TYPE Editorial
PUBLISHED 23 October 2024
DOI 10.3389/feart.2024.1508196

OPEN ACCESS

EDITED AND REVIEWED BY
Michael Lehning,
Swiss Federal Institute of Technology Lausanne, Switzerland

*CORRESPONDENCE
Karin Andreassen,
karin.andreassen@uit.no

RECEIVED 09 October 2024
ACCEPTED 14 October 2024
PUBLISHED 23 October 2024

CITATION
Andreassen K, Ruppel C, Liebner S, Hodson A and Knies J (2024) Editorial: Natural methane emissions in a changing arctic – implications for climate and environment.
Front. Earth Sci. 12:1508196.
doi: 10.3389/feart.2024.1508196

Editorial: Natural methane emissions in a changing arctic – implications for climate and environment

Karin Andreassen[1,2]*, Carolyn Ruppel[3], Susanne Liebner[4], Andrew Hodson[5] and Jochen Knies[1,2,6]

[1]CAGE - Former Centre for Arctic Gas Hydrate, Environment and Climate, UiT - The Arctic University of Norway, Tromsø, Norway, [2]iC3 – Centre for ice, Cryosphere, Carbon and Climate, UiT–The Arctic University of Norway, Tromsø, Norway, [3]U.S. Geological Survey, Woods Hole, MA, United States, [4]Geomicrobiology Section, GFZ – German Research Centre for Geosciences, Potsdam, Germany, [5]Arctic Geology Department, UNIS – The University Centre in Svalbard, Longyearbyen, Norway, [6]NGU - Geological Survey of Norway, Trondheim, Norway

KEYWORDS

methane, arctic, climate, cryosphere, atmosphere

Editorial on the Research Topic
Natural methane emissions in a changing arctic – implications for climate and environment

Introduction

Natural methane emissions have received significant attention in recent years due to the documented increase in atmospheric concentrations of methane and its elevated global warming potential relative to CO_2. Over the past decades, the Arctic has been warming nearly four times faster than the rest of the planet (Rantanen et al., 2022). Arctic amplification of global warming drives a pressing need to assess the current and future vulnerability of natural methane accumulations under continued high latitude warming.

Methane accumulations exist in a variety of Arctic settings, including deep-water marine environments, shallow-water continental shelves and fjords hosting relict subsea permafrost and gas hydrate, in and beneath onshore permafrost, and beneath glaciers and the Greenland Ice Sheet. Continued climate warming is making increased methane leakage from these accumulations more likely. Even deeper conventional gas reservoirs could leak methane as the overlying permafrost and gas hydrates degrade. These Research Topic were the focus of "Methane in a Changing Arctic," a conference convened by the Centre for Arctic Gas Hydrates, Environment and Climate (CAGE) at UiT—The Arctic University of Norway from 14–16 September 2022. CAGE was a Norwegian Centre of Excellence funded by the Research Council of Norway from 2013 to 2023, and a key focus of CAGE's research was related to the interaction between Arctic climate change and methane emissions.

CAGE's research legacy, along with the 2022 conference, sparked interest in developing the Frontiers Research Topic that has now produced 15 original research articles. These studies cover all aspects of methane migration, starting with the geosphere (e.g., sub-seafloor methane reservoirs) through the biosphere (e.g., microbes consuming this methane and acting as a critical sink) to the hydrosphere (e.g., ocean, other waters), the cryosphere (e.g., permafrost sediments, ice sheets, and glaciers) and potentially into the atmosphere. The papers collectively contribute to improved understanding of complex high-latitude methane emissions. The studies investigate timescales from the Pleistocene Ice Ages to the present, demonstrating how past methane seepage histories may inform future climate scenarios.

Methane in the geosphere: subsurface thermogenic, biogenic and abiotic sources

Methane emitted from seafloor or terrestrial seeps has long been known to originate with biotic processes. At lower temperatures, microbial decomposition of organic matter produces gas that has sometimes been referred to as biogenic. At higher temperatures, thermal cracking of heavier hydrocarbons at deeper depths generates thermogenic gas. Both microbial and thermogenic gases are considered biotic in origin owing to their ultimate reliance on organic matter as a substrate. It has also been suggested that methane can be generated abiotically during serpentinization of ultramafic rocks (Proskurowski et al., 2008; Cannat et al., 2010) in slow-to ultraslow-spreading mid-oceanic ridge environments and also during serpentinization in certain backarc systems (Wheat et al., 2020).

