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Editorial: The lifetime of methane bubbles through sediment and water column

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Editorial on the Research Topic
The lifetime of methane bubbles through sediment and water column

Gassy sediments of inland waters and oceans are abundant over the Earth. They host methane (CH_4), a potent greenhouse gas with a warming potential 27 times greater than CO_2 over a 100-years time span, whose concentration in the atmosphere has been rising by 1% per year over the last century (Forster et al., 2021).

CH_4 bubbles are discrete bodies of immiscible gas in a surrounding medium (Boudreau, 2012). Their lifetime starts from nucleation under supersaturated conditions in sediment and proceeds by their growth and subsequent migration in sediment and water column driven by buoyancy. The bubbles are diffusion-fed from the surrounding field of dissolved CH_4 in sediment fuelled by microbial or thermogenic decomposition of organic matter, or by gas hydrate dissociation (Kvenvolden, 1988; Martens et al., 1998; Boudreau, 2012).

CH_4 bubble presence affects the structural integrity, load-bearing capabilities, and effective physical and mechanical properties of sediments (Wheeler, 1990). They are a source of a permanent concern due to their potential destabilization of coastal and aquatic infrastructure.

CH_4 emission from the aquatic sediments to the water column is often dominated by ebullition. CH_4 bubble pathways and thus carbon fluxes from the aquatic sediments into the water column are highly variable in time and space, suggesting their dependence on the ambient conditions: e.g., changing hydrostatic and even atmospheric pressure, temperature or particulate matter flux to sediment, which become increasingly important in the context of global warming and sea level rise. Gaseous CH_4 often liberates *via* spatially distributed small- and large-scale outlets: seeps, vents, mud volcanoes, and pockmarks, serving as hot spots of CH_4 emission. However, there is a large uncertainty in the emission estimates.

Despite the growing knowledge, there are still fundamental open questions regarding all aspects of the bubble lifecycle. The thirteen papers comprising this Research Topic reflect the interdisciplinary nature of research on CH_4 bubble evolution in sediments and in the water column of inland waters and oceans. The contributions provide novel research results and methods for understanding the relevant processes, their temporal dynamics and spatial variability across different scales of the system. The order of the articles below follows the bubble lifecycle sequence.

Carty and Daigle studied the changes in geomechanical properties of the seafloor sediment in response to methane hydrate dissociation. Using a statistical model, they estimated organic carbon content in sediments along the U.S. Atlantic margin and used a one-dimensional sediment burial and methanogenesis model to simulate hydrate and gas formation at selected locations over a 120,000 years glacial cycle. In drained sediments, no failure was found to occur during hydrate dissociation. However, in undrained sediments, the criterion for shear failure is quickly met, even with low (e.g., between 0.2% and 1%) hydrate concentrations.

Madhusudhan et al. explore methane hydrate formation from CH_4 gas in water saturated sand by high-resolution synchrotron imaging. Hydrate develops at the outer bubble surface, which leads to a reduction in bubble size, bubble connectivity, and in origination of nano- to micro-sized bubbles. Effective medium rock physics modelling including a resonance effect shows that using an actual bubble size distribution rather than the uniform bubble size of the equivalent gas volume, produces more accurate geophysical gas estimates.

Painuly and Katsman studied a CH_4 bubble growth mechanism under the wave action, using a single-bubble mechanical/solute transport numerical model. Early and multiple sediment fracturing by the growing bubble manifested themselves at reduced overburden loads at wave troughs, amplified at shallow water depth. Bubbles matured in a shorter time in presence of waves, controlled by a larger wave amplitude to equilibrium water depth ratio and by a shorted wave period.

Marcon et al. (a) characterized spatio-temporal pattern in sediment gas content and its controls in a drinking water reservoir in Brazil. They used echo-sounding surveys to characterize the gassy sediment, and acoustic methodology for ebullition measurements in the water column. Correlations of sediment gas content with water depth, sediment thickness, and organic matter content were best reproduced by a trained artificial neural network model. The largest gas content was found in the shallower upstream part of the reservoir, accompanied by highest and continuous ebullition rates. In the deeper downstream part, elevated above the average gas content and intermittent ebullition dynamics were observed.

