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Bottom-up seafloor control on ocean trace-metal cycles

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Trace elements and their isotopes (TEIs) are key tracers of ocean and Earth system processes, yet the mechanisms controlling their large-scale distributions remain uncertain. Conventional "top-down" frameworks emphasize surface inputs, biological uptake, and reversible scavenging by biogenic particles. However, recent observations suggest this paradigm cannot fully explain the behavior of particle-reactive TEIs such as rare earth elements (REE) and neodymium isotopes (εNd), particularly in the deep Pacific.

Here we integrate water-column, sediment, and porewater REE and εNd measurements from the Pacific with diagenetic and ocean models. Water-column profiles demonstrate that Mn oxides, though a minor fraction of suspended particles, dominate REE scavenging. When represented realistically in ocean models, scavenging acts as a net sink throughout the water column, implying that additional sources are required to maintain observed Nd concentrations. Porewater data and modeling reveal a benthic flux generated by sediment diagenesis, comprising (1) a recycled component from previously scavenged elements, and (2) a "new" component produced by marine silicate weathering within sediments. Although recycled fluxes dominate elemental budgets, the new component is essential for generating the radiogenic εNd signature of Pacific Deep Water.

Ocean simulations incorporating oxide-driven scavenging, benthic sources, and bottom-intensified mixing reproduce the observed distributions of Nd concentration and εNd. These results highlight the key role of seafloor sediment in shaping TEI distributions. Our findings support a "bottom-up" framework in which particle-type-dependent scavenging, diagenetic recycling, and marine silicate weathering collectively control TEI behavior, with broad implications for interpreting marine tracers and understanding Earth system dynamics.