Oil & Natural Gas Technology

DOE Award No.: DE-FE0013531

Quarterly Research Performance

Progress Report (Period ending 12/31/2016)

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

Project Period (11/1/2013 to 10/31/2017)

Submitted by:
Marta E. Torres

Oregon State University
DUNS #: 053599908
104 CEOAS Admin. Bldg.
Corvallis, OR 97331-5503
e-mail: mtorres@coas.oregonstate.edu
Phone number: (541) 737-2902

Prepared for:
United States Department of Energy
National Energy Technology Laboratory

Office of Fossil Energy

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 will collect samples in three expeditions, the first of which happened Oct 7-21, 2014. We were able to also join an expedition to the area onboard the RV Helmer Hanssen during May15-29, 2015 and two other expeditions one onboard the RV Heincke August-September 2015, and June 2016. We completed a modification of the SOPO to include participation in an upcoming MeBo drilling expedition in August-September, 2016.

Progress, results, and discussion

1. Water column results. We finalized analyses of our extensive sampling campaign of the water column along the entire Barents Sea-Svalbard margin in August-September 2015. These data, which include concentrations, isotope measurements and methane oxidation rates document the significance of methane release at the upper limit of gas hydrate stability relative to additional sources on the shelf. Preliminary results were presented at the 2016 Gordon Research Conference on Natural Gas Hydrate (Galveston, TX, March 2016) and a manuscript has been submitted for publication to "Scientific Reports", also published by the Nature consortium and has an impact factor of ~5. The paper is now under review.

2. Geochemistry: Data from a series of cores recovered at on the fan of Storfjordrenna, west Barents Sea documents recovery of gas hydrate at ~ 0.82 mbsf indicate that the increase in methane flux inferred sulfate profile, may be linked to an enhanced gas hydrate dissociation in this area. Ongoing studies are aimed at testing this postulate, with the aim to bridge the gap between hydroacoustic flare detection in the water column and the mapping of hydrate reservoir at depth, and provide additional clues to unravel the complex interactions among ice, ocean, microbiology and climate and their sensitivity to both natural and anthropogenic change in Arctic regions. We presented these results at the Gordon Conference on Natural Gas Hydrates March, 2016. A revision of a manuscript on these observations entitled "A possible on-off switch for shallow water Arctic gas hydrate reservoirs", submitted to Nature Communications is now underway. We now completed analyses of major and minor ions as well as some selected Sr isotope data, which suggest a complex system with various fluid sources and advective flow regimes. More analyses are currently being conducted. Preliminary results were presented at a Gas In Marine Sediments conference to be held in Tromsoe, September 2016. Abstract is attached.

3. Data integration/synthesis for the Vestnesa seeps. I have been actively collaborating with Norwegian colleagues to synthesize data collected during various cruises to the Vestnesa

Ridge, with emphasis on the results from the CAGE15-5 expedition in which I participated. A manuscript with analyses of those data has been submitted to Marine Geology.

4. Microbiology sampling. Scott Klasek (funded by this grant) had the opportunity to join the CAGE team on an expedition during June 2016. The primary objective of this cruise (CAGE 16-5) was to use NTNU's remote-operated vehicle (ROV) for seafloor mapping and targeted sample collection at selected CAGE study locations, focusing on methane seepage areas west and south of Svalbard. A total of ten sediment samples from five locations (two seeps and three methane-rich sites overlying gas hydrates) were collected from ROV dives or by gravity coring and preserved in sterile anoxic bags at 4˚C for high-pressure incubations. Onboard alkalinity titration of porewaters identified appropriate depths for sampling sediment interfaces associated with the highest rates of anaerobic methane oxidation (sulfate-methane transitions). An additional 150 sediment samples from gravity cores and multicores were frozen for complimentary in situ microbial community analyses post cruise.

5. Microbiology incubations. To investigate how the microbial communities that anaerobically oxidize methane adapt temporally to increases in methane flux, and to relate community dynamics to changes in methane oxidation rates, sediments are being incubated at in situ temperatures and pressures in a timeseries under different methane concentrations. Methane consumption, sulfate reduction, and sulfide and dissolved inorganic carbon production will be measured. In addition to microbial community analysis, we plan to quantify cell abundances and functional genes and transcripts associated with anaerobic methane oxidation and sulfate reduction. This work is partially supported by a Deep Carbon Observatory Deep Life Cultivation Internship grant to enrich or cultivate carbon-cycling microbes from subsurface environments. We are currently 2 months into the 8 month incubation, with plans to complete the experiment by June 2017. Molecular analyses will be conducted during the 2017 summer, with a manuscript plan for the fall of 2017.

