Oil & Natural Gas Technology

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Quarterly Research Performance

(Period Ending 9/30/2018)

Characterizing Baselines and Change in Gas Hydrate Systems using EM Methods

Project Period (10/01/2016 – 09/30/2019)

Submitted by:

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Office of Fossil Energy

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EXECUTIVE SUMMARY

During this review period we continued to collect electrical conductivity measurements and cryogenic electron microscopy on samples of gas hydrate, and have produced a first draft of a paper for submission to *JGR*. We had a *Fire in the Ice* article published on our results of electrical conductivity studies of hydrate with pore fluids, and two AGU abstracts accepted.

We have carried out preliminary inversions of data from the Orca Basin CSEM survey, which show resistors in the area targeted by GOM∧2 drilling. We also see resistors associated with a slump feature on the western side of the survey area, as well as a conductive plume above a nearby salt body.

ACCOMPLISHMENTS

Major goals of project

Methane hydrates require cool temperatures, high pressures, and methane in excess of solubility to form, conditions that are met in both marine and permafrost regions worldwide. Concentrated accumulations of structural hydrate may be the target for resource exploitation, and there have been several production tests of natural gas from hydrate, both on land, such as at the Mallik site in NW Canada or the Mt Elbert test well on the Alaska North Slope, and in the ocean, such as in the Nankai Trough and an ice platform off Prudhoe Bay.

Much naturally occurring hydrate exists at the edge of thermodynamic stability, and as such represents an environmental hazard that threatens release of a potent greenhouse gas as a consequence of warming. Also, one way to produce methane from hydrate is to destabilize the structure by depressurization.

Current geophysical surveying methods for identifying hydrates, such as seismic methods and well logging/coring, are limited. Quantifying the volume fraction of hydrate in sediments is possible with careful processing and inversion of seismic data, although the relationship between seismic velocity (or attenuation) and hydrate concentration is complicated and usually needs to be calibrated with well data. Electromagnetic (EM) methods, on the other hand, are sensitive to the concentration and geometric distribution of hydrate because regions containing hydrate are significantly more resistive when compared to water saturated zones. The current state of the art for imaging gas hydrate using EM methods is represented by the Vulcan system developed by Scripps Institution of Oceanography. This system uses multiple, 3-axis EM receivers towed at source-receiver ranges of up to 1,000 m behind an electric dipole transmitter. The whole array (transmitter and receivers) is "flown" 50–100 m above the seafloor in order to (a) reduce noise, (b) avoid seafloor infrastructure and other obstacles, and (c) allow all three components of electric field to be measured. The Vulcan system was used in 2014 and 2015 to successfully collect 1,000 km of high quality data over gas hydrate prospects in Japan, as well as two studies offshore San Diego, California.

For the next advance in this technology, under the current agreement we will collect extensive 3D Vulcan data sets over two or three sites in the Gulf of Mexico where drilling and coring of hydrate systems has been, or will be, carried out. We plan to study the Walker Ridge 313, Orca Basin, and Green Canyon 781 prospects, but as we did under previous NETL funding, we will consult with DoE and the drilling consortium before choosing final targets. With 2–3 days of data collection over each prospect, we will be able to collect at least 10 lines of data 10–20 km long. With a line spacing of 500–1,000 m, this will provide a dense data set of 100–200 line km covering 50–100 square km.

Under prior NETL funding we designed a specialty pressure cell plumbed for high-pressure gas access, in which we formed gas hydrate samples while simultaneously measuring impedance spectra. Such impedance measurements of methane hydrate are needed for modeling of gas hydrate systems, yet had never been established prior to our work. Under the current agreement, we plan to extend these laboratory experiments to further utilize the unique apparatus we have designed, and build on our previous results and baseline measurements. We will introduce additional parameters that mimic the effects of induced or environmental factors that may act to destabilize gas hydrate systems and contribute to the onset of partial dissociation to solid or liquid water.

Work accomplished during the project period

In the last quarterly report, we showed results from methane hydrate synthesis experiments from frozen seawater. The seawater was quenched with liquid nitrogen, blended into a powder, and sieved to less than 250 μm. The goal with these experiments was to simulate the environment of which methane hydrate forms in nature (seawater, methane gas, high pressures, and low temperatures). Cryogenic SEM imaging of final, quenched samples continues to provide us with important insights into their evolution during synthesis and the final distribution of components within them.

