Double-Diffusive Layering after Magma-Ocean Crystallization

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The dynamical evolution of the Earth and other planetary bodies and their chemical differentiation are crucially dependent on the initial conditions and the resulting dominant internal convective processes. But even with today's computational techniques and power the understanding of how the planet's accessible observations (magnetic field, inner core, presence / absence of plate tectonics, geochemical signature of crustal material) are linked to its dynamical history is still incomplete.

A simple but plausible physical model, resembling a planet, shortly after core formation, consists of a compositionally stratified mantle, resulting from magma ocean crystallization. This early mantle is subjected to heating from below by the newly formed core and cooling from the top through the atmosphere.

In a series of numerical experiments, spanning a wide parameter range and different geometries (2D/ 3D Cartesian, 2D spherical annulus), we have explored such scenarios with respect to the thermal and dynamical evolution. The models typically include a strongly temperature dependent viscosity, combined with pressure-dependence.

We observe double-diffusive instabilities to generate distinct convective layers of virtual uniform composition and temperature, separated by sharp diffusive interfaces. This layering strongly controls the heat loss from the core and decouples the dynamics in the lower mantle from the upper part. As evolution proceeds layers typically merge and break down leading to episodic variations in the heat flow and the mixing properties of the flow.

Altogether an evolution emerges which is characterized by continuous but also spontaneous changes in the mantle structure, ranging from multiple to single layer flow. This evolutionary path of planetary mantle convection allows to interpret phenomena like stagnation of slabs at various depth or variations in the chemical signature of mantle upwellings in a new framework.