Oil & Natural Gas Technology

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Characterizing Baselines and Change in Gas Hydrate Systems using EM Methods

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

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EXECUTIVE SUMMARY

During this reporting period we completed the marine CSEM data collection in the Gulf of Mexico, collecting in all 359 line kilometers of data using a 1.6 km array of 6 Vulcan 3-axis electric field receivers. We have carried out initial data processing and all the data from all the instruments is of good quality.

We continued to carry out electrical conductivity measurements on gas hydrate with added sand and salt. Although we have had some difficulties with the equipment setup, the data collected from the successful runs is of good quality.

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

CSEM data collection.

During the last quarter we mobilized our field program out of Cocodrie, Louisiana, and deployed our instruments for the start of the first survey, at Walker Ridge 313. During this quarter we finished the data collection, and carried out preliminary data processing in order to evaluate data quality. Figures 1 and 2 show the survey area and planned survey lines. We were able to collect data along these lines essentially as planned.

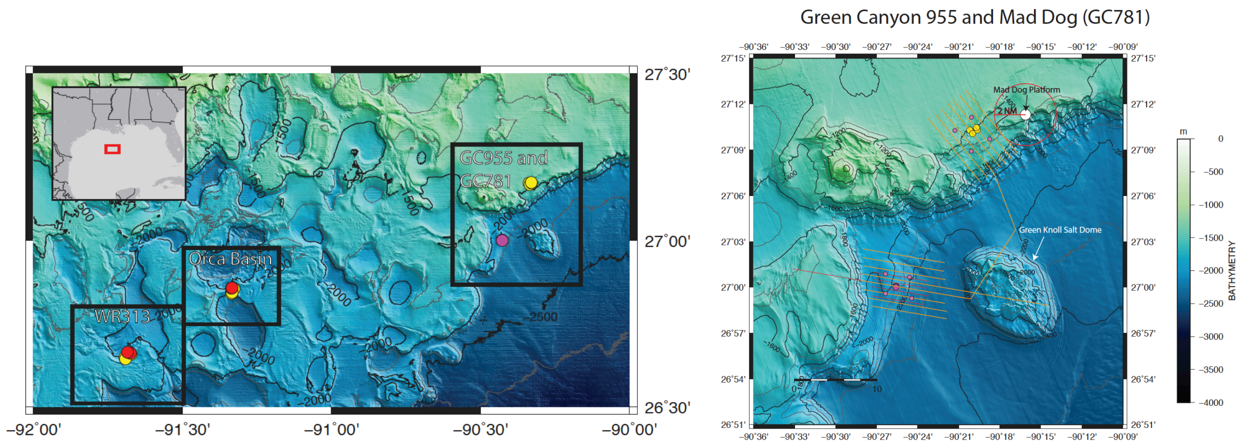

Figure 1. Left: Locations of the three work areas in the Gulf of Mexico. Right: Planned survey lines for the Green Canyon areas. Orange lines are CSEM track lines. Light purple circles are transponder drop locations. Red and yellow circles are primary and secondary drill sites, respectively, for the 2020 GOM^2 drilling campaign. Purple circles at GC955 were drilled earlier this year as a pressure coring test. Thin red lines are USGS 2D seismic lines.

