

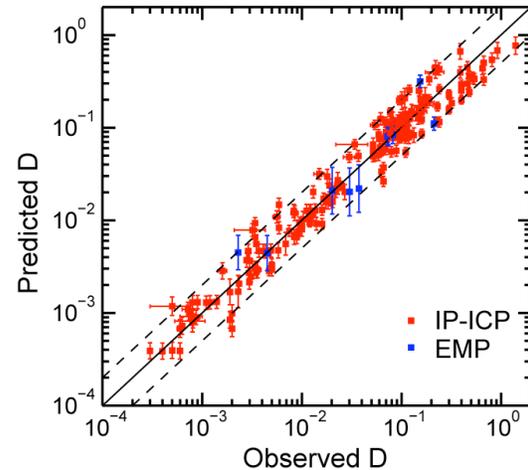
**SOME SPECULATIONS ON THE DISTRIBUTION OF REE BETWEEN ORTHOPYROXENE AND LUNAR PICRITIC GLASS MELTS AT MULTIPLE-SATURATION POINTS.** C. Sun, L. Yao, and Y. Liang, Department of Geological Sciences, Brown University, Providence, RI 02912 (Chenguang\_Sun@Brown.edu)

**Introduction:** Phase equilibrium studies have shown that lunar picritic glass melts are multiply saturated with olivine and orthopyroxene (opx) at 1.3~2.4 GPa and 1435~1560°C [1-5]. These multiple-saturation points in temperature-pressure space may represent minimum or average depth in a polybaric melting model [6]. Trace element and isotope characteristics of the mare basalts and picritic glasses suggest the importance of opx in their mantle sources [7-8]. Opx would have a great contribution for trace element fractionation during melting of cumulate sources, and is important to understanding the petrogenesis of mare basalts.

The trace element partition coefficient ( $D$ ) between mineral and melt is a function of pressure ( $P$ ), temperature ( $T$ ), and compositions of mineral and melt ( $X$ ) [9].  $D$  for REE ( $D_{\text{REE}}$ ) between clinopyroxene (cpx) and basaltic melts, for example, depends strongly on the  $\text{Al}_2\text{O}_3$  content in cpx [10]. As different mare basalts may have distinct cumulate mantle sources and melting paths, the  $P$ - $T$ - $X$  dependence of  $D_{\text{REE}}$  in opx could lead to markedly different interpretations of melt composition and melting process. In order to assess the variations of  $D_{\text{REE}}$  in opx during magma genesis in the lunar and terrestrial mantle, we have developed a parameterized model for  $D_{\text{REE}}$  in opx. As an example of lunar application in this study, we use our parameterized model to calculate  $D_{\text{REE}}$  in opx at selected multiple-saturation points of the picritic glass melts whose major element compositions were determined experimentally. We show that  $D_{\text{REE}}$  in opx varies by more than a factor of ten for various melt and opx compositions and need to be considered in future trace element modeling studies of lunar magma genesis.

**A Predictive Model:** REE and Y partition coefficients from a given opx-melt partitioning experiment can be quantitatively described by the lattice strain model [9]. We have analyzed published REE and Y partitioning data between opx and terrestrial basaltic melts, and parameterized key partitioning parameters in the lattice strain model ( $D_0$ ,  $r_0$  and  $E$ ) as functions of  $P$ ,  $T$  and  $X$ .  $D_0$  is found to positively correlate with Ca abundance in opx, and negatively correlate with temperature and Mg abundance in the M2 site ( $\text{Mg}^{\text{M2}}$ ) of opx.  $r_0$  is negatively correlated with Ca and positively correlated with  $\text{Mg}^{\text{M2}}$  in opx.  $E$  is positively correlated with  $r_0$ . Fig. 1 shows the excellent agreement between the predicted and the observed REE and Y partition coefficients between opx and terrestrial basaltic melt

from partitioning experiments reported in the literature and those measured in our laboratory.

