# Magmatic Evolution 1: Initial Differentiation.

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**Introduction:** The lunar samples retrieved by the Apollo 11 mission in 1969 provided the foundation for the magma ocean model for primordial differentiation of the Moon [1, 2]. Nearly 50 years later, this model remains the leading hypothesis describing the initial magmatic evolution of the Moon, including the formation of a widespread plagioclase-rich crust, the Eu-depleted mafic sources of lunar basalts, and urKREEP, the incompatible element enriched component. Over the past decade, testing of this hypothesis has continued, with investigations that focus on new meteorite samples or remote observations, as well as new experimental, geochemical, geophysical and chronological constraints on the timing of and key processes involved in the initial differentiation of the Moon. A central question of ongoing research continues to be whether the magma ocean remains the best model for early lunar history.

**Chapter Summary:** This chapter will review and synthesize recent advances on the following topics.

*New observations*. Anorthositic meteorites recently discovered and analyzed may represent further evidence for a global, extremely plagioclase rich crust with a potentially complex petrogenesis [e.g., 3]. Remote observations and compositional mapping may further reveal complexity in primordial and secondary crust [e.g., 4].

*Experimental constraints on magma ocean crystallization.* Experimental investigations have focused on evaluating the bulk composition and water content of the Moon, as well as crystallization mode, magma ocean depth and core size and composition [e.g., 5, 6]. The results of recent studies are also used to establish the potential crustal thickness that may result from magma ocean solidification, considering different processes of crystal segregation [e.g., 7].

*Geophysical and geochemical models of magma ocean crystallization.* Modeling has been employed to constrain the depth or thickness of crystallization products (crust, mantle, core), as well as the physical processes involved in crust formation, the parameters controlling overturn of magma ocean crystallization products and the timing of magma ocean solidification and cooling [e.g., 8, 9, 10].

*Chronological constraints on lunar differentiation.* Recent efforts have utilized refined analytical methods for measuring the ages of lunar crustal rocks and minerals, as well as determining model ages for the formation of lunar differentiation products including lunar basalt sources and urKREEP [e.g., 11, 12, 13]. Interpretation of lunar chronology is fundamentally linked to the magma ocean differentiation model derived from the combination of sample analyses, crystallization experiments and geophysical modeling.

**References:**

[1] Smith, J. V., *et al.* (1970) *Proc. A11 LSC* 1:897-925. [2] Wood, J. A., *et al.* (1970) *Proc. A11 LSC* 1:965-988. [3] Gross, J., *et al.* (2014) *EPSL* 388:318-328. [4] Yamamoto, S., *et al.* (2015) *JGR:Planets* 10.1002/2015JE004935. [5] Charlier, B., *et al.* (2015) *46th LPSC* Abstr. 1168. [6] Lin, Y. H., *et al.* (2016) *47th LPSC* Abstr. 1295. [7] Rapp, J. F. and Draper, D. S. (2016) *47th LPSC* Abstr. 2691. [8] Elkins-Tanton, L. T., *et al.* (2011) *EPSL* 304:326-336. [9] Steenstra, E. S., *et al.* (2016) *EPSL* 441:1-9. [10] Piskorz, J. and Stenvenson, D. J. (2014) *Icarus* 239: 238-243. [11] Borg, L. E., *et al.* (2011) *Nature* 477:70-73. [12] Gaffney, A. M. and Borg, L. E. (2014) *GCA* 140:227-240. [13] Nemchin, A., *et al.* (2009) *Nature Geo* 10.1038/NGEO417.

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