



Supplementary Information for

The volatile element evolution of chondrules through time

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This PDF file includes:

Fig. S1
Tables S1 to S3
SI References

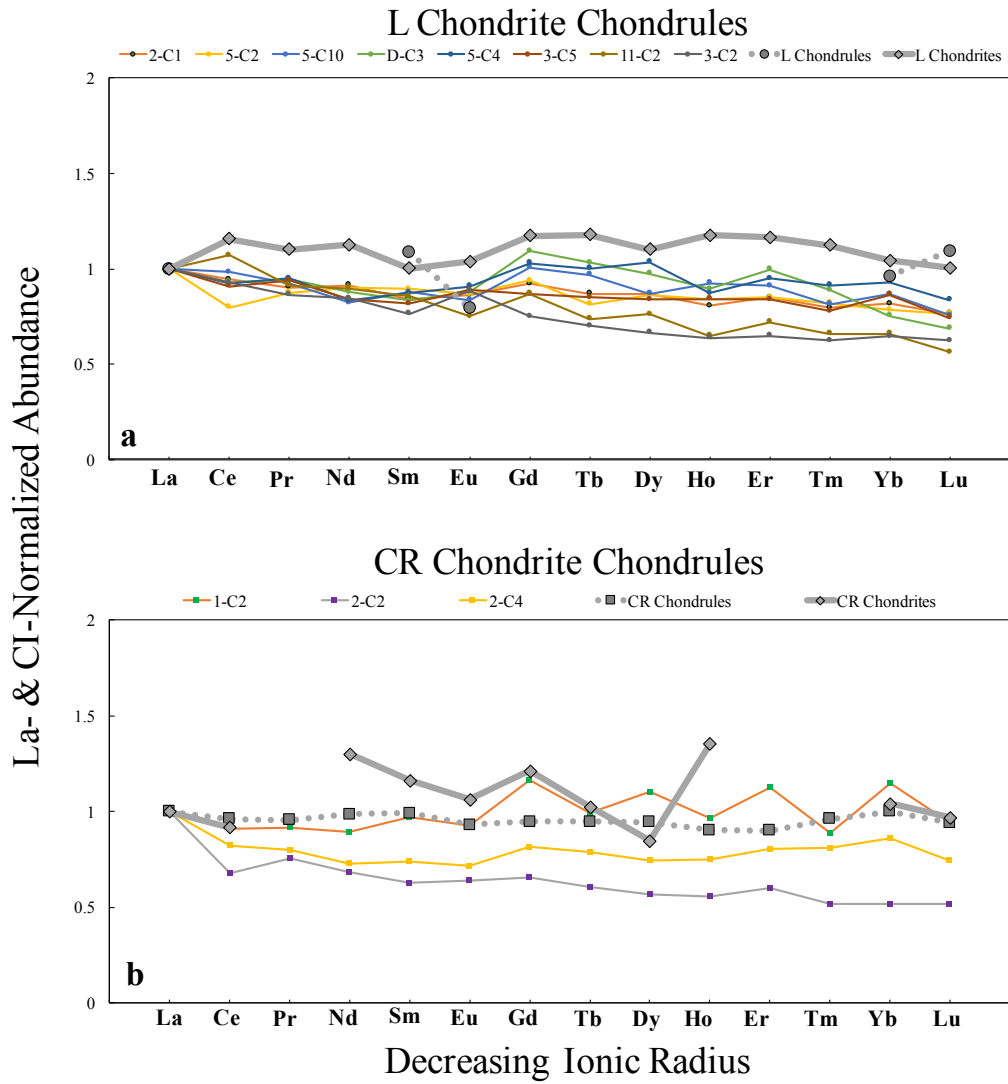


Fig. S1. Lanthanum- and CI-normalized REE abundances for (a) L chondrite chondrules and (b) CR chondrite chondrules. Where available, literature data have been included for both L and CR chondrite chondrules and their bulk meteorite hosts. Bulk data for CI, L and CR chondrites from (1). Bulk Earth values averaged from (2, 3). L chondrite chondrule data from (4), except Ti (5). CR chondrite chondrule data from (6). All data are as indicated in the legend.

