Illuminating the long-term storage of fluid-hosted volatiles in the SCLM from $^3$He/$^4$He, major- and trace elements in global mantle xenolith suites

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Helium isotopes are a powerful tracer of mantle sources; deep mantle $^3$He/$^4$He (> 10 Ra) are significantly higher than convecting depleted upper mantle (8 ± 1 Ra), and continental crust (<1 Ra). Far less is known about the origin, and temporal and spatial variability, of He in the sub-continental lithospheric mantle (SCLM). Here we integrate fluid-hosted He isotopes with lattice-hosted major- and trace-elements in olivine and pyroxene that reflects closed system evolution of He in SCLM over the last 3 Ga. In this model radiogenic He has grown into more depleted sub-cratonic lithosphere ($^3$He/$^4$He = 0.5– 6.5 Ra) that formed from higher temperature Archean mantle melts (olivine Mg# 91-95), than in younger (0 - 2 Ga) off-craton lithospheric mantle (Mg# = 88 - 92; $^3$He/$^4$He = 4 – 8.8 Ra). More than 70% of the depleted off-craton peridotites have $^3$He/$^4$He in the range typical of MORB (7-9 Ra), which implies that they originate as underplated residues from melting of the convecting asthenosphere with no evidence for the influence of deep primordial mantle ($^3$He/$^4$He > 10). Modest correlations occur between $^3$He/$^4$He and petrological-geochemical signatures of metasomatic enrichment (e.g. whole-rock SiO₂, modal orthopyroxene, LREE/HREE and LILE/HREE) in the off-cratonic xenoliths. These indicate that lithospheric mantle enrichment by carbonatite and small-fraction silicate melts/fluids derived from subducted oceanic lithosphere may have perceptibly decreased $^3$He/$^4$He.

We propose that the SCLM is dominantly sourced from the upper-mantle and subsequent He evolution is predominantly governed by time-dependent $^4$He-ingrowth with only a minor influence from metasomatic overprinting. In this scenario, the SCLM is a closed system for He and therefore represents a long-term reservoir for the storage of fluid-hosted volatiles (e.g. CO₂, H₂O).