Oil & Natural Gas Technology

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Quarterly Progress Report
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Gas Hydrate Dynamics on the Alaskan Beaufort Continental Slope: Modeling and Field Characterization
Project Period: October 1, 2012 –March 31st, 2017

Submitted by:

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ABSTRACT

The 4th quarter of FY2015 research focused on (1) data collection of methane hydrate systems off the US East Coast using the R/V Sharp, (2) continued circulation/editing of a draft manuscript assessing Atlantic Margin heat flow and hydrate stability based on recently collected ENAM seismic lines, (3) preparation and planning for the 2016 Arctic cruise, and (4) preliminary pore-pressure analysis using AVO models to assess hydrate stability on the Atlantic Margin. In general, the fourth quarter of FY 2015 was a tremendous milestone: preliminary results from the Atlantic cruise are still forth-coming, however, based on USGS reports, the research cruise was by all accounts very successful. SMU researchers have revised a manuscript assessing heat flow, hydrates, and hydrocarbon maturity on the US East Coast. This work has now completed internally review by co-authors and will soon be submitted. Results indicate a large source kitchen along the Atlantic margin and that some (perhaps a large percentage) of the hydrates in the region may actually have a thermogenic origin that has since been masked by biological activity breaking down the higher-order hydrocarbons. In addition, conversations with the M/V Norseman contractors have been positive, and SMU has tentatively secured mid-september as the cruise timeframe and port calls in Deadhorse which will minimize transit time/cost. Finally, in accordance with the goal of this study better constraining slope stability hazards associated with methane hydrate, SMU researchers have made some significant progress on pore pressure analysis of hydrates on the US East Coast by integrating AVO data from recently collected ENAM cruise data with rock physics models to constrain slope stability in the region. We anticipate preliminary pore pressure modeling results will be available by the second quarter of FY 2016, with some of these results highlighted at the Gordon Research Conference this coming February.

TABLE OF CONTENTS

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. In late 2014, the project was further expanded to include analysis of methane hydrates and slope stability off the US east coast. This research is part of a now 4.5 year study funded by the Department of Energy's (DOE) National Energy Technology Laboratory (NETL) that analyzes methane hydrate stability on both the Atlantic and Beaufort Margin. Key goals of this study include integrating and processing marine seismic data collected at the USGS as well as other publically available data 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 and similar environments. A major 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 continental margins. To accomplish these goals, researchers use geophysical (seismic, heat flow, CTD/XBT) data combined with numerical models to assess methane hydrate stability in space and time. Researchers also integrate regional coring and biological data with methane hydrate stability models to place further constraints on hydrate dynamics.

PROGRESS AND RESULTS

The R/V Sharp Cruise in the Western North Atlantic:
During September of 2015, researchers at the USGS, working closely with colleagues at OSU and UCLA, conducted a research cruise on the western Atlantic margin off the US east coast. As this cruise was only completed within ~1 week of the end of the quarter, results are very preliminary. Nonetheless, based on brief conversations with USGS and OSU researchers, the cruise was a tremendous success, with many of the key biological, geochemical, and geophysical datasets producing high quality initial results. Future reports will likely further highlight preliminary results from this cruise. Regarding costs, the entire cruise was on budget with the subcontract for the cruise of ~$227,000 paid by SMU (with no overhead charged to DOE) to the University of Delaware who operates the vessel.

SMU Atlantic Margin Research progress:
SMU researchers continue to model heat flow and methane hydrate stability on the U.S. Atlantic Margin. With this research, we've made significant progress on two fronts: The first focuses on 3D analysis of heat flow along the Atlantic margin; the second focuses on slope stability and pore pressure modeling of sediments in hydrate-rich areas along the US east coast. An update of current status and results of this work are outlined below:

(1) Completion of internal review of a draft manuscript: "Heat Flow Evolution of the Western N. American Margin Derived from BSRs: Implications for Hydrocarbon Formation," by *Phrampus et al.* A manuscript related to this research, lead by the SMU group, will

be submitted to *Marine and Petroleum Geology* Q1 FY2016. The results demonstrate not only where anomalous heat flow values and shallow BSRs exist in the subsurface but also provides the first basin-scale model for heat flow across the margin. The results are used to assess hydrocarbon source and maturation windows below the North Atlantic margin by modeling thermal evolution and sediment deposition/compaction with time. The paper provides the first 3D heat flow model and geothermal evolution of the western Atlantic Margin. Results show that heat flow on the margin is low, but increases seaward, and that hydrocarbon maturation occurs at depths of ~2km below the seafloor along the margin edge, consistent with seismic interpretations of source rock and thermogenic gas formation interpretations in seismic data. Analysis of seismic lines indicates significant "bright spots" exist in the zone of predicted hydrocarbon maturation, with faults that extend from this zone into the hydrate stability zone. It appears possible—perhaps even probable—that some of the methane associated with hydrate may source from this region.

