0.00	0.00	-	-	-	-	0.01	-	-	-
MgO	0.18	0.01	0.36	0.03	0.08	0.03	0.09	0.02	0.01	-	0.21	0.10	0.13	0.07
CaO	31.60	0.32	30.13	0.45	0.13	0.01	0.18		0.06	-	0.18	0.03	0.18	0.07
Na_2O	0.80	0.03	1.10	0.21	20.05	1.52	2.49	0.20	16.94	-	2.94	0.35	19.30	0.54
K_2O	0.15	0.04	0.11	0.04	3.11	0.18	1.27	0.11	2.97	-	1.13	0.12	2.90	0.19
P_2O_5	-	-	-	-			-	-	-	-	-	-	-	-
F	-	-	-	-			-	-	-	-	-	-	-	-
Cl	-	-	-	-			-	-	-	-	0.61	0.01	1.16	0.13
SO_3	-	-	-	-			-	-	-	-	-	-	-	-
Total	93.09		92.72		97.77		93.34		91.08		91.48		93.61	

Continued Table S3

Experiment	2-3-Ne		3-1-Ne		3-2-Ne		3-3-Ne		4-1-Ne		4-2-Ne		4-3-Ne	
Lig	NaCl		Na_2SO_4		Na_2SO_4		Na_2SO_4		Na_3PO_4		Na_3PO_4		Na_3PO_4	
Mineral	Ne		Ne		Ne		Ne		Ne		Ne		Ne	
Analysis	3		3		5		4		3		5		5	
		s.d.		s.d.		s.d.		s.d.		s.d.		s.d.		s.d.
SiO_2	47.45	1.58	50.03	1.69	41.83	0.60	49.99	0.42	46.63	0.25	40.16	0.84	46.20	1.99
TiO_2	0.11	0.11	0.04	0.06	0.05	0.04	0.07	0.10	0.10	0.07	0.11	0.06	0.30	0.12
Al_2O_3	33.47	2.14	33.45	0.54	28.26	0.50	32.93	0.28	30.76	1.43	28.63	0.93	34.78	1.15
FeO	5.30	0.93	5.20	0.27	4.90	0.25	5.44	0.22	6.72	0.65	5.79	0.40	6.70	0.23
MnO	0.07	0.06	-	-	-	-	-	-	-	-	-	-	-	-
MgO	0.33	0.23	0.16	0.07	0.20	0.09	0.17	0.02	0.19	0.03	0.16	0.06	0.08	0.01
CaO	0.29	0.16	0.23	0.01	0.30	0.05	0.32	0.01	0.76	0.35	0.34	0.18	0.13	0.03
Na_2O	3.09	0.34	2.47	0.28	11.30	0.56	2.27	0.02	2.46	0.11	14.06	0.85	2.37	0.21
K_2O	1.20	0.02	0.99	0.14	2.35	0.14	0.72	0.03	1.83	0.20	3.75	0.38	1.32	0.09
P_2O_5	-	-	-	-	-	-	-	-	0.24	0.18	0.10	0.04	0.13	0.02
F	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cl	1.52	0.03	-	-	-	-	-	-	-	-	-	-	-	-
SO_3	-	-	1.39	0.20	3.31	0.40	2.52	0.14	-	-	-	-	-	-
Total	92.82		93.98		92.50		94.43		89.68		93.11		92.01	

Continued Table S3

Experiment	4-1-Ap		4-2-Ap		4-2-Bu		4-3-Bu	
Lig	Na_3PO_4		Na_3PO_4		Na_3PO_4		Na_3PO_4	
Mineral	Ap		Ap		Bu		Bu	
Analysis	4		2		5		5	
		s.d.		s.d.		s.d.		s.d.
SiO_2	0.65	0.20	0.06	0.05	-	-	-	-
TiO_2	0.22	0.03	0.01	0.01	-	-	-	-
Al_2O_3	0.37	0.26	0.04	0.04	-	-	-	-
FeO	0.55	0.16	0.04	0.01	-	-	-	-
MnO	-	-	0.05	0.05	-	-	-	-
MgO	0.04	0.02	0.16	0.00	0.14	0.04	0.22	0.08
CaO	54.70	0.80	39.41	0.85	29.03	0.37	29.71	1.04
Na_2O	0.31	0.14	6.98	0.02	24.49	0.21	23.51	1.45
K_2O	0.36	0.16	0.88	0.02	2.22	0.14	2.16	0.06
P_2O_5	40.73	1.26	35.34	0.25	35.28	0.89	38.21	1.71
F	2.53	0.48	3.59	0.14	-	-	-	-
Cl	-	-	-	-	-	-	-	-
SO_3	-	-	-	-	-	-	-	-
Total	100.47		86.56		91.16		93.81	

Table S4. Trace element compositions of experimental melt (ppm) analysed by LA-ICP-MS. Abbreviation: s.d. standard deviation, statistical uncertainty calculated on the mean value; Lig ligand; SM silicate melt; CM quenched carbonate melt; Bu Buchwaldite.

