EGU22-1746
https://doi.org/10.5194/egusphere-egu22-1746
EGU General Assembly 2022

Crystallisation of the upper lunar magma ocean and implications for KREEP and crust formation

Weronika Ofierska, Max Schmidt, Paolo Sossi, and Christian Liebske
ETH Zürich, Institute of Geochemistry and Petrology, Department of Earth Science, Zürich, Switzerland

According to the canonical model, the Moon was formed in the aftermath of a giant impact, when the proto-Earth was struck by a Mars-size impactor leading to a debris disk from which the Moon accreted. This event is thought to have been sufficiently energetic to cause wholesale melting of the Moon. Solidification of the resulting Lunar Magma Ocean (LMO) involves plagioclase flotation and formation of an anorthositic crust that blankets the residual LMO. This crust may form directly through plagioclase flotation or involve more complex reprocessing mechanisms. Extensive fractional crystallization of the LMO likely led to formation of a residual KREEP component in the crust, enriched in K, REE, P and other incompatible elements relative to the bulk Moon, whose signature has been recognized in several lunar samples (e.g. feldspathic basalt).

The experimentally-constrained liquid lines of descent of a range of plausible LMO compositions bear strong resemblances to one another, crystallizing in the sequence olivine -> opx -> cpx + plagioclase -> quartz + Fe-Ti oxide. Crystallisation of olivine ± orthopyroxene prevails, depending on the composition, between 61-77 PCS (percent solidified), followed by the concomitant appearance of plagioclase + cpx at 1230±30 ^{o}C. Crystallisation of plagioclase marks the point at which the crystallisation sequences diverge owing to differences in bulk composition (e.g. refractory element content), which in turn influence phase saturation. Existing experiments on liquid lines of descent lack resolution, in particular at the point of quartz and Fe-Ti oxide saturation. Moreover, these experiments rarely proceed to the extent required to produce a KREEP component. In this work, we aim to more precisely determine the phase relations during crystallisation of the uppermost LMO, and assess possible mechanisms of formation of the KREEP component.

An isobaric series (8 - 5kbar) of six experiments on the bulk silicate Moon composition of O'Neill (1991) yields a crystallization sequence beginning at 1250 ^{o}C with olivine ± opx ± Cr-sp (69 PCS), followed by plagioclase and clinopyroxene at 1200 ^{o}C (77 PCS). Our mineral and melt major and trace-element abundances constrain the terminal stages of LMO crystallisation. Melt compositions remain near 45 wt% SiO_2 during the final crystallization stage while FeO increases from 12 wt% (bulk) to 20 wt% at plagioclase saturation. The Al_2O_3 and CaO budget is controlled by plagioclase crystallization (but not cpx) as the An# is as high as 97. We report mineral/melt partitioning coefficients for La, Ce, Nd, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Y, Zr, Th and U for plagioclase, pigeonite and high-Ca clinopyroxene and use the lattice strain model to evaluate these, also in the

context of literature data. These partition coefficients are therefore the most suitable for understanding the origin of the KREEP component.

Preliminary results suggest KREEP forms only after 99 PCS due to the evolved melt and the relatively rapid cooling rate of the surface magma ocean once crystal fraction is high. The last stage of eutectic crystallisation should lead to gabbroic rocks as the final crystallisation product.