

Methan meeting Ocean

8>11 june 2026 | Brest, France

Oceanic Methane

Interdisciplinary Meeting in Brest

Methane is the simplest organic molecule, yet it has a profound impact on Earth's climate and represents a dynamic component of the oceanic carbon cycle. This cycle is partly shaped by interactions between the geosphere - the largest methane reservoir - and the ocean, where methane distributions are highly variable and constitute a natural source to the atmosphere.

The oceanic methane cycle is governed by processes operating across multiple spatial and temporal scales. These include large-scale geological drivers such as sediment deposition, tectonic activity, and gas hydrate dynamics, as well as fine-scale biological and chemical transformations. The latter encompasses biologically mediated methane production and consumption through multiple pathways across a wide range of environments, from anoxic sediments to the oxic water column (the so-called "methane paradox"), as well as abiotic methane production associated with hydrothermal vent systems. Rapidly evolving technologies, particularly advances in methane sensors, isotopic techniques, and omics approaches, now offer unprecedented opportunities to observe, quantify, and constrain methane dynamics in the ocean.

Advancing our understanding of the oceanic methane cycle requires a broad and truly interdisciplinary approach, integrating expertise from microbiology and ecology, geology and geophysics, geochemistry and biogeochemistry, Earth system modeling, analytical chemistry, and sensor development. To foster interdisciplinary exchange and collaboration in oceanic methane research, we propose to host a three-day scientific meeting in Brest, preceded by a one-day pedagogical event dedicated to students and early-career scientists.

ORGANISING COMMITTEE

- Cédric Boulart – LEMAR
- Antoine Crémière – Geo-Ocean
- Sébastien Garziglia – Geo-Ocean
- Thomas Giunta – Geo-Ocean
- Laurent Toffin – BEEP

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PROGRAM

Session 1 | Methane production processes in oxic waters and sea-to-air fluxes

Session 2 | Marine methane microbial and macro-ecology: from molecules to ecosystems

Session 3 | Marine geology and geophysics: from deep structures to surface processes

Session 4 | Biogeochemistry across geosphere-ocean interface
Biogeochemistry across geosphere-ocean interface

Session 5 | Advances in methane measurement: novel methods and technologies



Aerial view of the IUEM, facing the Bay of Brest.
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MONDAY JUNE 8, 2026

PÔLE NUMÉRIQUE BREST IROISE (PNBI)

08:30 Welcome, Registration & Coffee.

Pedagogical day

09:00 Introduction (Antoine Crémière)

09:10 **Sebastien Garziglia** | Geomechanical controls and consequences of free gas in surficial sediments

09:40 **Olivia Fandino & Constant Agnissan** | Natural gas hydrates: fundamentals and insights from the Black Sea basin

10:10 coffee break

10:40 **Laurent Toffin & Gunter Wegener** | Marine methane microbiology: Methanogenesis and Methanotrophy

11:25 **Jörn Peckmann** | Mineral archives of methane-seep environments

11:55 **Thomas Giunta** | Tracing methane origin and processes: new insights from clumped isotopes

12:25 Lunch

13:30 **Cédric Boulart** | Oceans, an underestimated source of methane to the atmosphere?

14:00 **Arne Estelmann** | *In situ* and laboratory methane sensors

14:30 coffee break

15:00 Lab visit

TUESDAY JUNE 9, 2026

PÔLE NUMÉRIQUE BREST IROISE (PNBI)

08:30 Welcome, Registration & Coffee.

Session 1 | Methane production processes in oxic waters and sea-to-air fluxes

09:00 Introduction (Antoine Crémière)

09:15 **Mina Bizic** | Oxic Methane Production (OMP): What we know so far and where we should be heading.

10:00 **Coraline Leseurre** | Svalbard seawaters as a significant source of CH₄ to the atmosphere during summer 2024

10:30 coffee break

11:00 **Jérôme Chappellaz** | Dissolved methane sensing in Greenland fjords with the SubOcean MILS

11:30 **Axelle Brusselman** | The West Antarctic Peninsula: the sources of methane

12:00 **Silla Thomsen** | Oxic methane production from methylated substrates in the equatorial atlantic

12:30 Lunch

Session 2 | Marine methane microbial and macro-ecology: from molecules to ecosystems

13:30 **Gunter Wegener** | Anaerobic oxidation of methane in the ocean floor processes, controls, and how AOM feeds ancillary communities

14:15 **Marc Cozannet** | A variety of substrates for methanogenesis

14:45 **Cas Cornet** | Stratified and asymmetrical methane-cycling communities in the western Black Sea

15:15 Coffee break

15:45 **Evalien Baas** | Anaerobic oxidation of methane mediated by iron oxides and organic matter in coastal sediments

16:15 **Anna Wallenius** | Novel ANME-2a genus play a role in metal-dependent methane oxidation in Bothnian Sea sediments

16:45 **Daniel Birgel** | Organic sulfur compounds of methane-seep deposits

17:15 Poster Session & Drinks Reception

WEDNESDAY JUNE 10, 2026

PÔLE NUMÉRIQUE BREST IROISE (PNBI)

08:30 Welcome & Coffee.

Session 3 | Marine geology and geophysics: from deep structures to surface processes

09:00 **Aurélien Gay** | 4D fluid pipes: new insights into fluid migration in sedimentary basins

9:45 **Olivia Fandino** | Beyond Bulk Stability: The Role of Sedimentary Environment and Water Dynamics in Methane Hydrate Stability

10:15 coffee break

10:45 **Roger Urgeles** | Fluxes and fate of structurally controlled methane release in the gas hydrate province off the Antarctic Peninsula

11:15 **André Lion** | Multi-proxy exploration of cold seeps on the Gulf of Lion's margins (NW Mediterranean Sea)

11:45 **Miriam Römer** | Flares and mud volcanism: investigating marine methane emissions in the Gulf of Cadiz

12:15 Lunch

Session 4 | Biogeochemistry across geosphere-ocean interface

13:15 **Eoghan Reeves** | Probing the origins of abiogenic methane: a decade of changing views

14:00 **Suzanne Joanno** | High-temperature peridotite mylonites reveal deep organic carbon cycle at Oceanic Transform Faults

14:30 **André Pellerin** | Quantifying the role of geological carbon in the St. Lawrence Estuary: methane seepage and its role in estuarine carbon dynamics

15:00 Coffee break

15:30 **Christian Deusner** | Sluggish AOM in the Black Sea - An attempt to understand transient transport-reaction processes and unusual sulfate-methane-transition-zones (SMTZ)

16:00 **Wytze Lenstra** | Increased methane emissions from coastal waters due to sulfide inhibition of anaerobic methanotrophs

16:30 **Virgil Pasquier** | Sedimentary methane cycling: insights from microscale sulfur isotopes in pyrite

17:00 Poster Session & Drinks Reception

THURSDAY JUNE 11, 2026

INSTITUT UNIVERSITAIRE EUROPÉEN DE LA MER (IUEM) : AMPHI A

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9:45 **Santona Khatun** | Advancing greenhouse gas measurements: Continuous real-time observations of methane and nitrous oxide using a high-sensitivity in-situ sensor

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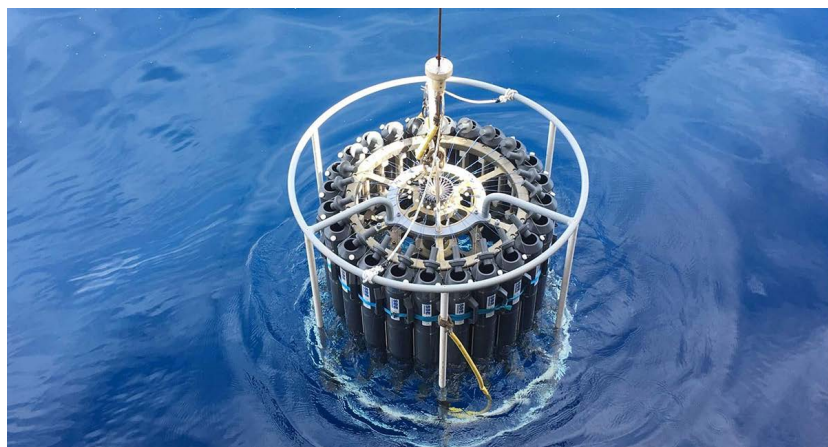
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Session

Methane production processes in oxic waters and sea-to-air fluxes

Invited speaker: Dr. Mina Bizic | TU Berlin



The global flux of oceanic methane to the atmosphere is unsurprisingly dominated by highly-productive shallow coastal environments, where methane is the product of methanogenesis in anoxic conditions. But methane oversaturation is also observed in most oxic ocean surface waters, including well-mixed coastal waters, a phenomenon known as the 'ocean methane paradox' (OMP). This session welcomes contributions on the comprehension of methane anomalies in the oceanic euphotic layer and on the estimation of sea-to-air fluxes in offshore environments via *in situ* measurements and/or modelling. The aim is not only to uncover the dynamics and processes driving the oceanic methane cycle but also to determine how the oceanographic community can contribute to the evaluation of methane fluxes through e.g. systematic measurements of methane during oceanographic cruises or the development of long-term high frequency observatories.

Oxic Methane Production (OMP): what we know so far and where we should be heading

Mina Bizic¹

1 | Department of Environmental Microbiomics, Technische Universität Berlin – Germany

Biological methanogenesis was, and still is, considered by many to be restricted to Archaea in anoxic conditions. Nevertheless, in the last five decades, increasing evidence revealed that methane can be produced by organisms also in fully oxygenated environments, a phenomenon termed "The Methane Paradox". A plethora of mechanisms responsible for this phenomenon have been identified or suggested. Some are substrate dependent, involving demethylation of methylated compounds, such as methylphosphonate, methylamines, or dimethylsulfoliopropionate. Others, are substrate independent like photosynthesis associated methane production, by phytoplankton (Cyanobacteria and algae).

Phytoplankton are ubiquitous across aquatic environments and are known to form blooms that are enhanced in frequency and intensity due to global warming and anthropogenic eutrophication. These blooms may contribute significantly to carbon sequestration via the biological carbon pump, yet this contribution may be attenuated by their methane production. To quantify this effect, we are calculating a methane production quotient (MPQ), representing the amount of CO₂ taken up which is released back in the form of methane. For Cyanobacteria the MPQ ranged between 0.16 % and 1.4 %, while for eukaryotic algae we have found values on the lower range (0.0004 % - 0.19 %).

Oxic methane production rates, are poorly constrained and are minimally considered in global methane budgets. Upscaling local measurements to a global scale is a major problem in bottom-up budget calculations. Recent data reveals that top-down budgets relying on atmospheric mixing models also face problems accounting for oxic methane production as ¹³C isotopic signature of methane produced in oxic environments bares signature overlapping with other classical sources.

I will give an overview of oxic methane production and the known mechanisms and suggest directions where emphasis can be put in coming years to better understand the contribution of oxic methane production to the global methane budget.

