Geochemical Perspectives Letters

Olivines in main-group pallasites: magma-ocean cumulates or partial melting residues?

J.-A. Barrat, L. Ferrière

Supplementary Information

The Supplementary Information includes:

- Samples and Analytical Procedures
- Tables S-1 and S-2
- Estimation of the D_{Er}/D_{Lu} Ratio for Olivine
- Figure S-1
- Supplementary Information References

Samples and Analytical Procedures

We analysed 12 olivine fractions prepared from 6 main-group pallasites. Details of the meteorite samples used in this study are given in Table S-1. Olivines (typically 200–250 mg) were leached in 6 M HCl at 120 °C during one hour before dissolution in order to remove adhering traces of metal and phosphates. Samples were examined carefully under a binocular microsope, and no inclusions were observed. Samples were rinsed twice in ultrapure water and dried before weighing. They were digested by sequential mixtures of HF/HNO_3, HNO_3 and HCl. Elemental abundances were determined using a high-resolution inductively coupled plasma-mass spectrometer Thermo Element 2 at the Institut Universitaire Européen de la Mer (IUEM), Plouzané (France), following a well-established procedure (see *e.g.*, Barrat *et al.*, 2012). Rare earth elements (REEs) were separated and concentrated (Barrat *et al.*, 1996) in order to improve the quality of the analyses. Results using the same methodology on many international standards (BCR-2, BIR-1, WS-E, Allende USNM 3529, UB-N, PCC-1) have been repeatedly reported elsewhere (Barrat *et al.*, 2012, 2014, 2016). Based on standards and many sample duplicates, the precision for abundances and trace element ratios [*e.g.*, Er/Lu or Ce/Ce*, where Ce* is the expected Ce concentration for a smooth CI-normalised REE pattern, such that $Ce_n = (La_n \times Pr_n)^{1/2}$] are in most cases much better than 5 % [two relative standard deviations (2 x RSD)].

Table S-1 Details of meteorite samples investigated in this study.

	Sample provenance	Mass (g)	Remarks
Admire-A	J.A. Barrat	0.266	Dunite
Admire-B	J.A. Barrat	0.275	Olivine fragments
Brenham-A	D. Stimpson	0.292	Olivine
Brenham-B	D. Stimpson	0.257	Olivine
Brenham-C	D. Stimpson	0.369	Olivine
Brenham-D	D. Stimpson	0.235	Olivine
Brenham-E	D. Stimpson	0.248	Olivine
Brenham-F	D. Stimpson	0.322	Olivine
Brenham-G	D. Stimpson		Olivine, data from Greenwood *et al.* (2015) and Barrat *et al.* (2016)
Esquel	NHM Vienna, #2432	0.288	Olivine fragments
Finmarken	NHM Vienna, #2533	0.270	Olivine fragments
Fukang	J.A. Barrat	0.312	Olivine
Jepara	J.A. Barrat	0.285	Olivine fragments

Table S-2 Trace element abundances of olivines from MGP.

	Y	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Yb	Lu	Sc	Co	Ca	P
	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	µg/g	µg/g	µg/g	µg/g
Brenham																			
Brenham-A	7.8	149	8	14.08	1.45	5.07	0.88	0.21	0.98	0.14	0.95	0.23	0.828	1.75	0.461	0.70	5.49	33	17
Brenham-B	6.12	267	9.63	15.94	1.73	5.5	0.86	0.18	0.92	0.14	0.93	0.22	0.729	1.44	0.395	0.58	5.33	27	14
Brenham-C	0.25	2.97	0.22	0.31	0.025	0.08	0.013	<0.004	<0.017	<0.002	0.022	0.0102	0.096	1.19	0.47	0.70	115	62	64
Brenham-D	0.24	4.03	0.3	0.53	0.064	0.261	0.047	<0.01	<0.017	<0.002	0.0139	0.0083	0.108	1.8	0.73	0.77	9.25	53	16
Brenham-E	0.37	4.63	0.9	0.88	0.075	0.28	0.028	<0.01	<0.02	<0.005	0.0239	0.0094	0.089	1.15	0.428	0.68	35.89	43	35
Brenham-F	3.67	140	4.89	8.79	0.9	3.07	0.49	0.12	0.47	0.074	0.54	0.13	0.5	1.94	0.588	0.31	6.5	33	14
Brenham-G*	35.2	1122	51.4	91.6	11.2	38.3	6.5	1.29	6.09	0.96	6.03	1.3	3.9	4.6	0.782	0.47	5.5	N.D.	16
other pallasites																			
Admire-A (dunite)	0.14	16.80	0.099	0.24	0.026	0.11	0.023	<0.02	<0.04	<0.007	0.0238	0.0042	0.0167	0.137	0.054	1.04	5.49	44	4
Admire-B (olivine)	0.42	11.03	0.62	1.08	0.091	0.3	0.048	0.011	0.047	0.0059	0.047	0.0135	0.079	0.51	0.15	1.55	6.83	105	7
Esquel	6.26	245	8.33	24.59	1.73	6.85	1.13	0.21	1.04	0.16	0.97	0.22	0.74	1.68	0.56	1.66	8.07	193	15
Finmarken	1.75	N.D.	0.83	0.69	0.067	0.23	0.047	<0.02	<0.04	0.0093	0.111	0.055	0.396	2.04	0.591	1.27	7.66	281	23
Fukang	0.21	5.11	0.21	0.38	0.045	0.16	0.021	<0.01	<0.03	<0.006	0.0223	0.0067	0.038	0.393	0.156	2.16	11.35	135	11
Jepara	1.09	11.05	0.43	0.73	0.094	0.35	0.071	0.015	0.062	0.01	0.097	0.041	0.27	1.43	0.391	1.20	6.84	43	35
Jepara (dupl.)	1.13	11.35	0.44	0.72	0.091	0.35	0.066	0.017	0.067	0.0095	0.094	0.041	0.283	1.44	0.391	N.D.	N.D.	N.D.	N.D.
Standard																			
PCC1 (n=2)	86.15	825	31.76	61.29	7.55	28.33	5.33	1.09	6.11	1.15	9.32	2.71	11.05	21.95	4.51	8.09	101	3668	5

*Brenham-G corresponds to results previously published in Greenwood *et al.* (2015) and Barrat *et al.* (2016).
dupl. = duplicate (the same sample was analysed twice for replication purposes).
N.D. = not determined.

