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U.S. Geological Survey Soil Carbon Research

Using samples from a field site at Alaska's Hess Creek, researchers from the Lawrence Berkeley National Laboratory, the U.S. Department of Energy Joint Genome Institute and the U.S. Geological Survey collaborated to study how permafrost-dwelling microbes generate greenhouse gases as their environments thaw.

Warming Arctic wakes up methane and microbes, study shows

by **GRETCHEN ROECKER**
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As global warming pushes temperatures in the Arctic up faster than anywhere else, concern is rising about releasing the vast reservoir of greenhouse gas-forming carbon trapped in permafrost.

The fate of the carbon could rest on some of the tiniest inhabitants of the frozen landscape: millions of microbes that respond rapidly to thaw, according to new research published in the on-line edition of Nature this week.

Microbes frozen for thousands of years can spring to life and digest the carbon to release heat-trapping gases into the atmosphere, amplifying warming and melting. Scientists can't yet predict how much of the carbon stored in Arctic permafrost will reach the atmosphere, but microbes could play a pivotal role.

"The microbial communities drive the release of carbon dioxide, methane and other greenhouse gases," said study co-author Rachel Mackelprang, a microbiologist with California State University at Northridge. "Without understanding the microbial contribution, it's hard to understand the whole system and to predict what's going to happen as permafrost melts."

Permafrost, defined as ground frozen for at least two years, covers more than one-fifth of the northern hemisphere, an area more than six times the size of the U.S. that could shrink by 25 percent due to warming by 2100. The mass of carbon trapped in its frozen organic matter – more than 1,600 gigatons – is at least twice the amount in the Earth's atmosphere.

"The concern is, as the climate warms and the permafrost melts, that organic carbon becomes accessible to microorganisms," said co-author Janet Jansson, a microbial ecologist at the Lawrence Berkeley National Laboratory in Berkeley, Calif.

To look at how microbes buried in permafrost react to warming, Mackelprang, Jansson and colleagues from the U.S. Department of Energy Joint Genome Institute and the U.S. Geological Survey analyzed frozen soil cores drawn from a forest at Hess Creek, in central Alaska. Their findings point to "an extremely dynamic process" of microbial activity in thawing permafrost, Mackelprang said.

After incubating the frozen soil for less than two days, the scientists observed a spurt of methane, a greenhouse gas at least 20 times more potent than carbon dioxide. Within a week the concentration dropped, after microbes that produce methane and those that consume it both became active. Some carbon dioxide escaped in the process.

Using metagenomics, the technique of sequencing all of the DNA in an environmental sample, scientists unearthed genetic information showing changes in the microbial population corresponding to the changes in measured methane.

"When we took the two cores and thawed them, they shifted very rapidly, both in microbial composition and function," Jansson said, noting the initial differences built up over more than a thousand years in the frozen soil samples. "By two days, they started to converge and look more like the active layer," the top layer of permafrost that thaws and refreezes seasonally.

As the soils thawed, defrosting a buffet of organic material, DNA markers for a range of microbes increased, including methanogens, which produce methane, and methanotrophs, which consume methane.

This spring, Marco Coolen, a geochemist at the Woods Hole Oceanographic Institution in Massachusetts, reported a similarly rapid response to thawing organic matter by permafrost microbes.

“This organic matter may be old,” Coolen said, “but as soon as it is exposed, the microbes quickly make enzymes to degrade the material.”

Using the DNA from the permafrost samples, the researchers assembled a draft of the complete genome of a novel methanogen, the first such construction from a complex soil metagenome.

Charles Greer, a microbiologist at the National Research Council of Canada's Biotechnology Research Institute, co-authored a 2009 report on the first metagenomic analysis of permafrost. Since the technique hasn’t been applied extensively in permafrost, finding a novel microbe isn’t unexpected, he said.

“We know so little about the microbial world in general, it’s only with more modern techniques that we’re gaining better insight into what’s there,” Greer said.

But sequencing a complete genome from the intricate soil system was a surprising result, Mackelprang said. She used software to reconstruct the genome from small DNA fragments in the soil.

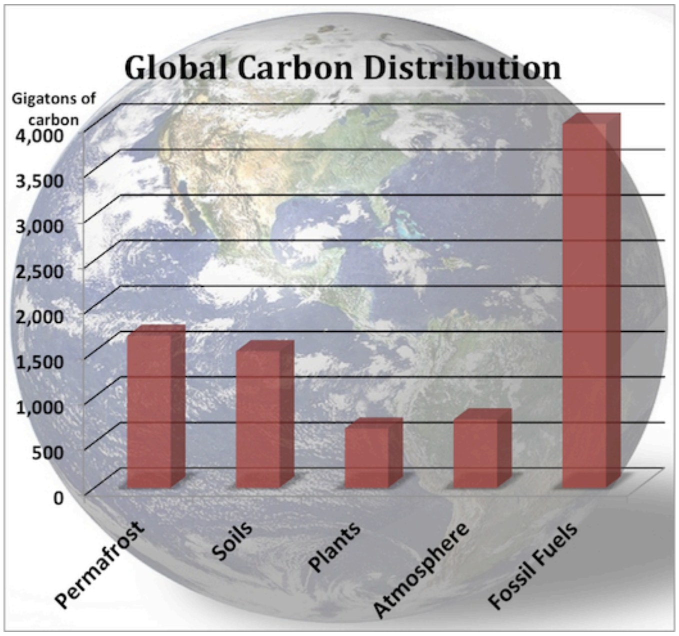
“It’s akin to taking the New York Times, ripping it into different pieces, and then trying to assemble those pieces to reform the newspaper,” Mackelprang said.

