

# Impact on permafrost, gashydrates and periglacial processes following climate changes in Greenland

Final report for the Geocenter project PERMAGAS

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## 1. Introduction

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 impacts on all aspects of the Arctic system including Arctic environment and socio-economy. More than 85% of the Arctic landscape is underlain by permanently frozen ground (permafrost) that is vulnerable to warming. Thawing has significant impact on the widespread permafrozen high-latitude peat lands and on the decomposition of marine gashydrates - both of which will significantly increase the rate of carbon dioxide and methane release to the atmosphere and thus influence global climate.

One problem in evaluating the impact of climate changes on permafrozen ground and gashydrates is a lack of long-term data series that enables a comparison of climatic variations with changes in gashydrates, permafrost and permafrost related processes. The study of permafrost and gashydrates by their very nature therefore involves both multi-disciplinary and inter-disciplinary approaches to understand and predict the energy exchanges at the Earth's frozen surfaces and to evaluate the impact of climate change on permafrost and gashydrate thawing.



## 2. Objectives

The objective of the project was to address central questions related to the impact of ongoing global climate change on permafrost and gashydrates in and around West Greenland in an attempt to link the offshore and onshore occurrences of frozen gas and ongoing methane production on land. The Permagas project has thus been a strategic initiative with the overall aim of creating a strong research group involving all partners of Geocenter Denmark and focusing on permafrost and gashydrate related topics.

The initiative also involved an important educational aspect to secure adequate education at the University in the fields of permafrost and gashydrates.

## 3. Project organisation

The project has been divided into three Work Packages (WP) covering the terrestrial environment, the marine environment and the past environment, and each WP were headed by a WP leader.

- *Project leader* Naja Mikkelsen
- *WP I: the terrestrial environment*. "Permafrost observatory at Disko: Sensitivity and feedback mechanisms of permafrost changes". WP leader Bo Elberling
- *WP II: the marine environment* : "Gashydrates and methane studies offshore Disko". WP leader Tove Nielsen
- *WP III: the past environment*: "Periglacial and permafrost related landscape-elements: a longer time scale". WP leader Svend Funder.

The original grant was awarded for the period 1. November 2010 – 31. October 2012. Due to a significant grant from Dansk Center for Havforskning a second marine geological cruise was undertaken by WP II, which led to a one year extension of the project in order to enable the processing of the collected material. The one year extension of the project was granted by the Geocenter Board of Directors.



## 4. Results – a brief account

The overall goals of the project have been fulfilled – both scientifically and from an educational point of view, and three conclusions may be highlighted:

WP I: Landscape-integrated measured methane uptake rates at dry tundra offsets methane release from wetlands.

WP II: Marine gas hydrates has for the first time ever been recognized offshore West Greenland, and the stability of the gas hydrates is going to be highly affected by the increasing global temperatures.

WP III: Lake cores from the island of Disko indicate a depositional history that may involve tectonic instability and gas seepage in the area.

### ***WP I: Permafrost observatory at Disko: Sensitivity and feedback mechanisms of permafrost changes***

The objective of the work package was

- to characterise the spatial variability of permafrost history and biogeochemical features within the upper 4-5 meters of the permafrost-active layer system across contrasting sites at different landscape types at Disko
- to characterize permafrost layers in terms of sediment or bedrock type, element stocks, ice content and ages
- to analyse the short and long-term potential and actual subsurface CO<sub>2</sub> and CH<sub>4</sub> production in relation to permafrost degradation and the associated changes in availability of microbes, substrate, nutrients, water and oxygen.

The Field work has been centered around four tasks: 1. Coring, sampling and pedogenetic description of arctic and permafrost soils as well as the landscape geomorphology at selected

sites at Disko. 2. Monitoring active-layer and permafrost temperatures, 3. In-situ chamber measurements for CH<sub>4</sub> emissions to the atmosphere, 4. Analysis of soil and permafrost samples and incubation experiments for short- and long-term potential mineralization rates (CO<sub>2</sub> and CH<sub>4</sub> production).

