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Helium isotopes in mantle-derived magmas controlled by partial melting

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The less radiogenic He isotopes (i.e. higher $^{3}He/^{4}He$) of several ocean island basalts (OIBs) compared to typical mid-ocean ridge basalts (MORBs), combined with differences in primordial and short-lived Ne and Xe isotopes, are generally considered to stem from long-term isolation of the deep-mantle source of these OIBs. However, global seismic tomography models have clarified that exchange of material occurs between upper and lower mantle via subduction of oceanic lithosphere. This is entirely consistent with the occurrence of subducted material in the deep-mantle sources of OIBs indicated by the radiogenic isotope compositions of lithophile elements (Sr, Nd, Hf, Pb), as shown by several contributions by Catherine Chauvel and Dominique Weiss. The origin of He isotope variations in mantle-derived magmas and especially the occurrence of highly unradiogenic $^{3}He/^{4}He$ in some plume-related lavas is, therefore, far from clear. Previous explanations of these ancient He isotopic signatures include melting of highly depleted sources, storage of primordial He in dense Fe-rich piles derived from magma ocean crystallisation, migration of solar-like He from the core to the lowermost mantle, or preservation of minimally processed material in the convecting mantle. Here we demonstrate that these hypotheses are not mutually exclusive, and their combination may satisfy the natural rock record. We address the origin of high $^{3}He/^{4}He$ in mantle-derived magmas by combining the geochemistry of oceanic basalts with those of intraplate continental mafic rocks, which best approximate their convective mantle sources. We show that the least radiogenic He isotopes are exclusively associated with high-degree melts, i.e. tholeiites with low concentrations of incompatible trace elements (e.g., Nb, Th), which are derived from sources that have experienced minimal addition of recycled crustal material. These compositions do not correspond to ancient mantle domains (e.g., similar to PREMA) scattered in the convective mantle. The association of high $^{3}He/^{4}He$ lavas with hot plumes combined with modelling of He diffusion in the mantle requires that ^{3}He is delivered to the deepest mantle by exchange with either the core or magma ocean residues at the core-mantle boundary.