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Methane evades microbes

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Microbial activity in marine sediment acts as a barrier that generally prevents methane from escaping. However, a survey from the Baltic Sea suggests that in many locations the microbial population falters and methane can pass through freely.

Carbon deposited in marine sedimentary environments (Fig. 1) is often converted to methane when competing metabolic processes are limited by a scarcity of oxidants. The result is a subsurface laden with substantial methane accumulations and a concentration gradient that favours methane transport towards the seafloor and atmosphere. This methane is prevented from inundating the ocean or atmosphere thanks to an outer zone in which sulfate penetrates the seafloor sediment and acts as an oxidant to provide a highly effective biofilter – or so we assumed. Writing in *Nature Geoscience*, Lapham et al.[1] reveal a flaw in this assumption, demonstrating instead that methane passes through this boundary unimpeded in many locations in the Baltic Sea and elsewhere.

Beginning in the 1970s geochemical evidence emerged for the anaerobic oxidation of methane with sulfate in marine sediments and anoxic waters along continental margins[2]. Chemical measurements, laboratory incubations and numerical modelling converged to convincingly demonstrate the existence of a microbial reaction zone situated vertically at the interface where subseafloor methane and seawater sulfate intersect. Vertical distributions for methane dissolved in sediment pore waters pegged the reaction zone where high concentrations of underlying methane gave way to low concentrations near to the seabed. The observed concave-up shape of these vertical methane profiles became the expectation across continental margin settings, save for cold seeps where methane can accumulate and pass directly into the ocean via fluid flow, gas hydrates or ebullition of free gas.

Interest in anaerobic methane oxidation shifted focus toward seep environments following a series of studies that capitalized on the natural microbial enrichment at seeps to identify responsible microbial partnerships[3,4]. In combination with rapidly-advancing technologies the scientific community has leveraged these natural enrichments for profound discoveries centering on the unusual biology of anaerobic methane oxidation. Plasticity has been demonstrated for the microbial arrangement, including the involvement of various taxa and different oxidants coupling to methane[5,6]. Evolutionary dynamics of the responsible organisms and enzyme systems have been revealed[7]. Metabolic biochemistries have been uncovered including flexibility of the core enzyme system to either produce or consume methane, and to act on non-methane hydrocarbons[8]. Novel genomic strategies have also emerged from these communities, as have insights from their viral predators[9,10].

While there has been tremendous excitement around the topic of anaerobic methane oxidation driven by advances in DNA sequencing,

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Fig. 1 | Scientists sample methane across the sulfate–methane transition zone in a fresh sediment core collected from the Santa Barbara Basin. By analysing dissolved methane concentrations in cores similar to this, Lapham et al.[1] found that methane evades microbial consumption more commonly than previously assumed.

chemical analysis, microscopy and computational methods, the recent work from Lapham et al.[1] provides a critical reminder that our reductionist knowledge of this process has outpaced our understanding of its environmental context. By systematically collecting sediment cores in the Baltic Sea and analysing the depth distributions of methane Lapham et al.[1] demonstrate that many locations lack canonical concave-up methane profiles and that variable but substantial amounts of methane pass freely through this zone. Even with this new insight, the global distribution of anaerobic methane oxidation in seafloor sediments remains a crude estimate, and the root causes of its failure remain hypothetical. Lapham et al. present a plausible explanation, that the occurrence of reactive organic material could shift anaerobic metabolisms in a way that is unfavourable for methane oxidation and drive a partial or complete failure of that ecosystem function. Still, the factors enabling or preventing development of an effective community remain uncertain. Crucially, we currently lack sufficient mechanistic understanding of the seafloor microbial ecosystem to explain the success or failure of its keystone organisms.

Methane is also an important climate consideration given its role as a greenhouse gas, and prevention of methane flux to the atmosphere is a key ecosystem service performed by anaerobic methane oxidizers. By some estimates, anaerobic oxidation consumes more methane than is ultimately released to the atmosphere from all sources combined. While the intermittent failure of anaerobic methane oxidizers may therefore seem a direct concern for atmospheric methane and climate, there are other microbes that pick up the slack.

To escape the sediment methane must first pass through a second barrier at the seafloor interface. The seafloor is commonly exposed to oxygen and nitrate and allows for populations of bacteria capable of consuming methane aerobically or perhaps coupled to nitrate. The interface of sediment methane with seawater oxygen or nitrate is typically narrow and scantly studied, but the metabolisms provide abundant energy and even relatively low methane fluxes may sustain an effective population. Even when methane escapes this second microbial perimeter and enters into the water column, methane oxidizing bacteria occur there too, with biological consumption commonly outpacing physical transport to the atmosphere.

Subseafloor methane must evade all three of these perimeters to escape microbial consumption and enter the atmosphere, equating to a triple failure of the microbial methane biofilter. While this degree of failure is common only to shallow seeps, there is a need to recast our thinking on human impacts such as regional-scale deoxygenation and benthic carbon loading through marine carbon dioxide reduction strategies that may weaken the biofilters. As we consider a future ocean altered by climate change and potential marine geoengineering solutions, a weakened methane biofilter should be considered and research targeted towards better understanding its susceptibility to failure.

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Competing interests
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