Oil & Natural Gas Technology

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Quarterly Report

January 2010 to March 2010

Gas Hydrate Characterization in the GoM using Marine EM Methods

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National Energy Technology Laboratory

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Office of Fossil Energy

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EXECUTIVE SUMMARY

We presented some of our results from the Gulf of Mexico gas hydrate cruise at a NETL/DoE Hydrate meeting held in Atlanta, Georgia, on January 25–29, 2010. At this meeting we learned of the latest JIP and Mississippi Canyon 118 results, enabling us to integrate the CSEM data with the JIP/MC118 findings. The meeting also provided an opportunity to develop future collaborations. We wrote and submitted a *Fire in the Ice Article* on the CSEM data collected over Mississippi Canyon 118. Some of our results were also presented at our annual sponsors' meeting (March 17-18). We have submitted a *First Break* article about our preliminary results from MC 118 and GC 955, scheduled to be published in June (2010). Reviews were returned in January of our paper on the 2.5D finite difference inversion of the Hydrate Ridge data and we have spent some time responding to the reviewers comments. We also submitted another paper to *Geophysical Journal International* on the geologic interpretations of the CSEM and MT data collected at Hydrate Ridge.

All the Vulcan data have now been processed and modeled as 1D apparent resistivity. Here we present some of the results from GC 955 and WR 313. Processed CSEM data has been distributed to our industry sponsers. The conductivity cell has been built.

PROGRESS, RESULTS, AND DISCUSSION

Phase 1.

Task 1.0: Project Management Plan. Completed November 5, 2008.

Task 2.0: Technology Status Assessment. This is embodied in the original proposal.

Task 3.0: Collect Marine CSEM Field Data. Completed October 26, 2008.

Task 4.0: Design and Build Conductivity Cell. We have purchased and machined all the parts for the hydrate conductivity cell, and are ready to proceed with tests on ice at Scripps, prior to installing the cell at Menlo Park for measurements on hydrate. We were hoping to make the first ice runs prior to our current cruise off Nicaragua (April 9 to May 15th), but the laboratory was busy preparing for the current operation. Our plan is to start experiments as soon as we return in May.

Task 5.0: Preliminary Field Data Interpretation. Completed October 2009.

Task 6.0: Make Hydrate and Hydrate/Sediment Conductivity Measurement. This is scheduled for later this year.

Task 7.0: Modeling and Inversion of Field Data. All of the OBEM data have been forward modeled and preliminary interpretations have been presented previously. In addition, the MC 118 Vulcan pseudosections were presented in the last quarterly report. Here we present Vulcan pseudosections for GC 955 and WR 313 and make comparisons with the OBEM data. 1D inversions of the data are planned for later this year.

The transmitter and receiver geometry was used to generate 1D half-space forward models for various resistivities using the Dipole1D code of Key (2009). The major axis of the polarization ellipse is used to select the half-space forward model that matches the recorded data, to create an apparent resistivity for each transmitter–receiver pair and a pseudosection projection technique is used to image the data. Figure 1 (left) shows a schematic of the data projection for mapping ranges into depths; the longer the transmitter-receiver offset the deeper that data point is projected. A similar approach is taken with the Vulcan data except that the Vulcan apparent resistivity pseudosections are generated using the total field from all three components of the electric field measured by the instrument. Forward modeling is again used to compute apparent resistivities as a function of frequency. The apparent resistivities are projected into depth using skin depths for each frequency as a length scale, as shown in Figure 1 (right).

