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Before animals, evolution waited eons to inhale

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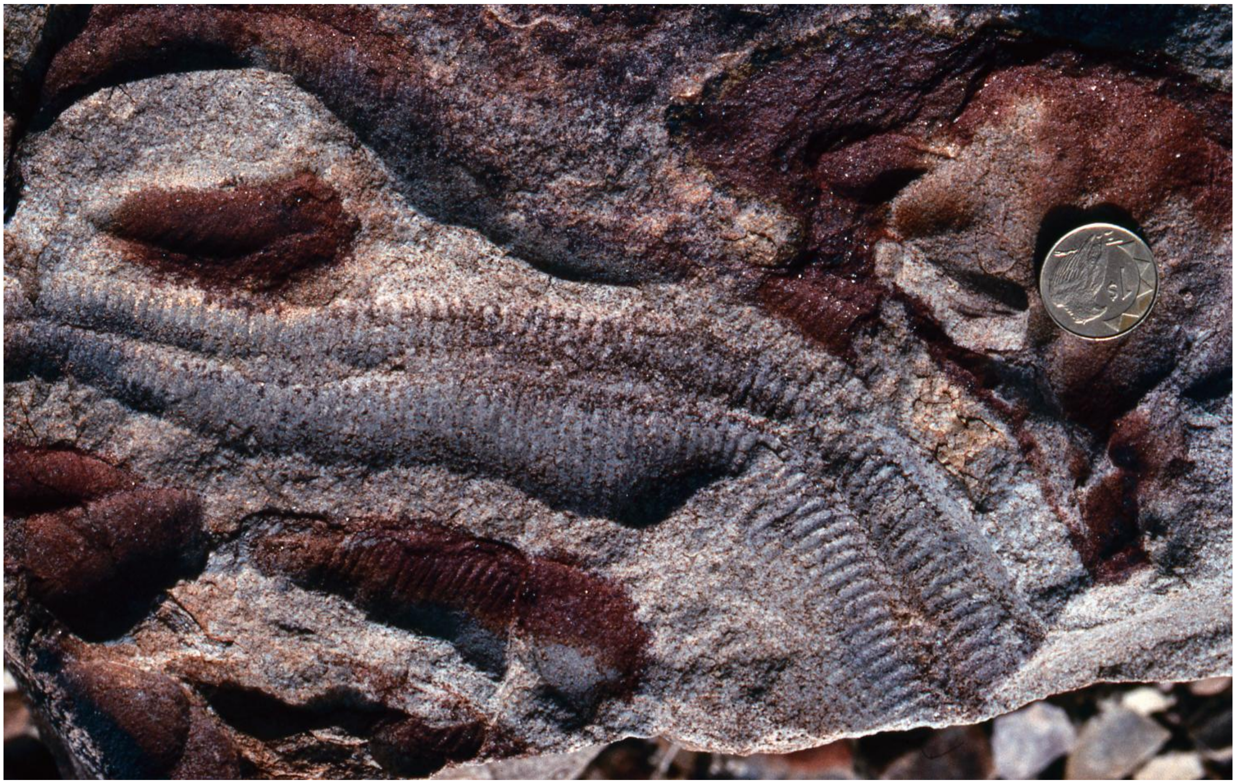


Earliest animals evolved in the mid to late Proterozoic Eon and lie deep in the fossil record. Credit: Douglas Erwin / National Museum of Natural History

A couple of times in four billion years, evolution has slowed to a crawl. And an eon or so has passed before more complex life forms, such as simple animals, could arise.

Evolution may have been waiting for a decent breath of oxygen, said researcher Chris Reinhard. And that was hard to come by. His research team is tracking down O2 concentrations in oceans, where earliest animals evolved.

By doing so, they have jumped into the middle of a heated scientific debate on what rising oxygen did, if anything, to charge up evolutionary eras. Now, Reinhard, a geochemist from the Georgia Institute of Technology, is shaking up conventional thinking with the help of computer modeling.

