Oil & Natural Gas Technology

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Quarterly Research Performance

Progress Report (Period Ending 12/31/2017)

Project Title

Assessing the response of methane hydrates to environmental change at the Svalbard continental margin

Project Period (11/1/2013 to 10/31/2018)

Submitted by:
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EXECUTIVE SUMMARY

In November 2013, Oregon State University initiated the project entitled: **Assessing the response of methane hydrates to environmental change at the Svalbard continental margin**. In this project, we will take advantage of a unique opportunity to collect samples from the Svalbard continental margin. The overall objective of this research is to constrain the biogeochemical response of the gas hydrate system on the Svalbard margin to environmental change. Because of a delay in the planned expedition, we reconfigured the program based on discussions with NETL program managers and submitted a revised SOPO. In the new plan, we collected samples in six expeditions: RV Helmer Hanssen, Oct., 2014; RV Helmer Hanssen, May, 2015; RV Heincke, July-August 2015 and August-Sept, 2015; RV Helmer Hanssen, June 2016, and MeBo drilling expedition in August-September, 2016.

The very productive outcome of this collaboration is evidenced on six papers published in highly ranked journals, with 2 more in preparation; two articles in the Fire in the Ice magazine; and more than 15 presentations at science conferences and meetings.

PROGRESS, RESULTS, AND DISCUSSION

1. Water column results. Water column analyses are completed and resulted in one publication in the journal "Scientific Reports" (www.nature.com/scientificreports) doi:10.1038/srep42997. And in an article in the FITI magazine (attached). These results were presented at two international conferences: Gordon Research Conference (Galveston, March 2016) and ICGH (Denver, June 2017).

2. Geochemistry: Geochemical analyses of cores is generating lots of data to constrain fluid flow and gas hydrate formation in the margin. A first paper detailing results from the gas hydrate mounds region was published in the journal Nature Communications on 7th June 2017(http://www.nature.com/ncomms) doi: 10.1038/NCOMMS15745. These results were presented in two international conferences: Gordon Conference on Natural Gas Hydrates March, 2016; and Gas In Marine Sediments conference to be held in Tromsoe, September 2016. Follow-up on this first paper continues, data was presented presentations at Goldschmidt Conference, Paris Aug 2017, and a paper under preparation postulates seepage evolution and decoupling of water and gas transport to explain pore water chemistry at various GHMs. New results from gas transport in fractures in a seep of Vestnesa Ridge is in progress, with preliminary results being presented in the upcoming EGU general assembly 2018 (abstract attached).

3. Data integration/synthesis for the Vestnesa seeps. Based on collaborations with Norwegian colleagues, a synthesis of the data collected during various cruises to the Vestnesa Ridge, were integrated in a manuscript published in Marine Geology (Panieri et al., 2017. This synthesis include results from the CAGE15-5 expedition in which I participated, and which was highlighted in a FITI article in 2015.

4. MSM57 expedition (29 July-07 September, 2016). Sample and data analyses from drilling expedition using the MeBo seafloor drill are underway. Results from samples offshore Prinz Karl Forland were presented at the ICGH in 2017, an a manuscript is now published in Nature Communications. Sediment cores drilled off Prinz Karls Foreland contain freshwater from dissociating hydrates. However, our modeling indicates that the observed pore water freshening began around 8 ka BP when the rate of isostatic uplift outpaced eustatic sea-level rise. The resultant local shallowing and lowering of hydrostatic pressure forced gas hydrate dissociation and dissolved chloride depletions consistent with our geochemical analysis. Hence, we propose that hydrate dissociation was

triggered by postglacial isostatic rebound rather than anthropogenic warming. Gas hydrate acts as a dynamic seal that regulates methane release from deep geological reservoirs. Hydrocarbon data recovered by drilling on Vestensa Ridge, was presented at the upcoming GeoBremen2017. Since we have generated more data on the isotopic composition of carbon in aqueous and gas phases in support of a manuscript in progress.

5. Microbiology incubations: A timeseries of incubations spanning several months was carried out on sediments collected from two regions overlying methane hydrates and one methane-free reference from CAGE cruise 16-5 (June-July 2016). Preliminary results are summarized in the Appendix, and are the topic of a dissertation for doctoral candidate Scott Klasek. These results will be presented at the upcoming Ocean Sciences meeting, Portland 2018.

