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Deep carbon and helium in mantle plumes

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It is well known that helium abundances in mantle-derived basalts are approximately and globally correlated with CO2. Recent experimental work on carbonate melting in the deep upper mantle [1] potentially throws new light on this connection. This work shows that small amounts of carbonate melts should be formed in upwelling mantle even at low carbon concentrations of as little as 100 ppm. Such carbonate melts are expected to be extremely mobile and may ascend through the upper mantle at rates exceeding 1 m/yr, especially in view of the recently measured high permeability of mantle rocks [2]. Although published partitioning and solubility data for helium in silicates cover a rather large range of values, we assume that helium is nearly as incompatible as carbon in the presence of a carbonate liquid. Thus, ascending carbonatite liquids should become the major carrier phase for mantle helium.

In several well-documented mantle hotspots ascribed to ascending mantle plumes, including Hawaii, Iceland and Galapagos, the high-3He/4He signal is asymmetrically distributed. In all three cases, the He signal is offset from the plume center in the “upstream” direction of asthenospheric flow driven by local plate motions. We propose that this asthenospheric flow tilts the plume. Primordial He, thought to be initially located in the plume center, is scavenged by a small amount of carbonatite liquid, which forms in the plume at depths of 400 km or more, migrates vertically through the tilted plume, and displaces the helium maximum from the plume core toward its margin.

We model this process for the Hawaiian plume to explain the 3He/4He maximum located in Loihi melts, which sample the front edge of this plume, rather than in Mauna Loa or Kilauea melts, which sample the core of the plume. The model predicts significant displacements of the He signal derived from plume cores and decoupling of He from Sr, Nd, Pb isotope signatures in tilted plumes.

[1] Dasgupta & Hirschmann (2006), Nature 440, 659-662. [2] Connolly et al. (2009) Nature. 462, 209-212.