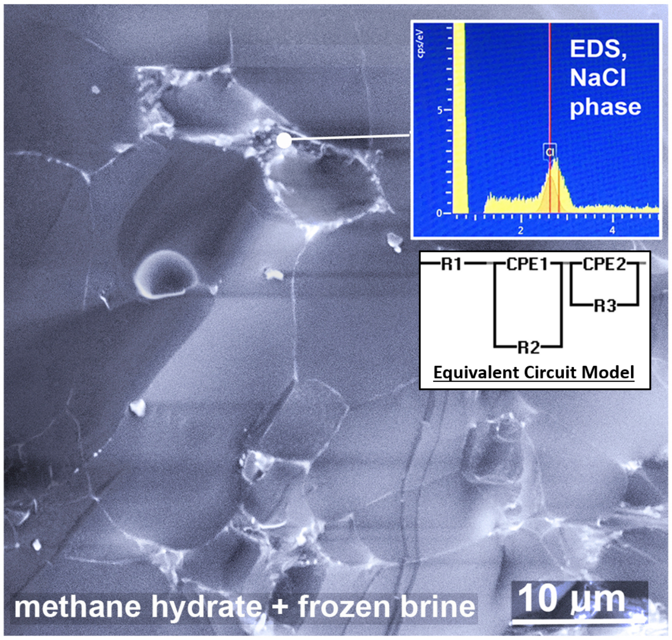

Figure 1. Cryo-SEM image included in the AGU abstract OS51F-1317.

During this quarter we mainly worked on submitting abstracts and working on a paper for submission to a journal. We have a draft in hand of a paper detailing our work on the influence of brine on the electrical properties of methane hydrate, and we have a meeting of the research team scheduled for early next quarter to discuss this in person, in detail, before submission. During this quarter we had an article published in the summer issue of Fire in the Ice. The two American Geophysical Union (AGU) fall meeting abstracts are:

OS51F-1317 Electrical characterization of methane hydrate with coexisting brine. Ryan Lu, Laura A. Stern, Wyatt L Du Frane, John C. Pinkston, Jeffery James Roberts and Steven Constable

Electromagnetic sensing measurements have proven effective as a complementary tool for mapping specific gas hydrate concentrations in nature. However, empirical information on gas hydrate petrophysics is still needed to better correlate field data with lab results. In this work, we investigated the electrical properties of polycrystalline methane hydrate with coexisting NaCl-bearing brine. Methane hydrate samples were synthesized from pure (triple-distilled) H2O seed ice mixed with finely ground (<75 m) NaCl salt, plus CH4 gas, and impedance was measured in-situ in a custom pressure vessel throughout synthesis. Conductivity was deduced from impedance spectroscopy results for temperatures between -20°C and +15°C. The addition of low total NaCl concentration ($\approx$0.25wt% NaCl) was found to effectively dope the resulting methane hydrate, eliciting a small but measurable increase in conductivity relative to pure methane hydrate by $\approx$ 1 log unit across the full temperature range. Higher total NaCl content ($\geq$1.0wt% NaCl), however, resulted in production of a coexisting fluid component (brine) that in some regions enveloped methane hydrate grains in a partially interconnected manner, as revealed by cryogenic SEM imaging of quenched samples. Our measurements indicate that at low temperatures where brine is unconnected or partially frozen, methane hydrate is the primary conduction medium, whereas at higher test temperatures for high salt content samples, the connected brine network provides an additional conduction path for current flow. In this presentation we quantify the effect of NaCl on methane hydrate electrical conductivity and show that our interpretations are consistent with equivalent circuit modeling of impedance results. Comparing electrical conductivity of all samples at the geologically-relevant temperature of 5°C shows a roughly log-linear relation between conductivity and NaCl concentration, with conductivity values for hydrate mixtures ranging from 3.1x10-5 S/m (no NaCl added) to 6.4x10-3 S/m (2.5wt% NaCl added).

and

OS54A-08 Quantifying Methane Hydrate in the Gulf of Mexico Using Controlled Source Electromagnetic Methods. Peter Kannberg and Steven Constable,

Controlled source electromagnetic methods are sensitive to pore fluid conductivity and are increasingly being used to identify and quantify electrically resistive gas hydrate deposits in seafloor sediments. In July 2017, using a deep-towed transmitter and receiver array, 360 line kilometers of CSEM data were collected at four sites in the Gulf of Mexico. This is the largest academic CSEM survey of gas hydrate to date. The four sites surveyed, Walker Ridge 313, Orca Basin, Mad Dog, and Green Canyon 955, are primary or secondary drilling sites of the upcoming GOM∧2 drilling program. Where possible, CSEM survey lines were towed coincident with seismic lines. The deep-towed array consists of a 100 m dipole antenna transmitting 270 A, with six, three-axis electric field receivers spaced every 200 m from 600-1600 m behind the transmitter. At 1600 m long, this is longest bathymetry tracking deep towed array ever deployed. Synthetic modeling showed that 1600 m source receiver offsets were necessary to accurately resolve the base of the hydrate stability field 800 m below seafloor. Initial results from WR313 show a buried salt body surrounded by a conductive halo resulting from high-salinity brines. Our resistivity models show increased resistivity interpreted to be hydrate collocated with a region where hydrate was found using borehole logging results. At Orca Basin, anomalously increased resistivity was again found at the proposed coring location of the GOM∧2 program, and are interpreted to be the result of hydrate deposits. Additional resistors are found in the shallow sediments underlying a slump scar, showing a correlation between slope failure and hydrate presence.

