Oil & Natural Gas Technology

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Quarterly Report

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Gas Hydrate Characterization in the GoM using Marine EM Methods

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EXECUTIVE SUMMARY Electrical conductivity measurements on laboratory hydrate continued and we began making measurements on hydrate-sediment mixtures. A meeting was held January 6 in Menlo Park with Laura Stern, Wyatt DuFrane, Jeff Roberts, John Pinkston, Steven Constable and Karen Weitemeyer to discuss the preliminary results from the cell and future directions for research. Wyatt is leading a Geophysical Research Letters submission about the first results on the temperature dependence of methane hydrate conductivity. A Geophysics paper was published this past November, 2010, about the 2D inversion of CSEM data collected at Hydrate Ridge. An abstract was submitted to the MARELEC meeting to be held here in San Diego June 2010 about the Vulcan instrument and the data collected at Mississippi Canyon 118. Revisions to the Geophysical Journal International submission are almost complete and we have been working with Anne Tréhu to include her tomographic seismic velocity inversion of the Hydrate Ridge data. The total field OCCAM inversions for the GoM data are working, but are taking a long time to run.

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: Preliminary Field Data Interpretation. Completed October 2009.

Phase 2.

Task 5.0: Design and Build Conductivity Cell. Completed July 2010, results presented in Year 2, Quarterly Report 3.

Task 6.0: Make Hydrate and Hydrate/Sediment Conductivity Measurements. Four methane hydrate samples have been made in the electrical conductivity cell each of which we refer to as a run. Run 1 consisted of hydrate with a thermocouple in the center of the sample to assess how to form hydrate in the cell. SEM images were made of the hydrate produced and were presented in the last quarter report. Run 2 was the first synthesis of hydrate with electrodes installed. Measurements of electrical conductivity were made while hydrate was synthesized and also as a function of temperature. Run 3 was the second synthesis of hydrate with conductivity measurements. In this run the temperature was increased incrementally to reduce the error and temperature gradients in the sample. Run 4 is the synthesis of methane hydrate within a sediment mixture: 50% volume ice and 50% volume OK-1 sand and is currently underway. Following this run SEM images will be made on the sample. The process of collecting the impedance spectra has been improved through the use of an Excel macro, so the data can be collected by a computer, rather then written down by hand. The runs are taking almost three weeks to complete, as more heating and cooling cycles are required to form hydrate in this relatively large cell. We can probably only expect to get a couple more runs out of the cell by March. However, with further funding there are many more avenues of further research such as making these same measurements on CO_2 hydrate to see if the conductivity depends on the captured gas phase.

We explain below how we compute the conductivity and activation energy for samples (Figure 1). The Arrhenius figure (Figure 2) only presents pure methane hydrate, as the sediment-hydrate mixture experiment has not yet completed.

Figure 1 is a cole-cole plot of the imaginary part of impedance, $|X|$, versus the real part, $|R|$ of polycrystalline methane hydrate from runs 2 and 3 at 4^oC. The impedance spectra are modeled by taking the impedance magntiude, $|Z| = (R^2+X^2)^{1/2}$, corresponding to the highest value of the impedance phase, $\theta = tan^{-1}(X/R)$. This corresponds to the length of the arc on the real axis in the cole-cole plot. The Z spectra were modeled with two parallel resistor-capacitor pairs in series. Fitting results are tabled in upper-left inset of Figure 1 with errors provided in parentheses. The lower resistance arc that dominates the high frequency portion of the spectra is a material property of the sample (R1, C1), and the larger resistance arc that dominates the low frequency portion of the spectra is caused by electrode polarization (R2, C2). The resistivity is computed by multiplying the resistance, R, by a geometric factor of 0.16m, which is the area of the measurement surface (average electrode area $=\pi(0.0254\text{m})^2$) divided by the sample thickness (0.0127m).

