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Lunar Magma Ocean Crystallization: Constraints from Fractional Crystallization Experiments

J.F. RAPP[1] AND D.S. DRAPER[2]

[1]Jacobs, NASA Johnson Space Center, Houston, TX 77058
[2]NASA Johnson Space Center, Houston, TX 77058

The currently accepted paradigm of lunar formation is that of accretion from the ejecta of a giant impact, followed by crystallization of a global scale magma ocean. This model accounts for the formation of the anorthosite highlands crust, which is globally distributed and old, and the formation of the younger mare basalts which are derived from a source region that has experienced plagioclase extraction. Several attempts at modelling the crystallization of such a lunar magma ocean (LMO) [1,2] have been made, but our ever-increasing knowledge of the lunar samples and surface have raised as many questions as these models have answered. Geodynamic models of lunar accretion suggest that shortly following accretion the bulk of the lunar mass was hot, likely at least above the solidus [3]. Models of LMO crystallization that assume a deep magma ocean are therefore geodynamically favorable, but they have been difficult to reconcile with a thick plagioclase-rich crust. A refractory element enriched bulk composition, a shallow magma ocean, or a combination of the two have been suggested as a way to produce enough plagioclase to account for the assumed thickness of the crust. Recently however, geophysical data from the GRAIL mission have indicated that the lunar anorthositic crust is not as thick as was initially estimated [4], which allows for both a deeper magma ocean and a bulk composition more similar to the terrestrial upper mantle. We report on experimental simulations of the fractional crystallization of a deep (~1100km) LMO with a terrestrial upper mantle-like (LPUM) bulk composition [5]. Our experimental results will help to define the composition of the lunar crust and mantle cumulates, and allow us to consider important questions such as source regions of the mare basalts and Mg-suite, the role of mantle overturn after magma ocean crystallization and the nature of KREEP.

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