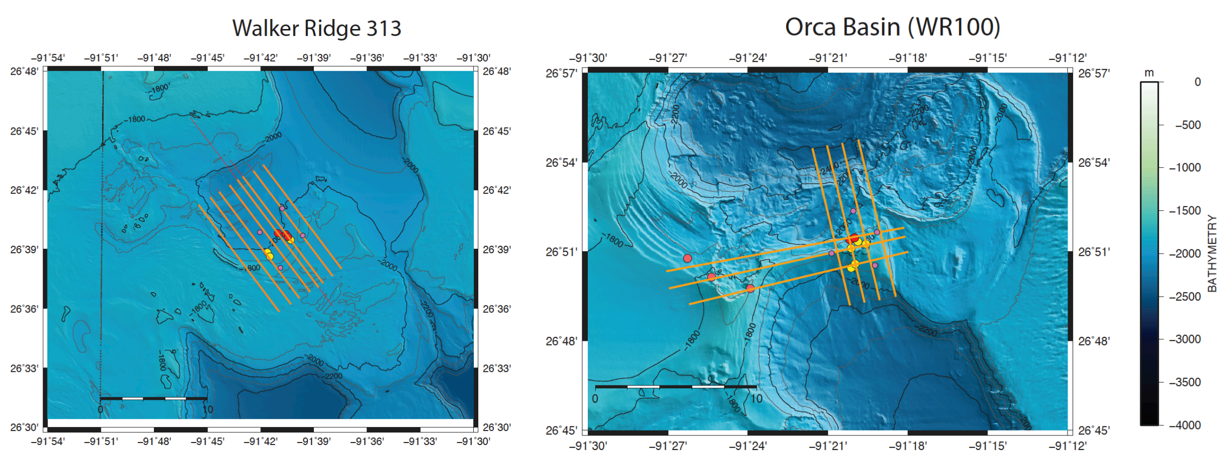

Figure 2. Left: Planned survey lines for Walker Ridge. Right: Planned survey lines for Orca Basin. Orange lines are CSEM track lines. Light purple circles are transponder drop locations. Red and yellow circles are primary and secondary drill sites, respectively, for the 2020 GOM^2 drilling campaign. Thin red lines are USGS 2D seismic lines.

We arrived on station at Walker Ridge 313 in the early hours of the 30th June and deployed the transponder net and CSEM array. The deployment went well and by 09:00 we were testing the transmitter prior to launch. We were collecting data at 50 m altitude above the seafloor by 11:35 and continued through 18:15 on the 2nd July. At that time we recovered the CSEM array and the transponder array, transiting to WR 100 and re-deploying the transponder net. The CSEM array was in the water over WR 100 at 17:00 on the 3rd July. The bathymetry over WR 100 was somewhat rugged, so we made the initial tow line at 100 m above the seafloor, but our 1600 m long receiver array did a good job of following the topography, so we dropped the transmitter down to an altitude of 50 m for the rest of the survey. We finished WR 100 at 10:00 on the 5th and recovered the CSEM and transponder arrays.

