Geobiologists uncover links between ancient climate change and mass extinction

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This is rock strata on Anticosti Island, Quebec, Canada, one of the sites from which the researchers collected fossils. Credit: Woody Fischer

About 450 million years ago, Earth suffered the second-largest mass extinction in its history—the Late Ordovician mass extinction, during which more than 75 percent of marine species died. Exactly what caused this tremendous loss in biodiversity remains a mystery, but now a team led by researchers at the California Institute of Technology (Caltech) has discovered new details supporting the idea that the mass extinction was linked to a cooling climate.

"While it's been known for a long time that the mass extinction is intimately tied to climate change, the precise mechanism is unclear," says Seth Finnegan, a postdoctoral researcher at Caltech and the first author of the paper published online in *Science* on January 27. The mass extinction coincided with a glacial period, during which global temperatures cooled and the planet saw a marked increase in glaciers. At this time, North America was on the equator, while most of the other continents formed a supercontinent known as Gondwana that stretched from the equator to the South Pole.

By using a new method to measure ancient temperatures, the researchers have uncovered clues about the timing and magnitude of the glaciation and how it affected ocean temperatures near the equator. "Our observations imply a climate system distinct from anything we know about over the last 100 million years," says Woodward Fischer, assistant professor of geobiology at Caltech and a coauthor.

The fact that the extinction struck during a glacial period, when huge ice sheets covered much of what's now Africa and South America, makes it especially difficult to evaluate the role of climate. "One of the biggest sources of uncertainty in studying the paleoclimate record is that it's very hard to differentiate between changes in temperature and changes in the size of continental ice sheets," Finnegan says. Both factors could have played a role in causing the mass extinction: with more water frozen in ice sheets, the world's sea levels would have been lower, reducing the availability of shallow water as a marine habitat. But differentiating between the two effects is a challenge because until now, the best method for measuring ancient temperatures has also been affected by the size of ice sheets.

The researchers analyzed the chemistry of fossils to determine the temperature during the Late Ordovician period. Shown are fossilized shells, brachiopods, trilobites, and gastropods, with a hammer for scale. Credit: Woody Fischer

The conventional method for determining ancient temperature requires measuring the ratios of oxygen isotopes in minerals precipitated from seawater. The ratios depend on both temperature and the concentration of isotopes in the ocean, so the ratios reveal the temperature only if the isotopic concentration of seawater is known. But ice sheets preferentially lock up one isotope, which reduces its concentration in the ocean. Since no one knows how big the ice sheets were, and these ancient oceans are no longer available for scientists to analyze, it's hard to determine this isotopic concentration. As a result of this "ice-volume effect," there hasn't been a reliable way to know exactly how warm or cold it was during these glacial periods.

But by using a new type of paleothermometer developed in the laboratory of John Eiler, Sharp Professor of Geology and professor of geochemistry at Caltech, the researchers have determined the average temperatures during the Late Ordovician—marking the first time scientists have been able to overcome the ice-volume effect for a glacial episode that happened hundreds of millions of years ago. To make their measurements, the researchers analyzed the chemistry of fossilized marine animal shells collected from Quebec, Canada, and from the midwestern United States.

The Eiler lab's method, which does not rely on the isotopic concentration of the oceans, measures temperature by looking at the "clumpiness" of heavy isotopes found in fossils. Higher temperatures cause the isotopes to bond in a more random fashion, while low temperatures lead to more clumping.

"By providing independent information on ocean temperature, this new method allows us to know the isotopic composition of 450-million-year-old seawater," Finnegan says. "Using that information, we can estimate the size of continental ice sheets through this glaciation." And with a clearer idea of how much ice there was, the researchers can learn more about what Ordovician climate was like—and how it might have stressed marine ecosystems and led to the extinction.

"We have found that elevated rates of climate change coincided with the mass extinction," says Aradhna Tripati, a coauthor from UCLA and visiting researcher in geochemistry at Caltech.

The team discovered that even though tropical ocean temperatures were higher than they are now, moderately sized glaciers still existed near the poles before and after the mass extinction. But during the extinction intervals, glaciation peaked. Tropical surface waters cooled by five degrees, and the ice sheets on Gondwana grew to be as large as 150 million cubic kilometers—bigger than the glaciers that covered Antarctica and most of the Northern Hemisphere during the modern era's last ice age 20,000 years ago.

"Our study strengthens the case for a direct link between climate change and extinction," Finnegan says. "Although polar glaciers existed for several million years, they only caused cooling of the tropical oceans during the short interval that coincides with the main pulse of mass extinction."

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