Oil & Natural Gas Technology

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Quarterly Progress Report
(Period ending June 30th, 2014)

Gas Hydrate Dynamics on the Alaskan Beaufort Continental Slope: Modeling and Field Characterization
Project Period: October 1, 2012 – September 30, 2015

Submitted by:

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ABSTRACT

FY2014 3nd quarter research associated with the DE-FE0010180 grant ended with progress on both numerical and biological modeling fronts. Uncertainties associated with the upcoming research cruise, however, remain. Progress on modeling front includes (1) the initial development of methane hydrate models comparing 1977 USGS legacy data with 2012 USGS data and (2) expansion of the model to include 2D advection. First order results indicate significant uncertainty exists comparing 1977 USGS legacy data with 2012 USGS data due to acquisition differences. Correcting/accounting for these uncertainties represents on-going research. Additionally, progress was made with further experimental development of synthetic methane seeps for integration with future cruise results. We continue our efforts to identify a potential ship that we might use as a research platform, and this has led to a series of suggestions that we will submit to the DOE for consideration.

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EXECUTIVE SUMMARY

In October 2012, Southern Methodist University in close partnership with The United State Geological Survey at Woods Hole and Oregon State University, began investigating methane hydrate stability in deep water (>100 mbsf) environments below Alaskan Beaufort Sea. This research is part of a three-year study funded by the Department of Energy's (DOE) National Energy Technology Laboratory (NETL). Key goals of this study include integrating and processing marine seismic data collected at the USGS with dynamic 2D/3D/4D heat flow models developed at SMU to determining the depth, location, and dynamics of methane hydrate stability along the Alaskan Beaufort Margin. A key component of this study is to constrain how the methane hydrate stability zone is changing with time. Additional goals of this study include determining areas where concentrated methane hydrate might exist in the subsurface and to understand the role methane hydrate plays in slope stability along the Alaskan Margin.

PROGRESS AND RESULTS

SMU Progress on numerical Modeling:

Current analysis of 1977 and 2012 seismic data show little difference in BSR depth. Additionally, it is unclear if seismic lines are exactly overlain (they are likely not). As a result, comparing/detecting difference between these seismic lines remains difficult and has required further processing in which we are attempting to scale the wavelets for each dataset to match each other. An additional issue is assessing whether other phenomena, such as fluid advection, impact BSR depth in this region. Fluid advection can dramatically affect the temperature regime in porous media because it is significantly more efficient at redistributing heat compared to diffusion. Because of this, fluid advection in areas where methane hydrate exist can greatly effect hydrate distribution within porous media. In theory, on the Beaufort margin, if submarine groundwater discharge from permafrost is cold enough and moves fast enough to transfer fluids from the shelf to the upper slope, this discharge could cool the sediments of the upper slope and enhance hydrate formation. In order to better constrain this anomaly we developed a finite volume (as opposed to finite difference diffusive model used previously), multi-phase flow, implicit method to solve for the pressure, temperature, and fluid saturation as fluid advects through a variably porous media across the Beaufort continental slope. Other flow regimes, such as deep advection, can also play an important role in hydrate stability, however we have not applied such regimes to this model yet.

This initial model is used to solve for temperature variations due to groundwater advection and determine the affect such fluid flow has on the hydrate stability regime. However, this model can be expanded to incorporate a large variety of different scenarios. Our initial pressure solver only solves for fluid pressure that we use to derive flow velocities. Yet we can incorporate additional pressure affects due to hydrate dissociation and overburden to determine locations of sediment weakening and potential slope failure locations in response to temperature, fluid flow, and hydrate variations. Additionally, our model accounts for multi-phase fluid flow. Incorporating fresh and saline waters, as well as gas flux, we can theoretically determine the location of both

hydrate dissociation and re-formation as the system responds to the multiple inputs by tracking the saturations of gas and water salinity. The end result will be a model to track the temporal changes in temperature, hydrate distribution, and pressure as the system adjusts to the evolving geological and hydrological system. This model, which is rapidly under development at SMU should more accurately account for advection than the previous diffusion based models used in our recent manuscript. The goal of this model is to determine what flow regimes are likely required to explain BSR shoaling along the margin (as opposed to changes solely in ocean temperature at the upper boundary condition). We will apply this result both to the 2012 and 1977 USGS data, which we continue to analysis and integrate with the modeling.

