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What core-mantle boundary topography can tell us about plume locations and the viscosity and density structure of thermochemical piles

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In order for the large low shear velocity provinces (LLSVPs) in the lowermost mantle to be chemically distinct from the rest of the convecting mantle, their properties such as density and viscosity must differ significantly from the ambient mantle. Previous studies have shown the importance of increased density to stabilize such large-scale thermochemical piles at the base of the mantle. More recently, it has been shown that an increase of intrinsic pile viscosity by about one order of magnitude will reduce long-term entrainment of the piles significantly, thus extending the lifetime of primordial LLSVP structures. The combination of excess density and increased viscosity can be explained, for example, by enrichment in iron-rich bridgmanite during the magma ocean stage of planetary evolution. Since these pile structures take active part in mantle convection by influencing its large-scale flow pattern, e.g. by affecting the source locations of plumes, we expect to see the influence of the LLSVPs on the core-mantle boundary (CMB) topography. Based on numerical models in a 2-D annular geometry, we calculate the dynamic topography for various pile densities and viscosities with special focus on the interface between piles and plumes. While the long-wavelength component of topography beneath the pile is mostly affected by the pile density, we identify a prominent short-wavelength pattern at the edge of the pile that allows us to discriminate piles with an intrinsic viscosity increase from those without. Moreover, this specific pattern of topography exhibits a characteristic time-evolution in connection with the cycle of plumes rising from the edges of the LLSVPs. Detection of this topography fluctuation, if seismologically possible, would allow us to predict locations from which a plume will rise in the near future, even though the plume head has not started to detach itself from the lower thermal boundary layer. The amplitude of the fluctuations may provide a constraint on the magnitude of the viscosity contrast between the thermochemical piles and lower mantle material that surrounds it.