

**EXPERIMENTAL STUDY OF THE PARTITIONING OF SIDEROPHILE ELEMENTS IN A CRYSTALLIZING LUNAR MAGMA OCEAN.** M. Galenas<sup>1</sup>, Righter, K.<sup>2</sup>, Danielson, L.<sup>3</sup>, Pando, K.<sup>3</sup>, and Walker, R. J.<sup>1</sup>, <sup>1</sup>Department of Geology, University of Maryland, College Park, MD 20742. [mgalenas@umd.edu](mailto:mgalenas@umd.edu), <sup>2</sup>NASA Johnson Space Center, Mailcode KT, 2101 NASA Pkwy, Houston, TX 77058. <sup>3</sup>ESCG, Houston, TX 77058

**Introduction:** The distributions of trace elements between the lunar interior and pristine crustal rocks were controlled by the composition of starting materials, lunar core formation, and crystallization of the lunar magma ocean (LMO) [1]. This study focuses on the partitioning of highly siderophile elements (HSE) including Re, Os, Ir, Ru, Pt, Rh, Pd and Au as well as the moderately siderophile elements Mo and W, and the lithophile elements of Hf and Sr. Our experiments also include Ga, which can be slightly siderophile, but is mostly considered to be chalcophile. Partitioning of these elements is not well known at the conditions of a crystallizing LMO.

Previous studies of HSE partitioning in silicate systems have yielded highly variable results for differing oxygen fugacity ( $fO_2$ ) and pressure [2-4]. For example, under certain conditions Pt is compatible in clinopyroxene [2] and Rh and Ru are compatible in olivine [3]. The silicate compositions used for these experiments were nominally basaltic. Ruthenium, Rh, and Pd are incompatible in plagioclase under these conditions[4]. However, this latter study was done at extremely oxidizing conditions and at atmospheric pressure, possibly limiting the applicability for consideration of conditions of a crystallizing LMO.

In this study we address the effects of pressure and oxygen fugacity on the crystal/liquid partition coefficients of these trace elements. We are especially interested in the plagioclase/melt partition coefficients so that it may be possible to use reverse modeling to constrain the concentrations of these elements in the lunar mantle through their abundances in pristine crustal rocks.

**Samples:** For our experiments starting materials consisted of a synthetic silicate composition (from [5]) chosen to produce large crystals of anorthositic plagioclase. Several mixtures of trace elements were also included. Experiments 1-5 had 5 wt % Re, Os, Ir, Ru, Rh, Pd, Pt, and Au while experiments 6-9 had 2 wt % Ru, Pd, and Au and 2 wt % Mo, W, Ga, and Sr added. The trace element suite was modified in order to minimize HSE alloy nugget formation at experimental conditions.

**Experimental Methods:** Experiments were all conducted at NASA JSC using the 1 bar gas mixing and high pressure experimental petrology facilities. For our experiments  $fO_2$  has been varied at 1 bar and will eventually be varied at high pressures as well. The ef-

fect of pressure has been investigated using a piston cylinder press. Future work will extend the pressure range from 0.0001-4 GPa.

Experiments 1-5 were conducted at 1 in muffle tube furnaces at controlled  $fO_2$ . Experimental charges started at 1400°C, were cooled to 1160°C over 12 hours and held at 1160°C for 10 days. Oxygen fugacity was varied from QFM to IW+1. Experiments 6-9 were conducted in a Quickpress piston cylinder apparatus. Each sample was loaded into a graphite crucible. The pressures attained were 1 GPa (experiments 6, 7, and 9) and 1.5 GPa (experiment 8). Once pressurized we ramped the temperature to 1500°C, which was maintained for 20 minutes and cooled to the final temperature (see Table 1) of the run at a rate of 1°C/minute. Once the final temperature was reached the samples were maintained at that temperature for 1-2 days before being quenched. The oxygen fugacity of the graphite capsule runs is estimated to be ~QFM-2.

Experimental oxygen fugacity was higher than than in the natural setting of the Moon in these initial experiments to demonstrate feasibility due to the difficulties posed by low solubilities and possible interference from nuggets at low  $fO_2$ . We will work at progressively lower  $fO_2$ s as we compile results that are demonstrably free of these complications.

**Analytical Methods:** Major element compositions of the experimental charges have been determined using a *JEOL 8900* electron probe microanalyzer at the University of Maryland. Trace elements were measured using the *Element 2* inductively coupled plasma mass spectrometer (ICP-MS), also at the University of Maryland, coupled with a laser which can measure concentrations to sub-ppm levels. The laser spot size was ~40µm with a 7 Hz repetition rate. Raw data have been processed using the LAMTRACE program. The standards used in calculations were NIST 610 and Filomena.

**Results:** The atmospheric pressure experiments produced both glass and large, homogeneous crystals. Run conditions and phases produced are listed in Table 1. In some experiments (3 and 4) visible HSE alloy nuggets formed within mineral phases and the glass, making crystal/melt partition coefficients impossible to determine. The fifth experiment, at IW+1, yielded the most promising mineralogy, producing anorthite, orthopyroxene, and olivine; it is shown as a back scattered electron (BSE) image in Figure 1. The bright phases near the top of the image are alloys. HSE con-

centrations (Re, Pt, and Os) were substantially above detection limits in both the plagioclase and glass phases. These results suggest that some of these elements are weakly compatible in plagioclase at these  $fO_2$  conditions. However, it is possible that the high concentrations are due to the presence of micronuggets causing overestimation of partition coefficients.

