https://doi.org/10.1038/s41561-025-01708-1

First breaths of a hospitable Earth

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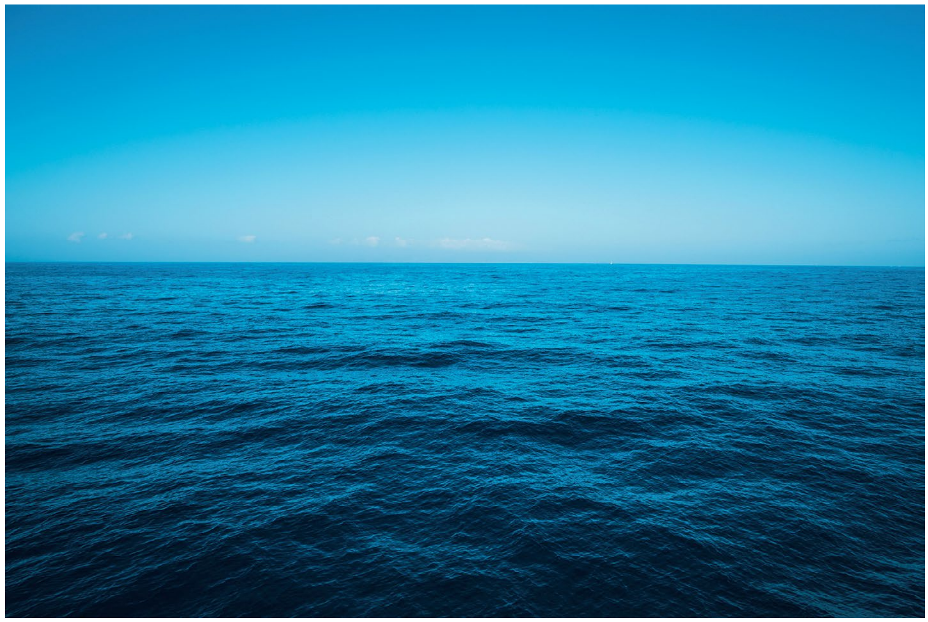
The oxygenation of the atmosphere was a pivotal point in Earth's evolution. Punctuated environmental perturbations in its run-up laid the foundations for this event.



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The rise in atmospheric oxygen that occurred between about 2.4 and 2.1 billion years ago was a fundamental step on the path towards the inhabited Earth we know today. This interval, known as the Great Oxidation Event, saw the earlier reduced atmosphere with negligible O_2 become increasingly oxygenated, along with shallow marine environments. Although O_2 only rose to around a few percent of present atmospheric levels initially[1], it allowed for the evolution of complex life and had a profound effect on geochemical cycling. However, the lead-up to the Great Oxidation Event is arguably as important as the event itself. In this issue, accompanied by an online focus of content from the *Nature Geoscience* archive, we explore the steps that led up to this event.

The seeds for oxygenation were sown earlier in the Archean with the evolution of cyanobacteria capable of producing O_2 as a byproduct of their photosynthetic metabolism. They have been traced back at least several hundred million years before the Great Oxidation Event[2]. Initially, all O_2 produced was consumed in reactions within the chemically reducing conditions of the atmosphere and ocean. It was not until the Great Oxidation Event that enough oxygen flooded the atmosphere to outstrip the capacity of this sink and persist on long timescales.

Increasing evidence suggests the Archean atmosphere and oceans had been in a state of flux for several hundred million years prior to the Great Oxidation Event[3,4]. Cyanobacteria were producing O_2 that was able to intermittently accumulate in certain environmental settings. This led to the idea of 'oxygen oases' and 'whiffs' — localized shallow marine areas that experienced transient episodes of higher O_2. However, details of the extent, longevity, and drivers of these events are unknown. Geochemists are answering these questions using tracers sensitive to the presence of O_2 on various spatial and temporal scales.

An Article by Liang et al. in this issue tackles this problem with nitrogen isotopes, which can record marine oxygenation. They look at banded iron formations that can give insight into the changes occurring in deeper marine shelf environments. Their results suggest that deeper settings were also experiencing fluctuating oxygenation levels for at least 200 million years prior to the Great Oxidation Event, with episodes of higher O_2 punctuated by a return to a reduced atmospheric state.

An Article by Chen et al. also explores the temporal and spatial extent of transient oxygenation episodes, using thallium isotopes to trace manganese oxide burial in the Archean ocean. They find evidence for widespread burial as early as 2.65 billion years ago. Importantly, this suggests marine sediments were persistently oxygenated at that time, over a regionally extensive area. These results also build a picture of widespread fluctuations in atmospheric O_2.

The drivers of these changes are complex to untangle, but an Article by Cañadas et al. explores the role phosphorus, a key nutrient, may have played. They look at samples that record surface water oxygen accumulation about 500 million years prior to the Great Oxidation Event and suggest that pulsed increases in phosphorus availability through anoxic recycling from sediments intensified photosynthesis, which in turn led to more O_2 production. We also highlight research on the roles volcanism and continental landmasses may have had to play in supplying phosphorus to drive transient oxygenation[5].

Taken together, these studies imply that O_2 was able to accumulate relatively early, at greater depths and over larger spatial extents than previously realized. The run-up to the Great Oxidation Event was clearly a time of flux, moving towards the oxygenated atmosphere that characterized the post-Archean Earth. In a News and Views, James Kasting explores the idea that some of these events may represent intervals when the entire Archean atmosphere flipped briefly to oxidizing conditions, before reverting to a reduced state. As Kasting points out, we don't have all the answers yet, but geochemists continue to develop innovative ways to explore these tentative steps towards an oxygenated atmosphere on Earth.

Published online: 13 May 2025

References

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