Breathing new life into Earth: New research shows evidence of early oxygen on our planet

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Today, oxygen takes up a hefty portion of Earth's atmosphere: Life-sustaining O_2 molecules make up 21 percent of the air we breathe. However, very early in Earth's history, O_2 was a rare - if not completely absent - player in the turbulent mix of primordial gases. It wasn't until the "Great Oxidation Event" (GOE), nearly 2.3 billion years ago, when oxygen made any measurable dent in the atmosphere, stimulating the evolution of air-breathing organisms and, ultimately, complex life as we know it today.

Now, new research from MIT suggests O_2 may have been made on Earth hundreds of millions of years before its debut in the atmosphere, keeping a low profile in "oxygen oases" in the oceans. The MIT researchers found evidence that tiny aerobic organisms may have evolved to survive on extremely low levels of the gas in these undersea oases.

In laboratory experiments, former MIT graduate student Jacob Waldbauer, working with Professor of Geobiology Roger Summons and Dianne Newman, formerly of MIT's Department of Biology and now at the California Institute of Technology, found that yeast - an organism that can survive with or without oxygen - is able to produce key oxygen-dependent compounds, even with only miniscule puffs of the gas.

The findings suggest that early ancestors of yeast could have been similarly resourceful, working with whatever small amounts of O_2 may have been circulating in the oceans before the gas was detectable in the atmosphere. The team published its findings last week in the *Proceedings of the National Academy of Sciences*.

"The time at which oxygen became an integral factor in cellular metabolism was a pivotal point in Earth history," Summons says. "The fact that you could have oxygen-dependent biosynthesis very early on in the Earth's history has significant implications."

The group's results may help reconcile a debate within the earth sciences community: About a decade ago, geochemists encountered sedimentary rocks containing fossil steroids, an essential component of some organisms' cell membranes. Making a single molecule of a sterol, such as cholesterol, from scratch requires at least 10 molecules of O_2; since the molecular fossils date back to 300 million years before the GOE, some have interpreted them as the earliest evidence of oxygen's presence on Earth. But because other evidence for the presence of oxygen in rocks of similar age is inconclusive, many geologists have questioned whether the fossilized steroids are indeed proof of early oxygen.

Waldbauer and colleagues suggest that perhaps O_2 was in fact present on Earth 300 million years before it spiked in the atmosphere - just at extremely low concentrations that wouldn't have left much of a trace in the rock record. They reasoned that, even at such low levels, this O_2 may have been sufficient to feed aerobic, sterol-producing organisms.

To test their theory, they looked to modern yeast as a model. Yeast naturally uses O_2, in combination with sugars, to synthesize ergosterol, its primary sterol. Yeast can also grow without O_2, so long as a source of ergosterol is provided. To find the lowest level of O_2 yeast can consume, the team set up an experiment to identify the point at which yeast switches from anaerobic to aerobic activity.

Waldbauer grew yeast cells with a mixture of essential ingredients, including ergosterol as well as glucose labeled with carbon-13. They found that, without oxygen present, yeast happily took up sterol from the medium but made none from scratch. When Waldbauer pumped in tiny amounts of oxygen, a switch occurred, and yeast began using O_2 in combination with glucose to produce its own sterols. The presence of carbon-13 differentiates the biosynthesized sterol from that acquired from the growth medium.

The scientists found that yeast are able to make steroids using vanishingly small, nanomolar concentrations of O_2, supporting the theory that oxygen - and its producers and consumers - may have indeed been around long before the gas made an appearance in the atmosphere.

"This shows us that yeast, and presumably many or all eukaryotes, can make sterols with very, very low concentrations of oxygen," says Alex Sessions, professor of geobiology at Caltech, who was not involved in this research. "The limit that they find is much lower than I - and I suspect most microbiologists - would have expected."

Waldbauer and Summons surmise that oxygen production and consumption may have occurred in the oceans for hundreds of millions of years before the atmosphere saw even a trace of the gas. They say that in all likelihood, cyanobacteria, blue-green algae living at the ocean surface, evolved the ability to produce O_2 via sunlight in a process known as oxygenic photosynthesis. But instead of building up in the oceans and then seeping into the atmosphere, O_2 may have been rapidly consumed by early aerobic organisms. Large oceanic and atmospheric sinks, such as iron and sulfide spewing out of subsea volcanoes, likely consumed whatever O_2 was left over.

"We know all kinds of biology happens without any O_2 at all," says Waldbauer, now a postdoc at Caltech. "But it's quite possible there was a vigorous cycle of O_2 happening in some places, and other places it might have been completely absent."

More information: www.pnas.org/content/early/201 … /1104160108.abstract

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