Oil & Natural Gas Technology

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Quarterly Research Performance Progress Report

(Period ending 09/30/2014)

Characterizing the Response of the Cascadia Margin Gas Hydrate Reservoir to Bottom Water Warming Along the Upper Continental Slope

Project Period: October 1, 2013 – September 30, 2016

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

In October 2013, the University of Washington initiated a three-year study funded through DOE-NETL entitled: Characterizing the response of the Cascadia margin gas hydrate reservoir to bottom water warming along the upper continental slope. The objective of this project is to understand the response of the WA margin gas hydrate system to contemporary warming of bottom water along the upper continental slope. Through pre-cruise analysis and modeling of archive and recent geophysical and oceanographic data, we have (1) inventoried methane hydrates along the WA margin and defined the upper limit of gas hydrate stability, (2) refined margin-wide estimates of heat flow and geothermal gradients, (3) characterized decadal scale temporal variations of bottom water temperatures at the upper continental slope, and (4) used numerical simulations to provide quantitative estimates of how the shallow boundary of gas hydrate stability responds to modern environmental change. These pre-cruise results have provided the context for a systematic geophysical and geochemical survey of methane seepage along the upper continental slope of the WA margin during a 10-day field program from 10-19 October 2014. This systematic inventory of methane emissions along this climate-sensitive margin corridor and comprehensive sediment and water column sampling program will focus on determining methane sources (microbial, thermogenic, gas hydrate dissociation), sinks, and fluxes within the sediment and water column, and how they relate to contemporary intermediate water warming.

The fourth quarter of this project was mainly focused on preparing for the 10-19 October 2014 research expedition on the *R/V Thompson* to characterize methane seepage along the upper continental slope of the Washington margin. The field program consisted of an along-margin multi-beam sonar survey of active methane seepage and targeted coring, water column sampling, and heat flow measurements. Sampling activities were focused at seep sites identified within the depth range that our earlier modeling efforts suggest gas hydrates should be dissociating in response to contemporary bottom water warming. During this quarter, we finalized expedition staffing, finished ordering sampling supplies and materials, prepared and packed these materials, and prepared and calibrated all of our analytical equipment for the expedition. In addition, we modified and assembled the University of Washington coring equipment, and trained the UW coring technicians. In preparation for the coring operations during the cruise, archive multi-channel seismic (MCS) and seafloor bathymetry data were further processed and analyzed to ensure we had the highest level of background information prior to coring operations. In addition, we constructed detailed seafloor slope maps for the entire WA upper continental slope. We also obtained the necessary permits to collect sediment samples in the Olympic Coast National Marine Sanctuary. The cruise plan was based on our earlier modeling efforts and analysis of the archive geophysical data. This plan was finalized with the objective of surveying the upper continental slope from the Strait of Juan de Fuca to the Columbia River with focused sediment and water column sampling at four seep sites at the up-slope limit of gas hydrate stability. The results of this successful research expedition will be provided in the next quarterly report. In addition to preparations for the October 2014 research expedition, we submitted a manuscript to *Geophysical Research Letters* detailing the results of our thermal simulations of long-term bottom water warming along the Cascadia margin and the impact on the upper limit of the Washington margin gas hydrate reservoir.

PROGRESS, RESULTS, AND DISCUSSION

Task 1.0 Project management and planning
Completed in previous reporting period - The project management plan was finalized and submitted on October 17, 2013.

Task 2.0 Compile relevant archive data
Completed in previous reporting period – We have compiled the relevant MCS profiles and swath bathymetry on the WA margin. All available high-resolution CTD, glider and ARGO float temperature profiles, extending to depths below 200 m, were extracted and compiled from the World Ocean Database 2013 (National Oceanographic Data Center) for the region 124.5°W to 127.5°W and 46.5°N to 48.5°N off the Washington margin. We have also compiled all of the acoustic backscatter data from archive and recent (EM122 and EM302 data) *R/V Langseth*, *R/V Thompson*, and *R/V Atlantis* expeditions at the Washington margin.

Task 3.0 Estimate sediment porosity and in situ thermal conductivities
Completed in a previous reporting period – We converted existing archive MCS data to Vp-vs-depth profiles and then used these data to estimate sediment porosities. From the estimated sediment porosities, we calculated thermal conductivities along the WA continental slope. We have completed a compilation of sediment core archives from legacy coring programs on WA margin for sediment lithology in order to provide guidance regarding the distribution and partitioning of the sediments into turbidites and pelagic sediments within a specific geographic area. These data are necessary to convert seismic velocities and structural components into a plausible model of thermal conductivity.