Svalbard seawaters as a significant source of CH₄ to the atmosphere during summer 2024

Coraline Leseurre¹, Bruno Delille², Axelle Brusselman², Hannelore Theetaert¹, Michiel T'jampens¹, Ozan Efe², Thanos Gkritzalis¹

¹ | Flanders Marine Institute – Belgium

² | University of Liège – Belgium

Methane (CH₄) is the second most important anthropogenic greenhouse gas after carbon dioxide (CO₂), with a global warming potential ~30 times higher. While open-ocean CH₄ is usually close to atmospheric equilibrium (~2% of the global CH₄ budget), emerging evidence suggests that shallow coastal regions may have a significant impact on the marine contribution, particularly in the Arctic shelf areas where the effects of climate change are amplified (e.g. Arctic amplification).

To better constrain the processes controlling CH₄ air-sea exchange in these regions, we investigated the sea surface CH₄ concentrations around Svalbard Archipelago (a moderately shallow shelf affected by glacial runoff and complex geology) during a summer cruise conducted on board the RV Skagerak (University of Gothenburg, Sweden) in August 2024. We observed systematically elevated CH₄ concentrations (mean 11 nmol L⁻¹) with clear spatial patterns linked to bathymetry and known hydrocarbon seep locations. The highest values (up to 105 nmol L⁻¹) occurred near marine-terminating glaciers in the Storfjorden and were not associated with strong salinity anomalies. This indicates that subglacial inputs from the glacier bedrock may dominate over the simple freshwater dilution from the glacial meltwater plume.

Using these observations, we demonstrate that Svalbard's surface waters acted as a pronounced source of CH₄ to the atmosphere during summer 2024. We will discuss the relative roles of geological seepage and subglacial pathways (especially in the context of the transition from marine to land-terminating glaciers) and their implications for present and future Arctic shelf CH₄ emissions.

Dissolved methane sensing in Greenland fjords with the SubOcean MILS

Jérôme Chappellaz, Sébastien Lavanchy, Christel Hassler, Bruno Delille, Hugo Cruz, Roberto Grilli, Samuel Jaccard¹

¹ | Institute of Earth Sciences University of Lausanne – Switzerland

With the currently enhanced warming at work in the Arctic, the retreat of the Greenland ice sheet transforms many marine-terminating glacier fjords into land-terminating ones. Such transformation can affect the transfer of nutrients in the fjords, but also the fate of dissolved methane from basal meltwater flows.

Regarding the latter, analyses of the deepest part of ice cores drilled at Summit in Central Greenland, in contact with bedrock, have revealed huge CH₄ concentrations in air bubbles, up to four orders of magnitude above atmospheric levels. Hence, it is plausible that basal meltwater in specific areas of Greenlandic outlets becomes largely enriched in dissolved CH₄. If released in the deepest sections of marine-terminating fjords, most of dissolved CH₄ should be oxidized in the water column. While a release from land rivers downstream from land-terminating glaciers would lead to direct outgassing into the atmosphere. The latter has indeed been observed in the river generated by Leverett glacier, close to Kangerlussuaq.

In summer 2023, 2024 and 2025, we participated to three expeditions conducted in southwest and west Greenland fjords, using the Swiss *Forel* sailing boat and the oceanographic vessel *Sanna* from Greenland. In each case, we not only collected discrete samples for dissolved CH₄ measurements. But we also deployed the SubOcean membrane-inlet laser spectrometer for continuous *in-situ* and real-time profiles of dissolved CH₄ at different stations along the fjords. With this presentation, I will summarize the main conclusions in terms of fjord specificities and resulting methane air-sea fluxes.

The West Antarctic Peninsula: the sources of methane

Axelle Brusselman¹, Odile Crabeck, Sofia Muller, Pablo Alejandro Araujo, Emil De Borger, Bruno Danis, Manuel Dall'osto, Francois Fripiat, Bruno Delille

1 | University of Liège – Belgium

Polar environments, and especially Antarctica, are a major source of uncertainty in the methane budget. This is due to the sparsity of data collection in Antarctica, which makes it difficult to understand methane dynamics in this region. This lack of data creates uncertainties in the global methane budget.

This research focuses on the role of the West Antarctic Peninsula (WAP) as a source of methane to the atmosphere in summer, with methane saturation ranging from 98 to 3000%. The methodology used focuses on a vertical approach, examining the atmosphere-sea ice-water column-sediment continuum.

Our results highlight two main sources of methane in the water column. The first one is the sediments, where methanogenesis occurs and is a common source of methane in shallow areas, with fluxes ranging from 0 to 6 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$. The second source is the subglacial runoff from the marine-terminating glacier in the WAP. Meltwater from the glacier can reach the bedrock beneath it and carry methane from the glacier base into the water column. This phenomenon has been investigated in Greenland (Lamarche-Gagnon *et al.*, 2019) but not yet in Antarctica. Meltwater from glaciers can raise methane saturation by up to 400% in some areas.

Our study also highlights the little contribution of the other compartments, such as sea ice or even the water column. Sea ice has very low methane concentrations at the end of the summer and serves more as a physical barrier than as a source or sink of methane. As for the water column, our study shows no link between methane concentration and chl_a, which has sometimes been observed in other studies.

Oxic Methane Production from Methylated Substrates in the Equatorial Atlantic

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4 | Institut Universitaire de Technologie - Brest/Morlaix – Université de Bretagne Occidentale (UBO) – France

The widespread occurrence of methane supersaturation in oxygenated oligotrophic surface waters cannot be explained by the common view of archaeal methane production in anoxic environments. These observations led to the so-called "methane paradox" describing biotic methane production in well-oxygenated waters.

This aerobic methane production can stem from photosynthesis and microbial degradation. Some microorganisms use methylated substrates as alternative nutrient sources to sustain their metabolism under otherwise nutrient-limited conditions, which releases methane as a byproduct of the microbial degradation. Several studies have shown that the degradation of methyl phosphonate (MPn) leads to methane supersaturation in surface waters of the North Pacific and North Atlantic. Others found that elevated methane concentrations in the surface layer of the Arctic Ocean and the western Pacific are linked to the metabolism of dimethyl sulfoniopropionate (DMSP) and sulfoxide (DMSO). Recently, degradation of methylamine (MeA) was identified as a methane source in an oligotrophic lake. However, these processes have not yet been shown to occur simultaneously.

Here, we aim to assess if MPn, MeA and DMSO can be a combined source of methane as well as how their contribution varies depending on the environmental nutrient conditions. We measured *in-situ* methane concentrations of the upper 300 m of the water column in the Equatorial Atlantic, an oligotrophic region, to calculate methane sea-air fluxes. To quantify the methane production due to the degradation of MPn, MeA and/or DMSO, we conducted natural seawater incubations in different regions.

This study will allow us to show whether multiple substrates can contribute to the overall methane flux and if nutrient conditions influence the relative contribution of the different degradation pathways.



SESSION

Marine methane microbial and macroecology: from molecules to ecosystems

Invited speaker: Dr. Gunter Wegener | MARUM



This session focuses on the microbial and macrofaunal ecology in marine environments, from the molecular mechanisms of methanogenesis and methane oxidation to their impacts on chemosynthetic ecosystems in sediments and water column. We welcome contributions integrating cultivation-based experiments, omics approaches, stable isotope probing, and biogeochemical analyses to elucidate the diversity, activity, and interactions of methane-cycling micro and associated fauna. Particular emphasis will be placed on studies linking microbial processes to ecosystem-scale methane dynamics, including sediment-water exchanges and benthic-pelagic coupling. This session aims to highlight the central role of organisms in controlling methane transformations and shaping the chemical and functional properties of marine ecosystems.

Anaerobic Oxidation of Methane in the Ocean Floor - Processes, Controls, and how AOM feeds ancillary communities

Gunter Wegener¹

¹ | Center for Marine Environmental Sciences [Bremen] – Germany

Anaerobic oxidation of methane (AOM) constitutes the dominant biological sink for methane in marine sediments, preventing roughly 90% of seafloor-derived methane from reaching the overlying ocean and atmosphere. This lecture synthesizes decades of field, laboratory, and molecular research to clarify AOM pathways, the composition and interactions of microbial consortia, and their geochemical signatures. Drawing on my work combining *in situ* sampling, incubation experiments, high-resolution geochemistry, and genomic and transcriptomic analyses, I will address four focal areas. First, AOM activity across natural habitats, from deep-sea cold seeps and hydrate-bearing sediments to more recently recognized niches, and the geochemical mechanisms that shape spatial variability. Second, emerging evidence on direct electron transfer between anaerobic methane-oxidizing archaea (ANME) and bacterial partners, including its mechanisms. Third, the metabolic flexibility of ANME lineages: genomic and expression data indicate capacity for alternative electron acceptors beyond sulfate. Fourth, metabolic by-products of AOM, notably disaccharide production, their release into the sedimentary milieu, and their role as substrates for heterotrophic community members, linking methane cycling to broader carbon turnover. I will conclude by identifying critical knowledge gaps and strategies to resolve the nature of AOM, particularly regarding the syntrophic interactions among the organisms.

A variety of substrates for methanogenesis

Marc Cozannet¹, **Sébastien Le Guellec**¹, **Karine Alain**²

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The number of methanogenesis substrates known to date has increased more than six-fold since the late 80s, bringing to 152 the number of proven substrates for methanogenesis, plus 41 putative substrates predicted on the basis of 'omic' and biochemical data. In particular, it was demonstrated that new classes of substrates, such as halogenated compounds, sulfur compounds or aromatics, enable methanogenesis. In this presentation, we take stock of all these known and putative substrates and present the Gibbs free energy changes under standard biological conditions for methanogenesis. We also discuss the sources of these substrates, the environments in which they occur and the taxa that use them to produce energy through methanogenesis. Given the diversity of anoxic environments in which these different substrates are found, methanogens could populate a greater number of ecological niches than previously thought.

Stratified and asymmetrical methane-cycling communities in the western Black Sea

Cas Cornet^{1,2,3}, **Stéphane L'Haridon**¹, **Enola Corrazzini**¹, **Antoine Crémière**⁴, **Thomas Giunta**⁴, **Xavier Phillippon**¹, **Françoise Lesongeur**¹, **Kai-Uwe Hinrichs**², **Laurent Toffin**¹

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2 | MARUM - Center for Marine Environmental Sciences [Bremen] – Germany
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The largest euxinic basin on Earth, the Black Sea, is characterised by prolific methane seeps and gas hydrates. However, the diversity and distribution of methanogenic and methanotrophic communities remain poorly constrained. Here, we investigate microbial community composition across the water column and deep subsurface at multiple sites sampled during the GHASS2 expedition (2021) at the Danube Canyon, Romania to assess the spatial distribution of methane-related lineages. Using 16S-rRNA gene amplicon sequencing, we show that (micro)aerobic methanotrophic bacteria (*Methylomonadaceae*) occur within and below the oxycline, shifting to co-occurring methanogenic (*Methanobacterium*, "*Candidatus Methanofastidiosales*") and anaerobic methanotrophic archaea (ANME-1) in deeper euxinic waters. In the seafloor, various ANME clades dominate methane seep sediments and authigenic carbonates. In contrast, we rarely detected ANME in deep subsurface environments and vertical geochemical profiles indicate "sluggish" sulphate-based methane oxidation, derived from the long overlap of high sulphate and methane concentrations, which implies the possible use of alternative pathways. Interestingly, diverse lineages of uncultivated *Methyloligellaceae* and *Methanomassiliicoccales* are ubiquitously abundant in these horizons and represent potential key taxa in subsurface methanotrophy and methanogenesis, respectively. Together, these findings establish a stratified and asymmetrical distribution of highly diverse methane-cycling communities at the Danube Canyon in the Black Sea, of which the majority remains uncharacterised.

