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

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Helium isotopes are a powerful tracer of mantle sources; deep mantle $^3He/^4He$ (> 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 SCLM samples to investigate the source and effect of depletion and enrichment.

We present new data for 43 peridotite and pyroxenite xenoliths (erupted < 100 Ma) from on- and off-craton settings. When combined with previously published data (n=70) there is a systematic global relationship between inclusion-hosted $^3He/^4He$ and 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 ($^3He/^4He$ = 0.5– 6.5 R_a) 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; $^3He/^4He$ = 4 – 8.8 R_a). More than 70% of the depleted off-craton peridotites have $^3He/^4He$ in the range typical of MORB (7-9 R_a), which implies that they originate as underplated residues from melting of the convecting asthenosphere with no evidence for the influence of deep primordial mantle ($^3He/^4He$ > 10). Modest correlations occur between $^3He/^4He$ and petrological-geochemical signatures of metasomatic enrichment (e.g. whole-rock SiO_2, 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 $^3He/^4He$.

We propose that the SCLM is dominantly sourced from the upper-mantle and subsequent He evolution is predominantly governed by time-dependent ^4He-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. CO_2, H_2O).