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- NEWS FOCUS

BIOGEOCHEMISTRY

'Inconceivable' Bugs Eat Methane on the Ocean Floor

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By devouring 300 million tons of methane each year, newly found archaea may help keep this greenhouse gas in check

Buried in the ocean floor are more than 10 trillion tons of methane—twice the amount of all known coal, oil, and other fossil fuels. Methane (CH_4) is also 25 times more potent, molecule for molecule, as a greenhouse gas than carbon dioxide is. That means that the ocean's hidden methane reservoirs could play havoc with the world's climate if they were to escape to the atmosphere. Yet most of the methane that does rise toward the surface of the ocean floor vanishes before it even reaches the water. On page 484 of this issue, a team of researchers provides the clinching evidence for where all that methane goes: It is devoured by vast hordes of mud-dwelling microbes that microbiologists once said couldn't exist.

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REPORT
Methane-Consuming Archaea Revealed by Directly Coupled Isotopic and Phylogenetic Analysis
Victoria J. Orphan et al.
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William Reeburgh of the University of California, Irvine, and other geochemists first stumbled on this enigma in the 1970s as they studied methane-rich regions of the ocean floor. Methane-producing microbes continually generate the gas deep below the ocean floor. But when the researchers checked the mud near the ocean floor's surface, they found the methane had all but disappeared. Perhaps, they speculated, another group of microbes dwelling in the shallow mud was eating the methane and converting it to carbon dioxide.

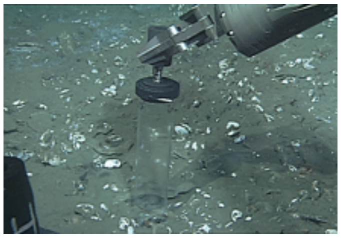
Other clues also hinted at the presence of methane feeders. Methane has a distinctively low ratio of carbon-13 to carbon-12 isotopes. The researchers discovered that in some places where the methane was seeping to the surface, there were carbonates—formed from carbon dioxide—that shared this remarkably low ratio. If methane feeders were consuming the gas and then releasing carbon dioxide low in carbon-13, that could account for the strange carbonates.

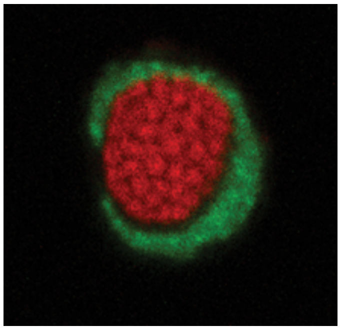
There was only one problem: The laws of biology seemed to forbid such a creature. Methane-eating bacteria are well known—but they thrive in fresh water and soils where oxygen is abundant, suggesting that oxygen is an essential agent for breaking down methane. The sediments on the ocean floor, however, are entirely oxygen free. “A lot of microbiologists were saying these organisms can't exist because they couldn't imagine that this reaction could yield sufficient energy without oxygen to support life,” explains Kai-Uwe Hinrichs, a biogeochemist at the Woods Hole Oceanographic Institution in Massachusetts and co-author of the current paper.

The mystery only deepened when geochemists measured levels of sulfate (SO_4^{2-}) in the ocean floor. The sulfate, normally present in sea water, penetrated into the mud but then abruptly disappeared in the sediment horizon, right where the methane vanishes. So, the geochemists reasoned, the same creatures that were destroying methane must also be destroying sulfate. But such an organism was even further beyond the imagination of microbiologists.

Looking for these improbable creatures would not be easy, because the exotic conditions in which they live cannot be replicated in the lab. Instead, microbiologists teamed up with biogeochemists to look for indirect signs of the microbes in the sediments. Hinrichs and his co-workers at Woods Hole and the Monterey Bay Aquarium Research Institute in California discovered that the mud in the Eel River Basin, off the coast of California, was packed with organic molecules—specifically, lipids from the cell walls of dead microbes. The lipids, they found, had a distinctive isotopic ratio suggesting they had been formed from methane. The researchers also found that the lipids had a structure that had been seen before only in archaea. (Archaea look superficially like bacteria, but they represent a separate domain of life.) Analyzing fragments of DNA collected from the sediments, Hinrichs and his co-workers confirmed in 1999 that the microbes were previously unknown archaea that make their homes in the mud.

