# Fossil greenhouse-gas emission from microbial use of rock-derived organic carbon

Rock organic carbon from glacial runoff, once assumed to be non-bioavailable, is identified as a substrate used by marine sedimentary microbes. This challenges the traditional view that rock organic carbon bypasses the active carbon cycle and indicates an additional source of fossil greenhouse-gas emissions on geological, or possibly even shorter, timescales.

**This is a summary of:**
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## The question

Organic carbon stored in sedimentary rocks and shales accounts for about 90% of global organic carbon[1]. It was synthesized, deposited and degraded millions of years ago, which might suggest that it is mere 'leftovers'. This rock-derived (or petrogenic) organic carbon is presumably inert and therefore expected to bypass the active carbon cycle after exposure or erosion[2], such as through glacial runoff.

However, over the past two decades evidence has been growing of a more complicated picture, particularly regarding the availability of rock organic carbon to microbes — which could have profound impacts on atmospheric carbon concentrations over geological time scales[3]. Current global fluxes of rock organic carbon are not well constrained. Furthermore, owing to anthropogenic climate change, the supply of sedimentary particles (including rock organic carbon) from glaciated catchments could increase[4] — possibly also increasing the amount available to microbial communities downstream, and simultaneously elevating the release of previously locked-up carbon to the active carbon cycle.

## The observation

We assessed the bioavailability of rock organic carbon in marine sediments of the heavily glaciated Hornsund Fjord, in Svalbard, Norway. The local sediments receive organic carbon from only two sources, which have distinctive radiocarbon signatures: freshly produced organic carbon from the water column ($F^{14}C$-1 — rich in radiocarbon); and ancient rock organic carbon ($F^{14}C$=0 — radiocarbon-free), which is the dominant source. Exploiting these starkly contrasting isotopic signatures, we were able to assess microbial utilization of these two carbon pools by performing compound-specific radiocarbon analysis on bacterial membrane lipids. Intact polar lipids (indicative of live microbes) were extracted from the sediments and their fatty-acid side chains were purified, for analysis of their $^{14}C$ content using accelerator mass spectrometry (Fig. 1a).

Based on the isotopic signatures of both substrates (water column and rock organic carbon) and the purified membrane–lipid fatty acids, we calculated the average contribution of the two substrates to the fuelling of microbial life in the subsurface. Our calculation using isotope mass balance suggests that the local subsurface bacteria utilize between 5 ± 2% and 55 ± 6% rock organic carbon (averaging 25 ± 16%; Fig. 1b) for their biosynthesis. So, although the freshly produced organic matter from the water column is preferentially utilized, rock organic carbon is not inert and does contribute to microbial energy consumption.

Our data also suggest that $CO_2$ and $CH_4$ — metabolic end-products from microbial degradation of organic matter — are similarly derived (up to 55%) from previously locked-up rock organic carbon. We hypothesize that there is a link between a lack of freshly synthesized organic carbon and the utilization of rock organic carbon: the microbes are forced to use the presumably less attractive substrate as an energy source.

## Future directions

Although our study does not allow us to estimate the actual rates of release of rock-organic-carbon-derived $CO_2$ or $CH_4$ to the water column or the atmosphere, it does provide further evidence for the important role of rock-organic carbon in the global carbon cycle. On geological time scales, this process can be expected to have an impact on atmospheric carbon levels, but on time scales of decades to centuries it is still debatable. However, there is a recent estimate[5] that the degradation of remobilized fjord sediments (often rich in rock organic carbon) during the last glacial maximum might have increased global $CO_2$ levels by about 50 ppm — which shows that further research on this topic is needed.

As well as the unknown rates of rock organic carbon degradation, the overall transport rates and their sensitivity to changing erosion due to climate change are big unknowns. A better understanding of subglacial sediment dynamics will be crucial to estimate the extent to which rock organic carbon degradation can contribute to atmospheric carbon levels.