While the new methanogen corresponded to the initial burst of methane from the thawing samples, Jansson said, the subsequent rise in methanotrophs mirrored the drop in methane. The methane-degrading microbes allow carbon to enter the atmosphere as carbon dioxide, but prevent some of the more potent greenhouse gas from escaping. Understanding that process in thawing permafrost could inform strategies to mitigate global warming.

“If you can identify some of the factors that would increase the activity of methanotrophs,” Greer said, “then you may be able to further limit the release of methane into the atmosphere.”

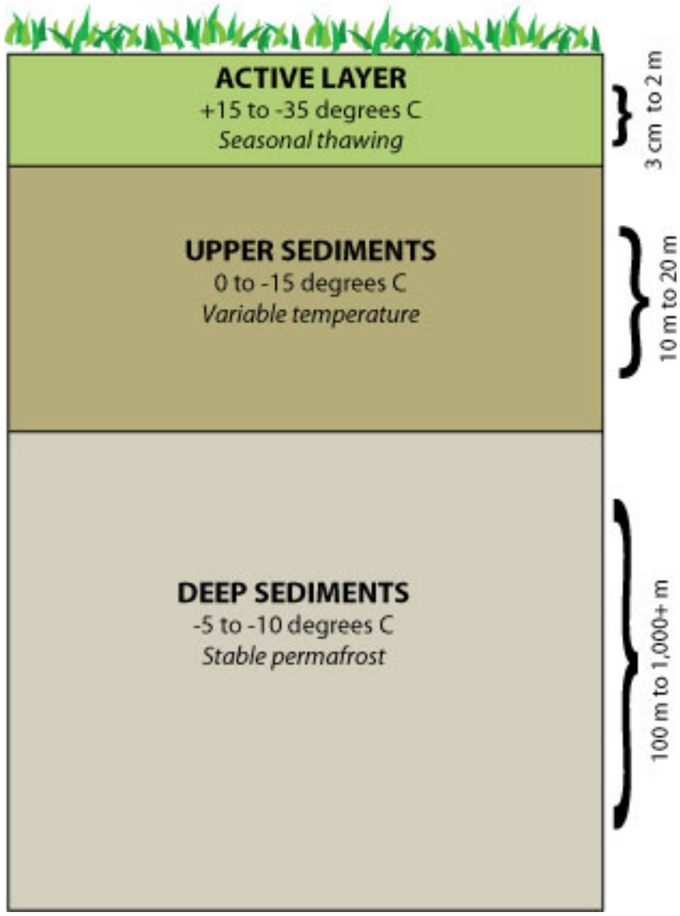
Characteristics of frozen soil and its microbial inhabitants from Alaska to Russia cannot be pinpointed in just a few thawed cores, so Jansson, Mackelprang and others are expanding their research to look at gene expression in a range of habitats.

“This is a first step in understanding what is going to happen when there’s large-scale thawing of permafrost in Arctic systems,” Mackelprang said. “We hope to use this as a springboard to ask intelligent questions about what’s going on in many different types of permafrost all across Earth.”



Produced by Gretchen Roecker/MEDILL. Data from Schaefer et al, National Snow and Ice Data Center (2011); Zimov et al, "Permafrost and the Global Carbon Budget" (Science, 2005)

While the ocean holds the largest portion of Earth's carbon - about 40,000 gigatons - emissions from fossil fuel have driven atmospheric carbon up from about 560 gigatons in the preindustrial period to at least 750 gigatons today. That's still less than half the amount of carbon trapped in permafrost, but as the Arctic soils thaw and expose organic matter to microbes, the stored carbon could escape as greenhouse gases. Fossil fuels in this chart refers to energy sources such as coal still stored in the earth.



Gretchen Roecker/MEDILL. Data from "Microbial Communities and Processes in Arctic Permafrost Environments," by Dirk Wagner, Ph.D.

A permafrost primer: Plants at the surface take in carbon dioxide from atmosphere, but freeze before being broken down. The uppermost "active layer" thaws each summer, allowing more plants to grow. Over hundreds to thousands of years, layers of carbon-rich material build up. Depth, temperature, moisture, nutrient content and other features vary greatly in the frozen ground at Earth's high latitudes, but permafrost is commonly defined as soil that remains at or below zero degrees C for at least two years.