Oil & Natural Gas Technology

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Quarterly Research Performance

(Period Ending 3/31/2018)

Characterizing Baselines and Change in Gas Hydrate Systems using EM Methods

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

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U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

Office of Fossil Energy

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EXECUTIVE SUMMARY

During this reporting period we started carrying out inversions of the Gulf of Mexico field data collected in July last year (2017). We carried out 2D inversion of two lines, one from WR 313 and one from WR 100 (Orca Basin). The fits to the data are very good, with misfits of around RMS 2 for a 2% error floor on the data. The inversion results look sensible and are consistent with seismic data.

We continue to collect electrical conductivity measurements and cryogenic electron microscopy on samples of gas hydrate with added salt, and now have results from five salt concentrations. We presented our work at the Galveston Gordon Conference in March and the Scripps Seafloor Electromagnetic Methods Consortium annual Workshop, also in March. We are drafting a Fire in the Ice article which is currently undergoing internal review.

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

Electrical conductivity measurements.

For this quarter, we continued to focus on two-component systems involving brine and methane hydrate to get a more fundamental understanding of the behavior of this system. The temperature cycling method has allowed us to fully react pure ice into methane hydrate. However, the addition of salt in mixtures with the starting seed ice caused some small amount of sample to remain as a brine regardless of the number of temperature cycles that were performed. For these two-component synthesis experiments, we mixed NaCl salt (<75μm) in concentrations of 0–2.5 wt% and seed ice (180μm–250μm) inside of a chest freezer maintained < -60°C. Fine grain salts were used to allow a more uniform distribution along the grain-boundaries of the slightly courser seed ice. The sample was transferred into the cooled vessel (≈25°C), which was then promptly transferred into a cooled d-limonene bath within a chest freezer (≈25°C). The bath sits above a temperature-controlled ring heater. The vessels were then pressurized with methane gas at a starting value of 2700 psi. The bath is then temperature cycled between -20°C and +15°C for 10 or more cycles, using electrical conductivity as an indicator of the presence of free water.

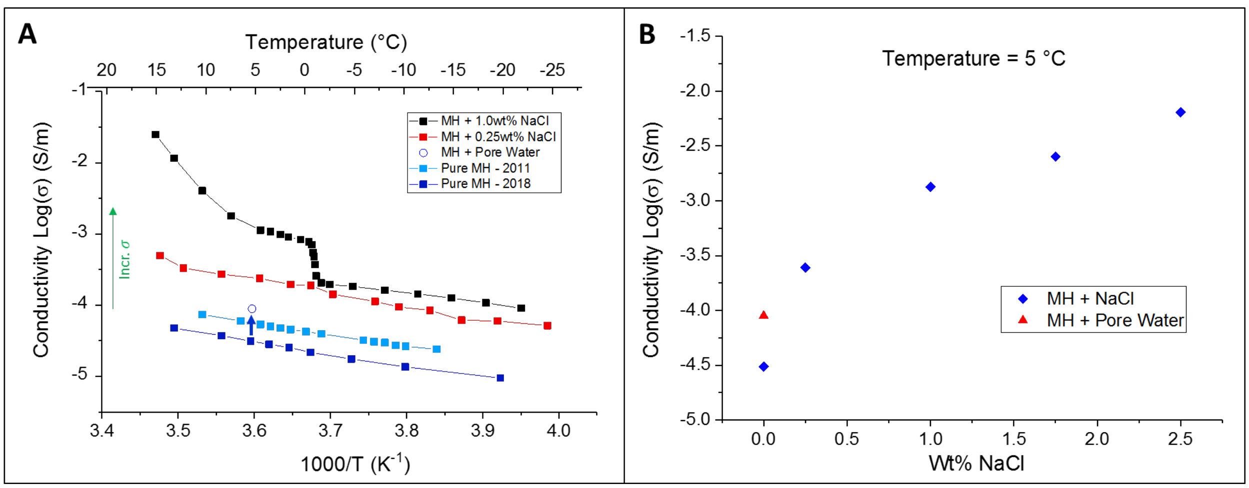

Figure 1. : (A) Conductivity (σ) of pure methane hydrate, methane hydrate with H_2O pore water (5°C data point only), methane hydrate with 0.25wt% NaCl and 1.0wt% NaCl; (B) Conductivity of all tests (0-2.5wt% NaCl) compared at 5°C.

