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On-, off-cratonic, orogenic and oceanic mantle roots: lithosphere unite

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Associated with Earth's crust is the underlying lithospheric mantle, which is often categorized according its surface availability for sampling. For example, we frequently describe sub-continental lithospheric peridotite xenoliths as on- or off-cratonic to highlight the approximate lithosphere stabilization age as being Archean or post-Archean and contrast them against the lithospheric peridotites recovered from present-day oceanic basins. Orogenic peridotites and ophiolites are obducted in subduction zones and mark paleo-suture zones in amalgamated continents.

Regardless of its present-day occurrence, lithospheric mantle is buoyant as a result of substantial extraction or mafic to ultramafic silicate melts. This depletion and buoyancy results in a thermal and mechanical boundary layer (lithosphere-asthenosphere boundary layer, LAB) and isolates Earth's lithosphere from the convecting mantle. The mineralogical and geochemical similarities of some of the oldest cratonic sub-continental lithosphere and highly-depleted young oceanic peridotites require common geochemical mechanisms that are capable of introducing well-correlated major element variability – until metasomatic enrichment masks the depletion signature. Efficient extraction of basaltic melts from the convecting mantle occurs at mid-ocean ridges and removes clinopyroxene and to some extent garnet leaving the olivine-rich buoyant residual lithospheric mantle.

We will examine the oceanic heritage of garnet and spinel-facies sub-continental lithospheric mantle in general, but focus on xenoliths (n = 62) sampled across the North Atlantic Craton (~700km, NAC), West Greenland at c. 600 and 200 Ma. These Greenlandic samples are strongly serpentinized, harzburgitic to dunitic peridotites and generally comprise less than 15% orthopyroxene and very little clinopyroxene (« 5%). If garnet is present it occurs in variable amounts (12 to 0.3%). Major element systematics of these peridotites are highly refractory with Al2O3 « 1.8 wt% and Mg/Si ranging between 1.43 and 1.61. These refractory characteristics set the NAC continental mantle roots distinctly apart from those of e.g. the Kaapvaal Craton but resemble the anticipated composition of refractory oceanic peridotites. Heavy rare earth element (HREE) concentrations of the Greenlandic whole rock peridotites are generally very low and consistent with numerical mantle melting models that suggest the complete removal of clinopyroxene, and the absence and/or complete removal of garnet during fractional polybaric mantle melting. Such exhaustion of garnet and clinopyroxene is best reconciled in a shallow melting environment (i.e. <3GPa) in a subduction- or mid-ocean-ridge-like setting suggesting an oceanic episode in the evolution of this cratonic portion of lithospheric peridotites. The platinum-group element systematics of these NAC peridotites are typically marked by Os and Ir abundances that are somewhat lower than those of primitive mantle. Importantly, Pt and Pd abundances are significantly depleted resulting in PGE systematics consistent with the extensive melt extraction derived from HREE systematics. Typically, Os isotopes of these Greenlandic samples are unradiogenic (gammaOs = -14.2 to -6.6) and result in TRDerupt model ages clustering between 2.7 and 3.2 and also at ca. 2.0 Gyr. These TRDerupt model ages correspond extremely well with the U-Pb zircon ages derived from the NAC trondjemite-tonalite-granodiorite continental crust (~2.8 Gyr) and the tectonic activity associated with the amalgamation and rifting of the NAC and adjacent crust to the NAC (Kangâmiut dykes ~ 2.0 Gyr; Nagssuqtoqidian ~1.8 Gyr).

Importantly, available data from other cratonic peridotites also show low HREE and Pt and Pd contents implicating a similar magmatic evolution of the terrestrial mantle as derived from the NAC peridotites. These HREE and Pt and Pd abundances indicate that it is possible that depletion in the Archean also occurred predominantly at shallow depths similar to present-day mid-ocean ridges or subduction-zones. Therefore, these North Atlantic Craton sub-continental peridotites clearly link together the long-term evolution of the convecting mantle with the formation of oceanic lithosphere and the magmatic generation of cratonic continental crust.