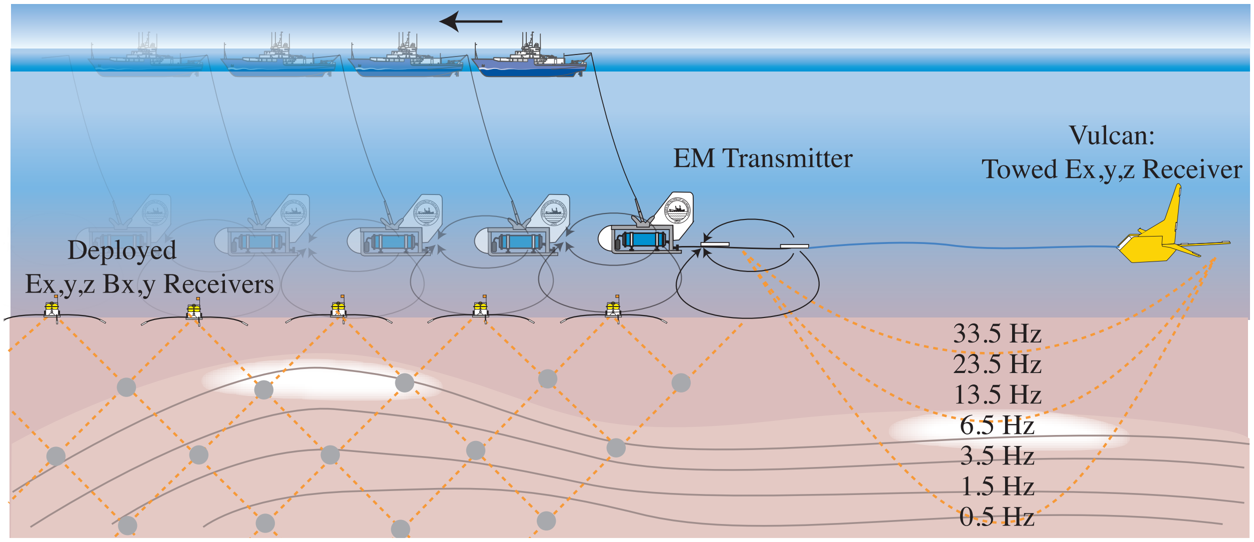

Figure 1: Marine CSEM system showing deployed OBEM instruments and the towed 3-axis electric field receiver called Vulcan. We can build apparent resistivity pseudosections two different ways: The left side shows apparent resistivities derived from OBEM instruments projected to a mid-point between the EM transmitter and receiver, at a pseudo-depth proportional to the transmitter-receiver offset. For the fixed-offset towed receiver (right), apparent resistivities from different frequencies can be projected at the common mid-point based on skin depth, with lower frequencies having larger skin depths/deeper penetration.

Pseudosections provide a way to observe lateral variations in resistivity and give qualitative depth relationships. However, they do not provide quantitative depth information, and so the depth scales in the following figures should not be taken literally. New results for the GC 955 and WR 313 are presented below.

Green Canyon 955

GC 955 is a prospect in intermediate water depth (1900–2200 m) located seaward of the Sigsbee Escarpment and at the mouth of Green Canyon, which brings sediments onto the deep seafloor. There is surface evidence of features often associated with hydrate, such as mud volcanoes. A surface channel is present in the bathymetry and channel sands are present at depth. One such channel sand is a target of the JIP, and is well defined in seismic data, which shows evidence of gas accumulation near the base of the hydrate stability field (McConnell et al., 2010; Hutchinson et al., 2008; Jones et al., 2008).

The CSEM survey occurred while a drill rig was present on the block and so the twenty OBEM receivers and two CSEM tow lines were chosen to avoid the anchor pattern of the rig (Figure 2). For this reason the CSEM lines do not intersect directly with the JIP drill locations. The N-S CSEM line is located in an area of four-way closure consisting of a bathymetric high cored by allochthonous salt above which sandy levee sands are sealed by a regional shale layer (Hutchinson et al., 2008). Faults here provide migration pathways for fluids (Hutchinson et al., 2008). This allochthonous salt is a large regional feature that is hour-glass shaped and extends to the South into Walker Ridge (McConnell et al., 2010 and references therein). Seismic horizon C, shaded in grey, is a channel sand expected to contain gas hydrate (Hutchinson et al., 2008) the extension of which the E-W CSEM line may cross. A horseshoe shaped scarp face also exists to the east, which likely resulted from internal failure due to fluid flow and gravitational forces at over-pressured sand cropping at the base of the Sigsbee escarpment (McConnell et al., 2010 and references therein). A similar process is likely occurring below the E-W line to the east of the area of four-way closure, where there is an amphitheater-shaped region of seep sapping (McConnell et al., 2010).

