Cooling, Crystallization and Overturn of the Lunar Mantle

SCHWINGER, S.*[1], NIKOLAOU, A.[1,2], PLESA, A.-C.[1], BREUER, D.[1]

[1]German Aerospace Center (DLR), Berlin
[2]Technical University of Berlin, dpt. Astronomy and Astrophysics
*correspondence: Sabrina.Schwinger@dlr.de

The chemistry and mineralogy of lunar rocks retrieved in the Apollo missions suggests that a global lunar magma ocean (LMO) existed in the early history of the moon [1,2]. Fractional crystallization of the LMO results in the formation of a compositionally layered lunar mantle within which the material density decreases with depth [3]. Since this density distribution is gravitationally unstable, the mantle layers tend to overturn towards a stable configuration by solid state convection. The degree to which the mantle is able to perform this overturn depends on the solid state viscosity of the material and thus on the thermal evolution of the lunar mantle.

We simulate the thermochemical evolution of the lunar mantle by combining models of LMO cooling, fractional crystallization and solid-state convection of the lunar mantle in order to evaluate the degree of lunar mantle overturn and the resulting compositional structure of the lunar mantle.

LMO cooling rates are determined using a 1D convection model that considers outgassing of the LMO and the potential blanketing effect of an early atmosphere. Fractional crystallization of the LMO is modeled using the software alphaMELTS [4,5,6]. Solid phases crystallizing in the LMO are assumed either to sink to the bottom, float to the top or remain in suspension, depending on their density relative to the density of the coexisting melt. The formation of primordial lunar crust on top of the LMO by floatation of plagioclase leads to thermal isolation of the LMO and thus to significantly slower cooling of the LMO and the underlying mantle. The combination of the LMO cooling and crystallization models allows us to determine the timing of crust formation and the accompanying change in the LMO cooling rate. Solid state convection of the lunar mantle that forms gradually from LMO cumulates is modeled using the solid state convection code GAIA [7].

This combined modeling approach allows us to evaluate the degree of lunar mantle overturn for a range of possible LMO depths and compositions and the resulting chemical stratification of the source regions of secondary lunar magmatism.

[1] Smith et al. (1970) *Proc. Apollo 11 Lunar Sci. Conf. 1*, 897–925. [2] Wood et al. (1970) *Proc. Apollo 11 Lunar Sci. Conf.* 965–988. [3] Elkins-Tanton et al. (2011) *EPSL* 304 326–336. [4] Smith and Asimow (2005) *G^3* 6 (2). [5] Ghiorso and Sack (1995) *Contr. Mineral. and Petrol.* 119, 197-212. [6] Ghiorso et al. (2002) *G^3* 3 (5), 1–35. [7] Hüttig et al. (2013) *Phys. Earth Planet. Inter.* 220, 11-18.