Numerical simulations of the coupled magmatism-mantle convection system in 2-D and 3-D geometries

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It is generally considered that a magmatism occurred very actively in the hot mantle in the early Earth. Ogawa (2014) proposed that a positive feedback can operate between the magmatism and the upwelling flows of solid-state mantle convection, by numerical experiments of a coupled magmatism-mantle convection system in two-dimensional Cartesian domains. In this study, we newly developed numerical models of the coupled magmatism-mantle convection in three-dimensional Cartesian box as well as in two-dimensional spherical annuli with various shapes, in order to investigate how the geometries of the convecting vessel affects the feedback between the magmatism and mantle upwelling (or "MMU feedback" in short).
We employed both three-dimensional rectangular box and two-dimensional spherical annuli with various ratios of their inner to outer radii. The solid-state convection of the mantle is assumed to be that of an isoviscous fluid with a very high viscosity. Mantle magmatism is modeled by the generation of liquid phase (magma) owing to the pressure-release melting induced by upwelling flows of solid-state convection and the motion of the generated magma as a permeable flow through the solid matrix. The permeable flow of magma was assumed to be driven by a buoyancy due to the density difference between the solid and the liquid phases.
We carried out preliminary experiments using two-dimensional spherical annuli by systematically varying the ratio of inner to outer radii and the Rayleigh number of solid-state convection of the mantle. Our results showed that the MMU feedback can operate in a qualitatively very similar manner when the Rayleigh number is sufficiently large. The threshold values of the Rayleigh number for the MMU feedback lie between $O(10^6)$ and $O(10^7)$, regardless of the shape of the spherical annuli. We also found that, despite the cooling due to solid-state convection and magmatism, the temperature in the mantle remains slightly higher for thinner spherical annuli with larger ratio of inner to outer radii. Our findings suggest that the curvature of the mantle can affect the operation of MMU feedback only in an indirect manner, by modulating the thermal state and the magma generation in the convecting mantle.

Keywords: mantle convection, magmatism, numerical experiment