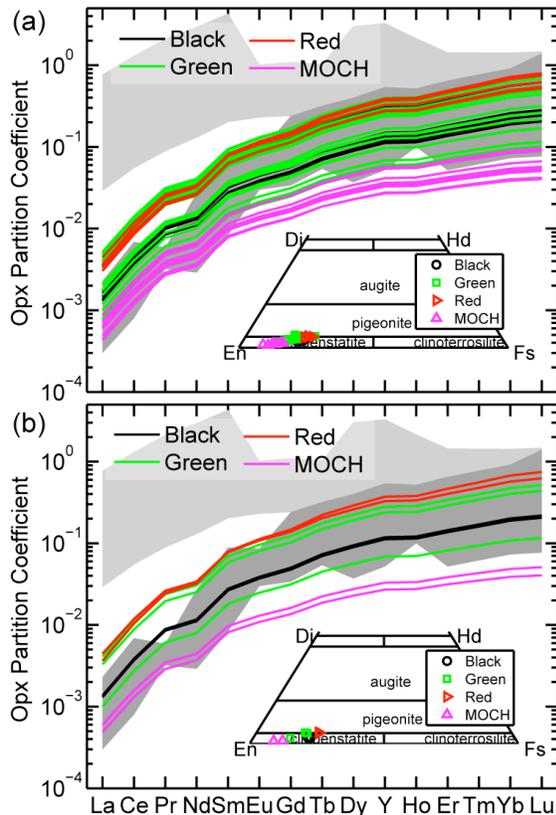


**Figure 1.** Predicted vs. observed  $D$  between opx and basaltic melt from partitioning experiments. *IP-ICP* represents data analyzed by ion probe and *LA-ICP-MS*, whereas *EMP* represents data analyzed by electron microprobe.

**Multiple-saturation Experiments** have been used to determine the phase relations of a primary magma: its depth of origin, temperature, and mineralogy of the source region [1-5, 11]. Multiple-saturation experiments indicate that low-Ti picritic glass melts are saturated with olivine + opx at 1.3~2.4 GPa and 1520~1560°C [4-5], whereas high-Ti picritic glass melts are saturated with olivine + opx at 1.5~2.4 GPa and 1435~1480 °C [1-3]. However, multiple-saturation points of high-Ti basalts may be difficult to interpret due to the possibility of ilmenite and/or armalcolite assimilation [11-12]. Nonetheless, multiple-saturation experiments can be used to estimate mineral and melt compositions relevant to lunar magma genesis.

**Predicted Opx D:** Given the opx composition,  $P$  and  $T$ , we can use our parameterized model to calculate  $D_{\text{REE}}$  in opx at multiple-saturation points. Fig. 2a shows predicted  $D_{\text{REE}}$  in opx for all opx from multiple-saturation experiments with different lunar glasses and a hybrid source [MOCH, 12], and Fig. 2b shows those for opx close to multiple-saturation points. For black glasses, the majority of  $D_{\text{REE}}$  in opx varies within a factor of two; for red glasses,  $D_{\text{REE}}$  in opx are greater than those from black glasses and vary within a factor of three; for green glasses,  $D_{\text{REE}}$  in opx have a larger variation (about a factor of ten); for MOCH,  $D_{\text{REE}}$  in opx are generally less than picritic glasses and vary within a factor of six. Opx from red glasses and some

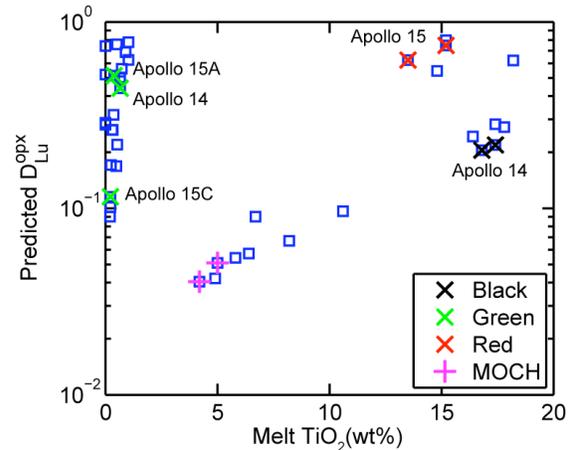
of green glasses have light REE less incompatible than the terrestrial samples, and opx from MOCH have mid and heavy REE more incompatible than the terrestrial ones. Note that opx close to multiple-saturation points of black glass, red glass and MOCH show distinct  $D_{REE}$  (Fig. 2b), but those from green glasses show two sets  $D_{REE}$  in opx, which corresponds to different multiple-saturation points [4-5]. It is evidence that opx saturated with picritic glass melts show a large range of  $D_{REE}$  suggesting that opx in the source of different picritic glasses may have distinct  $D_{REE}$ .



