Oil & Natural Gas Technology

DOE Award No.: DE-NT0005668

Quarterly Report

April 2009 to June 2009

Gas Hydrate Characterization in the GoM using Marine EM Methods

Submitted by:
Scripps Institution of Oceanography
University of California San Diego
La Jolla, CA 92093-0225

Principal Investigator: Steven Constable

Prepared for:
United States Department of Energy
National Energy Technology Laboratory

April 30, 2009

Office of Fossil Energy

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

During the third quarter we devoted our time to solving for the position and orientation of the transmitter (Y: UTM Easting, X: UTM Northing, θ: set or angle from north). This process involved modification of a marquardt inversion code called total field navigation which was developed for Weitemeyer's PhD thesis and was successfully applied to the Hydrate Ridge CSEM data set to solve for both transmitter and receiver geometries (see Chapter 5 in Weitemeyer, 2008). The total field navigation code uses the short range (<1000 m source-receiver offset) electromagnetic fields recorded at the receivers to invert for the position and orientation of the transmitter. At this stage the code has been tested on the Walker Ridge 313 north-south tow and the results are encouraging and demonstrate that this technique is suitable for use on the Gulf of Mexico CSEM data set. Further work is required before the process can be automated for all of the CSEM surveys collected in the Gulf of Mexico. Once we are satisfied with the results from the total field navigation code it will be made publicly available, and so the code is being written and tested with this in mind. In addition the code is being developed to use the OCCAM inversion to generate smooth models of transmitter parameters.

The PI (Steven Constable) and Karen Weitemeyer were involved in a 32 day research cruise off-shore Australia over a gas field in May/June. While this diverted our attention from the DoE project there was an opportunity to collect a small 15 site CSEM data set over a shallow gas and gas hydrate area. One of the successes of this research cruise is that the Barracuda navigation system that failed during the Gulf of Mexico cruise in October 2008 did work well off-shore Australia. This means that the location of the transmitter is well known for this survey and so we can use this CSEM data set as a benchmark for our total field navigation program, to determine how well it recovers the position of the transmitter.

Several presentations were delivered this quarter. Karen Weitemeyer was invited to give two presentations in Canberra, ACT, Australia: one on June 25th at the Australian National University during the weekly Research School of Earth Sciences seminar series and another on June 26th at Geoscience Australia for the Australian Society of Exploration Geophysicists monthly meeting. Steven Constable attended the MARELEC meeting in Stockholm, Sweden, July 7-9 2009 and presented a talk entitled *Applying marine EM methods to gas hydrate mapping* (co-authored by Weitemeyer).

Time was also spent writing a paper about the Hydrate Ridge inversion result; this will be submitted next quarter to Geophysics: *The practical application of 2D inversion to marine controlled source electromagnetic data* by Weitemeyer, Gao, Constable, and Alumbaugh. We also contributed information about the CSEM survey at Mississippi Canyon 118 for Tom McGee to be used in discussions with their funding agencies.

The conductivity cell design and testing has been delayed due to previously planned field experiments and focusing on getting CSEM results to the JIP.

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. This task has been delayed.

Task 5.0: Preliminary Field Data Interpretation.

Generating a merged EM/navigated data set has taken longer than anticipated because of the failure of the Barracuda navigation system while collecting the CSEM data. A first approach to obtain the transmitter position is based on the winch wire out and the transmitter's pressure-depth gauge to determine the distance behind the ship. The ship's GPS position is then used to back-project the position of the transmitter. However, the treatment of the navigation in this way was inadequate, as demonstrated by inconsistencies with the in-tow and out-tow data at each receiver. These inconsistencies result from both the unknown set of the transmitter (angle from north) and the unknown cross-track distance. Instead, the near field (< 1000 m) EM data can be used to solve for the transmitter position and orientation. This technique was used sucessfully in Weitemeyer's PhD thesis (2008) and is referred to as total field navigation. At each receiver the dipole field of the transmitter is measured and the amplitude and phases of the EM fields are distorted from what one would get for a pure horizontal electric dipole. These distortions directly relate to the position and orientation of the transmitter and can be modeled. The total field navigation approach should work much better for the GoM hydrate data than it did for the thesis data set, since the positions and orientation of the receivers is better known as a result of the dedicated receiver navigation carried out in the GoM and better recording compasses on each instrument.