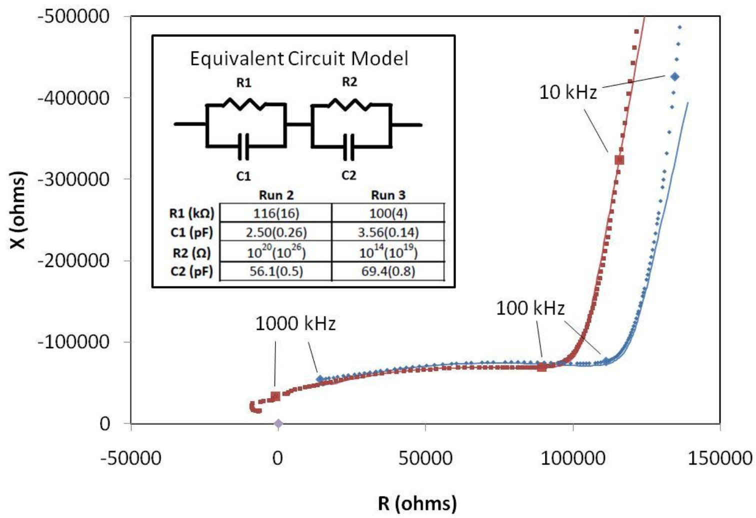


Figure 1: A Cole-Cole plot is shown for the hydrate sample from run 3 and 4 and in the top corner is an equivalent circuit model.

An Arrhenius relationship, $\sigma(T) = \sigma_o e^{-E_a/RT}$, is made between the electrical conductivity, $\sigma(T)$, and the reciprocal temperature T in Kelvin, (1000/T), where R is the universal gas constant = 8.314x10^{-3} kJmol^{-1}K^{-1}, σ_o is a pre-exponential constant, and E_a is the activation energy. The slope of Figure 2 is proportional to the activation energy. The activation energy for Run 3 and 4 are very similar. This is the first time an activation energy has been computed for methane hydrate, E_a=30.6kJ/mol. We are currently writing these results up for a Geophysical Research Letters article.

Task 7.0: Modeling and Inversion of Field Data. The OCCAM total field navigation program is now working. We used a test model to verify the accuracy of the code by generating electric (E_x, E_y, E_z) and magnetic (B_x, B_y) field responses for a 1 Ωm half-space with 63 transmitter positions (x, y, z, azimuth, dip) and 4 receiver positions (x, y, z) using the Dipole1D code of Key (2009). We contaminated these responses with 10% random gaussian noise and used these data for a synthetic test. An error structure was chosen with a noise floor of 10^{-15} V/Am^2 for electric field data and 10^{-17} T/Am for magnetic field data. The OCCAM total field navigation inversion code is used to find the 'true' transmitter positions (see Figure 3A for the starting model and the true solution for the x, y, and azimuth of the transmitter; see Figure 4 for a map view of the transmitter and receiver locations).

The starting model had an RMS of 23 and ran to an RMS of 2.0 in 12 iterations. Then this transmitter solution is stepped down to an RMS of 1.0 in 6 iterations. The final model with RMS 1.0 is shown in Figure 3B in blue and a selection of iterations are labeled to show the inversion's behavior. The solution initially diverges at transmitter numbers 20, 21, and 22, coinciding with the location of receiver s01, where some of the the electric and magnetic fields go through zero. OCCAM's regularization (smoothing between transmitter positions) removes this divergence in later iterations. The data and fits are shown in Figure