**Figure 2.** Predicted opx  $D$  for all opx from multiple saturation experiments (a) and predicted opx  $D$  only for those close to multiple-saturation points (b). Black, red, green and MOCH represent different starting compositions (black glass, red glass, green glass and MOCH, respectively). Light and dark shaded areas represent the ranges of cpx and opx  $D$  from partitioning experiments for terrestrial samples.

**Discussion:** To further investigate the variation of  $D_{REE}$  in opx, we plot  $D_{Lu}$  with  $TiO_2$  in the melt from multiple-saturation experiments (Fig. 3), and find two separate trends between  $D_{Lu}$  and  $TiO_2$  for low-Ti and high-Ti melts. Since  $D_{REE}$  in opx strongly depends on Ca content in opx, these two trends reflect the variation of CaO in opx with  $TiO_2$  in the melt. In general, opx  $D_{Lu}$  is positively correlated with  $TiO_2$  in the melt. A possible explanation for this is that Ti affects the melt structure, which in turn influences the trace element distribution

between mineral and mare basalts. In a companion study, we show that partition coefficients of high field strength elements (HFSE) in ilmenite decrease with the increase of  $TiO_2$  in the melt [13]. REE and HFSE, therefore, may be fractionated from each other during melting of an ilmenite-bearing harzburgite in the lunar cumulate mantle.



**Figure 3.** Predicted  $D_{Lu}$  in opx as a function of  $TiO_2$  content in the melt. Blue squares represent all opx from multiple-saturation experiments, and color crosses represent opx close to multiple-saturation points.

We should point out that our parameterized model is derived from partitioning experiments designed mostly for terrestrial composition, which are comparable to low-Ti mare basalt. Predicted  $D_{REE}$  between opx and high-Ti mare basalt are extrapolations and hence need further studies. The predicted  $D_{REE}$  also depends on opx composition from multiple-saturation experiments, which often have very short run durations. Mineral composition may not approach equilibrium, resulting in significant uncertainties of the estimation. Nonetheless, results from this preliminary study show that  $D_{REE}$  in opx may have large variations for different mare basalts at their multiple-saturation points, a prediction that needs to be further examined by laboratory partitioning studies. We suggest that Ti in the melt may have a significant effect on trace element distribution between mineral and mare basalts.

**References:** [1] Green et al. (1975) *LPSC*, 6, 871-893. [2] Delano (1980) *LPSC*, 11, 251-288. [3] Wagner and Grove (1997) *GCA*, 61, 1315-1327. [4] Elkins et al. (2000) *GCA*, 64, 2339-2350. [5] Elkins-Tanton et al. (2003) *Meteoritics & Planet. Sci.*, 38, 515-527. [6] Longhi (1992) *LPSC*, 22, 343-352. [7] Beard et al. (1998) *GCA*, 62, 525-544. [8] Shearer et al. (2006) *RMG*, 60, 365-518. [9] Blundy and Wood (1994) *Nature*, 372, 452-454. [10] Hill et al. (2000) *Lithos*, 53, 203-219. [11] Grove and Krawczynski (2009) *Elements*, 5, 29-34. [12] Singletary and Grove (2008) *EPSL*, 268, 182-189. [13] Dygert et al. (2011) *LPSC*, abstract, submitted.