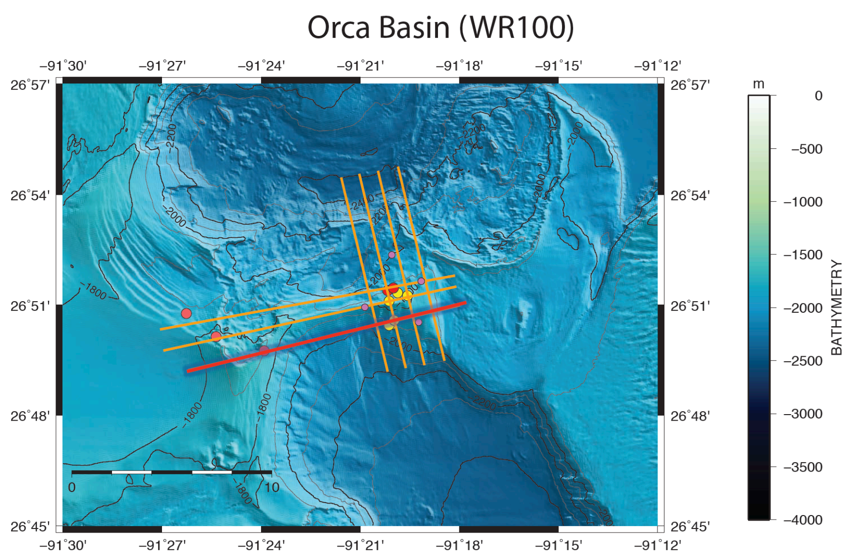

Figure 2. Map of the Orca Basin CSEM survey lines.

We continued with the inversion of data collected in the Gulf of Mexico, concentrating on the Orca Basin (WR 100) survey. Resistors are present on both the eastern and western sides of the survey area. The eastern resistors are associated with a large slump feature, with higher resistivities present as you move upslope (south). The western resistors are located in the area that is targeted for drilling as part of GOM^2. The three remaining lines to be inverted are on either side of line 4 and will help constrain hydrate concentration at the proposed drill sites.

The conductive plume on the left side of the plot overlies an uplifting salt body. The overlying sediments are heavily faulted, and likely provide a pathway for warm, salty fluids, which we are imaging. Line 2 was flown at 150 m above seafloor, 50 m higher than on the other lines, and may be affecting our ability to resolve the vertical conductive features we see on lines 1 and 3.

The north-south running line was modeled without including the salt brine pool to the north (which has a conductivity of 26 S/m) and that may be forcing conductors into the sediment as seen in the northernmost portion of line 4. We are currently running models to see if adding the brine pool affects the inversion.