Pseudosections for the E-W and N-S CSEM tows are shown for the OBEM receivers at the fundamental frequency of 0.5 Hz in Figure 2 (right). One main observation is that the N-S CSEM line is more resistive than the E-W CSEM line.

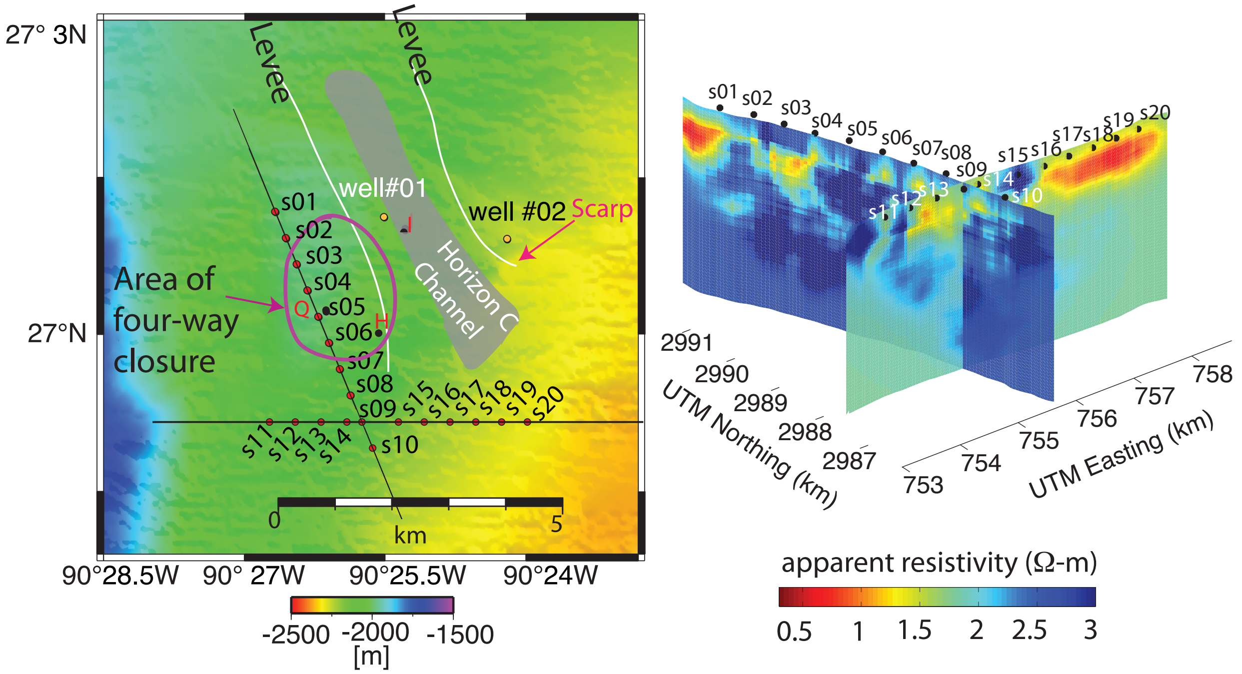

Figure 2. GC 955 survey map with annotations from Hutchinson et al. (2008) (left) and 0.5 Hz OBEM pseudosections (right). Bathymetry from NGDC.

This is likely caused by a regionally extensive N-S trending allochthonous salt body present along this line. The E-W line is perpendicular to this structure and its pseudosection is not dominated by the presence of salt. Gas hydrates were found in GC 955 well 'H' and 'Q', both targeting hydrate filled sands that are located in the area of four-way closure (McConnell et al., 2010). In addition, well 'H' also encountered fracture-filled hydrate above the sand target. The drilling at well 'Q' had to be aborted due to gas flow, either caused by hydrate dissociation or free gas (McConnell et al., 2010). The N-S pseudosection is resistive at site s05, consistent with the existence of hydrate in the coincident JIP well 'Q'. The N-S and E-W CSEM lines cross at site s09 and tie well.

