Oil & Natural Gas Technology

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Quarterly Report

October 2009 to December 2009

Gas Hydrate Characterization in the GoM using Marine EM Methods

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Prepared for:
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National Energy Technology Laboratory

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Office of Fossil Energy

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EXECUTIVE SUMMARY

During this last quarter we have been refining the data processing based on lessons learned during a survey conducted off Australia mid-2009. For example, we have found that phase estimates, especially those at higher frequencies, are dramatically improved by applying a clock drift correction for the receiver instruments. We are also re-running the data processing using some new code that allows robust averaging, better estimates of noise, and instrument by instrument calibrations. Seafloor instrument positions have been re-navigated to include the GPS to hull-transducer offset, which led to average changes in receiver positions of about 12 m. Our navigation software still needs some work, but our transmitter navigation solution is good enough to get some useful results that allow us to compare apparent resistivity pseudosections at Green Canyon 955 and Walker Ridge 313 with known geology and the JIP drilling interpretations. Inital interpretations have also been worked up for Alaminos Canyon 818. These preliminary interpretations exclude the short range data (< 600 m) as this is where the current navigation solution for the transmitter position and orientation is questionable. We have also processed up all the Vulcan data from Mississippi Canyon 118 as apparent resistivity depth sections based on frequency, with excellent results, that show resistive regions centered on southeast crater.

A meeting was held in early Novemeber at Menlo Park with Laura Stern, Jeff Roberts, John Pinkston, and Steve Constable. A second meeting was held just prior to AGU with William Durham, Jeff Roberts, John Pinkston, Steve Constable, and Karen Weitemeyer to make final plans for the conductivity cell. To date all parts are in hand and the cell is scheduled to be build shortly. Initial tests will be run on ice at Scripps.

A poster entitled “Preliminary results from the Gulf of Mexico gas hydrate CSEM experiment” was presented at AGU and we attended the DoE meeting in late January where we presented our preliminary results in a poster and a 45 minute talk. Version 1.0 of the transmitter navigation for all four surveys was distributed to our sponsors in early December.

We still want to make improvements to the navigation of the transmitter before 1D inversions are implemented on the the seafloor instrument data.

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. The design is complete and building will commence next quarter. Figure 1 shows the conductivity cell design. In the next quarter tests will be made on ice.

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. The field data have been forward modeled and preliminary interpretations of the data are present below. 1D inversions of the data are planned for later this year.

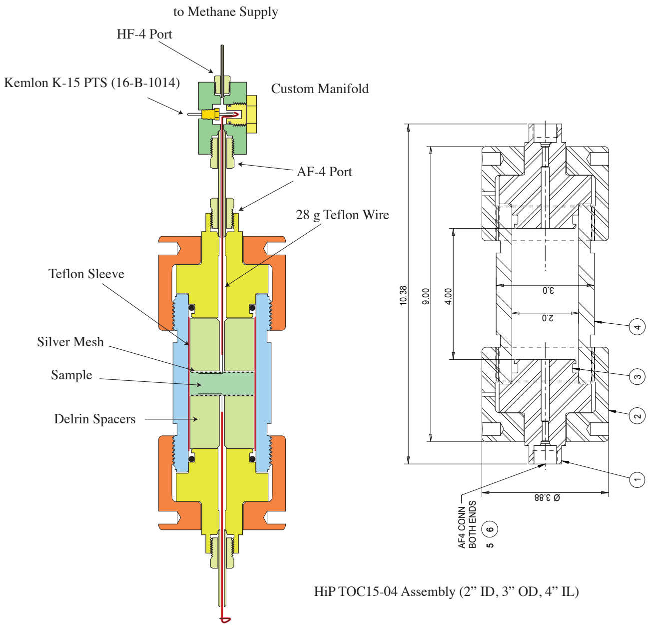


Figure 1. Conductivity cell design.

In the final report of 2009 we discussed some problems with MC 118 transmitter navigation; this past quarter was spent trouble-shooting this problem and an error was found in the way the absolute phase of the transmitter was handled for this particular survey. A clock drift correction was applied to all seafloor receivers and new calibration files were used for the electric field measurements. In addition, the new processing code produces a more robust error estimation, which will be useful when we invert the data. The ocean-bottom electromagnetic seafloor receiver (OBEM) data and Vulcan data have been reprocessed and re-navigated using the total field navigation program. Forward models were then generated using Key's (2009) Dipole 1D forward modeling code for all 10 CSEM Lines. Apparent resistivity pseudosections for the Vulcan data and the OBEM data are presented in Figures 2 and 3.

