Methane and possible gas hydrates in the Disko Bugt region, central West Greenland

Naja Mikkelsen, Troels Laier, Tove Nielsen, Antoon Kuijpers and Niels Nørgaard-Pedersen

Current climate models predict an annual temperature increase in the Arctic between 4° and 6°C by the end of the 21st century with widespread impact on the Arctic environment. Warming will lead to thawing of the widespread, permanently frozen, high-latitude peat-lands and to degradation of marine gas hydrates, both of which may increase the rate of methane release to the atmosphere. This will influence global climate as methane is a potent greenhouse gas with a large global warming potential. Marine gas hydrates are found worldwide on continental margins and frequently occur in the Arctic. Interpretation of seismic profiles has also indicated their presence in the Disko Bugt region in western Greenland.

In June 2011 a scientific cruise was undertaken in the Disko Bugt region (Fig. 1) to investigate the occurrence of methane and possible gas hydrates in the region. The cruise was part of a multidisciplinary scientific project *Impact on permafrost, gas hydrates and periglacial processes following climate changes in Greenland (Permagas)*. The project studies the impact of global climate warming on permafrost and gas hydrates in the Disko Bugt region. The aim of the project is to link marine and terrestrial occurrences of gas emissions.

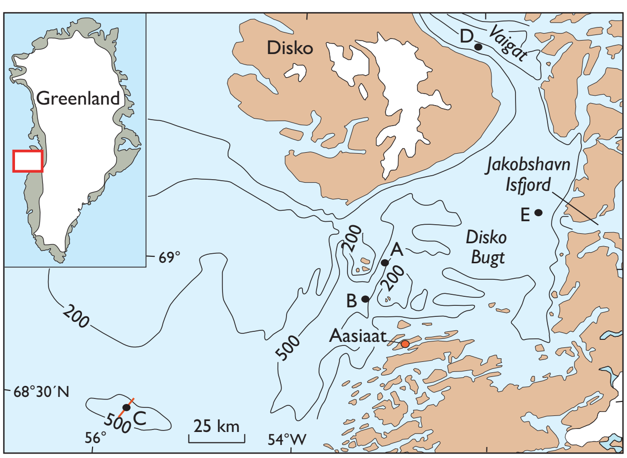

Fig. 1. Map of the Disko Bugt region. The black dots show core sites in Egedesminde Dyb (A, B), on the shelf off Aasiaat (C), in southern Vaigat (D) and off Jakobshavn Isfjord (E). Methane was encountered at sediment sites A and B, and traces of methane occurred at site C. At sites D and E, where pockmarks have been mapped during previous surveys, evidence of upwelling freshwater was found. Contours: 100, 200 and 500 m. The red line that crosses the core location at site C shows the position of the seismic profile in Fig. 3.

Marine gas hydrates

Gas hydrate is a crystalline solid consisting of gas molecules, usually methane, with each gas molecule surrounded by a frame of water molecules. Marine gas hydrates form under high pressure and low temperature in sediments below the seabed (Fig. 2). Depending on the bottom water temperature methane hydrate is typically stable in sea-floor sediments on the continental slope, but in high-latitude regions with low bottom water temperatures, the top of the gas hydrate stability zone may occur at shallower depths.

Gas hydrates are a potential energy resource as well as a potential risk for geohazards and the safe exploitation of sea bed resources (Kvenvolden & Rogers 2005). The worldwide amount of carbon bound in gas hydrates is conservatively estimated to total twice the amount of carbon found in all