6. MeBo Expedition: Geochemical/geological sampling during the MeBo cruise (cruise MSM-57) were coordinated by WeiLi Hong and Joel Johnson (see attached) . Pore water samples for isotopic analyses were shipped to OSU, and analyses are completed. Additional analyses are underway.

PROBLEMS OR DELAYS

Some problems were encountered with contamination of enriched samples for microbiology. We secured a place for Scott to sail on another expedition to Svalbard (June 2016), in which additional samples will be collected.

Recovery during the MeBo expedition was quite poor due to the glacial nature of the sediment encountered. Gravity cores provide a more continuous record of the shallow sediment.

PRODUCTS

- Two papers published on numerical model aspects of the project (attached). 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

- Paper submitted to Scientific Reports, now under review. Mau, S. Roemer, M, Torres, M. et al. 2016. Widespread methane seepage along the continental margin off Svalbard - from Bjørnøya to Kongsfjorden

- Paper submitted to Nature Communications, now under review. Hong W-L, Torres, M. et al., 2016. The on-off switch for shallow water Arctic gas hydrate reservoirs.

- Paper submitted to Marine Geology: Fluid flow in Vestnesa Ridge pockmarks: evidence for temporal and spatial variability of methane discharge into the Arctic by Giuliana Panieri, Stefan Bünz, Daniel J. Fornari, Javier Escartin, Pavel Serov, Joel J. Johnson, Pär Jansson, WeiLi Hong, Simone Sauer, Marta E. Torres, Rafael Garcia, Nuno Gracias (now under review.

- Abstract submitted to International Conference on Gas Hydrates, to be held in Denver June 2017.

Introduction

The MSM57 Expedition Leg 2 recovered MeBo drill cores and ship deployed gravity cores from multiple sites on the Western Svalbard margin (**Fig. 1**). The sites ranged in water depth from 340 to 1634 m. MeBo drill cores were either push cores (P) or rotary cores (R) depending on drilling conditions. Gravity cores were collected with solid plastic core liners for most cores, however to enable rapid core splitting, plastic bags were used for cores intended to sample shallow seafloor gas hydrate. MSM57-Leg 2 was predominantly focused on the upper upper continental margin, where abundant gas flares near the updip limit of gas hydrate stability, have been interpreted to result from recent gas hydrate destabilization (Westbrook et al., 2009 and Thatcher et al., 2013). In addition, MSM57-Leg-2 sampling included a MeBo site on Vestnesa Ridge (Bunz et al., 2012; Plaza-Faverola et al., 2015) and gravity core and temperature measurement in pockmarks above the gas hydrate system on Svyatogor Ridge (Johnson et al, 2015).

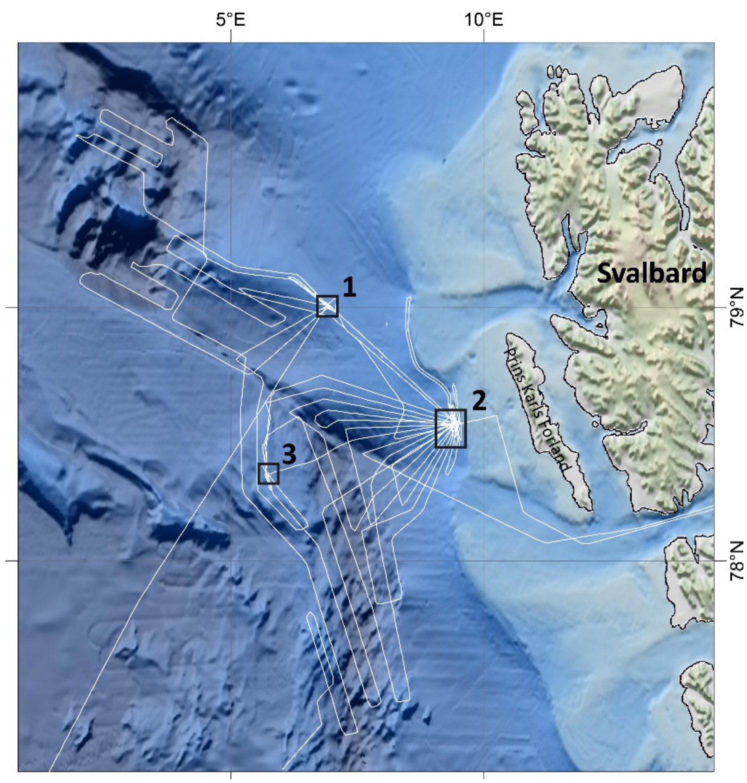

Figure 1: MSM57 Leg 2 study areas on the Western Svalbard margin. (1) Vestnesa Ridge, (2) Continental margin, (3) Svyatogor Ridge. MeBo cores were collected from