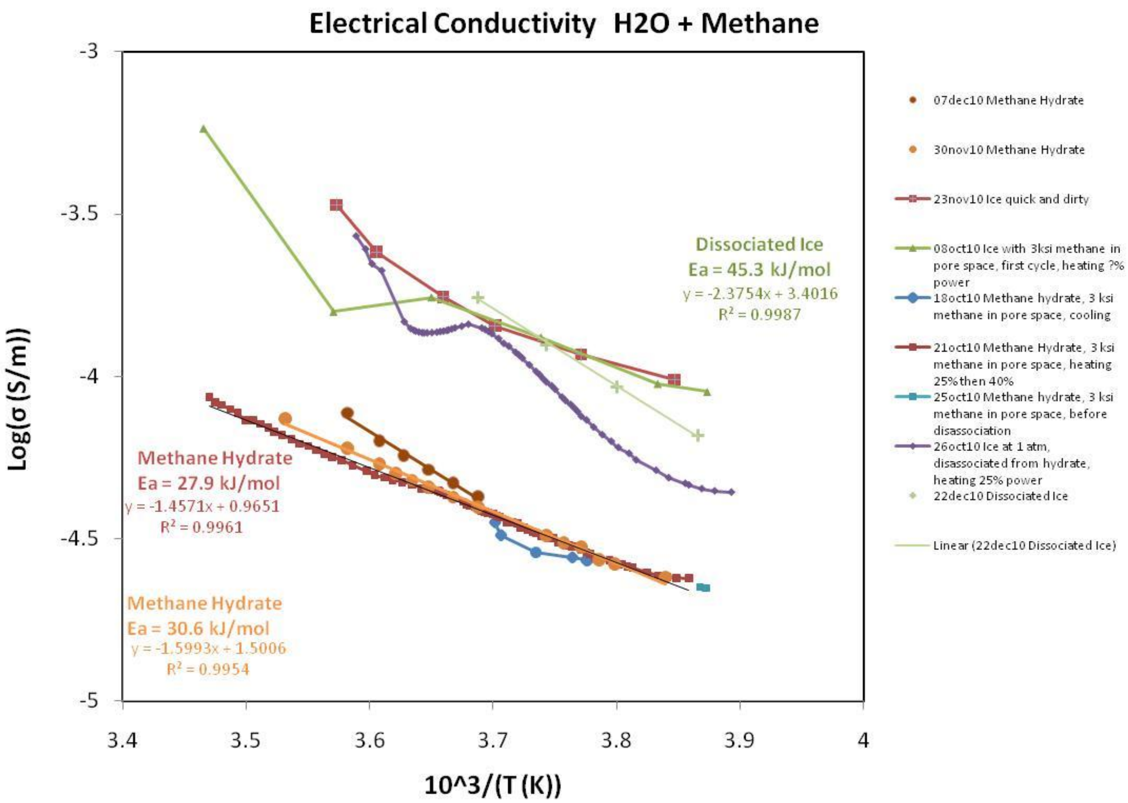


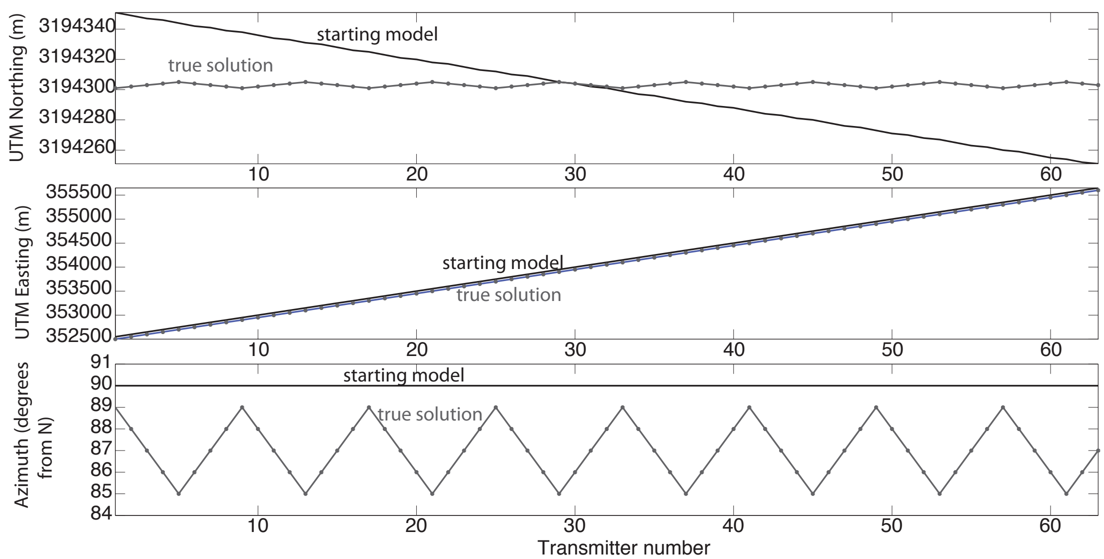
Figure 2: The slope of the Arrhenius relationship from runs 2 and 3 gives the activation energy for methane hydrate.