Task 4.0 Constrain hydrate distribution and geothermal gradients
Completed/In progress – We have evaluated Bottom Simulating Reflectors (BSRs) from the COAST MCS cruise to establish the distribution of gas hydrates and geothermal gradients along the WA margin in combination with heat flow measured during our recent WA margin heat and fluid flow survey (Johnson et al., 2013; Johnson et al., 2014). This work has been completed for the region surveyed during the COAST MCS expedition in 2012, which overlaps with our proposed track-line for our research expedition in October 2014. We are currently evaluating BSRs from other legacy datasets along the WA margin, including both commercial (Western Geophysical) and USGS MCS expeditions in the area.

Task 5.0 Analyze recent temperature data and long-term bottom water record
Completed in a previous reporting period – As stated in the Executive Summary, after filtering, there are 2122 high-quality, open-ocean temperature profiles that were linearly interpolated to 10 m depth intervals ranging from 50 to 1000 m. Averaged over the entire region, the temperature at the upper limit of gas hydrate stability shows persistent warming over the last 40 years. The time series also clearly shows the influence of the Pacific Decadal Oscillation (PDO) at the upper limit of gas hydrate stability. Taking into account other independent variables such as latitude, water depth, and the monthly Pacific Decadal Oscillation (PDO) index, our calculations studying sensitivity to methodological choices yield a constant and significant warming trend off the WA margin from 1960 to present.

Task 6.0 Non-steady state thermal simulations and impact of bottom water warming on the upper limit of the gas hydrate stability field

Completed in a previous reporting period – In collaboration with Robert Harris at Oregon State University we used a 2-D finite-element conductive heat flow model to simulate the change in temperature distribution in the shallow sediments at the upper limit of gas hydrate stability resulting from the warming intermediate-depth water temperatures. The upper boundary of the thermal model is based on the historic temperature records on the WA margin, and the bottom boundary condition is set by the heat flow estimated from regional BSR data, historic heat flow surveys, and borehole data. In situ thermal conductivity is estimated from MCS data using vertical seismic velocity profiles to estimate porosity, then porosity is converted to thermal conductivity (Task 3.0). Thermal diffusivities were also measured during a recent GeoPRISMS expedition off the coast of WA by Johnson and Solomon (Johnson et al., 2013, EOS: Homola et a., in press, Elementa, 2014). The base of the gas hydrate stability zone is calculated integrating the Pitzer equations in Tishchenko et al. (2005). The model is stepped through time over the 45-year historic record of bottom water temperatures for the WA margin. Results show that the upslope limit of the gas hydrate stability zone on the WA margin is sensitive to the contemporary warming of intermediate waters and retreats downslope over the 40-year period along all three profiles simulated along the margin. This modeling effort will also guide the field program in Phase II of the research project. The results of the characterization of the long-term bottom warming trend and these model simulations are described in Hautala et al. (*in press, GRL*).

Task 7.0 Planning and Preparations for Research Expedition

Completed this reporting period – During this reporting period, The PIs met weekly to discuss our sampling strategy, work flow, and cruise track. We completed planning and preparations for the October 2014 research expedition at the end of the quarter. The expedition occurred from 10-19 October 2014, and we successfully achieved the objectives of the cruise plan. Results from the expedition will be discussed in the next quarterly report.

CONCLUSIONS

The first six tasks comprise Phase 1 of the research project aimed at providing the context for a systematic geophysical and geochemical survey of methane seepage along the upper continental slope of the WA margin during a field program in October 2014. To date, the six tasks have been completed, however we are conducting additional work on Task 4.0 to expand our heat flow estimates to the northern segment of the WA margin. We completed preparations for the research expedition (Task 7), and successfully conducted the field program in October 2014 completing Phase II of this project. We are now ready to move on to Phase III focused on post-expedition analyses, interpretation, publication, and reporting.

MILESTONE STATUS

Milestone #1 – Determination of the gas hydrate distribution and geothermal gradients along the WA continental slope based on COAST MCS data
Completed June 2014, however additional work continues on legacy datasets north of the COAST survey area.

Milestone #2 – Finalize planning for cruise tracks/stations, identification of shipboard scientific party, and preparations for on-board data/sample acquisition and processing.

Completed September 2014.

COST STATUS

During the fourth quarter, $63,411 was spent to support additional analysis of archive geophysical data, to prepare the manuscript for submission to GRL, and for preparations and supplies/materials for the October 2014 research expedition.

PROBLEMS OR DELAYS

None.

PRODUCTS

Completion of this quarterly report

Hautala, S.L., Solomon, E.A., Johnson, H.P., Harris, R.N., Miller, U.K., *in press*. Contemporary ocean warming dissociates Cascadia margin gas hydrates, *Geophysical Research Letters*.