The Vulcan apparent resistivity pseudosections were generated using the total field from all three components of the electric field (E_x, E_y, E_z) measured by Vulcan. The total electric field is used because at MC 118 the Vulcan compass failed. Forward models were made for half-space seafloor resistivities of 0.3, 1, 2.5, 5, and 10 Ω-m and linearly interpolated between these modeled resistivities. Frequencies from 0.5 Hz to 43.5 Hz (stepping every 1 Hz) were used in forward modeling, but only frequencies below 15.5 Hz where used to generate the pseudosections because frequencies above 15.5 Hz are too sensitive to the geometry of the transmitter and Vulcan receiver. The frequencies were projected into a depth using skin depth attenuation and then a smoothing algorithm was used to generate the image seen in Figure 2. MC 118 is rather conductive with a background resistivity of 0.5-1 Ωm and is generally featureless except at the SE crater. No constraints were placed on the intercepting tow lines and so the fact that three lines independently give a resistive body at the SE crater assures us that this is an attribute of the data due to geology. The EW line that crosses through the SE crater is overlayed on chirp acoustic line 119 from Sleeper et al. (2006) in order to compare acoustic blanking to electrical conductivity. The acoustic blanking or wipeout zones at MC 118 are attributed to authogenic carbonate as well as free gas and gas hydrate (Lapham et al. 2008). Carbonate rocks are present on the crater floors and have been noted in the SW crater (McGee et al. 2009 and 2008). The SE crater has a pavement of dead methanotrophic clams and there is no evidence for recent venting, which suggests that the conduit which once supplied methane to these clams became blocked, perhaps due to hydrate formation (McGee et al. 2009 and 2008). We find that the SE crater resistor appears to have some depth extent and the acoustic blanking there is resistive. However, the acoustic blanking towards the SW crater is the background resistivity of 1 Ωm and this is attributed to the shallow carbonates present there

