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Plume heat flow in mantle convection with plate-scale flow mode

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We carried out numerical simulations of thermal convection to estimate plume heat flow transported by upwelling plume in the Earth's mantle convection with flow pattern fallen into `plate-like' regime. The mantle layer is modeled as 2-dimensional rectangular box with an aspect ratio of 5. The viscosity of mantle materials is depended on temperature, pressure and degree of damage. The damage is evolved with high viscous dissipation rate and healed by characteristic time depending on temperature. The viscosity contrast between `plate interiors' and `plate boundaries' is taken to be 10**5. The Rayleigh number based on uppermost mantle viscosity (10**20 Pas) is the order of that of Earth's mantle, O(10**8).

The heat flow transported by upwelling plume from bottom thermal boundary layer is around 25 to 30% of heat flow on the bottom surface (i.e., corresponding to CMB heat flow), regardless of changing basal heating rate (around 50% basal heating to 100% purely basal heating). The plume heat flow predicted by the topographic swell (so-called, `plume-swell') is at most a few percent of bottom heat flow, even if 100% basal heating rate is given, which is compatible with or a little larger than that estimated by `hotspot-swell', for example, around Hawaii hotspot [Sleep, 1990]. Whereas in the case with weak basal heating rate (around 50% basal heating), the height of topographic swell is too small. The height of so-called `mantle topography', which is synonymous with residual topography corrected the contribution of half-space cooling and crustal thickness, is comparable with that of the `super-swell' observed in southern Pacific (1km height) in the case of around 67% heating rate. In the case of 100% purely basal heating, the height are too large (3km), on the other hand, in the case of 50% basal heating rate, the height is negligible small. This result agrees with suggestion from Earth's thermal budget that the heat content in the deep mantle (i.e., the summation of heat involved in `enriched layer' at deep mantle as modeled by Kellogg et al. [1999] and that released by core cooling) is 2/3 of the total `mantle heat flow' (about 37TW). In the case including the effects of 410km to 660km phase transitions (the effects of density change and entropy change), the heights of plume swell are compatible to that in the case without the phase transitions.

In summary, we suggest that the estimation of plume heat flow predicted by hotspot-swell would not provide a constraint on that of heat flow from CMB (They are both no more than 10 % of total mantle heat flow), which disagree with earlier suggestion by Davies and Richards [1992], but is relevant to compare with plume heat flow from enriched layer in the deep mantle. In addition, the predicted plume heat flow might be underestimated at around 1/10 of real plume heat flow (around 20% of total surface heat flow), regardless of the location where plumes originate.