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Of mantle plumes and secondary scale convection from global seismic imaging

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Many questions remain on the detailed morphology of convection patterns in the mantle. In particular, the existence of deep mantle plumes has been the subject of debate ever since they were proposed to explain the presence of hotspot volcanoes. With the advent of numerical methods for accurate seismic wavefield computations, it is now possible to apply the tools of waveform tomography to better detect the presence, throughout the mantle, of slow velocity anomalies, previously "hidden" by wavefront healing effects not captured by approximate wave propagation methods.

Global-scale seismic long period full waveform tomography, based on state-of-the-art numerical wavefield computations, thus reveals a pattern of elongated bands of low shear velocity, most prominent between 200-350km depth, below the well-developed low velocity zone. These quasi-periodic finger-like structures of wavelength ∼2000 km align parallel to the direction of absolute plate motion for thousands of kilometers (French et al., 2013), and may manifest secondary scale convection set off by plate motions. Most prominent in the Pacific Ocean, they are present also in the Indian Ocean and the north and south Atlantic.

On the other hand the lower mantle structure is dominated by vertically elongated low velocity "columns" rooted at the base of the mantle, in the vicinity of those hotspots that are located above the two large low shear velocity provinces (LLSVPs). The vertical conduits are quite straight from the base of the mantle to 1000 km depth, but wider (500-1000 km) than expected from the standard "thermal plume" model, which suggest that their nature is thermo-chemical, or that a significantly different lower mantle rheology than usually assumed needs to be considered (French and Romanowicz, 2014, 2015). The roots of several of these broad plumes contain large ultra-low velocity zones (ULVZs). In particular, the ULVZ under Iceland has a regular, axi-symmetric shape, which suggests the presence of partial melt in the hot center of the plume roots (Yuan and Romanowicz, 2017).
In the extended transition zone (400-1000 km), these conduits become narrower and seem to interact with the secondary scale convection described above. This suggests the presence of a so far unresolved dynamic interplay between plate-driven flow in the low velocity zone and active influx of low rigidity material from deep mantle sources deflected horizontally beneath the moving top boundary layer.