Separation styles of liquid phase in a convecting solid mantle

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In studying evolution of planetary interiors, separation of liquid phase in mantle is one of the essential processes. In rocky mantle of terrestrial planets, this process is related to magma migrations in crust and mantle, and water rising at subduction zones. It is important to know how the separation of liquid phase proceeds, and how the background solid convection is affected by the flow of liquid phase.
Here we treat a simple setting for liquid phase separation in a convecting solid mantle. We do not include melting and solidification of the liquid phase as a first step. In this model, migration of liquid phase is modeled as a permeable flow. Density of the liquid phase is set to be slightly lighter than the surrounding solid phase. When the relative motion between the liquid and solid phases occurs, the porosity changes and the permeability at that volume is reduced or increased. There are two parameters controlling the flow in this system, those are, Rayleigh number (Ra) for the convection of solid phase, and the initial non-dimensional permeability (M) for the permeable flow of the liquid phase. We compared the timescale of separation at wide ranges of Ra and M. The geometry is a 3D rectangular cell or a quasi-2D box.
We identified that the styles of separation can be categorized into four cases; (a) rapid separation, (b) gradual separation, (c) slight separation, and (d) no separation. When the M is very large, the liquid phase rises with a high velocity. Consequently separation proceeds within a very short time independent on the convective flow of the solid phase (a: rapid separation). When the M is very small, separation does not occur and the convection of the solid phase proceeds including liquid phase in it (d: no separation). Two styles are recognized between these two extremes. In (b: gradual separation), the liquid phase gradually separates at upwelling regions of the solid phase convection. If the background solid convection is time dependent, the liquid phase of the entire system is efficiently removed to the surface. In (c: slight separation), the distribution of liquid phase is slightly evolved from the initial uniform state, but a balance between separation and entrainment of liquid phase is achieved and no further separation proceeds. We established a regime diagram of the styles of separation on the space of Ra and M. Convection of solid phase delays separations of liquid phase. The differences among styles are understood well by a competition between two velocities, permeable flow velocity and convection velocity of solid phase.

Keywords: mantle convection, separation of liquid phase, porous flow