These investigations have resulted in the presentation of a summer 2011 CH<sub>4</sub> budget is for a young Arctic landscape on Disko Island, Greenland where *in situ* CH<sub>4</sub> fluxes were combined with laboratory studies of CH<sub>4</sub> production and consumption for upland and wetland soils. Soil types were identified by plant community composition using a satellite image. *In situ* CH<sub>4</sub> fluxes were scaled to landscape level to assess the contributions of upland and wetlands.



A portable, high-precision gas analyzer was used and the quality of CH<sub>4</sub> flux chamber measurements were improved compared to conventional methods. This allowed consistent measures of both CH<sub>4</sub> emissions from wetland soils and CH<sub>4</sub> uptake from well-drained tundra soils. The average CH<sub>4</sub> fluxes were -1.6 and 5.2 mg m<sup>-2</sup>d<sup>-1</sup> for uplands and wetlands, respectively. Upland soils comprised more than 85% of the study area, compared to 10% of wetlands.

Scaled CH<sub>4</sub> fluxes showed that the landscape was a net sink of -24 kg CH<sub>4</sub> d<sup>-1</sup> during the study period. Incubation studies showed that uplands had lower CH<sub>4</sub> oxidation capacity than wetlands. In line with field observations, wetlands produced more CH<sub>4</sub> than upland soils, but rates dropped sharply with depth and were low in permafrost layers.

The findings of WPI show that CH<sub>4</sub> uptake in drier Arctic soils may offset emissions from wetlands. This young landscape has little potential for CH<sub>4</sub> production due to limited carbon accumulation in the soil. The precision of CH<sub>4</sub> flux measurements at low flux levels will enable monitoring of CH<sub>4</sub> uptake in drier Arctic ecosystems. This will increase our knowledge of their importance for CH<sub>4</sub> inventories and response to environmental change.





A separate investigation was undertaken on Disko by GEUS on the pools of organic matter under different vegetation types in Qaamassoq (Flakkehuk). Soil samples were collected at Qaamassoq from several depths below areas with different types of vegetation and analyzed for the total content of organic matter determined by loss of ignition, hot water extractable carbon and hot water extractable carbon. The latter methods provide knowledge of the composition of the organic matter. The results for the soil samples collected below crowberry, birch, and heather is given in Figure 1. The contents of all three carbon pools are higher in the upper 10-15 cm compared with pools in deeper depths. Maximum concentrations were measured in the near-surface layer below crowberry. The two water-extractable pools represent only small amounts of the total pool of organic matter. The results contribute to our understanding of carbon dynamics under Arctic conditions in a changing climate where the type of vegetation and the pools of organic matter may change.