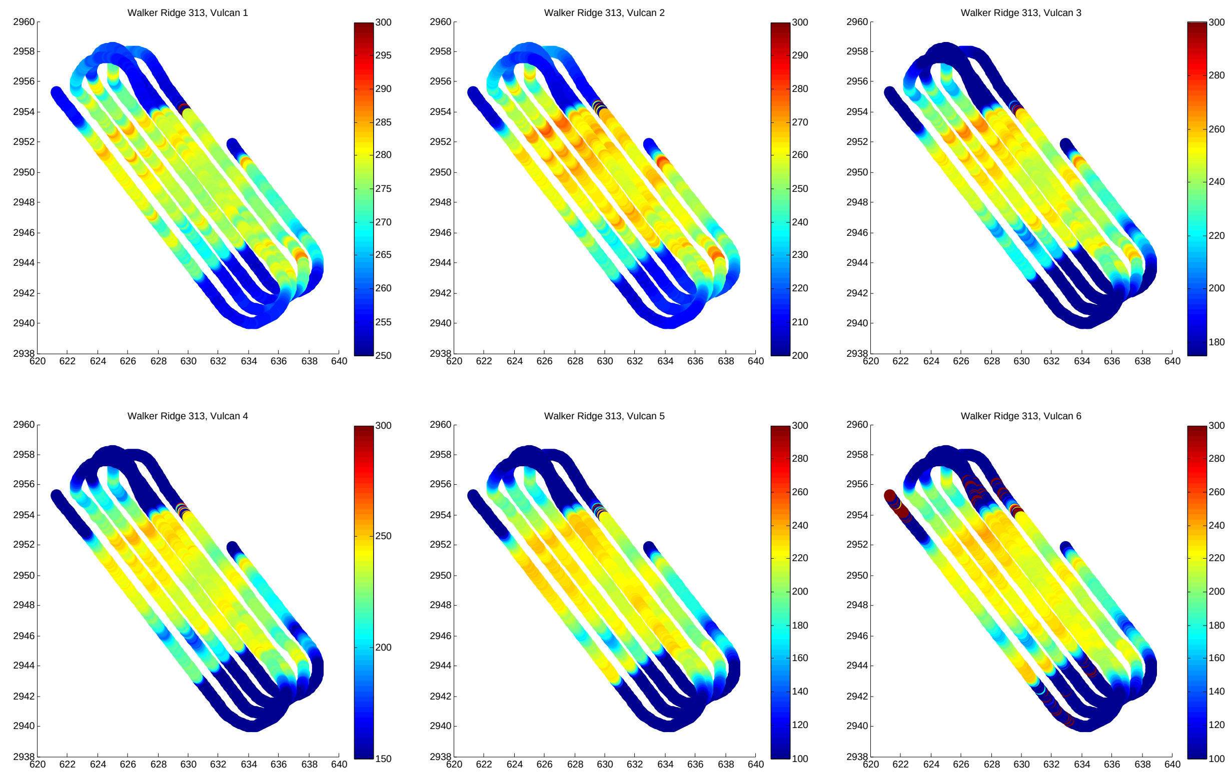

Figure 3. Phase (degrees) of CSEM fields at 1.5 Hz over WR 313, plotted in UTM coordinates (km). The sense of the phase is that red colors represent more resistive seafloor, and the blue colors represent turns at the end of the lines.

We had decided that Green Canyon 955 and 781 could be surveyed together, towing the CSEM array over Green Knoll between the two prospects, but this required putting transponder nets down over both prospects for our transmitter and receiver navigation. This was accomplished by 07:00 on the 6th and we were collecting data over GC 781 by about 10:00 on the 6th. We surveyed GC 781, towed over Green Knoll to GC 955, and finished the survey by early July 10th. We had a few hours in the schedule, so we towed the last line back over Green Knoll before recovering the arrays at 10:00 am. By midnight we had navigated and recovered the transponder arrays and were heading back to Cocodrie, tying up around noon on the 11th.

Throughout the survey, the CSEM equipment worked as designed and without any failures or problems. The one minor issue we had was that one navigation transponder was deployed disabled as a consequence of accidentally receiving a disable command during deck testing the acoustic releases of other units. Since we can navigate the CSEM transmitter using ranges from two acoustic transponders and depth, this should not compromise our survey. All told, we collected 359 line km of data, which exceeds our target of 200 line km set in Milestone 2. As we see below, data quality is excellent.

In Figures 3–5 we plot the phase of the CSEM responses at a frequency of 1.5 Hz (the third, and largest, harmonic of the 0.5 Hz transmitter waveform). The plots are divided into the three deployments of the CSEM system, and further divided by the 6 Vulcan receiver instruments, positioned at 557, 757, 957, 1157, 1357, and 1557 m source-receiver

