Spinning down to oxygen: How did the Moon's retreat cause microbial mats to accumulate oxygen in the atmosphere?

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Current models of planetary oxygenation for the Neoproterozoic struggle to explain the preceding billion years of low-oxygen stasis together with the relatively rapid increase of atmospheric oxygen towards present atmospheric levels. The marked increase of the Neoproterozoic Oxygenation Event (NOE) was the last major geochemical transition towards a profusely oxic planet. We developed a modeled understanding of the causal mechanisms of how the Moon's retreat from the Earth could render greater diel export of oxygen from benthic photosynthetic mats, resulting in a significant atmospheric oxygen accumulation.

The Earth-Moon orbit was in a resonant stability during the Precambrian with the Earth's mean rotation rate remaining at ~21h. An escape from resonance locking is considered to have occurred around 650 Myr ago, coinciding with the NOE, bringing the rotation rate towards the modern 24h. Using a mathematical model of benthic mats that considers abiotic and microbial chemical interactions under diffusive mass transfer settings, we explored the effect of daylength, the primary insolation dynamic, on the net oxygen export from photosynthetic mats.

Starting from a simple benthic mat with photosynthetic oxygen production by cyanobacteria, aerobic respiration, sulfate reduction and abiotic sulfide oxidation, a fundamental property of benthic photosynthetic systems emerges: longer daylengths leads to greater net oxygen export per day. This occurs due to the interaction of daylength-dependent light dynamics with the fixed mass transfer limitation through molecular diffusion. Considering mats of increasing biological plausibility – with anoxygenic photosynthesis, more complex metabolic regulation, varying redox conditions of the water column – shows that the dependence of net diel oxygen export on daylength becomes stronger.

The estimated accumulation of atmospheric oxygen (beyond burial rate of organic carbon) from the daylength-driven oxygen export from benthic photsynthetic systems could reach ~15% of present atmospheric levels within 100Myr after resonant escape.