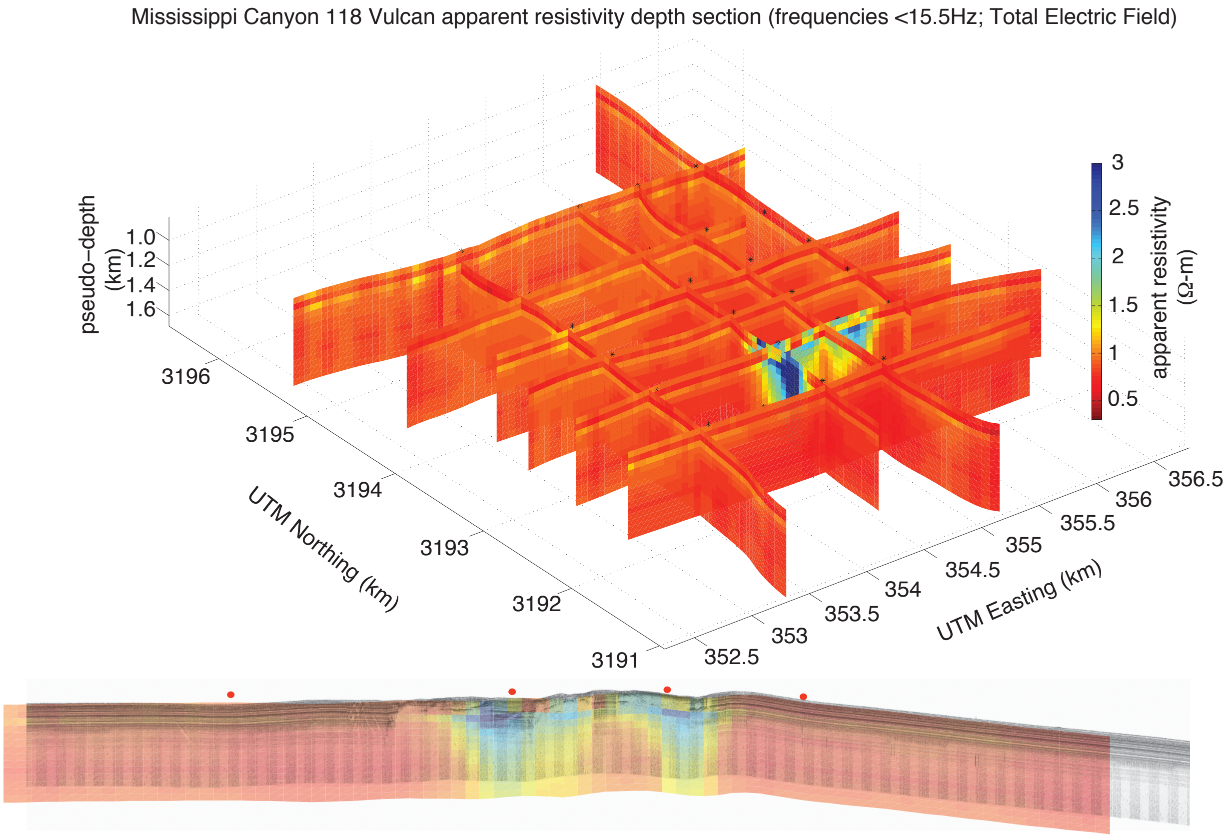


Figure 2. Apparent resistivity depth section based on frequency for Vulcan data collected at MC 118 and an EW transect from Line 5 overlayed on chirp acoustic data from Sleeper et al. (2006) which crosses the SE crater.

(Macelloni, pers comm.). This is significant, in that hydrate and carbonates, thought to be a confounding electrical resistors, are in fact differentiable here. Only drilling at the SE crater will confirm that it is hydrate.

The OBEM pseudosections for 6.5 Hz are shown in Figure 3 and give results consistent with the Vulcan pseudosections. Three CSEM tow lines independently give a resistor at the SE crater with a background resistivity of about 1 Ω-m. The seafloor receiver data images the top few km's of sediment and the Vulcan data images the top 100's of meters. Seafloor background resistivies are thus slightly elevated in the OBEM data as they are sampling a larger sediment volume. Inconsistencies in the OBEM pseudosections at the crossing points of NS and EW CSEM tow lines at site 9, are likely navigational errors, although they could be due to a deep resistor.

The next step is to carry out stitched 1D inversions of the Vulcan and OBEM data.

The Mississippi Canyon 118 result is a compelling argument that CSEM surveys are sensitive to the presence of hydrate in the Gulf of Mexico, and has given us confidence to make preliminary interpretations of the pseudosection results for the other survey locations. Preliminary interpretations are discussed for AC 818, WR 313, and GC 955, creating a consistent story with JIP drilling results and published articles about the three areas. The pseudosections provide a way to look at all of the data and observe lateral variations in resistivity, but pseudosections do not provide an image of resistivity variations with depth, only an inversion will be able to resolve the resistivity variations with depth. For this reason the depth scale has been removed from the pseudosections.