Figure 3 (left) shows Vulcan and 6.5 Hz and 0.5 Hz OBEM pseudosections for the E-W CSEM line. The three images tell a consistent story: a conductive region to the east (s16 to s20) and more resistive area on the slope of the bathymetry high (s15, s09, s14), grading into a interspersed conductive and resistive region at the bathymetric high (s11-s13). The deep resistor in the 0.5 Hz OBEM pseudosection is likely due to the allochthonous salt and the fact that it is barely seen in the 6.5 Hz OBEM pseudosection indicates it is a deeper structure. The resistive region below s11 in the OBEM data is observed in the Vulcan data as well, but is offset due to the different projection geometries of Vulcan and OBEM resistivities. JIP well 'H', located on the flank of the area of four-way closure, is about 1 km north of the E-W CSEM line and is roughly between s09 and s15. Drilling at 'H' found a shale section with fracture-filled hydrate which reaches the seabed and then a deeper occurrence of alternating gas hydrate and water pore fill bearing intervals within a single sand reservoir (McConnell et al., 2010). This is consistent with the resistive region between s15 and s14.

Hydrate was expected to be found in well 'I', which was drilled into the axis of the porous sand channel (horizon C), but water saturated sand with very little hydrate or free gas was encountered (McConnell et al., 2010). This channel sand likely extends to the south and is probably expressed as the more conductive region on the east side between s16 and s20.

The GC 955 N-S tow is shown in Figure 3 (right). The 0.5 and 6.5 Hz OBEM data are dominated by the N-S allochthonous salt, but the Vulcan data appears to be insensitive to its presence, being much more conductive than the OBEM data and having very little structure in the electrical resistivity across the line. Site 5 is roughly at the location

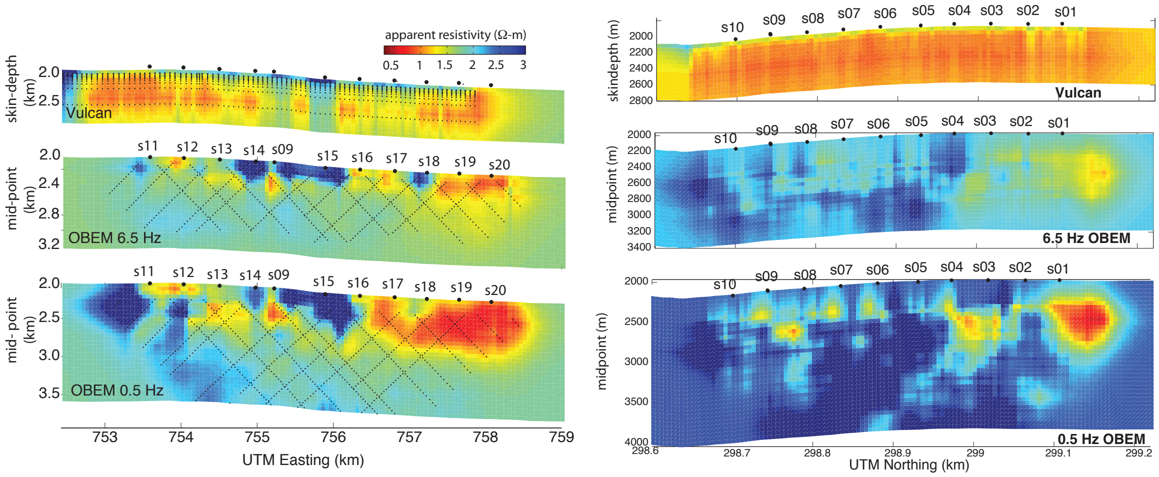

Figure 3: GC 955 E-W (left) and N-S (right) CSEM line for the Vulcan data (top), 6.5 Hz OBEM data (middle) and 0.5 Hz OBEM data (bottom).

of well ‘Q’ which had little evidence of gas hydrate in the upper mud-rich sediments despite its proximity to well ‘H’, which had fracture filled hydrate that reached the seabed (McConnell et al., 2010). In fact evidence for hydrate at ‘Q’ did not occur until about 430 mbsf in a tight section of the well log, and at a greater depth continued drilling caused gas flow (McConnell et al., 2010). This points out the sensitivity of Vulcan as a shallow surface resistivity mapper. The hydrate along the N-S tow is not expected until deeper in the section and is not detected by Vulcan here, whereas along the E-W line there is evidence from well ‘H’ of shallow hydrate and there are surface expressions of hydrate due to the proximity of a mud volcano, and so the shallow resistors along the E-W tow may be caused by shallow hyrdrate.