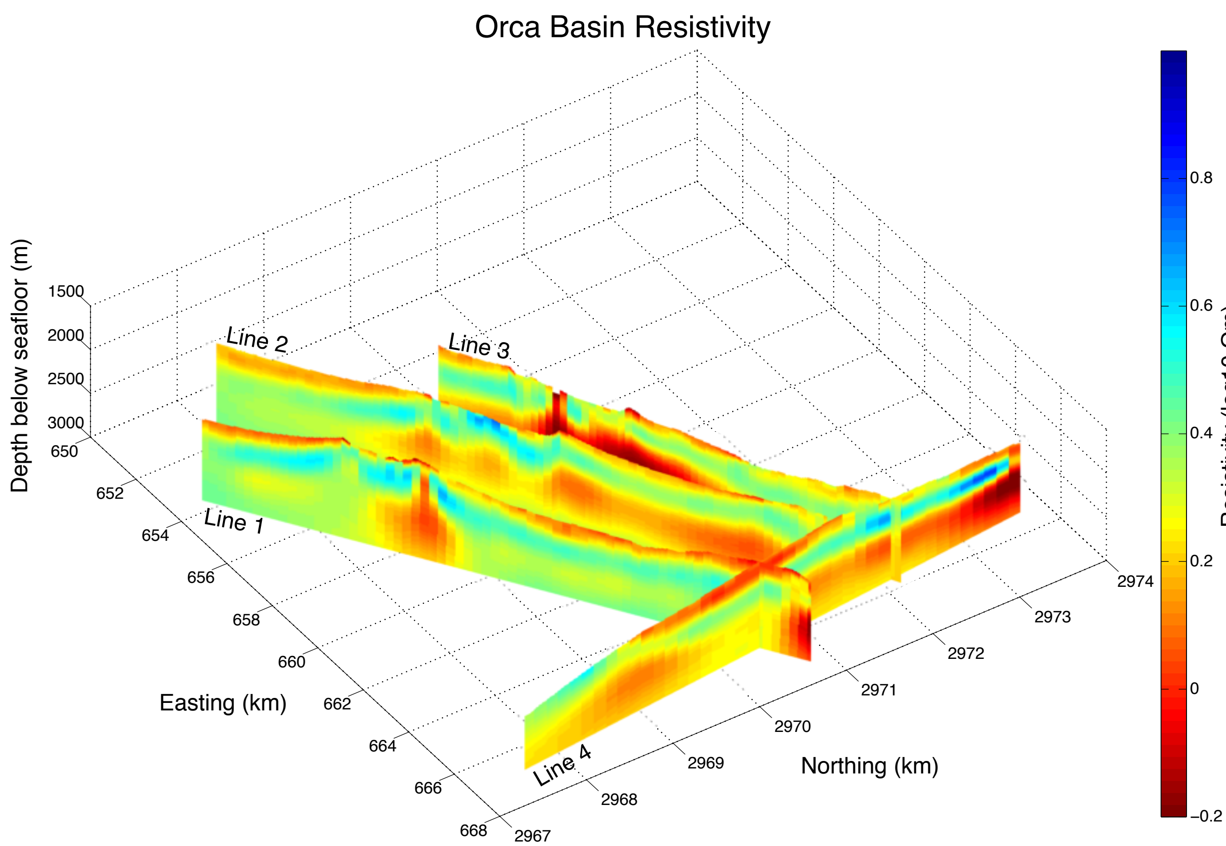

Figure 3. Fence plot of 2D inversions of four lines from Orca Basin. Blue/green is resistive relative to conductive (red) sediments.

Other activities

Training and professional development.

Peter Kannberg, then a PhD student at SIO, acted as co-chief scientist on the data collection cruise. He is currently working on this project as a postdoc.

Ryan Lu, a junior scientist at LLNL, continues work on the laboratory electrical conductivity studies and learning about hydrate synthesis and the operation of the conductivity cell.

SIO PhD students Dallas Sherman and Valeria Reyes-Ortega participated in the research cruise and learnt about the operation of the CSEM instruments. Sherman assisted with an industry-operated hydrate survey later in the year.

Peter Kowalczyk and Karen Weitemeyer, of Ocean Floor Geophysics, participated in the cruise as part of the industry cost-share component, and also gained some training in the operation of the equipment, which has been used for several proprietary surveys offshore Japan.

Plans for next project period.

During the next project period we will continue to invert the GoM CSEM data, and submit the *JGR* paper on the laboratory conductivity work.

Table 1: Milestone status report.

Milestone Title	Planned Completion Date	Actual Completion Date	Verification Method	Comments on progress
First set of conductivity runs	08/1/2017	08/1/2017	Internal review	completed
Field data collection	12/1/2017	06/12/2017	200 line km collected	completed
Second conductivity runs	12/30/2017	12/30/2017	Internal review	completed
Final set of conductivity runs	8/1/2018	8/1/2018	Internal review	completed
Field data inverted	12/1/2018		2D inversions done	ongoing
Publications(s) submitted	9/1/2019		At least 1 pub. submitted	imminent
Publications(s) accepted	12/30/2019		Publication accepted	

PRODUCTS

Project Management Plan. The revised Project Management Plan was accepted on 3 February 2017.

Project Web Page. http://marineemlab.ucsd.edu/Projects/GoMHydrate2017/index.html (check out the animated movie of the deep-two over Green Canyon at http://marineemlab.ucsd.edu/Projects/GoMHydrate2017/deeptowmovie.html)

Preliminary Cruise Report. http://marineemlab.ucsd.edu/Projects/GoMHydrate2017/CruiseReportReduced.pdf

Fire in the Ice article. Electrical Conductivity of Methane Hydrate with Pore Fluids: New Results from the Lab Ryan Lu, Laura A. Stern, Wyatt L. Du Frane, John C. Pinkston, and Steven Constable. Fire in the Ice, 18, 7–12.