Anaerobic oxidation of methane mediated by iron oxides and organic matter in coastal sediments

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Methane (CH₄) is a potent greenhouse gas. Coastal systems account for a large fraction of marine CH₄ emissions, emphasizing the need to understand coastal sources and sinks of CH₄. In coastal systems, most CH₄ is produced in sediments via methanogenesis and consumed through anaerobic oxidation of CH₄ (AOM), a process predominantly mediated by anaerobic methanotrophic archaea (ANME). AOM coupled to sulfate reduction is typically considered as the dominant CH₄ sink. However, in iron (Fe)- and organic-rich sediments, CH₄ oxidation may also be linked to the reduction of Fe (oxyhydr)oxides, organic matter (OM), or Fe (oxyhydr)oxide-OM coprecipitates, either directly or indirectly via a cryptic sulfur cycle that sustains sulfate-dependent AOM. While Fe-AOM has been demonstrated for coastal sediments, experimental evidence for AOM coupled to reduction of OM- and Fe (oxyhydr)oxide-OM coprecipitates is lacking. In this study, we assess whether there is potential for AOM coupled to reduction of Fe (oxyhydr)oxides, OM and Fe (oxyhydr)oxide-OM coprecipitates. Sediments were collected from the Bothnian Sea, a brackish basin receiving high inputs of Fe (oxyhydr)oxides and OM, and used in controlled incubation experiments. We present results from two experiments assessing the conversion of ¹³CH₄ to ¹³CO₂. We find evidence for AOM in all incubations, with higher initial rates in incubations with Fe (oxyhydr)oxides and OM when compared to Fe (oxyhydr)oxide-OM coprecipitates. Metagenomic sequencing of sediments from the Fe (oxyhydr)oxide- and OM-amended incubations revealed an enrichment in both ANME-2a/b archaea and potential metal-oxide reducing bacteria. Although a cryptic sulfur cycle cannot be fully excluded, our findings highlight that AOM in coastal sediments may be supported by a broader and more dynamic pool of electron acceptors (including OM and Fe (oxyhydr)oxide-OM coprecipitates) than currently considered. This highlights the metabolic versatility of ANME-2a/b and the potential importance of Fe-OM cycling for coastal CH₄ removal.

Novel ANME-2a genus play a role in metal-dependent methane oxidation in Bothnian Sea sediments

Anna Wallenius², Andy Leu¹, Robin Klomp², Simon Mcilroy¹, Gene Tyson¹, Caroline Slomp², Mike Jetten²

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Anaerobic methanotrophic (ANME) archaea are important players in the microbial methane cycle, mitigating methane emissions from anoxic environments. ANME are found ubiquitously in methane-rich sediments, where they can couple anaerobic methane oxidation (AOM) to different electron acceptors such as sulfate, metal oxides, and natural organic matter. However, we still lack understanding of the geochemical niches and preferred metabolic pathways of most ANME subclades, partly because recovery of high-quality metagenomically assembled genomes (MAGs) from sediments can be challenging. Here, we investigated the genomic potential and ecophysiology of ANME with respect to metal-dependent AOM in brackish metal-rich coastal sediments. With combined short and long-read sequencing and combination of different assembly and binning strategies, we recovered 8 high-quality ANME MAGs with high strain heterogeneity and analyzed the genomic potential for metal-AOM. Additionally, we monitored long-term methane-oxidizing enrichments with various electron acceptors from the same sediments. All MAGs belonged to *Candidatus* Methanocomedenaceae family (ANME-2ab) and clustered with an uncharacterized ANME-2a genus 'Kmv04' with only 2 representatives in public databases, which we proposed to name *Candidatus* Methanoborealis. Phylogenomic and metabolic analysis showed two different clusters within this genus; one comprising of MAGs from the Baltic Sea that showed high potential for extracellular electron transfer (EET) required for metal-AOM, and another with more diverse environments with less EET potential. The Baltic Sea *Ca.* Methanoborealis were the only canonical methanotrophs in the incubations during active methane oxidation and metal reduction, highlighting their potential role in metal-AOM. Our results contribute to the understanding of the phylogenomic and metabolic diversity in ANME subclades, which will help to further characterize novel ANME lineages from complex sediment samples.

Organic sulfur compounds of methane-seep deposits

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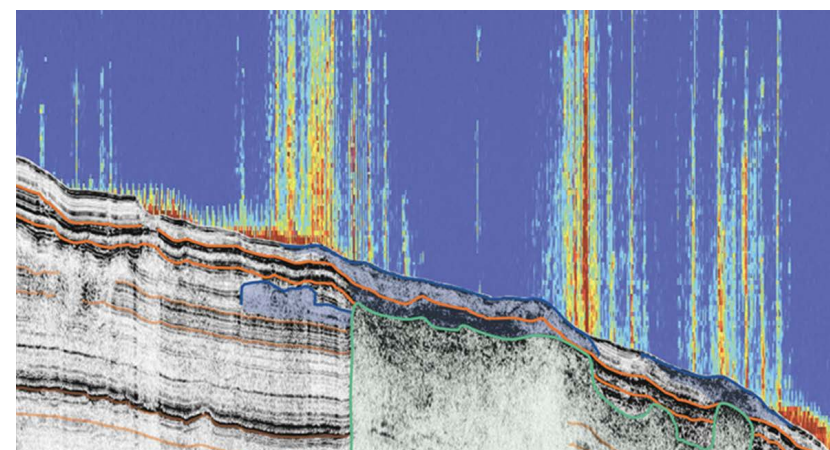
The biogeochemical process of sulfate-driven anaerobic oxidation of methane (SD-AOM) can be identified in methane-seeps by its characteristic lipid biomarker inventory. The commonly found lipid biomarkers at modern seeps comprise intact polar membrane lipids (IPLs) of anaerobic methane oxidizing archaea (ANMEs) like archaeols and glycerol dibiphytanyl glycerol tetraethers (GDGTs) with varying headgroups and low $\delta^{13}\text{C}$ values. In Cenozoic seeps, IPLs are degraded to core lipids, coming along with polar headgroup loss. In case of Mesozoic and Paleozoic seep carbonates, core lipids are further degraded to hydrocarbons such as phytane and biphytane, losing most of the information of the original membrane lipids. In addition to IPLs, accessory membrane lipids crocetane and PMI and their unsaturated derivatives are produced by ANMEs. In contrast to archaeols and GDGTs, crocetane and PMI are preserved in some Mesozoic and Paleozoic seep deposits, lacking the original double bonds. Recently, the inventory of ANME lipids has been complemented by organic sulfur compounds (OSCs) for Mesozoic and Paleozoic seeps. OSCs are common in marine environments typified by high TOC values and sulfidic conditions, including evaporitic environments where lipids of phototrophs form carbon-sulfur bounds, replacing double bonds. We identified OSC derivatives of PMI and phytane in the studied sites. Apparently, OSC formation can be induced at methane seeps by advective fluid flux, leading to particularly high hydrogen sulfide concentrations. In one of the seep deposits, OSCs are accompanied by unsaturated crocetenes and PMIs, which are absent in pre-Cenozoic seeps. This exceptional preservation of lipids is most likely caused by fast entombment associated with advective fluid flow and sulfidic conditions. There, pyrite is scarce, suggesting that scarcity of reactive iron must have limited the formation of iron sulfides. Under iron limitation, high levels of dissolved sulfide resulted in the sulfurization of ANME biomarkers during early diagenesis at shallow depth.

3

Session

Marine geology and geophysics: from deep structures to surface processes

Invited speaker: Dr. Aurélien GAY | Univ. Montpellier



Assessing the significance of marine gas sources to the global methane budget relies on the upscaling of local observations supported by the regional understanding of the geological and geomechanical factors controlling the accumulation and migration of free gas in the subsurface. This session aims at covering these interrelated topics with particular emphasis on quantitative ground modelling and numerical simulation of gas charging and flow. Contributions dealing with advances in geophysical methods for the detection and quantification of free gas in sediment and in the water column are welcome as well as field scale analyses of coupled flow and geomechanics.

4D fluid pipes: new insights into fluid migration in sedimentary basins

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Sedimentary basins are compartments of the upper crust where solids and fluids have accumulated over millions of years. With increasing burial depth, fluid content decreases progressively - a phenomenon known as diagenesis - but this slow process is punctuated by episodic migrations that redistribute mass and heat. The expelled fluids (water, CH₄, CO₂, hydrocarbons) rise through natural conduits called *pipes* and discharge at the seafloor, sustaining biological communities and forming distinctive structures: pockmarks, mud volcanoes, and injectites.

These pipes, which can exceed 250 m in diameter, were considered geological curiosities in the 1970s ; millions are now identified worldwide. Global methane emissions from natural geological sources are estimated at 18–63 Mt/yr, with offshore seeps contributing 5–10 Mt. Quantifying these fluxes is critical in a Net Zero perspective, especially as sea-level rise may intensify seafloor seepage. These structures also represent significant geo-hazards for offshore infrastructure, including cables, wind farms, and aquaculture sites.

Despite advances in seismic imaging, the internal architecture of pipes remains poorly resolved. They have never been directly drilled due to the risk of releasing large volumes of trapped gas. Current flux measurements provide only a present-day snapshot, failing to capture the temporal variability of past emissions.

We recently addressed these gaps through sandbox modeling and geophysical analysis, with three objectives: characterizing the 3D architecture of fluid pipes, understanding the dynamic mechanisms driving their formation and evolution, and quantifying expelled fluid volumes across their full lifespan - from deep source to seafloor discharge. Ultimately, this research will refine estimates of the atmospheric carbon budget and improve our understanding of Earth's past, present, and future climates.

Beyond Bulk Stability: The Role of Sedimentary Environment and Water Dynamics in Methane Hydrate Stability

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Methane hydrates constitute one of the largest reservoirs of carbon in marine sediments and play a key role in the global carbon cycle, as well as in geohazard and climate-related processes. Their stability is classically described by pressure-temperature conditions ; however, natural systems are far more complex, with sediment composition, pore structure, and fluid distribution exerting a strong control on hydrate formation and persistence. In particular, clay-rich sediments, which host a large proportion of natural hydrate deposits, remain poorly understood despite their importance in modulating gas storage capacity and stability . This study combines a synthesis of current knowledge with new experimental results investigating methane hydrate stability in controlled clay systems (montmorillonite, illite, and kaolinite) at several water contents. Our experiments reveal a marked shift in stability conditions relative to bulk hydrates, highlighting the combined effects of water activity, capillary pressure, and mineral surface interactions. Beyond equilibrium considerations, time-resolved measurements provide new insights into slow processes occurring within the sediment matrix. Notably, hydrate dissociation can occur after more than 10 hours under constant pressure and temperature conditions, pointing to a progressive redistribution of water within clay microstructures. These results emphasize that methane hydrate stability in natural sediments cannot be fully described by thermodynamic frameworks alone. Instead, it reflects a dynamic coupling between mineralogy, pore-scale water distribution, and transport processes.