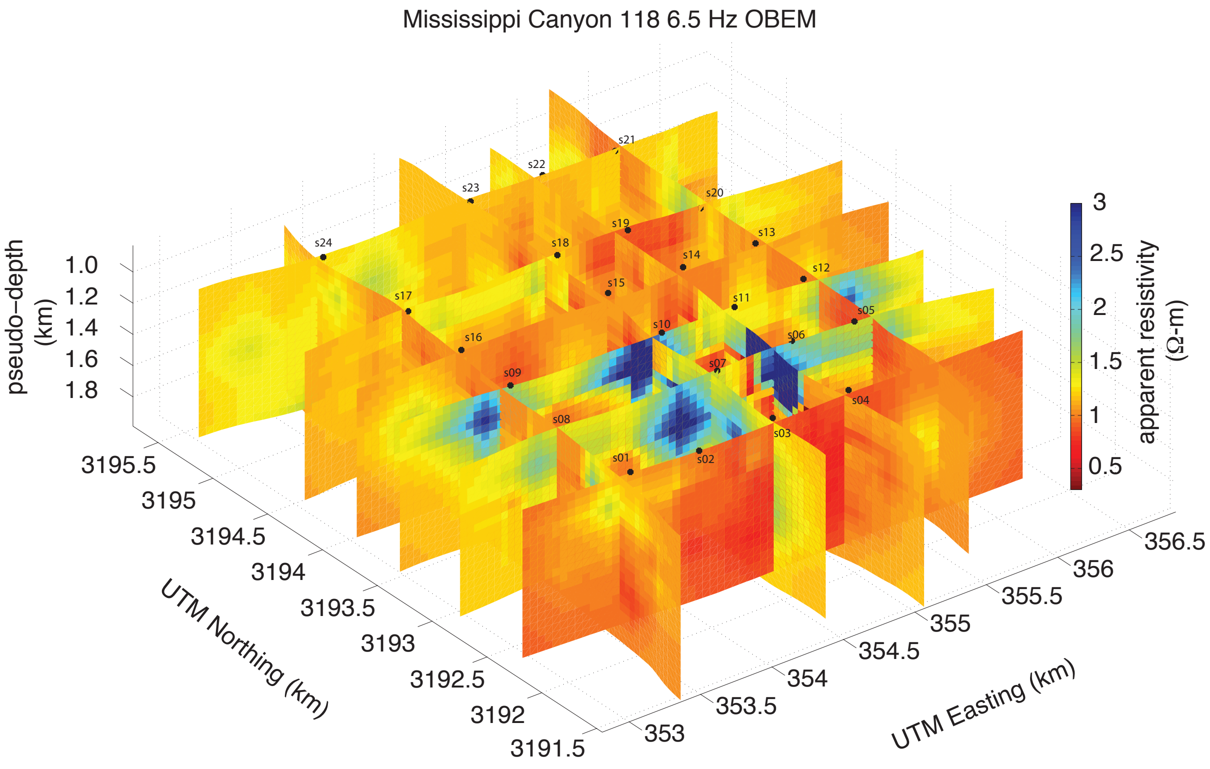
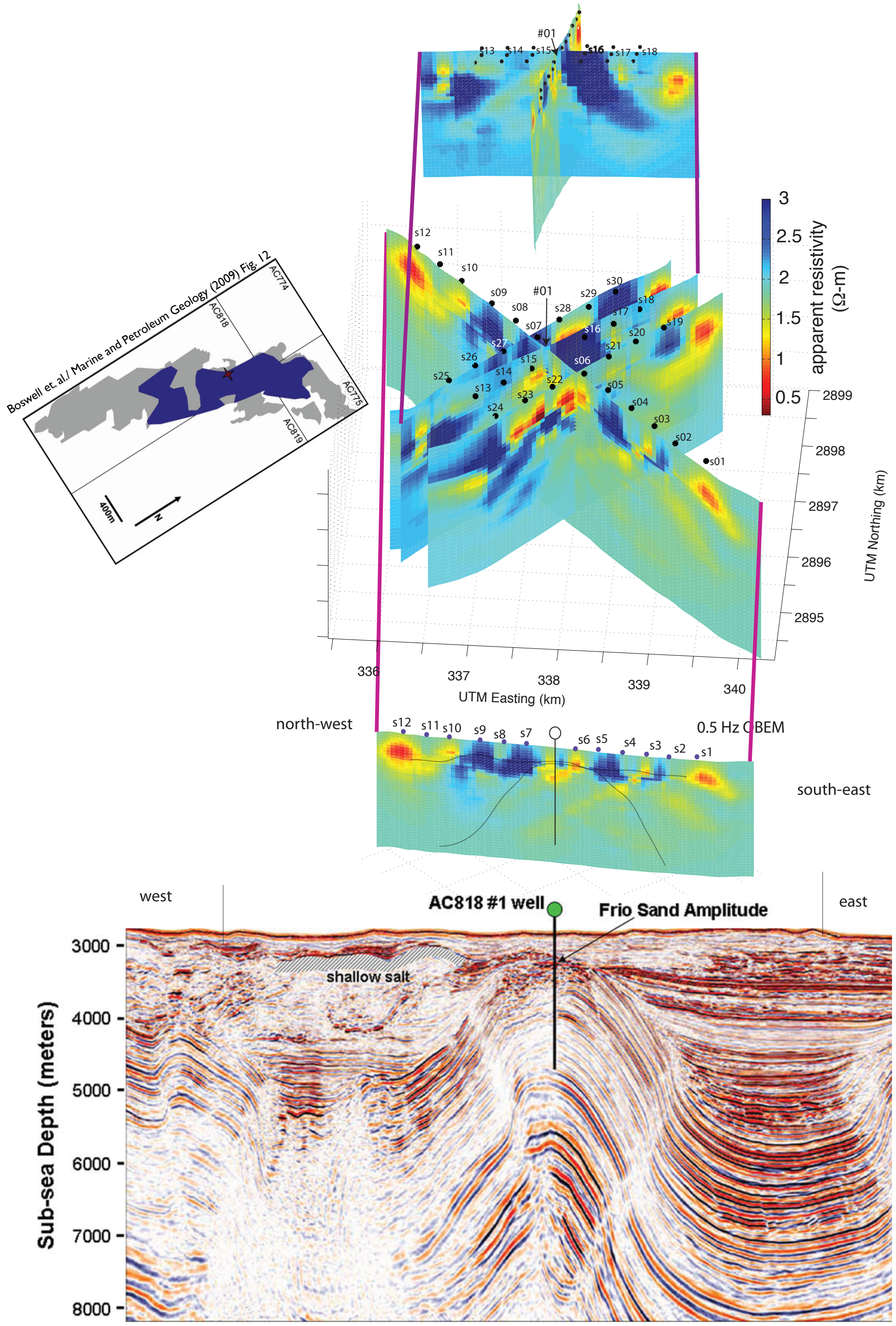