Experiment	0-0-SM		1-1-SM		1-2-SM		1-3-SM		2-1-SM	
Lig	-		NaF		NaF		NaF		NaCl	
Analysis	5		5		5		5		5	
		s.d.		s.d.		s.d.		s.d.		s.d.
Cs	78.11	2.15	75.91	0.29	79.90	0.32	91.70	0.63	53.23	2.82
Rb	104.78	2.64	106.62	0.59	108.44	0.65	111.15	0.65	81.70	4.65
Li	147.68	3.59	120.80	0.47	98.86	0.74	78.80	0.38	138.37	3.09
Ba	185.95	10.65	133.28	0.87	115.58	0.95	88.96	0.87	164.87	11.39
Sr	244.71	10.95	164.50	0.97	137.18	0.71	98.92	0.47	215.97	11.16
Be	254.57	13.40	188.32	1.80	156.88	1.02	135.86	0.90	224.30	10.19
Pb	210.05	11.22	183.34	1.14	166.96	1.27	154.80	0.64	199.63	12.09
Th	222.04	14.87	190.44	3.76	177.18	1.25	158.76	0.76	161.43	7.47
U	206.35	12.29	193.08	2.08	169.68	0.71	158.58	0.54	209.30	10.95
Hf	158.62	10.12	157.30	0.95	183.28	1.79	170.02	1.08	173.73	4.33
Zr	173.56	10.17	166.52	0.86	185.90	0.91	170.68	1.05	165.70	7.42
Nb	86.08	3.53	115.34	0.45	153.32	0.66	139.20	0.88	111.33	17.99
Ta	60.55	2.90	103.90	0.97	176.76	0.97	165.16	1.03	141.33	16.86
Mo	30.54	7.67	10.80	0.22	10.01	0.16	9.67	0.11	8.58	1.57
La	208.85	14.28	167.22	1.53	138.38	0.78	105.77	0.79	200.03	5.60
Ce	110.88	7.21	133.26	2.51	172.48	1.53	155.54	0.84	125.37	21.41
Pr	154.58	10.13	146.04	1.56	134.50	0.70	106.41	0.58	153.87	5.95
Nd	135.10	8.26	142.84	1.19	140.32	0.94	112.66	1.32	145.90	11.78
Sm	80.44	4.57	120.16	2.21	147.24	0.97	119.58	1.21	122.80	20.65
Eu	64.15	3.56	113.16	2.35	150.62	0.54	123.42	0.54	113.33	23.86
Gd	71.09	4.39	102.96	2.05	146.44	1.39	120.08	0.81	107.57	25.83
Tb	45.99	2.55	97.53	2.47	150.76	0.64	125.48	1.04	103.10	26.86
Dy	43.76	3.20	93.26	2.71	149.24	1.34	126.24	0.73	98.33	27.45
Er	56.19	2.98	95.54	2.60	149.28	1.46	126.72	0.85	99.73	25.73
Yb	82.71	3.71	117.92	2.78	159.86	0.77	137.48	0.77	118.83	23.19
Lu	100.97	4.64	129.20	2.49	163.28	1.36	139.92	0.78	131.80	18.26
Y	71.50	4.35	118.44	2.52	152.74	1.05	122.52	0.92	112.97	27.00
Sc	141.35	1.47	118.20	1.59	167.70	1.10	141.26	1.08	146.40	41.63
V	143.24	4.81	122.68	0.83	104.95	0.51	88.98	0.86	107.50	2.49
Cr	63.86	18.86	12.64	0.67	12.55	0.32	12.72	0.27	18.97	5.45
Mn	0.02	0.00	147.98	1.08	163.00	0.73	158.78	1.35	173.60	13.18
Co	193.44	5.51	172.46	1.12	153.56	0.88	148.94	0.91	190.20	19.90
Cu	642.08	25.45	302.62	6.81	390.48	2.52	466.46	1.56	315.87	16.29
Zn	362.29	13.46	254.68	4.12	201.98	1.21	193.74	1.54	296.90	15.24
Ga	191.86	7.03	179.68	0.84	181.80	0.42	170.68	1.00	198.77	3.72
Ge	109.84	8.25	119.60	0.63	178.04	0.67	165.50	0.91	142.63	15.65

