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# The evolution of microbial alkaline phosphatases and their role in phosphorus recycling across Earth's history

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Phosphorus (P) is an essential nutrient for life on Earth and has long been recognized as the key limiting factor for marine primary productivity over geologic timescales. Much of the oceanic P pool is bound within organic compounds derived from phytoplankton biomass, rendering it inaccessible without enzymatic breakdown. Marine microorganisms overcome this limitation largely by producing alkaline phosphatase enzymes, which hydrolyze phosphate esters and release bioavailable inorganic P that can be readily assimilated to meet cellular nutritional demands. Through this activity, alkaline phosphatases play a central role in regenerating P and regulating its availability, thereby shaping the structure and dynamics of the marine P cycle. Here, we reconstructed the emergence and proliferation of alkaline phosphatases to determine how the oceans' capacity to recycle P has evolved through time. We reconciled a time-calibrated tree of life with phylogenetic trees for the three most common prokaryotic alkaline phosphatase genes (*phoA, phoD, phoX)* to estimate the timing of gene acquisition through speciation, duplication, and horizontal gene transfer. Molecular clock analyses suggest that alkaline phosphatase enzymes originated in the Archean, with *phoA* emerging ca. 3.4 Ga and *phoD* and *phoX* ca. 2.9 Ga. Their early emergence indicates that the ability to exploit organic-bound P has been a fundamental microbial strategy for most of Earth's history, enabling early life to meet its cellular P demands despite nutrient scarcity. To explore when alkaline phosphatase genes spread, we quantified the occurrence of gene-specific events as a proportion of total speciations to determine when microbial lineages inherited and retained alkaline phosphatase genes, thereby gaining the capacity to recycle organic-bound P. We observed a rise in the spread of alkaline phosphatase genes beginning in the Mesoproterozoic and peaking in the Neoproterozoic, suggesting a strong selective pressure to acquire alkaline phosphatase enzymes at this time. We speculate that this spread may have occurred in response to the broader ecological transition from cyanobacteria- to algae-dominated oceans, increasing biomass production and P demands in surface waters. Taken together, our findings shed light on the underappreciated role of alkaline phosphatases in sustaining early microbial ecosystems and ultimately primary productivity throughout Earth's history.