Figure 3. Mississippi Canyon 118 OBEM apparent resistivity pseudosections.

The Alaminos Canyon 818 OBEM 0.5 Hz pseudosections are shown in Figure 4 (centre) with a closer examination of the EW-trending CSEM Line 1 (bottom) and NS-trending Line 2 (top). To substantiate our interpretations an EW seismic line (bottom of Figure 4) and an estimate for gas hydrate distribution in the Frio sand derived from a 3D seismic volume (left side of Figure 4) presented in Boswell et al. (2009b) are included in Figure 4.

All four pseudosections display a consistent image; for example all three NS trending pseudosections have a conductive region to the north-east (NE of sites 30, 18 and 19). The AC 818 pseudosections have a more complex resistivity structure when compared with the MC 118 pseudosections (also true of the WR 313 and GC 955 pseudosections discussed below) and the background resistivity at AC 818 is higher, varying from 1.5 to 2 Ω-m. A resistive region trends from the NE to the SW, and is consistent with the map view of the seismic derived hydrate distribution given in Boswell et al. (2009b). The NE to SW OBEM Line 2 pseudosection (Figure 4 top) has a large resistor to the north (site 16) and to the south (site 13 and 14) a pattern of conductive and resistive sediments that could be associated with the pattern of water saturated sand and hydrate bearing Frio sand (Figure 4 left) given in Boswell et al. (2009b). The NW to SE OBEM Line 1 pseudosection (Figure 4 bottom); has a resistive region (sites 9 and 8) associated with the shallow salt labeled in the seismic section. Seismic bright spots have been documented in Latham et al. (2008) and Hutchinson et al. (2008) and are thought to be associated with free gas. The pseudosections have a resistive region which may correspond to this seismic event (site 7). At the well location itself there is a very subtle resistive region in the shallow section, which could be associated with the LWD resistive region discussed in Smith et al. (2006), but more likely the NE to SW tows are capturing this resistive region. Under sites 5 and 4, a resistive region is present and may be associated with an inferred BSR discussed in Jones et al. (2008). AC 818 is on the Perdido fold 3 (Fiduk et al. 1999) which has pushed the Oligocene Frio sand into the hydrate stability zone (Boswell et al., 2009b, Hutchinson et al., 2008, Jones et al., 2008, Latham et al., 2008). This fold is shown in the EW seismic section and our pseudosections show it to have a background



Seismic Image from Boswell et al., (2009) *Marine and Petroleum Geology* Fig. 2

Figure 4. OBEM pseudosection crossplots for AC 818 at a frequency of 0.5 Hz and a closer examination of Line 1 (bottom) and Line 2 (top) with corresponding seismic data. The bottom seismic line is an EW transect showing where the Oligocene Frio sand is above the gas hydrate stability field labelled as Frio Sand Amplitude (Boswell et al., 2009b). The left map view shows in blue the gas hydrate distribution within the Frio sand and in grey the water saturated frio sand with low saturations of free gas (Boswell et al., 2009b).

resistivity of 2 Ω-m, attributed to the water saturated Frio sand.

Figure 5 contains a map view of the Walker Ridge 313 survey area with geologic annotations after Hutchinson et al. (2008) and pseudosections for frequencies of 6.5 and 0.5 Hz. The 6.5 Hz pseudosection is a subset of the 0.5 Hz pseudosection; the 6.5 Hz has a much shallower depth extent and not much structure is observed for this particular survey. Of note is the salt wall to the south and east where sites 9 and 14 are. This salt wall is in the 0.5 Hz pseudosection as a resistor that extends downwards into the pseudosection, the fact that it is barely present in the 6.5 Hz is a reflection of its depth. A closer look at the 0.5 Hz EW trending pseudosection is shown in Figure 6 with corresponding EW seismic line from Boswell et al. (2009a).