Fluxes and fate of structurally controlled methane release in the gas hydrate province off the Antarctic Peninsula

Roger Urgeles¹, Ricardo León², Miriam Mestre^{3,4}, M^acarmen Fernández-Puga⁴, Teodora Ortega⁴, Rafael Bartolomé³, Héctor Marín-Moreno⁵, Daisy Arkwright⁶, Maria De La Fuente⁷, Xavier Garcia³, Miguel Llorente², Manel Prada³

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We present multidisciplinary evidence of widespread methane seepage along the Pacific margin of the Antarctic Peninsula (AP). Using high-resolution seismic data, multibeam bathymetry, water-column imaging, sediment cores and water chemistry, we show that methane emissions to the water column originate from both deep thermogenic reservoirs and gas hydrate-bearing sediments. More than one hundred methane flares have been detected, many reaching several hundreds of meters in height, some among the tallest ever documented. The spatial pattern of methane release is controlled by active strike-slip fault systems, which act as major conduits for the upward migration of methane. These faults enable methane to bypass hydrate formation and microbial oxidation zones in the sediment. Seismic "bright spots", chloride-depleted pore waters and deep mud-volcano activity support the presence of focused gas flow from deep sources and potential hydrate dissociation. Hydrate stability in the region is sensitive to ongoing rapid environmental changes such as bottom ocean warming from upwelling Circumpolar Deep Water and glacio-isostatic rebound. These processes could thin the GHSZ, destabilize shallow hydrates and enhance methane emissions. Water-column measurements reveal that methane concentrations are supersaturated with respect to atmospheric equilibrium, with inferred sea air fluxes of 20-56 $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{d}^{-1}$. Methane bubbles, likely coated with methane hydrate, persist during ascent due to the cold Southern Ocean waters. These fluxes are comparable to those in active seep regions in the Arctic, indicating that parts of the Southern Ocean, traditionally viewed as a methane sink, can act as a significant, localized methane source to the atmosphere. The findings reveal a dynamic methane system sustained by deep geological processes and shaped by contemporary climate-driven changes. The AP emerges as a previously under-recognized contributor to the methane budget, with potential implications for regional ocean chemistry, carbon cycling, and climate feedbacks.

Multi-proxy exploration of cold seeps on the Gulf of Lions margin (NW Mediterranean Sea)

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Cold seeps are increasingly recognized as major components of continental margin systems, influencing sediment dynamics, methane cycling, and benthic ecosystems. In the Gulf of Lions (NW Mediterranean), recent high-resolution geophysical surveys acquired in the framework of offshore wind farm investigations revealed an exceptionally large population of more than 50,000 Seafloor Deformation Structures (SDS), including pockmarks and domes distributed across the continental shelf and upper slope. This study aims to explore and assess the activity, origin, and evolution of these seep-related structures, and to evaluate their role in present-day methane dynamics in the Gulf of Lions.

The combined interpretation of seismic data, ROV observations, benthic assemblages, and gas geochemistry provides evidence for active to quiescent seep systems controlled by stratigraphic architecture. High-resolution seismic profiles reveal vertical acoustic chimneys, bright spots, and gas-charged reservoirs indicative of focused fluid ascent. Direct observations within large pockmarks identified bacterial mats and authigenic carbonate crusts, demonstrating spatial coexistence of active seeping and more mature seep environments.

Benthic assemblages dominated by opportunistic foraminifera genera including *Bolivina*, *Bulimina*, *Uvigerina*, and *Cassidulina* further support methane-influenced conditions. Areas colonized by bacterial mats show increased species richness, whereas active seep zones display strong bio-coenosis depletion linked to sulfide-rich conditions generated by anaerobic oxidation of methane (AOM). Geochemical analyses indicate low-flux but active methane cycling. Strongly depleted $\delta^{13}\text{C}-\text{CH}_4$ values down to -90‰ indicate predominantly microbial methane production, while less depleted signatures suggest mixed methane sources and oxidation during migration through the sediment column.

These results support an evolutionary model linking dome formation, seep initiation, pockmark collapse, and post-seep hydrodynamic reworking. The study highlights the widespread and dynamic nature of methane seepage in the Gulf of Lions and provides new insights into the interactions between fluid flow, sediment deformation, and benthic ecosystems along passive continental margins.

Flares and Mud volcanism: Investigating Marine Methane Emissions in the Gulf of Cádiz

Miriam Römer ¹, Yann Marcon, Thomas Pape, Jan Kleint, Walter Menapace, Christian Borowski

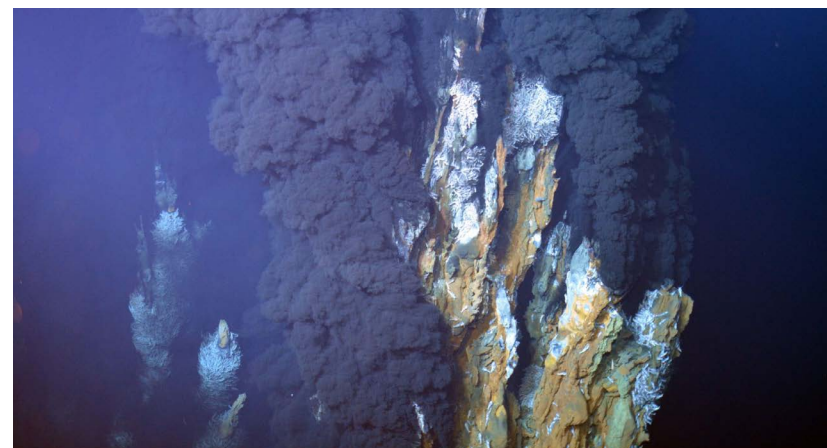
¹ | MARUM, University of Bremen, Germany – Germany

Mud volcanism is a well-known phenomenon in the Gulf of Cádiz. Mud volcanoes (MVs) in this region have been investigated intensively, mostly focussing on their sedimentological, geochemical and biological processes, but only very few studies reported about methane release from the seafloor, with systematic hydroacoustic mapping of the water column so far lacking. Recent research in the Gulf of Cádiz, a geologically complex and tectonically active region, has provided new insights into the distribution and dynamics of gas bubble emissions. Using multibeam echosounder and sub-bottom profiler data collected during expeditions in 2020 and 2024, we identified numerous previously undocumented seafloor gas emission (visible as flares in echograms). While these emissions are predominantly linked to MVs, our findings reveal that gas release is more widespread than previously recognized. Our analysis reveals over 100 distinct gas emission sites across 24 seafloor structures, with approximately half of the surveyed MVs exhibiting active bubble release during the surveys. Emissions are most concentrated at MV cones, but active gas bubble release was also observed in adjacent areas and at previously unrecognized seafloor features lacking typical morphological indicators of fluid expulsion. These results highlight the complexity and spatial variability of gas seepage in the Gulf of Cádiz and demonstrate the critical role of hydroacoustic methods in detecting active fluid migration pathways and emission sites.



Session Biogeochemistry across geosphere–ocean interface

Invited speaker: Dr. Eoghan Reeves | UiB



The geosphere contains the largest methane reservoirs, produced through microbial, thermogenic, and/or abiotic processes. We welcome studies aimed at distinguishing and quantifying the various methane production pathways in the subsurface, from abiotic to biotic processes, as well as processes that can occur at interfaces (such as mixing, diffusion, and degradation) during migration through the geosphere and eventual release into the ocean. These investigations are essential for constraining methane dynamics and assessing their impacts on oceanic systems.

Probing the origins of abiotic methane: a decade of changing views

Eoghan Reeves¹

¹ | Department of Earth Science [Bergen] – Norway

The origin of abundant CH₄ in seafloor hydrothermal vents on Earth has received persistent attention ever since these extreme ecosystems were first discovered in the late 1970s. This reflects the perceived central role of abiotic organic synthesis in models for a hydrothermal origin of life, and metabolic pathways that consume or produce CH₄ representing prime sources of energy for chemosynthetic microorganisms in modern vent ecosystems. Models for the formation of abiotic CH₄ and other hydrocarbons observed in vent fluids have historically invoked reduction of inorganic carbon (ΣCO₂) and/or CO via mineral- or metal-catalyzed 'Fischer-Tropsch-type' processes during active circulation of seawater-derived hydrothermal fluids that are highly enriched in dissolved H₂ arising from serpentinization of crustal host rock. Others have long suggested that leaching of CH₄ and low-molecular weight hydrocarbons from magmatic fluid inclusions hosted in plutonic rocks may contribute to the inventory of organic compounds observed. In the last decade a series of studies have examined the chemical and isotopic composition of actively venting submarine hydrothermal fluids, as well as volatile species trapped in fluid inclusions in plutonic rocks, yielding valuable insights into the chemical processes regulating the formation of CH₄. In addition, long-term experimentation and re-assessment of the mechanisms and rates of carbon reduction both with and without mineral catalysts have also clarified the likelihood of CH₄ formation abiotically at conditions found in hydrothermal fluids circulating in the sub-seafloor. Collectively, these results paint a picture where the reduction of inorganic carbon could simply be an inevitable process in heated crustal fluids, given sufficient residence time, moderate temperatures and abundant H₂, that does not inherently require a surface-catalyzed mechanism. This presentation will review our collective understanding of hydrothermal methane, and discuss the implications for single carbon molecules in seafloor environments on Earth and beyond.

High-temperature peridotite mylonites reveal deep organic carbon cycle at Oceanic Transform Faults

Suzanne Joanno¹, Cécile Prigent, Manon Bickert, Muriel Andreani, Alberto Vitale Brovarone, Gilles Montagnac, Clément Herviou, Bénédicte Ménez

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Oceanic methane is produced through multiple pathways, including abiotic processes driven by fluid-rock interactions in the lithosphere. While such processes have been investigated at mid-ocean ridges (MOR), oceanic transform faults (OTFs), which segment MOR, remain comparatively poorly constrained.

However, recent studies suggest that OTFs may be hydrothermally active plate boundaries. This is supported by evidence for deep interactions between mantle rocks and fluids within OTF domains, involving the downward percolation of seawater-derived fluids (to depths of ~ 25-30 km on (ultra)slow spreading ridges; Prigent *et al.*, 2020; Wang *et al.*, 2022), and the upward migration of carbon-rich magmatic fluids (Klein *et al.*, 2024). Additional support comes from observations at the Vema OTF, where alkaline, methane-rich fluids are discharged into the ocean (Devey *et al.*, 2018).

This study investigates methane and organic compound production at OTFs, using hydrated peridotites from the Shaka and Prince Edward OTFs of the Southwest Indian Ridge (SWIR). We characterized hydrous phases and fluid inclusions formed during high-temperature deformation (700-900°C), at depths of ~15-20 km within the fault zone.

Hydrated silicate phases (e.g. amphibole) are enriched in chlorine, boron and lithium, suggesting interaction with hydrothermal fluids during deformation.

Fluid inclusions (FIs), mainly hosted in olivine along deformation-related trails, record intense fluid-olivine reactions during rock cooling. Raman spectroscopy and FIB-SEM analyses reveal crystalline phases (including serpentine, brucite, magnetite) and gaseous species (CH₄ and H₂), consistent with serpentinization-driven hydrogen production and abiotic carbon formation. Methane concentrations (25-136 ppm) and δ¹³C-CH₄ values (-3.8 to -21.5‰), measured for the first time at OTFs, overlap with those from SWIR gabbros and sediment-starved hydrothermal systems; although further work is required to better constrain carbon sources.