Figure 1A compares the electrical conductivity (σ) versus temperature for pure methane hydrate, methane hydrate with pore water (5°C data point only), and methane hydrate with 0.25 and 1.0 wt% NaCl. Our 2018 measurements on pure methane hydrate match well with 2011 data, and the 0.3 log unit reduction in σ is due to improved purity of H_2O used for the starting seed ice. Adding pore water increases σ by about a 0.5 log unit at 5°C (blue arrow to open circle), although this is likely a conservative measurement as P and σ continued to stabilize at the conclusion of the test. NaCl imparts a markedly greater effect, whereby adding even 0.25wt% NaCl increases σ by an order of magnitude. The effect of NaCl is further quantified in Figure 1B; comparing all methane hydrate + NaCl mixtures at 5°C shows an almost logarithmic relationship between σ of the hydrate mixture and the NaCl concentration added.

Electrical current transport is largely dependent on the availability of charge carrier (Na^+ and Cl^-) migrations. Clean fracture surfaces through all but the 0.25wt% NaCl sample show thin but increasingly prominent rims of frozen brine surrounding grains or clusters of methane hydrate. The brine becomes increasingly interconnected with higher NaCl content, resulting in increased ion mobility and bulk electrical conductivity. NaCl at the 0.25wt% level appears to impart primarily a doping rather than brine-forming effect, as no frozen brine was observed in the quenched sample, and no transition in slope is observed with changing temperature (Figure 1A). However, all samples that we tested with $\geq$1.0wt% NaCl exhibited two slopes, such as the 1% NaCl sample shown in Figure 1A. The steeper slope at higher temperature reflects conductivity mechanisms through the interconnected brine, whereas at lower temperatures where the brine freezes, the primary current path is presumably through hydrate and possibly in combination with frozen brine. This is also evident during the synthesis of methane hydrate with 1.0wt% NaCl. At higher temperatures, impedance has very little frequency dependence indicating current is flowing through a resistor-like medium (brine). At lower temperatures, the impedance decreases with corresponding higher frequencies indicating current is primarily flowing through a capacitor-like medium (hydrate).

CSEM data interpretion.

This quarter we started inverting the marine CSEM data collected in July 2017. We use the adaptive finite element 2D code, MARE2DEM, developed by Kerry Key, to invert individual lines of data. Figure 2 shows the locations of the two lines we have inverted so far, from Walker Ridge 313 and Walker Ridge 100 (Orca Basin). Every survey setup has its own error structure and characteristics. In particular, this is the first time we have carried out a survey using 6 receivers extending to source–receiver ranges of 1,500 m. Once we understand the error structure for this 2017 survey, future inversions of the data should proceed more rapidly than these initial steps.

