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Climate science

Cold carbon storage

Lakes that form in thawing permafrost emit substantial amounts of greenhouse gases to the atmosphere. It emerges that large quantities of carbon can also be stored in sediments at the lake bottoms. See Letter P.452

SEBASTIAN SOBEK

Frozen soils in the Arctic contain more than twice the amount of carbon present as carbon dioxide in the atmosphere¹. In the worst-case scenario, climate warming will thaw these permafrost soils and release the long-stored carbon, making it available to microbes that degrade it to the greenhouse gases CO₂ or methane^{2,3}. This would further heat the atmosphere and accelerate permafrost thaw. However, it is by no means certain that the worst case is the most likely one. On page 452 of this issue, Walter Anthony *et al.*⁴ show that lakes that formed in thawing permafrost thousands of years ago have accumulated vast amounts of plant remains in sediments at their bottoms, building up a large carbon sink that has had a cooling effect on climate.

Permafrost thaw is nothing new. During the most recent ice age, the majority of northeastern Siberia and Alaska was covered not by ice, but by permafrost soils called yedoma⁵ up to 90 metres thick, which formed when wind-blown dust accumulated there and froze. The yedoma started to thaw some 15,000 years ago as the climate warmed, and the big chunks of ice contained within it melted to become lakes (called thaw or thermokarst lakes). As meltwater eroded the soils, large quantities of old carbon were released and degraded by aquatic microbes, leading to considerable emissions of methane gas — a process observed in present-day thaw lakes². Given that rapid climate change has partially triggered carbon release

in the past⁶, future prospects are worrisome.

However, lakes almost always act as both carbon sources and sinks. Although CO₂ and methane are emitted to the air, sinking particles form sediment at lake bottoms and thereby bury carbon. This process is well understood, and happens in a similar way in the ocean. But most studies on the carbon balance of lakes, including thaw lakes, have focused on greenhouse-gas emission — perhaps because gas emission is more obviously linked to climate change than is mud.

Walter Anthony and colleagues used shovels to dig up to 20 metres deep into the sediments of thaw lakes in Siberia (Fig. 1). This was possible because the thaw lakes have gone through a typical series of different phases: once formed, meltwater continued to erode the frozen soil until eventually a lateral or below-ground channel opened up and drained the water from the lake basins. The sediments were suddenly exposed to cold Arctic air and froze, forming a carbon-rich permafrost soil type called alas.

The authors found that carbon accumulated at high rates in permafrost thaw lakes that had formed after the most recent ice age. On the basis of observations of present-day thaw lakes, they infer that high nutrient levels supplied from thawing permafrost boosted the growth of aquatic plants such as mosses and sedges, and that near-zero oxygen levels and low temperatures in bottom waters inhibited microbial degradation of accumulating plant remains. By calculating gas emission and carbon burial back in time, Walter Anthony and co-workers conclude that thaw lakes acted as strong methane sources starting 15,000 years ago, but switched to become carbon sinks about 5,000 years ago. Summing up this behaviour for the past 15,000 years, it seems that thaw lakes have buried more carbon than they emitted to the atmosphere. The researchers estimate that this massive burial has resulted in alas carbon making up about one-third of today's carbon stock in permafrost soils in the region where yedoma is the dominant soil type.

Revealing a significant carbon sink in a region that is thought to be a hazard for climate change is a spectacular achievement. But, needless to say, uncertainties in the authors' large-scale, back-in-time calculations are large. Pronounced variations in gas emissions over space and time^{7,8} make generalizations challenging, even for fairly well-studied, present-day lakes; estimating gas emissions for the past 15,000 years necessarily relies on numerous assumptions.

For example, shifting environmental conditions may change the ratio of the amount of CO₂ and methane produced, as well as the extent of methane oxidation to CO₂ by aquatic microbes, thereby affecting estimates of the climate effect of gas emission. Also, the accumulated plant remains count as a carbon sink only if the plants used atmospheric CO₂ for growth, but intensive degradation of yedoma in the thaw lakes may have provided growing plants with yedoma-derived CO₂ — how much is uncertain. Irrespective of these and other uncertainties, Walter Anthony and colleagues' paper adds another layer to our picture of permafrost landscapes, and shows clearly that conclusions about ecosystem carbon balances that rely solely on atmospheric gas exchange are misleading^{9,10}.

But does the paper dispel the idea of massive, warming-induced carbon release from thaw lakes? Certainly not. The authors' calculations reveal that a pronounced methane-emission pulse occurred on thaw-lake formation, resulting in a climate-warming effect that lasted several thousand years. Even if sedimentary carbon burial in presently forming thaw lakes could alleviate — or even compensate for — gas emission in the long term, waiting for the cooling effect would take more time than we can afford if we are to avoid serious effects of climate change.

The probability of a huge carbon release will depend not only on climate, but also on

the degradability of alas carbon upon thaw: if we are unlucky, alas carbon degrades at similarly high rates to those reported for yedoma carbon¹¹, but information about this is scarce^{5,12}. We need to fill fundamental gaps in our understanding of the complex dynamics of the permafrost landscape if we are to predict the effects of climate change on such a huge carbon stock.

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1. Tarnocai, C. *et al. Glob. Biogeochem. Cycles* **23**, GB2023; <http://dx.doi.org/10.1029/2008gb003327> (2009).
2. Walter, K. M., Zimov, S. A., Chanton, J. P., Verbyla, D. & Chapin, F. S. *Nature* **443**, 71–75 (2006).
3. Schuur, E. A. G. *et al. Nature* **459**, 556–559 (2009).
4. Walter Anthony, K. M. *et al.* **511**, 452–456 (2014).
5. Zimov, S. A. *et al. Geophys. Res. Lett.* **33**, L20502; <http://dx.doi.org/10.1029/2006gl027484> (2006).
6. Walter, K. M., Edwards, M. E., Grosse, G., Zimov, S. A. & Chapin, F. S. III *Science* **318**, 633–636 (2007).
7. Rantakari, M. & Kortelainen, P. *Glob. Change Biol.* **11**, 1368–1380 (2005).
8. Bastviken, D., Cole, J., Pace, M. & Tranvik, L. *Glob. Biogeochem. Cycles* **18**, GB4009; <http://dx.doi.org/10.1029/2004GB002238> (2004).
9. Ciais, P. *et al. Biogeosciences* **5**, 1259–1271 (2008).
10. Mendonça, R. *et al. Nature Geosci.* **5**, 838–840 (2012).
11. Vonk, J. E. *et al. Geophys. Res. Lett.* **40**, 2689–2693 (2013).
12. Knoblauch, C., Beer, C., Sosnin, A., Wagner, D. & Pfeiffer, E.-M. *Glob. Change Biol.* **19**, 1160–1172 (2013).