GMS16

Gas in Marine Sediments

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Abstract Book

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Editors:

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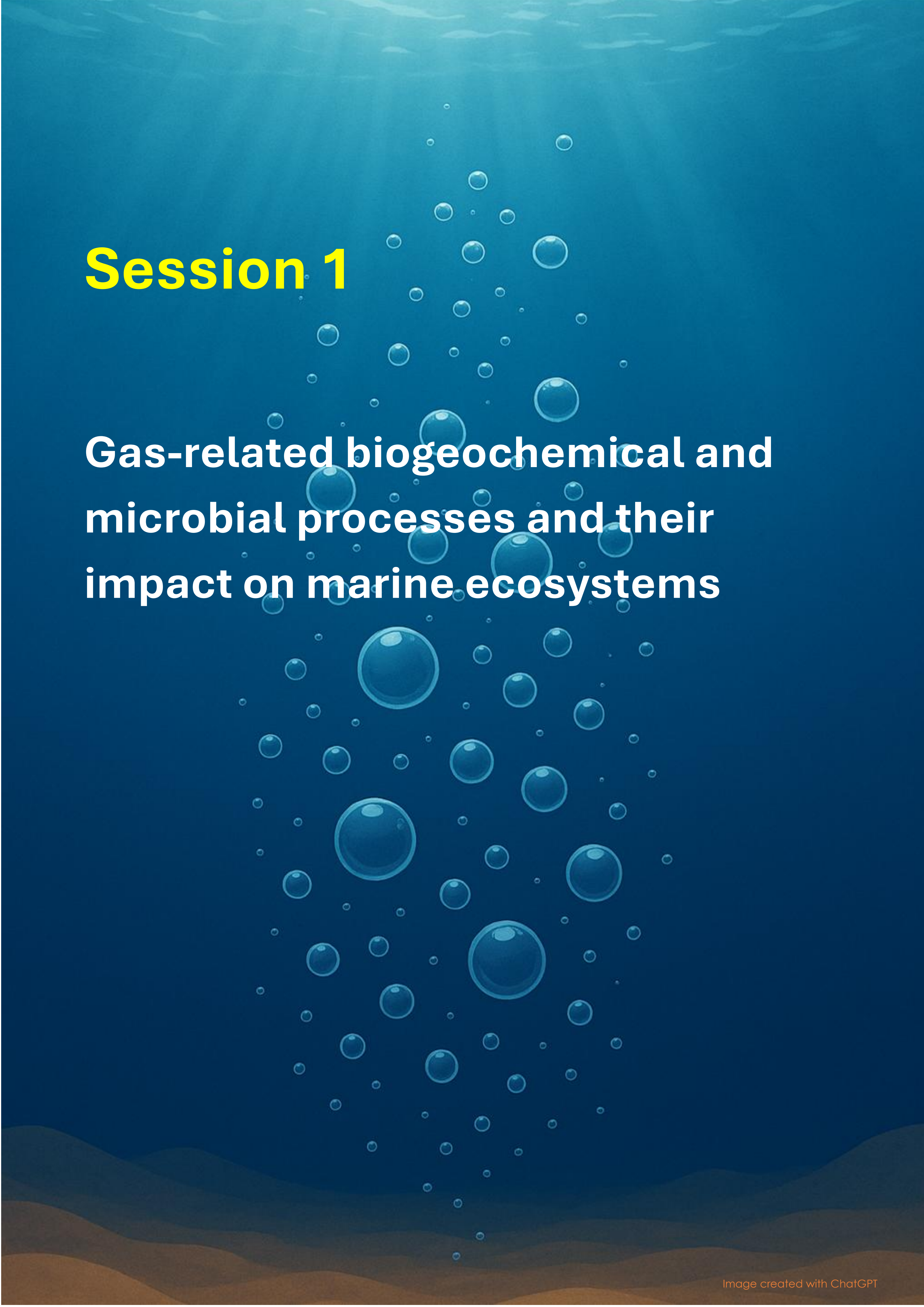

Session 1

Gas-related biogeochemical and microbial processes and their impact on marine ecosystems

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Living at Arctic and Southern Ocean methane seeps: insights into their benthic faunal

Katrin Linse*

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Abstract

Methane seeps along the continental margins of the Atlantic, Indian and Pacific Oceans are known for their unique ecosystems, harbouring large charismatic and endemic chemosymbiotic fauna, such as clams, tubeworms and squad lobsters. To date, polar seep communities are not known to comprise those large chemosymbiotic faunal elements. While Arctic seep communities have been studied since the 1990ies, Southern Ocean methane seeps were only discovered recently. Common Arctic seeps communities comprise symbiotic taxa like fine-tubed, siboglinid polychaetes, forming dense worm forest, and infaunal thyasirid bivalves next to a higher number of Arctic background fauna. Detailed taxonomic and ecological studies on the mostly small-sized seep-associated fauna are ongoing to assess their biodiversity, symbiotic dependences and their connections between Arctic seeps. An example is the faunal of the abyssal Molloy Ridge hydrate mounts. In the Southern Ocean, macrobiological research on seep fauna is in its infancy as first discoveries of active methane seepage dates to 2009 when gas seepage was discovered on the continental shelves of South Georgia and the Ross Sea. In both areas, the faunal seep communities are characterised by Southern Ocean background fauna, which seem to occur in higher abundances but lower species numbers. Large chemosymbiotic clams were only collected dead under the collapsed Larsen Iceshelf and alive in the hydrothermal Kemp Caldera. Overall, polar benthic faunal seep communities are different to non-seep communities. The effect of climate change on polar shelf ecosystems by influencing the activity of methane seepage is still unknown.

Keywords: benthic communities; faunal comparisons; Arctic; Molloy Ridge; Southern Ocean

Comparative study on the microbial diversity and metabolic processes in the sediments associated with gas hydrate and non-hydrate ecosystem

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Abstract

Cold seep ecosystems harbour diverse microbial communities which participate in biogeochemical processes and energy flow. This study compares the microbial diversity and metabolic functions using whole metagenome sequencing in the gas hydrate and non-hydrate sediments, in the Indian ocean. At both the sites, microbial communities were significantly diverse at the genus level (P= 2.80x10-5) and also with respect to their metabolic functions as revealed by COG annotation (P= 1.84x10-4) and KEGG pathway ($P<0.001$). In the gas hydrate ecosystem, indicator taxa like Desulfobacterales, Camphylobacteria, ANME-2a-2b, ANME-2c and ANME-1 associated with the methane and sulfur cycle were present. Besides, known hydrocarbon degraders of genus Corynebacterium, Zobellella and Microbacterium were also recorded. At this site, the genes affiliated to transportation of organic and inorganic molecules for mineralization to yield substrates for methanogenesis were dominant. In addition, the presence of genes associated to various pathways related to CO_2 fixation suggested the presence of chemosynthesis. While in the non-hydrate ecosystem, some known pathogens of genus Lawsonella, Cutibacterium and Mycobacterium were dominant indicating the presence of pollutant inputs. At this site, 14% and 13% of genes were associated with general function and replication, recombination and repair mechanisms respectively. Thus, indicating the ability of the microbial groups to maintain genetic stability ensuring the growth, survival and reproduction of the species under harsh/hostile conditions which may be influenced by pollutants. The present study demonstrates a 'microbial landscape' of microbial diversity and metabolism in the methane fueled hydrate ecosystem verses a non-hydrate ecosystem.

Keywords: metagenome, microbes, diversity, function, gene, cold seep

Methanogenesis and submarine groundwater discharge alter microbiology, geochemistry and mineralogy of continental shelf sea sediments: a case study from the S-E Baltic Sea

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Abstract

This study compares three different types of anaerobic sediments - methanic, methanic with groundwater seepage and methane-free - in terms of sediment and pore water geochemistry, microbial processes and sediment mineral composition. The study was carried out in the S-E Baltic Sea, where methane is widely distributed in shallow sediments, particularly in organic-rich silts. The study reveals significant differences in microbial activity in the three sediment types, which in turn has major implications for the rate of biotransformation of organic matter and the associated production of hydrogen sulphide and methane. Methane production in the study area occurs via CO_2 reduction or methyl fermentation, depending on environmental conditions. Sediments with groundwater infiltration contain more methane in the surface layer, and the sulphate-methane interface is closer to the sediment surface. In pore waters of methanic stations, dissolved inorganic carbon (DIC) and total alkalinity (TA) are significantly higher than in sediments where there is no methanogenesis and anaerobic oxidation of methane (AOM). In addition, the concentration of non-carbonate inorganic bases (NCIB), especially hydrogen sulphide, in the methane-free sediments is much higher than in methanic sediments. NCIBs can be oxidised; as a result, the role of non-methane sediments as an internal source of TA is smaller than that of sediments with active AOM. High concentrations of DIC in the pore water of methanic stations favour the precipitation of authigenic carbonates. These sediments contain less pyrite compared to sediments where methane is not present. The study was funded by the National Science Centre, Poland (2022/45/B/ST10/00395).

Keywords: methane, 16S rDNA metabarcoding, marine sediment, alkalinity, authigenic minerals

Geochemical signatures of seep dolomites in the Pearl River mouth basin: implications for paleo-methane fluid activities

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Abstract

Authigenic carbonates from the Baiyun Sag of the Pearl River Mouth Basin preserve critical records of fluid migration and anaerobic oxidation of methane (AOM). This study integrates $\delta^{13}C$, $\delta^{18}O$, $\delta^{34}S$ isotopes with mineralogical and geochemical analyses on three pyrite-rich dolomite samples to establish their genetic linkages to gas hydrate dissociation and shallow gas sources. The dolomites exhibit extremely negative $\delta^{13}C$ values (-27.56 ‰ to -43.66 ‰ V-PDB), confirming AOM as the dominant carbonate precipitation driver. Enriched Î $\delta^{18}O$ signatures and Fe-Ca anti-correlation suggest fluid contributions from both hydrate dissociation and shallow gas sources. Pyrite concentrations show positive correlation with carbonate content, while TS/TOC ratios (exceeding marine baseline values) and positive $\delta^{34}S$ values (up to +17.1‰) indicate sulfate reduction coupled to AOM. We propose a two-phase formation model: Phase I involved sulfate reduction coupled to AOM under reducing conditions, generating sulphide-rich fluids that precipitated ordered dolomite-pyrite assemblages. Phase II witnessed oxidative transformation of pyrite to hematite at the mineral margins due to post-seepage environmental changes. Findings demonstrate how seep carbonates archive fluid source transitions through coupled isotopic-mineralogical signatures, providing new insights into self-sealing mechanisms in methane seep systems. The study highlights the diagnostic value of authigenic minerals in reconstructing paleo-fluid dynamics and post-depositional redox shifts at cold seeps.

