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Numerical Simulation on Passive Flows in the Three-Dimensional Static Layered Mantle With Depth-Dependent Viscosity

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We conducted numerical simulation for the three-dimensional spherical mantle using our individual code to confirm rheology dependence in the passively excited flows for the cases of two different viscosity profiles. In the initial condition we assumed the static layered mantle with two thermal boundary layers near the surface and the core-mantle boundary (CMB). The mantle temperatures is fixed to 300 K at the surface and 4,000 K at the CMB. Top of the lower mantle is at ~ 2,000 K. In the first model, the viscosity has the temperature dependence which increases gradually from the CMB to the surface. The maximum and minimum values in viscosity are 3.8E+24 (Pa s) at the surface and 1.6E+22 near the CMB, respectively. The second model has depth-fixed viscosity profile in which the averaged viscosity of the lower mantle is higher than that of the upper mantle. The maximum viscosity in the second model is 5E+22 (Pa s) at ~ 1,900 to 2,000 km depth and the minimum is 1E+21 at both regions of~ 100 to 400 km and ~ 2,800 to 2,900 km depth. The simulation code used was developed with the finite difference method. To get time integration with high precision, we used the Newton method. We in this study neglected the effect of surface plate motions, mineral phase changes and internal heating, etc. The Rayleigh number (Ra) is ~ 1E+7.

To elucidate numerically the viscosity dependence in the passive mantle flows due to buoyant thermal anomaly in the static layered mantle, we input instantaneously a local cool mass (hereafter, case A) and great-circle cool ring (case B) as a finite negative buoyancy source near the top of the lower mantle, ~ 670 km depth. Also, as a finite positive buoyant source in the lowermost mantle layer, initial input of a local warm mass (case C) and great-circle warm ring (case D) were incorporated in the simulation.

We describe the simulation result of cases A to D for the two viscosity models: In both the viscosity models, due to the negative or positive buoyancy of the thermal anomaly inserted initially at ~ 670 km depth or at the CMB, respectively, the mantle drives gradually itself a large-scale viscous flow system.

The passively exerted flows in the second viscosity model show relatively higher velocities especially at distant regions from the buoyant source than those in the first model. For cases A and B, the angle distances for sites of the major upwelling measured from the locus of the initial input are ~ 30 deg. in the first model and ~ 35 deg. in the second model. For cases C and D, the angle distances measured from the initial input site to the place of the major downwelling are ~ 25 deg. in the first model and ~ 35 deg. in the second model. The detailed nature of the time-space pattern in the passive flows for the two viscosity models may reflect rheology dependent mantle dynamics.