In the Barents Sea, widespread seafloor seeps regularly emit thermogenic gases, reflecting the basin's status as a major hydrocarbon province characterized by deep oil and gas reservoirs. Serov et al. explore the origin of Barents Sea seeps, underscoring the role that Cenozoic tectonic uplift and extensive Quaternary glacial erosion (Lasabuda et al., 2021; Patton et al., 2022) have played in reducing the thickness of unlithified overburden sediment that could host widespread microbial methane generation. Analyses by Chand et al. of seep emissions at the Loppa High in the Southwest Barents Sea confirm a deep-seated thermogenic origin but also suggest significant microbial modification of gas chemistry during syn- and post-glacial storage of gas that had migrated into shallow sediments. The study postulates that water percolation through open faults could play a role in some seep gases being characterized by less than purely thermogenic composition.

Studies of abiotic methane remain relatively novel. In the eastern Fram Strait, Johnson et al. (2015) have suggested abiotic methane as the gas source for a long-lived hydrate system on young oceanic crust. Chand et al. investigate gas flares in this area, concluding that the gas primarily originates from thermal cracking of organic material (thermogenic process), with a minor contribution from possible abiotic crustal/mantle sources.

Methane in the hydrosphere: seep distribution and controlling processes

Extensive seafloor methane seepage has been detected in a variety of settings, including at high latitudes. Although seafloor gas releases at greater than ~100 m below sea level (mbsl) are unlikely to have a direct impact on atmospheric methane concentrations owing to the strong sink of water column aerobic methane oxidation (e.g., Ruppel and Kessler, 2017), the seeps still play a critical role in the carbon cycle and ocean chemistry and as hosts for seafloor chemosynthetic communities. A key difference between seafloor seep systems at temperate and high latitudes (e.g., in Scandinavia and surrounding areas) is the impact of past glaciations and loading/unloading cycles on the latter locations.

Gas seeps and fluid flow in Norwegian offshore regions have long been linked to previous glaciations (Crémière et al., 2016). The predominance of glaciological and geological controls on gas seepage is evident in new results from a 5,000 km^2 area of the northern Barents Sea shelf. In this area, Serov et al. document 21,700 seeps located on glacially eroded, exhumed, and highly faulted structural highs and leaking oil and thermogenic methane from deep reservoirs. They estimate seabed methane flux to be one to two orders of magnitude higher than at other seafloor seep provinces and predict that vigorous methane emissions will continue in the Barents Sea in the future.

Glaciations over the past 2.7 million years have strongly affected both the Barents Sea, which was repeatedly covered by grounded ice, and Vestnesa Ridge west of Svalbard, which was located seaward of ice sheets that terminated at the continental shelf break (Patton et al., 2016). A new seepage chronology for the Barents Sea reveals episodic emissions throughout the Holocene and suggests gas hydrate decomposition and post-glacial seismic activity as potential trigger mechanisms (Himmler et al.). For the deep-water gas hydrate system on Vestnesa Ridge, glacial cycles have partially controlled seepage histories by affecting fracture formation (Cooke et al.) and oceanographic and depositional patterns (Rasmussen and Nielsen).

Geological control also plays a role for the evolution of active gas seeps in western Svalbard fjords, where Rodes et al. describe widespread emissions for which the gas may originate in organic-rich rock sequences that also crop out in the fjords. Southwest of Svalbard, Bellec et al. describe seafloor indicators of seepage (e.g., carbonate crusts, bacterial mats, chemosynthetic organisms), but no active gas flares, at 800 mbsl, near the confluence of two fans associated with the mouths of glacial troughs. Sediment loading from these fans and the consequent evolution of overpressures may drive the seafloor seepage, which occurs in an area where a gas-charged seafloor dome is postulated to have developed and then subsequently deflated. This is a new setting for seepage on the Svalbard margin, where previous studies have focused on seepage from the continental slope and shelf. On the Norwegian shelf, Sinner et al. report an unusual seep site with active hydrocarbon leakage, yet lacking chemosymbiotrophic fauna, possibly due to highly localized methane flow pathways.