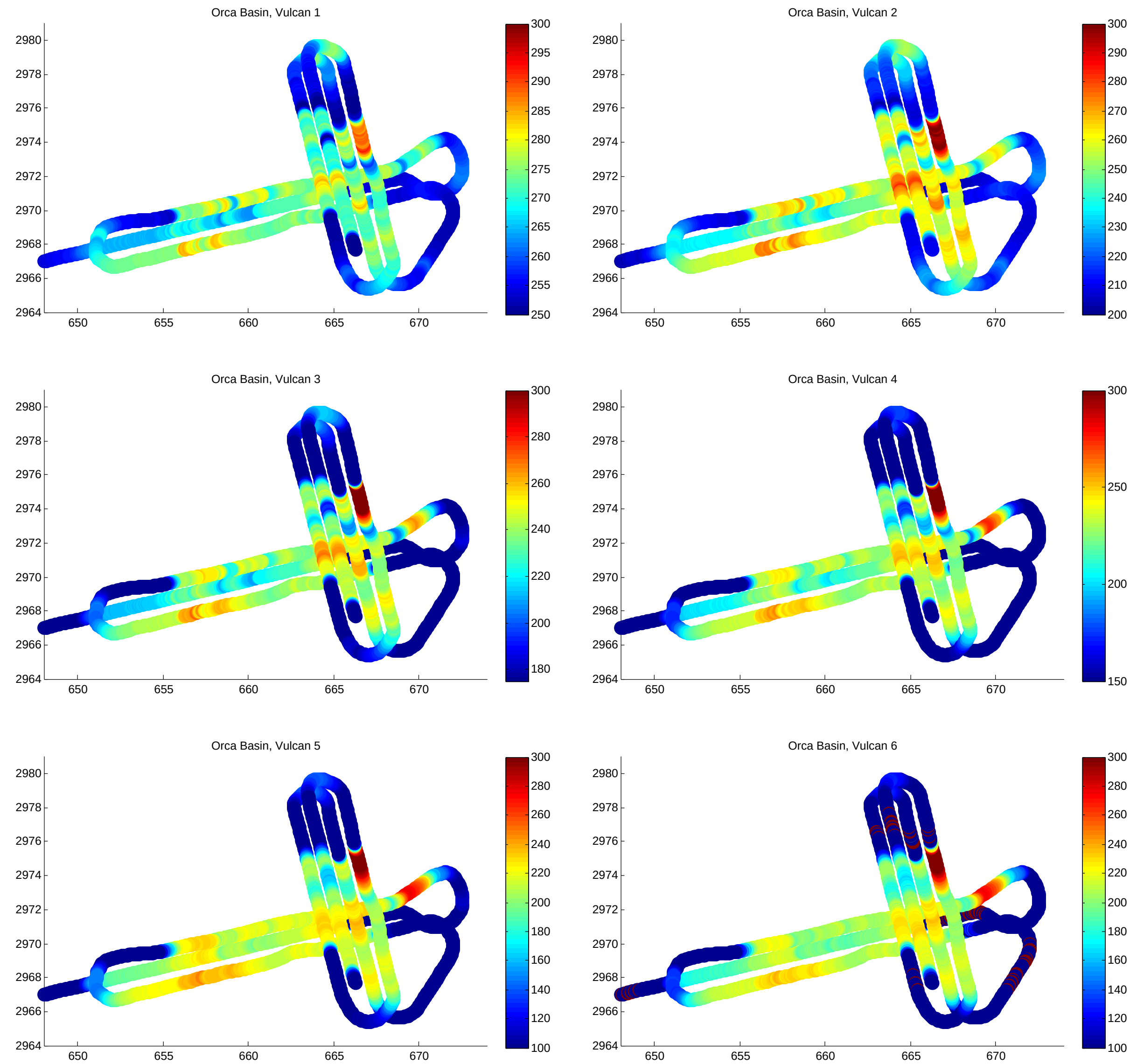

Figure 4. Phase (degrees) of CSEM fields at 1.5 Hz over WR 100 (Orca Basin), plotted in UTM coordinates (km). The sense of the phase is that red colors represent more resistive seafloor, and the blue colors represent turns at the end of the lines.

spacings (higher Vulcan numbers = larger spacings). We have not yet processed the acoustic transponder navigation data to derive accurate transmitter locations, so these plots have been made using an approximate navigation solution by taking the ship's position as a function of time and using the fact that the center of the CSEM array is about 1 hour behind the ship at the normal survey speed of 1.5 knots. Although this is only approximate, it does provide a reasonable picture of the data coverage and quality.