Smash the beaker

That thinking goes like this: "Atmospheric oxygen had a value of 'x' back then, and so we just assume that the whole ocean is a beaker that equilibrates with that value," Reinhard said. Then all evolving animals everywhere had the selfsame concentration of oxygen to live on.

But oceans are expansive and asymmetrical; deep here, shallower there, frosty at the poles, soupy at the girth. Turbulences, streams and temperatures distribute sediment, algae, salt—and gases like oxygen—into lopsided stores.

Oceans leave some areas teeming and others vacuous. Then they reshuffle their loads. Even today, concentrations of dissolved oxygen vary widely from ocean region to ocean region.

Equating the global ocean to a placid lab beaker? "This is an okay thought experiment to start with, but I think everybody would acknowledge over a beer that it's simplistic," said Reinhard, an assistant professor at Georgia Tech's School of Earth and Atmospheric Sciences.

Create a stir

So, he and his team modeled how oxygen entered oceans from the atmosphere and from aquatic sources, and how oceans might have shuffled it around during the mid to late Proterozoic Eon. That was 0.6 to 1.8 billion years ago, when the Earth's atmosphere had only fraction of the breathable oxygen it does today.

In the model, the ocean didn't share and share alike, but instead pushed dissolved O2 into areas of concentration that shifted starkly as corresponding concentrations in the atmosphere rose.

That has implications for the way scientists think about the timeframe for animal evolution on Earth and for future estimates for the probability of complex life on exoplanets.

The results and detailed modeling parameters appear on Monday, July 25, 2016, in the *Proceedings of the National Academy of Sciences*. The research was funded by the National Science Foundation and the NASA Astrobiology Institute.

Be unreliable

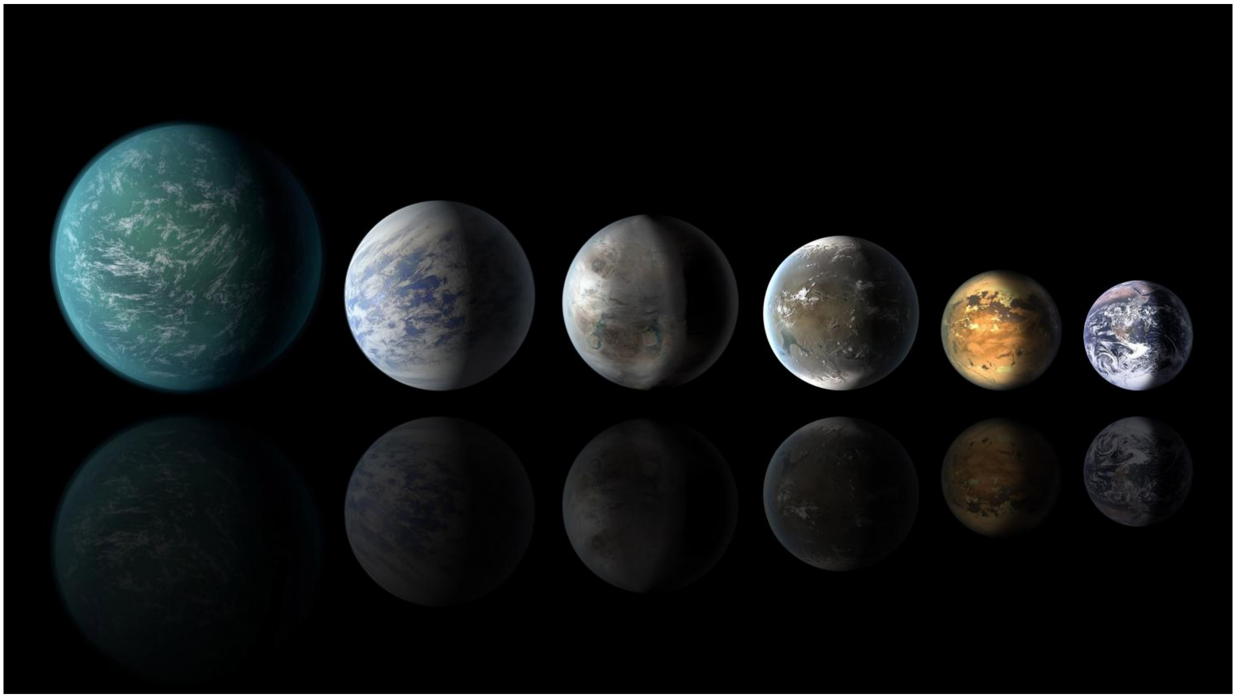
Humans and today's large animals would quickly suffocate in a Proterozoic-like world. And according to Reinhard's research, its oceans may not have been as conducive to evolution as previously thought.

