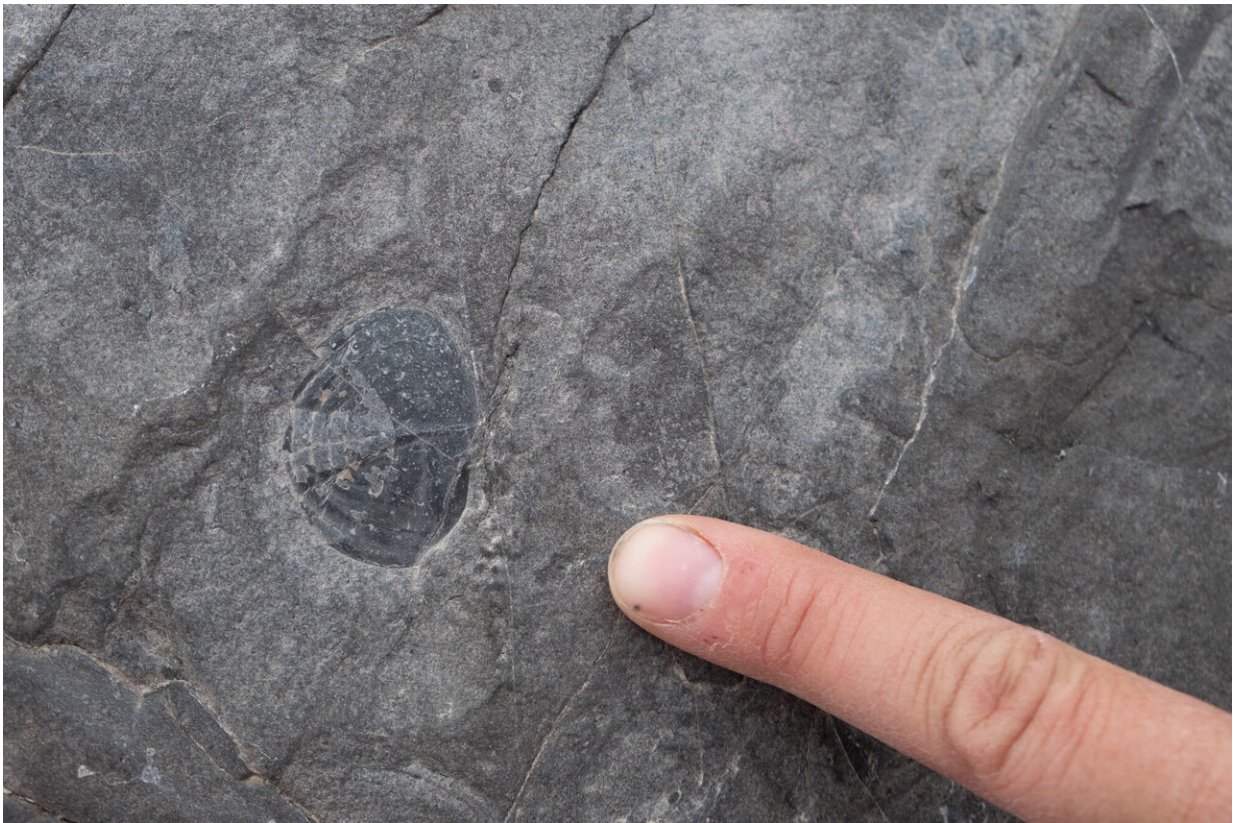


# Geologists produce new timeline of Earth's Paleozoic climate changes

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A finger points to a small trilobite fossil from the Ordovician strata in Svalbard, Norway. Credit: Adam Jost

The temperature of a planet is linked with the diversity of life that it can support. MIT geologists have now reconstructed a timeline of the Earth's

temperature during the early Paleozoic era, between 510 and 440 million years ago—a pivotal period when animals became abundant in a previously microbe-dominated world.

In a study appearing today in the *Proceedings of the National Academy of Sciences*, the researchers chart dips and peaks in the global temperature during the early Paleozoic. They report that these [temperature variations](#) coincide with the planet's changing diversity of life: Warmer climates favored microbial life, whereas [cooler temperatures](#) allowed more diverse animals to flourish.

The new record, more detailed than previous timelines of this period, is based on the team's analysis of carbonate muds—a common type of limestone that forms from carbonate-rich sediments deposited on the seafloor and compacted over hundreds of millions of years.

"Now that we have shown you can use these carbonate muds as climate records, that opens the door to looking back at this whole other part of Earth's history where there are no fossils, when people don't really know much about what the climate was," says lead author Sam Goldberg, a graduate student in MIT's Department of Earth, Atmospheric, and Planetary Sciences (EAPS).