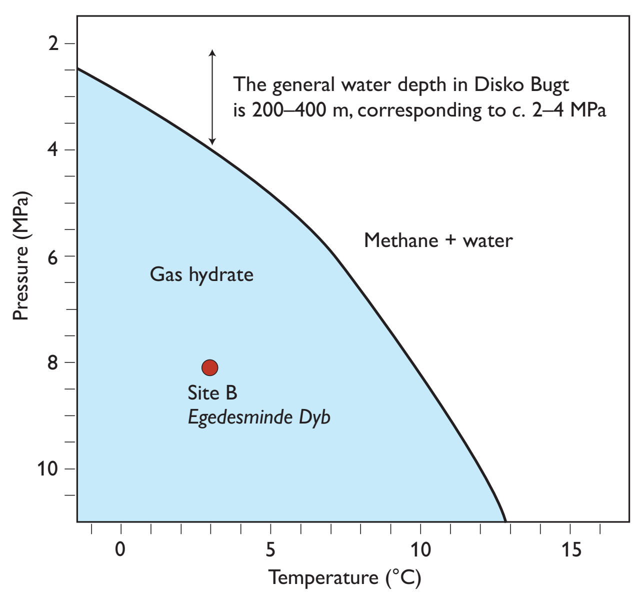

Fig. 2. Phase diagram showing the boundary between free methane (no colour) and gas hydrate (blue).

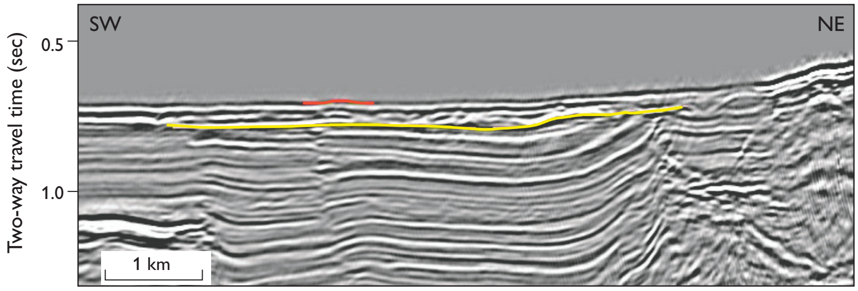

Fig. 3. Reflection seismic profile from site C (Fig. 1). The bottom-simulating reflector (yellow) at 75 msec two-way travel time below the seabed may indicate the occurrence of an up to 70 m thick gas hydrate zone. Pockmarks and seabed mounds (red) overlying faults in the shallow sub-seabed unit may be caused by seepage of free gas from beneath the gas hydrate zone. The seismic profile is part of released data acquired for the company Nunaoil in 1998.

known fossil fuels on Earth, and methane bound in hydrates amounts to approximately 3000 times the volume of methane in the atmosphere. In a warming world, methane from the dissociation of large and dynamic gas hydrate reservoirs therefore has the potential to influence oceanic and atmospheric carbon pools and thus influence global climate.

Gas hydrate may be recognised on seismic profiles by the presence of a so-called bottom-simulating reflector that marks the base of the gas hydrate stability zone (MacKay *et al.* 1994). The reflector is caused by the impedance contrast between the solid gas hydrate layer and free gas accumulations beneath. However, bottom-simulating reflectors are also found in areas without gas hydrates.

The Disko Bugt region

Since the discovery of extensive oil seeps north of Disko in 1992 (Christiansen *et al.* 1996), marine geologists' interest in the Disko Bugt region has increased significantly. However, little is known about the possible existence of gas hydrates on the continental margin, offshore West Greenland. The presence of pockmarks in Disko Bugt (Weinrebe *et al.* 2008) provides evidence of upwelling gas or fluid from the sea bottom. The bottom water temperature is *c.* 3°C in the Disko Bugt region and gas hydrates can be expected to occur at water depths exceeding 400 m, provided that methane occurs in high concentrations. During collection of a piston core in central Disko Bugt high gas content was demonstrated by the sudden escape of large amounts of strongly expanding gas that disrupted the sediment (Kuijpers *et al.* 2001). In addition, bottom-simulating reflectors have been observed on a number of seismic profiles from the area (Fig. 3).