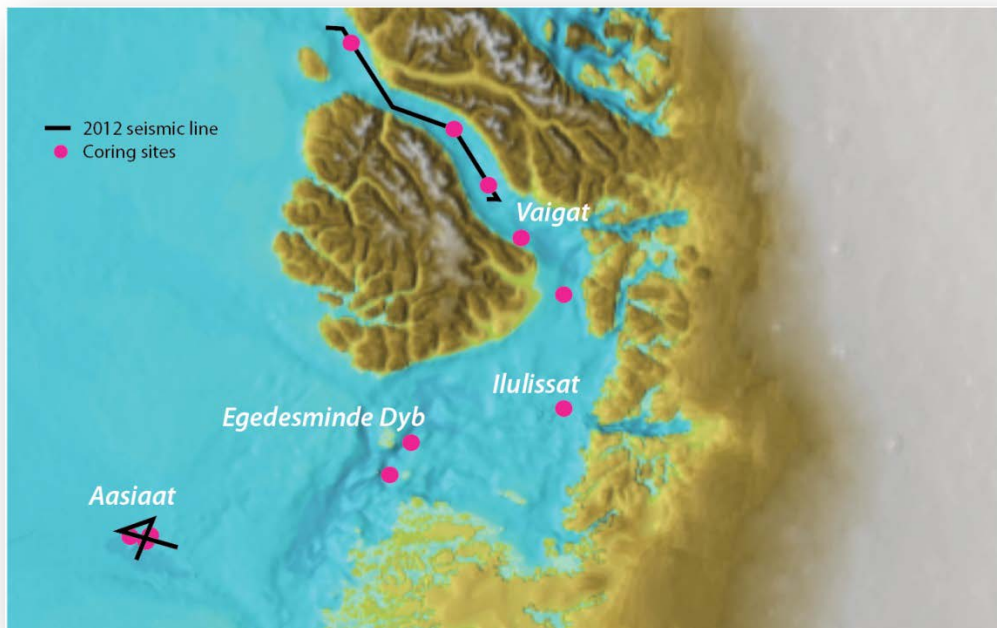


## **WP II: Gashydrates and methane studies offshore Disko**

The objectives of WP II were

- to compile and re-examine existing data in order to locate possible occurrence of methane and gashydrates in the offshore Disko Bugt area,
- to verify these findings through marine-geological fieldwork.

A three phase study strategy was applied in order to meet these objectives, i.e. an initial desk study based on existing data, followed by new data acquisition and subsequent post-cruise laboratory work and interpretation of the new material.



The desk study resulted in establishment of a project database containing existing seismic and acoustic data, bathymetry and oceanographic data, sediment cores and seabed samples, reports and published papers. Examination of these data revealed four sites within the Disko Bugt study area that shows evidence for possible presence of gashydrates or gas/fluid escape structures. The four sites were informally termed the Aasiaat, Vaigat, Ilulissat and Egedesminde Dyb sites.

New data were acquired during two marine-geological cruises with the Greenlandic research vessel R/V Pamiut in 2011 and 2012. The 2011 cruise was fully covered by the Permagas funds, while cost for the 2012 cruise was applied for and granted by 'Dansk Center for Havforskning'. Both cruises were very successful and all four pre-selected study sites were surveyed. In total, 10 seismic lines, 25 gravity cores, 31 Remohrlog cores and 1 CTD cast were acquired during 12 days fieldwork.

Post-cruise work was mainly concentrated on the sediment cores, which were sampled for various geochemical laboratory analyses, logged for lithology and magnetic susceptibility and sub-sampled for age dating. The seismic data, which were processed onboard during the cruise, were interpreted and correlated with pre-existing acoustic data and the results from the new sediment core investigations.



Integration of all old and new data has resulted in a new insight into the occurrence and nature of methane and gashydrate in the offshore Disko Bugt area. The echo sounder recordings proved the occurrence of pockmarks and flares in the eastern part of the study area. Sediment cores and geochemical data from this area, however, provide evidence for fluids instead of gas having led to the pockmark formation. Central in the study area, the 840 m deep Egedesminde Dyb might contain gashydrate but no free gas due to the limited thickness of the sediment layer. In the northern part of the study area, i.e. the Vaigat, the shallow seismic data show subbottom acoustic blanking, chimney structures, and pingo-like seabed features, and the echo sound records revealed the presence of flares, all pointing to active gas seepages. Sediment cores from here showed cracks and bubbles while opened indicating the occurrence of gas. At the southwestern entrance of Disko Bugt, the shallow seismic data showed acoustic turbulence and chimney structures, and the geochemical data point to the presences of upward migration of deeper-sourced gas. A deeper seismic record from the area suggests the presence of a Bottom Simulating Reflector (BSR) at c. 75 m subbottom depth.

Modeling of the occurrence and stability of gashydrates in the Disko Bugt area was undertaken as a Master thesis project. The modeling was based on all collected data from the two marine geological cruises and it showed that gas hydrate is present within the study area and the stability of gas hydrates is going to be highly affected by the increasing global temperatures.



### **WP III: Periglacial and permafrost related landscape-elements: a longer time scale**

WP III comprised two different tasks aiming at

- providing general environmental background and a longer time horizon for climatic change in the area by detailed mapping of periglacial and permafrost related landscape-elements in the Avfarssuaq valley – an area known for its gas-seepages
- undertaking sediment coring in lakes to provide a climatic and environmental history of the area.

