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Numerical convection modelling of a compositionally stratified lunar mantle

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Abstract

Full Moon convection models of lunar interior evolution are usually simplified in their compositional setup. They are often purely thermal convection-diffusion models, using a homogeneous mantle composition and a heat reservoir to model the core[1, 2]. Other models, mostly focussing on the role of ilmenite-rich rocks in the formation of lunar basalts and/or a lunar core, add only the ilmenite-rich layer at shallow depth[3, 4].

In this study, we develop models containing several compositions. The initial configuration of our models has a layered composition, to determine the influence of a more realisitic mantle stratification on mantle dynamics and the thermal evolution of the Moon.

1. Introduction

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, 4, 5]).

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.

1.1. Lunar Magma Ocean crystallisation

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 ($FeTiO_3$)[6]. Figure 1 schematically shows this layering due to magma ocean crystallisation. The high density ilmenite-rich layer at shallow depth was gravitationally unstable and this likely resulted in an overturn of the lunar mantle.

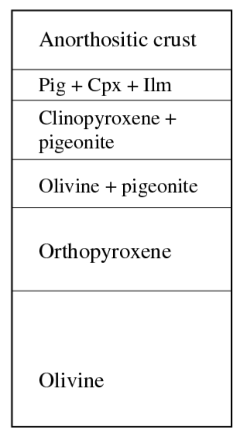


Figure 1: Layered mantle, resulting from the crystallisation of the Lunar Magma Ocean. Used as initial setup for the layered convection models. (After Snyder et al. [6])

1.2. Ilmenite and mantle overturn

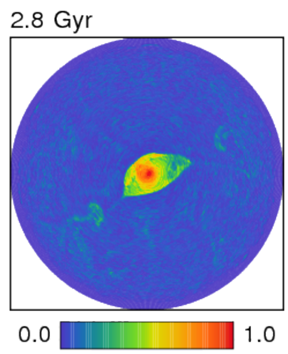
The dense ilmenite-rich layer, which crystallised at shallow depth beneath the crust, has been included when modelling the formation of the ilmenite-rich basalts found at the lunar surface[3] or to study the possible formation of an ilmenite-rich core in the lunar interior[4].

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.

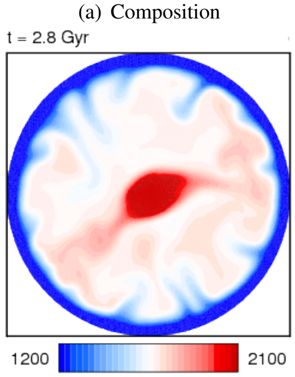
2. Modelling

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.

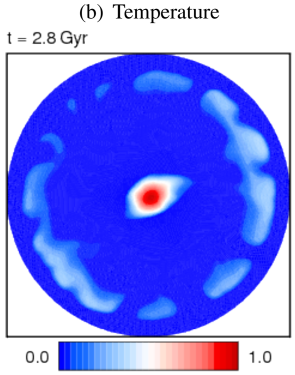
The initial setup consist of layering as originates from a crystallising magma ocean (Figure 1). The density and the thickness of the layers is varied to study the influence on both thermal and chemical mantle evolution. Figure 2 shows preliminary results of the formation of a small core due to the gravitational instability of the dense ilmenite-rich layer.



(a) Composition



(b) Temperature



(c) Percentage melt

Figure 2: Preliminary results, after [4]

3. Summary and Conclusions

Thermo-chemical convection models of the lunar interior have been performed, using a multi-component setup. This improvement over models with only one compositional degree of freedom allows for including a more realistic parametrisation of the physical properties of the different mineral components that resulted from fractional crystallisation of the early lunar magma ocean. The more realistic initial layering influences the timing and dynamics of lunar mantle overturn and associated basalt production.

Acknowledgements

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