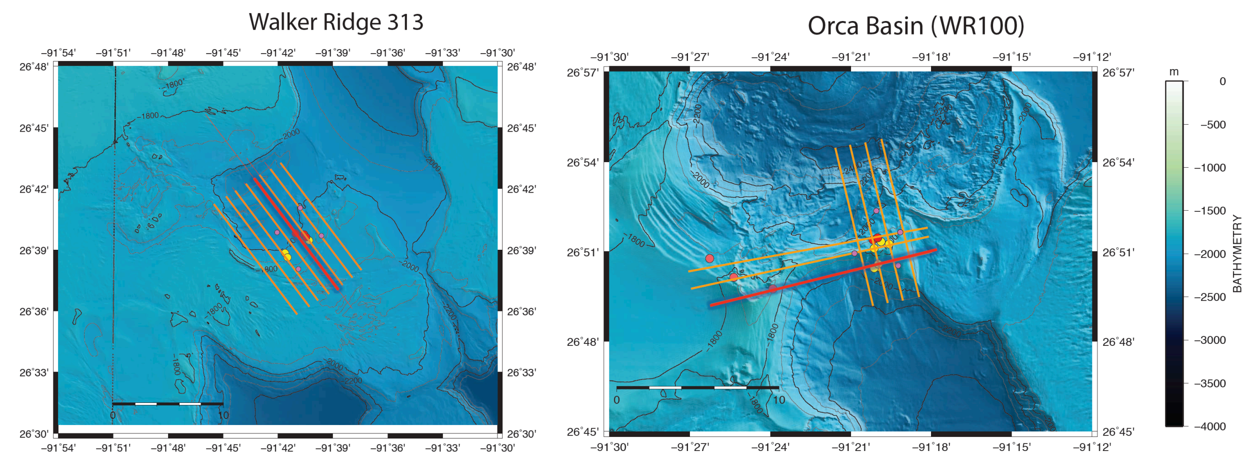

Figure 2. CSEM track lines lines (orange) for Walker Ridge 313 and for Orca Basin. Light purple circles are transponder drop locations used to navigate the transmitter and receiver (see last quarterly report). Red and yellow circles are primary and secondary drill sites, respectively, for the 2020 GOM^2 drilling campaign. Thin red lines are USGS 2D seismic lines. Thick red lines show the data used for 2D inversions.

Figure 3 shows an anisotropic inversion of line 2 collected over WR 313. As is often the case, we had to include anisotropy in order to avoid artifacts in the model and to fit amplitude and phase data simultaneously. However, we discovered that the inversion algorithm made the salt body to the SE of the line unrealistically anisotropic, at the expense of including anisotropy in the sediment, where it is expected to occur. We therefore fixed the salt body as a 100 Ωm isotropic feature, which produced a more reasonable model with a resistive feature which tracked seismic stratigraphy above the BSR.

Figure 4 shows the amplitude and phase data along with model response for inline electric field data at a single frequency of 3.5 Hz, for all 6 Vulcan receivers (range increases with receiver number). The fits are excellent, but there is a small residual bias between amplitude and phase for receivers 1 (the closest to the transmitter), and 5 (the second-farthest). Although the bias has little effect on the fits and models, we are investigating why it is there. There may be a systematic error in our navigation model, such as the altitude or heading for these particular receivers.

Figure 5 shows an inversion of Line 3 from Orca Basin. The fits are slightly better than for WR 313, and we see a

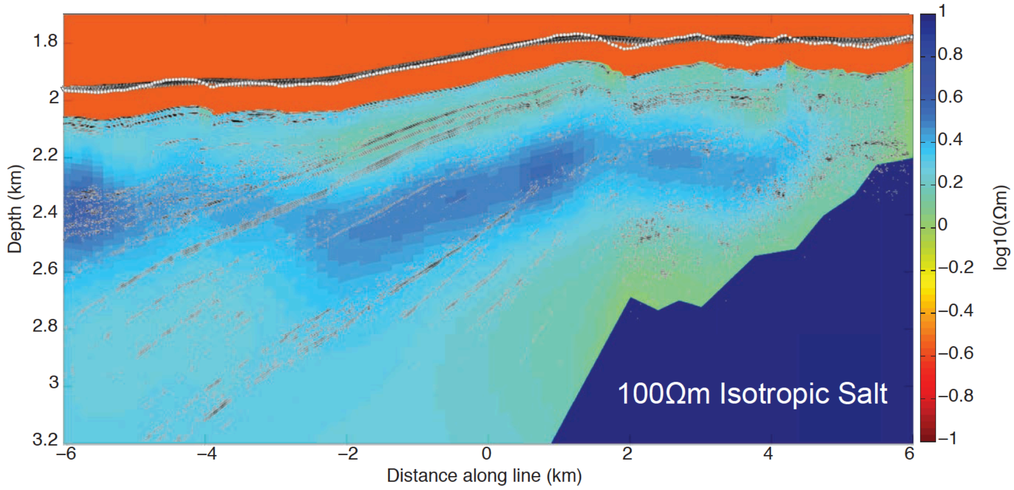

Figure 3. Vertical resistivity for a 2D anisotropic inversion of Walker Ridge 313 line 2, overlain on seismic reflectivity.

