Current Biology
Magazine

Feature

Permafrost thaw releases problems

The Arctic warms faster than the global average. This leads to thawing of permafrost soil and the release of carbon it has stored for millennia, threatening to further accelerate climate change. The frozen ground that so far has mainly yielded well-preserved megafauna remains could also unleash dangerous pathogens, such as anthrax. **Michael Gross** reports.

July 2016 brought an exceptional heat wave to the Yamal peninsula, in the northwest of Siberia. Although the area is well within the Arctic Circle, temperature maxima above 35°C were measured that summer. Thus, when reindeer in the area started dying unexpectedly, the veterinarians first suspected heat stroke as the likely cause.

Further investigations revealed, however, that an outbreak of anthrax was underway. Hundreds of reindeer died, among a total population of 800,000. Among the native nomadic reindeer herders, a boy and his grandmother died, and dozens of people had to be treated for the disease.

Before that hot summer, the area had been officially declared anthrax-free since 1968, and the precautionary measure of vaccinating reindeer against the disease had ceased to be obligatory in 2007. Genetic studies of the outbreak and other samples now suggest that the disease may be emerging as the frozen ground thaws.

Frozen layers

The group of Vitalii Temofeev at the State Research Centre for Applied Microbiology and Biotechnology at Obolensk, Russia, together with Gilles Vergnaud from the University Paris-Saclay, France, have analysed genetic data of samples from that outbreak in comparison with others obtained from frozen prehistoric animals discovered further east in Northern Yakutia in 2015. A preliminary report has been released as a preprint (bioRxiv (2018) https://doi.org/10.1101/486290).

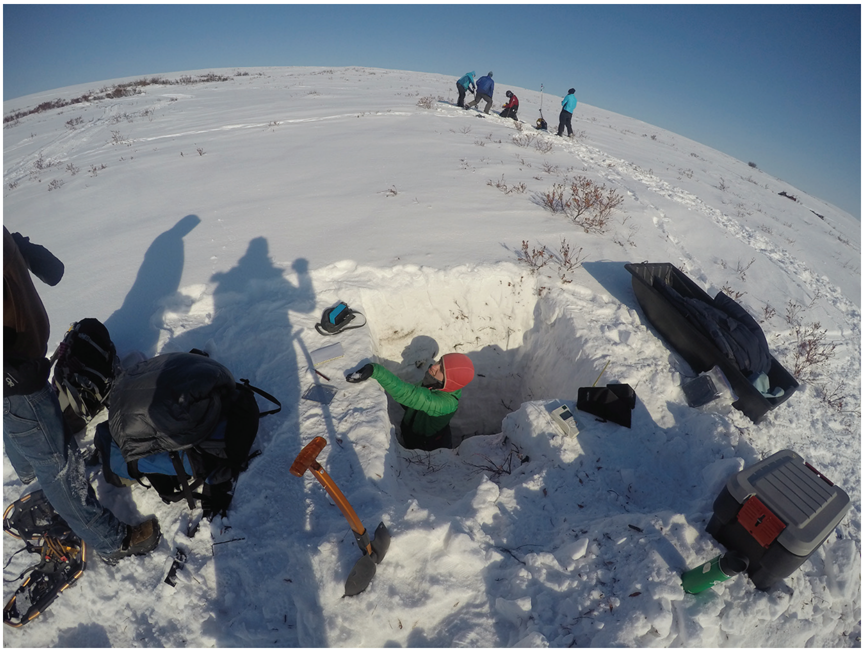
Genetic analyses of the samples from the 2016 outbreak showed that the *Bacillus anthracis* pathogens were all of the same strain, even across distances of hundreds of kilometres. There are no historic samples of the last outbreak in that location, which occurred in 1941. However, the authors conclude that the most likely explanation is that the frozen soil preserved the pathogen strain that was widespread in that outbreak for 75 years and released it when the exceptionally warm summer weather thawed deeper layers of the soil. A small amount of rain that fell in July 2016 may have helped to revive the bacilli from the frozen spores.

Thus, the authors conclude, permafrost soil may store viable anthrax pathogens for long periods of time. They could confirm this with their studies of samples from the Yakutia (North Eastern Siberia) region, where a serendipitous observation had led to the discovery of several different anthrax strains in soil layers above the well-preserved corpses of cave-lion cubs discovered six metres below the surface and dated to 5,000–10,000 years. The microbiological analyses showed that the prehistoric animals themselves were free of anthrax, and that the bacteria found in the layers above them reflect three separate introductions of the disease, which may be linked to different historic events.

At the top was a type B strain very similar to the Yamal strain, despite a distance of 2,000 kilometres, and thus likely linked to the widespread anthrax outbreaks of recent history, before vaccinations were introduced. This strain is found at depths of up to two metres and the authors suggest it may have reached Northern Yakutia in the course of the Russian conquests in the 17th and 18th centuries.