OSU Milestone #2 Progress on Artificial Methane Seep Experiments:

Progress related to the artificial methane seep experiments continued during this quarter. Daisy Castillo (UCSC) will build upon her research conducted last year along with Nick Davies (Whitman College), both supported through the NSF Research Experience for Undergraduates program at OSU/CEOAS. Castillo arrived in June and began extracting DNA from the 69 samples representing either sediments collected at the location of the artificial methane seeps created in 2013 or from lab based sediment columns that were stimulated using methane. Of these 69 samples Castillo has extracted DNA and evaluated DNA quality and quantity from 57 samples. She has successfully amplified DNA from 34 of these samples and prepared them for high throughput DNA sequencing in order to determine how microbial communities change in response to a new source of methane. These data are being used to formulate an abstract to be submitted to AGU for presentation at the Fall 2014 meeting. She is on track to complete the project by the end of September with a manuscript to be submitted for peer review.

To extend DOE-FE's support for this research we have applied to the Joint Genome Institute (JGI) - Environmental Molecular Sciences Laboratory (EMSL) Collaborative Science Initiative to use DOE Office of Science user facility research capabilities. The Letter of Intent directed to this call for proposals elicited an invitation to submit a full proposal that was submitted by Colwell and Michael Graw (OSU graduate student) at the end of May. The full proposal requested JGI and EMSL support of whole-genome shotgun sequencing and genome assembly (JGI resources) and metatranscriptomic and metabolomics analyses (EMSL resources). We await the July 31 announcement of review results. If funded, this will augment the studies already planned by our microbiology team in the Beaufort Sea and would lead to construction of metabolic models for microorganisms involved in anaerobic methane oxidation. With the geochemistry, geology, and geophysics also being conducted by the broader research team we are optimistic about the ability of the model to explain important aspects of a dynamic sediment system that responds to changes in physical properties of water and gas-rich sediments at high latitudes.

To prepare for field sampling in the Beaufort Sea, Graw is conducting data analysis on samples that he acquired this spring during the expedition off the Hikurangi Margin off New Zealand. These samples were collected from a region of high methane flux that are ideal for analytical preparations (microbial DNA and RNA extractions), and also measurement of porewater chemistries to diagnose sediment conditions in the context of microbial communities that are present. Graw has also started to work with a published genome for *Deulfosarcina variabilis* Hildenborough in the Pathway Tools program (SRI International, Menlo Park, CA), in order to learn ge-

nome annotation and metabolic network reconstruction. This will link to our planned research in the Beaufort because it provides a way of analyzing the metagenomics data that will be needed during genome assembly on samples from the Beaufort. Collaboration between Graw and Evan Solomon (Univ. Washington) may allow a chance to get Washington Margin samples for measuring rates of anaerobic oxidation of methane to practice that method.

USGS progress on ship scheduling:

During the past quarter, multiple discussion between USGS, SMU, and ship operators occurred to assess the viability of a research cruise in the Western Beaufort Sea next summer. Below is a letter provided to DOE outlining all of the potential possibilities we might consider to achieve objectives based on conversation during the past quarter. This letter was submitted to DOE at the end of the quarter:

Start of Letter
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To: Robert Vagnetti, Richard Baker, and Ray Boswell
From: Matthew Hornbach, Carolyn Ruppel
Re: Ship costs for DE-FE0010180

As you are aware, we learned in late autumn 2013 that the ship we had planned to use for coring/heat flow on the US Beaufort outer shelf and upper slope in September 2014 to complete the field component of DE-FE0010180 (with associated subaward to OSU and interagency agreement to the USGS) was no longer a possibility. Since we had counted on use of this vessel since the inception of the project, this was a serious setback. We subsequently investigated use of the USCGC Healy for 2014. Despite an outstanding good faith effort on the part of the Healyship scheduler at the Coast Guard, we were eventually told that her schedule could not accommodate us in the Arctic field season for 2014. Since then, we have taken a multipronged approach to addressing the issue of ship availability for 2015, even while SMU has continued to move forward on refining numerical models with existing data and OSU has developed new methods to handle samples. Having now investigated several ship options, we here summarize the situation and request further discussion with DOE about how to advance the project. As a reminder, we have approximately $350 K net budgeted in the award to cover ship costs at present. SMU waived the overhead on this entire amount. We request an opportunity to discuss these different options with you so that we can clarify a path forward towards a 2015 coring effort that would address the upper slope gas hydrate dynamics as we originally proposed.