Material and methods

During the cruise, up to 6 m long gravity cores and up to 2 m long cores, taken with a Max Planck Institute Rumohr Lot corer, were retrieved from five sites above and within the gas hydrate stability zone. The cores were sub-sampled for analysis of sediments and pore fluids (Fig. 4; Nielsen *et al.* 2011). The sediment cores were subjected to a number of geochemi-

Fig. 4. Plastic liners with 10 cm diameter cores sampled for pore water. The samples were analysed during the cruise for concentrations of methane, sulphate and dissolved sulphide. The Rhizon samplers were inserted into pre-drilled holes in the gravity core sections and pore water extracted by applying vacuum to the sampler when pulling the syringe piston.

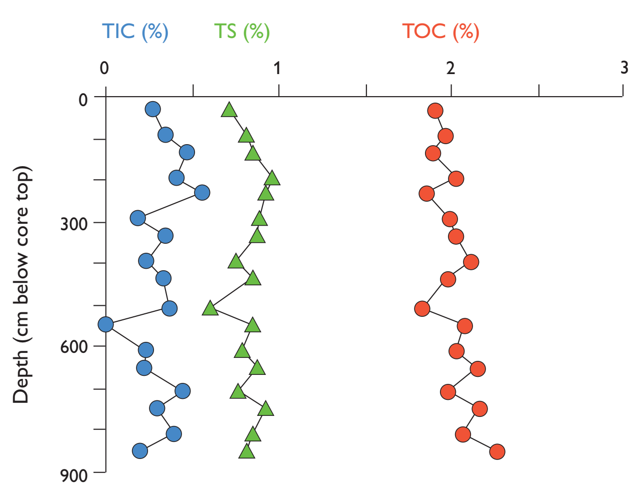

Fig. 5. Total inorganic carbon (TIC), total sulphur (TS) and total organic carbon (TOC) in a sediment core from site B in Egedesminde Dyb (after Kuijpers *et al.* 2001).

cal analyses, including measurements of methane concentrations and concentration of pore-water solutes (particularly sulphate), which aimed at providing data that could confirm the presence of gas hydrates.

Geochemical results and discussion

In the cores collected in Egedesminde Dyb at sites A and B (Fig. 1), which are situated within the gas hydrate stability zone, high pore-water methane concentrations were noted. However, the maximum methane concentration measured (*c.* 16 mM) is much below what is expected for methane saturation at 800 m depth in the Egedesminde Dyb (147 mM; Yamamoto *et al.* 1976). This is probably due to partial degassing during core retrieval. A pressure core barrel was not available during the cruise and the large drop in pressure during retrieval of the sediment cores would inevitably lead to loss of methane. Therefore it was not possible to prove the existence of small amounts of methane hydrate that may have formed as a result of *in situ* methane supersaturation. We did not observe any diagnostic features of hydrates either, such as trends in the chloride concentration or soupy sediment textures.

The methane is most likely microbial in origin and formed *in situ* as a result of organic matter degradation below the sulphate zone *c.* 0.5 m below the sea floor. This assumption is supported by the high content of organic matter in the sediment (total organic carbon = 1.9–2.3%; Fig. 5). Methane production is also promoted by the relatively high sedimentation rate in the area, 0.4–0.5 cm/year at site B (Moros *et al.*