Continued Table S4

Experiment	2-2-SM		2-3-SM		3-1-SM		3-2-SM		3-3-SM	
Lig	NaCl		NaCl		Na_2SO_4		Na_2SO_4		Na_2SO_4	
Analysis	5		5		5		5		5	
		s.d.		s.d.		s.d.		s.d.		s.d.
Cs	61.77	1.59	49.78	2.41	67.07	4.39	79.68	2.65	72.67	0.54
Rb	94.53	2.09	77.37	2.84	95.23	7.48	111.14	3.24	97.98	0.91
Li	152.93	2.23	145.42	5.52	134.43	11.80	150.28	4.24	121.12	1.42
Ba	182.98	4.48	178.12	9.48	153.93	15.20	177.82	5.25	151.58	1.96
Sr	244.48	4.78	243.48	13.29	201.73	18.62	231.36	5.63	198.52	2.60
Be	242.25	4.99	228.74	8.66	210.07	17.80	253.66	6.26	239.94	1.68
Pb	213.78	4.75	207.56	10.67	199.23	20.30	243.06	8.29	227.90	3.07
Th	191.00	3.64	132.48	6.14	151.30	15.41	236.76	9.77	187.44	3.34
U	225.33	5.25	203.72	10.53	193.53	20.42	256.16	8.86	230.72	3.83
Hf	171.40	3.92	169.30	6.65	144.27	13.99	172.96	7.65	166.48	4.46
Zr	173.33	4.54	160.82	6.70	142.70	13.28	184.38	8.83	169.98	4.86
Nb	113.13	9.03	97.22	2.69	81.79	7.39	130.64	4.46	90.52	0.82
Ta	139.93	8.08	118.30	3.67	97.77	9.03	136.40	5.92	115.38	1.66
Mo	7.71	0.62	5.65	1.33	10.13	4.88	8.74	2.07	5.22	0.11
La	216.13	2.38	188.78	8.89	186.13	20.05	249.02	9.26	221.52	1.90
Ce	116.50	9.75	72.94	2.66	106.10	11.10	131.96	4.88	112.72	1.32
Pr	146.85	5.25	113.32	4.22	140.30	14.08	174.04	5.17	154.22	1.85
Nd	126.60	7.88	95.18	3.19	125.67	13.05	143.18	5.89	128.94	2.22
Sm	89.35	12.12	62.18	3.54	86.10	8.45	83.04	2.61	76.46	1.00
Eu	80.18	14.64	51.86	3.44	73.40	7.63	67.86	2.51	62.11	1.01
Gd	71.78	14.73	44.33	3.52	62.57	6.45	57.48	2.02	51.49	0.51
Tb	66.98	15.80	39.21	4.32	54.55	5.70	50.26	2.07	44.63	0.60
Dy	64.13	16.36	36.72	4.42	49.13	5.45	45.99	2.02	41.59	0.56
Er	62.83	15.82	39.15	3.89	51.69	5.62	47.96	2.20	45.92	0.98
Yb	79.03	14.78	60.10	3.51	74.90	8.08	68.88	3.24	71.56	1.70
Lu	89.80	13.58	75.44	3.22	89.17	8.87	83.62	3.57	88.45	1.74
Y	75.98	15.34	47.50	3.88	69.10	7.23	63.80	2.62	59.69	1.03
Sc	122.15	9.86	133.16	5.33	111.77	9.20	109.56	3.46	99.94	3.25
V	117.58	1.17	98.51	4.89	113.10	9.49	140.58	4.41	115.80	1.01
Cr	16.47	3.21	11.19	5.67	14.36	6.27	10.71	1.18	7.32	0.36
Mn	166.83	5.61	163.56	5.47	140.53	12.41	160.30	3.83	155.00	1.58
Co	214.63	3.59	209.00	9.76	179.13	15.25	215.96	6.97	207.20	1.40
Cu	511.93	29.37	666.40	31.91	265.77	26.74	391.94	11.15	574.20	12.18
Zn	276.98	6.47	261.68	10.39	235.77	26.18	299.56	9.62	279.56	2.39
Ga	217.95	2.78	209.30	3.15	182.03	12.37	218.70	4.66	202.68	1.92
Ge	126.28	9.21	122.20	2.50	97.43	8.49	102.54	2.27	101.84	0.85

Continued Table S4

Experiment	4-1-SM		4-2-SM		4-3-SM		0-0-CM		1-1-CM	
Lig	Na_3PO_4		Na_3PO_4		Na_3PO_4		-		NaF	
Analysis	5		5		5		6		7	
		s.d.		s.d.		s.d.		s.d.		s.d.
Cs	84.01	2.15	100.35	0.56	82.22	1.04	286.89	59.55	68.43	13.34
Rb	119.93	1.81	130.88	0.95	110.21	1.04	568.93	42.57	209.00	14.72
Li	138.08	0.40	149.48	0.57	120.88	1.35	177.50	9.59	561.00	143.17
Ba	151.24	2.64	149.96	0.90	117.26	0.58	520.71	90.36	537.33	56.01
Sr	160.14	2.63	145.08	0.94	90.14	0.93	797.24	118.42	813.67	88.63
Be	194.72	2.16	191.96	0.56	157.64	2.06	100.39	17.52	84.03	7.63
Pb	188.10	0.94	183.58	1.72	154.18	1.08	187.20	45.63	132.03	29.23
Th	183.44	1.08	187.18	1.98	158.38	2.29	13.01	1.46	32.00	3.48
U	182.28	0.90	185.42	0.66	153.52	1.50	80.76	17.50	52.17	7.00
Hf	162.72	3.89	188.72	0.90	158.20	1.62	0.91	0.22	2.08	0.20
Zr	170.58	8.37	189.62	0.88	159.54	1.38	2.37	0.47	3.52	0.30
Nb	121.73	5.13	163.88	0.81	140.32	1.25	26.31	3.11	45.17	4.46
Ta	110.89	15.92	188.46	0.71	158.90	1.90	3.17	0.62	10.39	0.95
Mo	15.38	0.11	22.81	0.47	19.62	0.40	966.49	228.93	705.67	93.36
La	133.14	0.48	150.44	2.28	105.54	2.08	177.15	15.99	343.67	39.63
Ce	120.04	7.13	181.30	1.79	154.92	1.38	11.82	2.10	49.23	9.58
Pr	113.30	2.38	138.56	2.91	99.98	1.69	104.36	10.62	236.67	31.98
Nd	110.12	3.21	145.44	2.50	106.02	2.67	87.79	9.16	225.50	31.23
Sm	94.92	4.73	150.28	3.26	112.50	2.31	46.18	4.15	166.30	24.74
Eu	89.12	6.35	158.50	3.08	118.84	2.23	35.32	3.77	147.63	21.99
Gd	81.26	7.31	153.44	2.80	115.02	2.00	37.44	1.22	129.80	18.44
Tb	76.92	8.02	160.30	2.40	122.70	1.52	20.88	1.93	106.30	16.01
Dy	73.06	8.53	161.66	2.72	124.98	2.00	17.63	2.32	91.37	13.46
Er	73.39	8.74	162.00	2.18	125.76	1.89	16.74	2.05	74.47	11.64
Yb	94.82	7.75	176.36	1.81	138.70	1.94	17.94	1.62	67.90	9.77
Lu	106.21	5.95	179.54	1.53	140.70	1.61	19.60	1.61	67.33	8.19
Y	89.88	7.76	171.22	1.67	134.02	1.27	29.57	2.44	120.00	13.17
Sc	121.68	5.28	179.18	1.18	148.70	1.50	15.53	2.31	47.70	5.60
V	132.28	1.46	135.50	1.01	116.42	1.26	252.56	33.45	281.33	25.42
Cr	18.87	0.20	27.55	0.78	23.21	0.77	791.84	210.13	401.67	79.57
Mn	162.22	0.38	194.66	1.11	165.78	1.54	0.01	0.00	67.60	8.29
Co	173.68	2.63	178.38	0.69	150.62	0.82	68.85	30.79	58.77	8.35
Cu	250.56	11.43	327.80	3.46	222.74	2.79	361.67	112.04	129.00	17.57
Zn	223.82	2.59	222.40	1.67	184.02	2.07	25.40	6.73	36.70	7.64
Ga	166.70	0.35	178.30	1.39	152.74	1.32	12.17	0.50	10.85	1.04
Ge	127.98	5.66	184.88	2.04	157.50	1.97	6.37	0.54	16.93	1.97

