

Evidence for a persistently iron-rich ocean changes views on Earth's early history

September 7 2011



Researchers Chris Reinhard (front) and Noah Planavsky dig into a shale exposure in north China. Credit: Chu Research Group, Institute of Geology and Geophysics, Chinese Academy of Sciences

Over the last half a billion years, the ocean has mostly been full of oxygen and teeming with animal life. But earlier, before animals had evolved, oxygen was harder to come by. Now a new study led by researchers at the University of California, Riverside reveals that the ancient deep ocean was not only devoid of oxygen but also rich in iron, a key biological nutrient, for nearly a billion years longer than previously thought -- right through a key evolutionary interval that culminated in the first rise of animals.

"The implications of our work are far reaching," said Timothy Lyons, a professor of [biogeochemistry](#) and the principal investigator of the study. "We will need to rethink, in a fundamental way, all of our models for how life-essential nutrients were distributed in the ocean through time and space."

Study results appear in the Sept. 8 issue of *Nature*.

Previous ocean chemistry models

Most scientists agree that the [early Earth](#), before 2.4 billion years ago, contained only trace quantities of oxygen and that the oceans were dominantly full of dissolved iron. But there is far less agreement among scientists about the [chemical composition](#) of the ocean during the middle chapters of Earth's history in the wake of atmospheric oxygenation—about 2.4 to 0.5 billion years ago—when the diversity of organisms that we know today, including the animals, first got their footing.

Classic models for this time window maintain that the ocean, all depths, became rich in oxygen in parallel with its first accumulation in the atmosphere. This increase in oxygen in seawater has been linked to the disappearance of iron ore deposits known as 'banded iron formations,' the source of almost all of the iron used to make steel today. Oxygen, the argument goes, would have 'rusted' the oceans, stripping them of dissolved iron.



Drill core of shales and siltstones of the Lady Loretta Formation. The brown layers -- rich in iron-carbonate -- are a tale-tell sign of ferruginous conditions in the ancient ocean. Credit: Peter McGoldrick, CODES ARC Centre of Excellence in Ore Deposits, University of Tasmania

More than a decade ago, however, another idea gained traction: [hydrogen sulfide](#). Produced by bacteria in the absence of oxygen, hydrogen sulfide, it was argued, might instead have scrubbed the iron out of the ocean during Earth's middle history, dealing the fatal blow to the iron deposits. In an ocean full of hydrogen sulfide, diverse life-sustaining elements, including iron, can be stripped from the seawater, potentially causing a biotic crisis.

Fresh perspective

"The problem all along was a general lack of physical evidence in the oceans for the amounts of oxygen, iron, and sulfide in the Earth's middle history, particularly in a critical billion-year window between roughly 1.8 and 0.8 billion years ago," said Noah Planavsky, a doctoral student in UC Riverside's Department of Earth Sciences and the lead author of the new study. "Some earlier work supported a return to an iron-rich ocean 0.8 billion years ago. Rather than a return, however, we predicted that iron may have dominated the [deep ocean](#) continuously right up to the oxygenation and concomitant rise of animals a mere half-billion years

ago."

Planavsky and his colleagues at UCR and in Canada, Australia, and China sought to remedy the data deficiency. New rock samples they collected from across the globe suggest a previously unknown continuity in [ocean chemistry](#) over much of its history. These data, the first of their kind, point towards continuous oxygen-poor, iron-rich conditions for 90 percent of Earth's history, with oxygen and hydrogen sulfide, when present, limited mostly to the surface layers and along the margins of the oceans, respectively.

The task now is to reconsider whether the purported shortages of nutrients attributed to widespread hydrogen sulfide were indeed real and a throttle on early evolution. "Our new knowledge that the deep ocean was anoxic and iron-rich does not mean life had it easy, though," Lyons says. "Enough sulfide could have persisted around the edges of the ocean to severely limit other key nutrients. We are still testing this hypothesis."

Ironing out the details

The researchers' results also indicate that neither [oxygen](#) nor hydrogen sulfide turned off iron deposition around 1.8 billion years ago, when the last major iron ores were seen. They suggest instead that hydrothermal systems on the seafloor are the most important factor controlling the distribution of iron ore.

"These hydrothermal systems are high-temperature vents on the seafloor tied to magmatic activity, and they can pump huge amounts of iron into the ocean," Planavsky explained. "Previous researchers have suggested that there was a decrease in the amount of iron from hydrothermal systems around 1.8 billion years ago. Our results support this idea with compelling physical evidence, while showing that [iron](#) could persist in the [ocean](#) at levels below those necessary to form ore deposits."

"The next step is to better merge this refined chemical perspective with traditional and emerging views of evolving life, recognizing that life and the environment co-evolve in an intimate dance of cause-and-effect relationships," Lyons added.

Provided by University of California - Riverside

Citation: Evidence for a persistently iron-rich ocean changes views on Earth's early history (2011, September 7) retrieved 2 May 2024 from <https://phys.org/news/2011-09-evidence-persistently-iron-rich-ocean-views.html>

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