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Coupled zinc and iron isotope fractionation in mantle xenoliths: records of carbonated melt–lithosphere interaction

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Coupled zinc and iron isotopic variations in basaltic magmas are potential indices of recycled crustal materials that have modified their mantle sources. Nevertheless, how these isotopes fractionate in response to various types of mantle metasomatism is not well constrained as yet. Here we present high-precision Zn ($\delta^{66}Zn_{JMC\text{-}Lyon}$) and Fe ($\delta^{57}Fe_{IRMM\text{-}014}$) isotope data and *in situ* chemistry for direct mantle samples (peridotites, pyroxenites, and their mineral separates), occurring as xenoliths within Cenozoic alkaline basalts from northeast China. Based on mineralogy and chemical compositions, these xenoliths are classified into four groups. Group I peridotites are almost non-metasomatized, whereas Group II peridotites exhibit typical characteristics of carbonated silicate melt metasomatism (e.g., high La/Yb, low Ti/Eu). Compared with the mantle-like $\delta^{66}Zn$ (~0.18‰) and $\delta^{57}Fe$ (~0.03‰) values of Group I peridotites, Group II peridotites have variable and positively correlated $\delta^{66}Zn$ (-0.04‰ to 0.29‰) and $\delta^{57}Fe$ (-0.38‰ to 0.07‰; N = 6). The light Zn and Fe isotopic compositions of Group II peridotites are attributed to kinetic isotope fractionation during carbonated melt infiltration. Group I pyroxenites, characterized by low Mg# (100 × atomic ratio of Mg / (Mg + Fe); < 89) and positive Eu anomalies, have extremely high $\delta^{66}Zn$ (0.27‰ to 0.62‰) and $\delta^{57}Fe$ (0.19‰ to 0.84‰; N = 5). These pyroxenites are interpreted to be cumulates from carbonated silicate melts, akin to the host basalts originating from partial melting of the asthenospheric mantle containing recycled carbonates. By comparison, Group II pyroxenites have high Mg# (> 90) and display gradual modal variations in the composite xenoliths, consistent with being the product of silicate melt-peridotite reaction. These pyroxenites have higher $\delta^{57}Fe$ (0.02‰ to 0.24‰) but lower $\delta^{66}Zn$ (-0.05‰ to 0.03‰; N = 5) than those of the mantle. The negatively correlated Zn and Fe isotopic ratios suggest inter-diffusion-induced fractionation during silicate melt metasomatism. Collectively, these observations demonstrate that asthenosphere-derived, carbonated and silicate melts could induce substantial Zn and Fe isotopic heterogeneity in the lithospheric mantle through reaction and diffusion during mantle metasomatism. Therefore, coupled variations of Zn and Fe isotopes in mantle-derived rocks or magmas provide valuable approaches for tracing carbonated melt–lithospheric mantle interaction.