Figure 4 (top panel) shows a plot of the 0.5 Hz total electric field data (red dots) and the 1D half-space forward models (red lines) for the E-W and N-S tows. The forward models are tracking the data nicely and are generally about 1 ohm-m except in a few places for the EW tow. This suggests that what we are observing in the N-S tow is real and that some of the higher frequencies in the E-W tow are giving the resistivity structure observed there, although further analysis may be required to verify that the blandness in the N-S Vulcan result is real.

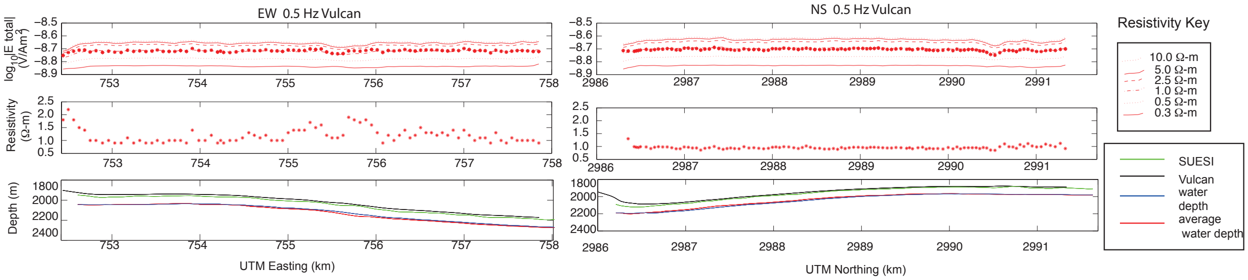

Figure 4: GC 955 EW and NS CSEM line for the 0.5 Hz Vulcan data and 1D half-space forward models (top), apparent resistivities (middle) and respective water depths to the transmitter (SUESI) and Vulcan as well as bathymetric profile.

Walker Ridge 313

The western region of the WR 313 basin is blocked by allochthonous salt to the south, east, and west, creating a closed basin allowing for the deposition of sand (Figure 4). Sediments enter from the north and build up against the salt wall, creating dipping strata of fine grained clays, interbedded silts, and fine grained sands in sheets and channel levee deposits (McConnell et al., 2010).

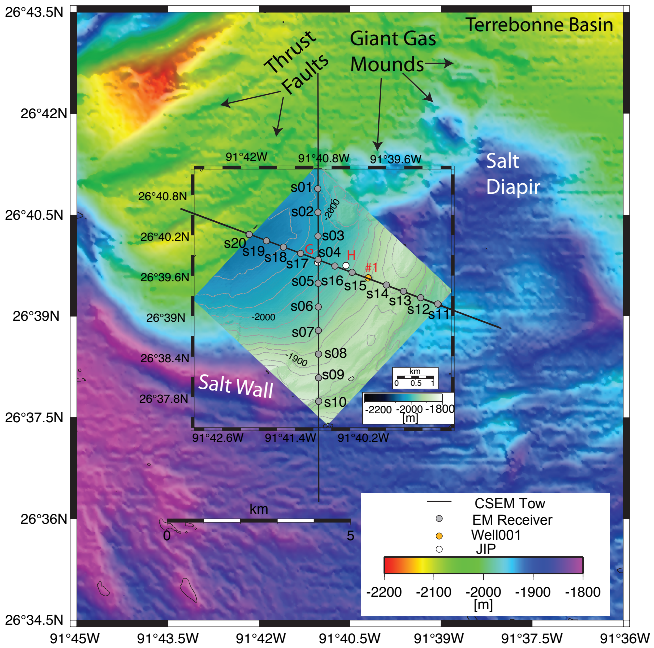

Figure 4: Map showing the layout of the WR 313 CSEM survey along with interpreted geology (after Hutchinson *et al.*, 2008) and locations of wells. Large scale bathymetry from NGDC, small scale from AOA Geophysics.

