# Experimental investigation of first-row transition elements partitioning between olivine and silicate melt: Implications for lunar basalt formation

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Fifteen experiments at 1 atm pressure and 1400 °C have been conducted to determine partition coefficients between olivine and silicate melt ($D^{\text{Ol-melt}}$) of the first-row transition elements (FRTE, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu and Zn), Ga and Ge in the system FeO-CaO-MgO-$Al_2O_3$-$SiO_2$ (FCMAS). Bulk iron contents are varied between 0 and 10 wt.% FeO, and oxygen fugacity ranges from 2 log units below the iron-wüstite buffer (IW-2) to 2 log units above the quartz-fayalite-magnetite buffer (QFM+2), covering a range of igneous processes involving olivine in terrestrial and lunar conditions. Results show that multi-valent Fe and V are redox-sensitive and more incompatible at oxidizing conditions, consistent with previous studies. The moderately volatile elements (Cu, Zn, Ga and Ge) become more volatile at reducing conditions. No correlation between partition coefficients and oxygen fugacity is observed for other multi-valent (Ti, Cr, Mn) and for homo-valent elements (Sc, Co and Ni). Most $D^{\text{Ol-melt}}$ show no sensitivity to bulk system iron contents, but $D_{\text{Cr}}^{\text{Ol-melt}}$ is significantly higher in our experiments compared to $D_{\text{Cr}}^{\text{Ol-melt}}$ derived from olivine-melt inclusion pairs in lunar samples with much higher FeO contents. $D_{\text{Ni}}^{\text{Ol-melt}}$ values are nearly constant at a range of oxygen fugacities above the IW buffer, but abruptly decrease when the system is iron metal saturated (below the IW buffer). As a result, $D_{\text{Co}}^{\text{Ol-melt}} / D_{\text{Ni}}^{\text{Ol-melt}}$ ratios that are constant (~0.3) at or above the IW buffer increase significantly (0.72-0.99) at IW-2. Using the newly derived partition coefficients, we re-assess two aspects of lunar basalt generation. First, we conclude that the Cr-rich nature of the olivines in lunar basalts compared to terrestrial basalts must be attributed to the Cr-nature of cumulate mantle source of lunar basalts, linked to the early crystallization of Cr-poor minerals olivine and orthopyroxene in the lunar magma ocean resulting in a shallow Cr-rich cumulates. Second, the higher Co/Ni ratios in olivine in high-titanium lunar basalts compared to olivine in low-titanium lunar basalts suggest the former were formed at more reducing conditions (below the IW buffer, saturated with metal).

Keywords: Olivine, Partition coefficients, Redox state, Lunar magma ocean