Numerical convection modelling of a compositionally stratified lunar mantle

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Convection modelling of the lunar interior is generally done in simplified models with either a homogeneous composition or only one compositionally distinct layer, depending on the focus of the study (e.g. [1, 2, 3, 4]). When such a compositionally distinct and relatively dense layer is used, the focus is typically on the overturn of the lunar mantle, due to the gravitational instability which originated from the crystallisation of an early lunar magma ocean.

It is generally assumed that the Moon accreted as a hot planetary body (independent of which process led to Moon formation). The Moon then consisted of a global magma ocean, which crystallised upon cooling. Calculations on this crystallisation process show that the result was a layered mantle, covered by a plagioclase flotation crust. The last material to crystallise at shallow depth below this crust was a layer rich in high density ilmenite ($FeTiO_3$)[5]. The high density ilmenite-rich layer at shallow depth was gravitationally unstable and this likely resulted in an overturn of the lunar mantle.

The dense ilmenite-rich layer, which crystallised at shallow depth beneath the crust, has been included when modelling the formation of the ilmenite-rich basalts found at the lunar surface[6] or to study the possible formation of an ilmenite-rich core in the lunar interior[3]. However, the compositional layering in the mantle below the ilmenite-rich layer is usually neglected and a constant background composition is used in the modelling instead. The deeper layering is likely to at least influence the timing of the overturn, but also the general dynamics. Therefore, this study investigates the influence of a more realistic mantle stratification on the overturn of the lunar mantle, using multi-component thermo-chemical convection models.

Thermo-chemical convection models were performed, using a 360 degree cylindrical finite element mesh. The convection equations for an incompressible, infinite Prandtl number fluid were solved using an extended Boussinesq approximation, which includes both viscous dissipation and adiabatic heating. Composition is described using tracer particles, advected by the flow. The initial setup consist of compositional layering as originates from a crystallising magma ocean. The density and the number of layers is varied to study the influence on both thermal and chemical mantle evolution.

These models show that the more detailed initial layering influences the timing and dynamics of lunar mantle overturn and associated basalt production. A clinopyroxene, pigeonite and olivine layer below the ilmenite-rich layer, with a density which is slightly higher than the densities of the mantle layers below, results in a significantly earlier overturn compared to a model containing only the ilmenite-rich layer.

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