Gas leak!

Global warming isn't a new phenomenon — sea-bed emissions of methane caused temperatures to soar in our geological past. But no one is sure what triggered the release. Quirin Schiermeier investigates.

Digging deep: the ship *JOIDES Resolution* has collected sea-bed samples that may shed light on the climate conditions endured by phytoplankton (inset) millions of years ago.

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About 55 million years ago, our planet emitted a spectacular burp. Trillions of tonnes of methane, until then safely locked up in soils and beneath the ocean floor, were released into the oceans and atmosphere. Methane is a greenhouse gas, so the result was a global-warming incident that has not been matched since — within a few thousand years, average temperatures in some areas rose by up to 8 °C.

Although the evidence for this warming is clear, what sparked the methane release is a mystery. Some researchers believe that the trigger was a small change in ocean temperature. Others suggest that a comet impact was responsible. Analyses of cores from ocean-drilling experiments may soon provide the answer, but the results might do more than shed light on ancient climate — they may also tell us what the long-term consequences of current global warming are likely to be.

The ancient warming, known as the Palaeocene/Eocene thermal maximum (PETM), is the most prominent climate episode of the past 65 million years. It was first identified in the late 1980s by oceanographers analysing oxygen isotope levels in a core drilled from the sea bed near Antarctica[1]. Water molecules containing the lighter oxygen-16 isotope evaporate more readily than those containing oxygen-18, so the relative proportion of oxygen-18 in the oceans rises if the temperature increases. Sedimentary rocks containing shells and plankton that formed in warm water also tend to be richer in oxygen-18. In the case of the Antarctic core, the ratio of the two oxygen isotopes in the sedimentary rocks showed that the sea surface temperature was about 12 °C before the PETM. But sometime in a 10,000-year window around the PETM, they leapt by 7–8 °C, and didn't return to pre-PETM levels until about 250,000 years later.

A sea change

Researchers wondered what could have caused such a jump. Hints lay in carbon isotopes extracted from the same marine sediments used to identify the PETM. Living organisms such as algae take up carbon-12 in preference to carbon-13 during photosynthesis, so the proportion of carbon-12 in sea water rises when less photosynthesis happens. This has a knock-on effect — the shells of marine animals that form in water where little photosynthesis is taking place also contain relatively high levels of carbon-12.

> The mechanisms that helped bring down temperatures in the past are still active today.

Sedimentary rocks containing shells dating from the PETM feature high amounts of carbon-12, but the levels are so high they cannot be explained even if all photosynthetic activity had ceased when they were formed. Researchers concluded that there must have been a massive release of carbon-12 into the ocean and atmosphere — an injection similar to, or perhaps exceeding, the total amount of carbon dioxide and other greenhouse-gas releases pumped into the atmosphere since the industrial revolution.

An explanation for the carbon-12 spike, now known as the methane-burp theory, was suggested in 1995 by Gerald Dickens, a geologist then at the University of Michigan in Ann Arbor[2]. He argued that the carbon came from methane hydrates — ice-like crystalline solids in which methane molecules are trapped inside frozen water. Then, as now, hydrates were found in Arctic tundra soil and the deep oceans near continental slopes. The gas fits the bill as it causes greenhouse warming, and the methane in hydrates is rich in carbon-12.

If the methane escapes from its icy cage, it can combine with dissolved oxygen in the ocean, in a reaction probably driven by bacteria, to produce carbon dioxide and water. Some of the carbon dioxide will escape to the atmosphere, along with some unreacted methane, where both act as greenhouse gases.

Hydrates are only stable in a narrow range of pressures and temperatures, so any ocean warming could disrupt these conditions, releasing more methane. Just a small amount of warming could kick-start a positive feedback loop between hydrate release and further warming, sending global temperatures soaring. According to recent work, 1,500–2,000 gigatonnes (10^9 tonnes) of carbon, rich in the lighter isotope, would need to have been added to the ocean–atmosphere system in less than 10,000 years to cause the temperature rise and create the distinctive carbon isotope ratio seen for the PETM[3].