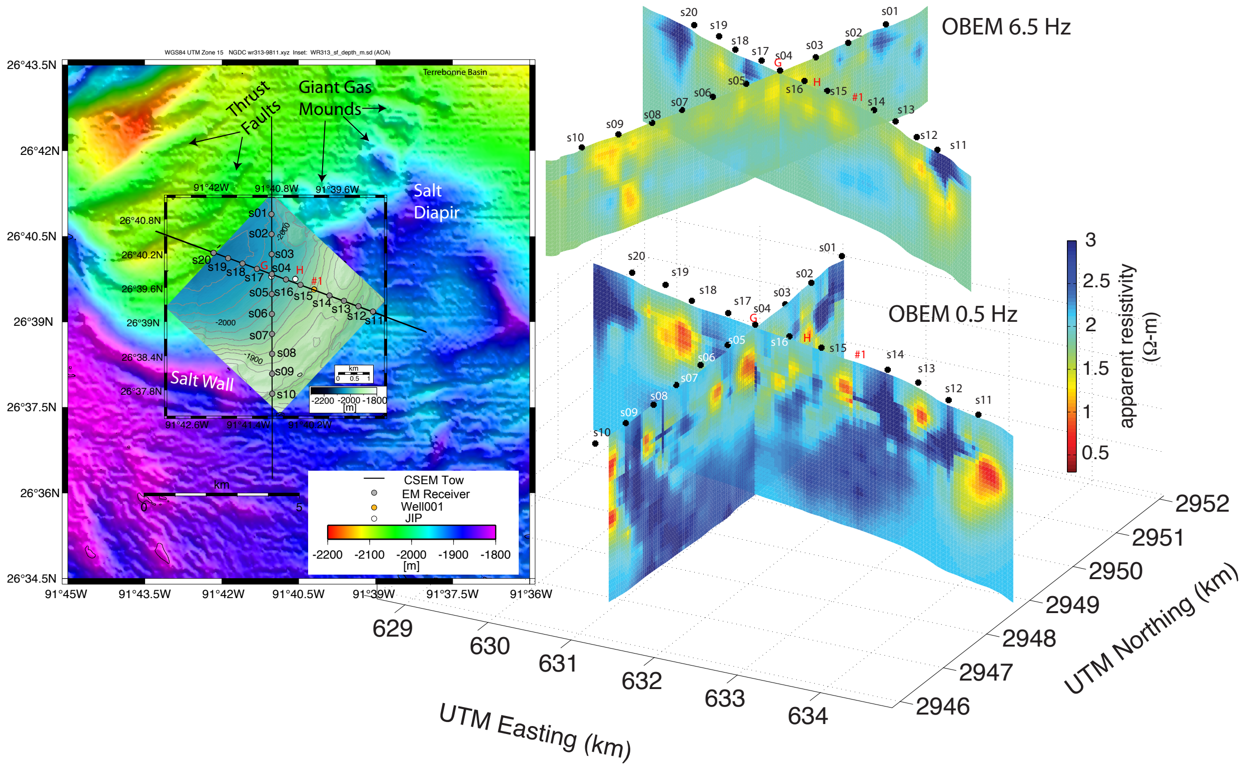


Figure 5. Walker Ridge 313 survey map with annotation from Hutchinson et al. (2008) (left) and OBEM pseudosection crossplots for 6.5 (top right) and 0.5 Hz (bottom right).

The JIP drilled two holes at WR313, 'G' and 'H', which are intersected by the EW CSEM Line. Hydrates were found in both wells in the top of the seismic section as stratal-bound facture-filling gas hydrate and also within sheeted sands (Boswell et al., 2009a). The pseudosections give resistive features under both 'G' and 'H' holes which could correspond with the JIP LWD resistivities. The pseudosections are perhaps capturing the dipping strata as shown in the seismic transect, but further analysis is required before this can be quantified.