5. A map view of the receivers and transmitter positions is shown in Figure 5 for the starting model, true model and final solution. There are some subtle differences in the center part of the tow and much larger differences are at the ends of the tow lines, which is illustrated more clearly in Figure 6, which shows the difference between the final solution and the true solution for easting, northing and azimuth. The largest variations are at the ends of the tow and for the northing component (up to a 50 m difference). This region is the least well constrained because the transmitter position is only observed by a single receiver. We have also tested solving for a half-space resistivity (ρ) at each transmitter, in addition to the x,y, azimuth (ϕ) parameters. Increasing the number of free parameters creates more disagreement at the ends of the lines between the final solution (also achieved RMS = 1.0) and the true solution (δ_x = -40 m, δ_y= -100 m, δ_ϕ= 8 ^{o}, δ_ρ= 0.2 Ωm). These model tests provide some guidance when solving for the transmitter position from the CSEM field data collected in the Gulf of Mexico.

For real CSEM data we need to consider what kind of 1D approximation to make for profiles that might be 2D or 3D. We chose an average water depth for the tow line, assign the receivers to be at this depth and use the transmitter's altitude data to set the depth of the transmitter. The dip of the transmitter antenna is computed by data collected from two depth gauges: one on the tail of the antenna, the second on the transmitter. A seawater conductivity-depth profile is collected by the transmitter's CTD (conductivity-temperature-depth) gauge and is used in the layered 1D resistivity model with a final terminating sea-floor resistivity. The Dipole1D code of Key (2009) has been adapted (by colleague David Myer) to compute a finite dipole length, rather then a point dipole, and so we include the length of the antenna (50 m) in solving for transmitter positions.

OCCAM total field navigation inversions have been run for Mississippi Canyon 118 tow 1. We have been exploring which components of the electric and magnetic field are optimal to use in the inversion. We have

A



B

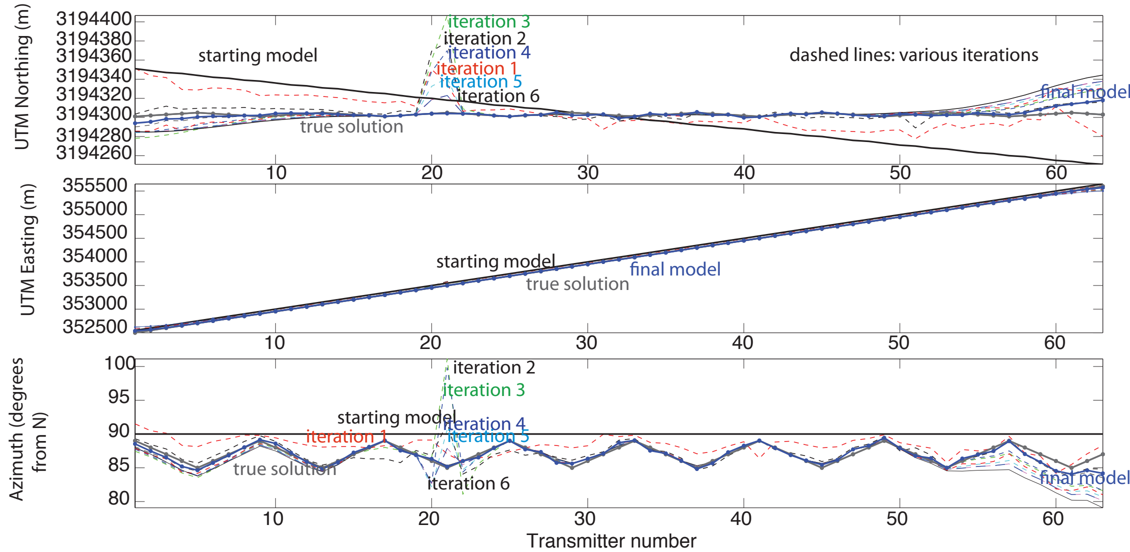


Figure 3: (A) Transmitter parameters, UTM Easting, UTM Northing and azimuth, are solved with the OCCAM total field navigation program. Shown is the true solution and the starting solution for each transmitter number. (B) Shown is the true solution, the starting solution, various iterations and the final solution for each transmitter number.