The convention used here is phase lead, projected into positive numbers. The effect of this is that red colors (larger phase lead, smaller phase lag) represent more resistive seafloor, while blue colors (smaller lead, larger lag) represents higher conductivity, and in this case highlights the turns where the array was lifted from the seafloor and into midwater. The plotting scale is somewhat arbitrary in order to highlight the phase variations for each Vulcan, so one should not read too much into any Vulcan to Vulcan variations in color.

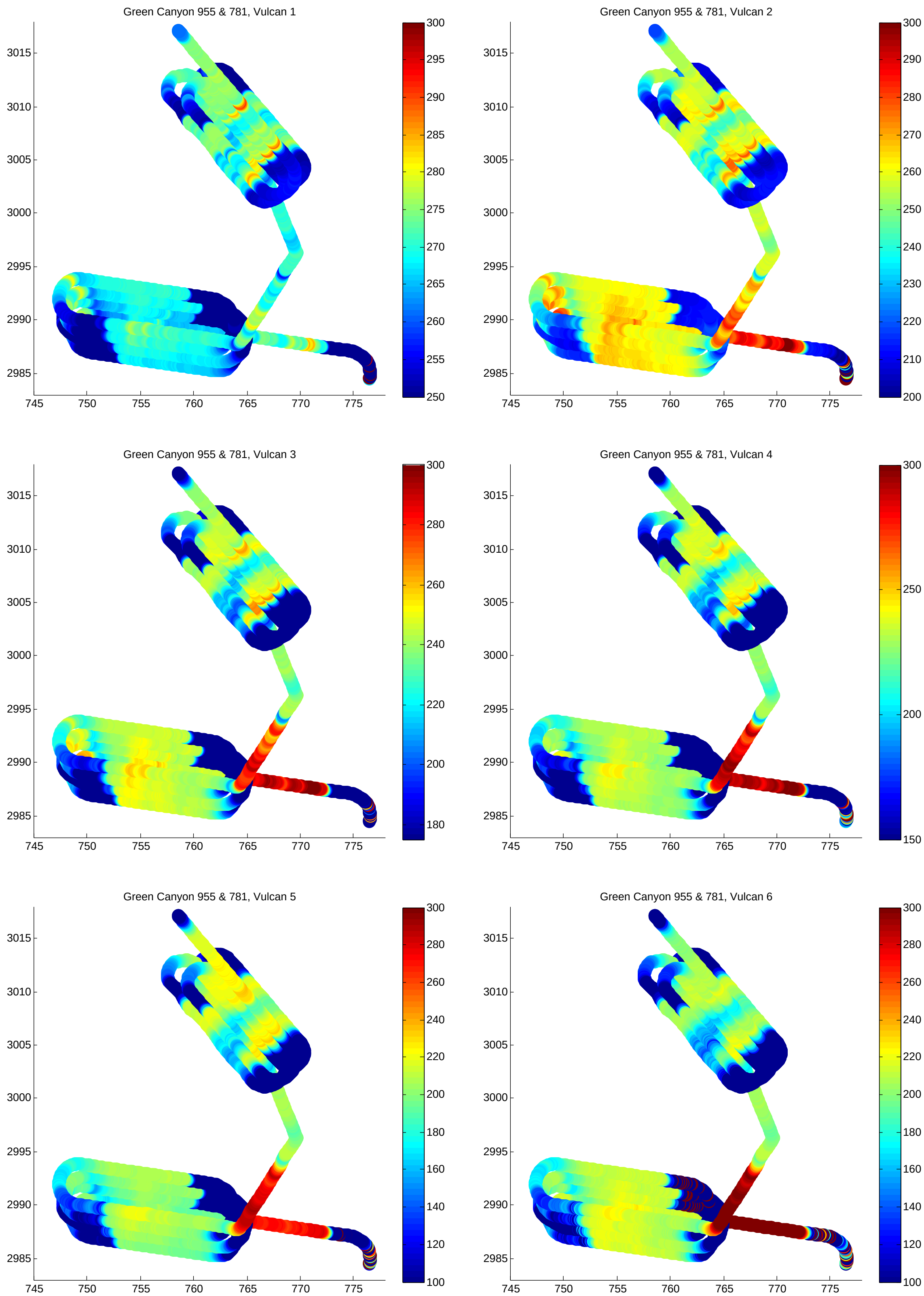

Figure 5. Phase (degrees) of CSEM fields at 1.5 Hz over GC 781 (Mad Dog, top) and GC 955 (bottom), plotted in UTM coordinates (km). The sense of the phase is that red colors represent more resistive seafloor, and the blue colors represent turns at the end of the lines. The red colors to the NE of GC 955 is the resistive response of salt in Green Knoll.

In Figure 3 (WR 313) we can see phase variations of around 50° that are highly coherent between lines. This is encouraging both from a data quality/reproducibility point of view, and an indication of our ability to get meaningful results using 2D inversion, which will be our next step.

At WR 100 (Figure 4) we see more complexity it the signals, and while some line-to-line consistency is evident, there is significant variation between lines. Most obviously, there is a very resistive area (red phases) in the north-east part of the survey, most likely associated with near-surface salt.