Goldberg's co-authors are Kristin Bergmann, the D. Reid Weedon, Jr. Career Development Professor in EAPS, along with Theodore Present of Caltech and Seth Finnegan of the University of California at Berkeley.

## **Beyond fossils**

To estimate Earth's temperature many millions of years ago, scientists analyze fossils, in particular, remains of ancient shelled organisms that precipitated from seawater and either grew on or sank to the seafloor. When precipitation occurs, the temperature of the surrounding water can

change the composition of the shells, altering the relative abundances of two isotopes of oxygen: oxygen-16, and oxygen-18.

"As an example, if carbonate precipitates at 4 degrees Celsius, more oxygen-18 ends up in the mineral, from the same starting composition of water, [compared to] carbonate precipitating at 30 degrees Celsius," Bergmann explains. "So, the ratio of oxygen-18 to -16 increases as temperature cools."

In this way, scientists have used ancient carbonate shells to backtrack the temperature of the surrounding seawater—an indicator of the Earth's overall climate—at the time the shells first precipitated. But this approach has taken scientists only so far, up until the earliest fossils.

"There is about 4 billion years of Earth history where there were no shells, and so shells only give us the last chapter," Goldberg says.





In this photo, taken in western Newfoundland, Canada, you can see microbial buildup from the early Ordovician strata. Credit: Kristin Bergmann

### **A clumped isotope signal**

The same precipitating reaction in shells also occurs in carbonate mud. But geologists assumed the isotope balance in carbonate muds would be more vulnerable to [chemical changes](#).

"People have often overlooked mud. They thought that if you try to use it as a temperature indicator, you might be looking at not the original ocean temperature in which it formed, but the temperature of a process that occurred later on, when the mud was buried a mile below the surface," Goldberg says.

To see whether carbonate muds might preserve signatures of their original surrounding temperature, the team used "clumped isotope geochemistry," a technique used in Bergmann's lab, which analyzes sediments for clumping, or pairing, of two heavy isotopes: oxygen-18 and carbon-13. The likelihood of these isotopes pairing up in carbonate muds depends on temperature but is unaffected by the ocean chemistry in which the muds form.

Combining this analysis with traditional oxygen isotope measurements provides additional constraints on the conditions experienced by a sample between its original formation and the present. The team reasoned that this analysis could be a good indication of whether carbonate muds remained unchanged in composition since their formation. By extension, this could mean the oxygen-18 to -16 ratio in some muds accurately represents the original temperature at which the rocks formed, enabling their use as a climate record.

## **Ups and downs**

The researchers tested their idea on samples of carbonate muds that they extracted from two sites, one in Svalbard, an archipelago in the Arctic Ocean, and the other in western Newfoundland. Both sites are known for their exposed rocks that date back to the early Paleozoic era.

In 2016 and 2017, teams traveled first to Svalbard, then Newfoundland, to collect samples of carbonate muds from layers of deposited sediment spanning a period of 70 million years, from the mid-Cambrian, when animals began to flourish on Earth, through the Ordovician periods of the Paleozoic era.

When they analyzed the samples for clumped isotopes, they found that many of the rocks had experienced little chemical change since their formation. They used this result to compile the rocks' oxygen isotope

ratios from 10 different early Paleozoic sites to calculate the temperatures at which the rocks formed. The temperatures calculated from most of these sites were similar to previously published lower-resolution fossil temperature records. In the end, they mapped a timeline of temperature during the early Paleozoic and compared this with the fossil record from that period, to show that temperature had a big effect on the diversity of life on the planet.

"We found that when it was warmer at the end of the Cambrian and early Ordovician, there was also a peak in microbial abundance," Goldberg says. "From there it cooled off going into the middle to late Ordovician, when we see abundant animal fossils, before a substantial ice age ends the Ordovician. Previously people could only observe general trends using fossils. Because we used a material that's very abundant, we could create a higher-resolution record and could see more clearly defined ups and downs."

The team is now looking to analyze older muds, dating back before the appearance of animals, to gauge the Earth's [temperature](#) changes prior to 540 million years ago.

"To go back beyond 540 million years ago, we have to grapple with [carbonate](#) muds, because they are really one of the few records we have to constrain climate in the distant past," Bergmann says.

**More information:** Samuel L. Goldberg et al., "A high-resolution record of early Paleozoic climate," *PNAS* (2021).  
[www.pnas.org/cgi/doi/10.1073/pnas.2013083118](http://www.pnas.org/cgi/doi/10.1073/pnas.2013083118)

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