New findings show a slow recovery from extreme global warming episode 55 million years ago

Most of the excess carbon dioxide pouring into the atmosphere from the burning of fossil fuels will ultimately be absorbed by the oceans, but it will take about 100,000 years. That is how long it took for ocean chemistry to recover from a massive input of carbon dioxide 55 million years ago, according to a study published this week in the journal *Science*.

James Zachos, professor of Earth sciences at the University of California, Santa Cruz, led an international team of scientists that analyzed marine sediments deposited during a period of extreme global warming known as the Paleocene-Eocene Thermal Maximum (PETM). Sediment cores drilled from the ocean floor revealed an abrupt change in ocean chemistry at the start of the PETM 55 million years ago, followed by a long, slow recovery.

"Most people have not thought about the long-term fate of all that carbon and what's involved in removing it from the system. There is a long timescale for the recovery, tens of thousands of years before atmospheric carbon dioxide will start to come back down to preindustrial levels," Zachos said.

Earlier studies using computers to run numerical models of Earth's carbon cycle have calculated similarly long timescales for absorption of the carbon dioxide currently being released into the atmosphere from fossil fuels, he said.

"Our findings are consistent with what the models have been showing for years. What we found validates those geochemical models," Zachos said.

The oceans have a tremendous capacity to absorb carbon dioxide from the atmosphere. Results from a large international research effort published last year indicated that the oceans have already absorbed nearly half of the carbon dioxide produced by humans in the past 200 years--about 120 billion metric tons of carbon.

When carbon dioxide dissolves in water it makes the water more acidic. Ocean acidification starts at the surface and spreads to the deep sea as surface waters mix with deeper layers. The sediment cores studied by Zachos and his coworkers showed the effects of a rapid acidification of the ocean during the PETM. The acidification was more severe than they had expected, suggesting that the amount of carbon dioxide that entered the atmosphere and triggered global warming during the PETM was much greater than previously thought.

The leading explanation for the PETM is a massive release of methane from frozen deposits found in the deep ocean near continental margins. The methane reacted with oxygen to produce huge amounts of carbon dioxide. Both methane and carbon dioxide are potent greenhouse gases and caused temperatures to soar during the PETM. Average global temperatures increased by about 9 degrees Fahrenheit (5 degrees Celsius), and the fossil record shows dramatic changes during this time in plant and animal life, both on land and in the oceans.

Previous estimates for the amount of greenhouse gas released into the atmosphere during the PETM were around 2,000 billion tons of carbon. Zachos said at least twice that much would be required to produce the changes observed in this new study.

"This is similar to the estimated flux from fossil fuel combustion over the next three centuries," he said. "If we combust all known fossil fuel reserves, that's about 4,500 billion tons of carbon. And now we know that the recovery time for a comparable release of carbon in the past was about 100,000 years."

The study's conclusions hinge on the effects of ocean acidification on the chemistry of calcium carbonate, the mineral from which certain kinds of phytoplankton (microscopic algae) and other marine organisms build their shells. When these organisms die, their shells rain down onto the seafloor. Marine sediments are typically rich in calcium carbonate from these shells, but increased acidity causes it to dissolve. The dissolution of calcium carbonate enables the ocean to store large amounts of carbon dioxide in the form of bicarbonate ions.

"The calcium carbonate sitting on the seafloor increases the ocean's buffering capacity, so that it can eventually neutralize most of the changes in acidity caused by the carbon dioxide accumulating in the atmosphere," Zachos said.

Sediments deposited at the start of the PETM show an abrupt transition from carbonate-rich ooze to a dark-red clay layer in which the carbonate shells are completely gone. Above the clay layer, the carbonates gradually begin to reappear.

This transition at the Paleocene-Eocene boundary was already well known from previous studies of sediment cores by Zachos and others. The new Science paper, however, presents the first results from a series of sediment cores covering the PETM over a broad range of depths in the ocean. The cores were recovered in 2003 from Walvis Ridge in the southeastern Atlantic Ocean.

This series of sediment cores enabled the researchers to trace changes in ocean chemistry over time at different depths in the ocean. This is important because the chemical equilibrium between solid calcium carbonate (calcite) and dissolved calcium and carbonate ions changes with depth. The dissolution of calcite increases not only with acidity, but also at the colder temperatures and higher pressures found in the deep ocean.

At a certain depth--currently 4 kilometers (2.4 miles) in the southern Atlantic--the calcite shells of dead plankton drifting down from the surface waters begin to dissolve. The point at which the dissolution rate exceeds the supply rate of calcite from above is called the carbonate compensation depth (CCD). The distinctive layers of clay that mark the PETM in sediment cores indicate that those sites were below the CCD at the time those sediments accumulated.

In the series of sediment cores from different depths on Walvis Ridge, Zachos and his coworkers observed a rapid shoaling (rising toward the surface) of the CCD due to the acidification of ocean waters.

"The CCD shoaled quickly from below the deepest site to above the shallowest site, producing a clay layer with no carbonate. And then the carbonate starts to reappear, first at the shallowest site, then deeper, eventually reaching the deepest site," Zachos said. "The time lag before the carbonates start to reappear is about 40 to 50 thousand years, and then it's another 40 thousand years before you see the normal carbonate-rich ooze again."

The dissolution of calcium carbonate provides only temporary storage of carbon dioxide. When the dissolved ions recombine to form calcite again, carbon dioxide is released. The long-term storage of carbon dioxide is accomplished through chemical weathering of silicate rocks, such as granite and basalt, on the land. As weathering removes carbon dioxide, however, the same buffering process that slowed the accumulation of carbon dioxide in the atmosphere starts to operate in reverse, gradually releasing stored carbon from the ocean back into the atmosphere.

"The ocean's role is to act like a temporary store for the carbon until these chemical weathering processes can remove it from the system. This is the theory of ocean carbonate chemistry that we were taught in graduate school, and here is a case study where you can actually see it happen," Zachos said.

These changes in ocean chemistry during the PETM coincided with a sharp reduction in marine biodiversity. For example, many species of bottom-dwelling phytoplankton that form calcite shells went extinct, possibly as a direct result of ocean acidification, Zachos said.

Within the past year, scientists have begun to detect similar changes in ocean chemistry in response to the rise in atmospheric carbon dioxide from fossil fuel consumption and other human activities. Researchers have also begun to worry about the potential ecological effects of ocean acidification. Whatever the effects may be of current increases in atmospheric carbon dioxide, we will probably have to live with them for a long time.

"Even after humans stop burning fossil fuels, the impacts will be long-lasting," Zachos said.

In addition to Zachos, the authors of the Science paper are Ursula Röhl of the University of Bremen, Germany; Stephen Schellenberg of San Diego State University; Appy Sluijs of Utrecht University, The Netherlands; David Hodell of the University of Florida; Daniel Kelly of the University of Wisconsin, Madison; Ellen Thomas of Wesleyan University and Yale University; Micah Nicolo of Rice University; Isabella Raffi of G. d'Annunzio University, Italy; Lucas Lourens of Utrecht University; Heather McCarren, a graduate student in Earth sciences at UC Santa Cruz; and Dick Kroon of Vrije University, The Netherlands.

This study was conducted as part of a five-year interdisciplinary project funded by the National Science Foundation to investigate the consequences of greenhouse warming for biocomplexity and biogeochemical cycles. In a related study led by Lourens and published this week in the journal Nature, the researchers reported on a similar, less extreme global warming event that occurred 2 million years after the PETM.

Source: University of California, Santa Cruz