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Two-Dimensional numerical simulations of mantle convection with chemical heterogeneity and continental drift

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We conducted numerical experiments of mantle convection in order to study the generation of ascending plumes in the presence of chemical heterogeneity and continental drift. In this study, we consider a convection of fluid with variable physical properties such as viscosity, thermal expansivity and conductivity, under the extended Boussinesq approximation, in a model of a two-dimensional rectangular box of 2900km height and the aspect ratio (width/height) of 12. The mantle materials are modeled by a mixture of two component fluids with different density. The convecting motion of fluid is driven by not only a thermal but also a chemical buoyancy coming from the variation in the content of denser component fluid. In addition, we impose a block of highly viscous fluid of 11600km width along the top surface, as a model of a supercontinent. We also take into account the effects of a drifting motion of supercontinent, by allowing a coherent (rigid) motion of continental block in the horizontal direction driven by the overall convection in the mantle. Our preliminary calculations showed that, when the effect of negative chemical buoyancy is sufficiently large, several dome-like structures of dense materials occur at the base of the mantle. The dome-like structures form broad regions of high temperature, which are quite similar to the large low shear-velocity provinces (LLSVPs) in the lowermost mantle of the Earth.

Our calculations demonstrated that the thermal and chemical state in the deep mantle described above is significantly affected by the presence of the continental block at the top surface. In particular, owing to a strong "blanketing effect", both thermally and chemically, caused by the continental block, a pile of dense and hot materials firmly develops beneath the initial position of the continent. The thermochemical pile, once it forms beneath the continental block, remains strong enough to dominate the overall convection in the mantle, causing intense ascending flows in its neighborhood. In addition, we found that, only when an appropriate amount of high density component (around 10% of the entire volume) is present in the mantle, convective flows can simultaneously yield the occurrence of continental drift and the long-term survival of LLSVPs.

Furthermore, from the observations of the temporal variations in convective planforms, we found that the thermochemical pile beneath the initial continental position is almost immobile for more than several gigayears: The pile of dense material remains stationary even after the continental block is swept away by the ascending flows originating from the root of the pile. This finding suggests that, considering the effect of chemical heterogeneity, the cycles of aggregation/dispersal of supercontinents are not necessarily associated with cyclic changes in convection patterns in the mantle, as opposed to the "1-2-1 model" proposed by Zhong et al. (2007).

Keywords: mantle convection, numerical simulation, chemical heterogeneity, supercontinent cycle, LLSVP, ascending plume