(2) slope stability/pore pressure analysis of hydrate-rich zones on the US East Coast Margin. Multiple recent studies indicate methane hydrate destabilization may lead to slope failure, sliding, and perhaps in some instances, tsunami generation. Our analysis based on last year's work on this project (and our recent publication in *JGR*) already demonstrates that hydrates are currently destabilizing both along the North Slope of Alaska and off the US eastern seaboard. Assessing slope stability requires a detailed assessment of in situ pore pressure. Higher pore pressures result in lower effective stress, with near lithostatic pressures implying very small changes in the subsurface stress regime will trigger failure. Thus, if we see evidence for locations with anomalously high subsurface pressures, we can effectively pin-point areas that are at highest risk for future slope failure in a region. Detecting subsurface pore pressure without in-situ measurements (via drilling or monitoring) however is difficult (but possible). A key tool for remotely detecting zones of elevated pore pressures in the subsurface is the integration of high resolution seismic velocity/amplitude data with rock physics models (e.g. Dvorkin et al., 1999; Mavko et al., 2011). Although the approach is limited in that it typically can only detect pore fluid pressures in excess of 60% lithostatic-hydrostatic pore pressure ratio (e.g. Hornbach & Manga, 2014), it is a proven tool for pin-pointing with meter-scale accuracy zones where near lithostatic fluid pressures exist. During the past 6 months, researchers at SMU (working with researchers at LDEO) have been using amplitude versus offset (AVO) analysis on high resolution seismic data to detect zones where anomalously high pore pressures likely exist in the subsurface. The current analysis conducted at SMU compares near offset versus far-offset seismic line stacks in sediments where clear BSRs exist in the subsurface. Comparison of these lines indicates surprising AVO anomalies that we have link directly to variations in Vp and Vs and Poisson's Ratio using rock physics models. Specifically, using forward models for amplitude versus offset (e.g. Shuey approximation), we reconstruct observed AVO anomalies using a best-fit approach for Vp and Vs and sediment matrix parameters derived from regional well logs. We then estimate in situ pore fluid pressure by integrating our best fit solution into a first-principles rock physics model. We are currently conducting this analysis to determine the location of where the highest pore fluid pressures exist above methane hydrate provinces along the US east coast. The next step of this analysis, however, involves constraining *why* these zones of high fluid pressure exist. This step will likely involve detailed time de-

pendent heat flow and hydrate stability modeling along the margin. We intent to present preliminary results for this work at the upcoming Gordon Research Conference in early 2016.

Preparations for the Fall 2016 heat flow cruise in the Beaufort Sea: During the past quarter, SMU has also been preparing for the upcoming 2016 cruise in Alaska. Currently we are working with Rob Harris at Oregon State University and contractors of the M/V Norseman II to ensure that the heat flow equipment we will use for the cruise is capable of being deployed easily from the ship. Rob Harris is traveling to SMU in November (next month) to discuss additional ship, shipping, and personel logistics. We have already conducted several conference calls with the operator, and will conduct an additional conference call with Rob and the Norseman personel on November 16th. The due diligence is still on-going, however, we intend to have it completed and our hope is that all contract negotiations finalized by December 31st (the end of the next quarter).

COST STATUS

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

--Total spent/encumbered for OSU subcontracting for research/personnel to date: ~$166,000

--Total funds spend/encumbered by SMU on research time/support to date:~$121,000
(SMU is currently in a no-cost extension)

--Total funds spent for subcontract for the R/V Sharp and associated ship costs: ~$227,000

PROBLEMS OR DELAYS

--None

CONCLUSIONS AND FUTURE DIRECTIONS

We remain on course with research, ship scheduling, and data analysis. We anticipate that FY 2016 will be perhaps our most productive with at least two paper submissions, an additional Arctic research cruise, and preliminary results from the Atlantic cruise making a splash later in the year.

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