Table S1. Lanthanum- & CI-normalized abundances for individual chondrules

Description	Element	<i>NWA 5697 (L3.10)</i>								<i>L Chondrule</i>	<i>L Chondrite</i>	
		2-C1	5-C2	5-C10	D-C3	5-C4	3-C5	11-C2	3-C2			
Rare Earth	<i>La</i>	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Ce	0.94	0.80	0.98	0.93	0.92	0.91	1.07	0.93			1.16
	Pr	0.90	0.88	0.93	0.95	0.95	0.94	0.91	0.86			1.10
	Nd	0.91	0.90	0.82	0.88	0.83	0.84	0.90	0.84			1.12
	Sm	0.84	0.89	0.88	0.83	0.87	0.82	0.85	0.76	1.09		1.00
	Eu	0.86	0.87	0.84	0.88	0.91	0.89	0.75	0.88	0.79		1.04
	Gd	0.92	0.94	1.01	1.09	1.03	0.87	0.87	0.75			1.17
	Tb	0.87	0.81	0.97	1.03	1.00	0.85	0.74	0.70			1.18
	Dy	0.87	0.86	0.87	0.97	1.03	0.84	0.76	0.67			1.10
	Ho	0.80	0.84	0.92	0.89	0.87	0.84	0.65	0.64			1.17
	Er	0.85	0.85	0.91	0.99	0.95	0.84	0.72	0.65			1.16
	Tm	0.79	0.82	0.81	0.89	0.91	0.78	0.66	0.62			1.12
	Yb	0.82	0.78	0.87	0.75	0.93	0.86	0.66	0.65	0.96		1.04
	Lu	0.76	0.77	0.76	0.69	0.84	0.74	0.56	0.62	1.09		1.01
Refractory	W	0.93	2.08	0.58	0.43	2.49	1.51	2.57				1.10
	Zr	1.42	1.45	2.28	2.36	2.60	1.80	1.88	0.79			1.21
	Mo	0.76	0.90	0.13	0.10	0.89	0.67	1.69	0.61			0.96
	Ti	0.62	0.98	1.14	1.09	1.07	0.73	0.72	0.60	0.60		1.13
	Nb	1.16	1.52	1.83	1.14	1.63	1.13	0.95				1.18
	Cr	0.28	0.41	1.05	0.60	0.81	0.68	0.34	0.21	0.74		1.03
Volatile	Mn	0.06	0.23	0.54	0.34	0.95	0.47	0.43	0.14	0.65		0.99
	Ag	0.05	0.12	0.07	0.07	0.07	0.06	0.11	0.16			0.18
	Sb	0.25	0.64	0.94	0.23	0.17	0.18	0.59	4.59			0.43
	Na	0.05	0.04	0.08	0.04	0.13	0.07	0.20	0.05	0.79		1.02
	Rb	0.03	0.07	0.08	0.06	0.07	0.06	0.10	0.01			0.90
	Cs	0.02	0.05	0.09	0.03	0.04	0.05	0.05				0.97
	Zn	0.004	0.004	0.002	0.004	0.003	0.005	0.013	0.004	0.04		0.13
	Sn	0.15	0.18	0.33	0.44	0.15	0.05	0.12	1.66			0.23
	Cd	0.02	0.02	0.03	0.04	0.02	0.01	0.01				0.03

Table S1 (continued)

Description	Element	NWA 6043 (CR2)					Bulk Earth
		1-C2	2-C2	2-C4	CR Chondrule	CR Chondrite	
Rare Earth	La	1.00	1.00	1.00	1.00	1.00	1.00
	Ce	0.91	0.68	0.82	0.96	0.92	0.98
	Pr	0.92	0.76	0.80	0.96		0.98
	Nd	0.90	0.69	0.73	0.99	1.30	0.99
	Sm	0.97	0.63	0.74	0.99	1.16	0.97
	Eu	0.93	0.64	0.72	0.93	1.06	0.95
	Gd	1.16	0.66	0.82	0.95	1.21	0.99
	Tb	1.00	0.61	0.79	0.95	1.02	0.99
	Dy	1.11	0.57	0.75	0.94	0.85	0.97
	Ho	0.97	0.56	0.75	0.90	1.35	0.96
	Er	1.12	0.60	0.81	0.90		0.99
	Tm	0.89	0.52	0.81	0.96		0.97
	Yb	1.15	0.52	0.86	1.00	1.04	0.99
	Lu	0.95	0.52	0.74	0.94	0.97	0.97
Refractory	W	2.15	1.33	11.27	2.20	0.90	1.01
	Zr	2.63	2.99	0.05	0.89	1.05	0.98
	Mo	2.33	2.36	10.07	1.39	1.15	1.01
	Ti	1.28	0.15	1.12	0.95	0.93	0.98
	Nb	1.96	1.21	2.12	1.12	1.52	1.00
	Cr	0.96	0.22	0.02	1.01	0.98	0.93
Volatile	Mn	0.29	0.25	0.01	0.60	0.65	0.31
	Ag	0.09	0.14	0.20		0.36	0.13
	Sb	0.13	8.39	0.58		0.45	0.18
	Na	0.07	0.05	0.00	0.08	0.50	0.20
	Rb	0.02	0.05	0.05	0.26	0.36	0.12
	Cs	0.02	0.02	0.04		0.34	0.11
	Zn	0.001	0.010	0.000	0.06	0.24	0.06
	Sn	0.05	0.51	0.18		0.33	0.10
	Cd	0.01	0.05	0.03		0.33	0.10