Option 1: Contract a Commercial Vessel

In April 2014, the USGS completed documentation and USGS ship contracting personnel reviewed a task order that was subsequently circulated by SMU to commercial operators with Arctic-capable vessels. The goal of this exercise was to seek informational bids to inform a possible future solicitation. The specifications were provided to four or five potential commercial operators that had been identified by the USGS in 2013. We had subsequent contact from three operators and extensive discussions with one operator. This operator provided a rough cost of $550K (including fuel) for 9 days of operations plus transit costs on their smaller vessel. The USGS

technical personnel responsible for piston coring within the Coastal and Marine Geology Program have subsequently held further discussions with this operator. The operator decided after discussions with the USGS technical personnel that we would require a larger (more expensive than $550K) vessel, one that was formerly a research ship. We were strongly encouraged by this operator to seek out other community colleagues who had funded research programs to also contract this same vessel next summer, thereby lowering the costs for transits, which could then be split between us. We have no leads on such groups. It is rare to be in our situation of having a funded project and being on the prowl for a vessel since NSF assigns the vessel at the time of funding. The vessel this operator has identified has no A-frame and would require significant modification to accommodate the cruise. This is possible as a last resort, but Ruppel and USGS operations personnel have significant concerns about jerry-rigging a transom, welding blocks to handle loads of several tons, and working with heavy equipment overhead under these conditions.

Bottom Line: A commercial charter is a long-shot given that we have had interest from only one company that would have to substantially modify its vessel to accommodate the corer. If this worked out, we are probably looking at costs in excess of $600K total ($250K higher than budgeted). Late Note: Overnight on 30 June, 2014 we were contacted by the same company whose ship/winch was not sufficient for coring in 2014. The information provided by this company has no indication that they now have a winch sufficient to handle the coring, the reason that we dropped this vessel in the first place. We are not certain why they responded to the informational call given that their equipment appears not to meet the specifications, but USGS operational personnel have reviewed their response, which is considered not viable at this time.

Option 2: Ask for a UNOLS vessel (with more funding)

In late winter 2014, the US Coast Guard provided us with $43K as the estimated day rate for the USCGC Healy for 2014. This day rate does not include costs borne directly by the Coast Guard (e.g., salaries) and is the rate negotiated with NSF for their operations. With an anticipated 5% increase in 2015, the cost would reach $45.15K per day. For the same $550K that was estimated for the total cruise cost (including transits) by the commercial vessel operator, we would be able to afford ~12 days total. This would have to include many days of the roundtrip transit from Dutch Harbor to the Arctic that all Healy users are required to share. NSF/Coast Guard would determine how many days of transit we are charged. A fair guess is that only about half of the 12 days would be available to us for mob/demob and actual coring. We caution that another USGS Project (e.g., paleoceanography, based in the climate group in Reston) has had to pull out of Healy cruises in the past due to charges for higher-than-deemed-fair numbers of transit days. A bill pending in the US House could place increased pressure on the shiptime for the USCGC Healy for 2015, and we are thus filing a UNOLS ship-time request immediately to get a placeholder in the system, with funding indicated as "pending."

The new Arctic UNOLS vessel R/V Sikuliaq will be operating her maiden season in 2015. She currently has only one month left on her 2015 schedule. We are filing a UNOLS ship-time request immediately. This is only a request, and it is expected that PIs often have multiple requests for ships operating in the same area. The Sikuliaq day rate is estimated to be $45K per day based on information provided by a USGS employee who is a member of the ship's oversight committee. Using the $550K estimated by the commercial charter, this would again translate into 12 days. Currently, the cost model is not clear for the Sikuliaq, but we would

certainly be required to pay partial transits to and from Seward for her as well, in addition to costs associated with personnel transfer to the ship while at sea. The number of shared days of transit would be determined by NSF. We have of course discussed our needs and available funding with several foreign operators, including Germany (which did not fund a proposed joint US/Canadian/British in the Mackenzie area for 2015), Sweden (which had approached various US government agencies about joint use of the Oden icebreaker starting in the 2015 timeframe), and Korea, which brought the ARAON into the Beaufort Sea, but did not conduct operations in the US EEZ, in 2013. We made no progress with any of these groups.

Bottom Line: We will file UNOLS ship-time requests stating that funding is "pending" for the Healy and the Sikuliaq. $560K total ($210K more than budgeted) would give us the ability to be credible in paying for transits (6 days?) and getting the proposed work completed (12.5 and 13 days, respectively, for the USCGC Healy and the R/V Sikuliaq if we can get on their schedules. We received an unpleasant email from NSF last year when we attempted to do a ship request with our then-existing funding ($350K) for 2014.