Modifications to the total field navigation code were necessary to get preliminary transmitter navigational parameters for the Walker Ridge 313 data set. Previously, the total field navigation code required the transmitter positions to be solved at a few 'nodal' points along the tow line and then linearly interpolated for the entire survey. Instead, we have altered the old marquardt code to solve for the X, Y, set (angle from north) and half-space resistivity for each transmitter location, since the known receiver locations mean that we have fewer parameters to solve for. The new marquardt code has been tested on 195 transmitters along the north–south tow at Walker Ridge 313 for only the fundamental frequency of 0.5 Hz and source–receiver offsets < 1000 m. The imaginary and real components are used to avoid difficulties in phase wrapping. The error associated with each data point is the standard deviation computed from the 1 minute averages of 2 second data, and is about 1% of the amplitude. For a single transmitter position there are 10 data points for each receiver (the real and imaginary components of E_x, E_y, E_z, B_x and B_y) and usually about three receivers observe the same transmitter. There are both fixed and free model parameters. Fixed model parameters are: the receiver X/Y positions and orientations, and the transmitter altitude, depth, and antenna dip (from the tail-buoy pressure gauge). The forward code used is Key's (2009) Dipole1D and so 1D approximations need to be made for the depth of the receiver relative to the transmitter, which we assigned to be the same as the water depth calculated from the transmitter's depth gauge plus the transmitter's altimeter. The parameters to be solved are each transmitter X/Y positions, antenna set, and seafloor resistivity. Various different data types have been tried, such as using only horizontal electric and magnetic fields or eliminating the vertical electric field data. Preliminary results indicated this process will work well, but a few improvements are still needed before we obtain a merged EM/navigated data set.

Figure 1 shows an example of the starting model and the final model for the transmitter X, Y, set and half-space resistivity. It includes plots of fixed model parameters: transmitter dip, depth, and the 1D model sea depth. A stratified seawater conductivity–depth profile and an initial resistivity of 2 Ωm were used. In some cases when the final model resistivities were inconsistent with neighboring resistivities, choosing a different starting resistivity resolved the discrepancy. Removing the vertical electric field data significantly improved the misfits. The vertical electric field data may be more sensitive to the seafloor structure then the other components of the EM field. A map view of the starting transmitter position and the final transmitter position is shown in Figure 2 along with the receiver positions. The resistivities consistently sit at just below 2 Ωm as a background resistivity with some variations up to 6 Ωm.

An example of the data and model responses is shown in Figures 3 and 4 for the Channel 1 and Channel 2 magnetic field data (model responses are rotated to match the known orientation of the receivers). Plotted are the real, imaginary, amplitude, phase, and normalized residuals versus transmitter number. Notice that the model responses are able to replicate the data phase jumps at site 6, and site 7 as well as some of the variations in the amplitudes at sites 1, 5, 10, and 7.

There are still a number of improvements to be made. The effect of including other frequencies needs to be investigated. There are is a minor problem to be resolved with the saturated magnetic field data, this appears to be an issue of sign convention between the model and the processed phase data. We need to further examine why the vertical electric field data does not provide good fits, although this same trend was observed in Weitemeyer's thesis.

The residuals and misfits are still too high. For this particular example the misfits are low for the first 20 transmitters

