EGU22-4994, updated on 17 Aug 2022
https://doi.org/10.5194/egusphere-egu22-4994
EGU General Assembly 2022

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

Ugur Balci[1], Finlay M. Stuart[1], Jean-Alix Barrat[2], and Froukje M. van der Zwan[3]
[1]Scottish Universities Environmental Research Centre, Rankine Avenue, East Kilbride G75 0QF, UK
(u.balci.1@research.gla.ac.uk)
[2]Univ. Brest, UMR 6539, Lab. des Sciences de L'Environement Marin, IUEM, 29280, Plouzané, France
[3]Earth Science & Engineering, KAUST, Thuwal, Saudi Arabia

Basalts from high flux intra-plate volcanism (Iceland, Hawaii, Samoa) are characterised by $^{3}He/^{4}He$ that are significantly higher than those from the upper mantle sampled at mid-ocean ridges. The prevailing paradigm requires that a largely undegassed deep Earth is enriched in primordial noble gases (^{3}He, ^{20}Ne) relative to degassed convecting upper mantle. However, the He concentration and $^{3}He/^{20}Ne$ ratio of high $^{3}He/^{4}He$ oceanic basalts are generally lower than mid-ocean ridge basalts (MORB). This so called 'He paradox' has gained infamy and is used to argue against the conventional model of Earth structure and the existence of mantle plumes. While the 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 26 to 11°N on the Red Sea spreading axis reveals a systematic southward increase in $^{3}He/^{4}He$ that tops out at 15 Ra in the Gulf of Tadjoura (GoT). The GoT $^{3}He/^{4}He$ overlaps the highest values of sub-aerial basalts from Afar and Main Ethiopian Rift and is arguably located over modern Afar plume. The along-rift $^{3}He/^{4}He$ variation is mirrored by a systematic change in incompatible trace element (ITE) ratios that appear to define two-component mixing between E-MORB and HIMU. Despite some complexity, hyperbolic mixing relationships are apparent in $^{3}He/^{4}He$-K/Th-Rb/La space. Using established trace element concentrations in these mantle components we can calculate the concentration of He in the Afar plume mantle. Surprisingly it appears that the upwelling plume mantle has 5-20 times less He than the convecting asthenospheric mantle despite the high $^{3}He/^{4}He$ (and primordial Ne isotope composition). This contradicts the prevailing orthodoxy but can simply be explained if the Afar mantle plume is itself a mixture of primordial He-rich, high $^{3}He/^{4}He$ (55 Ra) deep mantle with a proportionally dominant mass of He-poor low $^{3}He/^{4}He$ HIMU mantle. This is consistent with the narrow range of Sr-Nd-Os isotopes and ITE ratios of the highest $^{3}He/^{4}He$ Afar plume basalts, and is in marked contrast to high $^{3}He/^{4}He$ plumes (e.g. Iceland) that do not have unique geochemical composition. The HIMU signature of the Afar plume basalts implies origin in recycled altered oceanic crust (RAOC). Assuming that no He is recycled and using established RAOC U and Th concentrations, the low He concentration ($< 5 \times 10^{13}$ atoms/g He) of the He-poor mantle implies that the slab was subducted no earlier than 70 Ma and reached no more than 700 km before being incorporated into the upwelling Afar plume. We suggest that the

Afar plume acquired its chemical and isotopic fingerprint during large scale mixing at the 670 km transition zone with the Tethyan slab, not at the core-mantle boundary.

This study implies that large domains of essentially He-poor mantle exist within the deep Earth, likely associated with the HIMU mantle compositions. Further, it implies that moderately high-$^{3}He/^{4}He$ (< 30 Ra) mantle plumes (e.g. Reunion) need not contain a significant contribution of deep mantle, thus cannot be used a *priori* to define primitive Earth composition.