Overall, this study identifies OTFs as active sites of deep hydrogen and carbon cycling, and abiotic methane production, suggesting a potentially overlooked contribution to geosphere-ocean fluxes.

Quantifying the role of geological carbon in the St. Lawrence Estuary: methane seepage and its role in estuarine carbon dynamics

André Pellerin¹

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The St. Lawrence Estuary (SLE) hosts more than 3,000 pockmarks on the seafloor of the Laurentian Channel. The role of these features in the regional carbon cycle has remained largely unconstrained. In this presentation, I will introduce an ongoing multidisciplinary project aimed at quantifying the contribution of geological carbon seepage to the SLE's carbon dynamics. The SLE is a climatically sensitive system already experiencing expanding permanent bottom-water hypoxia driven by changes in ocean circulation and eutrophication, making the quantification of carbon sources important and interesting to overall biogeochemical processes. Acoustic surveys show SLE pockmarks associated with gas venting. A pilot expedition in 2024 confirmed bubble plumes rising from pockmark structures and a high-activity of macrofauna surrounding the pockmarks. A second expedition in 2025 enabled direct sampling of gases, pore fluids, and sediments from two distinct pockmarks. Gas composition analyses show gases are approximately 90% methane, with ethane present at the hundred-ppm level and stable carbon isotope values of methane of approximately -40‰ ($\delta^{13}\text{C}$), indicating a thermogenic or mixed thermogenic-microbial origin. These results motivated a broader research program with five objectives: (1) mapping and quantifying active outgassing across the SLE pockmarks using multibeam and EK-80 echosounder surveys; (2) constraining temporal variability in bubble fluxes and estimating net geological carbon fluxes to the water column; (3) characterizing gas origin and assessing impacts on water column chemistry and air-sea methane exchange; (4) evaluating the assimilation of geological carbon into benthic microbial and faunal communities; and (5) investigating potential links between active gas emissions and submarine slope instability. Dedicated expeditions are planned to achieve these goals. We present this project with hope of discussing further methodological and field approaches to measurements with groups working on seep geochemistry, bubble flux quantification, and benthic ecology at cold seeps.

Sluggish AOM in the Black Sea - An attempt to understand transient transport-reaction processes and unusual sulfate-methane-transition-zones (SMTZ)

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Site-specific conditions in the Western Black Sea (W-BS) provide a unique opportunity to study processes underlying SMTZ formation and improve the understanding of marine methane turnover. Porewater profiles in some sediment cores from the W-BS show uncommon SMTZ characteristics. Sulfate and methane profiles overlap over several meters, indicating that Anaerobic Oxidation of Methane (AOM) is not sufficiently efficient to result in a more common SMTZ shape, i.e. sulfate and methane being depleted in a narrow sediment interval. This overlap is not exclusive but most pronounced below the W-BS seafloor, which is influenced by variable solids deposition from the Danube and Dniepr rivers, and post-glacial limnic-marine transition. Several reasons have been proposed to explain porewater profiles and apparent AOM inefficiency, including the absence, slow growth or inhibition of methanotrophic archaea. Furthermore, AOM might interact with other processes, e.g. organoclastic sulfate reduction or non-sulfate dependent AOM. Here, we analyze complementary datasets from cruises M142, RV Meteor (GEOMAR), and GHASS-2, RV *Pourquoi pas ?* (IFREMER). We compare core lithologies, porewater and solid phase compositions, and 16S-rRNA data to constrain biogeochemical processes and test different hypotheses underlying SMTZ formation. Numerical modelling suggests that AOM could, in principle, explain porewater profiles, however, this requires substantial variability of AOM rates at well-separated depth intervals. Our results indicate that microbial metabolism shaping porewater profiles is strongly influenced by non-methane substrates, and that sapropel (unit II) and limnic layer (unit III) positioning and thickness are relevant parameters. Molecular analyses indicate a low abundance of methanotrophic archaea, except at a few specific locations and depths. Our results help to constrain substrate availability, growth rates, and relative contributions of methane- vs. non-methane-driven processes. Considering transient effects related to sediment deposition and limnic-marine transition of the Black Sea, our results improve the understanding of post-glacial Black Sea evolution.

Increased methane emissions from coastal waters due to sulfide inhibition of anaerobic methanotrophs

Wytze Lenstra¹, **Olga Zygadlowska**^{1,2,3}, **Niels Van Helmond**, **Jessica Venetz**¹, **Annelies Veraart**¹, **Anna Wallenius**^{1,4}, **Mike Jetten**^{1,5}, **Caroline Slomp**¹

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4 | Stockholm University – Sweden

5 | Lund University – Sweden

Sediments in eutrophic coastal systems are increasingly releasing the greenhouse gas methane, indicating that the microbial methane filter is becoming less efficient. Recent work suggests that elevated concentrations of toxic hydrogen sulfide (HS), associated with eutrophication and deoxygenation, can inhibit anaerobic methane-oxidizing archaea (ANME). However, the extent to which this mechanism operates across coastal systems and its impact on methane emissions is currently unclear. In this study, we combine field and modeling results and show that inhibition of anaerobic methanotrophs by toxic H₂S explains the enhanced methane release from coastal sediments. Furthermore, by using a compiled geochemical data set from more than 110 coastal sediment cores worldwide, we show that benthic methane release is positively correlated with porewater HS concentrations and hence is widespread. We also show that methane emissions from coastal systems with porewater H₂S in the millimolar range are up to a factor 7 higher than the average for global estuaries. Coastal sediments produce 45-61 Tg of methane yearly. Further weakening of the coastal methane filter because of inhibition by H₂S related to eutrophication and deoxygenation could allow a major fraction of this methane to be emitted to the atmosphere, further impacting climate change.

Sedimentary methane cycling: insights from microscale sulfur isotopes in pyrite

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3 | Weizmann Institute of Science – Israel

Methane (CH₄) is a major component of the global carbon cycle and a potent greenhouse gas, yet the controls on its production, consumption, and storage in marine sediments remain poorly constrained. In particular, the role of sea-level fluctuations in modulating sedimentary methane dynamics and their potential impact on atmospheric methane remains unclear.

In marine sediments, methane is produced during organic matter degradation and largely consumed via anaerobic oxidation of methane (AOM), a process coupled to microbial sulfate reduction. This coupling links methane cycling to the sedimentary sulfur cycle, especially at the sulfate-methane transition zone (SMTZ), where distinct isotopic signatures can be recorded.

This project develops a novel proxy based on microscale sulfur isotope measurements ($\delta^{34}\text{S}$ and $\Delta^{33}\text{S}$) in pyrite to reconstruct methane dynamics in sediments. Pyrite formed in association with AOM carries characteristic isotopic fingerprints reflecting methane availability and sulfate reduction regimes. By resolving these signatures at the grain scale, it becomes possible to track relative variations in methane concentration and identify methane-influenced diagenetic environments.

Preliminary microscale sulfur isotope data from the Gulf of Lion (PRGL-1 4 borehole) reveal distinct pyrite populations with isotopic signatures consistent with variable methane availability across glacial-interglacial cycles. These results highlight the potential of this approach to reconstruct past changes in benthic methane dynamics from sedimentary archives.

Sea-level variations are expected to modulate methane cycling by controlling sedimentation rates, organic matter burial, and porewater structure, thereby influencing the position and intensity of the SMTZ. By integrating microscale isotope data with well-constrained Pleistocene records of sea level and atmospheric methane, this project aims to quantify how sedimentary methane reservoirs and fluxes respond to environmental change.



Session

Advances in methane measurement: novel methods and technologies

Invited speaker: Arne Estelmann | IOW



Advances in technology and innovative approaches for methane analysis are providing new insights into the biogeochemical cycle of methane. This session invites contributions on cutting-edge tools, including sensors, as well as emerging analytical methods such as clumped isotopes. It will showcase improvements in spatial and temporal measurement resolution, reductions in analytical bias and uncertainty, intercomparisons, and the integration of these techniques into multidisciplinary frameworks.

Comparing the Performance of Submersible *In Situ* Sensors for Dissolved Methane

Arne Estelmann¹, Michael Glockzin¹, Ralf Prien¹, Gregor Rehder¹

¹ | Leibniz Institute for Baltic Sea Research Warnemuende – Germany

Methane is the second-most important anthropogenic greenhouse gas and an important biogeochemical parameter in aqueous environments. The detection of dissolved methane is essential for the perception of ecosystems, to understand processes across the sediment-water interface and to estimate greenhouse gas fluxes across the water-atmosphere interface. Although precise sampling-based laboratory measurement methods exist, they are time-intensive, labor-intensive and high-cost, while being constraint in spatial and temporal resolution. Therefore, *in situ* methane sensors are crucial for improved observations.

Today, the *in situ* measurement of atmospheric methane is matured and can provide high accuracy at low limits of detection. In manifold applications, these sensors have been combined with equilibrators setups for surface water methane quantification, too. However, only few commercially available submersible *in situ* sensors for dissolved methane exist. In the past decade, only two of these instruments have been able to resolve the environmentally relevant concentration range below 100 nmol/kg. Recently, several working groups have presented newly designed *in situ* methane sensors.

Hence, we conducted a laboratory intercomparison of the commercially available and advanced prototype (TRL > 6) *in situ* methane sensors using a custom-built test tank equipped with a methane reference system and auxiliary sensors. Five different sensors (nine in total) were submerged in freshwater and exposed to different methane concentrations between 2 and 200 nmol/kg at temperatures between 7 and 25 °C for over 20 days. We evaluated the systematic and random error of the sensor systems, response times, robustness to temperature variations, short term drifts and hypoxia. For each system, different strengths and limitations were found, indicating that sensor suitability depends strongly on environmental conditions and research objectives.

With this intercomparison, we offer a readiness assessment of currently and soon available methane sensors in the low concentration range. Additionally, we provide practical guidance for selecting appropriate instruments in future studies.

Advancing greenhouse gas measurements: Continuous real-time observations of methane and nitrous oxide using a high-sensitivity *in-situ* sensor

Santona Khatun¹, Jérôme Chappellaz¹

¹ | Ecole Polytechnique Fédérale de Lausanne – Switzerland

Accurate quantification of greenhouse gas (GHG) emissions from lakes remains limited by the lack of high-resolution, *in situ* measurements capable of resolving strong spatial and vertical heterogeneity. In particular, simultaneous observations of methane (CH₄) and nitrous oxide (N₂O) at fine spatial scales are rarely achievable with conventional sampling approaches. Recent advances in underwater mass spectrometry now offer new opportunities for real-time, multi-gas profiling in aquatic environments.

Here, we present the application of an *in-situ* membrane inlet laser spectrometer instrument (SubOcean), a high-resolution analytical sensor enabling continuous measurements of dissolved CH₄ and N₂O in aquatic systems. We demonstrate its capabilities through deployments in two contrasting Swiss lakes: a large mesotrophic system (Lake Geneva, 580 km²) and a smaller eutrophic lake with pronounced basin morphology and a narrow constriction (Lake Zug, 38 km²). The SubOcean system provided continuous vertical profiling across multiple stations, resolving fine-scale spatial structure in both gases with high temporal and spatial resolution.

The measurements reveal strong vertical and lateral gradients in both CH₄ and N₂O that would be difficult to resolve using discrete sampling. CH₄ and N₂O distributions varied consistently with stratification and basin morphology, with pronounced metalimnetic features and localized concentration maxima associated with hydrodynamic boundaries. Importantly, the system captured co-occurring spatial heterogeneity in both gases, highlighting its capability for multi-parameter GHG mapping, including methane in oxic freshwater environments.

