Helium isotope signatures of the mantle transition zone

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Helium isotope compositions of basalts play a critical role in defining models of Earth's chemical structure. The higher $^{3}He/^{4}He$ ratios of plume-related basalts relative to mid-oceanic ridge basalts (MORB) are taken as key evidence of a primordial undegassed reservoir with high $^{3}He/^{4}He$ ratios present in the Earth's lower mantle. However, the preservation of such a reservoir over the Earth's history has been questioned based on geophysical evidence of slab subduction into the lower mantle. Further, He isotopes in basalts are affected by plume entrainment, degassing, and crustal contamination. We studied twenty-four super-deep, sub-lithospheric diamonds from the Juina area, Brazil, to obtain a new view of the He isotopic composition of the deep mantle, unaffected by the above processes.

Fluid inclusions within these super-deep diamonds, likely from transition zone depths (410-660 km), have $^{3}He/^{4}He$ ratios correlating with $\delta^{13}C$ values from the diamond host. High $^{3}He/^{4}He$ ratios (>MORB) are associated with higher ^{3}He concentrations and the lowest $\delta^{13}C$ values, whereas low $^{3}He/^{4}He$ ratios are associated with mantle $\delta^{13}C$ values. Trace element patterns and Sr and Pb isotopic compositions of these fluid inclusions indicate the presence of subducted pelagic sediments and oceanic crust/lithosphere. The Pb isotopic compositions of the fluid inclusions show a similar variation as OIBs, from the EMII to the HIMU end-member. These features are best explained as the result of differential mass balance, with low [He] in the subduction fluids supplying the organic carbon and trace elements, and high [He] with high $^{3}He/^{4}He$ ratios in fluids associated with a plume. These new data indicate a high $^{3}He/^{4}He$ source must at least be present >410 km depth and likely in the lower mantle, and has implications for mantle convection and the preservation of chemical heterogeneities in the mantle.