Do Mantle Plumes Preserve the Heterogeneous Structure of their Deep-Mantle Source?

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It has been proposed that the spatial variations recorded in the geochemistry of hotspot lavas, such as the bilateral asymmetry recorded at Hawaii, can be directly mapped as the heterogeneous structure and composition of their deep-mantle source. This would imply that source-region heterogeneities are transported into, and preserved within, a plume conduit, as the plume rises from the deep-mantle to Earth's surface. Previous laboratory and numerical studies, which neglect density and rheological variations between different chemical components, support this view. However, in this paper, we demonstrate that this interpretation cannot be extended to distinct chemical domains that differ from surrounding mantle in their density and viscosity. By numerically simulating thermo-chemical mantle plumes across a broad parameter space, in 2-D and 3-D, we identify two conduit structures: (i) bilaterally asymmetric conduits, which occur exclusively for cases where the chemical effect on buoyancy is negligible, in which the spatial distribution of deep-mantle heterogeneities is preserved during plume ascent; and (ii) concentric conduits, which occur for all other cases, with dense material preferentially sampled within the conduit's centre. In the latter regime, the spatial distribution of geochemical domains in the lowermost mantle is not preserved during plume ascent. Our results imply that the heterogeneous structure and composition of Earth's lowermost mantle can only be mapped from geochemical observations at Earth's surface if chemical heterogeneity is a passive component of lowermost mantle dynamics (i.e. its effect on density is outweighed by, or is secondary to, the effect of temperature). The implications of our results for: (i) why oceanic crust should be the prevalent component of ocean island basalts; and (ii) how we interpret the geochemical evolution of Earth's deep-mantle are also discussed.