Methane in the cryosphere

The cryosphere (i.e., permafrost, ice sheets, and glaciers) forms a frozen cap that traps underlying gas, preventing it from reaching the surface (Walter Anthony et al., 2012; Andreassen et al., 2017). Permafrost formed during past glaciations persists today across vast swaths of Arctic regions, and Birchall et al. highlight the widespread existence of vapor phase gas accumulations below permafrost-bearing sediments in some areas. In recent years, a surprising finding has been that circulating water transports dissolved gas from sub-permafrost and subglacial locations to the forefields of glaciers (Kleber et al., 2023). A paper in this Research Topic (Kleber et al.) adds to this narrative, describing the complex and interconnected hydrologic system that is crucial to these gas transport processes.

Ice sheets and offshore grounded ice have long been known to interact with methane systems in the underlying sediments. Damm et al. demonstrate that sea ice may also play a crucial role in the Arctic methane cycle. They present new insights showing that sea-ice leads may serve as sinks for atmospheric methane as they refreeze and suggest that this process may take on added importance as the Arctic Ocean transitions into a regime of only seasonal ice cover.

Methane in the biosphere: the microbial filter

Anaerobic methane-oxidizing bacteria present in seafloor sediments (Hinrichs et al., 1999) and aerobic oxidizers in the water column (e.g., Mau et al., 2013) constitute powerful microbial biofilters that mitigate emissions from water-covered areas. In Arctic marine cold seep provinces, De Groot et al. show that bubble-mediated transport and translocation via ocean currents shape microbial community structure and affect the efficiency of the aerobic water column methane sink. In a very different setting, Kleber et al. demonstrate that microbial oxidation is a strong summertime sink mitigating the release of methane from gas-charged subglacial groundwaters. In winter, shallow groundwater systems freeze, reducing subsurface methane oxidation and leading to higher methane emissions. Based on laboratory incubation experiments, Sert et al. reveal that water column aerobic methane oxidation alters dissolved organic matter (DOM) composition towards increased molecular diversity. They show that addition of methane affects DOM characteristics even if the water column was previously associated with a non-seep site and low methane oxidation rates.

Methane in the atmosphere

Continued Arctic warming is liberating carbon that is currently trapped in the cryosphere, and a fraction of this carbon will ultimately be released to the atmosphere as methane. Due to methane's potency as a greenhouse gas, appropriate attribution of natural methane emissions to various sources and geographic regions has taken on greater significance. In a contribution focused on determining if Arctic methane emissions are increasing, Lan and Dlugokencky summarize direct measurements of Arctic methane concentrations, calculate changes in interpolar differences, and apply atmospheric tracer transport models. They conclude that most of the increase in global atmospheric methane can be attributed to emissions from microbial sources in the tropics and that Arctic contributions have not increased significantly in the past four decades.

Author contributions

KA: Writing–original draft, Writing–review and editing. CR: Writing–original draft, Writing–review and editing. SL: Writing–original draft, Writing–review and editing. AH: Writing–original draft, Writing–review and editing. JK: Writing–original draft, Writing–review and editing.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. This is a contribution to CAGE: Centre for Arctic Gas Hydrate, Environment and Climate, and to iC3: Centre for ice, Cryosphere, Carbon and Climate, and was supported by the Research Council of Norway (RCN) through its Centres of Excellence funding scheme, project numbers 223259 and 332635.