AGU abstracts:

Kannberg, P., and S. Constable, 2017: Deep-towed CSEM survey of gas hydrates in the Gulf of Mexico. Contributed paper at the Fall AGU meeting, New Orleans.

Lu, R., L.A. Stern, W.L./ Du Frane, J.C. Pinkston, J.J. Roberts and S. Constable, 2018: Electrical characterization of methane hydrate with coexisting brine. Contributed paper at the Fall AGU meeting, Washington.

Kannberg, P., and S. Constable, 2018: Quantifying Methane Hydrate in the Gulf of Mexico Using Controlled Source Electromagnetic Methods. Contributed paper at the Fall AGU meeting, Washington.

The following papers acknowledge this or past DoE funded research:

Sherman, D., and S.C. Constable, 2018. Permafrost extent on the Alaskan Beaufort Shelf from surface towed controlled-source electromagnetic surveys. *Journal of Geophysical Research: Solid Earth*, **123**, 1–13, /doi.org/ 10.1029/2018JB015859.

Weitemeyer, K., S. Constable, D. Shelander, and S. Haines, 2017. Mapping the resistivity structure of Walker Ridge 313 in the Gulf of Mexico using the marine CSEM method. *Marine and Petroleum Geology*, **88**, 1013–1031, /doi.org/10.1016/j.marpetgeo.2017.08.039.

Sherman, D., P. Kannberg, and S. Constable, 2017. Surface towed electromagnetic system for mapping of subsea Arctic permafrost. *Earth and Planetary Science Letters*, **460**, 97–104.

Constable, S., P. K. Kannberg, and K. Weitemeyer, 2016. Vulcan: A deeptowed CSEM receiver. *Geochemistry, Geophysics, Geosystems*, **17**, doi:10.1002/ 2015GC006174.

Du Frane, W., L.A. Stern, S. Constable, K.A. Weitemeyer, M.M. Smith, and J.J. Roberts, 2015. Electrical properties of methane hydrate + sediment mixtures. *Journal of Geophysical Research*, **120**, 4773–4787, doi:10.1002/2015JB011940.

Weitemeyer, K., and S. Constable, 2014. Navigating marine electromagnetic transmitters using dipole field geometry. *Geophysical Prospecting*, **62**, 573–593, doi: 10.1111/1365-2478.12092.

Du Frane, W.L., L.A. Stern, K.A. Weitemeyer, S. Constable, J.C. Pinkston, J.J. Roberts, 2011. Electrical properties of polycrystalline methane hydrate. *Geophysical Research Letters*, **38**, doi:10.1029/2011GL047243.

Weitemeyer, K.A., S. Constable, S. and A.M. Trehu, 2011. A marine electromagnetic survey to detect gas hydrate at Hydrate Ridge, Oregon. *Geophysical Journal International* , **187**, 45-62.

Weitemeyer, K., G. Gao, S. Constable, and D. Alumbaugh, 2010. The practical application of 2D inversion to marine controlled-source electromagnetic sounding. *Geophysics*, **75**, F199–F211.

Weitemeyer, K., and S. Constable, 2010. Mapping shallow geology and gas hydrate with marine CSEM surveys. *First Break*, **28**, 97–102.

PARTICIPANTS AND OTHER COLLABORATING ORGANIZATIONS

Name:	Steven Constable
Project Role:	PI
Nearest person month worked:	1
Contribution to project:	Management, scientific direction
Funding support:	Institutional matching funds
Foreign collaboration:	Yes
Country:	Canada
Travelled:	No

Name:	Peter Kannberg
Project Role:	PhD student/SIO
Nearest person month worked:	3
Contribution to project:	Data processing and inversion.
Funding support:	This project
Foreign collaboration:	Yes

Country:	Canada
Travelled:	No

Name:	Laura Stern
Project Role:	Scientist/USGS
Nearest person month worked:	1
Contribution to project:	Gas hydrate synthesis and conductivity measurements.
Funding support:	USGS
Foreign collaboration:	No

Name:	Wyatt DuFrane
Project Role:	Scientist/LLNL
Nearest person month worked:	1
Contribution to project:	Postdoc supervision/conductivity measurements.
Funding support:	This project
Foreign collaboration:	No

Name:	Ryan Lu
Project Role:	Junior Scientist/LLNL
Nearest person month worked:	1
Contribution to project:	Conductivity measurements.
Funding support:	This project
Foreign collaboration:	No

CHANGES/PROBLEMS

There are no changes or problems arising from this review period.

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