Seismic data exhibit phase reversals in steeply dipping strata, which are interpreted as a transition from gas-charged sand to overlying gas-hydrate saturated sand (Hutchinson et al., 2008). Twenty OBEM receivers were deployed in two intersecting lines coincident with a 3D seismic volume, an industry well WR 313 #1, and two subsequent JIP well locations drilled in the spring of 2009 at site 4 ('G') and between sites 16 and 15 ('H'). The transmitter was towed about 75 m above the seafloor in a roughly west to east line and then a north to south tow line.

Pseudosections for Vulcan and 0.5 Hz and 6.5 Hz OBEM data are shown in Figure 5 for the E-W (left) and N-S (right) tows. The 6.5 Hz data have a much shallower depth extent and exhibit relatively little resistivity structure. Of note is the salt wall to the south and east where sites 9 and 14 are located. This salt wall is evident in the 0.5 Hz pseudosection as a resistor that extends downwards into the pseudosection. That it is barely present in the 6.5 Hz is an indication that it has a deeper depth extent. Hydrates were found in both wells in the top of the seismic section as strata-bound facture-filling gas hydrate and also within the dipping sheeted sands (horizons blue, orange, and green) that occur deeper in the well (Boswell et al., 2009a). The pseudosections may be capturing the dipping strata but further analysis is required before this can be quantified. The pseudosections give resistive features under both 'G' and 'H' holes in the E-W line, which could correspond with the JIP LWD resistivities.

The Vulcan pseudosections presented here are an update from WR 313 pseudosections presented previously; earlier pseudosections were made using preliminary transmitter navigation, which has since been improved using our total field navigation program. The Vulcan pseudosesctions at WR 313 now give a consistent story with the OBEM pseudosections; the resistivies are similar in value and similar in structure. Furthermore, the crossing Vulcan pseudosections tie well.

References:

Boswell, R., Collett, T., Frye, M., McConnell, D., Shedd, W., Mrozewski, S., Guerin, G. and Cook, A. [2010] Gulf of Mexico Gas Hydrate Joint Industry Project Leg II: Technical Summary.

http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/JIPLegII-IR/

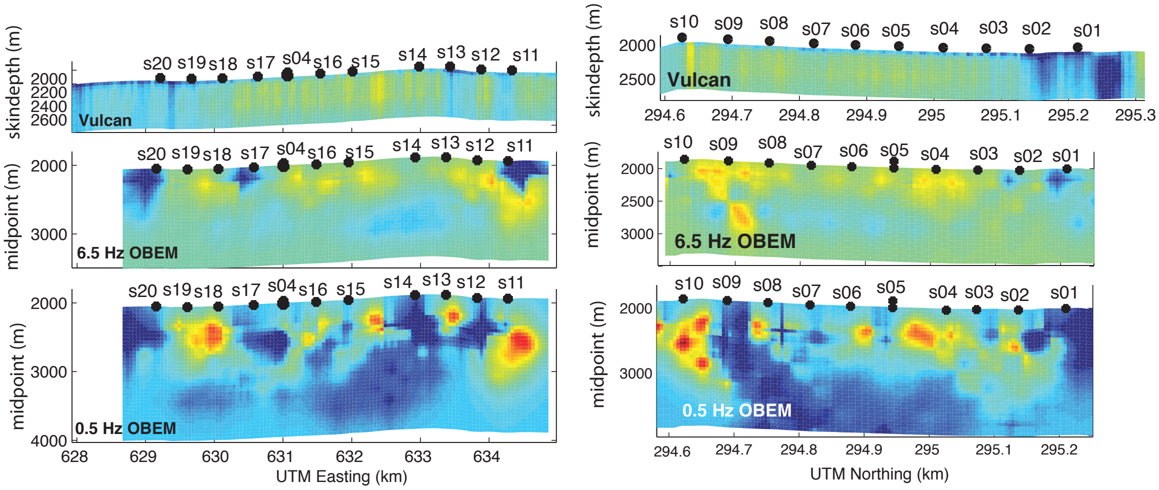

Figure 5: WR 313 EW CSEM line (left) and the WR 313 NS CSEM line (right) for the Vulcan data (top), 6.5 Hz OBEM data (middle) and 0.5 Hz OBEM data (bottom).

Cook, A., G. Guerin, S. Mrozewski, T. Collett, R. Boswell. 2010. Gulf of Mexico Gas Hydrate Joint Industry Project Leg II: Walker Ridge 313 LWD Operations and Results.