Keywords: dolomites, anaerobic oxidation of methane, the Pearl River Mouth Basin, isotope geochemistry, gas hydrate dissociation

The cycling of key substances and its environmental effects in the cold seep area of the Okinawa Trough

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Abstract

The Okinawa Trough, a representative back-arc basin in the western Pacific, hosts coexisting cold seeps and hydrothermal vents that provide a unique natural laboratory for studying material-energy coupling in deep-sea extreme environments. The multibeam bathymetry, porewater geochemistry, and microbial metagenomics were employed to systematically reveal three-dimensional linkages between these systems through tectonic, geochemical, and biological processes for the first time. Key findings demonstrate that basin-scale fractures dominate fluid migration pathways, and gas chimney structures control gas hydrate distribution, which confirms tectonic activity is the fundamental driver of seep-vent connectivity. The Fe (III) derived hydrothermally diffuses through plumes to cold seep areas, driving iron-dependent anaerobic oxidation of methane (Fe-AOM). This process promotes the formation of distinctive cold-seep carbonate rocks and enhances carbon sequestration efficiency compared to conventional sulfate-dependent anaerobic oxidation of methane (SD-AOM) pathways. Microbial communities within the seep-vent transition zone exhibit selective enrichment of thermophilic archaea (ANME-1a). Functional gene analysis confirms that cross-habitat horizontal gene transfer as a key adaptation strategy for multi-interface environments. Collectively, these discoveries support a novel "Tectonic Conduit-Iron-Driven Sequestration-Genetic Convergence" coupling model, demonstrating how Fe-AOM and SD-AOM collectively establish dual biogeochemical barriers for deep-sea methane consumption. The study advances understanding of back-arc fluid dynamics, provides a framework for gas hydrate resource assessment, and elucidates deep biosphere adaptation mechanisms, offering critical insights into global subseafloor fluid-solid coupling processes.

Keywords: hydrothermal activities; cold seeps, Okinawa Trough, interaction, anaerobic oxidation of methane

Microbial community structure and metabolic potential across deep-sea vent seep transition zones in the Okinawa Trough

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Abstract

The Okinawa Trough (OT), a back-arc basin hosting both hydrothermal vents and cold seeps, offers an ideal setting to investigate microbial responses to overlapping geochemical processes. Through molecular and geochemical analyses, we found that activities from both hydrothermal vents and cold seeps significantly shape microbial community structure and function. Hydrothermal sediments exhibited reduced microbial abundance but showed enrichment of typical hydrothermal taxa such as Hyphomicrobiaceae. In methane-rich cold seeps, redundancy analysis (RDA) indicated that dissolved ions and sulfate were the primary drivers of methane-metabolizing communities. The abundance of mcrA genes and relative enrichment of ANME-1a correlated with elevated dissolved iron, suggesting iron-dependent anaerobic methane oxidation (Fe-AOM), with ANME-1a playing a key role. Strong seep zones were dominated by Bathy-1, JS1, Methanofastidiosales-6, ANME, and Methanomassiliicoccales, potentially serving as bioindicators of active seepage. We identified three distinct methane oxidation pathways: (1) ANME-mediated AOM in high-flux seeps; (2) nitrate-dependent AOM by Methylomirabilaceae in hydrothermal areas; and (3) aerobic oxidation by Methyloligellaceae in weak seep sediments. At site G07, influenced by hydrothermal activity, organic matter degradation coupled with sulfate and manganese oxide reduction led to NH4+ accumulation. This ammonium was oxidized by Nitrosopumilaceae to produce NO2-, supporting AOM linked to denitrification. Microbial network analysis revealed higher connectivity but lower modularity in weak seep zones, indicating diffuse interactions and niche overlap. These findings enhance our understanding of methane cycling and microbial adaptation in deep-sea environments shaped by the interplay of hydrothermal and seep processes.

Keywords: microbial community, methane oxidation, vent-seep transition zones, sediment, Okinawa Trough

The abundance, diversity and trophodynamics of the macrobenthos at the South Georgia shelf methane seeps

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British Antarctic Survey, UK

Abstract

One-quarter of global marine methane, a potent greenhouse gas, is estimated to be stored in Southern Ocean sediments. Ongoing climate-driven ocean warming and ice shelf retreat threaten the stability of sedimentary gas hydrates, potentially triggering methane release and the development of methane seeps. While seepage may originate from multiple sources, gas hydrate destabilisations likely contribute to the formation and persistence of active seeps in this region. The ecological implication for the diverse sub-Antarctic and Antarctic benthos remains uncertain. This study investigates macrobenthic assemblages at active methane seeps on South Georgia's continental shelf, examining patterns in species richness, abundance, and the environmental variables shaping community composition. Seven shelf troughs with active methane seeps were surveyed during RV Meteor (M134, 2017) and RV Polarstern (PS133-2, 2022) expeditions. Across 23 stations, species richness ranged from 6 to 51 morphospecies; abundances ranged from 3,303 to 30,326 ind. m^2. Stations with elevated methane and sulfate fluxes and hydrogen sulfide at depth had higher diversity, while elevated surface sulfide and dominated by iron-reduction had lower abundances and species richness. Stable isotope ($\delta^{13}C$, $\delta^{15}N$, δ34S) and functional trait analyses of fauna were used to evaluate the incorporation of methane-derived carbon into benthic food webs and how seep presence interacts with benthic ecosystem functioning. Assemblages lacked megafaunal chemosymbiotic taxa and were dominated by annelids and arthropods; molluscs and echinoderms were notably scarce. Seep habitats associated with near-surface hydrates had lower richness, and fewer calcifying taxa indicating potential risks to the Antarctic benthic biodiversity under future seep expansion.

Keywords: sub-Antarctic, microbial mats, remotely operated vehicle (ROV), multicorer samples, stable isotopes

Formation of volatile hydrocarbons at the Central Mediterranean Ridge west and south of Cretes

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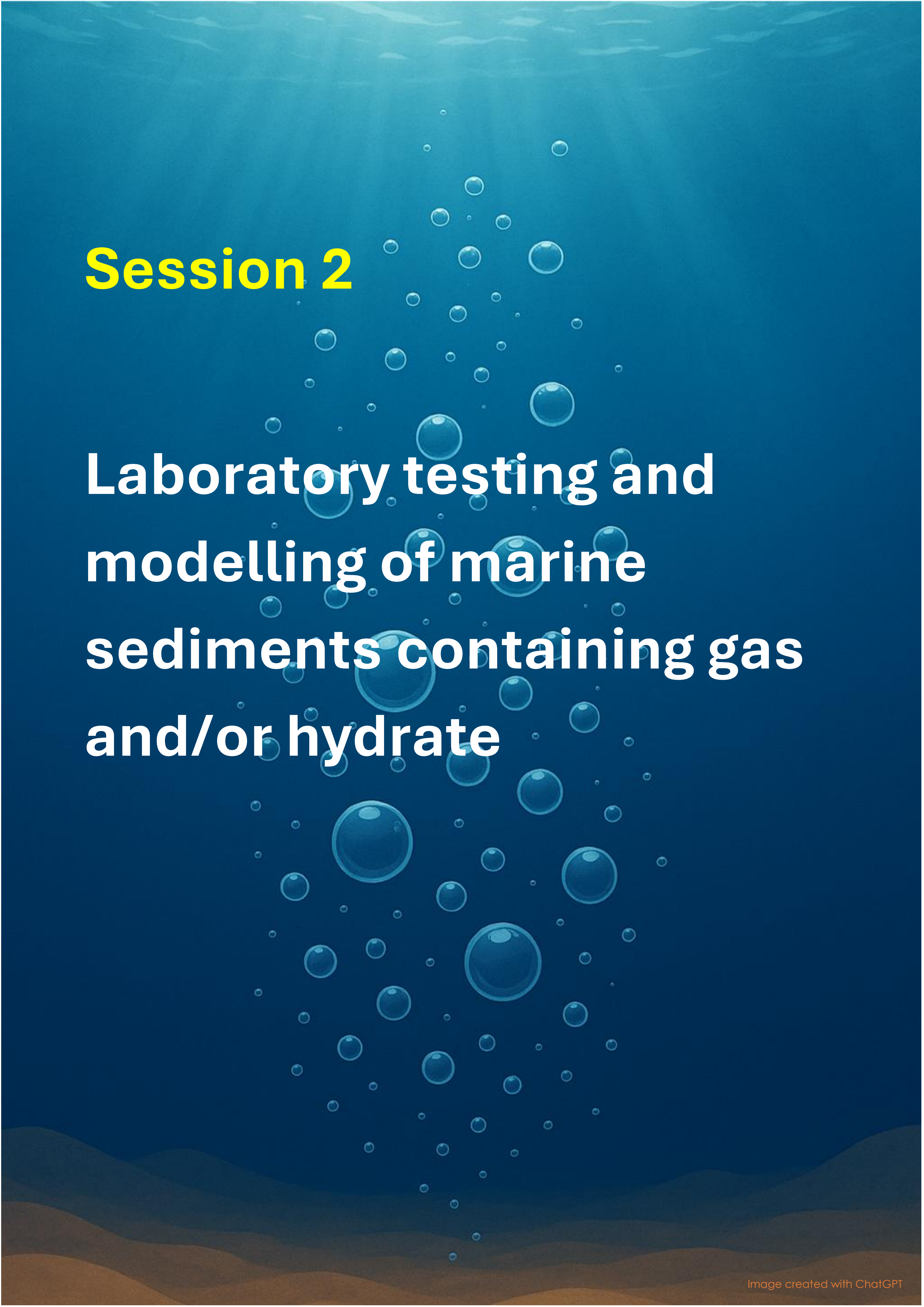
Abstract

Substance migration from great depth occurs at numerous sites along the Central Mediterranean Ridge. During subduction of the oceanic African Plate beneath the Eurasian Margin, transformation of organic matter and fluid-rock interactions lead to the formation and transport of mobile components. In 2020, during cruise SO278, 13 discharge structures within three mud volcano (MV) areas were investigated – Cobblestone Area (CA), Olimpi Mud Volcano Field (OMV), and United Nations Rise (UNR). Gas and pore-water samples from shallow sediment cores were analyzed to identify hydrocarbon sources and assess the current fluid flow.