The type A strain found at two to three metres depth may have arrived with the migration of the Yakut population of herders, who arrived from the Lake Baikal region in the 14th to 15th century. The earliest introduction of anthrax, this time a different strain of type A leaving spores buried up to four metres deep, may have arrived with the Mongol conquests. As these involved the movements of large numbers of horses, the authors suggest that these animals are a likely culprit for first introducing anthrax to the frozen wastelands of Siberia where it was preserved exceptionally well.

Unearthed: Thawing permafrost soils in the Arctic have enabled access to fossils but may also release ancient pathogens. The image shows megafauna remains, possibly a bison mandible, discovered in an excavation tunnel in Alaska. (Photo: Travis Shinabarger/Flickr.)



Cold spell: Research is only beginning to characterise the complex biogeochemical situation that will unfold as large areas of permafrost soil are thawing due to climate change. The photo shows researchers from several US institutions investigating the impact of vegetation on permafrost soils (Environ. Res. Lett. (2018) *13*, 105006). (Photo: Los Alamos National Laboratory.)

The conservation of these pathogen spores in the permafrost may be good news for fundamental research into the evolution of the bacillus. It is believed to go back to a single source in Africa, so tracing its family tree and linking it to known historic movements of large numbers of people and animals is a fascinating jigsaw puzzle to play.

On the other hand, it also means that the permafrost may harbour further dangerous disease strains that we don't yet understand fully. As man-made climate change continues to defrost the soils that have remained frozen for centuries, these pathogens are likely to emerge and cause further trouble.

"A significant part of present tundra territory in the past was a tundra-steppe and steppe," Timofeef explains. "Those landscapes were suitable for the existence of large herds of herbivores. And if there are large concentrations of animals, it is a welcoming environment for pathogens circulating, and for epizootics [epidemics among animal species]. And these pathogens nowadays can be frozen in permafrost. Microorganisms capable of forming spores (the form that is resistant to environmental factors) may pose a particular hazard."

Anthrax, which is feared as a biological agent that can be weaponised and used against people, like in the 2001 letters in the US, is already a very worrying prospect. Other diseases of the past could be even worse if they take us by surprise. But what other problems will arise from the frozen ground?

Methane makers

The main reason to worry about the thawing permafrost is its potential to produce a positive feedback loop accelerating climate change. Essentially, warming releases carbon which adds to the problem. In this process, microbial communities play a crucial role as they ultimately decide the pathway that this carbon takes. Will it be released as methane, the most potent greenhouse gas, or as carbon dioxide? Can it be kept in the biomass or even sequestered in minerals? The largely unknown answers to these questions could dramatically influence the trajectory of climate change.

The group of Gene Tyson from the University of Queensland at Brisbane, Australia, together with colleagues from the USA and from Sweden, has recently conducted a metagenomic study of 214 soil samples taken along a permafrost thaw gradient at a well-characterised climate change study site in Sweden (Nature (2018) *560*, 49–54). From the metagenome data, the researchers assembled 1,529 separate genomes of bacteria, archaea and fungi.

Of the 95 archaea characterised in this study, 76 were methane producers using hydrogen or carbon dioxide. The authors conclude that they are likely to be the major source of methane emissions from thawing permafrost, as other kinds of methane producers were much less prominent. Along the gradient, the abundance, diversity and activity of these microbes increased as the thaw deepened.

This is in agreement with another recent study from Christian Knoblauch at the University of Hamburg, Germany, and colleagues, who showed with long-term incubations that methanogens in permafrost are awakening very slowly, taking weeks to years to reach their maximal production (Nat. Clim. Change (2018) *8*, 309–312). Thus, previous studies which have analysed samples of permafrost soil on shorter timescales may have underestimated the methane release and thus the climate impact of its thawing.

The metagenome study of Tyson and colleagues revealed further complexities that remain to be studied in more detail, including new kinds of metabolism, and the suspected metabolic collaboration (syntrophism) of several groups of microbes based on the transfer of hydrogen. The ecology of these communities could dampen or strengthen the climate feedback loop. In the latter case, their activities could have disastrous consequences.

Another aspect of the microbial ecology in thawing permafrost that hasn't been addressed yet is the role of viruses. In the last ten years, studies of marine microbial ecology have shown that bacteriophages play a much bigger role than previously thought. By lysing as many as a third of all marine microbial cells in a day, they close nutrient cycles, facilitate gene transfer, and shape the evolution of their host species.

Much less is known about the role of viruses in soils, but the group of Matthew Sullivan at the Ohio State University at Columbus, USA, has reported findings suggesting that viruses also shape the microbial ecology and specifically the methane production in thawing permafrost soils (Nat. Microbiol. (2018) *3*, 870–880). The research showed that viral abundance correlated with methane dynamics. The authors conclude that a better understanding of the role of viruses in these soils could help to predict and possibly even change their methane emissions as they thaw.