The first task, field work in the Avfarssuaq valley, was not possible, because of logistic difficulties. It was instead decided to concentrate on the second objective, where logistics on the Disko Island could be shared with WP I. Lake sediment cores were therefore retrieved from the lake Saningassup tasia (“Morænesø”) not far from the Arctic Station in Qeqertarsuaq. Owing to its proximity to the station, this lake is fairly easy to reach with equipment, and has already a research-history: The lake was cored in 1980-81 (unpublished), and is presently being monitored as part of the Arctic Station’s monitoring program. Its history is therefore of wider interest. Surprisingly the results show that this lake has had a turbulent and unusually complex history, and investigations for possible reasons for this are continued and may have a bearing on gas seepage and tectonic instability.





In lieu of the lacking remote sensing data WP III project members will continue after the closure of the Permagas Project to look into obtaining high-resolution multispectral satellite imagery from collaborators in Denmark. If successful, members from WPI1 and WP III will resume efforts to develop a classification using this imagery combined with ground control data obtained during the field work in 2011.

After detailed echo sounding of Morænesø's bathymetry, cores were taken from three locations in the lake. This was done between July 1<sup>st</sup> and 18<sup>th</sup> 2011 in cooperation with WP I. To provide an age model for the cores 16 AMS C14 dates have been obtained from the most promising core and a record of environmental change was obtained through XRF scanning as well as analyses of changes in bulk density, water content, organic matter and carbonates. This part of the project was managed by WP I-participants.

The results show that the lake originated as a small embayment from Disko Bugt, and became isolated as a lake by isostatic emergence c. 10,000 years ago. With its moderate size (c. 400 x 200 m), its moderate drainage area, its gentle in- and outflow, and its even and vegetated surroundings, the lake should under normal circumstances hold a long continuous record of organic sediment going back to its origin. Surprisingly however, none of the many cores obtained from all parts of the basin give a continuous record from this time: the C14 dates, sudden jumps in sediment chemistry, and pollen analysis all show that on several occasions sediment - covering up to 4000 years of sedimentation - has been removed from the lake bottom, and apparently disappeared through the outflow.

The WP III members continue their work in order to try find the cause of this abnormal behavior, which as a working hypothesis, may owe to tectonic instability and gas seepage in the area, thus adding new and unexpected aspects to the Permagas studies in the Disko Bugt area.

## 5. Educational aspects

The following students have successfully completed their Master thesis program based on Permagas material:

- Alejandro Jose Barrera Romero, November 2012.
- Niels Jakob Bruun Kristensen, November 2013
- Louise Kristine Berg, November 2013:



## 6. Additional funding

After the successful marine geological cruise in 2011 onboard R/V 'Paamiut' from Naturinstituttet in Nuuk, it was decided to apply 'Dansk Center for Havforskning' (DCH) for an additional cruise the following year. DCH generously granted 997.800 DKr which enabled WP11 to undertake a successful cruise in 2012 with R/V EU 'Paamiut'.

Also the COST Action ES0902 'PERGAMON' has provided supplementary funds for the Permagas project by facilitating XRF core analyses at the Royal Netherlands Institute for Sea Research, Texel.

## 7. Concluding remarks and acknowledgements

The grant given to the Geocenter project “Impact on permafrost, gashydrates and periglacial processes following climate changes in Greenland ” has successfully completed all tasks outline in the proposal.

The project group therefore wants to extend to the Geocenter Board of Directors their gratitude for the project award.

## 8. Publications and Outreach

### 8.1. Scientific publications

Jesper Riis Christiansen; Christian Juncher Jørgensen, Louise Kristine Berg, Alejandro Barrera Romero, Bo Elberling: 2013: CH<sub>4</sub> uptake in young arctic soils in Greenland offsets hot spot emissions from wetlands. MS (in prep)

Nielsen,T, Laier,T, Kuijpers,A, Mikkelsen,N., Nørgaard-Pedersen,N & Rasmussen,T.L.2013. A search for gashydrates in the Disko Bugt area offshore central West Greenland. Submitted to Geo-Marine Letters. Geological Research.

Mikkelsen N, Laier T., Nielsen T., Kuijpers A., and Nørgaard-Pedersen N 2012: Methane and possible gas hydrates in the Disko Bugt region, central West Greenland. Geological Survey of Denmark and Greenland Bulletin 26, 69–73.