The methane concentration profiles indicate active upward fluid flow in most MV areas. The stable carbon and hydrogen isotope composition of CH_4, which provides information about the predominant hydrocarbon source(s), varies greatly between individual structures. For example, the $\delta^{13}C$-values of CH_4 at the 11 structures in the OMV vary between –67‰ and –28‰, suggesting that it originates from microbial and thermogenic sources in varying proportions. The only structures examined in the CA and the UNR show $\delta^{13}C$-CH_4 values more negative than –59%, indicating the predominance of microbial methane. The compositions of pore-water also vary with some MVs showing high salinity, while others exhibit freshening with depth. However, the $\delta^{2}H$-relationships between pore-water and methane indicate that the formation of the microbial methane fraction is unaffected by the salinity and occurs through carbonate reduction.

Overall, the isotopic differences demonstrate that various processes on different spatial scales drive fluid formation beneath MV areas of the Central Mediterranean Ridge, illustrating its complex geochemical dynamics.

Keywords: Central Mediterranean Ridge, mud volcano, methane, pore-water, isotopic composition



Session 2

Laboratory testing and modelling of marine sediments containing gas and/or hydrate

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Periodic states and emergent complexities in gas hydrate dynamics

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Abstract

Gas hydrate (GH) dynamics in marine sediments are far more complex and unpredictable than conventionally understood, with fundamental implications for Earth system science, hazard assessment, and climate prediction. Conventional understanding dictates that long-term gas hydrate dynamics converges to a fixed steady state. However, using high-fidelity numerical modeling and theoretical analysis, we have shown that under certain geological settings the long-term solutions of pressure, temperature, salinity, and GH distribution can show a cyclic (periodic) character instead of a fixed steady-state. These cyclic solutions are an intrinsic property of the GH dynamics and are not related to any external triggers like changes in sedimentation rates, sea-level, bottom water temperature, salinity, or organic matter fluxes. Moreover, these cyclic states appear only for some combination of parameters, while for other parameters the standard fixed steady-state is achieved (i.e. high-fidelity model shows convergence with conventional models). This duality of the steady-state behavior (also called 'bifurcation') in GH dynamics contained within the same high-fidelity model is a consequence of the flow modulation by a continuously evolving hydrate layer placed in the path of the upward migrating gas, also called the gas hydrate "nozzle effect". Very simply, this effect can be described as the balance of forces between gas buoyancy, burial, and acceleration/deceleration due to hydrate phase change.

Remarkably, these cyclic phenomena mean that large-scale gas release events, changes in pore-fluid conditions, or even geomechanical instabilities can occur without environmental triggers, challenging deeply held assumptions of causality in subsurface geology. As a consequence, classical steady-state models may dramatically under- or over-estimate regional as well as global gas hydrate inventories and associated risks.

The existence of period states and bifurcations imposes irreducible uncertainty on predictions, demanding new theoretical and stochastic approaches for interpreting field data and assessing geohazard risks and climate vulnerability. Furthermore, rapid climate change could drive stable GH systems into unstable periodic or chaotic regimes, potentially amplifying risks of gas escape and landslides.

This keynote will present the latest insights into these new dynamical states, their mathematical underpinnings, and their implications for our understanding of the Earth's subsurface.

Modelling the contribution of methane hydrates to the Late Paleocene – Early Eocene hyperthermal events

Mark V. Elbertsen*, Marlow J. Cramwinckel, Lucas J. Lourens

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Abstract

Past warm periods can provide valuable information on the dynamics of the climate system under elevated greenhouse gas concentrations, providing analogues for our potential future climate. For example, superimposed on the already high global average temperatures of the Late Paleocene – Early Eocene (~56 to 48 Ma) are several short-term warming events of up to 8 °C known as "hyperthermals". These events are associated with massive releases of isotopically light carbon, suggesting that dissociation of marine methane hydrates might have played a key role. To analyse the contribution of methane hydrates during these hyperthermal events, we extend the existing carbon cycle box model LOSCAR with a box for methane hydrates. Through addition of a variable organic carbon burial flux, methanogenesis, and calculation of the temperature-dependent gas hydrate stability zone, we aim to model the time-varying volume of marine methane hydrates. By running simulations using the Early Eocene climate as a background state and orbital solutions with noise as forcings, we can analyse the dynamic response between methane hydrates and temperature fluctuations and shed more light on the role of methane hydrates during hyperthermal events.

Keywords: methane hydrates; Eocene; modelling; carbon cycle; hyperthermals

Gas hydrate and methane gas dynamics in response to warming Arctic

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Abstract

High-latitude regions are extremely sensitive to the climate change and rising bottom water temperatures which directly affect subseafloor carbon cycle dynamics. The impact of Arctic changes highly depends on the amount of marine and terrestrial permafrost-associated gas hydrate deposits and gas reservoirs. As a result of destabilization and re-mobilization of these deposits, large amounts of potent greenhouse gases, mostly methane and carbon dioxide, could be most likely released from submarine sediments into the water column and finally to the atmosphere. Current estimates of the methane in hydrates occurring in these environments are highly uncertain (ca. 27-540 gigatons of methane) as estimated using diverse upscaling methods. The large variability in these values is based on numerous assumptions in key parameters required to define the inventory, such as (but not limited to) pressure/temperature conditions, in situ gas hydrate saturation levels, composition of hydrocarbons and associated hydrate structures, and porosity of host-sediments. Here, we will present the new multi-1D high-resolution modeling results and the estimates of the gas hydrate stability zone (GHSZ) thickness, gas hydrate budgets, and the sulfate-methane transition zone (SMTZ) depths for the Arctic regions in the present-day and in the year 2100 based on the IPCC low- and high- warming trends of the bottom water temperatures.

Keywords: Arctic, gas hydrate, numerical modelling, warming trends, methane

Experimental and numerical investigation for the biogeochemical process of methane released from gas hydrate

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Abstract

Large quantities of methane are stored in natural gas hydrates within shallow marine sediments. With the onset of global warming, the released methane from these hydrates migrates and transfers through the sedimentary column, water column, and atmosphere. This process leads to seawater acidification and a reduction in oxygen content within marine waters, thereby significantly impacting marine ecology. A laboratory experiment is conducted to characterize the consumption of methane by microorganisms under both aerobic and anaerobic conditions. The study investigates how various marine environmental factors such as temperature, pressure, and methane transport flux influence both methane oxidation bacteria and the overall methane transformation process. Furthermore, a quantitative model is established to understand the extent of microbial methane consumption. Based on this model, a comprehensive numerical model is proposed that incorporates fluid flow dynamics along with dissolution, diffusion, and oxidation processes to track the fate of released methane from hydrate deposits within overlying sediments. It is determined that temperature plays a crucial role in controlling methanotrophic activity due to its significant impact on microbial growth rates. Additionally, pore pressure and velocity of migrating methane also have some effect on methanotrophic activity. However, their influence is comparatively lesser than that exerted by temperature variations. The numerical simulations can capture complex processes involved in sedimentary environments. It is observed that most of the consumed methane undergoes anaerobic oxidation while only under exceptional circumstances does aerobic oxidation occur when there is substantial seepage surpassing anaerobic zones. Finally, it can be concluded that almost all released methane from hydrate deposits is consumed by microorganisms residing within sediments without reaching into the water column.

Keywords: gas hydrate, aerobic/anaerobic oxidation, numerical and experimental simulation, sedimentary environments, methane release

Numerical analysis of triaxial compression of methane hydrate bearing sediment using the discrete element method

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Abstract

The influence of different methane hydrate (MH) morphologies on the mechanical behaviour of methane hydrate-bearing sand (MHBS) was investigated through triaxial compression simulations using the Discrete Element Method (DEM). Experimental triaxial compression of MHBS is widely conducted for geotechnical and energy-related applications, and DEM is a common method to simulate these tests. In natural and laboratory-formed MHBS, various hydrate morphologies have been observed, such as pore-filling types that occupy the pore space in sands and grain-coating types that adhere to the surfaces of sand grains. The result of triaxial compression tests must be different depending on how the morphology of MH in the sand sediment.

To evaluate how MH morphology affects the mechanical response of MHBS, numerical models were constructed in which MH was discretised as bonded particle assemblies. To reproduce each morphology, numerical models were developed by distributing MH particles either within the pore spaces or around sand grains in distinct configurations. Simulations were then conducted under different shapes of MH morphology and MH saturations. The resulting stress–strain behaviours and deformation characteristics were compared to investigate morphology-dependent mechanical trends.

Acknowledgement: This research was entrusted by the Ministry of Economy, Trade and Industry, Japan as a part of the research for production method and modelling of methane hydrate in the MH21-S R&D consortium.

Keywords: methane hydrate, discrete element method, triaxial compression, morphology, fracture

Data-driven mechanical framework for methane hydrate-bearing soils

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Abstract

Methane hydrate-bearing sediments have attracted growing interest due to their potential as an unconventional energy resource and their role in offshore geohazard risk. These sediments contain methane hydrates, which are crystalline compounds where methane molecules are enclosed within water-based cages, commonly found in marine deposits along continental margins. The vast quantities of methane stored in these formations offer significant promise for energy extraction, yet also pose engineering challenges. The presence of hydrates within the sediment pore structure significantly alters the soil's mechanical behavior, complicating efforts to simulate extraction processes and design stable offshore production systems.