Option 3: Work in Another Geographic Region

The original proposal focused on upper slope gas hydrate dynamics in response to changing climate and argued for the US Beaufort as a study site because (a) the Arctic is undergoing more rapid climate change than other places; (b) the USGS has acquired a great deal of baseline data on this margin; (c) upper slope BSRs are visible in the legacy USGS seismic data, making it possible to develop robust numerical models for the impact of oceanographic change on gas hydrates; (d) the USGS has anecdotal evidence that upper slope gas hydrates may be and should be breaking down on this margin; and (e) Ruppel leads a large group of proponents that has submitted an IODP pre-proposal for this margin. DOE has also had clear interests in the Alaskan Arctic for over 5 years.

With the late 2012 and summer 2013 discovery of over 300 upper slope seeps on the US Atlantic margin by the USGS/NOAA/SMU groups (work by Skarke, Ruppel, and others), an alternate option is to rework the DOE project to focus on upper slope gas hydrate breakdown on the northern US Atlantic margin, particularly where over 200 seeps possibly related to this dissociation occur between Washington and Baltimore canyons. The recent round of methane emissions at these seeps may be related to documented warming of the upper intermediate waters in the past 30 years (Ruppel collaboration with Biastoch) and changes in the North Atlantic Oscillation (Skarke, Ruppel, and others paper in review). Rick Colwell has stated that the same microbiological approaches that he had planned for the upper slope in the Beaufort Margin are applicable on the northern US Atlantic margin, with the added bonus that known seeps mean access to seafloor microbial mats and that sample preservation is logistically much more straightforward on the US margin, instead of in the remote Arctic. John Pohlman, who has worked with the USGS in the Arctic since 2008, believes that the US Atlantic margin has more to offer than the US Beaufort at this point in terms of the biogeochemistry and known seep sites. He has also pointed out that very few of the appropriate types of coring cruises and analyses have ever been systematically completed on the northern part of the US margin. A provocative, but preliminary, pore water dataset recovered on long-stored cores from the upper slope of the New England margin by a USGS summer student in 2013 yielded evidence of dramatic fluid flow related to the interplay of gas hydrate dynamics, fractured rocks, and evaporites. Ruppel is already deeply involved in the

Atlantic Margin seep work on several papers and other projects/cruises. Her heat flow data (collected as her postdoctoral work in 1992), which were acquired as site survey for ODP Leg 164, remain the only Atlantic Margin data available, apart from sparse temperature determinations in boreholes. Any new heat flow data acquired by this project would expand the dataset of thermal constraints on this margin dramatically. Ruppel is also talking with community members about the possibility of shifting the upper slope gas hydrate dynamics aspects of the Beaufort IODP drilling proposal to the US Atlantic. Because the work we proposed for the Beaufort is process-oriented and can be carried out at many different locations and because the logistics are so much easier in the Atlantic, this may make sense if DOE were interested in this option and a rescoping of the proposal. Hornbach and his student, Ben Phrampus, published their first modeling study on upper slope gas hydrate breakdown for the southern part of this margin in Nature in 2012. This summer, the USGS NAMSS website based in Santa Cruz (managed by Patrick Hart) will begin serving many thousands of kilometers of industry MCS data for this margin, through an agreement between BOEM and the USGS that will have the USGS assume responsibility for providing data to the public for all US EEZ. Hornbach is involved in a NSF GeoPRISMs project on the R/V Langsethin autumn 2014 that will collect a few high-resolution profiles on the northern part of the margin.
Bottom line: The existing $350K for shiptime could pay for over 20 days on the R/V Sharp, an intermediate vessel out of University of Delaware that has an excellent track record with the USGS corer. Her availability for 2015 is very limited however (March or September, both difficult time windows for the mid-Atlantic, as of June 20, 2014). $350K could pay for 15 days on the R/V Endeavor out of the University of Rhode Island (~13 working days once transit of 1 day each way were counted). URI has availability on the R/V Endeavor in April/May 2015 (but the USGS corer is not available in May 2015) and then again later in the summer 2015. Either ship is suitable for coring.

End Letter

COST STATUS

Approximate costs incurred on DOE Grant by SMU (not including SMU matching):

--RA support + fringe for Hornbach's graduate student, Ben Phrampus and summer support for Hornbach: ~$16,831

--Subcontract to OSU for research support and cruise preparation:$3,781

--Overhead: ~$9000.

Total approximate expenditures charged to DOE on SMU Grant in Quarter #3: ~$29,612

PROBLEMS OR DELAYS

None, besides 1 year cruise delay noted during the last quarter and continued concerns about access to a research vessel for next summer.

CONCLUSIONS AND FUTURE DIRECTIONS

We continue to make progress assessing the dynamics of methane hydrate stability on the Beaufort Margin and the evolution of potential seeps at these sites. We have hope to have a clearer path forward for a summer 2015 cruise by the end of FY2.

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