Continued Table S4

Experiment	1-2-CM		1-3-CM		2-1-CM		2-2-CM		2-3-CM	
Lig	NaF		NaF		NaCl		NaCl		NaCl	
Analysis	5		5		5		8		5	
		s.d.		s.d.		s.d.		s.d.		s.d.
Cs	297.20	75.47	458.67	107.14	254.00	4.24	247.50	26.16	414.25	38.96
Rb	190.34	44.17	298.33	9.67	423.67	24.44	197.75	42.61	427.25	169.01
Li	565.00	61.30	1008.00	8.64	260.40	24.54	183.50	8.44	100.68	23.63
Ba	445.92	44.79	943.33	75.46	210.10	3.70	282.00	56.41	172.45	34.31
Sr	706.42	8.59	1393.33	128.15	280.67	2.05	344.00	45.98	181.35	28.04
Be	160.50	15.86	402.33	13.02	46.98	6.07	30.45	9.27	11.22	1.02
Pb	151.90	16.78	217.00	9.63	158.67	7.32	57.88	21.86	128.75	21.68
Th	49.68	1.49	134.67	6.24	2.31	0.56	3.15	0.52	0.80	0.10
U	65.96	4.02	121.70	3.75	87.90	10.17	26.65	5.40	20.63	2.69
Hf	4.59	0.88	7.30	0.64	0.14	0.04	0.31	0.03	0.15	0.06
Zr	6.70	0.94	11.00	0.78	0.25	0.07	0.55	0.04	0.20	0.08
Nb	77.66	1.21	170.33	7.32	13.10	2.56	28.30	3.32	11.69	1.23
Ta	23.02	2.45	43.17	2.21	1.61	0.41	4.06	0.78	1.46	0.40
Mo	533.80	43.95	871.00	122.87	498.33	21.51	712.75	254.85	927.00	42.60
La	343.32	4.64	784.67	50.18	54.40	1.98	63.13	9.50	23.49	3.29
Ce	68.56	5.87	143.33	9.46	8.93	0.75	8.37	1.45	2.08	0.21
Pr	249.14	3.53	585.00	39.22	30.05	1.59	33.85	5.23	10.79	1.56
Nd	254.70	4.24	598.33	56.35	26.05	3.41	27.55	3.94	8.53	1.23
Sm	223.16	6.02	538.67	31.54	14.71	1.20	15.58	2.57	4.24	0.61
Eu	215.18	5.84	516.67	42.77	11.69	1.65	12.73	1.89	3.21	0.42
Gd	206.00	3.10	499.00	34.32	10.69	0.98	11.06	1.63	2.48	0.34
Tb	183.74	3.62	449.67	31.04	10.01	1.10	8.53	1.35	1.81	0.25
Dy	167.02	4.12	408.00	31.63	9.05	0.56	7.19	1.19	1.43	0.19
Er	138.42	3.79	343.67	24.61	8.81	0.75	5.77	0.88	1.25	0.15
Yb	119.80	5.56	306.00	23.72	8.75	0.60	5.51	0.89	1.52	0.19
Lu	113.98	4.98	288.33	17.75	8.27	1.83	5.62	1.08	1.73	0.23
Y	210.14	5.29	530.67	28.99	10.56	1.57	8.71	1.40	1.98	0.24
Sc	93.90	3.11	245.00	5.66	8.05	1.31	5.66	1.01	2.61	0.29
V	408.72	28.38	557.33	12.68	640.75	85.42	346.25	118.40	393.00	64.66
Cr	564.40	52.58	1309.67	224.63	631.25	65.23	645.25	391.52	1054.25	249.98
Mn	87.82	3.70	183.00	3.56	45.75	4.34	67.45	8.94	46.55	12.57
Co	60.77	2.64	110.93	3.52	47.40	17.70	35.58	12.65	42.43	17.48
Cu	214.12	30.25	476.00	25.57	248.75	33.77	334.50	43.29	368.75	136.10
Zn	29.74	6.04	53.17	7.35	15.50	2.07	24.18	8.34	13.01	0.30
Ga	14.41	1.05	22.07	1.95	4.73	1.10	7.65	1.40	3.35	0.43
Ge	38.34	1.20	62.40	1.98	8.25	0.67	7.37	0.84	6.14	0.35

