# The lunar magma ocean hypothesis under siege

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In the absence of plate tectonics, geochemical signatures of lunar rocks may directly provide insights into early differentiation processes on the Moon. The concept of a global lunar magma ocean (LMO) is the most accepted hypothesis explaining lunar silicate differentiation. A key challenge to this concept is that LMO crystallization (e.g., [1]) and Sr-Nd isotopic closure of lunar crustal rocks, also including anorthosites that formed as LMO flotation cumulates, may postdate Moon formation by up to 150 Myr.

In support of the LMO hypothesis, a multitude of studies found that primary LMO cumulates can well explain compositions of low- and high-Ti mare basalts, for instance their characteristic trace element and radiogenic Nd and Hf isotope compositions (e.g. [1-3]). Further, the highly fractionated U/W and Th/W in KREEP (the residual LMO liquid), indicate that W was less incompatible than on Earth, a vestige of the much more reducing nature of the Moon [3].

Here we discuss our recent findings and potential end member scenarios that may reconcile the pros and cons of the LMO hypothesis. Either 1) the Moon is younger than previously thought, 2) the LMO was no global lunar feature and the accessible lunar samples provide a biased and incomplete picture, 3) tidal heating by the early Earth and cumulate overturn significantly prolonged LMO crystallization, or 4) KREEP formation, the $^{146}$Sm-$^{142}$Nd mantle isochron, and anorthosite ages do not date LMO solidification but instead reflect a young, global thermal perturbation that did not erase the elemental properties of previously formed LMO products. Possibly, the recently discovered small $^{182}$W excesses in lunar rocks [4] and excesses and deficits in $^{182}$W abundances in old terrestrial rocks [5] may place the Moon-forming giant impact event within the first 60 Myr of solar system history, when $^{182}$Hf was still extant, thus excluding scenario 1).

[1] Sprung et al. (2013) *EPSL* **380**, 77-87. [2] Münker (2010) *GCA* **74**, 7340-7361. [3] Fonseca et al. (2014) *EPSL* **404**, 1-13. [4] Kruijer et al. (in press) *Nature*. [5] Walker et al. (2015) *LPSC* abstract 1857.