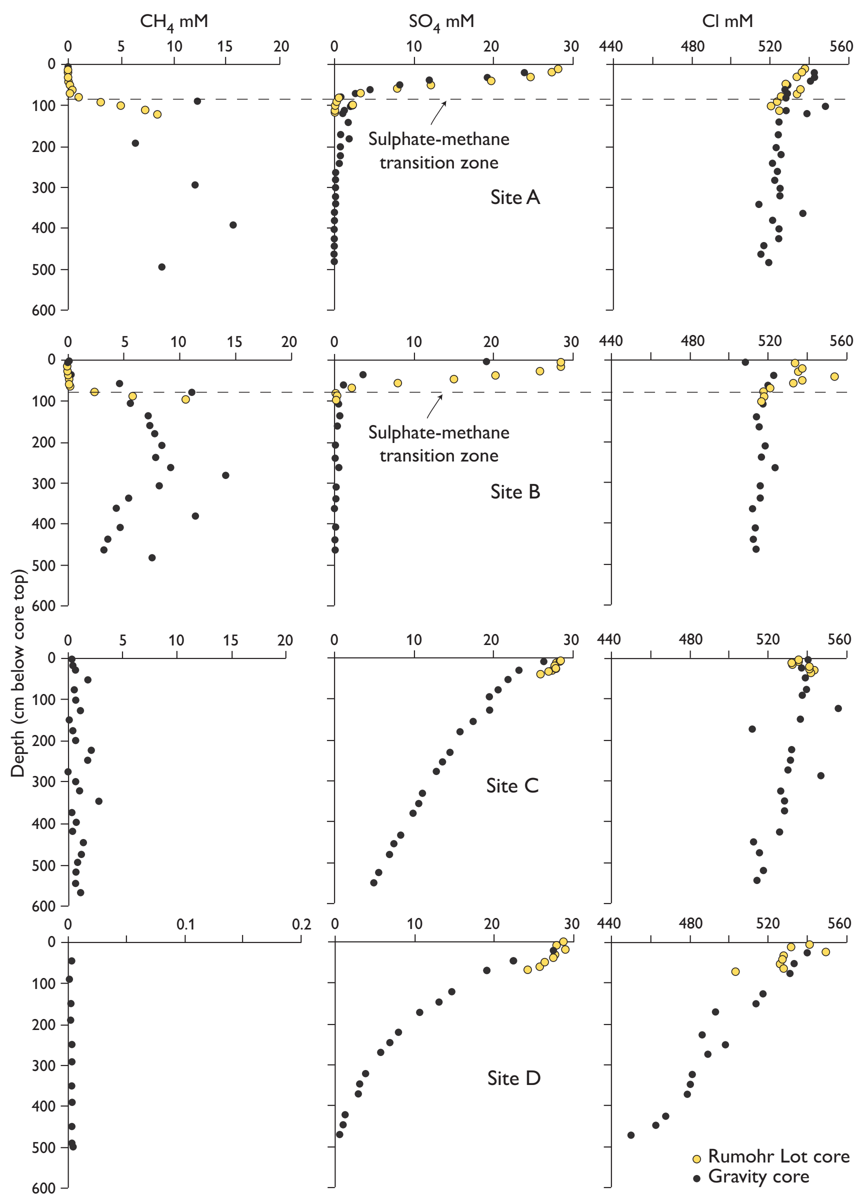

Fig. 6. Pore-water concentration profiles of dissolved methane, sulphate and chloride from sediment cores retrieved from Egedesminde Dyb (sites A (842 m) and B (865 m)), off Aasiaat (site C, 544 m) and from Vaigat (site D, 469 m). Yellow symbols: short Rumohr Lot cores, black symbols: gravity cores. Concentrations are in mM (millimoles per litre).

2006) that allows for a high proportion of easily degradable organic matter to enter the zone of methanogenesis (Henrichs & Reeburgh 1987).

At site C in the area west of Aasiaat the much lower methane concentration than at sites A and B may be explained by the high sulphate concentration (Figs 1, 6), which generally excludes the presence of methane (Iversen & Jørgensen 1985). Still the concentration of methane is significantly above background values for other sulphate pore-water concentrations in the Disko Bugt region. This may suggest upward migration of methane from gas hydrates as indicated by seismic data from the area (Fig. 3). The slight decrease in pore-water chloride concentrations with depth (Fig. 6) may further sustain the assumption of an upward migration of fluids depleted in chloride from below.

Pore-water sulphate in sediment cores from site D located in the southern end of the strait Vaigat is almost exhausted at approximately 5 m below the sea floor (Figs 1, 6). However, the low sulphate concentration is presumably not entirely due to *in situ* microbial sulphate reduction, as the decrease in pore-water chloride concentration with depth indicates a considerable contribution of freshwater from submarine groundwater discharge (Fig. 6).

