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Dynamic oxygenation of the early atmosphere and oceans

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The traditional view of the oxygenation of the early atmosphere and oceans depicts irreversibly rising abundances in two large steps: one at the Great Oxidation Event (GOE) ca. 2.3-2.4 billion years ago (Ga) and another near the end of the Neoproterozoic. This talk will explore how the latest data challenge this paradigm. Recent results reveal a far more dynamic history of early oxygenation, one with both rising and falling levels, long periods of sustained low concentrations even after the GOE, complex feedback relationships that likely coupled nutrients and ocean redox, and dramatic changes tied through still-emerging cause-and-effect relationships to first-order tectonic, climatic, and evolutionary events.

In the face of increasing doubt about the robustness of organic biomarker records from the Archean, researchers are increasingly reliant on inorganic geochemical proxies for the earliest records of oxygenic photosynthesis. Proxy data now suggest oxygenesis at ca. 3.0 Ga with a likelihood of local oxygen build up in the surface ocean long before the GOE, as well as low (and perhaps transient) accumulation in the atmosphere against a backdrop of mostly less than ca. 0.001% of the present atmospheric concentration. By the GOE, the balance between oxygen sources and sinks shifted in favor of persistent accumulation, although sedimentary recycling of non-mass-dependent sulfur isotope signatures allows for the possibility of rising and falling atmospheric oxygen before the GOE as traditionally defined by the sulfur isotope record. Recycling may also hinder our ability to precisely date the transition to permanent oxygen accumulation beyond trace levels.

Diverse data point to a dramatic increase in biospheric oxygen following the GOE, coincident with the largest positive carbon isotope excursion in Earth history, followed by an equally dramatic drop. This decline in Earth surface redox potential ushered in more than a billion years of dominantly low oxygen levels in the atmosphere—at perhaps much less than 1% of modern levels, as suggested by new chromium isotope data—and persistent anoxia in the deep ocean with euxinia limited to productive ocean margins. Under conditions of ca. 1-10% euxinic seafloor, bioessential trace metals would have been drawn down to levels that may have deleteriously impacted the availability of fixed nitrogen in the oceans and, through associated redox-dependent feedbacks, sustained comparatively low global levels of primary production and corresponding deficiencies in biospheric oxygen.

This episode of intermediate redox gave way to increases in ocean-atmosphere oxygen that appear to predate the Sturtian glaciation. Although the causes behind this transition are not well understood, they are certain to reflect relationships among large-scale tectonic, climatic, and biotic drivers of nutrient availability and organic carbon production and burial. Oxygen during the Ediacaran, following the Marinoan glaciation, likely rose and fell episodically in ways that must have impacted the diversity and ecological relationships among early animals. Also, the low oxygen concentrations purported for the mid-Proterozoic are consistent with the long-held, but recently challenged, suggestion that the rise of animals was ultimately coincident with, and likely causally related to, a Neoproterozoic rise in oxygen.