

Ediacaran pristine Phosphorites from the Cuddapah Basin, India: Rare Earth Element mobilization, accumulation and enrichment mechanisms

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Phosphorites, widely distributed across terrestrial sedimentary basins, have recently been highlighted as a potential economic source of rare earth elements (REE) among the many non-traditional critical mineral resources. The global transition to a sustainable economy relies heavily on REEs. In India, domestic REE production comes exclusively from heavy mineral beach sands, while nearly 85% of annual demand is met through imports, underscoring the need for alternative domestic sources.

Here, we document the first identified occurrence of REE-enriched pristine phosphorites from India, exploring the mechanisms behind REE mobilization, accumulation and enrichment within the Proterozoic Cuddapah Basin. The Ediacaran phosphatic beds have been found to be laterally interbedded between shales overlain by flaggy limestones, deposited during normal regression of the sea, which has transitioned into a forced regression favoring the deposition of overlying quartzites. Whole-rock analysis reveals REE+Y concentrations up to six times (1075 ppm) that of Post-Archean Australian Shale (~180 ppm), primarily hosted in fine-grained fluorapatite.

The average whole rock and fluorapatite elemental concentrations, relative to upper crust and average seawater composition indicate seawater inputs dominate the REE budget, while lithogenous sources contribute to the majority of the composition. Early diagenetic processes, including porewater-mediated remobilization and redox-driven redistribution are suggested to have modified the primary geochemical signatures, particularly enhancing MREE enrichment.

The primary authigenic apatite was found to be initially dissolved by acidic pore waters and subsequently reprecipitated as anhydrous fluorapatite enriched in F⁻ and REE+Y under alkaline conditions. During early diagenesis, Mn (oxy)hydroxides and organic matter preferentially scavenged and adsorbed MREE, which were later released through desorption with Mn-reductive dissolution above the sulphate reduction zone. Post-diagenetic

hydrothermal activity, likely linked to igneous intrusions, facilitated the formation of Fe-Mg chlorite (chamosite), redistributing REE and P within the interbedded shales.

These findings underscore the potential of sedimentary basins for REE enrichment and emphasize their importance in meeting the growing demand for REE in renewable technologies.