Continued Table S4

Experiment	3-1-CM		3-2-CM		3-3-CM		4-1-CM		4-2-CM	
Lig	Na_2SO_4		Na_2SO_4		Na_2SO_4		Na_3PO_4		Na_3PO_4	
Analysis	4		10		5		5		5	
		s.d.		s.d.		s.d.		s.d.		s.d.
Cs	159.57	53.59	213.15	35.91	341.60	18.74	439.50	44.50	271.67	117.93
Rb	120.23	26.60	408.50	48.87	304.80	64.19	433.50	2.50	298.33	133.63
Li	123.93	81.27	254.18	76.45	287.64	14.70	719.00	121.00	366.67	94.04
Ba	98.73	60.14	313.30	53.78	371.00	35.58	775.00	15.00	431.67	103.76
Sr	125.43	79.24	309.60	29.54	518.28	8.18	938.50	181.50	484.33	96.78
Be	7.61	2.10	22.98	1.99	26.38	3.44	64.70	11.30	65.07	15.69
Pb	34.30	14.00	88.10	12.72	147.58	15.40	259.00	47.00	201.33	45.55
Th	0.92	0.53	3.16	0.48	3.63	0.23	28.25	2.45	23.27	6.53
U	13.52	6.49	23.01	2.50	79.92	35.64	55.40	3.70	64.10	25.76
Hf	0.07	0.03	0.13	0.04	0.21	0.02	1.73	0.13	3.66	1.45
Zr	0.11	0.03	0.25	0.07	0.42	0.02	3.55	0.05	3.77	2.55
Nb	3.50	1.93	16.88	1.55	17.97	1.76	73.80	6.20	82.03	23.78
Ta	0.46	0.25	2.08	0.59	2.84	0.30	16.05	0.95	17.63	8.80
Mo	315.73	78.59	225.43	37.44	824.40	345.38	1180.00	180.00	996.67	232.14
La	25.13	15.97	65.88	5.30	89.56	6.70	313.00	29.00	216.77	47.06
Ce	2.24	1.33	5.89	0.86	7.95	0.65	56.95	7.05	52.90	20.15
Pr	14.03	9.15	35.05	2.91	45.96	3.36	216.50	19.50	155.83	29.67
Nd	11.95	7.52	27.03	2.04	36.02	3.08	203.50	17.50	173.63	38.35
Sm	6.58	4.24	12.51	1.18	17.44	1.49	151.00	15.00	138.83	26.69
Eu	5.00	3.25	9.35	1.00	12.52	1.23	132.50	12.50	146.70	35.45
Gd	4.03	2.60	7.42	0.94	9.54	0.81	117.00	13.00	123.63	25.82
Tb	2.91	1.92	5.50	0.74	6.91	0.62	95.50	9.50	111.63	22.04
Dy	2.36	1.52	4.48	0.67	5.76	0.51	81.95	8.05	98.30	20.94
Er	1.95	1.25	3.60	0.47	5.16	0.40	64.85	7.15	76.57	19.48
Yb	2.14	1.31	3.92	0.37	6.54	0.42	59.55	5.45	65.83	16.36
Lu	2.18	1.32	4.23	0.43	7.48	0.60	58.60	6.40	57.70	17.21
Y	3.46	2.32	6.29	0.66	8.85	0.69	97.00	9.00	97.13	25.88
Sc	1.85	0.58	3.91	0.57	6.58	1.14	41.40	4.70	40.00	13.01
V	126.77	24.78	161.45	20.68	368.60	127.53	606.50	123.50	372.00	81.62
Cr	259.63	87.41	322.97	41.76	791.60	302.84	1615.00	145.00	1164.67	35.26
Mn	19.70	9.76	32.13	3.04	47.92	3.50	136.50	18.50	160.00	51.08
Co	24.37	12.98	27.82	5.96	44.58	2.06	116.00	4.00	103.50	16.77
Cu	46.30	6.40	128.73	25.15	327.42	17.90	256.00	6.00	291.67	39.75
Zn	4.20	2.32	9.14	1.79	13.84	3.13	37.15	11.25	38.83	14.09
Ga	0.99	0.54	4.06	0.61	5.92	0.65	14.30	0.10	17.13	5.28
Ge	1.35	0.51	4.71	0.77	7.03	0.82	27.10	2.50	30.90	13.02

