Nutrient-O_2 feedbacks and Proterozoic pO_2 regulation

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Earth's O_2 evolution was not unidirectional. Despite major oxygenation during the GOE and subsequent Lomagundi Event, proxy records collectivity suggest that atmospheric pO_2 fell precipitously and remained low, perhaps as low as 0.1% of the present atmospheric level (PAL), during the mid-Proterozoic. The level at which pO_2 stabilized during this time remains controverisal because long-term maintanance of exceptionally low pO_2 during this 'Boring Billion' interval is difficult to reconcile with photochemical models that predict O_2 bistability and a tendancy for 'runaway' oxygenation post-GOE. The current generation of photochemical models, however, assume static O_2 production and do not account for the possibility that biospheric O_2 fluxes are sensitive to atmospheric pO_2.

We suggest that feedbacks within the N cycle may allow the stabilization of atmospheric pO_2 at a much lower level than today, independent of atmospheric processes. Under O_2 deficient conditions, an increase in O_2 concentrations in surface environments translates to an increased capacity for the conversion of NH_4^+ to NO_3^- via nitrification and, therefore, greater potential for the loss of bioavailable N via denitrification and NO_3^--dependant methanotrophy. The result is a negative feedback in which oxygenation tends to promote N scarcity and disfavor O_2 accumulation [1].

Meanwhile, mid-Proterozoic surface ocean conditions would have been suboptimal for cyanobacterial N fixation and may have impeded the replenishment of biospheric N—further disfavoring oxygenation. Potential obstacles to N fixation include: (1) O_2 inhibition of nitrogenase and (2) metal cofactor limitation, which is suggested by muted Mo enrichments in Proterozoic shales. Widespread N scarcity, therefore, may provide a mechanism to throttle O_2 accumulation in Earth's atmosphere despite the photochemical instability of low O_2 atmospheres.

[1] Fennel, K., Follows, M., and Falkowski, P.G. (2005) The co-evolution of the nitrogen, carbon and oxygen cycles in the Proterozoic ocean, *American Journal of Science*.