Earth's early ocean cooled more than a billion years earlier than thought (w/ Video)

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Green and orange photosynthetic microbial mats line an outflow channel from a hot spring in Yellowstone National Park. These thin mats grow only where the downstream water temperature falls below 73 C. The mats become thicker and more complex as the temperature drops. Stanford researchers found evidence for cooler waters in the ancient global ocean that would have allowed photosynthetic life to spread far beyond such narrow confines. Credit: Michael Tice, Texas A&M University

(PhysOrg.com) -- The scalding-hot sea that supposedly covered the early Earth may in fact never have existed, according to a new study by Stanford University researchers who analyzed isotope ratios in 3.4 billion-year-old ocean floor rocks. Their findings suggest that the early ocean was much more temperate and that, as a result, life likely diversified and spread across the globe much sooner in Earth's history than has been generally theorized.

It also means that the chemical composition of the ancient ocean was significantly different from today's ocean, which in turn may change interpretations of how the early atmosphere evolved, said Page Chamberlain, professor of environmental earth system science.

When rocks form on the ocean floor, they form in chemical equilibrium with the ocean water, incorporating similar proportions of different isotopes into the rock as are in the water. Isotopes are atoms of the same element that have different numbers of neutrons in the nucleus, giving them different masses. However, because the exact proportion of different isotopes that go into the rock is partly temperature dependent, the ratios in the rock provide critical clues into how warm the ocean was when the rock formed.

Previous studies of similarly aged rocks had looked only at oxygen isotope ratios, which suggested that in the Archean era (about 3.5 billion years ago), the ocean temperature was at least 55 degrees Celsius and may have been as high as 85 C, or 185 F. At a water temperature so perilously close to the boiling point, the only organisms that could have thrived would have been extremophiles - life forms adapted to extreme environments - such as the microbes that live in the intense heat of deep-sea hydrothermal vents or in hot springs such as at Yellowstone National Park.

But isotope ratios recorded in rocks on the ocean floor are also dependent on the chemical composition of the seawater in which those rocks formed, and the past studies assumed the composition of the ancient ocean was essentially what it is today, which the Stanford study did not.

Using a relatively new approach, Michael Hren and Mike Tice, both

Stanford graduate students at the time, analyzed hydrogen isotopes as well as oxygen isotopes in chert, a type of fine-grained sedimentary rock consisting primarily of quartz. The chert they studied was from an ancient deposit, formerly underwater but now on dry land in South Africa.

From a cauldron to a nice warm bath

"By looking at both oxygen and hydrogen in these ancient rocks we were able to put some constraints on how different the ancient ocean composition may have been from today, and then use that composition to try to determine how hot the ancient ocean was," said Hren, who is the lead author of a paper describing the work being published online Nov. 12 by *Nature*. Tice and Chamberlain are coauthors.

Having data from isotope ratios of two elements allowed the researchers to calculate upper and lower bounds for the range of temperature and composition that could have given rise to the observed ratios. They determined that the ocean temperature could not have been more than 40 C (104 F) - the temperature of a hot tub - and may have been lower in some parts.

"This means that by 3.4 billion years ago, there were at least some places on the surface of the Earth where organisms that could not survive in these hot hydrothermal conditions could exist and thrive," Hren said. "It also suggests that the chemical composition of the ancient ocean was probably not identical to today, as previous studies assumed. It may have been quite different."

The researchers found that the ratio of the two stable isotopes of hydrogen in the chert was tilted away from the heavier of the isotopes - called deuterium.

"The ancient ocean had a lot more hydrogen in it, relative to deuterium, than modern oceans," Chamberlain said.

If the composition of the Archean ocean was significantly different from today, then the atmosphere must have been markedly different, too, owing to the ease with which gases move across the air-water boundary as the ocean and lower atmosphere strive to stay in a rough equilibrium.

That means that sometime during the past 3.4 billion years, the ocean had to lose a lot of hydrogen to the atmosphere to bring the hydrogen isotope ratio in seawater to where it is today. And since oxygen, not hydrogen, has built up in Earth's atmosphere over that same period of time, the atmosphere must have discharged a lot of hydrogen to the only other place it could go: space.

Hren said that some recent models of the early Earth atmosphere suggest that there may have been a prolonged period of hydrogen escaping to space, which would be consistent with the Stanford team's findings.

Little land, but happy lives on the early Earth

The chemical composition of air and water weren't the only things different about Earth during the Archean era.

"We are talking about a time when, if you were looking at the Earth from space, you would hardly see any land mass at all," Tice said. "It would have almost been an ocean world."

The chert samples came from a formation called the Buck Reef Chert, which covered a broad area from shallow to deep marine environments. Some of the chert was probably deposited on the slopes of a volcanic island, similar to those in the Hawaiian Islands, that had gone extinct, cooled, eroded and slowly subsided under the sea, he said.

Tice collected the chert samples from South Africa several years ago while he was a graduate student with Don Lowe, professor of geological and environmental sciences. In 2004, Lowe and Tice described a fossil microbial ecosystem preserved in some of the chert that was deposited on a shallow submerged platform, which they deduced was photosynthetic. Tice said the temperature setting was probably somewhat comparable to a modern day tidal flat, where similar photosynthetic microbial mats flourish today, although the depth of the Archean setting was similar to continental shelves of today.

"At the higher temperatures that were hypothesized earlier, those organisms could have survived but they would have had a harder time," he said. "At the temperatures we are suggesting, they would have been completely comfortable. They would have been happy.

"And that is significant because photosynthetic organisms, even bacteria, form the base of essentially every modern food chain," Tice added.

Buck Reef Chert: The outcrop that provided samples for this study. Image credit: Mike Tice

Checking the chert

With major ramifications for the ocean, atmosphere and nature of life on the early Earth coming out of their study, the researchers know their work is likely to receive some scrutiny.

"Anytime you are dealing with something that has been on Earth for 3.4 billion years, it is always going to be a question of whether these are pristine or not," Chamberlain said.

But the cherts the Stanford team worked with "are particularly good rocks," he said, "because they have not been stuck deep in the Earth, crushed and heated, and so they preserve something of what the original oceans were like."

Still, to rule out any alteration of the rocks, Hren said they did calculations to see what would happen if the chert had been subjected to later hydrothermal water flowing through it, or other post-depositional processes that could potentially alter the chemistry of the samples.

"We can show some of the data has been altered by later fluids, but some of it is recording this original ocean composition and temperature data," he said. "So by looking at these two separate trends, we can see which data reflects this original formation.

"I think it is really giving us a better idea of these conditions at a very early time in the Earth's history," Hren said.

Source: Stanford University (news : web)

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