Beyond the specific lake systems, these results highlight the analytical potential of the SubOcean sensor for advancing *in-situ* greenhouse gas research in aquatic environments, including marine systems. The ability to simultaneously resolve CH₄ and N₂O at high spatial resolution represents a significant step forward in aquatic sensor technology, enabling more detailed characterization of greenhouse gas distributions and strengthening the observational basis for emission quantification and assessment.

Poster Abstracts

Linking pore-water geochemistry, gas composition and sediment properties to hydrate dynamics at two active seepages sites in the western Black Sea

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Cold seeps are seafloor environments where methane-rich fluids migrate upward from the subsurface and are released into the ocean. These systems represent key interfaces in the marine methane cycle, linking deep geological reservoirs to the water column and potentially the atmosphere. They host intense biogeochemical activity, including microbial methanogenesis and anaerobic oxidation of methane (AOM), and are commonly associated with the formation and accumulation of natural gas hydrates (NGH) within shallow sediments. Understanding the interactions between fluid flow, methane transformation, and hydrate dynamics in these environments is therefore critical for constraining marine methane budgets and assessing their sensitivity to environmental change. In this study, we investigate shallow gas hydrate systems from two methane-rich environments on the Romanian margin of the Black Sea: a fault-controlled ridge crest (HRC) and the newly surveyed Flora Mud Volcano (FMV), sampled during the GHASS2 cruise (2021, N/O *Pourquoi Pas?*) (Riboulot *et al.*, 2021). We combine sediment characterization, pore-water geochemistry, and gas hydrate analyses (molecular and isotopic composition, and Raman spectroscopy) to explore hydrate formation processes and their links with fluid circulation. At the HRC site, variable chloride anomalies provide evidence for localized heterogeneity in fracture-controlled methane supply and gas hydrate formation dynamics. At both sites Gas composition indicates a predominantly microbial origin of methane, while Raman spectroscopy reveals minor incorporation of H₂S in hydrates at FMV, pointing to chemical heterogeneity of hydrate-forming fluids. Pore-water profiles demonstrate active anaerobic oxidation of methane coupled to sulfate reduction (AOM-SR), sugges-

ting that sulfide incorporated in hydrates is primarily produced *in situ*, with possible contributions from deeper reduced fluids. These results highlight the strong coupling between fluid pathways, hydrate occurrence, and geochemical zonation in shallow sediments of the Romanian margin. They also emphasize that minor hydrate-bound gases may serve as key tracers of subsurface processes in marine hydrate systems.

Assessing the effects of pressure, temperature, and concentration on membrane sensors: evaluation of HydroC-CH₄ under controlled conditions in the GEORGE Project

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Methane (CH₄) is a potent greenhouse gas whose oceanic sources remain poorly constrained, partly due to the lack of reliable *in-situ* sensors capable of operating across the full range of deep-sea conditions. Within the framework of the Horizon Europe GEORGE project, which aims to develop next-generation autonomous sensors for marine carbon budget measurements, we evaluated two HydroC CH₄ sensors (4H-JENA, 3,000 m and 6,000 m depth ratings) under controlled hyperbaric conditions. Experiments were conducted in a hyperbaric chamber using a methane-saturated flow system. Methane concentration was increased sequentially, with each step followed by homogenization and pressure-temperature cycles. Water samples were collected at each condition and analyzed by GC-FID as a laboratory reference method for sensor comparison and validation. Results show good agreement between sensor partial pressure measurements and GC-FID reference analysis ($r^2 > 0.995$). However, calibration slopes exhibit a significant pressure-dependent trend, with partial pressure increasing by over 40% between 10 and 250 bar, particularly above 14 $\mu\text{mol L}^{-1}$ methane concentrations. Part of this pressure dependence may reflect the thermodynamic correction of the Bunsen solubility coefficient for *in-situ* hydrostatic pressure (Weiss, 1974; Grilli *et al.*, 2021), which is not accounted for in the standard Wiesenburg & Guinasso (1979) formulation. Whether this correction fully explains the observed sensor response, or whether additional membrane-related effects contribute, remains to be established. These findings highlight the need for pressure-dependent calibration to ensure reliable dissolved methane measurements in deep-sea environments. Work is ongoing to establish an empirical calibration equation linking methane concentration to pressure and temperature, and to characterize sensor

response times under varying physicochemical conditions. Field validation using discrete GC-FID sampling will be required to confirm sensor performance under real oceanographic conditions.

Contrasting methane isotope and archaeal profiles reveal heterogeneous methane cycling in Hakefjorden–Byfjorden coastal sediments

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Coastal sediments can both produce and consume methane, within centimetre-scale depth intervals missed by low-resolution sampling. Here, we combined centimetre-scale porewater profiles of CH₄ concentration, δ¹³C-CH₄, δ²H-CH₄, DIC, δ¹³C-DIC, sulfate, contaminant patterns, and archaeal communities from eight sediment profiles collected across the upper 25 cm of the Hakefjorden–Byfjorden system near Stenungsund, Sweden. Across all sediment samples, 248 organic contaminants were detected.

Methane concentrations ranged from methane-poor profiles with submicromolar to low micromolar CH₄ to one methane-rich profile exceeding 1400 μM CH₄. Methane isotopes spanned a broad range: δ¹³C-CH₄ ranged from –89‰ to –43‰, while δ²H-CH₄ ranged from –252‰ to +183‰. The most depleted methane isotope values occurred where methane accumulated with depth, consistent with active methane production. In contrast, enriched δ¹³C-CH₄ values, especially when combined with strongly positive δ²H-CH₄ values, indicate partial methane oxidation. DIC increased with depth, while δ¹³C-DIC became lighter in most profiles; sulfate remained present in several profiles but dropped strongly in the methane-rich profile.

Microbial profiles contextualized the isotope and geochemical patterns. Hydrogenotrophic methanogens were common in depth intervals with depleted methane isotope values, consistent with methane production from CO₂ reduction. Methylotrophic-capable methanogens were most evident in the methane-rich profile, especially at middle depths, and occurred at lower abundance elsewhere.

Methanofastidiosales were widespread across profiles, supporting a possible role for methylated substrates in methane cycling. Anaerobic methane-oxidizing archaea occurred mainly in the methane-rich profile, whereas aerobic methane oxidizers occurred across several profiles, with stronger signals generally near surface or middle-depth intervals. Contaminant load alone did not correlate

with methane accumulation: some highly contaminated profiles remained methane-poor, while the methane-rich profile contained approximately 500 ng·g⁻¹ total organic contaminants.

Elucidating microbial contribution to hydrothermal methane through an integrated approach

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Methane (CH₄) emitted from marine hydrothermal systems is a key compound for understanding hydrothermal fluid circulation and the functioning of chemosynthetic ecosystems associated with these deep and dark environments. CH₄ can be produced either abiotically through geochemical reactions or biologically by methanogenic archaea. Discriminating between these two sources relies mainly on the analysis of carbon and hydrogen isotopic signatures. However, the interpretation of these signatures remains uncertain. This is because isotopic fractionation associated with microbial methanogenesis is still poorly constrained under the high-pressure and high-temperature conditions characteristic of hydrothermal environments. To better understand this microbial contribution to methane production, our project aims to develop an integrated approach organised in two complementary steps. First, an experimental component consists of studying the physiology of hyperthermophilic methanogenic archaea under controlled thermodynamic conditions (temperature, pressure, substrate availability) in order to constrain the isotopic fractionation associated with methanogenesis. In parallel, an environmental approach is based on the analysis of samples collected during the HERMINE 3 cruise, aiming to characterize the thermodynamic conditions as well as the diversity and metabolic potential of microbial communities inhabiting these ecosystems at the thermal limits of life. In addition, mesocosm-based experimental cultures will be developed to better reproduce hydrothermal ecological conditions. Our preliminary experimental results suggest that under thermodynamically favorable conditions, isotopic fractionation associated with methanogenesis may be significantly reduced, consistent with observations reported by Takai *et al.* (2008). These findings highlight the need to reassess the isotopic criteria currently used to discriminate CH₄ sources in hydrothermal environments.

Gas emissions along the North Anatolian Fault system and their impact on the water column

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The North Anatolian Fault (NAF) system exhibits widespread active venting of methane and higher hydrocarbons along offshore fault segments. Best documented occurrences are in the Main Marmara Fault zone, which exhibits intense gas seepage over its creeping segment. Recent observations also suggest fluid emissions are occurring further west, in the North Aegean Sea. In this region, the NAF system divides into several branches that spread over a 150 km wide area. In this broad deformation zone we observe liquid hydrocarbon emissions, detected from space with Synthetic Aperture Radar imagery, and these likely represent only a fraction of the total fluid emissions as methane is undetectable by this method. (1) Several emission sites are located in Limnos Basin, a narrow 1200 m deep pull-apart basin characterized by gravitational tectonics and anomalous oxygen consumption in the water column. (2) Emission sites are also found on the shelf north of Skyros-Edremit Trough where offshore faults are poorly mapped although a Mw 7.0 earthquake (one of the largest recorded in the Aegean domain) occurred in this zone in 1968. (3) In the North Aegean Trough, seismic surveys have shown widespread presence of gas in sediments and a diapir like conduit imaged on the Sinthonia branch of the NAF may represent an important gas-only emission site. The abundance and diversity of active seeps in this tectonically active zone makes Marmara Sea and North Aegean Sea choice areas to address several questions regarding methane emission processes, for instance: relationships between deep seated active faults and seafloor manifestations ; factors (e.g.: seafloor depth, presence of liquid hydrocarbons) influencing the variability of benthic chemosynthetic ecosystems ; impacts of fault-related methane emissions on the water column in semi-confined basins ; factors influencing methane oxidation at the seafloor and in the water column and its transfer to the atmosphere.

Earthquakes can drive hydrocarbon seepage along the Cyprus arc

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Monitoring hydrocarbon seepage, whether harmful liquid or potent gas, is crucial for understanding the factors driving expulsion and is also necessary for comprehensive integration into carbon budgets. While hydrocarbon seepage occurs naturally in marine environments, the role of earthquakes in hydrocarbon seepage and, therefore, the way this interaction contributes to the carbon budget remain poorly understood. Earthquakes are known to activate mud volcanoes in sub-aerial conditions, with hydrological responses typically occurring within days. Here, we show that major earthquakes occurring in 2023 along the East Anatolian Fault triggered hydro-carbon expulsion hundreds of kilometers away from the epicenter, with one site having never shown any evidence of hydrocarbon seepage before. Satellite data show that, 9 days after the mainshock, seepage began and resulted in a 71% increase in volume output over the following 6 months. The calculated energy densities for at least 4 earthquakes in the sequence fall within the range reported for known cases of earthquake-activated mud volcanoes. These observations confirm that earthquake-triggered hydrocarbon seepage may play a significant role in the carbon budget, although the gas flux associated with triggered seepage remains to be quantified. In the future, hydrocarbon seepage systems near active seismic zones should be closely monitored and incorporated into carbon budgets.

