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On the nature and morphology of the large low shear velocity provinces of the Earth's lower mantle

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The existence of two large low shear velocity provinces (LLSVPs) at the base of the earth's mantle with a strong equatorial "degree 2" signature has been known since the development of the first global seismic tomographic models of the earth's lower mantle (Dziewonski, 1979; Dziewonski and Woodhouse, 1986). In the last few decades, their existence has been confirmed in many studies, and they are generally associated with the global upwelling flow in the lower mantle, but their precise nature and role in the earth's evolution and present-day dynamics is still debated. Several indirect clues point to their stability for the last 250-300 Ma, and possibly much further back in geological time. It has been suggested that they may be of a different composition than surrounding regions and some authors have argued that they may be denser than the ambient mantle to a significant height above the CMB.

One of the key questions in furthering our understanding of the LLSVPs is how high they extend as coherent and compositionally distinct structures above the core-mantle boundary (CMB). Because of their very strong long wavelength signature, which persists to at least 1500 km above the core-mantle boundary, many studies assume that they are compact structures across that depth range. However, recent high resolution tomographic studies clearly show that they are the base of about 20 broad mantle plumes that rise quasi-vertically from the CMB to around 1000 km depth, and then meander through the upper part of the mantle towards a subset of hotspots roughly located above the LLSVPs. I argue that the strong degree 2 and, more generally, long wavelength component of the LLSVPs that is present across much of the lower mantle's depth range is actually due to the remarkable distribution of this bundle of plumes. The laterally continuous character of the LLSVPs thus appears to be limited to the bottom 200-300 km of the mantle, or an even thinner region near the CMB.

Models that invoke the presence of compositionally distinct, compact piles extending significantly above that depth are thus inconsistent with seismic observations, as are models where lower mantle upwellings encompass the entire width of the LLSVPs. Rather, the so-called lower mantle upwelling "return flow" may be limited to relatively narrow channels contained within the imaged discrete plumes, which are surrounded by a very stagnant highly viscous ambient lower mantle. The low shear velocity halo in which the plumes are imbedded in current tomographic models may be either due to insufficient resolution or to a residual temperature effect not directly related to upwelling motion. Higher than average density regions of significant thickness may be limited to the plume roots, at least some of which have been shown to contain large ultra-low velocity zones. In the lower viscosity upper 1000 km of the mantle, the plumes are entrained by mantle wind into the more vigorous secondary scale convection. To reproduce the seismic observations, geodynamic models need to consider a significantly different rheology for the lower mantle than is generally assumed.