

Transition metals in komatiitic olivine: Proxies for mantle composition, redox conditions, and sulfide mineralization potential

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ABSTRACT

We present the results of a comprehensive study on the concentrations of first-row transition elements (FRTE: Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, and Zn), as well as Ga and Ge, in liquidus olivine from 2.7–3.5 Ga old Al-undepleted and Al-depleted komatiites from the Kaapvaal and Zimbabwe Cratons in southern Africa, the Yilgarn Craton in Australia, and the Superior Craton in Canada. The sample set includes komatiites that remained sulfur-undersaturated upon emplacement, as well as komatiites that reached sulfide saturation owing to assimilation of crustal sulfur.

All olivine grains display concentrations of Mn, Zn, Ge, Co, Fe, Mg, and Ni similar to the Bulk Silicate Earth (BSE) values, with significant negative anomalies in Sc, Ti, V, Cr, Ga, and Cu. Olivine from the studied Al-depleted komatiites displays on average higher $100\times\text{Ga}/\text{Sc}$ ratios (>5) than olivine from Al-undepleted komatiites (≤ 5). Because garnet preferentially incorporates Sc over Ga, the data suggest that elevated Ga/Sc ratios in komatiitic olivine are indicative of garnet retention in the source region of komatiites, highlighting the potential of olivine trace element chemistry as a proxy for the depth of komatiite melting and separation of the magma from the melting residue. Copper concentrations in the studied olivine grains are controlled by sulfur saturation of the host komatiite during olivine crystallization. Olivine from sulfur-undersaturated komatiite systems displays Cu concentrations mostly between 1 and 10 ppm, whereas olivine from sulfide-bearing komatiites has Cu contents of <0.5 ppm. Because komatiites contain some of the world's highest metal tenor magmatic Ni-Cu sulfide deposits, the Cu variability in olivine as a function of the sulfide-saturation state highlights a potential application of olivine chemistry in the exploration for sulfide ore deposits.

Olivine from the Paleo-Archean (3.5–3.3 Ga) komatiites displays overall higher V/Sc ratios ($V/\text{Sc} = 2.1 \pm 0.96$; 2 S.D.) than olivine from their Neo-Archean (2.7 Ga) counterparts ($V/\text{Sc} = 1.0 \pm 0.81$, 2 S.D.). Vanadium and Sc behave similarly during partial melting of the mantle and are similarly compatible in majorite garnet. However, V is redox-sensitive and its compatibility in olivine increases as the system becomes less oxidized, whereas Sc is redox-insensitive. We argue that olivine from the studied Paleo-Archean komatiites crystallized from more reduced magmas than their Neo-Archean counterparts. Elevated Fe/Mn ratios in olivine from Paleo-Archean komatiites mimic the V/Sc signatures and are interpreted to reflect that Fe^{2+} is more compatible in olivine than Fe^{3+} . These results imply that V/Sc and Fe/Mn in komatiitic olivine may potentially provide insight into the evolution of the oxidation state of the Archean mantle. Additional studies that integrate the chemistry of komatiitic olivine with those of relict interstitial glass and melt/fluid inclusions are encouraged to fully understand and quantify the potential of FRTE in olivine as a proxy for the oxidation state of the mantle sources of komatiite magmas.

Keywords: Komatiite, olivine, Archean mantle evolution, first row transition elements, oxygen fugacity, laser ablation ICP-MS