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Zn and Fe isotopes indicate that kimberlites and silica-undersaturated magmas derive from similar asthenospheric mantle sources

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Introduction

Mantle-derived silica-undersaturated magmas (ranging from melilitite, nephelinite, and basanite to kimberlite) occur widely on Earth. However, their petrogenesis and source compositions are not well understood. Kimberlites contain distinct asthenospheric and lithospheric mantle components. Disentangling their relative contributions is a challenging yet important goal in the quest to understand potential temporal and spatial variations in the mantle sources of kimberlites. Towards this aim, we analyzed the Zn and Fe isotope compositions of 50 kimberlites previously well characterized for bulk-rock major-trace and radiogenic isotope compositions.

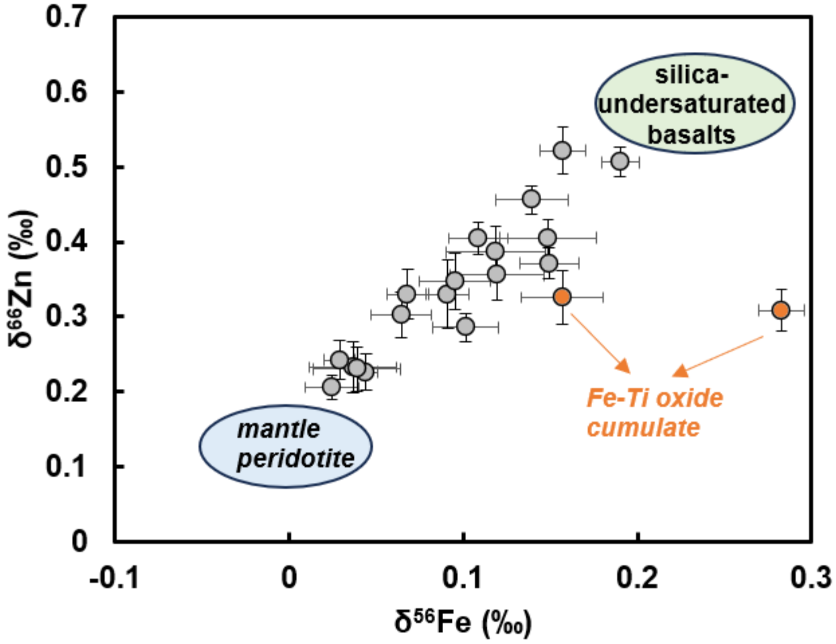

Figure 1: the Zn-Fe isotopic correlation of kimberlites. The two orange samples are Fe-Ti oxide cumulates.

Results

The Zn and Fe isotope compositions of whole rock kimberlites examined in this study (δ^{66}Zn = 0.21-0.52‰; δ^{56}Fe = 0.02-0.28‰) define a robust positive correlation (R^2 = 0.87), spanning from isotopically light compositions typical of mantle peridotites to anomalously heavy compositions that are similar to those of strongly silica-undersaturated silicate magmas such as melilitites and nephelinites (Figure 1). The Zn-Fe isotope compositions of kimberlites are inversely correlated with whole rock Fe/Ti ratios and olivine rim Mg# (Figure 2).