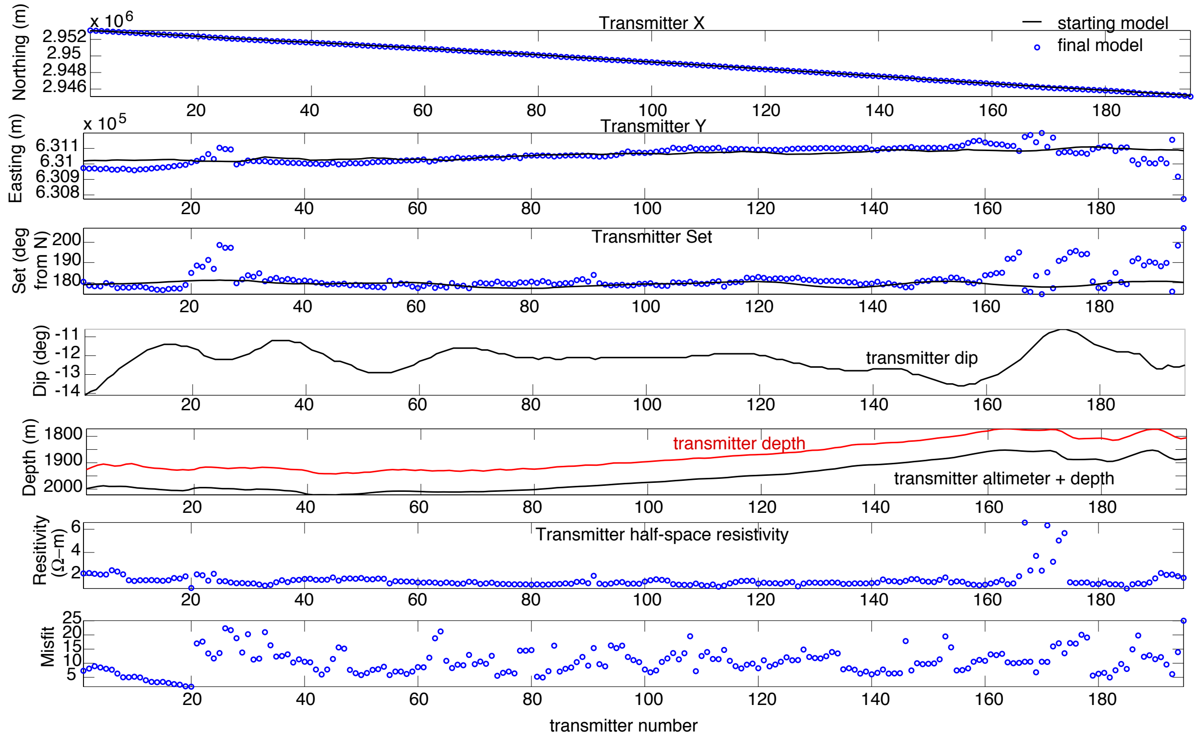

Figure 1. Example of total field navigation parameters solved for in the NS WR 313 tow: X,Y, set, half-space resistivity. Included are the measured and fixed parameters: dip, depth, altitude. The final panel displays the misfit for each transmitter number.

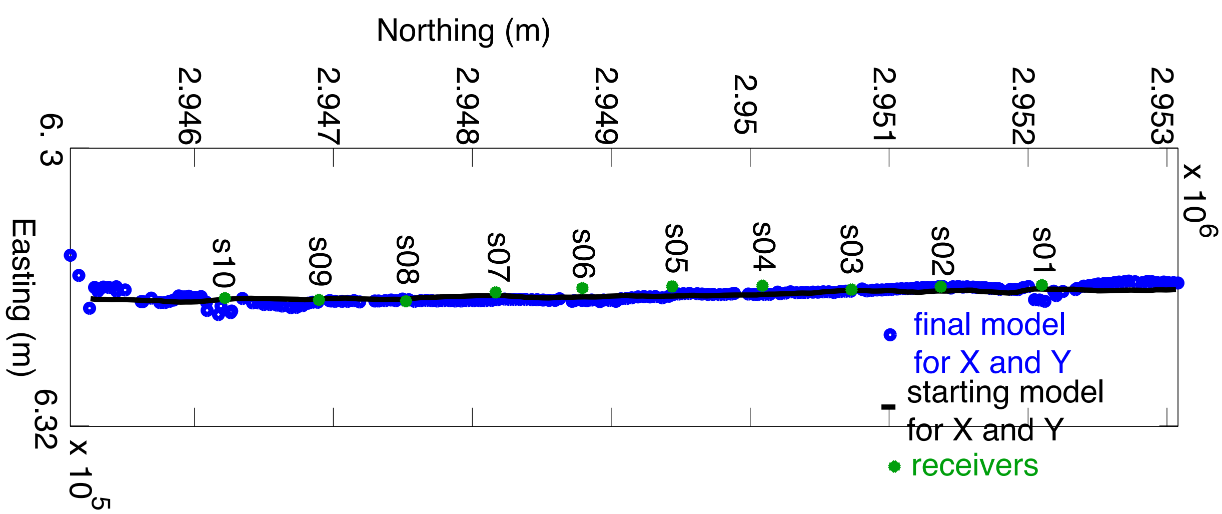

Figure 2. Map view of starting model transmitter X,Y and final transmitter X,Y, with receiver locations.

and then the remainder of the tow has larger variations in the misfit. The larger misfits often correspond to where the set and easting parameters are both scattered. Marquardt can sometimes converge to a local minimum, and so we use different starting values for the inversion runs. However, a better next step is to replace the individual Marquardt fits with a combined OCCAM inversion of the entire data set, which will force the individual transmitter parameters to be smooth along the tow line, which should improve the model significantly. OCCAM is also more robust to variations in starting model.

