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Decoupled upwelling between the lower and upper mantle; petrologic and seismic interpretation of mantle plumes

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Seismic tomography reveals the presence in the lower mantle of vast regions with lower-than-ambient seismic velocities. These regions are interpreted to be composed of material that is hotter and compositionally different from surrounding mantle. Observed tomographic velocity anomalies in the lower mantle translate into temperature anomalies of 200-400 degrees, if the plume is anhydrous, or 130-340K if the plume is water-rich. Nolet et al (abstract this meeting) argue that the plumes contain up to 0.3% absolute excess Fe, and that they are rising with velocities between 0.3 to 5cm/yr.

Most, but not all, of the anomalous regions in the lower mantle are located beneath oceanic islands that are interpreted to mark the sites of upper mantle plumes. However there is little correlation between the temperatures in the lower mantle, as inferred from seismic tomography, and the temperature of the upper mantle plumes, as inferred from the petrology and geochemistry of the volcanic rocks. The hottest currently active upper-mantle plume is Hawaii. Backtracking to the primary magma using the compositions of picritic glasses and olivine phenocrysts indicates that the primary melt contained about 20% MgO and formed from a plume which, if anhydrous, was about 200K hotter than ambient mantle. The lower mantle beneath Hawaii is very poorly imaged, but does not appear to correspond to a region of abnormally high temperature. At Reunion and Kerguelen, two active hotspots that erupt picrites containing magnesian olivine phenocrysts, temperatures in the upper and lower mantle coincide: the excess temperature of the upper mantle plume is 150-200K and that

of the lower-mantle anomalies is 160-200K at depths of 800-1000km. In contrast, the three largest lower-mantle anomalies do not coincide with high-temperature plumes in the upper mantle. At Afar, only a small volume of alkali magmas is currently forming by partial melting beneath a thin oceanic lithosphere, and the source is best described as a “lukewarm spot”, little hotter than ambient upper mantle. Yet the seismic anomaly beneath Afar is large, both in terms of volume and temperature: at a depth of 800km, it is over 1000km in diameter and its excess temperature is estimated as 320K if dry or 270k if wet. A similar contrast exists in Polynesia and Cape Verde, where low-flux alkali magmas form from weak, tepid or moist plumes in the upper mantle. These regions overly large, hot, rapidly upwelling anomalies in the lower mantle (340K if dry or 300K if wet, at a depth of 1000km beneath Cape Verde; 365K if dry or 340K if wet at 1900km beneath Tahiti). Finally there is virtually no surface expression of the large anomaly beneath the Chatham seamount west of New Zealand.

There are several ways to interpret these results: (1) the transition zone may form a barrier that hinders the passage of hot upwelling mantle. In regions such as Reunion, the transit is efficient, but in most other regions, both temperature and mass flux is lost. As shown independently in numerical models, upwelling lower mantle material may become dispersed and flow laterally when a lower mantle plume reaches the base of the upper mantle. (2) The lower mantle plumes may be wet and water may be lost at the transition zone (erupted OIB show little evidence of high water contents). (3) The mismatches may result from the pulsed flow in both the lower and upper mantle.