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Unmasking weathering pathways using Neodymium stable isotopes

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Neodymium (Nd) stable isotopes offer a promising but still emerging tool for tracing weathering processes in the critical zone. While radiogenic Nd isotopes ($^{143}Nd/^{144}Nd$) in soils and rivers have long been used to constrain weathering processes, or input from external sources, they are insensitive to the active formation of secondary minerals or the accumulation of organic material that fundamentally influence rare earth element mobility. In contrast, stable Nd isotopes ($\delta^{146}Nd$) have the potential to capture isotopic variations associated with mineral dissolution, secondary phase precipitation, and organic-metal interactions, yet natural datasets remain sparse. Here we present an integrated radiogenic-stable Nd isotope dataset for soils, pore waters, and rivers from a basaltic catchment in western Iceland, spanning a range of weathering intensities and redox conditions.

Soils show a systematic shift toward high $\delta^{146}Nd$ values with increasing weathering, reflecting preferential removal of light Nd isotopes into secondary phases, and incorporation into heavy organo-metallic complexes. In well-drained, oxic soils, clay and Fe-oxyhydroxide formation dominate stable Nd, whereas in waterlogged, organic-rich soils, organo-metallic complexation exerts a primary control. Pore waters consistently display higher $\delta^{146}Nd$ than their host soils, preserving the influence of rainwater infiltration (at shallow depths), and secondary mineral formation, and enhanced basalt dissolution (at greater depths). For rivers, radiogenic Nd indicates congruent weathering of the bedrock, but stable Nd isotopes exhibit markedly heavy $\delta^{146}Nd$ signatures that covary with Sm/Nd ratios, consistent with substantial removal of light Nd isotopes into clays and other secondary phases.

Together, these results demonstrate that Nd stable isotopes provide a sensitive new tracer of weathering reactions and organo-metallic interaction. Future applications may include quantifying secondary mineral formation, tracing critical-zone biogeochemical change, and integrating Nd stable isotopes into large-scale weathering models.