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Tracing Diagenetic Pathways of Sedimentary Phosphorus Enrichment During the Paleoproterozoic

CHENYI TU[1], GINNY WINTERS[2], BULUSU SREENIVAS[3], ANDREY BEKKER[2] AND MICHAEL A. KIPP[1]

[1]Duke University
[2]University of California, Riverside
[3]National Geophysical Research Institute

Phosphorus (P) is an essential element for all life and is widely regarded as the ultimate limiting nutrient governing marine primary productivity and organic carbon burial. Through these processes, it exerts a fundamental control on atmospheric CO_2 and O_2 levels over geological timescales. Phosphorites—the most P-enriched sedimentary deposits—thus provide a valuable archive for reconstructing past marine P cycling. However, the origin of ancient phosphorites remains debated: do their occurrences reflect changes in the global marine P inventory, or are they primarily the result of local depositional conditions?

Here, we propose to employ a suite of isotopic tracers—specifically calcium (Ca) and magnesium (Mg) isotopes—to shed light on this question. These isotope systems offer strong potential for unravelling the diagenetic histories of ancient carbonate rocks, distinguishing between sediment-buffered and fluid-buffered diagenesis, and can be extended to phosphate rocks as well. Constraining the diagenetic regimes of these P-enriched rocks could ultimately help trace the origin of the P they host. In this study, we focus on the ~1.7 Ga Jhamarkotra Formation of the Aravalli Supergroup, exposed near Udaipur, India, and characterized by phosphatic, stromatolitic carbonates. This succession represents one of the oldest major phosphogenic events in the geologic record. Here we use Ca and Mg isotope ratios in both carbonate and phosphate mineral phases to evaluate their diagenetic histories. If fluid-buffered (open-system) conditions are associated with P enrichment, this could be consistent with a seawater source of P to these phosphatic carbonates. Alternatively, if sediment-buffered (closed-system) conditions dominate, this may indicate a greater contribution from organic-derived P within sediments, although a seawater-derived component cannot be entirely excluded. In either case, P burial may have been governed primarily by local depositional processes. The data generated here will provide key insights into the diagenetic evolution of P-rich carbonates and, more broadly, into the mechanisms driving P enrichment in the ancient rock record.