Continued Table S4

Experiment	4-3-CM		4-2-Bu		4-3-Bu	
Lig	Na_3PO_4		Na_3PO_4		Na_3PO_4	
Analysis	5		3		4	
		s.d.		s.d.		s.d.
Cs	205.80	5.25	0.69	0.25	0.78	0.06
Rb	460.50	82.72	7.78	0.24	12.02	0.10
Li	188.00	8.53	53.24	0.41	79.70	0.70
Ba	385.50	11.51	171.57	1.25	377.43	1.69
Sr	279.50	13.69	1000.00	2.94	1728.33	16.52
Be	68.55	3.21	0.32	0.20	0.28	0.09
Pb	213.50	8.84	26.29	0.08	56.76	0.20
Th	29.25	1.46	17.21	0.41	44.68	0.43
U	46.48	2.82	0.41	0.00	0.08	0.00
Hf	2.75	0.19	0.37	0.18	0.66	0.06
Zr	4.24	0.28	0.40	0.10	0.78	0.02
Nb	112.40	5.92	0.37	0.13	0.46	0.02
Ta	22.18	1.41	0.20	0.16	0.19	0.03
Mo	575.75	18.16	2.56	0.37	4.08	0.18
La	154.08	7.84	373.37	1.50	905.90	3.61
Ce	58.18	2.96	10.28	0.32	28.27	0.25
Pr	115.40	6.04	297.63	1.99	733.30	6.17
Nd	116.83	6.04	316.87	4.00	775.00	2.16
Sm	108.80	5.77	265.20	2.79	671.33	4.03
Eu	104.90	5.47	249.20	3.20	630.03	1.60
Gd	96.03	4.98	232.43	1.86	581.93	5.52
Tb	90.28	4.62	194.23	1.01	494.20	2.98
Dy	83.20	4.24	169.03	0.25	431.43	0.39
Er	70.95	3.68	128.70	2.26	331.20	0.91
Yb	62.43	3.22	102.40	3.34	263.37	2.69
Lu	58.28	3.00	96.20	2.86	245.23	1.36
Y	93.30	4.58	154.57	1.37	399.27	1.11
Sc	47.30	2.36	25.01	0.45	65.63	0.45
V	199.20	7.19	52.54	0.39	65.37	0.62
Cr	1080.00	13.98	13.63	1.09	21.37	0.24
Mn	203.75	9.59	14.58	0.40	30.82	0.22
Co	115.28	5.80	7.90	0.21	16.73	0.23
Cu	267.45	12.28	9.56	0.51	14.76	0.32
Zn	65.95	4.90	2.98	0.23	6.19	0.19
Ga	23.13	1.31	3.18	0.24	6.80	0.05
Ge	37.75	2.08	4.93	0.32	11.12	0.28

Table S5. Calculate partition coefficients between different phases. Abbreviation: Lig ligand; SM silicate melt; CM quenched carbonate melt; Bu Buchwaldite; D distribution coefficients.

Experiment	0-0		1-1		1-2		1-3		2-1	
Lig	-		NaF		NaF		NaF		NaCl	
D	$D^{CM/SM}$		$D^{CM/SM}$		$D^{CM/SM}$		$D^{CM/SM}$		$D^{CM/SM}$	
		s.d.		s.d.		s.d.		s.d.		s.d.
Cs	3.673	0.769	5.929	0.176	4.503	0.945	5.002	1.169	4.771	0.265
Rb	5.430	0.429	1.960	0.138	2.995	0.407	2.684	0.088	5.186	0.420
Li	1.202	0.071	6.750	1.185	5.745	0.622	12.791	0.125	1.882	0.182
Ba	2.800	0.512	4.406	0.421	4.845	0.389	10.604	0.855	1.274	0.091
Sr	3.258	0.505	5.131	0.540	5.345	0.068	14.085	1.297	1.300	0.068
Be	0.394	0.072	0.859	0.041	1.341	0.101	2.961	0.098	0.209	0.029
Pb	0.891	0.222	0.930	0.160	1.325	0.101	1.402	0.062	0.795	0.061
Th	0.059	0.008	0.178	0.019	0.321	0.009	0.848	0.039	0.014	0.004
U	0.391	0.088	0.448	0.036	0.546	0.024	0.767	0.024	0.420	0.053
Hf	0.006	0.001	0.010	0.001	0.014	0.005	0.043	0.004	0.001	0.000
Zr	0.014	0.003	0.015	0.002	0.021	0.005	0.064	0.005	0.002	0.000
Nb	0.306	0.038	0.464	0.039	0.590	0.008	1.224	0.053	0.118	0.030
Ta	0.052	0.011	0.075	0.009	0.090	0.014	0.261	0.013	0.011	0.003
Mo	31.643	10.922	145.742	8.746	87.969	4.468	90.035	12.739	58.081	10.905
La	0.848	0.096	2.055	0.238	2.567	0.036	7.419	0.478	0.272	0.012
Ce	0.107	0.020	0.407	0.072	0.426	0.034	0.922	0.061	0.071	0.014
Pr	0.675	0.082	1.614	0.220	1.983	0.028	5.498	0.370	0.195	0.013
Nd	0.650	0.079	1.554	0.219	1.928	0.033	5.311	0.504	0.179	0.027
Sm	0.574	0.061	1.381	0.207	1.664	0.042	4.505	0.268	0.120	0.022
Eu	0.551	0.066	1.298	0.196	1.573	0.039	4.186	0.347	0.103	0.026
Gd	0.527	0.037	1.281	0.181	1.562	0.025	4.156	0.287	0.099	0.026
Tb	0.454	0.049	1.106	0.166	1.364	0.025	3.584	0.249	0.097	0.027
Dy	0.403	0.061	1.010	0.147	1.284	0.029	3.232	0.251	0.092	0.026
Er	0.298	0.040	0.838	0.124	1.104	0.027	2.712	0.195	0.088	0.024
Yb	0.217	0.022	0.651	0.084	0.909	0.035	2.226	0.173	0.074	0.015
Lu	0.194	0.018	0.608	0.064	0.857	0.031	2.061	0.127	0.063	0.016
Y	0.414	0.042	1.152	0.113	1.686	0.036	4.331	0.239	0.093	0.026
Sc	0.110	0.016	0.525	0.048	0.767	0.019	1.734	0.042	0.055	0.018
V	1.763	0.241	5.284	0.208	4.142	0.271	6.264	0.155	5.960	0.807
Cr	12.400	4.923	81.443	6.514	76.211	4.337	102.961	17.793	33.282	10.158
Mn	0.626	0.113	0.630	0.056	0.716	0.023	1.153	0.024	0.264	0.032
Co	0.356	0.159	0.515	0.048	0.447	0.017	0.745	0.024	0.249	0.097
Cu	0.563	0.176	0.730	0.059	0.699	0.078	1.020	0.055	0.788	0.114
Zn	0.070	0.019	0.168	0.030	0.201	0.030	0.274	0.038	0.052	0.007
Ga	0.063	0.003	0.054	0.006	0.074	0.006	0.129	0.011	0.024	0.006
Ge	0.058	0.007	0.174	0.017	0.206	0.007	0.377	0.012	0.058	0.008
Partition coefficient ratios										
$D^{Zr/Hf}$	2.370		1.419		1.492		1.502		1.933	
$D^{Nb/Ta}$	5.839		6.227		6.556		4.682		10.347	
$D^{La/Lu}$	4.371		3.380		2.995		3.600		4.335	