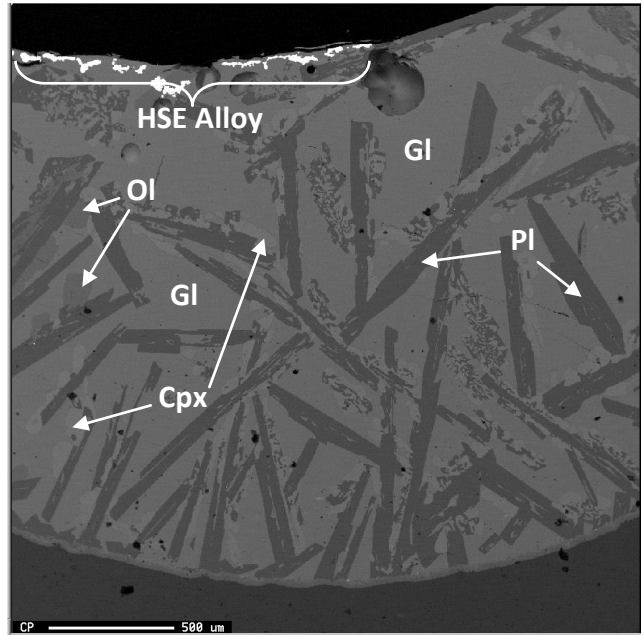
In the piston cylinder experiments we found plagioclase in only experiment 9 which had a final run temperature of 1125°C. The olivine, plagioclase, and spinels were compositionally homogenous in terms of major element composition. The pyroxenes appear to be homogenous in experiments 6 and 7 but in 8 and 9 there appear to be a zonation between orthopyroxene and clinopyroxene (Figure 2). Trace element concentrations have been measured for the piston cylinder experiments. Concentrations were lowest for the HSE elements in all phases. Olivine show measurable concentrations of all elements of interest. Concentrations of Hf, Mo, and Au were below the limit of detection in plagioclase. Gold was also below the limit of detection in glass in experiment 9. Pyroxenes in experiments 6, 8, and 9 had measurable concentrations of all the elements of interest while those in experiment 7 did not have measurable Au and Pd. We did see evidence of the presence of nuggets in anomalous spikes of HSE rich material within the phase being ablated.

To conclude Pd, Ru, and Au appear to be compatible in olivine and pyroxene while Re, Pt, Os, and Ru are possibly weakly compatible in plagioclase. However, more analyses must be done to ascertain the reproducibility of this partitioning behavior.

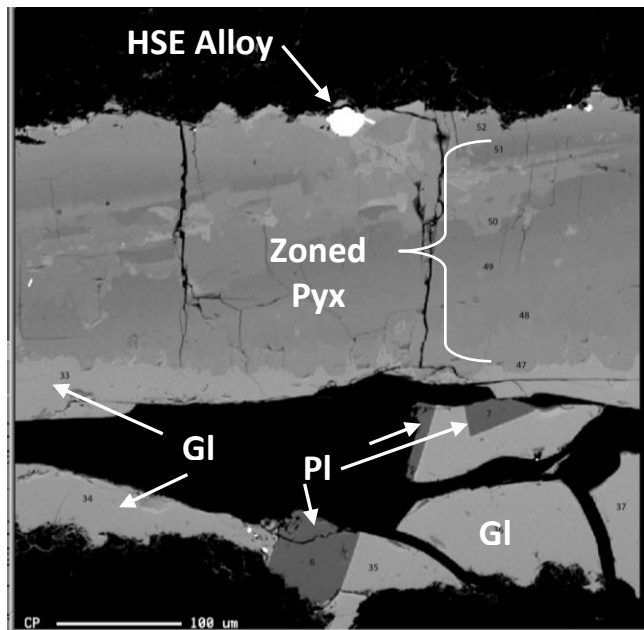
**References:** [1] Warren, P. (1985) *Ann. Rev. Earth Planet. Sci.* 13, 201-240. [2] Righter et al. (2004) *Geochim. Cosmochim. Acta.*, 68, 867-880. [3] Brenan et al. (2003) *Earth Planet. Sci. Lett.* 212 135– 150. [4] Capobianco, C. and Drake, M. (1991) *LPSC XXII*, Abstract #1089. [5] Longhi, J. (2003) *J. Geophys. Res.*, 108, 5083-5099.

**Table 1:** Experiment run conditions. Abbreviations for phases are gl-glass, pl-plagioclase, ol-olivine, sp-spinel, opx-orthopyroxene, cpx-clinopyroxene, pyx-both opx and cpx present.

Exp	T (°C)	P (GPa)	$fO_2$	Phases
1	1160	0.0001	IW+1	Gl,Pl,Ol, Sp
2	1160	0.0001	IW+1	Gl,Pl,Ol, Sp
3	1160	0.0001	QFM	Gl, Pl,Ol, Opx
4	1160	0.0001	QFM	Gl, Ol, Cpx,
5	1160	0.0001	IW+1	Gl,Pl,Ol,Opx
6	1200	1.0	QFM-2	Gl, Ol, Pyx
7	1150	1.0	QFM-2	Gl, Ol, Pyx
8	1150	1.5	QFM-2	Gl, Pyx, Sp
9	1125	1.0	QFM-2	Gl, Pl, Pyx



**Figure 1:** BSE image of experiment 5. Bright phases near top are HSE alloy nuggets. Plagioclase laths, clinopyroxene, and olivine are also present in a glass matrix.



**Figure 2:** BSE image of experiment 9. Phases present include plagioclase and zones of calcic and subcalcic pyroxene in a glass matrix.