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Reconstructing weathering profile evolution in intensely weathered landscapes using REE geochemistry and stable Nd isotopes

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Weathering processes can facilitate the enrichment of critical metals, such as rare earth elements (REE). However, knowledge gaps with understanding REE mobility, groundwater chemistry and weathering intensity controls persist, particularly within deeply and intensely weathered landscapes (e.g., Australia, India and Brazil). Within weathering profiles, REE mobility has traditionally been traced through REE patterns and anomalies, as well as radiogenic isotopes (e.g., Sm-Nd isotope system). Although these approaches give insight into sediment provenance and pH and redox control on REE mobility, intense weathering, overprinting and recycling compromise the effectiveness of these proxies. Novel stable Nd isotopes ($^{146}Nd/^{144}Nd$, expressed as $\delta^{146}Nd$), however, demonstrate potential as a weathering and REE mobility tracer within deeply and intensely weathered profiles. Here, we present the effectiveness of both traditional (REE geochemistry and Sm-Nd isotopes) and novel ($\delta^{146}Nd$) tracers in reconstructing weathering profile evolution at the Lady Ada Au pit, Yilgarn Craton, Western Australia.

The Lady Ada weather profile comprises both (from bottom to top) in-situ (fresh rock, saprock and saprolite) and transported (transported cover and soil) weathering horizons. Traditional REE mobility tracers highlighted two significant groundwater table positions: a precursor shallow, ‘fresh’ and circumneutral-alkaline groundwater, and a successive deep, saline and acid-circumneutral groundwater. Stable Nd isotopes within the Lady Ada weathering profile indicated a significant shift towards light isotope fractionation with progressive weathering in the upper saprolite ($\delta^{146}Nd$ of ca. -0.029‰ in the fresh rock and ranging to -0.233 ‰ in the upper saprolite). Light $\delta^{146}Nd$ compositions in the upper profile indicate inner-sphere REE complexation onto clay minerals [1], where progressive weathering preferentially leaches outer-sphere complexes. Therefore, coupling traditional and novel techniques significantly broadens our understanding of REE mobility and REE-mineral associations during landscape evolution.

[1] Luo, K., Wang, R. J., Zhu, G. H., He, X. Y., Wei, G. J., & Ma, J. L. (2025). Granite weathering and rare earth mineralization: Insights from stable neodymium isotope in tropical saprolites. *Geochimica et Cosmochimica Acta*.