To address these challenges, various mechanical models have been proposed, many of which are adapted from classical soil mechanics frameworks. Although based on different assumptions, several of these models reproduce similar experimental results. This highlights the difficulty of accurately capturing MHBS behavior.

This study presents a data-driven methodology that avoids reliance on predefined assumptions. Instead, it extracts key mechanical features directly from experimental observations. By mapping test data into a continuous stress space, the method identifies critical aspects such as the yield function, strain hardening, and plastic flow direction. The analysis reveals consistent patterns, including deviatoric hardening, an almost flat yield surface, and a non-associative flow rule.

These empirically derived insights are incorporated into a new constitutive model specifically developed for hydrate-bearing sediments. The proposed framework provides a clearer and more physically meaningful basis for predicting the mechanical response of MHBS in engineering applications, particularly in the context of methane extraction and offshore structural stability.

Keywords: methane hydrate-bearing soil, mechanical model, data-driven analysis, experimental study, mapping approach

A laboratory acoustic study of fluid and ice saturation effects in sands

Hanif S. Sutiyoso*, Sourav S. Sahoo, Laurence J. North, Ismael H. Falcon-Suarez, Angus I. Best, Tim A. Minshull

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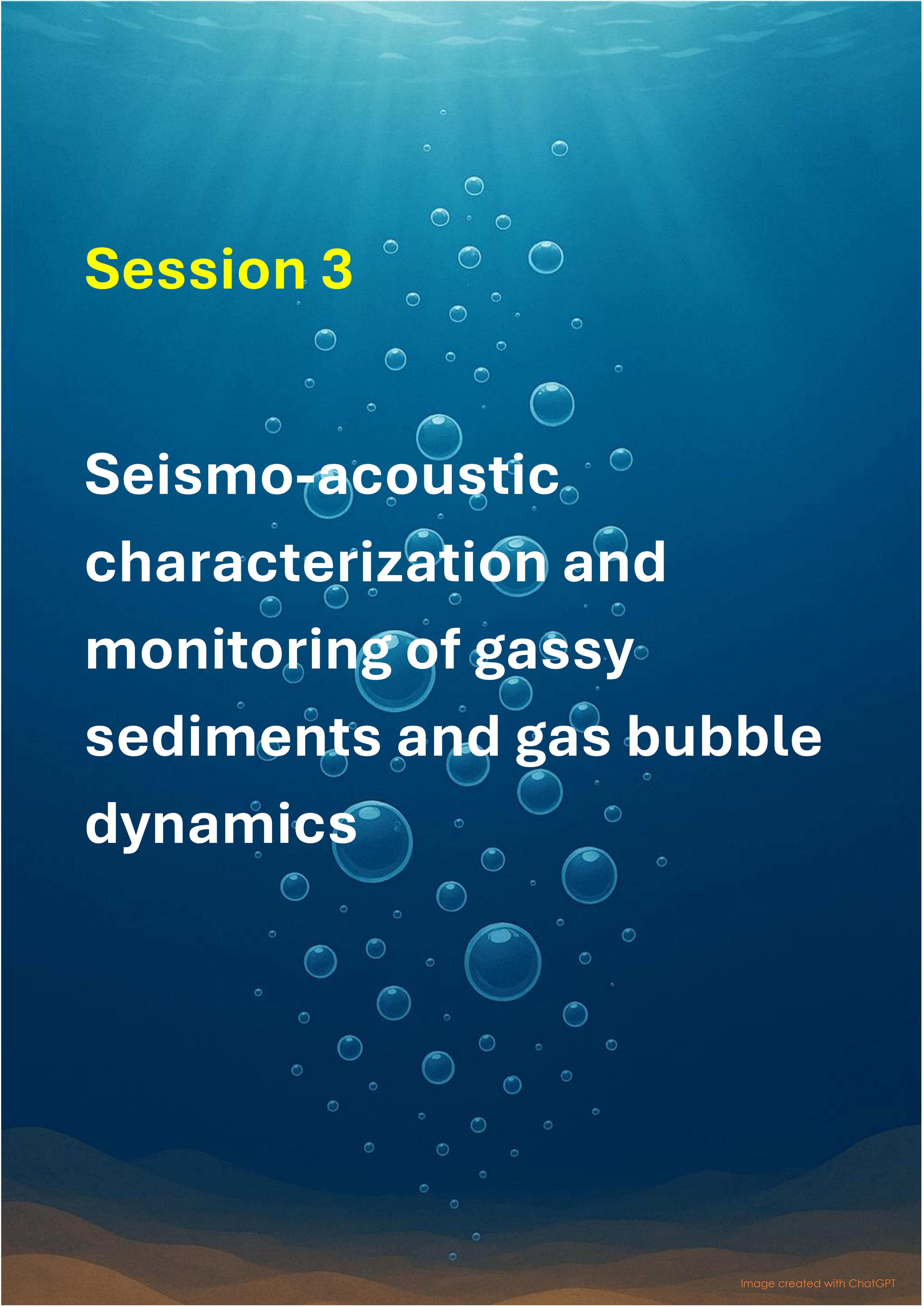
Abstract

Acoustic wave velocity and attenuation are widely used to investigate subsurface sediments, as they provide information on composition, fluid content, and stability. In permafrost regions, where sediments often contain variable amounts of ice, understanding how these acoustic properties respond to changing ice and water saturations is important for monitoring thaw processes and assessing environmental risks. This study presents new laboratory measurements of compressional wave velocity and attenuation in unconsolidated sands under controlled pressures up to 10 MPa, using a custom-built pulse tube operating in the sonic frequency range (1–20 kHz), relevant to well-logging survey.

For water-saturated sands, velocity decreases with increasing saturation until about 75%, then rises again, while attenuation increases at low saturations before slightly declining. In ice-bearing sands, as ice melts, velocity consistently decreases and attenuation increases, with the strongest effects observed at lower pressures, where ice contributes more to the strength of the sediment framework. These results highlight that both effective pressure and the way ice is distributed in pore spaces play a major role in shaping the acoustic response.

Overall, the experiments demonstrate the complex interactions between water, ice, and sediment grains, and provide new insight into how acoustic signals can be used to estimate ice content and sediment stability in permafrost. While this study does not focus on gas systems, the findings may also support future efforts to distinguish gas hydrate reservoirs from ice-bearing sands in permafrost regions.

Keywords: compressional, velocity, attenuation, ice, sand



Session 3

Seismo-acoustic characterization and monitoring of gassy sediments and gas bubble dynamics

Image created with ChatGPT

Constraining the physical properties of chimney/pipe structures in sedimentary basins

Jonathan Bull*

**University of Southampton, UK*

Abstract

Chimney or pipe structures are commonly imaged in sedimentary basins, both in seismic reflection profiles and in outcrop, and are thought to be focussed fluid-flow pathways which hydraulically connect deeper stratigraphic layers with the sedimentary overburden and the seabed. In this talk I will discuss whether submarine chimney and pipe structures are a consequence of (1) a fracture network that has been reactivated by pore fluid pressure which facilitates the migration of fluids upwards; and (2) shallow sub-seafloor lateral migration of fluids along stratigraphic interfaces and near-surface fractures. I will evaluate recent field and laboratory work on constraining fluid pathways including in-situ permeability and discuss likely methane fluxes from natural versus anthropogenic sources. Finally, I will look at the relevance of this work to monitoring above marine carbon capture and storage complexes.

Acoustic methods for characterizing gas-containing sediments (Lake Kinneret, Israel, as a case study)

Boris Katsnelson*, Ernst Uzhansky, Andrey Lunkov, Regina Katsman

**Dr. Moses Strauss Department of Marine Geosciences, Leon H. Charney School of Marine Sciences, University of Haifa, Haifa, Israel*

Abstract

Gas presence changes effective mechanical and physical properties of aquatic muds, which makes gas accumulations distinguishable by remote acoustic sensing. A method for determining the gas bubble characteristics in shallow sedimentary layer, such as cumulative gas content, characteristic sizes of bubbles, thickness of gas-saturated layer, and others, is designed. This method is based on processing and analysis of acoustic sounding data, due to high sensitivity of geo-acoustical parameters to the presence of gas bubbles. Our acoustic sounding methods include measuring the reflection and scattering coefficients of low- and high-frequency signals (300 Hz -10 kHz), carried out using a broadband source and a receiving system (a single hydrophone or a vertical line array), when the source and receiver are in a close proximity (distance up to few tens of meters). This allows obtaining an angle and frequency dependence of the corresponding coefficients, in particular resonance frequency in reflection from the layer with low sound speed, which allow us estimating characteristics of gassy layer. A long-range waveguide propagation can be used as well, if the distance from the source to the receiver is up to 5 km. This permits estimating the averaged parameters over studied area. The theoretical basis for the given methodology and its validation in the Lake Kinneret, Israel, are presented.

Acknowledgements: The work is supported by the U.S.-Israel Binational Science Foundation, grant No. 2018150.