E. SUESS/GEOMAR KIEL

Caged in: methane trapped in icy hydrates may have caused global warming millions of years ago.

Bubbling under

Evidence for the methane-burp theory comes from studies of Blake Nose in the subtropical Atlantic off the coast of South Carolina. These indicate that 55 million years ago a major sea-bed landslide occurred in the region[4]. Methane release, which would have destabilized the ridge, is one possible cause. The burp theory is also backed by climate simulations. This January, for example, Gavin Schmidt and Drew Shindell, atmospheric chemists at Columbia University in New York, published a simulation confirming that the amount of methane thought to have been released from hydrates is consistent, in terms of its lifetime in the atmosphere and its greenhouse effects, with the estimated temperature changes at different latitudes during the PETM[5].

But this still begs the question of what prompted the methane release. A recent suggestion by Dennis Kent, a geologist at Rutgers University in New Jersey, invokes the impact of a comet containing large amounts of carbon-12 (ref. 6). Kent says that the impact would have vaporized parts of the comet, adding carbon to the atmosphere and triggering methane release from the hydrates.

The idea has some intriguing evidence to support it. For example, Kent points out that there is a jump in the levels of iridium found in fossils dating back to the PETM[7], and that comets are often rich in iridium. But one crucial part of the story is missing — the crater that such an impact would have left, although it could be hidden on the ocean floor.

Other researchers argue that a change in ocean conditions could have caused the release[8]. Global sea surface temperatures were increasing by about 0.5–1.0 °C every million years at the time of the PETM. This rise could have reached a threshold level that altered ocean circulation, channelling destabilizing warm water towards the hydrates.

So which mechanism was the trigger? It is still unclear exactly what “uncorked the bottle”, says Miriam Katz, a marine geologist at Rutgers University. Katz has developed models to see whether a change in ocean circulation could release enough methane to start the warming[9], or whether other causes, such as sea floor landslides, could have triggered an abrupt degassing of methane reservoirs[4]. “With existing data, neither mechanism can be identified unequivocally as triggering methane release,” she says.

Core issue

But new information should soon be available. Last month, the US drilling ship *JOIDES Resolution* completed a two-month expedition to the Walvis Ridge, off the coast of Namibia. Sediment cores were recovered from five sites, and these should provide a better picture of conditions at the time of the PETM. By using these data to improve their models, researchers hope to rule out all but one of the possible trigger mechanisms.

Apart from the cause of the PETM, climatologists are also interested in its impact, and how the warming was reversed. Studying the PETM, says Ursula Röhl, a marine geologist at the University of Bremen in Germany who sailed on the *JOIDES Resolution* expedition, provides climate scientists with an extreme test of climate theory and models. It also helps them to understand how current global warming might affect life on land and in the oceans, she adds.

Although details of the transfer of carbon between rocks, the atmosphere and the ocean were different 55 million years ago — the total amount of carbon dissolved in the ocean was probably greater than it is now, for example — the underlying mechanisms are not. “The basic biogeochemical reactions and processes, including the biological pump that draws down carbon dioxide from the atmosphere to the deep ocean, should be the same,” says James Zachos, a palaeoceanographer at the University of California, Santa Cruz, who also sailed on the *JOIDES Resolution*.

This biological pump is probably responsible for the gradual return of temperatures to their pre-PETM levels. The process may have been helped by increased growth of plants and plankton[10]. Higher temperatures are likely to have accelerated the physical and chemical erosion of soils and rocks, for example, raising the amount of iron and phosphate washed into the ocean. These nutrients drive photosynthesis, and cause more carbon to be absorbed by organisms in the upper oceans.

The good news, then, is that the mechanisms that helped to bring down temperatures in the past are still active today. Increased amounts of vegetation, ocean phytoplankton and erosion could all act as a natural brake on today’s global warming. But studies also suggest that we shouldn’t rely on these systems to rein in global warming in the short term. “The climate events at the PETM boundary teach us that the Earth can help itself,” says Richard Corfield, a marine geochemist at the University of Oxford. “But we should always bear in mind that it took at least 100,000 years to recover.” ■

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