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## EXPERT OPINION

"The authors have cleverly chosen an ideal site and analytical approach that provide new insight into a 'hot topic' in organic geochemistry — respiration of rock organic carbon. By determining the bioavailability of rock organic carbon delivered to Arctic fjord sediments, they further constrain this mostly overlooked process that acts as a source of atmospheric $CO_2$ over geologic timescales." **Jordon Hemingway, ETH Zürich, Zürich, Switzerland.**

## FIGURE

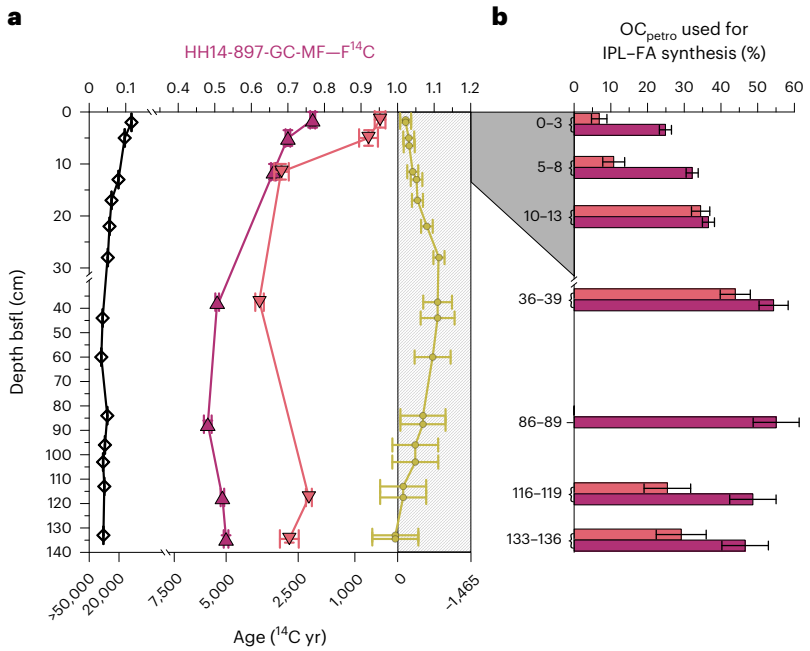


**Fig. 1 | Data for the sediment core HH14-897-GC-MF from the Hornsund Fjord. a**, Radiocarbon signatures of total sedimentary organic carbon (black diamonds); of intact polar-lipid fatty acids from living microbiota that degrade organic carbon in the subsurface (magenta and pink triangles, representing two specific bacterial fatty acids); and of the modelled dissolved inorganic carbon, which is the expected signature of marine primary organic carbon production (yellow circles). Axes show the $F^{14}C$ values (top) and corresponding $^{14}C$ age (bottom) against core depth, in metres below sea floor (bsfl). **b**, From the two fatty-acid signatures, we have estimated the utilization of rock organic carbon, shown at different core depths and varying from 5 ± 2% to 55 ± 6%. 

## BEHIND THE PAPER

This project evolved from an initiative by Witold Szczuciński, who approached Gesine Mollenhauer with the suggestion to apply compound-specific radiocarbon analysis to a well-dated long sediment core from Hornsund Fjord, Svalbard, as a means of investigating the fate of organic matter supplied to fjord sediments from land. I became part of this project in 2019, first exploring if and how the method was applicable to downcore sediments during my master thesis. It became apparent that these sediments contain organic matter derived from only two sources, making them ideal for investigating the long-term fate of rock organic carbon. I followed up this initial work as a PhD student from 2020 onwards, expanding the project to two more core locations, and developing more complex solutions for a robust estimate of the isotopic compositionfrom marine primary productions. The complexity of the work and the multitude of different disciplines, involving all co-authors, increased substantially over time. **M.R.**

## REFERENCES


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   **This paper illustrates the potental impacts of increased sediment mobilization on the milennial scale.**


## FROM THE EDITOR

"This work stands out to me because the authors have used an elegant geochemical technique to uncover the modern ecological importance of really old carbon. Their work will set the stage for improved understanding of the fate of rock-associated organic carbon in a warming world." **James Super, Senior Editor, *Nature Geoscience*.**