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Origin and implications of He-depleted Afar mantle plume

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The deep Earth retains a higher proportion of the primordial noble gases (^{3}He, ^{20}Ne) than degassed convecting upper mantle thus basalts from high flux intra-plate volcanism have $^{3}He/^{4}He$ that are higher than mid-ocean ridge basalts (MORB). However, the He concentration and $^{3}He/^{20}Ne$ of high-$^{3}He/^{4}He$ oceanic basalts are generally lower than MORB, inconsistent with the prevailing paradigm. This can be explained by the disequilibrium degassing of shallow melts but it highlights the challenge of reconstructing the primordial volatile inventory of the deep Earth from oceanic basalts.

The $^{3}He/^{4}He$ of basalt glasses dredged from the Red Sea spreading axis systematically increase southward reaching a maximum value of 15 R_A in the Gulf of Tadjoura, Djibouti. This is located over the modern Afar plume. In $^{3}He/^{4}He$-K/Th-K/Nb-Rb/Nb and Rb/U space the Red Sea basalts define hyperbolic mixing between MORB and HIMU mantle components. Using established trace element concentrations in these end-members we show that the upwelling plume has ~12 times *less* He than the asthenospheric mantle despite the high-$^{3}He/^{4}He$. This contravenes the prevailing orthodoxy and appears to require the high-$^{3}He/^{4}He$ mantle is no enriched in He. This observation can most simply be explained if the Afar mantle plume is itself a mixture of primordial He-rich, high-$^{3}He/^{4}He$ deep mantle with a proportionally dominant mass of He-depleted low-$^{3}He/^{4}He$ HIMU mantle. The HIMU signature of the Afar plume basalts implies on origin in recycled altered oceanic crust (RAOC). Using established RAOC U and Th concentrations, the low He concentration (< 3.6 x 10^{13} atoms He/g) of the Afar plume implies that the slab was subducted no later than ~35 Ma and reached less than 700 km before being incorporated into the upwelling mantle. We suggest that the Afar plume acquired its composition during large scale mixing at the 670 km transition zone rather than the core-mantle boundary.

This implies that large domains of He-depleted mantle exist within the deep Earth, likely associated with subducted slabs. Further, it implies that moderately high-$^{3}He/^{4}He$ (< 30 R_A) mantle plumes (e.g. Reunion) need not contain a significant contribution of deep mantle, thus should not be used to define primitive Earth composition.