Earth system oxygenation: Toward an integrated theory of Earth evolution

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The cause of the progressive oxygenation of Earth's biosphere remains poorly understood. The problem is bounded by the interplay of three irreversible, secular changes: (1) the escape of H to space, which makes the planet more oxidized; (2) the evolution of photoautotrophy – which converts solar energy into redox disequilbrium – and related metabolisms; and (3) the cooling of the planet, which affects the exchange of material between Earth's reduced interior and relatively oxidized surface through a variety of processes.

The first of these changes is quantitatively considered elsewhere, and is connected to the other two because H escape depends on atmospheric H_2 and CH_4 contents.

The second of these changes is an area of vigorous research, particularly over the past decade. Important work included efforts to constrain the timing of key evolutionary events using organic geochemical and genomic records, and to understand the timing and tempo of environmental oxidation, particularly preceding the "Great Oxidation Event" (GOE) at ~2.4 Ga. As the community sorts through various debates, evidence is accumulating that the pre-GOE period was a dynamic era of transient "whiffs" of oxidation, most likely due to small amounts of biogenic O_2 that appeared as early as ~3.0 Ga. The implication is that O_2 sinks generally overwhelmed substantial O_2 sources through the first half of Earth history, and that a decrease in sink strength and/or increase in source strength could have resulted in increasing instability of trace pO_2 in the runup to the GOE.

The most likely sinks are coupled to reductants in Earth's interior, which leads us to the third major change—secular cooling of the planet. It is almost certain that this cooling led to changes in mantle dynamics, rates of plate motion, and melting behaviors, which in turn affected volcanism, crust composition, hydrothermal and metamorphic alteration, ocean nutrient budgets, and recycling at subduction zones. These factors have all been considered as possible drivers of surface redox evolution, but typically in isolation. We are tackling the grand challenge of developing an *integrated* theory of Earth evolution, grounded in the physics of a cooling planet, and motivated by the implications for chemical evolution of the biosphere. The framework of such a theory will be presented.