What was the Proterozoic oxygen level and what regulated it?

T.M.Lenton[1], S.J.Daines[1], B.J.W.Mills[2]

[1]College of Life and Environmental Sciences, University of Exeter, Exeter EX4 4QE, UK (t.m.lenton@exeter.ac.uk)
[2]School of Earth and Environment, University of Leeds, Leeds LS2 9JT, UK

Whilst there is consensus that atmospheric oxygen (pO_2) remained below the present atmospheric level (PAL) for more than 1.5 billion years following the Paleoproterozoic Great Oxidation Event (GOE), the actual oxygen levels, and the mechanisms that stabilised them, remain outstanding puzzles. However, we contend that available data interpreted with quantitative models can help solve both puzzles.

Specifically, hypothesised pO_2<0.001 PAL [1] is inconsistent with evidence for spatially heterogeneous redox structure of the Proterozoic ocean. Under pO_2<0.001 PAL, the ocean would have reverted to an 'oxygen oases' scenario, indistinguishable from a pre-GOE pO_2~10^{-5} PAL, i.e., disequilibrium of the surface ocean O_2 with respect to the atmosphere and fully anoxic deeper waters [2]. This holds for a range of assumptions about the biota (or lack of it) and nutrient levels. Furthermore, if we accept evidence for deeper ocean spatial redox structure, and some form of biological carbon pump, this constrains the ratio of O_2 to ocean limiting nutrient concentration to have been ~0.4 of present [2].

A different model [3] for long-term erosion, weathering and biogeochemical cycling shows that stable low pO_2 levels can be explained by the tectonic recycling of previously accumulated sedimentary organic carbon, combined with the oxygen-sensitivity of oxidative weathering. The results indicate a strong negative feedback regime when atmospheric oxygen concentration is of order pO_2~0.1 PAL, but that stability is lost at pO_2<0.01 PAL. Within these limits, the carbonate carbon isotope ($\delta^{13}C$) record becomes insensitive to changes in organic carbon burial rate, due to counterbalancing changes in the weathering of isotopically-light organic carbon. This can explain the lack of secular trend in the Precambrian $\delta^{13}C$ record, and reopens the possibility that increased biological productivity and resultant organic carbon burial drove the Great Oxidation Event.

[1] Planvsky, N.J. *et al.* (2014) *Science* 346, 635-638.
[2] Lenton, T.M. & Daines, S.J. (2017) *Ann. Rev. Mar. Sci.* **9**, 31-58.
[3] Daines, S.J., Mills, B.J.W. & Lenton, T.M. (2017) *Nat. Comms.* **8**, 14379.