Keywords: acoustic methodology, geo-acoustic parameters, gas bubbles, geo-acoustic inversion, low-velocity layer

Evaluation of dynamics and bubble sizes of methane gas in sediments of Lake Kinneret, Israel: Insights from a multiannual acoustic investigation and physical modelling

Ernst Uzhansky, Regina Katsman*, Andrey Lunkov, Boris Katsnelson

**Dr. Moses Strauss Department of Marine Geosciences, Leon H. Charney School of Marine Sciences, University of Haifa, Haifa, Israel; ** presenter*

Abstract

CH_4 gas content is accommodated in discrete bubbles in shallow aquatic sediments. The gas dynamics and micro-scale bubble descriptors are controlled by a diversity of physical, mechanical and biogeochemical processes that vary spatially and temporally over the aquatic system. First, a multiannual (2015-2021) acoustic database on gas content (evaluated based on the sound speed inferred from the reflection coefficient) in sediments of Lake Kinneret, Israel, was compiled. Conducted multivariate regression analysis indicates that short-leaving CH_4 production peaks act as major controls on sediment gas content in the medium-deep parts of the lake (water depth > 12 m), where the hydrodynamic regime and slopped bottom transport the autochthonous organic matter. In contrast, the water depth predictor has the least significance, being explained by a lack of ebullition. Second, based on single bubble shape and size dependence on mechanical properties of muds, a macro-scale bubble size distribution model was designed. Results of five acoustic measurements, conducted in 2016 and in 2022 at water depths between 23 m 37 m, were explored by a frequency analysis. This revealed a spectral notch around 2584 Hz in 2016 and between 3027 and 4373 kHz in 2022 being interpreted as corresponding to a maximum equivalent spherical bubble diameter of 7.95 mm in 2016 and 4.50-6.54 mm in 2022, which is consistent with direct measurements obtained in 2016 by another research group at the same spatial locations.

Acknowledgements: This project is supported by the U.S.A-Israel Binational Science Foundation, grant No. 2018150

Keywords: methane bubble, aquatic muds, gas dynamics, acoustic methodology, bubble size

Degassing mud volcanoes in the Gulf of Cádiz

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Abstract

Gas bubble emissions in marine environments are indicators of subsurface geological activity and biogeochemical processes. 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, we identified previously undocumented seafloor gas emission sites that are primarily, but not exclusively, associated with mud volcanoes (MVs). Although many of the MVs in the Gulf of Cádiz have already been described as being in an active stage, only few studies have reported gas bubble release. So far, no study focused on hydroacoustically-derived water column anomalies indicating gas bubble emissions in the Gulf of Cádiz. Our study, based on data collected during two expeditions in 2020 and 2024, shows that gas bubble emission is widespread in the study area. In total, more than 100 gas bubble emissions were detected at 24 different seafloor structures. About half of the MVs studied showed evidence of gas bubble release at the time of the surveys. The majority of emissions were spatially associated with MVs, with a high concentration at their cones, although some also occur in surrounding areas. Furthermore, gas bubble emissions were detected at previously undiscovered structures and even in seafloor areas that lacked obvious morphological features typically associated with fluid release. Our research underscores the complexity of gas seepage in the region and emphasizes the value of hydroacoustic surveys in identifying active emission sites and understanding fluid migration pathways.

Keywords: mud volcano, gas bubble emissions, hydroacoustics, Gulf of Cádiz

Hydroacoustic monitoring of volcanic gas seeps using hydrophones and DAS

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Abstract

A strong link between volcanic activity and the level of degassing in surrounding waters has long been suspected. However, without accurate methods to quantify variations in marine gas flux, this relationship has been difficult to characterise. Fortunately, hydroacoustic techniques are emerging as an ideal tool for the long-term monitoring of subaqueous volcanic seeps. These techniques analyse the spectral acoustic emissions of seeps (effectively listening to the sound of bubbles being released) to determine the size and number of bubbles emitted per second and thus quantify the volume of gas released. By correlating these measurements with traditional volcanic monitoring techniques (e.g. passive seismology), researchers can empirically prove (or disprove) a relationship and potentially identify new pre-eruption behaviours allowing for improved early warning systems.

This talk will introduce the concept of bubble acoustics, explain the acoustic inversion process, and present several case studies linking volcanic activity to quantified subaqueous gas emissions. Examples will include Poás (Costa Rica), Panarea (Italy), Dziani Dzaha (Mayotte), Lake Kivu (DRC), Laacher See (Germany), and Askja (Iceland). Finally, we will present recent work using Distributed Acoustic Sensing (DAS), AKA fibre optic cables, which offers a low-cost and scalable solution for acoustically measuring gas emissions across significantly larger areas (> 1 km).

Keywords: hydroacoustic, volcanic, DAS, monitoring, quantification

Time-lapse seismic monitoring of hydrogen storage: is the cushion gas – hydrogen contrast truly undetectable?

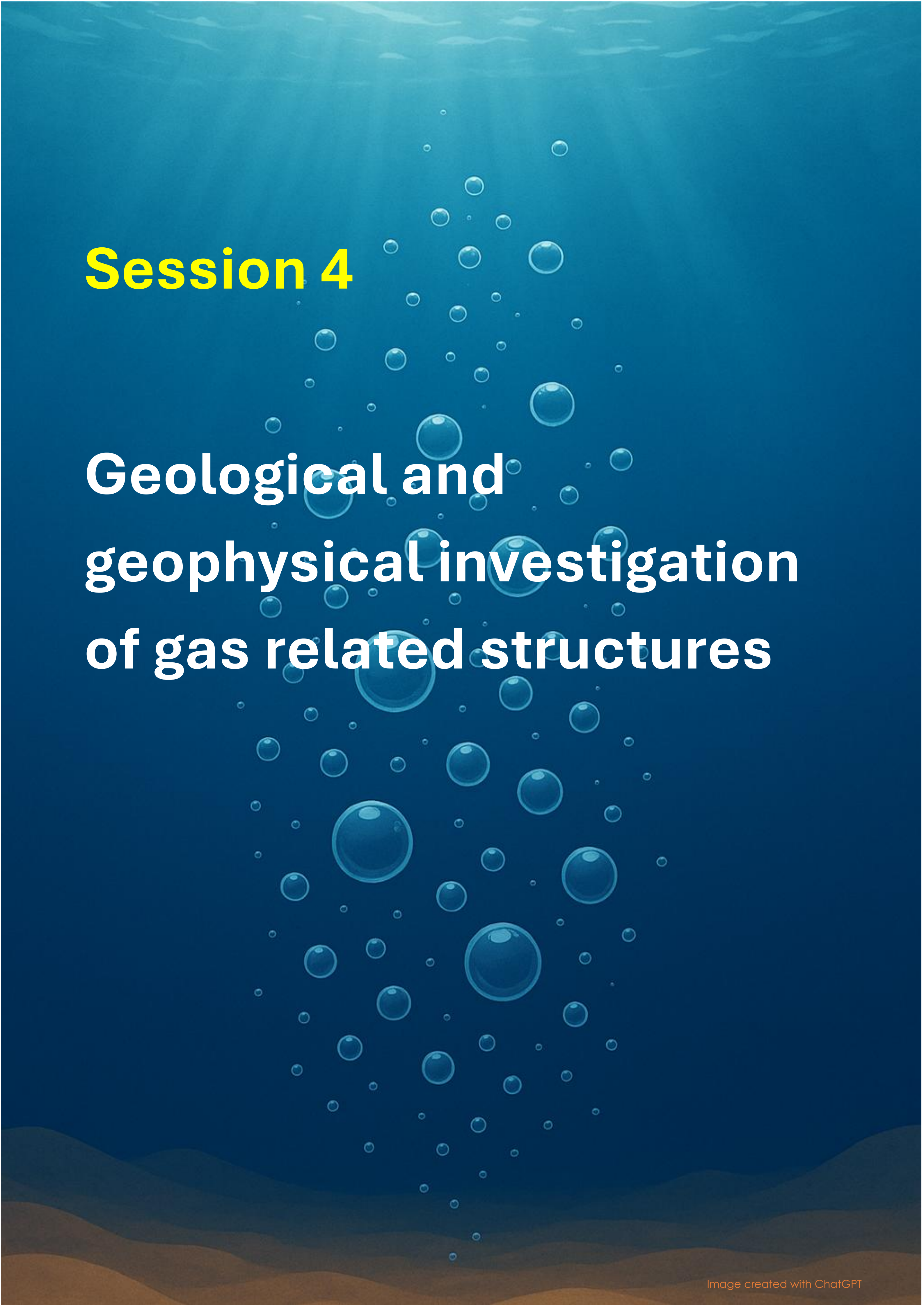
Giorgos Papageorgiou, Ismael Falcon-Suarez, Maria-Daphne Mangriotis*

** National Oceanography Centre, Southampton, UK; ** presenter*

Abstract

Seasonal hydrogen storage in porous formations involves a one-time loss of hydrogen as cushion gas. This cushion gas, estimated to be up to half of the reservoir capacity by volume, is necessary to maintain pressure and enhance seasonal recoverability of the injected hydrogen. The high economic cost associated with hydrogen production has led to engineering alternatives involving cheaper options for the cushion gas, such as nitrogen, CO_2 and methane. Whilst these options are viable from a financial and reservoir engineering perspective, they present challenges for monitoring the hydrogen reservoir. Time-lapse seismic is a proven technology to detect fluid migration and distribution, and potential leaks, as well as injection/production-related geomechanical changes in the subsurface for oil & gas, geothermal, and CO_2 sequestered reservoirs and more recently subsurface hydrogen storage. However, hydrogen storage monitoring presents a challenge for seismic characterization of the cushion gas – hydrogen interface, as for several cushion gases, there is insufficient elastic contrast with the hydrogen. We argue that while the elastic impedance contrast may not produce a strong seismic reflection, the viscoelastic impedance contrast, which results from differences in seismic attenuation due to (primarily) fluid viscosity effects, may be in fact detectable. We present the theoretical model, and numerical seismic simulations based on laboratory-tested seismic properties of rock samples with several gas compositions.

Keywords: hydrogen storage, time-lapse seismic, cushion gas, viscoelastic contrast



Session 4

Geological and geophysical investigation of gas related structures

Image created with ChatGPT

New discoveries of hydrocarbon seepages on the Norwegian Continental Shelf

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Abstract

The Norwegian Continental Shelf (NCS) hosts some of the largest and most productive hydrocarbon provinces in Europe, extending from the North Sea, Norwegian Sea, and Barents Sea. Hundreds of thousands of active and extinct natural seeps have been documented all over the NCS, highlighting that methane degassing is a natural process that has been long lasting, especially after the last glaciation. So far uncertainty remains regarding the impact of these methane seeps in the acidification of the oceans and how much of this gas is ultimately reaching the atmosphere contributing to global carbon emissions. In the framework of the WELLFATE project, new hydrocarbon seepage sites have been identified along the west coast of Norway and investigated using multidisciplinary methods, including geophysical surveys, seafloor sampling, and direct observations.