11 sites on the continental margin and 1 site on Vestnesa Ridge. Gravity cores were collected from all three regions.

MSM57 Leg 2

Sediment Core Description

During the expedition, detailed sedimentologic observations and descriptions were recorded manually for each core section on visual core description sheets. A wide variety of features that characterize the sediments were recorded, including lithology, grain size, sedimentary structures, color, diagenetic precipitates, and core disturbance. This information was synthesized for each core in Strater® 5.0.710 software package by Golden Software, LLC, which generates a one-page graphical description of each core. On the graphical core descriptions the core photos and recovery at each site are shown, as well as the magnetic susceptibility profiles for each core and additional details about the samples taken. A cruise report summarizing the detailed results of the MSM57 expedition, including the graphical core descriptions, will be published through the University of Bremen by March 2017. Below we summarize some of the highlights from the shipboard sedimentology work completed at sea.

Continental Margin Sites

Cores collected from the upper continental margin sites were quite variable in their lithology at the core section scale between clay, silty clay, sandy clay, pebbly clay, clayey sand, sand, and pebbly sand, with variable amounts of gravel to pebble sized rocks deposited by ice rafting and/or glacial debris associated with trough mouth fan deposition, meltwater discharge, and bottom current activity on the upper slope throughout the Quaternary. Given maximum seafloor penetration of ~38 m at these sites, and the high sedimentation rates associated with trough mouth fans, we suspect most of the recovered records represent deposition during the late Pleistocene to recent, however no biostratographic or other age constraints were determined at sea. Core tops in both the MeBo and gravity cores collected on the upper continental margin sites commonly contained pebbles at the surface that were also observed on seafloor imagery captured by the MeBo. These pebbles and cobbles of variable lithology are likely exposed at the seafloor due to known bottom current activity (Rebesco et al, 2013 and Eiken and Hinz, 1993) that has removed or inhibited deposition of the fine sediment fractions. Given the difficult and variable lithology, maximum core recovery in the MeBo cores was limited to 52%. Discontinuous stratigraphy due to gaps in recovery in the MeBo cores make correlation of the recovered cores difficult using lithology or magnetic susceptibility. However, gravity cores appear to have recovered similar stratigraphy at sites proximal to each other. Very similar porewater ammonium profiles in both the MeBo and gravity cores suggest nearly uniform organic matter degradation within a common stratigraphy.

Smear slide examination of the fine sediment fraction compositions shows the continental margin sediments are dominated by angular to subrounded rock fragments and mineral grains (quartz, quartz rich lithics, heavy minerals and both microcline and plagioclase feldspars) of clay to fine sand size. Dropstone compositions identified during core description included quartzite, biotite schist, sandstone/siltstone, and occasional intrusive igneous and coal pebbles. Many of the dropstones showed evidence of *in situ c*hemical weathering, containing weathering rinds that stained the surrounding sediments. Marine biogenic tests and carbonate shell fragments from macro-organisms are largely diluted by the strong lithogenic sediment components at these sites, however some planktonic foraminifera, carbonate shell fragments, and siliceous sponge spicules were occasionally observed in smear slide and macroscopically on the split core surface. Because smear slides exclude the largest grains in a sediment fraction, coarse fraction (>63 micron) sediment examination may reveal a more accurate estimate of the biogenic fraction. It is noteable that visible foraminifera were observed during core splitting in some clay dominated intervals. Macroscopic bivalve shells (possibly chemosynthetic) were observed both as fragments and larger pieces (>1cm) during core description and are noted in the descriptions. Black iron sulfide precipitates of both iron monosulfides and pyrite were observed in smear slide, as fine dusty precipitates or cubic crystals in non-framboidal circular clusters, and on the split core surfaces as black patches or darker colored black zones within the sediments. Authigenic carbonates were present in several cores as discolored (usually lighter tones) patches in clays, nodules, or fully cemented sediment intervals and were confirmed through smear slide and reaction (calcium carbonate) or delayed reaction (dolomite) with 10% HCl. Gas hydrates were not recovered from any of the continental margin sites.

