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Formation of lunar anorthosites through serial-like magmatism

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The lunar magma ocean (LMO) model, originally developed from studies of Apollo samples, remains a cornerstone for understanding the Moon's early differentiation. However, increasing evidence for compositional heterogeneity within the lunar crust challenges the classical view of an anorthositic crust formed solely by flotation of plagioclase from a globally homogeneous magma ocean.

We investigate the major- and trace-element compositions of plagioclase, pyroxene, olivine, and glass in the lunar polymictic feldspathic breccia NWA 13859. Olivine and pyroxene display a wide range of Mg# (42–91), contrasting with plagioclase narrow anorthite content (An95–98) and uniform REE concentrations. Melts calculated to be in equilibrium with plagioclase show correlated compatible elements (e.g., Sr and Ba) consistent with fractional crystallization, whereas decoupled incompatible element ratios (e.g., Th/Sm and Zr/Sm), together with plagioclase REE and major-element systematics, indicate the involvement of additional processes. Geochemical modelling indicates that the chemical variations of NWA 13859, and more broadly of lunar anorthosites, require an initial fractional crystallization of mantle-derived melts before either mixing with variably evolved LMO residual melts or assimilating their fractionated products.

We suggest that partial melts of KREEP-free LMO mantle cumulates produced by mantle overturn evolve through fractional crystallization before interacting with LMO residual melts or their fractionated products at crustal levels and generate lunar anorthosites. This hybrid scenario reconciles compositional, petrological, and geochemical constraints and supports a serial-like magmatism framework for the formation of lunar highlands anorthosites.

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