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From MOR depletion to fore-arc metasomatism: petrogenetic modeling and Re-Os constraints from the mantle section of Nidar Ophiolite, NE Ladakh, India

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Supra-subduction zone (SSZ) peridotites provide critical constraints on mantle wedge processes by recording the effects of slab-derived fluxes, high-degree melting, and subsequent melt–rock interaction. This study investigates depleted harzburgites and associated dunites from the Nidar Ophiolite Complex, exposed along the Indus–Tsangpo Suture Zone and interpreted as fragments of Neo-Tethyan oceanic lithosphere formed in a fore-arc SSZ setting. The mantle section comprises variably depleted harzburgites crosscut by dunite bodies, preserving evidence of high-degree melting, focused melt transport, and interaction with boninitic melts. Boninitic melts represent extreme SSZ magmas generated from highly depleted mantle sources fluxed by hydrous slab-derived components. We integrate whole-rock major and trace element geochemistry, mineral chemistry and Re–Os isotopic compositions with thermodynamic modeling using alphaMELTS. Modeling simulates (i) initial mid-ocean ridge melting, (ii) slab-fluid induced flux melting of depleted harzburgite to generate boninitic melts, and (iii) subsequent interaction between these melts and refractory mantle residues leading to dunite formation. Re–Os systematics are used to constrain the timing and extent of melt extraction and to evaluate open-system modification during melt percolation. Spinel compositions show elevated Cr# [Cr/(Cr+Al)] in both harzburgites and dunites, consistent with high degrees of prior melt depletion. This interpretation is supported by whole-rock trace element systematics, where both lithologies display comparable heavy rare earth element (HREE) abundances. Harzburgites and dunites exhibit near-chondritic to radiogenic $^{187}Os/^{188}Os$ ratios (0.1255–0.1344) coupled with low Re/Os ratios, suggesting an ancient melt-depleted mantle source that experienced later open-system overprinting, likely during localized melt–rock interaction or addition of radiogenic Os-bearing components. Importantly, this overprinting produced variable light rare earth element (LREE) enrichment without complete resetting of bulk Os isotopic signatures. We propose a three-stage evolutionary model involving (1) mid-ocean ridge depletion, (2) slab-fluid driven flux melting during subduction initiation, and (3) focused migration and reaction of boninitic melts producing dunite channels and trace element refertilization. Combined geochemical, isotopic, and modeling results thus highlight the role of melt–rock interaction in generating chemical heterogeneity in fore-arc mantle wedges.