The role of remineralization in Archean phosphorus limitation

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The macronutrients nitrogen (N) and phosphorus (P) are key regulators of marine primary productivity. Because some organisms can fix atmospheric N_2 into biomass, it is thought that P – which only enters the oceans via continental weathering – likely sets the pace of marine biological productivity on geological timescales. Recent findings of low P concentrations in Archean marine sedimentary rocks have led to a near consensus view that P levels were much lower at this early stage in Earth's history. The most common mechanisms invoked for this P scarcity involve scavenging of P from the water column via iron (Fe) minerals. However, new data have shown that the P contents of Archean marine sedimentary rocks do not correlate with Fe concentrations, and rather seem to be best explained as arising from deposition of P in biomass. Here we propose a solution to this conundrum: limitation of Archean P levels via muted biomass remineralization. Using a simple box model, we show that the scarcity of oxidants in the Archean ocean would have likely led to high burial efficiency of organic matter (and associated P). Such a system would have had low steady-state P concentrations, and would have required an increased supply of oxidizing power (perhaps rising seawater sulfate levels) to shift toward higher P levels, and correspondingly higher productivity. We propose that this mechanism could help explain the delayed oxygenation of Earth's atmosphere several hundred million years after oxygenic photosynthesis first arose.