1. Problems or delays

No delays or problems during this quarter

Products

- Two papers published on numerical model aspects of the project. Full citations:
  Peszynska, M., Medina, F.P., Hong, W.L. and Torres, M.E., 2015. Reduced Numerical Model for Methane Hydrate Formation under Conditions of Variable Salinity. Time-Stepping Variants and Sensitivity. Computation, 4(1), p.1.

  Peszynska, M., Hong, W.L. Torres, M.E., and Kim, J-H., 2015. Methane Hydrate Formation in Ulleung Basin Under Conditions of Variable Salinity: Reduced Model and Experiments. Transport Porous Media DOI 10.1007/s11242-016-0706-y

- A paper published in Nature-Scientific Reports with water column results.
  Mau, S., Römer, M., Torres, M.E., Bussmann, I., Pape, T., Damm, E., Geprägs, P., Wintersteller, P., Hsu, C.W., Loher, M. and Bohrmann, G., 2017. Widespread methane seepage along the continental margin off Svalbard-from Bjørnøya to Kongsfjorden. Scientific Reports, 7.

- A paper published in Nature Communications on the gas hydrate mounds.
  Hong, W. L., Torres, M. E., Carroll, J., Crémière, A., Panieri, G., Yao, H., & Serov, P. (2017). Seepage from an arctic shallow marine gas hydrate reservoir is insensitive to momentary ocean warming. Nature communications, 8, 15745.10.1038/NCOMMS15745.

- A synthesis paper on Vestnesa Ridge published in Marine Geology:
  Panieri G, Bünz S, Fornari DJ, Escartin J, Serov P, Jansson P, Torres ME, Johnson JE, Hong W, Sauer S, Garcia R. An integrated view of the methane system in the pockmarks at Vestnesa Ridge, 79° N. Marine Geology. 2017 Aug 1;390:282-300.

- A paper published in Nature Communications on PKF hydrate dissociation by isostatic rebound: Wallmann K, Riedel M, Hong WL, Patton H, Hubbard A, Pape T, Hsu CW, Schmidt C, Johnson JE, Torres ME, Andreassen K. Gas hydrate dissociation off Svalbard induced by isostatic rebound rather than global warming. Nature communications. 2018 Jan 8;9(1):83.

- Abstracts submitted since the last quarterly report: Ocean Sciences meeting, Portland Feb. 2018 and the EGU General Assembly, April 2018 Vienna (attached)

ARTICLE

DOI: 10.1038/s41467-017-02550-9 OPEN

Gas hydrate dissociation off Svalbard induced by isostatic rebound rather than global warming

Klaus Wallmann[1], M. Riedel[1], W.L. Hong[2,3], H. Patton[3], A. Hubbard[3,4], T. Pape[5], C.W. Hsu[5], C. Schmidt[1], J.E. Johnson[6], M.E. Torres[7], K. Andreassen[3], C. Berndt[1] & G. Bohrmann[5]

Methane seepage from the upper continental slopes of Western Svalbard has previously been attributed to gas hydrate dissociation induced by anthropogenic warming of ambient bottom waters. Here we show that sediment cores drilled off Prins Karls Foreland contain freshwater from dissociating hydrates. However, our modeling indicates that the observed pore water freshening began around 8 ka BP when the rate of isostatic uplift outpaced eustatic sea-level rise. The resultant local shallowing and lowering of hydrostatic pressure forced gas hydrate dissociation and dissolved chloride depletions consistent with our geochemical analysis. Hence, we propose that hydrate dissociation was triggered by postglacial isostatic rebound rather than anthropogenic warming. Furthermore, we show that methane fluxes from dissociating hydrates were considerably smaller than present methane seepage rates implying that gas hydrates were not a major source of methane to the oceans, but rather acted as a dynamic seal, regulating methane release from deep geological reservoirs.