The following year a team of German researchers led by Antje Boetius of the Max Planck Institute for Marine Microbiology in Bremen got the first look at the actual microbes. To do so, they fashioned probes that could latch onto the DNA sequences discovered at Eel River. The probes were designed to glow when they reached their target, revealing the archaea.





Mystery revealed. Microbiologists found hints of these gas-gobbling archaea (shown in red, surrounded by bacteria, in green) by sampling the mud in the Eel River Basin, off the coast of California.

CREDITS: (TOP TO BOTTOM) MBARI; ANTJE BOETIUS AND ARMIN GIESEKE

Looking at the glowing archaea under a microscope, Boetius discovered that they were not solitary creatures. They lived in tightly packed clusters of about 100 individuals, surrounded by a shell of bacteria. Boetius and her co-workers gathered DNA from the bacteria and found that they belonged to a group of species that consume sulfates. “I was very surprised, because it seemed to be too logical to be true,” jokes Boetius.

In her report last year, Boetius proposed that the archaea and the bacteria live in some kind of biochemical symbiosis. The bacteria may use the waste products made by the archaea—such as molecular hydrogen and carbon compounds—to help them get energy from sulfate. At the same time, the bacteria might somehow allow the archaea to feed on methane without oxygen.

But as of 2000, neither team had direct evidence that these particular archaea were actually feeding on methane. The only way to confirm those suspicions was to borrow a tool from a very different field—an ion microprobe that had already revolutionized geology and paleontology.

Ion microprobes fire precise beams of ions at targets, blasting microscopic pits in their surface. The liberated atoms can then be measured to determine their isotopic composition. These instruments have enabled researchers to date the oldest minerals on Earth (*Science*, 22 December 2000, p. 2239) and to recognize the isotopic traces of the oldest signs of life (*Science*, 3 January 1997, p. 38). Christopher House of Pennsylvania State University, University Park, and his co-workers had recently adapted ion microprobes to measure the carbon isotopes found in individual microbes. “We went to a system where we dried the microbes on a piece of glass, and we found that it worked quite well,” he explains. House teamed up with the researchers from Woods Hole and the Monterey Bay Aquarium to put the newly discovered archaea-bacteria aggregates in the sights of a microprobe.

For the first time, the researchers succeeded in identifying the microbes and then directly measuring their carbon isotopes. And, as they report in this issue, those isotopes clearly show that these specific archaea feed on methane and that the bacteria in turn get most or all of their carbon from the archaea.

Previous research on these microbes “was compelling, but this one is convincing,” says Reeburgh. All that remains now is to determine exactly what sort of chemistry goes on between the two microbes. “We still don't know what chemicals are being processed. But I keep telling people, we're on the right street, we're approaching the house, and we're about to knock on the door.”

These methane-eating microbes—once thought to be impossible—now look to be profoundly important to the planet's carbon cycle. Hinrichs and Boetius estimate that they devour 300 million tons of methane every year, about as much as humans now inject into the atmosphere with agriculture, landfills, and fossil fuel burning. But on early Earth, these microbes might have been even more significant. Atmospheric scientists have suggested that methane levels in the atmosphere may have been 1000 times higher than they are today, created initially by volcanoes and later by methane-producing microbes (Science, 25 June 1999, p. 2111). At first, this methane may have been beneficial, creating a greenhouse effect that kept the planet from freezing. But if the rise in methane had gone unchecked, Earth might have become too hot for life, as Venus is today. We may have the evolution of methane-eating archaea to thank for saving us from that grim fate. “If they hadn't been established at some point in Earth's history,” says Hinrichs, “we probably wouldn't be here.”

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