Acknowledgments

We thank Peter Swarzenski (USGS) and Pam Swarzenski (USGS) for comments that improved the manuscript. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

Andreassen, K., Hubbard, A., Winsborrow, M., Patton, H., Vadakkepuliyambatta, S., Plaza-Faverola, A., et al. (2017). Massive blow-out craters formed by hydrate-controlled methane expulsion from the Arctic seafloor. *Science* 356, 948–953. doi:10.1126/science.aal4500

Cannat, M., Fontaine, F., and Escartín, J. (2010). "Serpentinization and associated hydrogen and methane fluxes at slow spreading ridges," in *Geophysical monograph series (Washington DC, USA: American geophysical union)*, 188. doi:10.1029/2008GM000760

Crémière, A., Lepland, A., Chand, S., Sahy, D., Condon, D. J., Noble, S. R., et al. (2016). Timescales of methane seepage on the Norwegian margin following collapse of the Scandinavian Ice Sheet. *Nat. Commun.* 7, 11509. doi:10.1038/ncomms11509

Hinrichs, K. U., Hayes, J. M., Sylva, S. P., Brewer, P. G., and DeLong, E. F. (1999). Methane-consuming archaebacteria in marine sediments. *Nature* 398 (6730):802–805. doi:10.1038/19751

Johnson, J. E., Mienert, J., Plaza-Faverola, A., Vadakkepuliyambatta, S., Knies, J., Buenz, S., et al. (2015). Abiotic methane from ultraslow-spreading ridges can charge Arctic gas hydrates. *Geology* 43, 371–374. doi:10.1130/G36440.1

Kleber, G. E., Hodson, A. J., Magerl, L., Mannerfelt, E. S., Bradbury, H. J., Zhu, Y., et al. (2023). Groundwater springs formed during glacial retreat are a large source of methane in the high Arctic. *Nat. Geosci.* 16, 597–604. doi:10.1038/s41561-023-01210-6

Lasabuda, A. P. E., Johansen, N. S., Laberg, J. S., Faleide, J. I., Senger, K., Rydningen, T. A., et al. (2021). Cenozoic uplift and erosion of the Norwegian Barents shelf—a review. *Earth Sci. Rev.* 217, 103609. doi:10.1016/j.earscirev.2021.103609

Mau, S., Blees, J., Helmke, E., Niemann, H., and Damm, E. (2013). Vertical distribution of methane oxidation and methanotrophic response to elevated methane concentrations in stratified waters of the Arctic fjord Storfjorden (Svalbard, Norway). *Biogeosciences* 10, 6267–6278. doi:10.5194/bg-10-6267-2013

Patton, H., Hubbard, A., Andreassen, K., Winsborrow, M., and Stroeven, A. P. (2016). The build-up, configuration, and dynamical sensitivity of the Eurasian ice-sheet complex to Late Weichselian climatic and oceanic forcing. *Quat. Sci. Rev.* 153, 97–121. doi:10.1016/j.quascirev.2016.10.009

Patton, H., Hubbard, A., Heyman, J., Alexandropoulou, N., Lasabuda, A. P. E., Stroeven, A. P., et al. (2022). The extreme yet transient nature of glacial erosion. *Nat. Commun.* 13, 7377. doi:10.1038/s41467-022-35072-0

Proskurowski, G., Lilley, M. D., Seewald, J. S., Früh-Green, G. L., Olson, E. J., Lupton, J. E., et al. (2008). Abiogenic hydrocarbon production at Lost City hydrothermal field. *Science* 319 (5863), 604–607. doi:10.1126/science.1151194

Rantanen, M., Karpechko, A. Y., Lipponen, A., Nordling, K., Hyvärinen, O., Ruosteenoja, K., et al. (2022). The Arctic has warmed nearly four times faster than the globe since 1979. *Commun. Earth Environ.* 3, 168. doi:10.1038/s43247-022-00498-3

Ruppel, C. D., and Kessler, J. D. (2017). The interaction of climate change and methane hydrates. *Rev. Geophys.* 55, 126–168. doi:10.1002/2016RG000534

Walter Anthony, K., Anthony, P., Grosse, G., and Chanton, J. (2012). Geologic methane seeps along boundaries of Arctic permafrost thaw and melting glaciers. *Nat. Geosci.* 5 (6), 419–426. doi:10.1038/ngeo1480

Wheat, C., Seewald, J., and Takai, K. (2020). Fluid transport and reaction processes within a serpentinite mud volcano: South Chamorro Seamount. *Geochim. Cosmochim. Acta.* 269, 413–428. doi:10.1016/j.gca.2019.10.037