Hutchinson, D.R., Shelander, D., Dai, J., . McConnell, D., Shedd, W., Frye, M., Ruppel, C., Boswell, R., Jones, E., Collett, T., Rose, K., Dugan, B., Wood, W. and Latham, T. [2008] Site Selection for DOE/JIP Gas Hydrate drilling in the northern Gulf of Mexico. Proceedings of the 6th International Conference on Gas Hydrates (ICGH 2008), Vancouver, British Columbia, Canada July 6-10 2008.

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Task 8.0: Estimate Quantitative Hydrate Volumes from Field Models and Laboratory Studies. This task commences later this year.

Task 9.0: Technology Transfer. The raw data have been distributed to the sponsors (February, 2009) and preliminary results were presented at the Seafloor Electromagnetics Consortium annual meeting March 18 and 19, 2009. Constable attended the SEG meeting and the Vulcan data was well received with the potential for further research in developing Vulcan systems for third parties. Version 1.0 of the transmitter navigation was distributed to sponsors in early December 2009. At our annual Seafloor Electromagnetics Consortium meeting held March 17 and 18, 2010 Vulcan results at MC 118 were presented and well received. Processed data were distributed to sponsors at the end of March 2010.

Task 10.0: Final Publication. This task is scheduled for Budget Period 3.

CONCLUSION. The conductivity cell has been built and tests on ice will commence shortly. Vulcan pseudosections have been made for all surveys. However, further analysis of Vulcan pseudosections for GC 955 NS tow line and the AC 818 tow lines is necessary to determine the validity of the current results. There are still concerns with the navigation, and so we are limiting our data anlysis to polarization ellipse maximum (Pmax) for the OBEM data and total electric field for the Vulcan data, which appears to work well. Our group has recently updated the 1D forward modeling code to take into account the length of the dipole rather then assuming a point dipole and so we are in the process of remodeling the data using the finite length dipole, which will also be used for the 1D inversions to be preformed later this year. Processed data have been distributed to sponsors and manuscripts have been written, published, and/or submitted for publication.

COST STATUS

Table 1: Project costing profile for Budget Period 2, Quarter 1 (estimated)

Time period	Cost share	DoE Plan	DoE Actual
January 2010	$0	$9784	$8,000
February 2010	$0	$9784	$12,000
March 2010	$0	$9784	$8,000
Totals	$0	$29,352	$28,000

Salaries:

Steve Constable, the PI charged a week in February acting as project leader/manager .

Karen Weitemeyer, a post-doctorate scholar during the budget review period, charged January, February and March salaries.

MILESTONE STATUS

Milestone log for Budget Period 1.

Milestone 1: Revised Project Management Plan. Task 1.0, completed 3 November, 2008.

Milestone 2: Submission of Technology Status Assessment. Task 2.0, embodied in the original proposal.

Milestone 3: Preparation of marine instrumentation for shipping. Task 3.0, completed 30 September, 2008. Equipment was tested in the laboratory and trucked to Fort Lauderdale. Critical milestone for tasks 5,7,8,9,10.

Milestone 4: Carry out field program in GoM. Task 3.0, completed 26 October, 2008. Field program was completed more than successfully, with one extra survey area covered and 15 more stations than proposed. Critical milestone for tasks 5,7,8,9,10.

Milestone 5: Produce initial cruise report Task 3.0, completed 30 January, 2009.

Milestone 6: Design conductivity and pressure cell. Task 4.0, work completed. Critical milestone for tasks 6, 8, 9, 10.

Milestone 7: Generate merged EM/navigated data set. Task 5.0, work completed. Critical milestone for tasks 7, 8, 9, 10.

Milestone 8: Construct conductivity/pressure cell Task 4.0, work completed. Critical milestone for tasks 6, 8, 9, 10.

Milestone 9: Make calibration tests of cell using water standard Task 4.0, work in progress. Critical milestone for tasks 6, 8, 9, 10.

Milestone 10: Install cell in Menlo Park and make initial hydrate measurements Task 4.0, work not yet started. Critical milestone for tasks 6, 8, 9, 10.