Continued Table S5

Experiment	2-2		2-3		3-1		3-2		3-3	
Lig	NaCl		NaCl		Na_2SO_4		Na_2SO_4		Na_2SO_4	
D	$D^{CM/SM}$		$D^{CM/SM}$		$D^{CM/SM}$		$D^{CM/SM}$		$D^{CM/SM}$	
		s.d.		s.d.		s.d.		s.d.		s.d.
Cs	4.007	0.436	8.321	0.881	2.379	0.814	2.675	0.459	4.701	0.260
Rb	2.092	0.453	5.522	2.194	1.263	0.296	3.676	0.453	3.111	0.656
Li	1.125	0.058	0.692	0.165	0.922	0.610	1.691	0.511	2.375	0.124
Ba	1.346	0.311	0.968	0.199	0.641	0.396	1.762	0.307	2.448	0.237
Sr	1.336	0.190	0.745	0.122	0.622	0.397	1.338	0.132	2.611	0.054
Be	0.108	0.038	0.049	0.005	0.036	0.010	0.091	0.008	0.110	0.014
Pb	0.264	0.102	0.620	0.109	0.172	0.072	0.362	0.054	0.648	0.068
Th	0.016	0.003	0.006	0.001	0.006	0.004	0.013	0.002	0.019	0.001
U	0.114	0.024	0.101	0.014	0.070	0.034	0.090	0.010	0.346	0.155
Hf	0.002	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.001	0.000
Zr	0.003	0.000	0.001	0.001	0.001	0.000	0.001	0.000	0.002	0.000
Nb	0.243	0.036	0.120	0.013	0.043	0.024	0.129	0.013	0.198	0.020
Ta	0.024	0.006	0.012	0.003	0.005	0.003	0.015	0.004	0.025	0.003
Mo	107.815	33.891	164.129	39.442	31.168	16.913	25.805	7.456	157.992	66.269
La	0.277	0.044	0.124	0.018	0.135	0.087	0.265	0.023	0.404	0.030
Ce	0.062	0.014	0.029	0.003	0.021	0.013	0.045	0.007	0.071	0.006
Pr	0.207	0.037	0.095	0.014	0.100	0.066	0.201	0.018	0.298	0.022
Nd	0.197	0.034	0.090	0.013	0.095	0.061	0.189	0.016	0.279	0.024
Sm	0.160	0.037	0.068	0.010	0.076	0.050	0.151	0.015	0.228	0.020
Eu	0.144	0.037	0.062	0.009	0.068	0.045	0.138	0.016	0.202	0.020
Gd	0.142	0.039	0.056	0.009	0.064	0.042	0.129	0.017	0.185	0.016
Tb	0.123	0.036	0.046	0.008	0.053	0.036	0.109	0.015	0.155	0.014
Dy	0.113	0.034	0.039	0.007	0.048	0.031	0.097	0.015	0.138	0.012
Er	0.083	0.027	0.032	0.005	0.038	0.025	0.075	0.010	0.112	0.009
Yb	0.075	0.017	0.025	0.003	0.029	0.018	0.057	0.006	0.091	0.006
Lu	0.062	0.015	0.023	0.003	0.024	0.015	0.051	0.006	0.085	0.007
Y	0.103	0.030	0.042	0.006	0.050	0.034	0.099	0.011	0.148	0.012
Sc	0.042	0.009	0.020	0.002	0.017	0.005	0.036	0.005	0.066	0.012
V	3.508	1.007	3.990	0.686	1.121	0.238	1.148	0.151	3.183	1.102
Cr	48.178	24.973	94.230	52.688	18.085	9.976	30.156	5.116	108.083	41.698
Mn	0.404	0.055	0.285	0.077	0.140	0.071	0.200	0.020	0.309	0.023
Co	0.222	0.059	0.203	0.084	0.136	0.073	0.129	0.028	0.215	0.010
Cu	0.612	0.093	0.553	0.206	0.174	0.030	0.328	0.065	0.570	0.033
Zn	0.158	0.030	0.050	0.002	0.018	0.010	0.031	0.006	0.050	0.011
Ga	0.030	0.006	0.016	0.002	0.005	0.003	0.019	0.003	0.029	0.003
Ge	0.065	0.008	0.050	0.003	0.014	0.005	0.046	0.008	0.069	0.008
Partition coefficient ratios										
$D^{Zr/Hf}$	1.646		1.442		1.521		1.769		1.912	
$D^{Nb/Ta}$	10.176		9.753		9.097		8.469		8.076	
$D^{La/Lu}$	4.448		5.422		5.531		5.234		4.782	