"What really matters for the early evolution of animals is ocean oxygen. To a certain degree, it's really shallow sea floor oxygen that matters," Reinhard said.

Those ocean shallows are called benthic regions, and in the Proterozoic

Eon, they received plenty of sunlight and nutrients key to evolution. Even today, they're teeming with life, which makes them popular places for snorkeling and fishing.

But the new model shows oxygen levels there may have been unreliable during the mid to late Proterozoic Eon.



Georgia Tech's oceanic oxygen distribution model could offer insight into the possibility of complex life on exoplanets. Research is funded in part by NASA Astrobiology Institute. Credit: NASA/Ames/JPL-Caltech

Rob the rich

Earliest metazoans, the term for multicellular beings that are animals, may have done alright with scarce amounts and survived O2 droughts—periods of anoxia. But they also evolved into a world of rising breathable oxygen.

Reinhard's computational model accounted for scenarios from atmospheric oxygen concentrations of 0.5 to 10 percent of today's levels.

At low concentrations, the simulation showed oceanic oxygen building up around the equator, where hot spots in the water produced higher amounts of it. Then—as the atmosphere began filling with oxygen—in the oceans, it shifted toward the poles, where cold water was able to hold on to more of it.

Formerly oxygen-rich regions were robbed of conditions friendly to animal evolution.

In the beaker way of thinking, higher atmospheric oxygen should have meant evenly rising levels of oceanic oxygen for animals evolving everywhere, even in those depleted regions. "In reality, the ecology they would have been facing would have been pretty severe," Reinhart said.

Follow dead animals

Reinhard's team could have framed the study around other organisms but chose metazoans. "We focused on animals principally because that's where we have the best empirical constraints for the oxygen levels that the organisms need," he said.

Their evolution also left behind a calendar convenient to scientific study - a progressive fossil record that became more complex as oxygen levels rose.

In Earth's roughly 3.7-billion-year history of life, animals turned up in about the most recent third. Furry, feathery and even scaly animals have only appeared in the last few hundred million years.

As oxygen became plentiful, critters got bigger, smarter, faster, and became predators and prey. Pursuit and flight accelerated as gasping lungs and gills pulled in more of the powerful oxidant to exponentially boost metabolism.

Evolution went into overdrive, diversifying the fossil record over time. But dive back down into it a billion or so years, to the mid to late Proterozoic, and animal fossils get smaller and simpler. You find little, squishy sponges and jellyfish.

Think (eco)logically

Their stony imprints mark the beginnings of that very complex evolution, and they may point to oxygen concentrations at the time.

"We were focusing on changes in atmospheric oxygen during the time period in which animals appear in the fossil record and trying to link that quantitatively to the oxygen levels early animals would have needed," Reinhard said.

His computational oxygen distribution model was based on the current constellation of Earth's continents - vastly different from that of the Proterozoic Eon.

But Reinhard said that difference would not change the conclusions. And the concepts they support should also apply to predictions about life on exoplanets with differing continental structures.

"The basic take-home—that we need to be thinking ecologically rather than just in terms of a single oxygen level—is going to prove to be pretty robust," he said.

That beaker? May have just flown out the window.

More information: Earth's oxygen cycle and the evolution of animal life, *Proceedings of the National Academy of Sciences*, www.pnas.org/cgi/doi/10.1073/pnas.1521544113

Provided by Georgia Institute of Technology

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