Milestone 11: Preliminary interpretation of field data Task 5.0, work completed.

Milestone 12: Webpage updated Task 9.0, January 30 2009.

Milestone 13: Produce Phase 1 Report Tasks 1-5, completed 2 November 2009. Task 4 given a 6 month extension.

ACCOMPLISHMENTS

- Collection of the Marine CSEM Field Data

- Conductivity cell completed.

- Processing of the data is completed.

- Two Fire in the Ice article were published one in 2009 and the other in 2010.

- Participated in a "Spot Light on Research" article for Fire in the Ice in 2009.

- Raw data and processed data have been distributed to sponsors (2009, 2010).

- Generated merged transmitter navigation with the CSEM data using the Total field navigation program and distributed this version to the sponsors in early December 2009.

- Generated pseudosections for the 0.5 Hz and 6.5 Hz CSEM data transmissions for all 14 tows of the 4 surveyed areas in the Gulf of Mexico 2010.

- Generated pseudosections for Vulcan at MC 118 and GC 955 and preliminary interpretations of the data, 2010.

PROBLEMS OR DELAYS The design and construction of the conductivity was given a six month extension. The construction of the cell is complete. We are still making improvements to the navigation, as ranges < 600 m are unsatisfactory with the current navigation program. We want to make an OCCAM-type total field navigation program that will generate smooth models for transmitter location and will improve navigation at the end of tow lines when fewer data constrain the inversion. For this we will also implement a finite dipole rather then the point dipole approximation for the transmitter antenna used for all forward models to date.

PRODUCTS

- Revised Project Management Plan.

- A project website was set up:

  http://marineemlab.ucsd.edu/Projects/GoMHydrate/index.html

  Cruise Report is available for download.

- Project Summary:

  project summary outlining project goals and objectives on the NETL project Web site.

- Collection of Marine CSEM data in the Gulf of Mexico:

Data distributed to sponsors early February.

- Fire in the Ice article published Winter 2009.
- NETL kick off meeting, Morgantown, WV - January 6, 2009

  The PI delivered a project overview presentation.

- Talked at the 2009 MARELEC Meeting - Stockholm, Sweden - July 7-9 2009

  The PI will present a talk entitled *Applying marine EM methods to gas hydrate mapping*

- Submitted the first quarter report February 2 2009.
- Invited talk at LLNL mid march

  Steven Constable delivered a presentation:

  Marine Electromagnetic Methods for Mapping Gas Hydrate

- SIO Seafloor Electromagnetics Consortium annual meeting, La Jolla, CA - March 18-19, 2009

  Karen Weitemeyer delivered two presentations:

  Marine EM for gas hydrate studies, with first results from the Gulf of Mexico

  Using Near field data to navigate controlled source electromagnetic data

- Submitted the second quarter report April 2009.
- Australian show and tell, and 2 talks

  Karen Weitemeyer delivered a presentation at two venues in Canberra, Australia:

  Marine EM for gas hydrate studies, with first results from the Gulf of Mexico

- Submitted the third quarter report July 2009.

  Steven Constable delivered a presentation in Japan:

  Marine Electromagnetic Methods for Mapping Gas Hydrate

- Submitted the Phase 1 report October 2009.
- AGU Poster presentation December 2009

  Karen Weitemeyer and Steven Constable

  Marine EM for gas hydrate studies, with first results from the Gulf of Mexico

- DoE Atlanta Hydrate Meeting January 25-29 Talk and Poster

  Karen Weitemeyer and Steven Constable

Applying Marine EM Methods the Gas Hydrate Mapping

- Submitted the first quarter report of Year 1 January/February, 2010.

- Fire in the Ice article published March 2010.

Test of a new marine EM survey method at Mississippi Canyon 118, Gulf of Mexico

- SIO Seafloor Electromagnetics Consortium annual meeting, La Jolla, CA - March 17-18, 2010

Karen Weitemeyer and Steven Constable delivered a presentation:

Results from the GoM gas hydrate studies

- Processed Data distributed to sponsors late March, 2010 and early April, 2010.

- First Break Article submitted for publication in this years (2010) June issue.

Mapping shallow geology and gas hydrate with marine CSEM surveys

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