Adding further layers of complexity to the picture, geologists caution that mineral weathering can also change the carbon balance in either direction. As Scott Zolkos from the University of Alberta at Edmonton, Canada, and colleagues report, weathering surface minerals after permafrost thaw in the western Canadian Arctic is driven by sulphuric acid in certain environments. Unlike the weathering process driven by carbonic acid, this process will enhance rather than reduce carbon dioxide release (Geophys. Res. Lett. (2018) *45*, 9623–9632).

Other biogeochemical cycles may also be affected by microbes revived after long dormancy. In an astonishing example not linked to permafrost but to extremely arid soil in the Australian desert, researchers led by Guibing Zhu at the Chinese Academy of Sciences in Beijing and by Lorenz Schwark at the University of Kiel, Germany, have demonstrated that anammox bacteria, which are linked to globally important processes in nitrogen cycling (Curr. Biol. (2012) *22*, R1–R4) can be revived after more than 10,000 years of dormancy (ISME J. (2018) https://doi.org/10.1038/s41396-018-0316-5).

Defrosting damage

Naively, one could imagine that pushing back the boundaries of the permanently frozen and thus hardly usable soil could be a positive for human activities, such as agriculture and resource extraction. Indeed, in a recent breakdown of economic losses and gains expected due to climate change, countries with large areas of permafrost like Russia and Canada are listed among the very few economies likely to benefit (Curr. Biol. (2018) *28*, R1221–R1224).

However, the problems that can arise from the thawing soil are manifold and very poorly understood so far. Beyond the threats of resurging ancient diseases and carbon emissions accelerating climate change, there are also risks of chemical and physical dangers.

For instance, Kyra St. Pierre from the University of Alberta at Edmonton, Canada, and colleagues analysed water downstream of thaw slumps (landslides of ice-rich permafrost ground thawing rapidly) and discovered significant concentrations of mercury and methylmercury (Environ. Sci. Technol. (2018) *52*, 14099–14109). The authors estimate that 88,000 tonnes of mercury, representing 5% of the total stored in northern permafrost soils, are at risk of being released into the biosphere. Methylmercury, in particular, is notorious for readily entering the food chain posing a risk of poisoning to animals and humans alike.

Dangers can also arise from the simple mechanical fact that the ground that has been rock solid for millennia will now become soft and mobile. Even though permafrost areas tend to have very few human inhabitants, Jan Hjort from the University of Oulu, Finland, and colleagues found in a modelling study that nearly four million people and 70% of current infrastructure in the Arctic are at risk of being affected. Even if the goals of the Paris agreement are met, there will still be substantial infrastructure damage, the authors conclude.

David McGuire from the University of Alaska at Fairbanks and colleagues also used modelling to assess how the different possible trajectories of climate change will affect the carbon dynamics in the permafrost region of the northern hemisphere (Proc. Natl. Acad. Sci. USA (2018) *115*, 3882–3887). They calculate that under the best-case trajectory, RCP4.5 (Representative Concentration Pathway limiting radiative forcing to 4.5 W/m^2), which would require a 75% reduction of carbon emissions within this century, the carbon losses from the permafrost could remain small or even turn into gains, as increases in vegetation may more than compensate for the carbon lost to the atmosphere. Under the less optimistic RCP8.5 scenario, however, the amount of soil carbon lost to the atmosphere would be dramatic.

All the more reason to tackle climate change now, before all of these problems come out of the frozen ground to haunt us.

Michael Gross is a science writer based at Oxford. He can be contacted via his web page at www.michaelgross.co.uk

Q & A

Jenny Saffran

Jenny Saffran is Vilas Distinguished Achievement Professor of Psychology at the University of Wisconsin–Madison. She began her research career as a high school volunteer in an infant development lab at Swarthmore College and continued to study infant language development as an undergraduate at Brown University. She received her PhD in Brain and Cognitive Sciences at the University of Rochester in 1997, working with Elissa Newport and Richard Aslin. She has been a Professor at the University of Wisconsin–Madison since 1997, where she runs the Infant Learning Lab at the UW–Madison Waisman Center.

Who were your key early influences? My parents. My mother was Eleanor Saffran, an eminent cognitive neuropsychologist at Temple University who studied the effects of adult-onset brain damage on language and cognition. I still remember hearing her tell us over the dinner table about the fascinating patients she had seen that day at work. I trace my interest in language to those childhood conversations. My dad was Bernie Saffran, an Economics Professor at Swarthmore College. He was renowned at Swarthmore as an exceptional teacher and mentor — roles that I greatly benefited from myself throughout my childhood.

What drew you to your specific field of research? For as long as I can remember, I've been fascinated by questions of nature and nurture. Language is a great area of study in this regard, as it clearly requires both influences: even very intelligent non-human animals struggle to learn human language structures, suggesting biological factors at play, while experience determines which language(s) any given human learns. Infants are a logical place to look for answers to questions of nature and nurture. I also really enjoy the challenges of trying to figure out how infants are learning, given that we can't ask them directly. The methodological issues are very interesting, and the work takes a great deal of patience — often a single study takes years to complete.