Multiple Equilibria in pO_2: Archean, Proterozoic, Phanerozoic

T.A. LAAKSO* AND D.P. SCHRAG

Dept. of Earth and Planetary Sciences, Harvard Univ., Cambridge MA 01420 USA
(*correspondence: laakso@fas.harvard.edu)

Atmospheric pO_2 has changed by orders of magnitude over Earth history. However, we lack a coherent theory of oxygen dynamics that can explain either the abrupt oxidation events at each end of the Proterozoic, or the particular pO_2 values associated with the intervening periods. We propose that a single dynamical framework should be able to explain this entire history of pO_2.

Using a simple biogeochemical model, we have shown that the oxygen-dependence of organic carbon burial can stabilize pO_2 at Phanerozoic levels. However, this feedback prevents stability at lower Proterozoic levels, unless the increase in burial efficiency is balanced by a compensating decrease in total primary production [1]. Therefore, there must exist a positive feedback linking phosphorus inputs to pO_2. This relationship may arise from the kinetics of iron oxidation, and the increased P adsorption capacity of freshly-formed iron oxyhydroxides.

This system of feedbacks creates a two-state atmosphere, in which pO_2 remains less than 0.1 PAL until a large perturbation drives it toward modern values. The Neoproterozoic snowball events, which coincide with a period of oxidation, are such a perturbation. Insoluble oxygen is pumped to the atmosphere from productive polynyas, but limited air-sea gas exchange decouples pO_2 from its regulating process, marine organic carbon burial.

In a very low oxygen atmosphere such as the Archean, ($pO_2<10^{-5}$ PAL) the stabilizing feedback is likely to be reaction with a hydrogen- or methane-rich atmosphere, rather than reaction with organic carbon. The concentration of these reducing species would then be controlled primarily by hydrogen escape. However, a sufficiently large perturbation in pO_2 would increase thermospheric absorption of solar radiation and warm the hydrogen exobase, increasing escape rates. This would drive down $p(\Sigma H_2)$ until oxygen could stabilize at a higher level: the Great Oxidation Event.

This perturbation can also be explained by a conspicously-timed snowball event. A large drop in surface temperature and atmospheric water vapor limits OH production, slowing H_2 oxidation kinetics and allowing a transient increase in O_2, until the stable Proterozoic state is achieved.

[1] Laakso & Schrag (2014) *EPSL* **388**, 81-91.