

Exploring the role of alternative phosphorus species in Precambrian biogeochemical cycles: A genomics approach

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Some geochemical data suggest that phosphate was biolimiting in Earth's early oceans. Life may have overcome this by using alternative phosphorus species such as phosphonates, which may have been more bioavailable. Phosphonates are organic molecules with a direct carbon-phosphorous bond which renders them relatively stable. They make up a considerable proportion of total dissolved organic phosphorous (~ 25 %) in the global ocean and are used by a wide variety of planktonic microbial communities. However, there is little information on phosphonate availability in geological records, so it remains unknown whether and how these molecules contributed to phosphorous cycles in the past. To address this gap, we use a phylogenetics approach to predict when phosphonate utilisation pathways evolved in microbial communities. Results of Bayesian molecular clocks and gene-tree-species-tree reconciliations suggest that Neoproterozoic microbial communities could catabolise phosphonoacetaldehyde using the enzymes PhnX, PhnZ and PhnW. Whereas methods of producing phosphonates using PEP mutase and phosphonoacetaldehyde dehydrogenase evolve later, towards the end of the Paleoproterozoic. Enzymes for utilising small reduced phosphorous molecules, including hypophosphite and phosphite using HtxB, HtxA and PtxB also seem to emerge after the Great Oxidation Event, in the Meso- or Paleoproterozoic (Figure 1). Together, these results provide insight into how microbial communities have contributed to biogeochemical cycles of phosphorous using complex organic molecules. To fully understand how these novel metabolisms impacted biogeochemical cycles of phosphorous, carbon and oxygen and why they emerged when they did will require further understanding of nutrient availability and microbial competition through time.

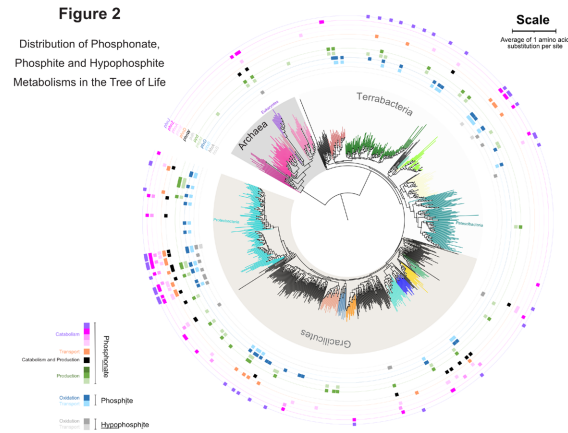


Figure 1

Estimated Origin of Phosphonate, Phosphite and Hypophosphite Metabolisms

