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A decade of progress in studies of Archean oxygenation

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The Great Oxidation Event (GOE) was originally defined as an interval of time marking the transition from an essentially oxygen-free atmosphere to one that never again dipped to those very low pre-GOE levels. For more than a decade, however, the GOE has been narrowed to the point in Earth history around 2.4 billion years ago when mass-independent (MIF) fractionation of sulfur isotopes disappeared from the geologic record and never reappeared. At the same time, many researchers advanced the notion that oxygenic photosynthesis predated the GOE by at least a few hundreds of millions of years, thus placing the burden on simultaneous oxygen sinks to explain the persistence of biospheric oxygen deficiency. And as one might predict in the face of a dynamic balance between oxygen sources and sinks, incipient oxygenation occurred across a continuum of spatiotemporal scales—from micro-niches within microbial mats to regional 'oases' in the productive portions of the sunlight-rich surface ocean to transient 'whiffs' of oxygen in the atmosphere. The latter may have been capable of supporting oxidative weathering of the continents and associated diagnostic elemental fluxes to the ocean. In other words, oxygen production was on the scene and played out dynamically in space and time, as we should expect for a trace gas in a still strongly reducing world, but many if not most of the present signals of Archean oxygenation do not demand accumulation in the atmosphere.

This talk will be a review of a decade of research and a signpost for future directions. In particular, we will examine the predicted inorganic geochemical fingerprints and model relationships of mats and crusts versus oases versus whiffs. Also discussed will be the newest evidence for the timing of initial biological oxygen production and the inability of traditional proxies, such as detrital pyrite, to track oxygen cycling within the ocean. These traditional proxies are also challenged to quantify oxygen production and accumulation in the atmosphere. At the same time, recycling of older MIF-S signals in the rock record has the capacity to blur the sharpness of the GOE and to mask transient oxygenation during the Archean. The history of microbial innovation will be explored against this backdrop of shifting redox, along with the range of views of what finally triggered the seemingly irreversible step in oxygenation at the GOE. Although irreversible in the sense of marking a permanent rise of oxygen to a level that no longer favored preservation of MIF-S atmospheric signals, we caution against any view that imagines that post-GOE oxygen dynamics were unidirectional. New suggestions of dramatic increases and decreases throughout the Proterozoic suggest otherwise. In fact, our newest results indicate that the mid-Proterozoic may have been much more like the Archean in terms of the oxygen landscape of the ocean and atmosphere—perhaps characterized by dynamic oases and whiff-like increases of its own—compared to the intervals immediately before and after. All this added perspective casts the notion of the GOE and its purported singular effect on the biosphere in a very different light.