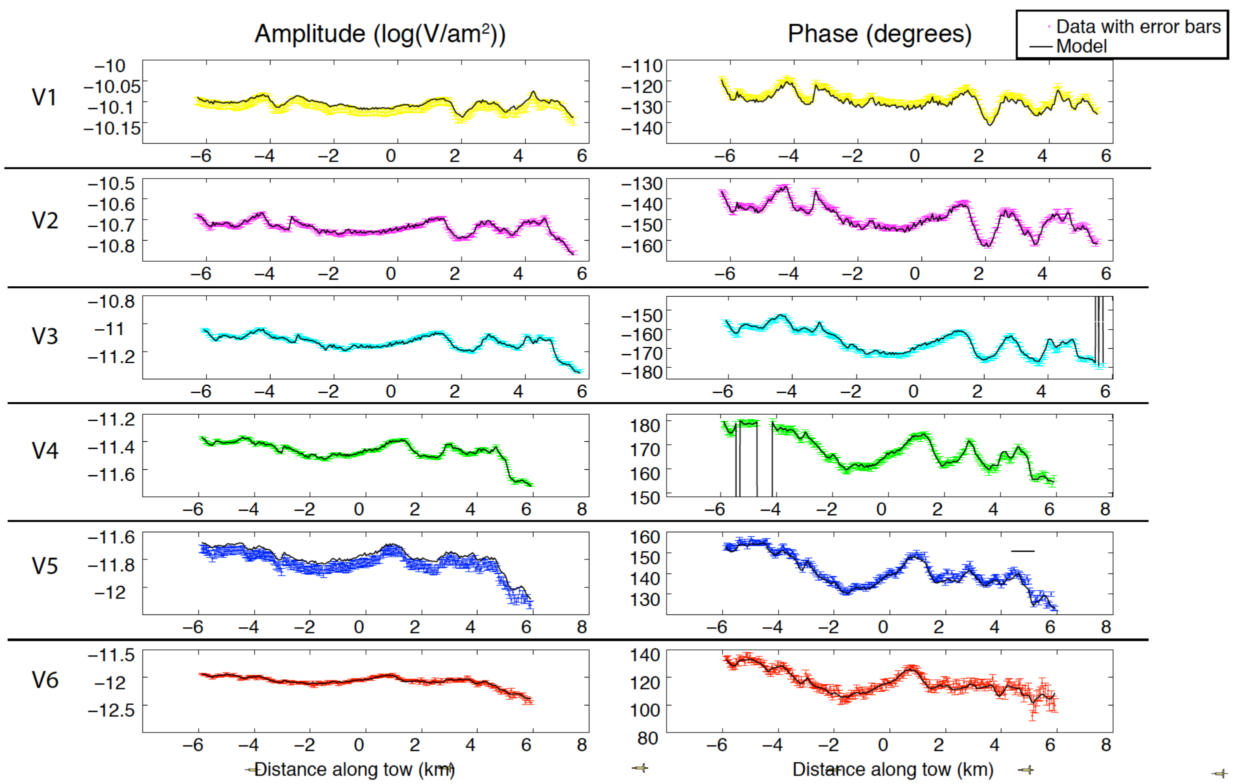

Figure 4. Data fits for the inversion model shown in Figure 3, horizontal electric field at 3.5 Hz. Data are fit to RMS 2.1 with an error floor of 2%.

resistor at the location of the drilling target. Intriguingly, there are pronounced near-surface resistors near the slump scar on the western edge of the prospect. We need to verify that these are not artifacts, but they may reflect shallow hydrate that might have played a role in the slump event.