Estimation of the D_{Er}/D_{Lu} Ratio for Olivine

We used the experimental results obtained by Evans *et al*. (2008) to estimate the partition coefficient ratios for olivine. In a $\log(D_X/D_{Lu})$ vs. Ionic radius diagram (Fig. S-1), the mean values obtained are very well modelled using a Lagrangian (3rd order polynomial) regression, as shown by a correlation coefficient close to 1 (r = 0.9987). A D_{Er}/D_{Lu} ratio = 0.34 is obtained.

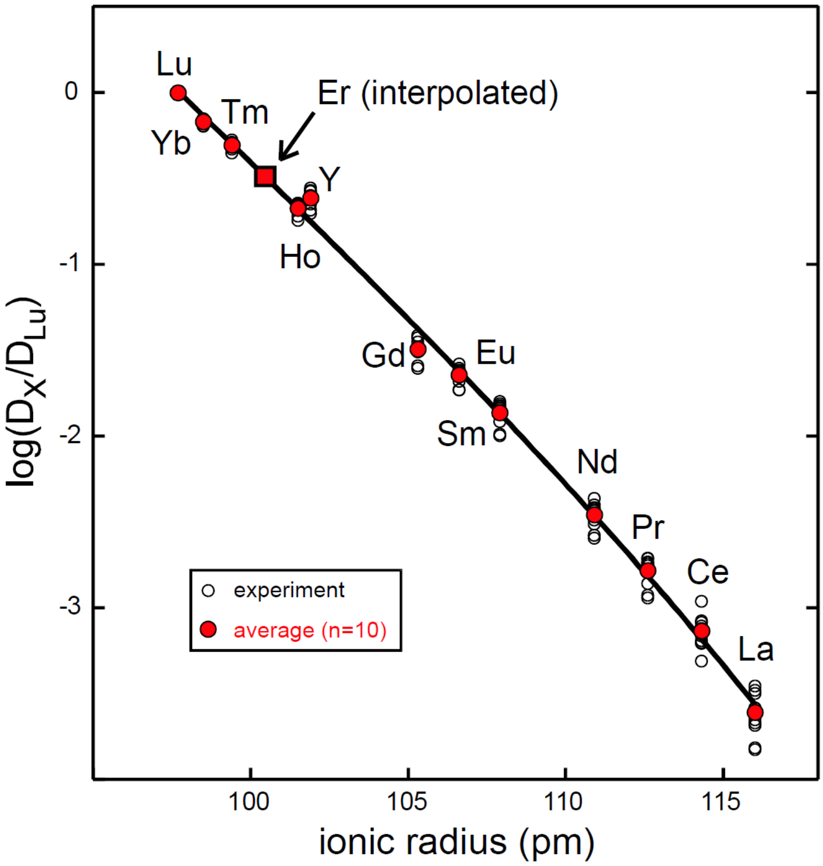

Figure S-1 $\text{Log}_{10}(D_X/D_{Lu})$ *vs*. ionic radius for the olivines based on experimental results obtained by Evans *et al*. (2008).

Supplementary Information References

Barrat, J.A., Keller, F., Amossé, J., Taylor, R.N., Nesbitt, R.W., Hirata, T. (1996) Determination of rare earth elements in sixteen silicate reference samples by ICP-MS after Tm addition and ion exchange separation. *Geostandards Newsletter* 20, 133–139.

Barrat, J.A., Zanda, B., Moynier, F., Bollinger, C., Liorzou, C., Bayon, G. (2012) Geochemistry of CI chondrites: Major and trace elements, and Cu and Zn isotopes. *Geochimica et Cosmochimica Acta* 83, 79–92.

Barrat, J.A., Zanda, B., Jambon, A., Bollinger, C. (2014) The lithophile trace elements in enstatite chondrites. *Geochimica et Cosmochimica Acta* 128, 71–94.

Barrat, J.A., Dauphas, N., Gillet, P., Bollinger, C., Etoubleau, J., Bischoff, A., Yamaguchi, A. (2016) Evidence from Tm anomalies for non-CI refractory lithophile element proportions in terrestrial planets and achondrites. *Geochimica et Cosmochimica Acta* 176, 1–17.

Evans, T.M., O'Neill, H.St.C., Tuff, J. (2008) The influence of melt composition on the partitioning of REEs, Y, Sc, Zr and Al between forsterite and melt in the system CMAS. *Geochimica et Cosmochimica Acta* 72, 5708–5721.

Greenwood, R.C., Barrat, J.A., Scott, E.R.D., Haack, H., Buchanan, P.C., Franchi, I.A., Yamaguchi, A., Johnson, D., Bevan, A.W.R., Burbine, T.H. (2015) Geochemistry and oxygen isotope composition of main-group pallasites and olivine-rich clasts in mesosiderites: Implications for the "Great Dunite Shortage" and HED-mesosiderite connection. *Geochimica et Cosmochimica Acta* 169, 115–136.