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Biogeochemical controls on REE-rich mud formation: implications from an Nd–P mass-balance model

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"REE-rich mud" is increasingly discussed as an unconventional resource for critical rare-earth elements (REEs) demanded by green and high-tech industries [1]. This deposit type corresponds to pelagic clay with anomalously high REE abundances, often expressed as pronounced heavy-REE enrichment. A central feature of REE-rich mud is that biogenic calcium phosphate (BCP; fish-bone/teeth apatite) serves as a dominant host phase for REEs, linking sedimentary REE enrichment to marine phosphorus (P) cycling and biological productivity [2].

Preliminary Nd–P one-box mass-balance work [3] suggested that fish-derived P burial may represent a non-negligible fraction of total P burial in pelagic settings, implying that variability in the oceanic P cycle could exert first-order control on the conditions under which REE-rich mud forms. However, such a simplified framework cannot explicitly reflect processes that shape upper-ocean nutrient gradients and recycling, including the redistribution of phosphate availability, with downstream consequences for the production and burial of fish debris (BCP).

Here we develop an expanded Nd–P mass-balance framework that incorporates heterogeneous surface nutrient regimes while tracking the principal P burial pathways—burial associated with organic matter, burial via authigenic phases (Ca-phosphate and Fe-bound P), and burial associated with fish debris (BCP)—together with neodymium (Nd) as a representative REE.

Using sensitivity analyses and targeted scenario experiments, we evaluate how changes in surface nutrient patterns, biologically mediated P cycling, and export/burial efficiency alter the inferred contribution and distribution of BCP burial, and we discuss implications for the conditions favorable to REE enrichment and REE-rich mud formation.

[1] Kato et al. (2011) Nat. Geosci. 4, 535–539. [2] Ohta et al. (2020) Sci. Rep. 10, 9896. [3] Matsunami et al. (2025) AGU Annual Meeting 2025, PP24B-08.