Table S2. Lanthanum-normalized abundances and Mn/Na ratio for individual chondrules

Description	Element	<i>NWA 5697 (L3.10)</i>								L Chondrule	L Chondrite
		2-C1	5-C2	5-C10	D-C3	5-C4	3-C5	11-C2	3-C2		
Relative/O ₂	Mn/Na	0.5	2.2	2.7	3.3	2.9	2.5	0.8	1.2	0.3	0.4
Rare Earth	<i>La</i>	<i>1.00</i>	<i>1.00</i>	<i>1.00</i>	<i>1.00</i>	<i>1.00</i>	<i>1.00</i>	<i>1.00</i>	<i>1.00</i>	<i>1.00</i>	<i>1.00</i>
	Ce	2.49	2.11	2.59	2.45	2.43	2.39	2.82	2.44		3.05
	Pr	0.36	0.35	0.37	0.38	0.38	0.37	0.37	0.34		0.44
	Nd	1.79	1.76	1.61	1.72	1.63	1.65	1.76	1.65		2.20
	Sm	0.54	0.57	0.56	0.53	0.56	0.52	0.55	0.49	0.69	0.64
	Eu	0.21	0.21	0.20	0.21	0.22	0.22	0.18	0.21	0.19	0.25
	Gd	0.78	0.80	0.86	0.93	0.88	0.74	0.74	0.64		1.00
	Tb	0.14	0.13	0.15	0.16	0.16	0.13	0.12	0.11		0.19
	Dy	0.92	0.92	0.93	1.04	1.10	0.89	0.81	0.71		1.17
	Ho	0.19	0.20	0.22	0.21	0.21	0.20	0.15	0.15		0.28
	Er	0.58	0.58	0.62	0.68	0.65	0.57	0.49	0.44		0.79
	Tm	0.08	0.09	0.09	0.09	0.10	0.08	0.07	0.07		0.12
	Yb	0.56	0.53	0.59	0.51	0.63	0.59	0.45	0.44	0.65	0.71
Lu	0.08	0.08	0.08	0.07	0.09	0.08	0.06	0.07	0.12	0.11	
Refractory	W	0.37	0.82	0.23	0.17	0.99	0.60	1.02			0.43
	Zr	23.6	24.0	37.9	39.2	43.2	29.9	31.1	13.1		20.1
	Mo	2.97	3.51	0.51	0.41	3.49	2.64	6.60	2.37		3.77
	Ti	1168	1830	2136	2038	1994	1363	1341	1126	1116	2107
	Nb	1.23	1.61	1.94	1.21	1.74	1.20	1.01			1.26
	Cr	3159	4627	11827	6776	9119	7646	3783	2394	8378	11604
Volatile	Mn	513	1926	4461	2781	7832	3898	3586	1179	5374	8145
	Ag	0.05	0.10	0.06	0.06	0.06	0.05	0.09	0.14		0.16
	Sb	0.14	0.37	0.54	0.13	0.10	0.10	0.34	2.64		0.25
	Na	1002	862	1679	834	2684	1561	4231	1004	16805	21698
	Rb	0.27	0.72	0.79	0.58	0.72	0.63	0.98	0.07		8.81
	Cs	0.01	0.04	0.07	0.02	0.03	0.04	0.04	0.00		0.79
	Zn	4.82	6.02	3.15	5.91	4.64	6.18	16.99	5.94	47	179.25
	Sn	1.07	1.29	2.39	3.20	1.09	0.36	0.89	11.98		1.70
	Cd	0.06	0.07	0.09	0.13	0.04	0.02	0.04			0.09

Table S2 (continued)

