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Multiphase Dynamics of Magma Oceans

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Since the earliest study of the Apollo lunar samples, the magma ocean hypothesis has received increasing consideration for explaining the early evolution of terrestrial planets. Giant impacts seem to be able to melt significantly large planets at the end of their accretion. The evolution of the resulting magma ocean would set the initial conditions (thermal and compositionnal structure) for subsequent long-term solid-state planet dynamics. However, magma ocean dynamics remains poorly understood.

The major challenge relies on understanding interactions between the physical properties of materials (e.g., viscosity (at liquid or solid state), buoyancy) and the complex dynamics of an extremely vigorously convecting system. Such complexities might be neglected in cases where liquidus/adiabat interactions and density stratification leads to stable situations. However, interesting possibilities arise when exploring magma ocean dynamics in other regime. In the case of the Earth, recent studies have shown that the liquidus might intersect the adiabat at mid-mantle depth and/or that solids might be buoyant at deep mantle conditions. These results require the consideration of more sophisticated scenarios. For instance, how does bottom-up crystallization look with buoyant crystals?

To understand this complex dynamics, we develop a multiphase phase numerical code that can handle simultaneously phase change, the convection in each phase and in the slurry, as well as the compaction or decompaction of the two phases. Although our code can only run in a limited parameter range (Rayleigh number, viscosity contrast between phases, Prandlt number), it provides a rich dynamics that illustrates what could have happened. For a given liquidus/adiabat configuration and density contrast between melt and solid, we explore magma ocean scenarios by varying the relative timescales of three first order processes: solid-liquid separation, thermo-chemical convective motions and magma ocean cooling.