Oxygen's challenge to early life

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Researcher Benjamin Gill near the top of a stratigraphic section at Lawsons Cove, Utah. Credit: Steve Bates.

The conventional view of the history of the Earth is that the oceans became oxygen-rich to approximately the degree they are today in the Late Ediacaran Period (about 600 million years ago) after staying relatively oxygen-poor for the preceding four billion years. But biogeochemists at the University of California, Riverside have found evidence that shows that the ocean went back to being "anoxic" or oxygen-poor around 499 million years ago, soon after the first appearance of animals on the planet, and remained anoxic for 2-4 million years. What's more, the researchers suggest that such anoxic conditions may have been commonplace over a much broader interval of time, with their data capturing a particularly good example.

The researchers argue that such fluctuation in the ocean's oxygenation state is the most likely explanation for what drove the rapid evolutionary turnover famously recognized in the fossil record of the Cambrian Period (540 to 488 million years ago).

They report in the Jan. 6 issue of *Nature* that the transition from a generally oxygen-rich ocean during the Cambrian to the fully oxygenated ocean we have today was not a simple turn of the switch, as has been widely accepted until now.

"Our research shows the ocean fluctuated between oxygenation states 499 million years ago," said co-author Timothy Lyons, a professor of biogeochemistry, whose lab led the research, "and such fluctuations played a major, perhaps dominant, role in shaping the early evolution of animals on the planet by driving extinction and clearing the way for new organisms to take their place."

Oxygen is a staple for animal survival, but not for the many bacteria that thrive in and even demand life without oxygen.

Understanding how the environment changed over the course of Earth's history can clue scientists to how exactly life evolved and flourished during the critical, very early stages of animal evolution.

"Life and the environment in which it lives are intimately linked," said Benjamin Gill, the first author of the research paper, who worked in Lyons's lab as a graduate student. Gill explained that when the ocean's oxygenation states changed rapidly in Earth's history, some organisms were not able to cope. Further oceanic oxygen affects cycles of other biologically important elements such as iron, phosphorus and nitrogen.

"Disruption of these cycles is another way to drive biological crises," he said. "Thus both directly and indirectly a switch to an oxygen-poor state of the ocean can cause major extinction of species."

The researchers are now working on finding an explanation for why the oceans became oxygen-poor about 499 million years ago.

"What we have found so far is evidence that it happened," Gill said. "We have the 'effect,' but not the 'cause.' The oxygen-poor state persisted for 2-4 million years, likely until the enhanced burial of organic matter, originally derived from oxygen-producing photosynthesis, resulted in the accumulation of more oxygen in the atmosphere and ocean. As a kind of negative feedback, the abundant burial of organic material facilitated by anoxia may have bounced the ocean to a more oxygen-rich state."

Gill stressed that understanding past events in Earth's distant history can help refine our view of changes happening on the planet presently.

"Today, some sections of the world's oceans are becoming oxygen-poor – the Chesapeake Bay and the so-called 'dead zone' in the Gulf of Mexico are just two examples," he said. "We know the Earth went through similar scenarios in the past. Understanding the ancient causes and consequences can provide essential clues to what the future has in store for our ocean."

In the study, Lyons, Gill and their team examined the carbon, sulfur and molybdenum contents of rocks they collected from localities in the United States, Sweden, and Australia. Combined, these analyses allowed the team to infer the amount of oxygen present in the ocean at the time the limestones and shales were deposited. By looking at successive rock layers, they were able to compile the biogeochemical history of the ocean.

Lyons and Gill were joined in the research by Seth A. Young of Indiana University, Bloomington; Lee R. Kump of Penn State University; Andrew H. Knoll of Harvard University; and Matthew R. Saltzman of Ohio State University. Currently, Gill is a postdoctoral researcher at Harvard University.

Provided by University of California - Riverside