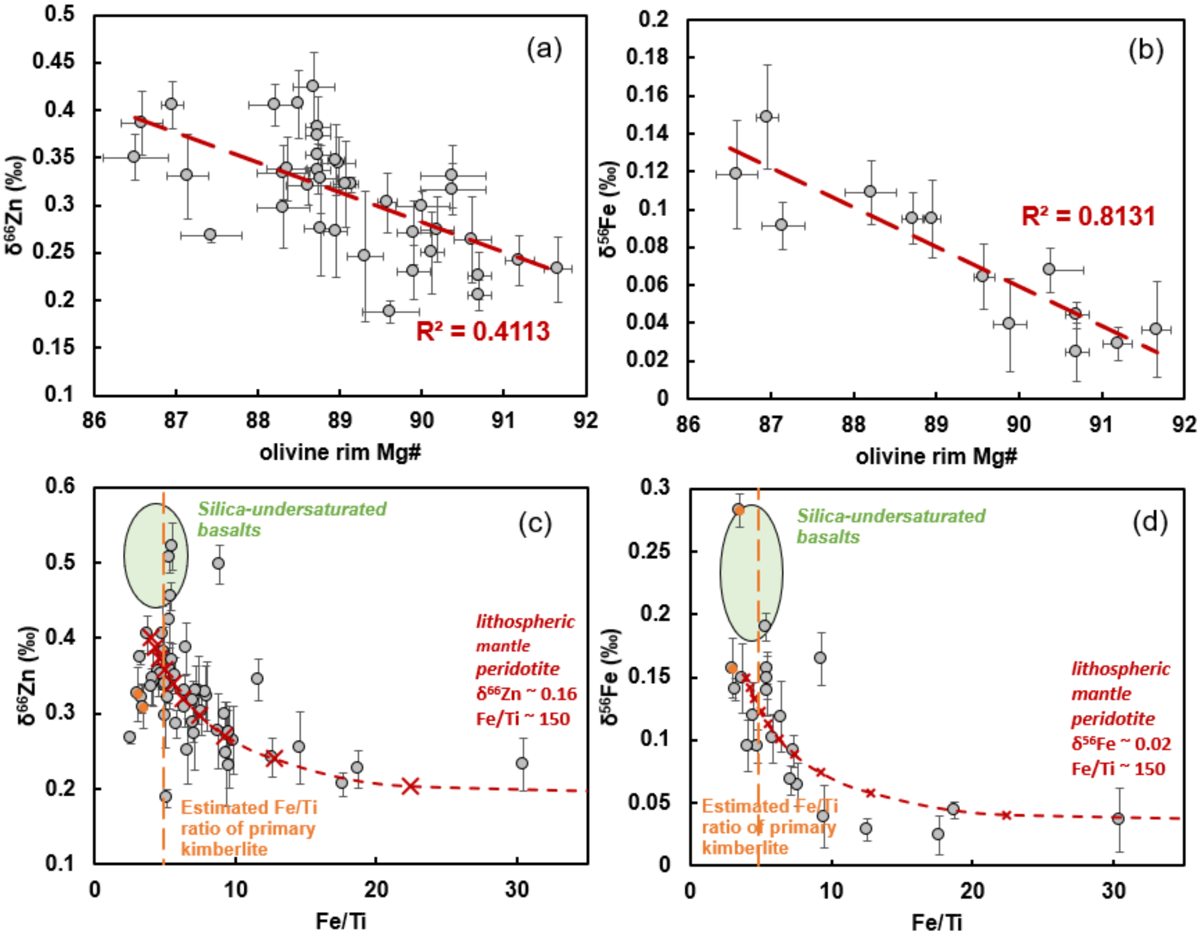

Figure 2: Plots of kimberlite Zn-Fe isotopes vs (a, b) olivine rim Mg#, and (c, d) whole rock Fe/Ti ratios. The red curves in (c, d) represent mixing between primary kimberlite and lithospheric mantle peridotite. The orange dotted line in (c, d) is the estimated Fe/Ti ratio of primary kimberlite melts.

Discussion and conclusions

The correlations between bulk-rock Zn-Fe isotopes, Fe/Ti contents and olivine Mg# are best explained by mixing between a common primary kimberlite melt composition (low Fe/Ti, high δ^{66}Zn-δ^{56}Fe) and lithospheric mantle peridotites (high Fe/Ti, low δ^{66}Zn-δ^{56}Fe). Primary kimberlite melts have the heavy δ^{66}Zn-δ^{56}Fe compositions, and potentially extend beyond those of silica-undersaturated basaltic magmas (e.g., melilitites, nephelinites; Figure 3). These data also demonstrate that no kimberlite is free of lithospheric peridotite contribution.

The cause of such high δ^{66}Zn-δ^{56}Fe values documented in mantle melts is poorly understood. These compositions may reflect variable contributions from isotopically heavy recycled materials such as carbonated pyroxenite (Wang and Liu, 2021; Xu et al., 2024) which, however, must be geographically and temporally ubiquitous in the source of silica-undersaturated melts. We argue that these heavy Zn-Fe isotopic compositions of kimberlites cannot result from recycled materials for three reasons. First, the sources of global kimberlites do not contain significant subducted carbonates required to generate high d^{66}Zn based on mantle-like and/or lighter C isotopes for kimberlites globally (Giuliani et al., 2022). Second, the major element composition of kimberlites records equilibrium with peridotite rather than pyroxenite (Giuliani et al., 2023), which implies that their Zn and Fe isotopic compositions are controlled by fractionation between minerals present in peridotite. Third, plots of Zn and Fe isotopes against proxies of partial melting degrees show progressive increases in δ^{66}Zn and δ^{56}Fe with decreasing degrees of melting from komatiites and picrites to melilitites and finally kimberlites (Figure 3). These lines of evidence combined suggest that the most parsimonious explanation for high δ^{66}Zn-δ^{56}Fe values in kimberlites and silica-undersaturated melts is isotopic fractionation associated with partial melting of similar peridotite sources with mantle-like Zn and Fe isotopes. The Zn-Fe isotope data also support the hypothesis that kimberlites and silica-undersaturated basaltic magmas derive from similar mantle sources under different P/T conditions dictated by variable lithospheric thickness (Cai et al., 2023).

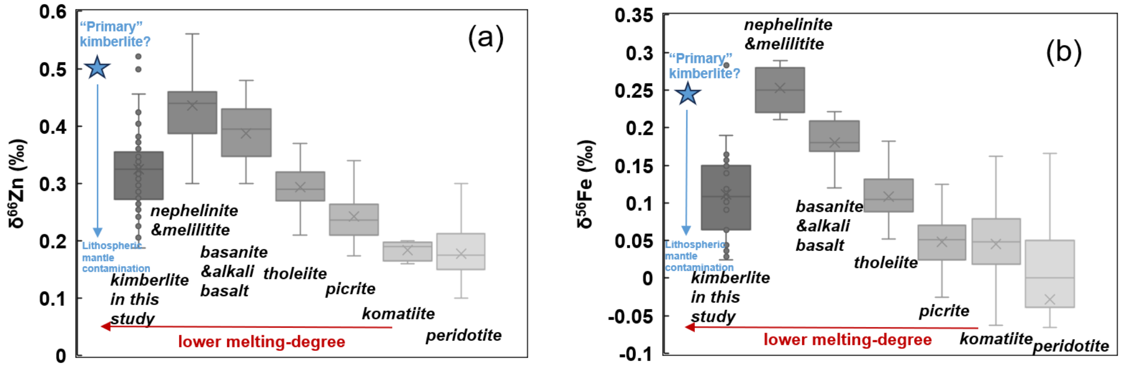

Figure 3: Box and whisker plots of Zn-Fe isotopic compositions of mantle melts and peridotites. The kimberlite data were analyzed in this study, and other data are from the literature.

References

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