### 8.2. Oral and poster presentations

Laier, T, Nielsen, T, Kuijpers, A, Nørgaard-Pedersen,N, & Mikkelsen, N. 2013: Gas hydrate on the West Greenland shelf indicated by BSR and shallow sub-seafloor study. Pergamon Symposium. Geomar, Germany. November 2013.

Mikkelsen, N.; J. B. Kristensen; Laier, T.; Nielsen, T.; Kuijpers, A.; Nørgaard-Pedersen, N. Kristensen, J.B. 2013. Methane and possible gas hydrates offshore central West Greenland. Poster med Abstract. 17. Dansk Havforskermøde Abstract p. 128

Mikkelsen, N. Kristensen, J.B, Kuijpers, A.; Lair, T.; Nielsen, T., .Nørgaard -Pedersen. N: 2013. Methane, seepage structure, flares, and possible gas hydrates offshore Central West Greenland. Greenland Climate Research Center, Nuuk. Annual Meeting. November 12 – 13. 2013

Nielsen, T., Lair, T.; Mikkelsen, N.; Kuijpers A. 2012: Permagis fieldwork 2012 – the Marin part. Pergamon Science Meeting Bruxelles. November 2012.

Louise Berg, Christian J. Jørgensen and Bo Elberling 2013. CH<sub>4</sub> and CO<sub>2</sub> flux measurements at foru contrasting vegetation types at Disko West Greenland. Poster presentation; Geocenterdagen,



21.11.2013

Kristensen, J.B, Mikkelsen, N; Bjerrum, C.; Kuijpers, A., Lair, T.; Nielsen, T.; Nørgaard- Pedersen. N. 2013: Gas hydrates and methane studies offshore Disko. Poster presentation; Geocenterdagen, 21.11.2013

Ulla Kokfelt, Svend Funder, Kamilla Tibian, Bo Elberling, Niels J. Korsgaard 2013: Missing sediments of a lake on Disko – evidence of tectonic earthquakes and gas seepage? . Poster presentation; Geocenterdagen, 21.11.2013

### **8.3. Reports**

Nielsen, T, Laier, T. Mikkelsen, N. og Kristensen, J. Bruhn: 2011: Permagas project: sampling gashydrates in the Disko Bay area. Cruise report – R/V Paamiut 20<sup>th</sup> to 26<sup>th</sup> June 2011. Danmarks og Grønlands Geologiske Undersøgelse. Rapport 2011/105.

Nørgaard-Pedersen, N. 2012: Scanning analyses of sediment cores from West Greenland Disko Bay gashydrate sites. Report conc. Cost Action ES0902

Nielsen, T., Laier, T.; Rasmussen, T., Nørgaard-Pedersen, N., Szttybor, K., Hansen, E., Stolk A. & Kuijpers, A.: 2012: Surveying for gashydrates offshore Central West Greenland. Permagas Cruise report – R/V Paamiut. 9th–17 th July 2012. Danmarks og Grønlands Geologiske Undersøgelse rapport 2012/99.

Student report 2011: Methane dynamics in a permafrost landscape at Disko Island, West Greenland  
Field course 2011. University of Copenhagen. Student report, 91 pages

### **8.4. Newspaper articles**

Mikkelsen, Naja 2010: Brændende is udgør ny energikilde. Sermitisaq, 50, p. 31

Mikkelsen, Naja 2011: Biologer og geologer på togt med "Paamiut", Sermitisaq 30, 2011, s. 26-27

### **8.5. TV and radio interviews**

Landskabet der prutter. En undervisnings- og TV dokumentar om hvad der sker når permafrosten tør. Chibal Film. DR

### **8.6. Master thesis reports**

Alejandro Jose Barrera Romero 2012. Gas production and genetic analysis of methane-cycling communities in permafrost. Master Thesis - November 2012

Niels Jakob Bruun Kristensen, 2013: Gas hydrate stability, formation and distribution within the Disko Bay area, West Greenland. Master Thesis - November 2013

Louise Kristine Berg 2013: Spatial variation of CH<sub>4</sub> production and consumption- a snapshot from a young arctic landscape system, Disko, West Greenland. Master Thesis. November 2013