Additional field work was conducted during the cruise in an area off the mouth of Jakobshavn Isfjord (site E). Pockmarks observed during an earlier multibeam survey in that area (Weinrebe *et al.* 2008) were suspected to have formed due to upward gas migration (Hovland & Svendsen 2006). However, the absence of methane together with the sediment texture observed in sediment cores from the area indicate that the pockmarks form from upwelling water and not from gas seepage.

Concluding remarks

The geochemical data obtained as a result of the 2011 cruise to the Disko Bugt region indicate that gas hydrates may occur in the region. Further investigation of the possible gas hydrates will continue during a new cruise in the area in 2012.

Acknowledgements

The 2011 cruise was supported by a grant from Geocenter Denmark to the project *Permagas*. The success of the cruise depended very much on the operational skills of the captain and crew of the R/V *Paamiut* and the smooth co-operation during the cruise with a scientific team from the Greenland Institute of Natural Resources.

References

Christiansen, F. G., Bate, K.J., Dam, G., Marcussen, C. & Pulvertaft, T.C.R. 1996: Continued geophysical and petroleum geological activities in West Greenland in 1995 and the start of onshore exploration. Bulletin Grønlands Geologiske Undersøgelse **172**, 15–21.

Henrichs, S.M. & Reeburgh, W.S. 1987: Anaerobic mineralization of marine sediments organic matter: rates and role of anaerobic processes in the oceanic carbon economy. Geomicrobiology Journal **5**, 191–237.

Hovland, M. & Svendsen, H. 2006: Submarine pingoes: indicators of shallow gas hydrates in a pockmark at Nyegga, Norwegian Sea. Marine Geology **228**, 15–23.

Iversen, N. & Jørgensen, B.B. 1985: Anaerobic methane oxidation rates at the sulphate–methane transition in marine sediments from Kattegat and Skagerrak (Denmark). Limnology Oceanography **30**, 944–955.

Kvenvolden K.A. & Rogers B.W. 2005: Gaia's breath – global methane exhalations. Marine and Petroleum Geology **22**, 579–590.

Kuijpers, A., Lloyd, J.M., Jensen, J.B., Endler, R., Moros, M., Park, L.A., Schulz, B., Jensen, K.G. & Laier, T. 2001: Late Quaternary circulation changes and sedimentation in Disko Bugt and adjacent fjords, central West Greenland. Geology of Greenland Survey Bulletin **189**, 41–47.

MacKay, M.E., Jarrard, R.D., Westbrook, G.K. & Hyndman, R.D. 1994: Origin of bottom-simulating reflectors: geophysical evidence from the Cascadia accretionary prism. Geology **22**, 459–462, *http://dx.doi.org/10.1130/0091-7613(1994)022%3C0459:OOBSRG%3E2.3.CO;2*

Moros, M., Jensen, K.G. & Kuijpers, A. 2006: Mid- to late-Holocene hydrological and climatic variability in Disko Bugt, Central West Greenland. The Holocene **16**, 357–367.

Nielsen, T., Laier, T., Mikkelsen, N. & Kristensen, J.B. 2011: Permagas project: Sampling gas hydrates in the Disko Bay area. Cruise Report – R/V Paamiut 20 to 26 June 2011. Danmarks og Grønlands Geologiske Undersøgelser Rapport **2011/105**, 40 pp.

Weinrebe, W., Kuijpers, A., Klaucke, I., Fink, M., Jensen, J.B. & Mikkelsen, N. 2008: High-resolution bathymetry of Disko Bay and Ilulissat Icefjord, West Greenland. American Geophysical Union fall meeting, San Fransisco, California, 15–19 December 2008 (Abstract C31E-0563).

Yamamoto, S., Alcauskas, J.B. & Crozier, T.E. 1976: Solubility of methane in distilled water and seawater. Journal of Chemical and Engineering Data **21**, 78–80.

Authors' address

Geological Survey of Denmark and Greenland, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark. E-mail: *nm@geus.dk*