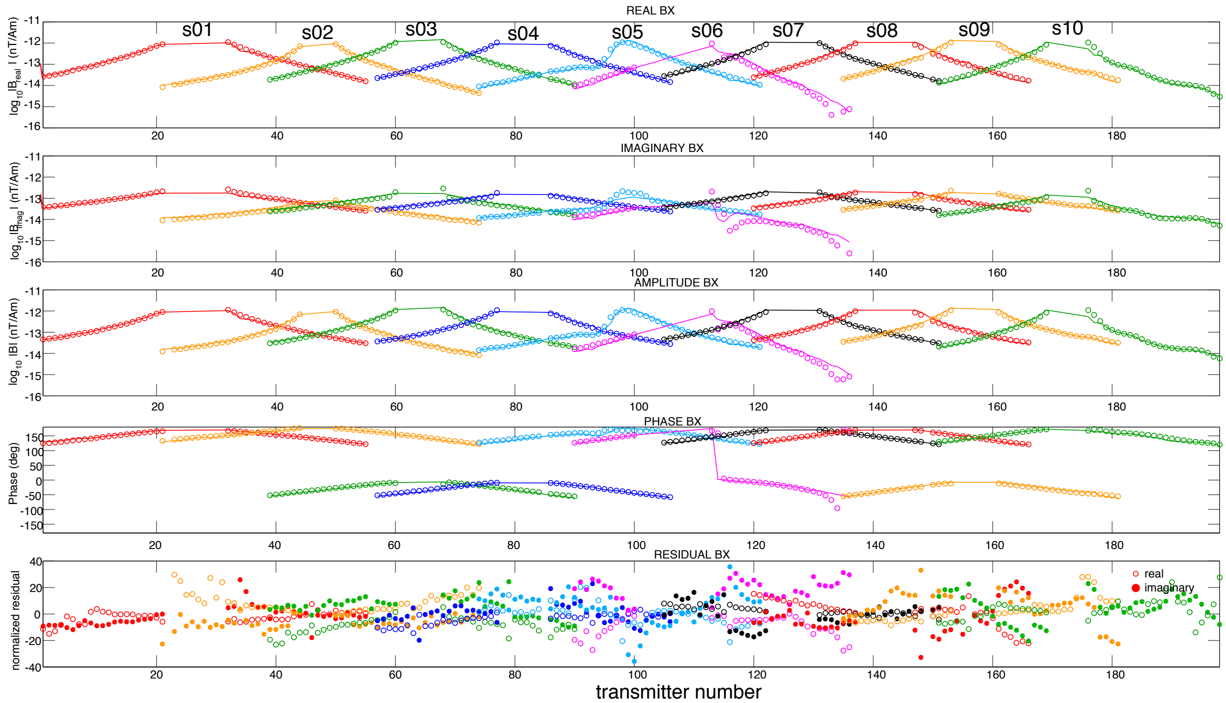

Figure 3. Channel 1 (B_x) real, imaginary, amplitude, phase and residual plots versus transmitter number.

