Chronology of the Lunar Magma Ocean

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The concept of the Lunar Magma Ocean (LMO) differentiation is central to the interpretation of all available lunar samples. It suggests stratification of lunar mantle, formation of lunar crust composed of Ferroan Anorthosite (FAN) by plagioclase flotation and evolution towards the residual liquid enriched in incompatible elements, producing the KREEP (high K, REE and P) reservoir. The LMO model is used to explain all subsequent magmatic activity on the Moon that includes both plutonic rocks and Mare basalts.

While the basic principles of the model were developed immediately after the delivery of lunar samples by the Apollo missions, timing and duration of this major differentiation process on the Moon remains uncertain. Recent Nd, Hf and Pb isotope data obtained for both Mare basalts and KREEP-rich rocks indicate a major differentiation event on the Moon at about 4.36-4.38 Ga [1, 2, 3]. However, the significance of this event is interpreted in different ways. Some studies argue that Nd and Hf model ages concentrated around 4.36-4.38 Ga combined with a 4360±3 Ma age of FAN sample 60025 [4] indicate fast LMO crystallisation near this time [1, 2] and, as a consequence, late formation of the LMO and the Moon almost 200 million years after the first condensation in the Solar System. Other studies suggest that the highly radiogenic nature of lunar Pb requires extended evolution in a high-μ ($^{238}U/^{204}Pb$) reservoir and therefore that the 4.36-4.38 Ga event represents KREEP separation during the last stages of the LMO crystallisation [3], while the complete process of the LMO solidification was longer than just a few tens of million of years.

The currently available information is not sufficient to resolve the existing controversy. The fast LMO crystallisation assumes that investigated samples represent a sufficent range of stages in the LMO solidification from early to late differentiates, although it is possible that only last 15-25% residual LMO melt fractions are represented by the existing sample collections. On the other hand Pb evolution models of the LMO are heavily dependent on the assumptions about U and Pb partitioning between the solid products of crystallisation and the residual melt.

[1] McLeod et al. (2014) *EPSL* **396**, 179–189; [2] Gaffney & Borg (2014) *GCA,* **73**, 514-527; [3] Snape et al. (2016) *EPSL* **451**, 149–158; [4] Borg et al. (2011), *Nature* **477**, 70-72.