The Sensor for Aqueous Gases in the Environment

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The fast response SAGE sensor realizes a meaningful advancement for *in-situ* dissolved methane and carbon dioxide sensing. Compared to existing slow response sensors that require tens of minutes to over an hour to measure a signal, SAGE performs measurements in several minutes without sacrificing on sensitivity or selectivity. This fast response enables continuous high-quality spatial mapping or "sniffing" of dissolved CH₄ or CO₂ underwater using remotely controlled or autonomous vehicles. Hand-portable or flow-through versions also enable analysis of surface waters or discrete samples, eliminating the need to transport samples back to the lab. SAGE's primary innovation is the use of a micronscale hollow-core optical fiber in place of a traditional large gas cell for the spectroscopic analyzer. This reduces the amount of gas needed for analysis by several orders of magnitude. Since the gas extraction is what fundamentally limits this kind of sensor's response time, the extremely small sample volume results in a drastically faster response. The technology is at a high technology readiness level (TRL) and has been demonstrated in a range of field environments from wetlands to continental shelf to the deep ocean.

Vertical distribution of methane-cycling microbial communities in an active volcano-tectonic hydrothermal system

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The Reykjanes peninsula, located in the southwest of Iceland, along Mid-Atlantic Ridge (MAR), represents one of the few subaerial exposures of an oceanic ridge. This unique geological setting drives intense tectonic and magmatic activity, particularly in the Krýsuvík-Kleifarvatn area, where lacustrine hydrothermal vents exhibit cyclic recharge and discharge processes linked to tectonic activity. In 2000, a Mw 5.8 earthquake triggered a 12% drop in the volume of Kleifarvatn lake due to crustal dilatation over 18 months, followed by an increase in the heated hydrothermal fluxes, which migrated upward to the lake floor.

To investigate the methane cycle in this unique and dynamic low-sulfate lake (~50 times lower than seawater), influenced by hydrothermal outflows and distal volcanic eruptions, we analyzed the vertical distribution of methane-cycling microbial communities in these sediments. Sediment cores up to 120 cm long were collected at three sites: two located above the magmatic chamber and proximal to hydrothermal outflows, and one outside the hydrothermal influence zone.

Geochemical and microbial analyses revealed active methane cycling in this environment, likely driven by hydrothermal fluxes and/or associated geothermal gradient. The dominance of methane identified in hydrothermally influenced sites over heavier hydrocarbons ($C_1/C_{2+} > 102$), and its remarkably low $\delta^{13}C-CH_4$ (down to -94.1%), strongly suggest a microbial origin. Taxonomic profiling of microbial assemblages uncovered a wide diversity of archaeal and bacterial taxa, including methane-cycling lineages. Notably, diversified methanogens were detected, particularly within the *Methanomassiliicoccales* order, consistent with $\delta^{13}C-CH_4$ depletion.

In sediment of the hydrothermally influenced area, the upper sediments were marked by a Sulfate–Methane Transition Zone (SMTZ). This zone was characterized by the presence of *Methanosarciniales* and ANME-2d (*Candidatus Methanoperedenaceae*) alongside *Desulfosarcinaceae*, strongly suggesting an active AOM. It was further evidenced by elevated abundances of *dsrA* and *mcrA* genes. Future analysis of Metagenome Assembled Genomes will provide insights into metabolic pathways.

Authigenic magnetite indicates microbial iron reduction in methanic sediments

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Microbial methane production, migration, and transformation are widespread in continental marine sediments, which significantly influences the biogeochemical iron cycle. Microbial iron reduction commonly occurs in shallow iron-rich subsurface layers and leads to the formation of biogenic magnetite. However, in the sulfate-methane transition zone (SMTZ), sulfate-driven anaerobic oxidation of methane produces ample hydrogen sulfide, which typically causes the dissolution of magnetite and other reactive iron oxides. In contrast, sulfate reduction is typically insignificant in the deeper methanogenic zone due to the lack of sufficient sulfate. Instead, elevated concentrations of dissolved ferrous iron have been reported in methanic sediments, suggesting the local presence of microbial iron reduction. To date, this process is still enigmatic, and its mechanism in the environment is poorly understood.

In this study, we investigated methane-rich sediment sites from different areas of the South China Sea. We identified abundant newly formed authigenic magnetite at multiple sites and horizons (Lin *et al.*, 2021, 2024). Moreover, 16S rRNA gene analyses revealed that methanogenic archaea, including *Methanosarcina* and *Methanocella*, were enriched in magnetite-bearing samples, suggesting a possible role in iron reduction and magnetite formation (Lin *et al.*, 2024). The discovery of a new type of authigenic magnetite provides robust evidence for microbial iron reduction in methanic sediments. These findings are probably crucial for interpreting sedimentary magnetic signals and understanding iron cycling in deep sedimentary environments.

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Geochemical evidences for methanogenesis and anaerobic methane oxidation in the Gulf of Lions cold seeps

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Recently discovered cold seep systems on the continental shelf of the Gulf of Lions provide new opportunities to investigate methane cycling and carbon dynamics in the Mediterranean Sea. Although biogeochemical processes have been extensively studied in the Rhône prodelta, geochemical data from distal shelf areas and newly identified seep sites are scarce. This study aims to characterize dissolved CO₂ and CH₄ concentrations and isotopic compositions in cold seep sediments distributed across the continental shelf and upper slope of the Gulf of Lions.

Ten sites located between 70 and 300 m water depth were sampled using interface corer, corresponding to dome and pockmark morphologies associated with active seep indicators such as bacterial mats and gas flares. Dissolved gases in porewaters and bulk sediment gases were analyzed using headspace equilibration methods coupled with gas chromatography and cavity ring-down spectroscopy. Stable carbon isotopes of methane and carbon dioxide ($\delta^{13}\text{C-CH}_4$ and $\delta^{13}\text{C-CO}_2$) were measured in both dissolved and bulk gas compartments.

Methane concentrations reach up to 290.96 nmol/L of sediment in dissolved phases and 4.36 $\mu\text{mol/L}$ of sediment in bulk gas analyses, while $\delta^{13}\text{C-CH}_4$ values range from -43.63 to -87.75‰ VPDB. These values are consistent with those reported in low-flux biogenic methane seep systems. The combined measurements of dissolved and bulk gas phases using concentration and isotopic datasets provide a more comprehensive assessment of methane dynamics than analyses restricted to a single compartment, improving the discrimination of gas production, consumption, and migration processes within the sediments. Principal component analysis reveals strong spatial variability between sites and provides evidence for active methanogenesis, anaerobic oxidation of methane, and the coexistence of competing microbial pathways controlling carbon cycling.

Controls on the cadmium isotopic composition in seepage sediments in the Sea of Marmara

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Cold seeps are hydrogen sulfide-rich environments that potentially serve as significant sinks in the marine cadmium (Cd) cycle, yet are poorly constrained. Here we present Cd-isotope data from an 11.15 m-long sediment core recovered from an active methane seep in the Sea of Marmara. The core comprises a 6.35 m-thick marine unit on top and a 4.2 m-thick lacustrine unit below. The marine unit consists of an upper 4.9 m-thick part (interval 1) deposited essentially under oxic water column, and a Holocene sapropel unit (Interval 2, 4.9–6.95 mbsf) below, deposited under suboxic-anoxic conditions. In Interval 1, negative correlations between $\delta^{114/110}\text{Cd}$ and pyrite sulfur contents strongly suggest sequestration of isotopically light Cd into CdS. In contrast, within the sulfate–methane transition zone (SMTZ, upper 0.5 m upper part of Interval 1), quantitative CdS precipitation yields authigenic $\delta^{114/110}\text{Cd}$ values ($\sim 0.34\%$) comparable to seawater, establishing Cd isotope systematics as a reliable potential proxy for paleoceanographic reconstructions. In the Holocene sapropel, CdS together with organically bound Cd dominates the authigenic Cd pool, whereas in the oxic lacustrine sediments (interval 3) Cd is mainly associated with organic matter and Fe-oxyhydroxides. This study provides the first observational constraints on the isotopic composition of Cd in seepage sediments, and its results support the use of Cd isotope systematics in environmental and paleoceanographic reconstructions.

Oases on the Seafloor: Microhabitats Shape Arctic Cold Seep Communities

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Life in most marine ecosystems depends on organic matter produced at the surface of the ocean. In contrast, chemosynthesis-based ecosystems (CBEs), like cold seeps, are fueled by microbial oxidation of reduced compounds like methane and sulfide in anaerobic conditions. These systems sustain elevated benthic biomass compared to the oligotrophic deep sea, functioning as biological oases within otherwise desert-like conditions of the surrounding seafloor. In a rapidly warming Arctic, understanding how macrofaunal and meiofaunal assemblages mediate sediment biogeochemical cycling and carbon transfer to higher trophic levels is increasingly urgent. Yet, how these communities respond to fine-scale heterogeneity within CBEs remains poorly understood.

Here, we quantified meiofaunal and macrofaunal assemblages across distinct microhabitats at an Arctic cold seep, focusing on worm tufts, microbial mats, and surrounding regular sediment. Meiofaunal abundances varied markedly among samples (14–4996 ind./10 cm²), peaking in worm tufts and reaching their lowest values in microbial mats. Nematodes dominated all samples (> 80% relative abundance). Macrofaunal abundance and biomass were significantly higher (~ 3 times) in worm tufts than in regular sediment, where macrofaunal richness also peaked. In contrast, meiofaunal richness was highest in regular sediment and lowest in microbial mats. Both meiofaunal and macrofaunal community composition showed strong microhabitat separation, and macrofaunal communities differed significantly among microhabitats. Similar to community level patterns, preliminary statistical analyses on nematode taxonomy reveal substantial variability between microhabitats, including pronounced differences in both abundance and family-level composition. This high turnover indicates strong small-scale environmental heterogeneity within seep habitats and suggests that nematode communities are sensitive indicators of microhabitat conditions.

Together, these findings highlight the importance of fine-scale habitat heterogeneity in structuring benthic communities at Arctic cold seeps and suggest that such microhabitat variability plays a key role in sustaining biodiversity and ecosystem functioning.

Methane Accumulation linked to Phytoplankton Activity in the Greenland Water Column: New Insights from Arctic Profiles

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Not long ago, biological methanogenesis was considered to be exclusive to Archaea in anoxic conditions. In the last two decades it was demonstrated that methane (CH₄) could also be produced in oxic conditions, a term coined as Oxidative Methane Production (OMP). Phytoplankton, consisting of Cyanobacteria and eukaryotic planktonic algae, are ubiquitous, being found in nearly all illuminated environments on Earth, were also shown to contribute to OMP through several mechanisms. While on a local scale their contribution to the global methane budget may seem minor, given their abundance, on a global scale it is likely significant. Phytoplankton form massive blooms, that are enhanced in frequency and intensity due to global warming and anthropogenic eutrophication, likely increasing their contribution to OMP and global CH₄ emissions. Methane emissions from oceanic environments have been assessed, yet the data is sparse due to the nature of sampling cruises and inability to use remote sensing for methane measurements over water. To assess the phenomenon of OMP in arctic oceanic environments, we determined methane concentrations along depth profiles in the western Greenland area comprising the Labrador Sea and the Baffin Bay. These were obtained during the MSM139 research cruise¹ and analysed in the context of existing productivity-associated parameters. We have found that productivity parameters are often closely associated to methane concentrations in the water column, supporting a phytoplankton-associated methane production phenomenon. By quantifying OMP across major oceans, we can further untangle the contribution of OMP to total oceanic methane production and start identifying its causes.