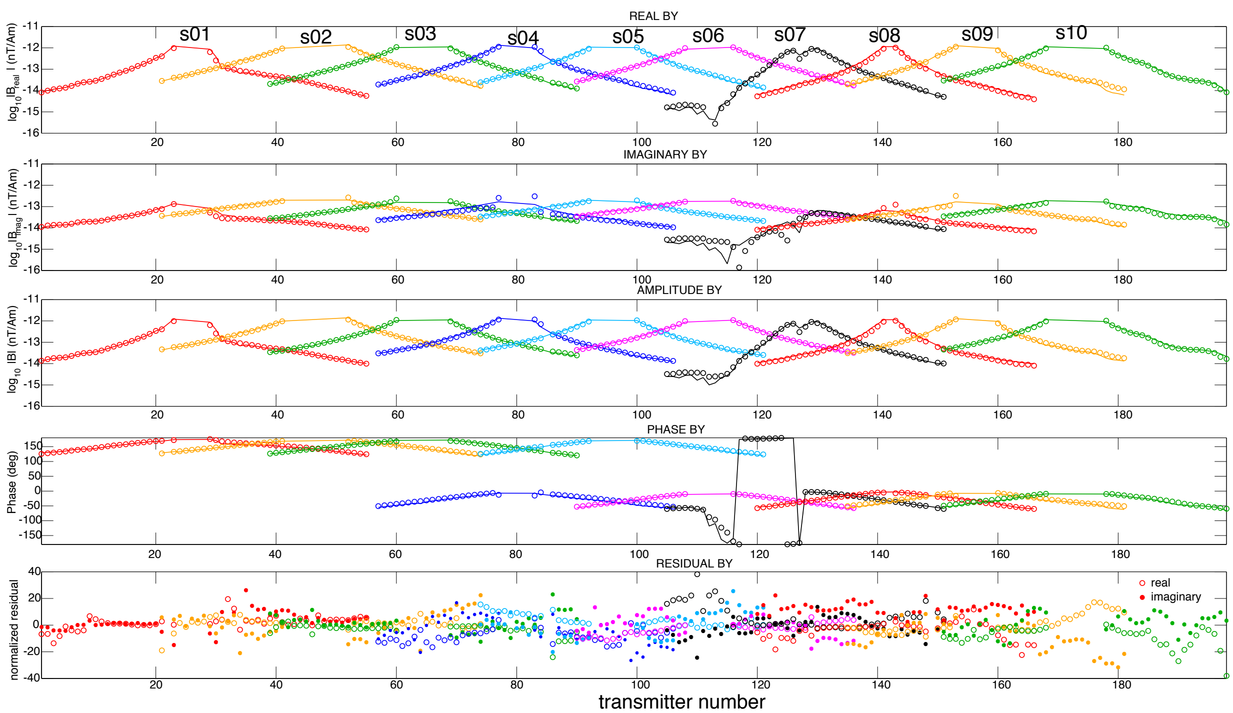

Figure 4. Channel 2 (B_y) real, imaginary, amplitude, phase and residual plots versus transmitter number.

Task 6.0: Make Hydrate and Hydrate/Sediment Conductivity Measurement. This task is scheduled for later this year and Budget Period 2.

Task 7.0: Modeling and Inversion of Field Data. The bulk of this task is scheduled for Budget Period 2. However, we have made some progress in understanding inversion of hydrate CSEM data through our continued work on the Hydrate Ridge data set, which we inverted in collaboration with Schlumberger (see Figure 5).

