CHALLENGES IN MODELING MELTING PROCESSES IN GEODYNAMIC MODELS OF THE LUNAR MANTLE

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The early Moon was covered by a global magma ocean that is assumed to have undergone fractional solidification during cooling - as evidenced by the anorthositic crust. With complete fractionation of the lunar magma ocean (LMO), the solid mantle consists of layers with different compositions, densities, and melting temperatures. After solidification, the layers mix due to solid-state convection, meanwhile some of the mantle material melts and rises to the surface. The melted material is the origin of the secondary crust, which consists of Mg suite rocks and the mare basalts that are still found on the lunar surface. The amount and timing of secondary melt production can therefore be used to constrain the modeling of melting processes in the lunar mantle and improve our understanding of the magmatic evolution of the Moon.

The temporal evolution of crust formation has been studied in previous work by e.g. Laneuville et al. (2013) and Zhao et al. (2019). The former neglect the formation of a fractionated mantle and assume a simple homogeneous mantle composition - those models typically overestimate the amount of secondary crust. Zhao et al. (2019), in turn, used the layered mantle structure of Snyder et al. (1992). Here, the layers differ in density and concentration of heat-producing elements. This latter study only considers the melting of ilmenite bearing cumulates (IBC), which crystallize below the crust during the last stage of magma ocean solidification.

In the present work we investigate the formation of the secondary crust in more detail. For this purpose, we consider individual melting temperatures for all cumulate layers and the latent heat consumption during melting. Furthermore, we consider the change in solidus and density of the remaining mantle material as melt is extracted to form the crust. The amount of melt produced is currently assumed to be a linear interpolation between solidus and liquidus - an approach often used in thermochemical evolution models. We discuss this simplified approach, and also show that it is a poor approximation due to the non-modal melting of the material. We track the timing and amount of melting that occurs throughout lunar evolution and compare it to constraints based on our knowledge of Mg-suite rocks and mare basalts.

In our model, we use the layered lunar mantle according to the magma-ocean solidification model presented in Schwinger & Breuer (2022) and assume that no material is mixed during solidification. The complex stratification can be approximated by 5 main layers: above the core-mantle boundary there is a layer that is almost pure olivine, then one dominated by orthopyroxene, above that a mixture with mainly clinopyroxene, and a layer formed by ilmenite-bearing accumulations and KREEP material below the anorthositic crust. We use the mantle convection code GAIA (Hüttig 2013) to model the thermochemical evolution of this layered structure of the lunar mantle. We use an Arrhenius law to calculate the depth- and temperature-dependent viscosity and account for core cooling and radioactive decay. Solid-state convection in the lunar mantle leads to mixing of the different layers. The mixing of the layers, and thus the change in mantle composition, is tracked using a particle-in-cell method (Plesa et al. 2013), where the tracer particles contain important information such as composition, density, mantle depletion, and melting temperatures.

Preliminary results indicate that the early formation of Mg-suite rocks requires the onset of mantle convection prior to complete solidification of the LMO. To explain the long-lived volcanism, visible in the Mare basalts, further model modifications are required, such as the use of the non-linear melting approach, but also the consideration of a primitive mantle below the crystallized magma ocean.

Literature:
Laneuville M. et al. (2013) JGR Planets; Zhao Y. et al. (2019) EPSL; Schwinger S. and Breuer D. (2021) PEPI; Hüttig C. et al. (2013) PEPI; Plesa A.C. et al. (2013) IGI Global;