Figure 4 shows the two Green Canyon prospects, which again show good line to line coherence, and a pronounced resistive signature, especially at longer source-receiver offsets, associated with Green Knoll.

It should be noted that we have eight times the amount of data shown above. Although we have plotted only one harmonic (1.5 Hz), we also have data at 0.5 Hz, 3.5 Hz, and 7.5 Hz, with signals above the noise floor on all Vulcans, as well as vertical electric field components.

Electrical conductivity measurements.

In the last quarter we made our first run in the electrical conductivity cell, a baseline measurement on pure methane hydrate. At the end of the run we partially dissociated the sample through depressurization in order to produce a hydrate product with a coexisting liquid water phase. The cryo-SEM images showed a very interesting texture with water distributed in segregated patches, either a result of water migrating from dissociating hydrate grains and pooling, or dissociation preferentially occurring in the patches. The texture of the methane hydrate grains, which appear eroded on the boundaries, does suggest some dissociation that is spread evenly through the sample.

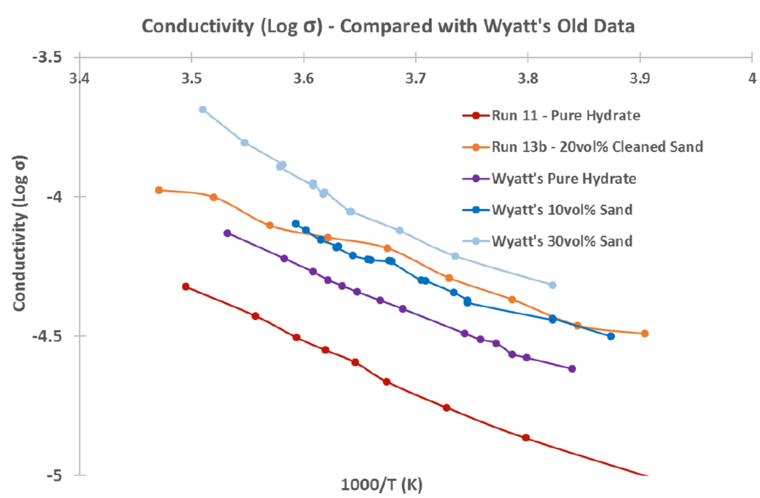

Figure 6. Log(conductivity) versus reciprocal temperature (Arrhenius plot) of conductivity runs compared with data from DuFrane *et al.* (2015) ("Wyatt's"). The current pure hydrate run (Run 11) is less conductive that the earlier run because of improved purity of the seed ice, but the activation energy (slope) is almost identical. The current hydrate plus sand run (Run 13b) again has a similar activation energy and falls within the expected conductivity range.