Svyatogor Ridge

Three gravity cores from the Svyatogor Ridge were collected from two pockmarks along its crest. These pockmarks lie above a well-developed gas and gas hydrate system that lies offset from Vestnesa Ridge along the Molloy transform fault, and could be charged by both biotic and abiotic methane (Johnson et al., 2015). Previous water column flare mapping and gravity coring during CAGE-UiT led expeditions to this region have not documented methane seeps in the water column or sampled gas hydrates or significant gas in cores collected in these pockmarks, suggesting many of the pockmarks, although morphologically distinct, are inactive at present. Sediments recovered in the gravity cores were composed predominantly of clays and silty clays that varied in color (brown, olive brown, greenish grey, to grey). Smear slide examination revealed, a similar lithogenic sediment compositon as the continental margin sites, however, with a higher proportion of foraminifera. Core description revealed few dropstones in these records and iron monosulfides were present throughout most of the stratigraphy. No authigenic carbonate occurrences were observed.

Vestnesa Ridge

Cores collected from Vestnesa Ridge, Lunde Pockmark, during Leg 2 included a single MeBo core and a gravity core. Abundant gas hydrate was recovered at this site as well as authigenic carbonate nodules and crusts. This site was extensively cored during MSM57 Leg 1, and our leg 2 sampling was intended to supplement the earlier Leg 1 effort.

References

Bünz, S., Polyanov, S., Vadakkepuliyambatta, S., Consolaro, C., Mienert, J., 2012. Active gas venting through hydrate-bearing sediments on the Vestnesa Ridge, offshore W-Svalbard. Marine Geology 332–334, 189-197.

Eiken, O.,Hinz,K.,1993.ContouritesintheFramStrait.Sediment.Geol.82,15–32.

Johnson, J.E., Mienert, J., Plaza-Faverola, A., Vadakkepuliyambatta, S., Knies, J., Bünz, S., Andreassen, K., and Ferré, B., 2015. Abiotic methane from ultraslow-spreading ridges can charge Arctic gas hydrates. Geology, v. 43, no.5, p. 371-374, doi:10.1130/G36440.1

Plaza-Faverola, A., Bünz, S., Johnson, J.E., Chand, S., Knies, J., Mienert, J., Franek, P., 2015. Role of tectonic stress in seepage evolution along the gas hydrate-charged Vestnesa Ridge, Fram Strait. Geophysical Research Letters 42, 733-742.

Rebesco,M., Wåhlin, A., Laberg, J.S., Schauer, U., Beszczynska-Möller, A., Lucchi, R.G., Noormets, R., Accettella, D., Zarayskaya, Y., Diviacco, P., 2013. Quaternary contourite drifts of the Western Spitsbergen margin, Deep Sea Research Part I: Oceanographic Research Papers, vol. 79, pp. 156-168, http://dx.doi.org/10.1016/j.dsr.2013.05.013.

Thatcher, K.E., Westbrook, G.K., Sarkar, S., Minshull, T.A., 2013. Methane release from warming-induced hydrate dissociation in the West Svalbard continental margin. Journal of Geophysical Research B, Solid Earth 118 (1), 22-38.

Westbrook, G.K., Thatcher, K.E., Rohling, E.J., Piotrowski, A.M., Pälike, H., Osborne, A.H.,Nisbet, E.G., Minshull, T.A., Lanoisellé, M., James, R.H., Hühnerbach, V., Green, D., Fisher, R.E., Crocker, A.J., Chabert, A., Bolton, C., Beszczynska-Möller, A., Berndt, C., Aquilina, A., 2009. Escape of methane gas from the seabed along the West Spitsbergen continental margin. Geophys. Res. Lett., 36, L15608, doi:10.1029/2009GL039191

National Energy Technology Laboratory

626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940

3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880

13131 Dairy Ashford, Suite 225
Sugarland, TX 77478

1450 Queen Avenue SW
Albany, OR 97321-2198

2175 University Ave. South
Suite 201
Fairbanks, AK 99709

Visit the NETL website at:
www.netl.doe.gov

Customer Service:
1-800-553-7681