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Thermochemical Structure of Upper Mante Beneath Hotspot Swells

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A model that involves ponding and lateral spreading of hot thermal plumes in the mantle asthenospheric channel was first employed by Morgan (1968) to explain the ocean topography away from the Reunion hotspot. A number of mechanisms controlling the plume-lithosphere interaction has later been suggested to explain the geometry of hotspot swells and distribution of surface volcanism: gravity flow and upside down drainage of plume material (Sleep 1997), shear-driven upwelling (Ballmer et al. 2013), viscous fingering due to Saffman-Taylor instability (Shoonman et al. 2017), and the horizontal transport in solitary waves (Rudge et al. 2008). A large number of models exists due to a lack of constraints on the long-term rheological behaviour of the lithosphere-asthenosphere system. In addition, recent studies emphasized the role of compositional buoyancy on the plume dynamics. Thermochemical plume heads may potentially acquire a neutral or even negative buoyancy with respect to the upper mantle rocks due to a combined effect of cooling and compositional heterogeneity (Dannberg & Sobolev 2015).

High-resolution seismic tomography and satellite geodesy data provide important constraints on the physical properties of the lithosphere-asthenosphere system, and, thus, can be used to test the existing hypotheses. Three Cenozoic hotspot regions, characterized by visible mantle upwelling in thermal plumes, have been selected in this study: the North Atlantic region (Iceland Plume), western North America (Yellowstone Plume), and the western Indian Ocean (Reunion Plume). The results of the GOCE satellite mission provide a uniform spatial coverage of the globe including the study regions with the full gravity gradient tensor data. Morever, the GOCE gravity data fill the existed resolution gap at the wavelengths of 200-1000 km which is crucial for density modeling of the lithosphere and asthenosphere.

Preliminary spectral analysis of the satellite gravity data above selected hotspot swells suggests that the negatively buoyant plume heads in the upper mantle can be ruled out. The modelled elevated surface topography above a hot low-density asthenospheric channel is in a good agreement with the observed long-wavelength topography, gravity anomalies, surface heat flow and GPS velocities. The self-consistent computation of phase equilibria and physical properties, indicate that adiabatic isotropic shear wave speeds are in general agreement with the results of seismic tomography. At the same, the theoretical predictions using realistic geotherms and pyrolitic composition can account only for $\sim$50% of the actual velocity variation. The remaining part is probably related to strong compositional variations, thermally-activated anelastic deformation mechanisms and/or partial melting. In addition, a detailed history of the absolute plate motion needs to be included to account for the heat advection with the lithosphere.