Phosphite: An energy source for life on Earth and beyond

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Phosphorus (P) is an essential nutrient for all life and predominantly exists on Earth as oxidized phosphate (P^{+5}). Consequently, our understanding of the origins of life have been hampered by the yet unresolved "phosphorus problem", which describes the paradoxical dependence of life on phosphate, despite its unreactive and insoluble nature, resulting in its limited bioavailability. Mounting evidence suggests that reduced P compounds, such as phosphite (HPO_3^{2-}), were a likely source of soluble P on early Earth and could have ushered the development of P-dependent life. Meteors enriched in metal phosphides were likely sources of HPO_3^{2-}, further suggesting that reduced P may have been a relevant constituent of primitive life. Recently, two autotrophic organisms were identified that use HPO_3^{2-} as an electron donor for cellular energy metabolism. This metabolism, called dissimilatory phosphite oxidation (DPO), circumvents P limitation while concomitantly providing non-phototrophic energy for carbon fixation, factors which are crucial for aphotic deep subsurface survival and potentially for extra-terrestrial life. However, DPO is poorly understood, with only two representatives that are both phylogenetically and geographically disparate. In an effort to understand the diversity and prevalence of this metabolism, our group established 42 DPO enrichments from six different wastewater facilities throughout the San Francisco Bay area. Over 70% of our enrichments showed DPO activity, with representative enrichments from each of the six sample sites. No phosphite oxidation occurred in heat-killed controls. Furthermore, DPO activity was not observed with nitrate, sulfate, or perchlorate as alternative electron acceptors and only occurred coupled to CO_2 reduction. We hyper-enriched one of our DPO cultures (SV3) to the extent of achieving a clean 16S amplicon signal most closely related to one of the two known DPO representatives, Phox-21 in the GW-28 clade of the Deltaproteobacteria. SV3 only grew lithoautotrophically with CO_2 as the sole electron acceptor and carbon source. The observation that all known DPO representatives are autotrophic suggests that DPO may be biochemically linked to CO_2 fixation. If true, DPO could represent a major, unrecognized means of primary production. Our work couples physiological studies and metagenomic analyses to determine the prevalence of DPO on Earth while touching on the implications of these findings on carbon fixation, global P geochemistry, and the search for extra-terrestrial life.