

When the Moon gives you the KREEP – the residual lunar magma ocean and liquid immiscibility

WERONIKA OFIERSKA, MAX W. SCHMIDT, PAOLO A.
SOSSI AND CHRISTIAN LIEBSKE

ETH Zürich

Presenting Author: wofierska@ethz.ch

Solidification of the Lunar Magma Ocean (LMO) is the leading theory for producing the anorthositic highland crust that make up ~80 % of the Moon's surface. The crust exhibits a ubiquitous presence of a K, REE and P-enriched component (KREEP), which is thought to origin from the remains of the LMO. However, it remains uncertain whether this component was formed due to extended crystallization alone or whether other processes contributed, especially with evidence of liquid immiscibility present in lunar samples. To now, there is lack of crystal-liquid equilibria of the latest stages of the LMO and of trace element partitioning between their phases.

Here, we present an experimental study of phase equilibria during the latest stage of the LMO (from plagioclase crystallisation to the final remnants of liquid), complemented with trace element partitioning data. Based on these experiments, we discuss the extent and role of liquid immiscibility in producing KREEP-like trace element signatures.

We performed an isobaric series of experiments on the bulk silicate Moon with terrestrial refractory elements, but lower Mg-number (Mg#83). It starts at 1250°C, which corresponds to 74 percent solidification (PCS) and olivine ± orthopyroxene crystallization. The crust fractionation products are plagioclase and clinopyroxene at 1200°C (77 PCS), 7th step lead to final crystallization at 1000°C (99 PCS) with liquid immiscibility ± plagioclase ± pigeonite ± ilmenite ± quartz. P₂O₅, which widens the two liquid separation field, partitions into the basaltic melt whereas K₂O into the felsic melt. Thus, KREEP must have formed before any liquid immiscibility. Additionally, we report mineral/melt and melt/melt partitioning coefficients for lanthanide, Hf, Y, Zr, Th and U for plagioclase, pigeonite and high-Ca clinopyroxene. Subsequently, we use the lattice strain model to evaluate these, also in the context of literature data, to understand the origin of the KREEP component.

We conclude that the KREEP component can only be generated by extensive fractional crystallization of the LMO, but prior to liquid immiscibility. At 95 PCS the O'Neill bulk Silicate Moon reaches the solvus for two immiscible silicate melts, which segregate into a basaltic and a felsic component.