The Sentinel Seep (800x200m) located in the Norwegian Trench in the northern North Sea revealed to be an active seepage site where the Quaternary sediment package is unusually thin. The gas appears to be sourced from a large (~1,800 km^2) shallow gas pocket imaged as an amplitude anomaly identified on the seismic data. Here laterally extensive carbonate buildups and seep mounds are populated by a large variety of chemosymbiotic fauna, pervasive microbial mats and fish and, to our knowledge unique and spectacular coral colonies erecting in the water column for several meters. The carbonate buildups caused fishing gears to be entangled, which ultimately discouraged further trawling, and indirectly allowed the habitat and ecosystem to develop.

Further to the north-west, along the upper headwall of the Tampen Slide in the northern distal part of the Norwegian Trench, we investigated a field of pockmarks and craters associated with shallow seismic anomalies. Ongoing seepage was identified in the water column multibeam data, and surveyed sites showed the presence of carbonate buildups and microbial mats. One of the sites (named “G”) features a subrounded circular crater, and gas/mud expulsion was identified from the flanks of one of the central mounds representing a potentially new mud volcano discovery. Another site (named “O”) appears as a well-defined circular crater and displays individual rounded depressions entirely covered by multicoloured microbial mats.

Moving south over the Tampen area on the western bank of the Norwegian trench, we combined a large 800 km^2 multibeam and water column survey with high resolution seismic profiles and gas geochemistry analyses from active seepage sites. Results revealed the

presence of nearly 2000 gas flares, 175 of which are associated with wells. Reflection seismic data confirm the presence of shallow gas deposits trapped in the topmost glaciogenic wedge of the west shoulder of the Norwegian trench. Selected profiles have been used to trace back the potential fluid migration pathways from deeper units where mature source rocks and reservoirs are located. We suggest that deep-seated tectonic discontinuities facilitate vertical migration while shallower clinoforms and sub-horizontal sedimentary interfaces control lateral fluid movements.

Geochemical analyses show that methane is the main seeping gas with a shallow microbial signature at all investigated sites. The gas flares identified in the different regions have been grouped in different classes according to width, height and intensity to have a comparable catalogue. An ROV was used to measure flux at different classes of seepage sites, and these estimates can be applied to quantify the volume of methane emissions at all the classified flares on the NCS. These findings are relevant to understanding the environmental impact of gas seep activity on the ocean capacity to act as a sink to carbon release in the atmosphere.

Methane seeping in the gas hydrate province of the Antarctic Peninsula facilitated by crustal strike-slip faults

Roger Urgeles*, Ricardo León, Rafael Bartolomé, Manel Prada, Miriam Mestre, Maria De La Fuente, Xavier Garcia, Michela Giustiniani, Héctor Marín-Moreno, Umberta Tinivella, Maria del Carmen Fernández Puga, Teodora Ortega

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Abstract

A Bottom Simulating Reflector (BSR) associated with the presence of gas hydrates is widely present north of the South Shetland Islands, spanning an area exceeding 5,000 km2. Potential glacio-isostatic and tectonic uplift, possibly combined with ocean bottom-water warming, may have induced gas hydrate dissociation, leading to methane release into the Southern Ocean. During a research cruise conducted aboard the RV Sarmiento de Gamboa in January-February 2025, we acquired high-resolution multichannel seismic profiles, swath bathymetry, water column acoustic data, sediment cores, and water samples. The water column was also surveyed using a CTD rosette equipped with multiple sensors, including a methane detector. Acoustic imaging of the water column revealed several methane plumes near the upslope limit of the gas hydrate occurrence zone. The most prominent plumes are associated with sinistral strike-slip faulting on the continental slope. The faults, imaged in the bathymetric and seismic data, evidence recent activity, shown by clear seafloor displacement. Plumes, as depicted by anomalies on the methane sensor and acoustic data, occur in 300 to 3000 m water depth, and vanish very close to the sea surface to ~300 m water depth. These plumes indicate the potential for methane to migrate toward the atmosphere and underscore the importance of quantifying how methane consumption within the water column may influence local acidification.

Acknowledgments: This study was funded by project PID2020-114856RB-100 / AEI / 10.13039/501100011033 (ICEFLAME)

Keywords: gas-hydrate, methane seeps, Southern Ocean, strike-sleep faulting, water column imaging

Strike slip mud volcano system in the accretionary wedge of the South Shetlands Islands (Antarctic Peninsula)

Ricardo León, Roger Urgeles, Rafael Bartolomé, Ferran Estrada, Maria del Carmen Fernandez-Puga, Maria de la Fuente, Luis Galán, Xavier Garcia, Michela Giustiniani, Clara Estela Jimenez-Tejero, Miguel Llorente, Ana Manrique, Miriam Mestre, Teodora Ortega, Manel Prada

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Abstract

In the South Shetland Pacific margin (Antarctica), an active system of mud volcanoes has been identified. Mud volcano systems are commonly found worldwide in compressional settings, typically associated with thrust faults or diapirs; however, they are relatively rare in strike-slip environments. During the ICEFLAME cruise (January-February 2025), multibeam echosounders, high-resolution multichannel seismic data, and gravity cores were acquired. The resulting bathymetric mosaics reveal sigmoidal diapiric ridges aligned with NW-SE sinistral strike-slip shear structures. Conical mounds atop these ridges, along with stacked bi-conical features observed in seismic profiles, are interpreted as mud volcano systems. The bi-cone structures are separated by high-amplitude, normal-polarity reflectors. Numerous acoustic blanking veins and chimneys beneath the ridges suggest preferential fluid migration pathways. Water column echosounders detected prominent gas flares, indicating ongoing fluid emission activity. Additionally, low-density structures observed in gravity core sediments indicate the presence of methane within the sediment column.

These observations reveal an atypical setting for mud volcanism, where strike-slip tectonics may play a key role in focusing fluid flow along pre-existing weaknesses. The spatial association between mud volcanoes and sinistral shear structures suggests that lateral tectonic deformation can drive vertical fluid migration in accretionary wedges. These findings provide new examples that complement alternative models of mud volcano formation and highlight the need to further explore strike-slip systems as active components of seafloor fluid fluxes.

Keywords: mud volcanoes, strike slip, Antarctica, gas flares, seismic

Mapping the methane gas hydrates stability zone beneath the Antarctic Ice Sheet from 40 Ma to the year 3000

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Abstract

The collapse of the Antarctic Ice Sheet (AIS) is one of the Earth's core climate tipping elements on Earth and has important implications for global sea level rise and climate stability. However, its impact on the global carbon cycle remains critically ignored in the current global carbon budget.

This is especially critical because the Antarctic Sedimentary Basins (ASBs), beneath and around the AIS, are believed to contain substantial reservoirs of the potent greenhouse gas methane (CH_4) stored in methane hydrates. These hydrates form and remain stable in the gas hydrate stability zone (GHSZ) defined by specific conditions of high pressure and low temperature. First estimates of the present-day reservoir indicate that subglacial ASBs could host ca. 400 PgC in the form of methane gas hydrates. Yet, the exact size, spatial distribution and vulnerability of this reservoir to projected ice mass loss remains unknown.

Here, we present the first mapping of the GHSZ in ASBs, quantifying its volume and tracing its evolution from the onset of glaciation 40 million years ago to the year 3000 under two Shared Socio-economic Pathways (SSPs).

Preliminary results indicate that the potential present-day volume of the GHSZ in ASBs ranges from 0.9 to 3.4 x10^6 km3. A significant portion (60-70%) of this volume resides in the subglacial environment, predominantly beneath the East Antarctic Ice sheet. In a next step, we will quantify the amount of biogenic CH_4 that could have accumulated in ASBs within this stability zone and identify its vulnerability to projected AIS mass loss.

Keywords: methane, hydrates, sediments, subglacial, Antarctic

Insights into the Tuaheni North landslide from shallow gas and hydrate accumulations along the Hikurangi Margin, New Zealand

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Abstract

This study investigates the morphology and timing of Tuaheni North, a significant landslide within the Tuaheni Landslide Complex on New Zealand's Hikurangi Margin. We provide insights into the timing and style of Tuaheni Northâ€™s slope failures, which may help identify their causes and recurrence patterns.

Our findings indicate that the Tuaheni North margin experienced multiple slope failure events, resulting in the displacement of approximately 11.2 km^3 of sediment. The landslide is spatially coincident with extensive subsurface gas accumulations beneath both the sediment source and sink areas. Prominent bottom simulating reflections (BSRs) reveal the presence of free gas at the base of the gas hydrate stability zone (GHSZ). The potential role of gas and hydrate in triggering slope failure remains uncertain, and warrants further investigation. Instead, this study uses gas hydrate for dating the submarine landslide without sediment core analysis.

BSRs are non-stratigraphic seismic reflections primarily controlled by sediment temperature. Submarine landslides alter the thermal field beneath the seafloor, and resulting shifts in GHSZ can be used to infer the timing of these events. We use this novel method to estimate the ages of the two major slope failures at ~37 ka and ~23 ka, highlighting a substantial time gap between them. Our geophysical data analyses confirm clear correlation between two major source volumes from Tuaheni North and corresponding downslope mass transport deposits (MTDs), indicating two distinct events. An intermediate layer separating the stacked MTDs likewise suggests a significant time gap between the failures.

New Zealand's Hikurangi Margin, known for its extensive gas hydrate and landslide activity, has over 2,200 recently identified slope failures. The 2-D age-dating method developed in this study can be applied to similar regions where gas hydrates and landslides coexist, both within New Zealand and globally.

