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The thermochemical Hawaiian plume and its dynamic influence on upper mantle discontinuities

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The anomalous seismic structure of the upper mantle at the Hawaiian hotspot, including the X-discontinuity at 310 km depth and a perturbed 410, has been ascribed to large quantities (>40%) of recycled eclogite in the Hawaiian mantle plume. These estimates far exceed the classical geodynamic constraints of 15-20%, suggesting the existence of additional mechanisms driving eclogite accumulations.

We tackle this discrepancy by superimposing discrete heterogeneities of recycled eclogite to a plume featuring a realistic mechanical mixture composition. This approach allows us to entrain higher amounts of denser material and quantify its segregation in the 310-410 km depth range. To reproduce the ample spectrum of buoyancy fluxes reported for the Hawaiian hotspot, we test plume radii of 80-100 km, excess plume temperatures of 200-300 K, and recycled heterogeneity fractions between 5 and 20%.

Our 8 best-fit cases yield average eclogite accumulations of 19.5% at 310 km and 21-25% at 410 km, with peaks of 21-24% and 26-32%, respectively. This uniformity indicates that higher eclogite entrainments do not substantially increase material segregation in the mid-upper mantle.

We demonstrate that, while the Hawaiian plume has the potential of recycling more than 18% denser material, high segregations are unsustainable over geological timescales, and excess entrainments above 20% would require unrealistic buoyancy fluxes. Our findings provide the first quantitative constraint of the dynamic relationship between the Hawaiian mantle plume and the X-discontinuity, critically advancing our understanding of the influence of recycled eclogite on mantle discontinuities.