This quarter we have experienced some challenges with the data acquisition system, probably as a result of wear and tear on the conductivity cell, electrode leads, etc., as a result of the quenching in liquid nitrogen necessary to carry out the cryo-SEM imaging. Dissociation by reduced pressurization has proved to be a little challenging, and we are still working on that technique. However, we continue to make progress.

Figure 6 shows two runs made during the current project compared with data from the previous study. The agreement is good. Figure 7 shows cryo-SEM images of quenched hydrate-ice-sand mixture from Run 13b. The quartz sand grains are hard to see because they tend to be covered by hydrate or ice, but where they are exposed during dissociation they can be distinguished by Si peaks in the EDS (energy-dispersive X-ray spectroscopy) spectra.

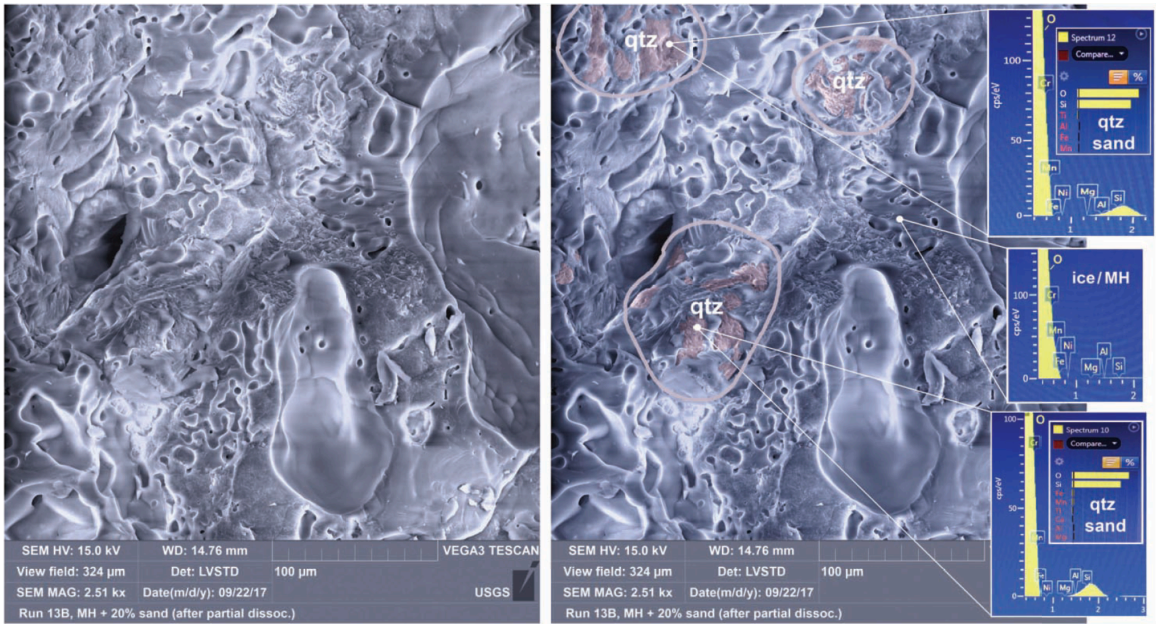

Figure 7. Cryo-SEM images of quenched hydrate-ice-sand mixture. The right panel shows the sand distribution using false color.

We have submitted an AGU abstract to the 2017 Fall Meeting, describing the data collection in the Gulf of Mexico.

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 postdoc 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.

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	ongoing
Final set of conductivity runs	9/1/2018		Internal review	
Field data inverted	12/1/2018		2D inversions done	
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

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:	Planning field program. Experimental design.
Funding support:	This project
Foreign collaboration:	Yes
Country:	Canada
Travelled:	No

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

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

CHANGES/PROBLEMS

We have had some failures of laboratory conductivity runs, which we are addressing. Otherwise there are no changes or problems.

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