Keywords: submarine landslide, gas hydrate, Tuaheni landslide, mass transport deposit, New Zealand

Pockmark occurrence in the Northern Gulf of Mexico influenced by glacial cycles and hydrate stability

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Abstract

On the continental slope of the northern Gulf of Mexico, pockmarks concentrate near the estimated updip edge of the hydrate stability zone (HSZ). We identified 5,691 pockmarks in the northern Gulf of Mexico by combining existing records with manually mapped pockmarks from bathymetric data. Nearly 70 percent of the pockmarks occur within 330-600 m water depth and the number of pockmarks drops abruptly at water depths >600 m. Based on hydrate stability modeling, we argue that the updip edge of the HSZ shifted downslope since the last glacial maximum. This downslope shift caused hydrate dissociation and released charged free gas resulting in pockmark formation on the seafloor. Moreover, we observe that fluctuations in the updip edge of the HSZ since the last glacial maximum (from 330 to 605 m water depth) coincide with increased pockmark abundance. On other continental margins, pockmarks have been observed within a similar water depth range, suggesting that the loss of hydrate stability during deglaciation is a worldwide phenomenon that created intense fluid emission from the seafloor.

Keywords: pockmarks, hydrate stability zone, last glacial maximum, deglaciation, hydrate dissociation

Multidisciplinary research on newly discovered pockmarks in the Gdansk Basin, SE Baltic Sea

Aleksandra Brodecka-Goluch*, Katarzyna Lukawska-Matuszewska, Jakub Idczak, Andrzej Borkowski, Grzegorz Rzepa, Maciej Manecki

* *University of Gdansk, Faculty of Oceanography and Geography, Poland*

Abstract

Recent studies (2019-2024) carried out in the south-eastern part of the Baltic Sea revealed the presence of numerous pockmarks at the sea bottom. Most of these features occur in different deepwater parts of the Gdansk Basin, in the areas named MET1, MET3 and MET4. Their presence is associated with gas or freshwater seepage and their current activity varies significantly - some of them seem to be inactive while the others continuously release gas and periodically release freshwater. Multidisciplinary investigations conducted in the period of 5 years have been focused on: (1) their impact on the marine environment, (2) observations of their activity (freshwater/gas release), (3) comparison of geochemistry in pockmark sediments in relation to nearby reference sites, (4) mineral precipitation in sediments of active pockmarks, (5) microbial community composition of pockmark sediments, and (6) analyses of gas released to the water column from active pockmarks. The obtained results showed that e.g. pockmark activity may impact the release of nutrients to the water column which may further boost primary production; pockmarks may act as traps for pollutants; gas and freshwater release may significantly change the composition of sediments during early diagenesis. Some of the consequences of pockmarks presence and activity in a relatively shallow, brackish-water, semi-enclosed, human-impacted Baltic Sea may be more pronounced than in the open sea with standard salinity.

Acknowledgments: The research was partially funded by the National Science Centre, Poland (Projects No. UMO-2016/21/B/ST10/02369 and UMO-2022/45/B/ST10/00395). Parts of the study conducted onboard RV Oceanograf were covered by the grant no. 40/E-335/SPUB/SP2019.

Keywords: pockmarks, Baltic Sea, gas seepage, freshwater outflow

Gas emission dynamics in Arctic Fjords of Svalbard: A spatio-temporal analysis

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**The University Centre in Svalbard*

Abstract

In this study, we investigate the spatial and temporal variability of gas emissions of the shallow-water (13 to 280 m.b.s.l.) of the Isfjorden fjord system, the largest fjord in western Svalbard. The Svalbard archipelago is a hydrogeologically complex region, and its subsurface environment is host to a diverse range of fluids in various phases (e.g., groundwater and free, dissolved or hydrate-bound gas), whose dynamics are strongly influenced by the “cryospheric cap” formed by permafrost and glacier ice cover. However, the Arctic, and particularly Svalbard, is experiencing accelerated warming, affecting both the cryospheric cap and the water circulating in its fjords. This has the potential for increased methane release into the water column and to the atmospheric carbon pool. Although some constraints exist onshore, far less is known about the emissions from climate-sensitive near-shore fjord environments. For this reason, an extensive hydroacoustic dataset was collected in September 2023, complementing earlier surveys in August 2015 and June 2021. The datasets show significant seepage across Isfjorden, laying the foundation for quantifying gas fluxes, identifying emission hotspots, and understanding the mechanisms that control gas migration from the subsurface to the water column in Isfjorden. A 4-year PhD project will start at the University Centre in Svalbard (UNIS) in November 2025 to quantify present-day spatial and temporal gas emissions and to better understand the controls and dynamics of methane release in response to ongoing and past rapid environmental changes in Isfjorden and other fjords in Svalbard.

Keywords: gas seepage, hydroacoustics, methane, shallow fjords, Svalbard archipelago

Poster Session

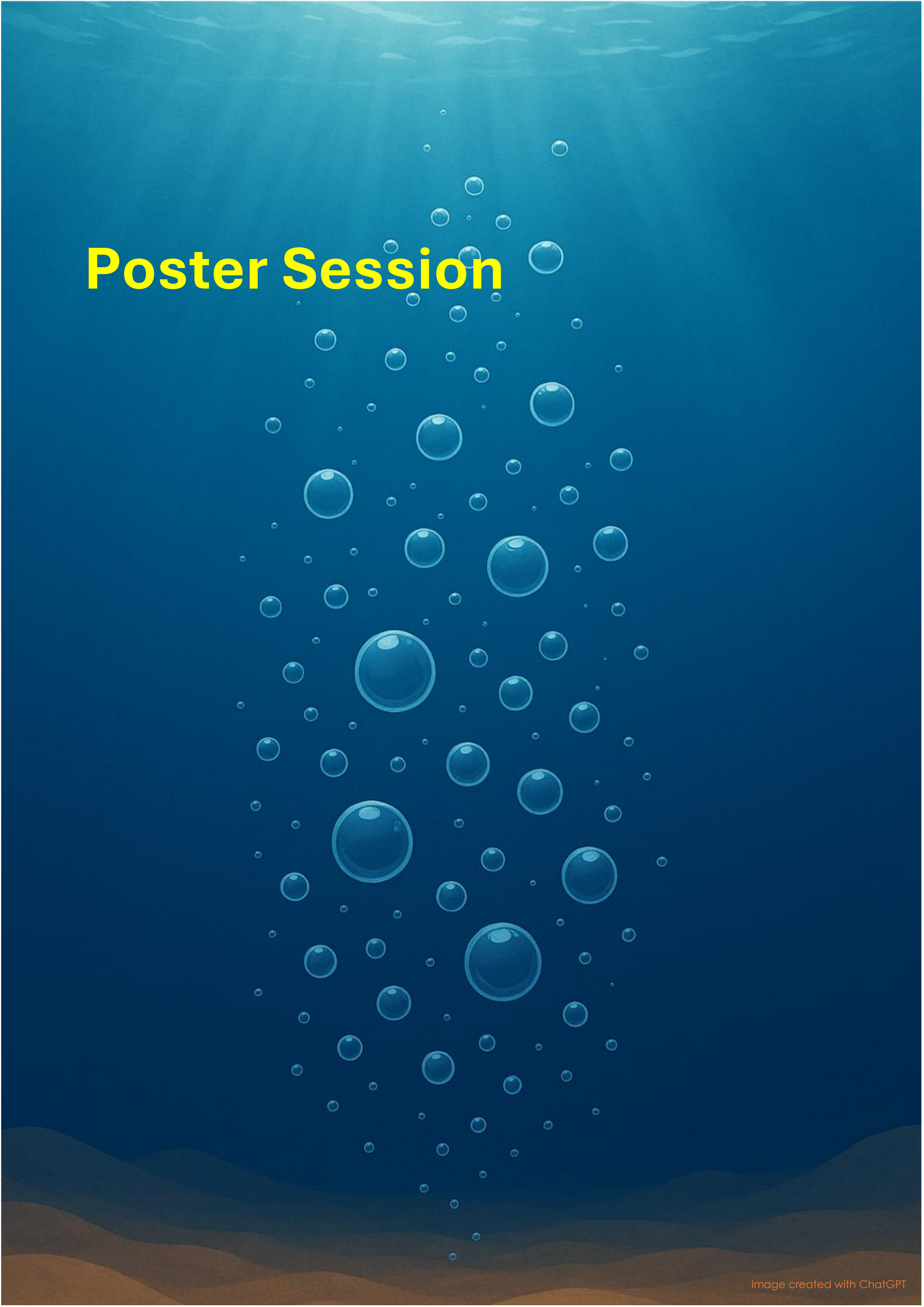

Image created with ChatGPT

Safe ground-truthing of shallow gas interpretation: linking water column anomalies to seismic data

Lucia Perez Belmonte*, Jon Basset, Florian Beranger, Bernt M. Christiansen, Inger Helene Gram Reese, Ole-Marius Hafstad Solvang, Linda Kaldheim, Dag Lundqvist, Thomas Reichel, Peter Sabel, Erling Sundvor, Sadjia Cherifa Ait-Djafer

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Abstract

In the context of shallow gas interpretation, our service department within an oil and gas operator faces significant challenges in validating anomalies identified in 2D High Resolution (2DHR) and conventional 3D seismic data. Due to safety concerns, ground-truthing by drilling directly into seismic anomalies is not an option; therefore, we must relocate drilling sites when shallow gas seismic indicators are present.

This presentation highlights case studies where we established correlations between water column anomalies and seismic anomalies. By utilizing a comprehensive suite of marine geophysical data—including Multibeam echosounder, side scan sonar, cone penetration tests (CPTs), and various seismic datasets (2DHR, 3D High Resolution, and 3D conventional seismic)—we demonstrate how these links provide reliable evidence of gas presence.

Data acquired from the Norwegian Continental Shelf (NCS) illustrate the effectiveness of this approach in tracing gas migration pathways and enhancing our geological understanding. This correlation improves interpretations and plays a crucial role in operational decision-making, allowing safe navigation of potential gas hazards.

We will detail our methodologies and findings, emphasizing the integration of diverse datasets for accurate shallow gas assessments, ultimately enhancing safety and operational efficiency in marine exploration and production.

