Cyanobacterial oxygenic photosynthesis dominated Mid-Proterozoic primary productivity

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Mid-Proterozoic oceans were largely anoxic, with Fe-rich and sulfide-rich regions separated in space and time. Although this timeframe post-dates the evolution of oxygenic photosynthesis in ancestral cyanobacteria and the Paleoproterozoic accumulation of oxygen during the Great Oxidation Event, it is unclear if primary production was the domain of oxygenic cyanobacteria or if environmental conditions favored other phototrophic metabolisms.

Carbon isotope ratios in sedimentary organic C provide the most continuous paleo-metabolic record through this time and could, in principle, identify the dominant primary producers. Our Monte Carlo simulations of Mid-Proterozoic C isotope values suggest that this record is inconsistent with C isotope fractionation by modern cyanobacteria, even at elevated experimental CO_2 [1]; however, all extant cyanobacteria employ a sophisticated biochemical and biophysical C concentrating mechanism (CCM) to increase the efficiency of C fixation under low CO_2. Here we investigate the relevance of this modern physiological adaptation to cyanobacterial C isotope fractionation.

We use a genetic system in the model cyanobacterium Synechococcus sp. PCC 7002 to create physiological analogs of ancient cyanobacteria lacking CCMs and investigate their corresponding response in C isotope fractionation. Our experiments show that at pH and CO_2 concentrations relevant to the Proterozoic, the full isotope effect associated with C fixation by RuBisCO is expressed. These results reconcile the discrepancy between C isotope fractionation by cyanobacterial primary producers and the Mid-Proterozoic C isotope record. It appears that, for at least ~1 billion years after the evolution of oxygenic photosynthesis, cyanobacteria were the ecologically dominant primary producers in the global ocean.

[1] Popp BN, et al. (1998) Geochim Cosmochim Acta 62(1):69–77.