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Heterogeneous lunar crust formation

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The existence of the lunar highlands is the strongest evidence for the presence of a magma ocean after formation of the Moon. They are thought to have formed by flotation of anorthosite during crystallization of a global magma ocean and to be homogeneous over the lunar surface. This view is in agreement with other observations such as their old formation ages and the complementary Eu anomaly in mare basalts, providing a good working hypothesis for early lunar evolution [1]. However, recent geochemical analyses suggest that a more complex understanding of the differentiation of the Moon is required.

In particular, the formation ages of the Mg-suite rocks are an issue. They are intrusions in the anorthositic crust, and are therefore expected to be younger [2]. However, despite many studies, their formation age range remains comparable to that of highland rocks, which is in contradiction with the accepted sequence of events [2]. A way to solve this timing issue would be to consider variability in spatial origin for the different samples, and a non-uniform crystallization process.

In addition, geochemical analyses of anorthosites from lunar meteorites also suggest that multiple magma sources may have existed [3,4]. These meteorites may originate from a different portion of the crust than the Apollo samples and are therefore a good reminder for the necessity of a sample return mission from the lunar farside. Finally, remote sensing observation of the distribution of Mg# at the surface also suggests a longitudinal variability from Mg-rich anorthosite on the farside to a Fe-rich, more evolved crust, on the nearside [5].

An updated magma ocean crystallization model is therefore required in order to incorporate these new constraints. As the crystallization of the magma ocean sets the stage for potential overturn, heat sources emplacement and more generally sets the initial conditions for the subsequent, long-term evolution, we can expect any new understanding of magma ocean evolution to also have implications for many other lunar evolution models.

In this presentation I will review some recent constraints on magma ocean crystallization and present modelling work that takes into account differential cooling between hemispheres. I will show which conditions are required in order to explain the chemical heterogeneities and discuss implications for formation ages and global heat sources distribution.

[1] Warren (1985), Annu. Rev. Earth. Planet. Sci., [2] Borg et al. (2017) LPSC #1075, [3] Gross, Treiman & Mercer (2014), Earth Planet. Sci. Lett. [4] Russell, et al. (2014), Phil. Trans. R. Soc. A. [5] Ohtake, et al. (2012), Nat. Geosci..