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Low He content of the high $^3He/^4He$ Afar mantle plume: Origin and implications of the He-poor mantle

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Basalts from high flux intra-plate volcanism are characterised by $^3He/^4He$ that are higher than the upper mantle sampled at mid-ocean ridges. The prevailing paradigm requires that the deep Earth has retained a higher proportion of the primordial noble gases (^3He, ^{20}Ne) relative to degassed convecting upper mantle. However, the He concentration and $^3He/^{20}Ne$ ratio of high-$^3He/^4He$ oceanic basalts are generally lower than mid-ocean ridge basalts (MORB). While this so called 'He paradox' can be resolved by disequilibrium degassing of magmas it highlights the difficulty in reconstructing the primordial volatile inventory of the deep Earth from partially degassed oceanic basalts.

Basalts from the Red Sea spreading axis reveal a systematic southward increase in $^3He/^4He$ that tops out at 15 Ra in the Gulf of Tadjoura (GoT), which is located over the modern Afar plume. Hyperbolic mixing in $^3He/^4He$-K/Th-Rb/La space in E-MORB and HIMU mantle illustrates that the upwelling plume has 5-20 times *less* He than the asthenospheric mantle despite the high-$^3He/^4He$. This can most simply be explained if the Afar mantle plume is itself a mixture of primordial He-rich, high-$^3He/^4He$ deep mantle with a proportionally dominant mass of He-poor low-$^3He/^4He$ 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 ($< 5 \times 10^{13}$ atoms/g He) of the Afar plume implies that the slab was subducted no later than 70 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-poor mantle exist within the deep Earth, likely associated with subducted slabs. Further, it implies that moderately high-$^3He/^4He$ (< 30 Ra) mantle plumes (e.g. Reunion) need not contain a significant contribution of deep mantle, thus cannot be used to define primitive Earth composition.