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Analysis of microbial communities in marine sediments enriched at *in situ* conditions undergoing anaerobic methane oxidation rates that vary with methane concentration and time

Scott Klasek
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Doug Bartlett

Anaerobic oxidation of methane (AOM) is a microbial process that removes the majority of methane from marine sediments before it can reach the overlying hydrosphere. AOM is mediated by anaerobic methanotrophic archaea (ANME) that currently remain uncultured. Understanding the dynamics of AOM communities may aid in characterizing spatiotemporal variation in subsurface methane emission on societally-relevant timescales (months to years).

To investigate how AOM communities change over time under different amounts of added methane, sediments were collected from Storfjordrenna, south of Svalbard (CAGE cruise 16-5), a location where increasing methane supply in the sediments has been recently confirmed. Three samples from core depths with high, low, or no methane flux were preserved anoxically and incubated in triplicate with artificial seawater media at *in situ* pressure and temperature (4 MPa, 4˚C) for 1, 4, and 8 months in batch conditions at added dissolved methane concentrations of 0, 1.5, and 5 mM.

Measured AOM rates range from 58–210 nmol g bulk sediment^{-1} day^{-1} in samples incubated with 1.5 mM CH_4, and 160–560 nmol g bulk sediment^{-1} day^{-1} in samples with 5 mM CH_4. All sediment types showed equal AOM rates at 1.5 mM CH_4, while at 5 mM CH_4, higher AOM was observed in the sediment with the highest native methane flux after 60 days ($p < 0.05$). CH_4 concentration did not affect the AOM rate of the reference sample after 240 days of incubation. A positive correlation between sulfide production and AOM rates was observed only in the seep sediment (R^2=0.52).

Microbial communities will be characterized by 16S rDNA sequencing, and enumeration of copy numbers of *mcrA* and ANME 16S genes are expected to increase with time and methane concentration. Integrating AOM rates with successional patterns in methane seep microbial communities as they are exposed to methane under *in situ* conditions is an important way to assess how they may respond to changing methane fluxes in the marine subsurface.

Fracture controlled fluid transport induced microbial activities in Vestnesa Ridge

Haoyi Yao[1], Wei-Li Hong[1, 2], Giuliana Panieri[1], Friederike Gründger[1], Marta E. Torres[3], Simone Sauer [1,2,4], Moriz F. Lehmann[5] and Helge Niemann[1,5,6]

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Fracture-controlled fluid/gas migration from deep hydrocarbon reservoirs towards the seafloor can be found at Vestnesa Ridge (Arctic Ocean, west of Svalbard, at 79°N). Vestnesa is an NW-SE trending ridge with drifted sediment featuring several pockmarks of which pockmarks 'Lunde' and 'Lomvi' are the most active ones based on acoustic flares. While large-scale fractures building pathway for fluid/gas migration are commonly observed in seismic profiles, the role of small-scale fractures/micro fractures on biogeochemical forcing in near-surface sediments is not well constrained.

Herein, we report on a rare observation of a fracture in near-surface sediments (30 cm below the seafloor, cmbsf) at the Lomvi pockmark. We visualized the fracture by rotational scanning X-ray of a multicore. Furthermore, detailed porewater geochemistry and lipid biomarker investigations from three cores recovered from the Lunde and Lomvi pockmarks provide first-hand evidence of interactions between fluid/gas transport and biogeochemical processes in near-surface sediments.

The investigated sediment cores (fractured vs non-fractured) revealed different geochemical and biogeochemical characteristics reflecting different stages/modes of fluid and methane transport. At Lunde pockmarks, we found relatively low concentrations of non-depleted DIC (~-5 to 20‰), and low contents of methanotropic lipid biomarkers indicating mostly diffusion-dominated transport of pore water solutes and methane. In contrast, in sediments featuring the shallow fracture at pockmark Lomvi, we found extremely high contents of strongly depleted DIC (-40 ‰), and high concentrations of ^{13}C depleted lipid biomarkers diagnostic for AOM as well as high contents of both methane and sulfate. The fractured sediments thus represent advection-dominated transport where fluids and gases transport into shallow, sulfate-rich sediments is facilitated by the fracture.

The fractured sediment environment is a transient state and dominated by advection of fluid and gas. This fuels the shallow AOM communities in a broader sediment horizon where methane and sulfate overlap. In contrast, the non-fractured environment is dominated by diffusion of fluid and gas only supporting low amounts of AOM communities.

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