Atmospheric redox evolution and life

DAVID C. CATLING[1], S. KADOYA[1], R. W. NICKLAS[2], I. S. PUCHTEL[2], A. D. ANBAR[3]

[1]Univ. of Washington, Dept. Earth & Space Sci. / Astrobiology Program, Seattle, WA (dcatling@uw.edu)
[2]Dept. of Geology, Univ. of Maryland, College Park, MD
[3]School of Earth & Space Exploration, ASU, Tempe, AZ

Atmospheres on rocky worlds tend to evolve from reducing to oxidized. Photochemical products from a strongly reducing atmosphere on the early Earth could have driven the origin of life. Indeed, escape-driven fractionation of Xe isotopes is permissive of an H_2-rich Hadean atmosphere [1]. Then, by the early Archean, evidence suggests weakly reducing air and a microbial biosphere [2].

Later, atmospheric oxygenation occurred, but its timing is poorly understood. One key issue is a 100s of Myr gap between evidence for the earliest oxygenic photosynthesis and the Great Oxidation Event (GOE). Recent data show that the Archean mantle became progressively oxidized [3,4]. Thus, Archean volcanic gases would have been more reducing than today, and by rapidly consuming O_2, these gases could have delayed the GOE.

Here, we find that the trend in volcanic gas composition inferred from mantle redox data combined with O_2 fluxes derived from the carbon isotope record predict a ~2.4 Ga GOE. We quantify K_{oxy}, a ratio of O_2 sources to kinetically rapid sinks. An anoxic atmosphere has $K_{oxy} < 1$, and the GOE occurs when crossing the $K_{oxy} = 1$ threshold (Fig. 1).

Thus, mantle oxidation plausibly set the tempo for atmospheric oxygenation and thus for biological evolution. Ultimate drivers of mantle oxidation could be either mixing of a redox-heterogeneous mantle or time-integrated oxidation from escape of hydrogen. Such a linkage between planet interior and atmosphere may apply to other Earth-like planets. In turn, the timing of oxygenation may limit the prevalence of aerobic life and thus biological complexity.

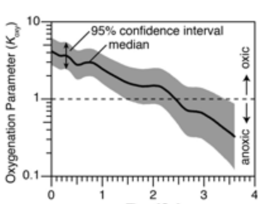

Fig. 1. The evolution of K_{oxy}, calculated from volcanic O_2 sinks using a data-derived mantle redox trend and a global O_2 source derived from the carbon isotope record [5].

[1] Zahnle et al. (2019) *GCA* 244, 56-85. [2] Catling & Kasting (2017) *Atmospheric Evolution on Inhabited and Lifeless Worlds*, CUP [3] Aulbach & Stagno (2016) *Geology* 44, 751-754 [4] Nicklas et al. (2019) *GCA* 250, 49-75. [5] Kadoya et al., in prep.