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New ROV-operated temperature gradient probe for detecting and quantifying fluid transfers at the ocean floor

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Conventional measurements of temperature gradients and heat fluxes in the deep ocean are performed using long probes, 2 to 20 meters in length, equipped with very high-precision thermal sensors. These sensors must be inserted vertically into the sediment using a heavy ballast. The accuracy of the probe insertion into the sediment depends on vessel positioning, sea state, and currents, and is sometimes difficult to assess. The DeepSea'nnovation* project proposes the development of deep-sea temperature probes 60 cm long that can be operated by remotely operated underwater vehicles (ROVs). Miniaturization, the use of suitable and modern sensors, and modularity of use will require specific developments.

The main objective of this development is to provide probes that will measure the temperature gradient in the first 60 cm of sediment below the seafloor with high spatiotemporal resolution. Two versions of the probes, one tethered and one autonomous, will allow for use in different diving scenarios and improved control and monitoring of measurements. Heat flow can be obtained by combining gradient measurements with thermal conductivity measurements on sediment cores obtained, for example, with a vibro-corer.

Temperature gradient and heat flow measurements performed with m°C accuracy in the deep ocean will enable the detection and study of fluid transfers on the ocean floor (hydrothermal circulation, fluid seeps, etc.). These circulations are still poorly understood, but they define areas of high mineralization (sulfides, carbonates, gas hydrates) and unique ecosystems on the ocean floor.

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Global evolution of oceanic methane hydrate stability from 1993 to 2023

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Although climate change is mainly observed at the Earth's surface, ocean circulation is also evolving, and the seabed is subject to temperature fluctuations. Seafloor sediments are often permeated by methane hydrates, whose stability primarily depends on pressure and temperature conditions. Any variation in seabed temperature can alter the stability of methane hydrates. Their dissociation, resulting from unstable conditions, may release large amounts of methane into the water column.

In this work, we computed the depth of the gas hydrate stability zone (GHSZ) at the global scale and analyzed its changes over the period 1993–2023 at 5-year intervals, with the aim of investigating the impact of climate change on methane hydrate stability. The calculations were performed using oceanographic salinity and temperature data. The spatial resolution of the analysis is $1/12^\circ$ in longitude and latitude, and the water column was divided into 50 different layers.

The high resolution and completeness of the dataset allowed us to obtain precise global-scale multidecadal trends in subseafloor methane hydrate stability. Over the analyzed period, the number of model cells experiencing GHSZ thinning greatly exceeds those showing GHSZ thickening, particularly in the Southern Hemisphere. In addition, several hotspots of significant GHSZ variation were identified, as well as regions where the GHSZ completely vanished during the 30-year period considered. Although 30 years represents a relatively short timescale, it is sufficient to reveal a consistent trend linking global warming to the progressive thinning of the GHSZ.

Sulfur and methane geochemistry in the Black Sea – from shelf to deep basin: preliminary results from the EU DOORS project Cruise in 2024

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The Black Sea, the world's largest permanently anoxic basin, provides a unique natural laboratory for investigating early diagenetic processes and their imprint on sediment geochemistry. We present preliminary porewater and sediment geochemical data from four sites covering a wide range of water depths and variable sediment compositions, sampled during the EU DOORS project cruise aboard R/V Mare Nigrum in June 2024.

The studied sites exhibit several sedimentary environments, with terrigenous deposits on the shelf, turbidite sequences on the slope, and biogenous sediments in the deep basin. Porewater profiles of sulfate and methane reveal sulfate-methane transition zones at variable depths across the sites, reflecting site-specific organic matter reactivities and anaerobic methane oxidation activities. Sulfur isotope compositions of chromium reducible sulfur, as well as porewater sulfate in these modern sediments, allow us to evaluate how isotopic signals are transformed and preserved in marine sediments with varying redox conditions and methane fluxes. These preliminary results offer early insights into how local diagenetic conditions shape the geochemical signatures that are ultimately buried and preserved long-term.

Ghost of Seagrasses Past: Understanding the Geochemistry of ancient carbon reservoirs

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Seagrass meadows are ecologically significant ecosystems that contribute substantially to global oceanic primary productivity and play a pivotal role in carbon cycling and blue carbon storage. However, their capacity for long-term carbon sequestration is complicated by their natural production of methane, which may persist post-mortem and potentially offset their carbon burial benefits. Despite their ecological and climatic importance, the evolutionary history of seagrasses and their role in geological carbon cycling remain poorly constrained, largely due to the scarcity of seagrass body fossil preservation in the geological record. In the absence of such fossils, organic geochemical proxies, particularly lipid biomarkers have emerged as primary tools for reconstructing past seagrass presence and ecology. Our study investigates n-alkane biomarker signatures associated with well-preserved seagrass body fossils from Rhodes Island, Greece from Pliocene–Pleistocene deposits with the aim of establishing reliable paleoecological proxies for ancient seagrass ecosystems. These samples contain a very low total organic carbon (~0.04) and the low Pristane/Phytane ratios (0.52–1.11) indicates anoxic to suboxic depositional conditions, suggesting significant organic matter degradation under low-oxygen settings. Our results identify consistent n-alkane peaks at C₂₁, C₂₃, and C₂₅ as characteristic of fossil seagrass material. These findings establish a robust n-alkane framework for identifying ancient seagrass ecosystems in the geological record. Future work will focus on elucidating the mechanisms driving ancient versus modern biomarker divergence and scanning for anaerobic methane oxidation biomarkers. These proxies will then be applied to reconstruct seagrass distribution, ecological adaptations, and ecosystem resilience across key intervals of environmental change in Earth history.

Heavy molybdenum isotope compositions archived in seep carbonates from the Black Sea

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Molybdenum isotopes ($\delta^{98}\text{Mo}$) are widely applied as a redox proxy to reconstruct past oceanic oxygenation. Black shales are commonly used as archives of $\delta^{98}\text{Mo}$ seawater composition, yet a significant isotope offset occurs when the seawater environment is not strongly sulphidic. Carbonate rocks have recently been put forward as an archive for seawater Mo isotopic composition. In particular, pure aragonite cement in seep carbonate rock – the formation of which is driven by sulphate-driven anaerobic oxidation of methane – from open oxic ocean environments has been demonstrated to reflect seawater $\delta^{98}\text{Mo}$ values. However, Mo fractionation between seawater and carbonate cement in sulphidic bottom-water environments remains unknown. The Black Sea is the largest sulphidic basin in the world, with an average $\delta^{98}\text{Mo}$ value of 2.7‰ and highly sulphidic conditions ($(\text{H}_2\text{S}) > 11\mu\text{M}$) in deep waters. At greater depths below the chemocline, Mo removal into sediments is quantitative, and the cement that precipitates at seeps is low-Mg calcite (LMC) rather than aragonite. Samples from the shelf of the western Black Sea (ca. 200m depth) and from the Dolgovskoy mound (ca. 2000m depth) were analysed to unravel their $\delta^{98}\text{Mo}$ values. At shelves, aragonite displays $\delta^{98}\text{Mo}$ values (relative to NIST3134=0.25‰) close to ambient seawater, with an average value of 2.68‰ (n=16). In the deep Black Sea, however, LMC ranges from 3.1 to 4.6‰ (average 3.9‰, n=9), representing the highest values recorded for carbonate minerals to date and significantly higher than those in ambient seawater. Interestingly, microbial mats coexisting with the seep carbonates show similar $\delta^{98}\text{Mo}$ values to LMC. These extreme values apparently reflect a significant enrichment of heavy Mo isotopes in the local microenvironment due to the locally high sulphide levels and low Mo concentrations. Therefore, carbonate minerals that precipitate in such highly sulphidic microenvironments might not reflect seawater composition but local microbial activity in sedimentary microenvironments.

Seasonal controls on methane dynamics and air–sea fluxes in a Greenlandic fjord

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Arctic fjords are dynamic land–ocean interfaces, linking terrestrial inputs with marine biogeochemical processes, yet their role in controlling methane (CH₄) dynamics and emissions re-mains poorly constrained. Here, we present a seasonal comparison of CH₄ dynamics in Nuuk Fjord, Greenland (64.9°N, 50.0°W) based on observations from an early spring campaign and late summer conditions characterized by enhanced freshwater discharge. Preliminary results reveal clear seasonal contrasts in both CH₄ distribution and air–sea fluxes. During early spring, the water column is relatively well mixed, leading to more homogeneous CH₄ concentrations and comparatively stable conditions for gas exchange. In contrast, late summer conditions are characterized by strong stratification driven by glacial melt and riverine inputs, promoting the development of a meltwater layer with variable CH₄ concentrations. These seasonal differences appear to influence CH₄ fluxes, with indications of enhanced variability-and potentially elevated emissions-during the stratified summer period compared to early spring conditions. The observed patterns suggest that freshwater-driven stratification and changes in vertical mixing play a key role in modulating methane accumulation and release to the atmosphere. Under strongly stratified summer conditions that may limit vertical transport from sediment sources, preliminary observations point toward a sustained supply of CH₄ to surface waters associated with riverine and glacial runoff, potentially contributing to enhanced emissions. This study highlights the importance of seasonal transitions in controlling CH₄ dynamics in Arctic fjord systems.

Ring Indices: The Potential Archaeal Lipid Indicator For Methane Seepage Intensity at Cold Seeps

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Methane removal efficiency at cold seeps typically depends on fluid flow dynamics, necessitating robust proxies to quantify seepage intensity and further provide their implications for the carbon cycle. We analyzed lipid biomarkers of Haima cold seeps sediments (South China Sea (SCS)) to develop improved GDGT-based seepage intensity indices. Anaerobic oxidation of methane (AOM), mediated by anaerobic methane-oxidizing archaea (ANME) and sulfate-reducing bacteria (SRB) is evidenced by the low sn2-hydroxyarchaeol/archaeol ratios (< 1.1), abundant glycerol dialkyl glycerol tetraethers, and δ¹³C isoprenoids -methane values of – 63‰ to – 7‰ (average – 35‰). Combined δ¹³C values (isoprenoids to– 107‰ ; SRB lipids – 43‰ to – 20‰) and unresolved complex mixtures, we demonstrated that thermogenic methane with minor microbial contributions and oil degradation serve as the major carbon sources. We developed the ring indices (Ring Index (RI) and modified RI-OH') and methane index (MI) as the methane seepage tracers. The ring indices indicate robust inverse correlations with MI in seep carbonates and sediments (R² > 0.62). Ring Index values consistently remain below 2.5 when MI exceeds 0.4, while RI-OH' demonstrates a marked increase at MI > 0.7. Both indices demonstrate rapid increases (ΔRI = 0.5–2 ; ΔRI - OH' = 0.01–0.3) as MI approaches 1 (ΔMI = 0.02), showing 0.5–100× sensitivity enhancements from ANME-derived isoGDGTs 1–3 and OH-GDGTs 1–2 accumulation. Furthermore, our analysis of AOM - derived aragonite proportion in cold-seep carbonates reveals the correlation with RI and MI (R² = 0.21), confirming the utility of RI for qualitative methane flux assessment. This dual-proxy approach integrates ring indices with MI through microbial membrane adaptation, establishing comprehensive methane seepage dynamics tracers.

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