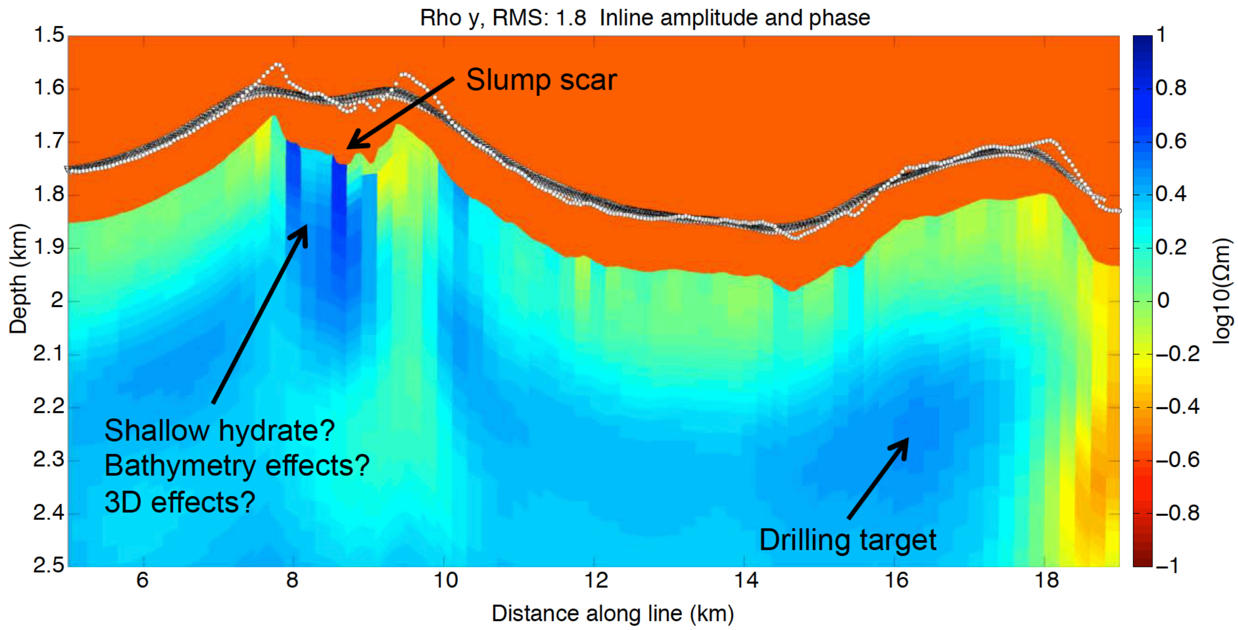

Figure 5. Inversion of line 3 from WR 100 (Orca Basin). We plot horizontal resistivity to highlight features near the slump scar on the western edge of the prospect.

Other activities

Peter Kannberg presented a poster a the Gordon Research Conference in Galveston, February 25–March 2, 2018. Both Ryan Lu and Peter Kannberg both gave presentations at an industry sponsors' workshop at Scripps in late March.

Training and professional development.

Peter Kannberg, PhD student at SIO, acted as co-chief scientist on the data collection cruise. He plans to submit his thesis by the end of summer and will continue work 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.

Plans for next project period.

During the next project period we will continue to collect laboratory data at Menlo Park, and continue with the data processing and inversion of the CSEM field data, with emphasis on the Orca Basin prospect. We will write and submit an article to *Fire in the Ice* on the laboratory studies to date, and begin writing a journal article on the same 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		Internal review	completed
Final set of conductivity runs	9/1/2018		Internal review	
Field data inverted	12/1/2018		2D inversions done	ongoing
Publications(s) submitted	9/1/2019		At least 1 pub. submitted	
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

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

The following papers acknowledge this or past DoE funded research:

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

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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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