Continued Table S5

Experiment	4-1		4-2		4-3		4-2		4-3	
Lig	Na_3PO_4		Na_3PO_4		Na_3PO_4		Na_3PO_4		Na_3PO_4	
D	$D^{CM/SM}$		$D^{CM/SM}$		$D^{CM/SM}$		$D^{Bu/SM}$		$D^{Bu/SM}$	
		s.d.		s.d.		s.d.		s.d.		s.d.
Cs	5.232	0.546	4.038	1.175	2.503	0.071	0.007	0.003	0.010	0.001
Rb	3.615	0.059	2.426	1.021	4.178	0.752	0.059	0.002	0.109	0.001
Li	5.207	0.876	3.944	0.629	1.555	0.073	0.356	0.003	0.659	0.009
Ba	5.124	0.134	4.505	0.692	3.288	0.100	1.144	0.011	3.219	0.022
Sr	5.860	1.137	4.866	0.667	3.101	0.155	6.893	0.049	19.174	0.270
Be	0.332	0.058	0.496	0.082	0.435	0.021	0.002	0.001	0.002	0.001
Pb	1.377	0.250	1.508	0.248	1.385	0.058	0.143	0.001	0.368	0.003
Th	0.154	0.013	0.180	0.035	0.185	0.010	0.092	0.002	0.282	0.005
U	0.304	0.020	0.498	0.139	0.303	0.019	0.002	0.000	0.001	0.000
Hf	0.011	0.001	0.024	0.008	0.017	0.001	0.002	0.001	0.004	0.000
Zr	0.021	0.001	0.027	0.013	0.027	0.002	0.002	0.001	0.005	0.000
Nb	0.606	0.057	0.774	0.145	0.801	0.043	0.002	0.001	0.003	0.000
Ta	0.145	0.022	0.139	0.047	0.140	0.009	0.001	0.001	0.001	0.000
Mo	76.703	11.713	77.146	10.215	29.339	1.105	0.112	0.017	0.208	0.010
La	2.351	0.218	2.051	0.314	1.460	0.080	2.482	0.039	8.583	0.173
Ce	0.474	0.065	0.427	0.111	0.376	0.019	0.057	0.002	0.183	0.002
Pr	1.911	0.177	1.627	0.215	1.154	0.063	2.148	0.047	7.334	0.139
Nd	1.848	0.168	1.666	0.265	1.102	0.063	2.179	0.046	7.310	0.185
Sm	1.591	0.177	1.331	0.179	0.967	0.055	1.765	0.043	5.967	0.128
Eu	1.487	0.176	1.304	0.224	0.883	0.049	1.572	0.037	5.302	0.100
Gd	1.440	0.206	1.158	0.169	0.835	0.046	1.515	0.030	5.059	0.100
Tb	1.241	0.179	1.018	0.138	0.736	0.039	1.212	0.019	4.028	0.055
Dy	1.122	0.171	0.880	0.130	0.666	0.036	1.046	0.018	3.452	0.055
Er	0.884	0.143	0.687	0.120	0.564	0.030	0.794	0.018	2.634	0.040
Yb	0.628	0.077	0.543	0.093	0.450	0.024	0.581	0.020	1.899	0.033
Lu	0.552	0.068	0.464	0.096	0.414	0.022	0.536	0.017	1.743	0.022
Y	1.079	0.137	0.861	0.151	0.696	0.035	0.903	0.012	2.979	0.029
Sc	0.340	0.041	0.339	0.073	0.318	0.016	0.140	0.003	0.441	0.005
V	4.585	0.935	5.336	0.603	1.711	0.065	0.388	0.004	0.561	0.008
Cr	85.595	7.741	84.580	1.750	46.536	1.664	0.495	0.042	0.921	0.032
Mn	0.841	0.114	1.260	0.262	1.229	0.059	0.075	0.002	0.186	0.002
Co	0.668	0.025	0.866	0.094	0.765	0.039	0.044	0.001	0.111	0.002
Cu	1.022	0.052	1.258	0.122	1.201	0.057	0.029	0.002	0.066	0.002
Zn	0.166	0.050	0.273	0.063	0.358	0.027	0.013	0.001	0.034	0.001
Ga	0.086	0.001	0.159	0.030	0.151	0.009	0.018	0.001	0.044	0.001
Ge	0.212	0.022	0.285	0.070	0.240	0.014	0.027	0.002	0.071	0.002
Partition coefficient ratios										
$D^{Zr/Hf}$	1.957		1.119		1.528		1.061		1.178	
$D^{Nb/Ta}$	4.189		5.565		5.740		2.088		2.823	
$D^{La/Lu}$	4.261		4.417		3.525		4.632		4.925	

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