Figure 7 shows a survey map view of Green Canyon 955 with annotations from Hutchinson et al. (2008) and the OBEM pseudosections for 0.5 and 6.5 Hz data. Recall that at the time of the CSEM survey a drill rig was present and so we could not collect CSEM Lines coincident with the JIP drill targets. Thus, we have only one hole, 'Q', which intercepts with the NS CSEM Line. The JIP 2009 drilling campaign also collected LWD data at holes 'I', and 'H'. The 'I' hole found very little hydrate whereas the 'H' and 'Q' wells encountered hydrate (Boswell et al., 2009b) The NS trending CSEM line is much more resistive then

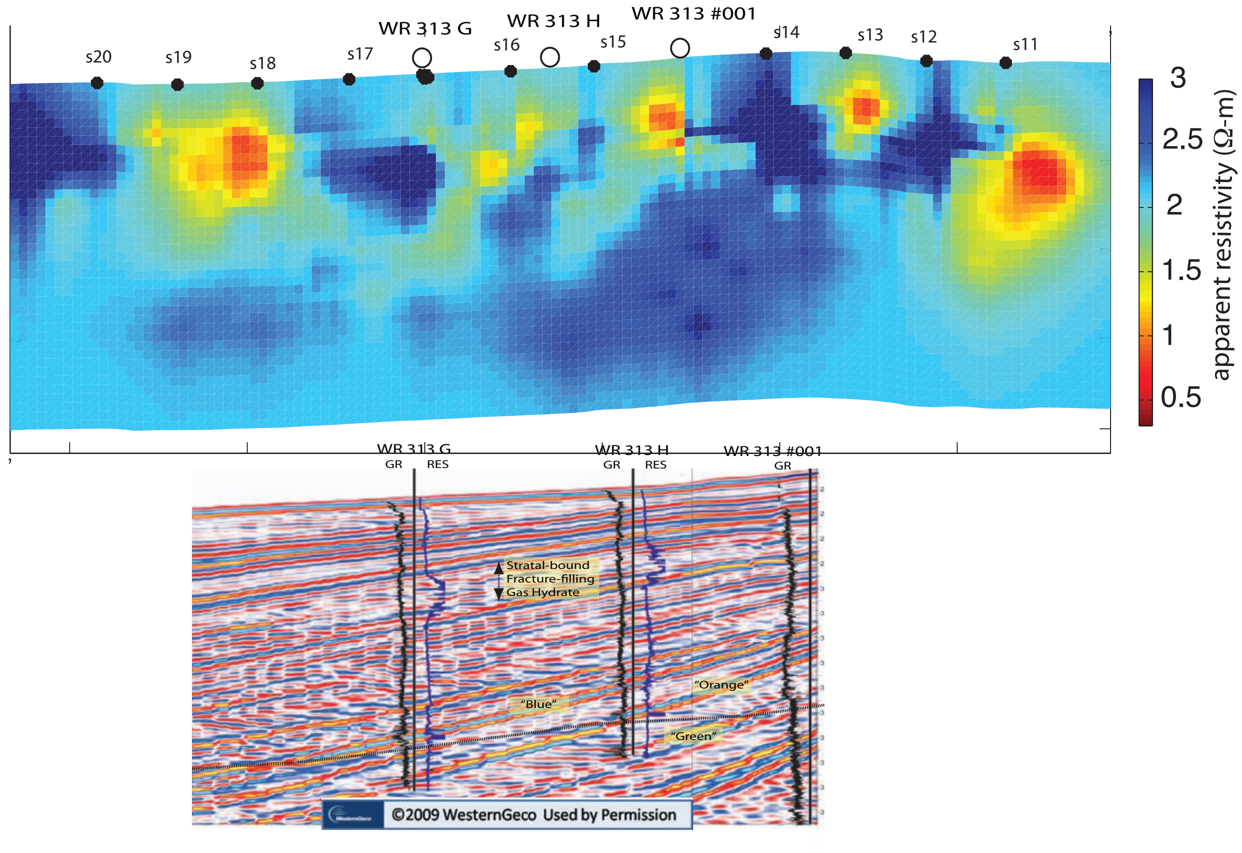


Figure 6. WR 313 EW-trending 0.5 Hz OBEM pseudosection and seismic line from Boswell et al. (2009a).

the EW tow line, which could be associated with hydrates located within the area of four way closure or could be related to the salt that cores the bathymetric high (Hutchinson et al., 2008) along this line. The hydrates are thought to be within channel levee sands and seismic horizon C; these features are annotated in the survey map (Hutchinson et al. (2008) and Jones et al. (2008)). The conductive feature under sites 16-20 could be associated with these levee and channel sands or with unconsolidated sediments deposited from the scarp face to the north.

