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Branching of plumes at 660 km discontinuity and bounds on lateral viscosity contrast in the lower mantle

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Recent high-resolution seismic imaging of the transition-zone thickness beneath the Hawaiian hotspot (Cao et al., 2010) has evidenced a considerable uplift of the 660 km discontinuity west of Hawaii without a correspondent depression of the 410 km discontinuity. Such a structure is consistent with the geodynamical scenario of a deep-mantle plume first deflected horizontally at 660 km depth and then reemerging, away from its lower mantle source, as a secondary plume aligned with the present-day location of the hot-spot. Using a cylindrical model of mantle convection featuring multiple phase transitions and pressure-dependent thermodynamic properties according to recent mineral physics evidence, we investigate the conditions under which such a peculiar plume morphology can be realized. We focus on the magnitude $\Delta\eta_T$ of the lateral viscosity contrast due to temperature variations and show that this factor plays a first-order role on the dynamics of plumes if pressure-dependent thermal expansivity and conductivity are taken into account. For small values ($\Delta\eta_T \sim 10$), large-scale upwellings are generated at the bottom thermal boundary layer that have enough buoyancy to pass undisturbed the endothermic transition at 660 km depth in an essentially vertical fashion. For higher values ($\Delta\eta_T \sim 10^2 - 10^3$) mantle layering becomes more pronounced, plumes are thinner and weaker, still with enough buoyancy to reach the 660 km discontinuity but not to penetrate it. Instead, they travel horizontally along the 660 km boundary following the top part of lower mantle convection cells and rise again through the upper mantle at a distance from their parent plume also controlled by $\Delta\eta_T$. Our findings argue for the importance of using a temperature-dependent viscosity in numerical models that feature pressure-dependent thermodynamic properties and on the possibility of using plume dynamics to bound the temperature viscosity contrast in the lower mantle.

Cao Q., R.D. van der Hilst, M.V. de Hoop, S. Shim. Complex plume dynamics in the transition zone underneath the Hawaii hotspot: seismic imaging results. DI23C-02, AGU Fall Meeting 2010, San Francisco.