eliminated the use of saturated magnetic field data, as clearly the phases are being effected by saturation, while the electric field data are not. We have started to eliminate the vertical electric field data, which are more sensitive to the transmitter altitude and depth and receiver depth, making the 1D approximation is invalid for these data. Several inversions have been undertaken with different combinations of data and solving for different sets of transmitter parameters: (1) transmitter x, y, and azimuth; (2) transmitter x, y, azimuth, and resistivity; (3) transmitter x, y, azimuth, and a single resistivity for the entire model space. The

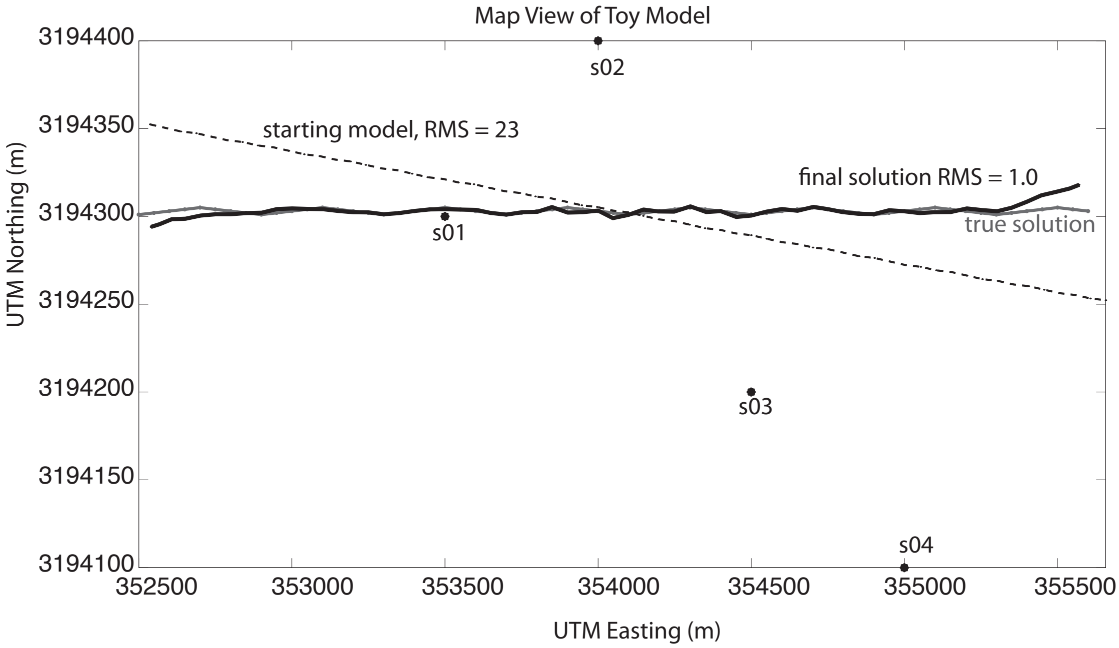


Figure 4: Map view of the transmitters and receivers.