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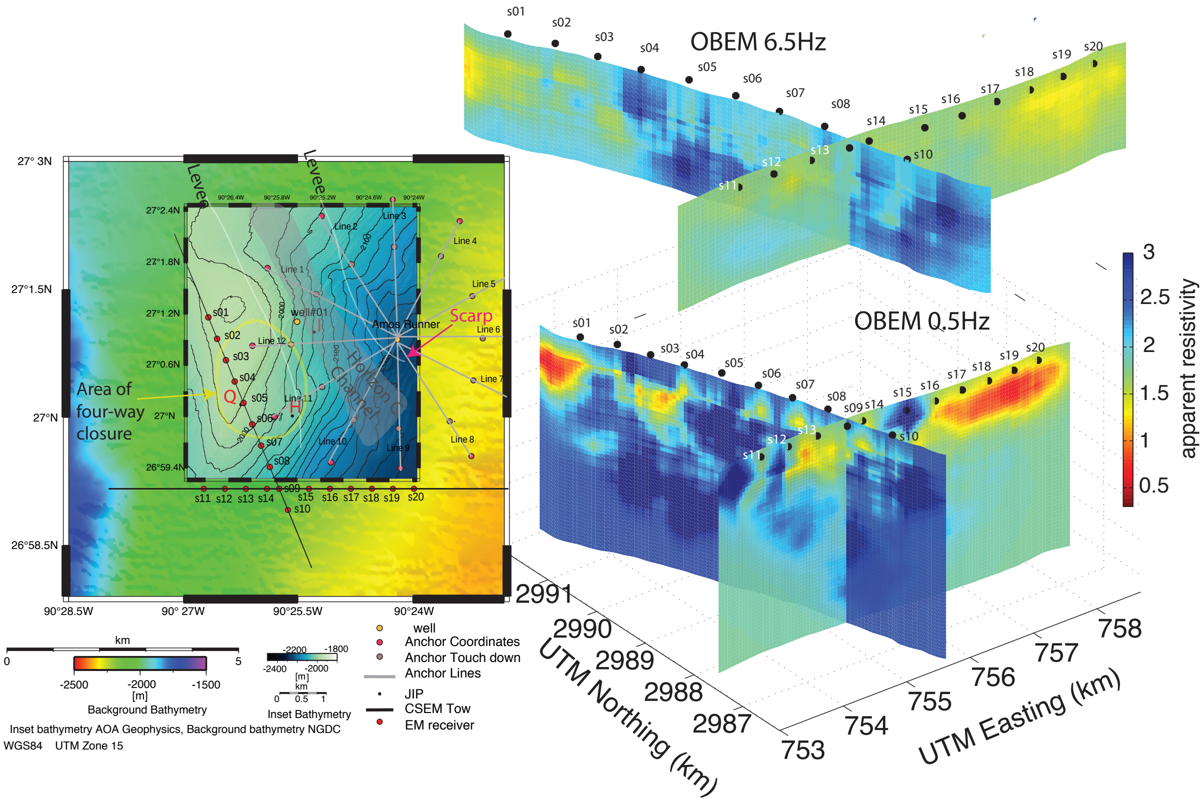

Figure 7. GC 955 survey map with annotations from Hutchinson et al. (2008) (left) and OBEM pseudosections for 6.5 (top right) and 0.5 Hz (bottom right).

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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 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. A poster was presented at the 2009 Fall AGU Meeting. Version 1.0 of the transmitter navigation was distributed to sponsors in early December.

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

CONCLUSION. The MC 118 data have been reprocessed using a new processing code and the total field navigation code was used to renavigate the transmitter. This made improvements to the data analysis. The Vulcan and OBEM pseudosections give a resistive region over the SE crater, an old inactive vent site thought to have hydrate blocking the fluid pathways (McGee et al. 2008). Preliminary interpretations of all pseudosections have been made for AC 818, WR 313, and GC 955. All parts of the conductivity cell are in hand and building commences next quarter.

COST STATUS

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

Time period	Cost share	DoE Plan	DoE Actual
October 2009	$0	$9784	$8097
November 2009	$0	$9784	$11,613
December 2009	$0	$9784	$7786 (est.)
Totals	$0	$29,352	$27,496

Salaries:

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

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

- Processing of the data is completed.

- 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.

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

- 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.

- Generated pseudosections for Vulcan at MC 118 and preliminary interpretations of the data.

PROBLEMS OR DELAYS

The design and construction of the conductivity was given a six month extension. The design is complete and all parts are in hand to begin construction. 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.

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

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

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