Description	Element	<i>NWA 6043 (CR2)</i>			CR Chondrule	CR Chondrite	Bulk Earth
		1-C2	2-C2	2-C4			
Relative/ O_2	Mn/Na	1.5	1.9	1.5	3.1	0.5	0.6
Rare Earth	<i>La</i>	<i>1.00</i>	<i>1.00</i>	<i>1.00</i>	<i>1.00</i>	<i>1.00</i>	<i>1.00</i>
	Ce	2.40	1.80	2.17	2.54	2.42	2.59
	Pr	0.37	0.30	0.32	0.38		0.39
	Nd	1.75	1.34	1.43	1.93	2.55	1.93
	Sm	0.62	0.40	0.47	0.63	0.74	0.62
	Eu	0.22	0.15	0.17	0.23	0.26	0.23
	Gd	0.99	0.56	0.69	0.81	1.03	0.84
	Tb	0.16	0.10	0.12	0.15	0.16	0.16
	Dy	1.18	0.60	0.79	1.00	0.90	1.03
	Ho	0.23	0.13	0.18	0.22	0.32	0.23
	Er	0.77	0.41	0.55	0.61		0.68
	Tm	0.09	0.06	0.09	0.10		0.10
	Yb	0.78	0.35	0.59	0.68	0.71	0.68
Lu	0.10	0.06	0.08	0.10	0.10	0.10	
Refractory	W	0.85	0.53	4.46	0.87	0.35	0.40
	Zr	43.6	49.5	0.9	14.8	17.4	16.2
	Mo	9.14	9.26	39.41	5.43	4.52	3.93
	Ti	2398	282	2104	1780	1742	1841
	Nb	2.09	1.29	2.26	1.19	1.61	1.07
	Cr	10800	2470	238	11438	11016	10456
Volatile	Mn	2356	2084	64	4945	5355	2561
	Ag	0.08	0.12	0.17		0.31	0.11
	Sb	0.07	4.82	0.33		0.26	0.11
	Na	1556	1098	42	1618	10645	4292
	Rb	0.20	0.48	0.48	2.59	3.55	1.17
	Cs	0.01	0.01	0.03		0.27	0.09
	Zn	1.36	14.02	0.12	87	323	74.85
	Sn	0.40	3.72	1.32		2.35	0.75
	Cd	0.02	0.14	0.08		0.97	0.31

Table S3. Literature data and calculated Mn/Na ratios

Description	Element	CI	Bulk Earth	L3 Chondrule	L Chondrite	CR Chondrule	CR Chondrite
Relative fO_2	Mn/Na	0.4	0.6	0.3	0.4	3.1	0.5
Rare Earth	La	0.235	0.43	0.490	0.318	0.38	0.310
	Ce	0.62	1.11		0.970	0.97	0.750
	Pr	0.094	0.17		0.140	0.15	
	Nd	0.46	0.83		0.700	0.74	0.790
	Sm	0.15	0.26	0.340	0.203	0.24	0.230
	Eu	0.057	0.099	0.094	0.080	0.09	0.080
	Gd	0.2	0.36		0.317	0.31	0.320
	Tb	0.037	0.067		0.059	0.06	0.050
	Dy	0.25	0.44		0.372	0.39	0.280
	Ho	0.056	0.098		0.089	0.08	0.100
	Er	0.16	0.29		0.252	0.23	
	Tm	0.025	0.044		0.038	0.04	
	Yb	0.16	0.29	0.320	0.226	0.26	0.220
Lu	0.025	0.044	0.057	0.034	0.04	0.032	
Refractory	W	0.093	0.171		0.138	0.33	0.11
	Zr	3.9	6.9		6.4	5.68	5.4
	Mo	0.92	1.68		1.2	2.08	1.4
	Ti	440	787	547	670	683	540
	Nb	0.25	0.46		0.4	0.5	0.5
	Cr	2650	4470	4105	3690	4388	3415
Volatile	Mn	1940	1095	2633	2590	1897	1660
	Ag	0.200	0.048		0.05		0.095
	Sb	0.135	0.045		0.078		0.08
	Na	5000	1835	8235	6900	621	3300
	Rb	2.3	0.5		2.8	1.0	1.1
	Cs	0.19	0.038		0.25		0.084
	Zn	315	32	23	57	33	100
	Sn	1.7	0.32		0.54		0.73
	Cd	0.69	0.13		0.03		0.3

Bulk data for CI, L and CR chondrites from (1). Bulk Earth values averaged from (2, 3). L chondrite chondrule data from (4), except Ti (5). CR chondrite chondrule data from (6).

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