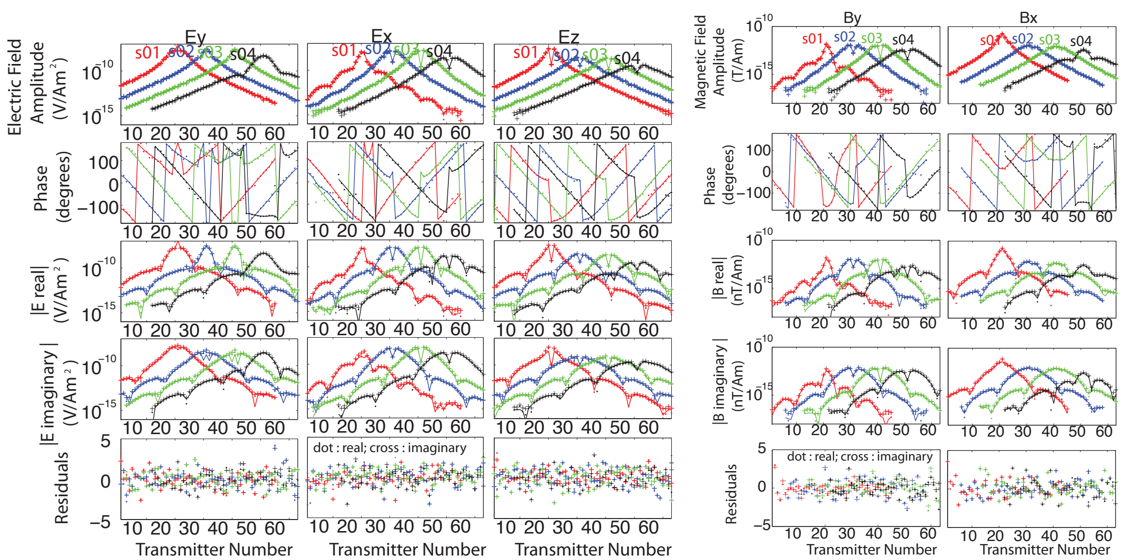


Figure 5: Amplitude, phase, real component, imaginary component and residuals are plotted for the electric and magnetic fields for each transmitter-reciever pair of the data (crosses or dots) and the final model (lines) with RMS of 1.0.

approach has been to take a gradual approach to reducing misfit - first ask for an RMS of 5.1 and then to RMS of 1.1 (error of 10% of the amplitude is used in all cases). The inversions are taking a long time and we are working on speeding up the process.

Task 8.0: Estimate Quantitative Hydrate Volumes from Field Models and Laboratory Studies. This task is scheduled to be completed next quarter.

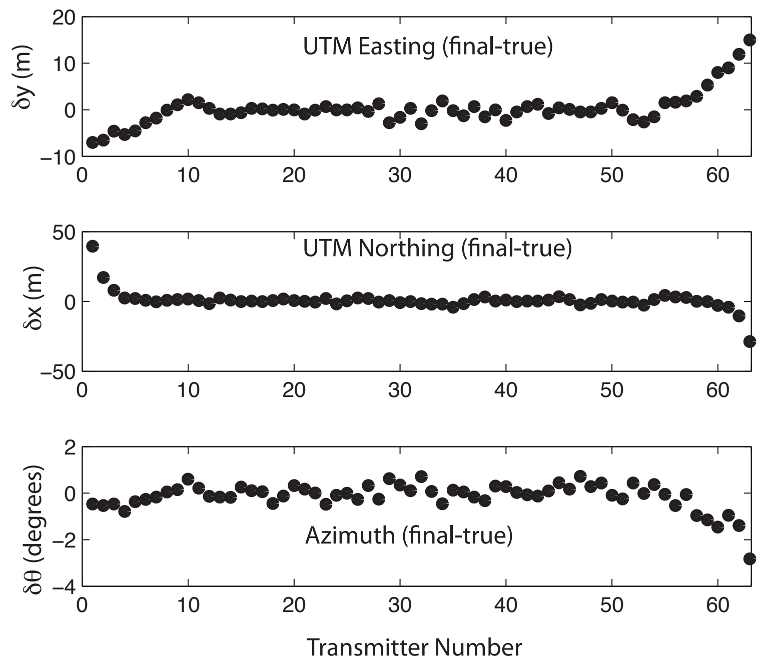


Figure 6: Difference of the final model and the true solution.

Phase 3.

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. Version 1.0 of the transmitter navigation was distributed to sponsors in early December. 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. We have undertaken a project to further develop the Vulcan technique with an industry partner. We have also started a collaboration with Carolyn Ruppell to develop a similar system to be used to map permafrost in the Beaufort sea.

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

CONCLUSION. Electrical conductivity measurements on laboratory hydrate have been successfully undertaken with the activation energy computed for methane hydrate for the first time. The OCCAM total field navigation program is working and the focus will be on refining the navigation for all surveys with this new piece of code. We are preparing for many presentations of the data later this year; at out annual consortium meeting in March, MARELEC in June and the ICGH in July.

COST STATUS

Table 1: Project costing profile for Budget Period 2, Quarter 4

Time period	Cost share	DoE Plan	DoE Actual
October 2010	$0	$8000	$7684
November 2010	$0	$8000	$7684
December 2010	$0	$8000	$7684
Totals	$0	$24000	$23052

Salaries:

Karen Weitemeyer, a post-doctorate scholar during the budget review period, charged October, November and December salaries.

MILESTONE STATUS

Milestone log for Budget Period 2.

