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Rayleigh-Benard convection in spherical shell with infinite Prandtl number at high Rayleigh number

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Mantle convection has many complex aspects, such as internal heating, strong temperature dependence of the viscosity, the yield strength of the materials, existence of the phase transitions, and so on. The Earth's mantle convection should be affected by these complexities, but its basic understanding has been constructed through the researches on simple Rayleigh-Benard convection. When we simplify the model of Earth's mantle convection in the Rayleigh-Benard setting, Rayleigh number (Ra) for the present Earth is supposed to be around 10ˆ7, and it would have been much higher for the ancient Earth. In the geological time scale, the material of the Earth's mantle behaves as a very viscous fluid, that is, extremely high Prandtl number (Pr) fluid. So the inertia plays no role for the dynamics of the mantle. Therefore, it is necessary for the study on Earth's mantle dynamics and its evolution to clarify the nature of Rayleigh-Benard convection at high Ra with very high Pr.

We carried out simulations of the Rayleigh-Benard convection with infinite Prandtl number and high Rayleigh numbers in the spherical shell geometry to understand the thermal structure of the mantle and the evolution of the Earth. We attained the numerical results for Ra ranging five orders above the critical value. For all Ra, the convection pattern is illustrated as follows; the sheet-shaped downwelling and upwelling flows originate from the boundary layers and concentrate gradually into cylindrical flows. We examined the relationship between Ra and the Nusselt number (Nu), and obtained that Nu is proportional to Raˆ0.3. The analysis of the convection pattern reveals that the structural scale differs between the boundary region and the isothermal core region. The structure near the boundary region is characterized by the cell type structure constructed by the sheet-shaped downwelling and upwelling flows, and that of the core region by the plume type structure which consists of the cylindrical flows.