Keywords: shallow gas detection, seismic anomalies, water column anomalies, marine geophysics, operational safety

Biogeochemical impacts of hydrogen leakage from offshore geological storage

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Abstract

Offshore hydrogen storage in depleted hydrocarbon reservoirs, like CO_2 storage, can support low-carbon energy systems and indirectly reduce CO_2. While the environmental risk of CO_2 leakage from offshore Carbon Capture and Storage reservoirs into near-surface sediments is well characterized, the biogeochemical consequences of H_2 leakage from a geological reservoir are less well understood and are likely to differ substantially.

In this study, we conducted laboratory experiments to: (i) understand the dominant biochemical reactions that would occur upon H_2 leakage into marine near-surface sediments, (ii) identify the changes in microbial community structure and reactions when exposed to different leakage scenarios, and (iii) identify potential biogeochemical tracers for leakage from an offshore hydrogen reservoir and compare them with those for CO2. For this, we reacted different sediments with seawater enriched in H2, CO_2, or N_2 (as control).

Similar to previous experiments, the CO_2 treatment leads to carbonate dissolution, evidenced by a drop in pH and an up to a tenfold increase in Total Alkalinity. In contrast, in the H_2 treatments, both pH and Total Alkalinity increased, likely due to microbial sulphate reduction stimulated by hydrogen. We also observed consistent phosphate release in the H_2 treatments, which can reflect either iron reduction in the sediments and the associated release of phosphate or pH-driven desorption.

These findings highlight that H_2 leakage into marine sediments can trigger specific biogeochemical processes compared to CO_2, demonstrating the need for tailored risk assessments and the development of specific biogeochemical tracers for offshore hydrogen storage monitoring.

Keywords: offshore H_2 storage, environmental impact assessment, marine sediments, biogeochemistry

New insights into geomorphology and activity of deepwater pockmarks in the Gdansk Basin, southern Baltic Sea

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Abstract

The presence of numerous pockmarks - seafloor structures usually associated with fluid seepage from sediments - has been confirmed in the Polish sector of the Baltic Sea. In 2019-2024, their detailed identification was carried out using hydroacoustic equipment installed on the research vessel r/v Oceanograf. During the survey, a multibeam echosounder, split-beam echosounders and a sub-bottom profiler were used, which enabled a comprehensive analysis of seafloor morphology, internal structure of surface sediments, as well as the water column above the pockmarks. Four areas in the southeastern part of the Baltic Sea were surveyed: MET1, MET3, MET4, and P1. The results indicate the varied morphology and activity of the pockmarks. Generally, in the MET1, MET3 and MET4 areas, an intense release of gas bubbles into the water column was observed. During the investigations, the MET1-BH pockmark (about 10 m deep and about 50 m in diameter; with an intensive gas flare) and an extensive (1200 m x 520 m) MET1-MP pockmark were mapped in the MET1 area. In addition, in the MET3 area, a subsurface 5 km long â€œfurrowâ€� filled with gassy sediments, lying beneath compacted sediments, was revealed. Pockmarks in the MET4 area, reaching relative depths of up to ~5 m turned out to be arranged along NW-SE oriented lines. In contrast, numerous small pockmarks in the P1 area exhibit no evidence of gas either in the water column or in bottom sediments. This suggests a different formation mechanism compared to the structures observed in the other surveyed areas.

Keywords: pockmark, gassy sediments, gas bubbles, hydroacoustic research, Baltic Sea

Depositional evolution and geohazard potential of a large gas and hydrate turbidite province in the Perdido belt, Gulf of Mexico

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Abstract

We present preliminary results from a deep-water turbidite system located in the Perdido fold and thrust belt in the northern Gulf of Mexico (GoM) (~2500 m water depth). From a basin analysis perspective, those sediments belong to Cenozoic-aged sequences, specifically the Wilcox Formation (Paleocene-Eocene) and the Frío formation (Oligocene), both associated with sea level lowstands. Within these turbidite systems, gas, oil and gas hydrate coexist in near-seafloor sediments and they are overlain by a submarine landslide.

To characterize the turbidite systems, we use a combination of geophysical (reflection seismic, well logs) and geochemical (gas chromatography) datasets. We apply eXchroma RGB seismic data processing, which significantly enhances the ability to interpret stratigraphy and lithology of complex gravitational depositional systems. A bottom simulating reflection (BSR), located ~350 m below the seafloor, potentially acts as sealing mechanism for Oligocene reservoirs. These reservoirs contain both microbial and thermogenic gas, along with other hydrocarbon phases such as oil and gas hydrates.

The submarine landslide is located within 1 km from several drilling platforms including Perdido Spar (the world's deepest offshore production facility). The landslide exhibits potential geological hazard associated with an active fault network and hydrocarbon-charged turbidites. We estimate the affected area to be ~31 km^2 and we date the slope failure to be younger than 10 ka, using the transient response of gas hydrate stability. Seismic attributes and well data indicate the presence of seafloor pockmarks aligned with a major normal fault, suggesting active fluid migration pathways and future geohazard potential.

Keywords: deep-water turbidites, gas hydrate, submarine landslide, Gulf of Mexico, channel deposition

Evidence for gas hydrate-filled fractures at the sulfate-methane transition zone

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Abstract

Using X-ray Computed Tomography (X-CT) of shallow sediment cores from the IODP Expedition 372 in the Hikurangi Margin, we have identified a network of near vertical, low-density structures that we argue are relics of gas hydrate filled fractures. These fractures occur at 17 mbsf, near the sulfate-methane transition zone (SMTZ). These fractures are open, with fracture widths ranging from 0.5 to 5 mm and lengths ranging between 7 and 60 mm. The fractures have high dip angles and diffuse, wispy boundaries. We propose that these relic fractures represent early-stage hydrate formation in shallow fine-grained sediments, where hydrate forms in secondary pore space. Additionally, we hypothesize that as microbial methane production increases with depth, the fractures will propagate into longer fractures to accommodate more hydrate formation.

We identify similar fractures in the Japan Trench and the Gulf of Mexico, which support the hypothesis that shallow hydrate-filled fractures may be widespread but remain underreported due to limited X-CT imaging of shallow sediment intervals. Shallow, gas hydrate within fractures could result in rapid methane transport to the seafloor if dissociated, having implications for climate sensitive environments. Expanding the application of X-CT scanning to shallow sediment cores, particularly across and below the SMTZ, is crucial to improving detection and understanding of near-seafloor hydrate systems and their potential environmental impacts.

Keywords: gas Hydrate, fractures, sulfate-methane transition zone, methane transport, X-ray computed tomography

Evaluation of mechanical and physical characteristics of aquatic muds by geotechnical methods, for assessment of methane bubble descriptor

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Abstract

The physical and mechanical characteristics of gas-free aquatic muds govern methane bubble descriptors such as size, shape, and orientation. This study quantifies these characteristics in Lake Kinneret (Israel) muds using two gravity cores (A and B) collected at 27.5 m and 33 m water depths along the northwestern transect on March 23, 2025. The cores were sectioned at 5 cm intervals, and total density, water content, Atterberg limits, and undrained shear strength were measured. From these indices, we derived undrained Young's modulus, small-strain shear modulus, and Mode I fracture toughness. Stiffness parameters were estimated from Atterberg limits, while fracture toughness was obtained from correlations with shear strength. Depth-dependent shear strength was measured and numerically estimated, both showing an increasing trend with depth and maximum values of 1.8 kPa (core A at 1.55 m) and 1.6 kPa (core B at 1.75 m). Good agreement between measured and estimated values supports the applied approach. The suspension-sediment interface was identified from density transitions (core A: density is 1.28 g/cm^3 at 0.675 m; core B: density is 1.27 g/cm^3 at 0.775 m). Dynamic Young's modulus, evaluated from ultrasonic P-wave velocities, produced irregular results attributed to voids and cracks in intact cores, emphasizing the need for repeated testing on remolded, homogenized samples. Overall, our findings show that Atterberg limits and geotechnical indices provide an effective framework for predicting small-strain stiffness and fracture properties of aquatic muds, offering essential input for improved quantification of methane bubble descriptors in acoustic models.

Keywords: methane bubble descriptors, muddy sediment elastic properties, geotechnical indices, geoacoustic modeling, Lake Kinneret

Gas dynamics and geophysical monitoring in marine sediments: insights from methane hydrates, CO_2 venting, and pulse tube experiments

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Abstract

Gas bubble dynamics in marine sediments, involving methane (CH_4) and carbon dioxide (CO_2), influence both natural geohazards and engineered subseafloor applications. Experimental and modelling studies now provide new insights into methane bubble behaviour, hydrate formation, geophysical property evolution, and CO_2 leakage impacts. High-resolution synchrotron X-ray computed tomography of methane hydrate formation in water-saturated sand captured bubble evolution through distinct stages of nucleation, break-up, and coalescence, while quantifying hydrate film growth. Neural network–based segmentation further highlighted the dynamic interplay between methane bubbles and hydrate development, showing non-monotonic changes in bubble size. Complementary laboratory core experiments with acoustic and ultrasonic measurements revealed how hydrate morphology modifies geophysical properties. Bubble resonance modelling demonstrated that evolving bubble populations strongly influence sediment geophysical responses, linking microscale bubble dynamics to effective medium rock physics models and field-relevant observations. These results quantified the impact of hydrate morphology on velocity and attenuation, providing direct connections between pore-scale processes and macroscopic geophysical signatures.

Core-scale investigations of CO_2 venting in North Sea sediments identified systematic changes in elastic and transport properties during CO_2 flow. These measurements improved leakage detection sensitivity and supported the calibration of rock-physics models for saturation estimation.

Together, these studies integrate CH_4 and CO_2 processes across pore to core scales, connecting microscopic gas–hydrate interactions, bubble resonance, and experimental observations with macroscopic geophysical monitoring. The findings advance understanding of gas–sediment interactions, with implications for geohazard assessment, offshore infrastructure stability, and secure carbon storage strategies.

Keywords: gas bubble resonance, methane hydrate, bubble film, effective medium modelling, pulse tube