Milestone 10: Design conductivity and pressure cell. Task 5.0, completed January 2010. Critical milestone for tasks 6, 8, 9, 10.

Milestone 11: Construct conductivity/pressure cell Task 5.0, completed April 2010. Critical milestone for tasks 6, 8, 9, 10.

Milestone 12: Make calibration tests of cell using water standard Task 5.0, completed July 2010. Critical milestone for tasks 6, 8, 9, 10.

Milestone 13 Install cell in Menlo Park and make initial hydrate measurements Task 5.0, completed October 2010. Critical milestone for tasks 6, 8, 9, 10.

Milestone 14 Make at least two runs of measurements on conductivity cell Task 6.0, completed December 2010. Critical milestone for tasks 6, 8, 9, 10.

Milestone 15 Quantitative modeling of conductivity results Task 6.0, work in progress. Critical milestone for tasks 6, 8, 9, 10.

Milestone 16 SEG abstract submitted Task 9,10, substituted for an abstract at the 20th International Workshop on EM induction in the Earth, Giza, Egypt. Sept 2010.

Milestone 17. Quantitative modeling of field data Task 7.0, to be completed 31 March 2011 Critical milestone for tasks 8, 9, 10.

Milestone 18 Conductivity results report Task 6, to be completed 31 March 2011

Milestone 19 Geological modeling and hydrate volume estimation Task 8, to be completed 31 March 2011 Critical milestone for tasks 9, 10.

Milestone 20 Web page updated Task 9, to be completed 31 March 2011

Milestone 21 Produce Phase 2 report Tasks 6-8, to be completed 31 March 2011

Milestone 22 Fall AGU abstracts submitted Tasks 9,10, substituted for two abstracts submitted to the Seventh International Conference on Gas Hydrates from July 17-21, 2011 in Edinburgh, Scotland,

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 preliminary navigation models and distributed this version to the sponsors in early December 2009 and March 2010.

• 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, GC 955, AC 818, and WR 313 and preliminary interpretations of the data, 2010.

• First Break article published this June (2010).

• Completed calibration tests of cell using water standard.

• Installed the cell in Menlo Park, formed hydrate in the cell, and produced SEM images of this sample.

• Made electrical conductivity measurements on three hydrate samples.

• Published a Geophysics paper: "The practical application of 2D inversion to marine controlled source electromagnetic data"

PROBLEMS OR DELAYS The design and construction of the conductivity cell was given a six month extension in 2009, the cell has successfully made several electrical conductivity measurements on hydrate and hydrate-sediment mixtures. However, we have discovered that because of the large sample size, these runs are taking much longer to equilibrate the anticipated, reducing the total number of runs we can make in the proposed project period. Improvements to the transmitter navigation are in progress and the 1D OCCAM total field navigation code is working, but, again, these runs are slower then we expected.

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.

• Talk given at the 2009 MARELEC Meeting - Stockholm, Sweden - July 7-9 2009

Steve Constable presented *Applying marine EM methods to gas hydrate mapping*

• Submitted the first quarter report February 2 2009.

•Steve Constable gave an invited talk at LLNL mid march 2009 called:

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.

• Karen Weitemeyer gave two invited talks in 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 by 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, 2010. A talk and Poster presented by KW and SC

Applying Marine EM Methods the Gas Hydrate Mapping

• 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 published this June (2010).

    Mapping shallow geology and gas hydrate with marine CSEM surveys

- Attended the 20th Electromagnetic Induction Workshop in Giza, Egypt September 18-25, 2010, and presented a poster.

    Mapping gas hydrates and shallow sedimentary structure in the Gulf of Mexico using marine CSEM

- Submitted two abstracts to the 7th International Conference on Gas Hydrates (ICGH7), July 2011.

    One by Constable, Du Frane, Pinkston, Weitemeyer, Roberts, Stern, Durham, on

    Electrical resistivity of laboratory-synthesized methane hydrate

    The second by Weitemeyer and Constable on

    The development of marine electromagnetic methods for gas hydrate mapping

- Geophysics paper published this Fall (2010).

- Abstract submitted to the 2011 MARELEC Meeting - San Diego, USA - June 20-23 2011

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