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Early evolution and dynamics of Earth from a molten initial stage

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Abstract

It is now well established that most of the terrestrial planets underwent a magma ocean stage during their accretion. On Earth, it is probable that at the end of accretion, giant impacts like the hypothesised Moon-forming impact, together with other sources of heat such as conversion of gravitational energy of formation into heat, radioactive decay, heat losses from the core at the core-mantle boundary, electromagnetic induction heating and tidal heating, melted a substantial part of the mantle. The thermal and chemical evolution of the resulting magma ocean most certainly had dramatic consequences on the history of the planet, influencing the chemical composition of the mantle after differentiation, the style of tectonic regime prevailing in the solid-state mantle and its habitability.

Considerable research has been done on magma oceans using 1-D models [1], [5], [3]. However, its dynamics, evolution from a molten state to the present day solid state, and crystallisation are still not fully understood and are more complex than a 1-D formulation. Recent advances in computational methods and resources allow us to address numerically more complex problems, with higher resolution and multiple physics incorporated. Moreover, new developments in mineral physics that indicate that melt can be denser than solid at high pressures [2] can have very important impacts on the classical views of the solidification of magma oceans [4].

The goal of our study is to understand and characterize the influence of melting on the long-term thermo-chemical evolution of rocky planet interiors, starting from an initial molten state (magma ocean). Our approach is to model viscous creep of the solid mantle, while parameterizing processes that involve melt. We will be testing existing published 1-D parameterisations of magma ocean dynamics and extending them into 2-D models. To address this problem, the numerical code StagYY [6] is used. Some details about this code are the following: it uses a finite-volume scheme for advection of temperature, a multigrid solver to obtain a velocity-pressure solution at each timestep, tracers to track composition, and a treatment of partial melting and crustal formation. Enhancements in the code related to the physics and parameterisation of melting have been implemented, however additional improvements are still needed.

We will be showing our most recent results for the evolution of an Earth-like planet from a molten initial state, while testing different scenarios and addressing the implications that a magma ocean may have had on the history of the planet.

References

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