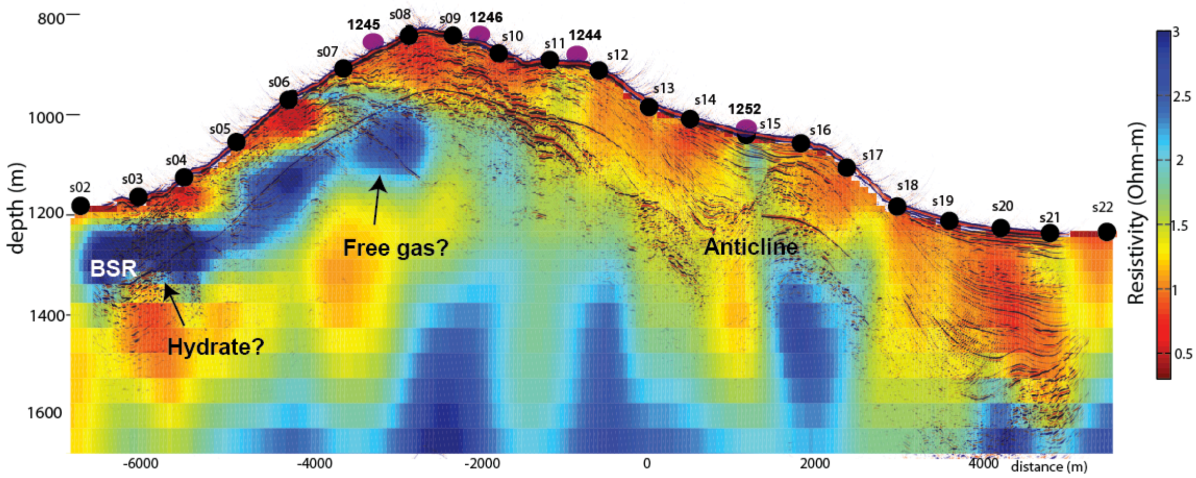

Figure 5. Inversion of Hydrate Ridge CSEM data set, done in collaboration with Guozhong Gao and David Alumbaugh of Schlumberger/EMI Technology Center. Resistive material (blue) is interpreted as gas hydrate above the BSR, and free gas below.

Task 8.0: Estimate Quantitative Hydrate Volumes from Field Models and Laboratory Studies. This task is scheduled for Budget Period 2.

Task 9.0: Technology Transfer. The 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.

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

CONCLUSIONS

We have made a good start to obtaining accurate navigational parameters for the transmitter and we expect to have this finished and have apparent resistivity pseudosections produced on time by the end of next quarter. Although our attention was diverted by a 32 day research cruise off-shore Australia, we were able to collect data relevant to this project. The conductivity cell component of the project has been delayed, but will be re-started next quarter now that progress has been made on the other tasks.

COST STATUS

Table 1: Project costing profile for Budget Period 1, Quarter 3

Time period	Cost share	DoE Plan	DoE Actual
April 2009	$65,327	$9,784	$6,733
May 2009	$1,904	$9,784	$6,667
June 2009	$0	$9,784	$15,308
Totals Q3	$67,231	$29,352	$28,709

Table 2: Cumulative costing profile

Time period	Cost share	DoE Plan	DoE Actual
Totals Q1	$528,141	$499,378	$481,123
Totals Q2	$25,306	$29,352	$49,621
Totals Q3	$67,231	$29,352	$28,709
Totals	$620,678	$558,082	$559,453

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 underway. Critical milestone for tasks 6, 8, 9, 10.

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

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

Milestone 9: Make calibration tests of cell using water standard Task 4.0, work not yet started. 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 underway.

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

Milestone 13: Produce Phase 1 Report Tasks 1-3, completed. Tasks 4.0 and 5.0 are ongoing and have been delayed.

ACCOMPLISHMENTS

• Collection of the Marine CSEM Field Data

• Conductivity cell design underway.

• Processing of the data is underway.

• A Fire in the Ice article was published.

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

• Data distributed to sponsors.

PROBLEMS OR DELAYS

Task 4 – the design and construction of the conductivity cell – has progressed more slowly then anticipated. This is in part due to our attention being diverted to obtain a quick result for the JIP hydrate drilling campaign as well as a commitment to a large CSEM experiment conducted offshore Australia. Task 5 – Generate merged EM/navigated data set – has also progressed more slowly due to the failure of our Barracuda navigation system while at sea. As a first step, and in order to obtain a quick result for the JIP, we used wire out, pressure and altimeter data in the transmitter to project back the position of the transmitter, however, the treatment of the data in this way was inadequate resulting in significant inconsistencies for in tows and out tows at each receiver. Instead we have been modifying the total field navigation code used for Weitemeyer's PhD thesis to solve for transmitter position and orientation. It has been applied to the WR 313 data set and further testing is required before we can apply this code to all of the surveys from the Gulf of Mexico.

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.

• 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 May 1 2009.

• Presentation at the 2009 MARELEC meeting - Stockholm, Sweden - July 7-9 2009

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

• Two Invited Seminars in Canberra, ACT, Australia:

1) Research School of Earth Sciences, Australian National University, June 25 2009

2) Australian Society for Exploration Geophysicistst at Geoscience Australia, June 26 2009

Karen Weitemeyer presented a talk entitled:

Marine Electromagnetic Methods for Gas Hydrate Characterization

National Energy Technology Laboratory

626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940

3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880

One West Third Street, Suite 1400
Tulsa, OK 74103-3519

1450 Queen Avenue SW
Albany, OR 97321-2198

2175 University Ave. South
Suite 201
Fairbanks, AK 99709

Visit the NETL website at:
www.netl.doe.gov

Customer Service:
1-800-553-7681