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Continuing He/U fractionation in the mantle and the generation of high 3He/4He ratios in ocean island basalts

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Models for the structure of the mantle must explain how the 3He/4He ratios in MORB and OIB are distributed. Various models suggest that OIB He with higher ratios is stored in separate, high He/U reservoirs since early Earth history, although there are difficulties in creating and isolating such reservoirs. Alternatively, it has been suggested that domains with high He/U ratios have been created in the convecting mantle, with continuous replacement of those domains destroyed during convective mixing. These domains can be either depleted by melting, if He is more incompatible than U, or are U-depleted regions enriched by He-rich fluids. In these cases, the He is derived from the convecting mantle, and the 3He/4He ratio is preserved in these domains, while the rest of the mantle continues to evolve to lower ratios. This requires that the 3He/4He ratio of the mantle was at least as high as the highest values seen in OIB until relatively recently, since the lifetime of the domains is limited by destructive mixing and melting of the mantle. However, the He isotope evolution of the upper mantle has not been comprehensively modelled to determine if such scenarios are plausible. The evolution of He isotopes in the convecting mantle can be determined from the production rate of 4He through time (i.e. the history of mantle U and Th concentrations based on continental growth models) and the He degassing rate. Initial and present mantle He concentrations and isotope compositions provide the boundary conditions. Using the well-constrained limits on the boundary conditions, and a wide range of possible He degassing histories and mantle U/Th depletion histories, it can be shown that the convecting mantle had 3He/4He ratios as high as those seen in Hawaii and Iceland only prior to 3Ga, and likely as early as almost 4Ga. Therefore, high He/U

domains created in the mantle more recently cannot account for the full range of OIB He isotope signatures. Rather, there must be involvement of material that has maintained such high ratios in a separate reservoir that must have been generated early in Earth history. A mechanism for isolating these domains is required to prevent their destruction by convective mixing over much of Earth history. This is consistent with models that store such He signatures in a deep layer in the mantle or in the core. Other constraints from noble gases, including the balance of the K-40Ar system, the fluxes of heat and 4He, and the distribution of Xe isotopes, place further requirements for the creation of mantle reservoirs early in Earth history and their long-term preservation.