Yatsuk et al. report results of gas geochemical studies of seafloor sediments of the East Siberian Sea from three expeditions (2008, 2016, 2020). Increased concentrations of CH_4 and hydrocarbon gases encountered at some stations indicate a predominance of thermogenically derived gases. The stable isotopic composition of carbon was determined for CH_4, C_2H_6, and CO_2 in gases desorbed from marine sediments. The suggested hydrocarbon classification system outlines eight regional gas sources.

Rovere et al. describe their finding of dozens of flares in the southeastern Tyrranian Sea, originating in a hybrid volcanic-sedimentary basin. CH_4 and CO_2 release corresponds to areas of subsurface doming and diapirism that could be related to seafloor hydrothermal vent complexes fed by igneous intrusions. Their results indicate that magmatic activity has been the main driver of fluid flow in this area.

Silva et al. investigated the oil and gas release from a destroyed oil platform in the Gulf of Mexico. Atmospheric CH_4 measurements above the plumes revealed a ~6 times greater concentration than baseline. After installation of a containment device preventing oil release, the measurements showed only slightly elevated CH_4 concentrations although bubbles were still observed to rise. Oil was suggested as a greater source of CH_4 to the atmosphere than associated gas bubbles.

The study by Marcon et al. (b) focusses on gas emission variability using continuous long-term sonar monitoring offshore Vancouver Island. The results show that the diurnal and semi-diurnal tides influence the timing of the onset and cessation of bubble emissions, but the tides do not seem to modulate the vigor of the active gas emissions.

Turco et al. present a quantitative assessment of total CH_4 release on the Hikurangi Margin, off New Zealand. Using a split beam echosounder, the CH_4 fluxes at five seep sites releasing CH_4 bubbles were estimated at 8.66 and 27.21 kg $\times 10^6$ kg of CH_4 per year. The results were extrapolated on an existing gas seep database and reveal between 2.7×10^8 and 9.32 kg $\times 10^8$ kg of CH_4 released into the water column at the Hikurangi Margin each year.

Zhao et al. analysed continuous, high-frequency ebullition time series from a boreal pit lake during the open-water season. 22 out of the 24 ebullition events that were observed during the 4-month period occurred during low atmospheric pressure. The authors provide empirical equations that incorporate a pressure threshold to model the time-series of ebullition events and demonstrate good agreement between the observed and predicted ebullition fluxes.

Riedel et al. provide a synthesis of the research conducted over 20 years at a highly investigated seep area at Barkley Canyon, offshore Vancouver Island, characterized by thermogenic gas seepage and Structure II and Structure-H gas hydrate mounds. This site is situated on a remnant of a rotated fault block that had slipped off the canyon wall, and the location of the gas hydrate mounds is controlled by a combination of fault-focused fluid migration from a deeper reservoir and fluid seepage along more permeable strata within the rotated slope block.

Veloso-Alarcón et al. calibrated lander-based hydroacoustic measurements of bubble flow rates using optical information and investigated the spatial and temporal variability of gas flow rates at a seep area offshore Oregon, United States. Optical measurements were obtained from a stereo camera and provided information on bubble size distributions and rising speeds, to quantify bubble flow rates within the ensonified area of a horizontally oriented multibeam echo sounder (~1700 m^2). The explored bubble streams revealed a modulation of the gas flux by near-bottom-currents associated with the tidal regime.

Snyder et al. report on gas plumes in the Tartar Strait, northernmost Japan Sea, and analysed their interaction with water masses and the degree of their contribution to greenhouse gas emissions. Their results point on a key role of the Amur River discharge in determining shallow, subsurface and even intermediate water circulation in the Tatar Strait. The atmospheric CH_4 fluxes demonstrated no enrichment compared to a reference site estimated in 2019, while fluxes above the plumes were much higher in 2015.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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