Electrical Resistivity Investigation of Gas Hydrate Distribution in Mississippi Canyon Block 118, Gulf of Mexico

Project Quarter 1 Report

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ABSTRACT

Electrical methods offer a potential geophysical approach to determining the sub-bottom distribution of gas hydrate in the deep marine environment. Gas hydrate is essentially non-conductive. Hence, sediments with pore spaces partially filled with hydrate are more resistive than surrounding sediments. To date, attempts to map the sub-bottom distribution of gas hydrates using electrical methods have been done on an experimental basis using the controlled source electromagnetic method (CSEM). The CSEM method involves the generation of low-frequency EM signals from a source instrument and the reception of the signals by separate receiver instruments.

This project will evaluate an alternative electrical method, the direct current resistivity (DCR) method, for gas hydrate exploration. The DCR method involves the injection of a direct current between two source electrodes and the simultaneous measurement of the electric potential (voltage) between two or more receiver electrodes. In applications in which electrical coupling to the environment is not a problem and large source-receiver offsets are not required, the DCR method provides subsurface information comparable to that produced by the CSEM method, but with much less sophisticated instrumentation. Because the receivers are simple electrodes, large numbers can be deployed at relatively low cost.

To evaluate the direct current resistivity DCR method for use in future commercial gas hydrate exploration, a prototype seafloor DCR system will be developed and used to conduct experiments at a site of known hydrate occurrence in Mississippi Canyon Block 118 (MC 118). The intent is not to develop a system that is optimized for collecting data in a production mode, but rather to develop a flexible system that can be used to conduct multiple experiments. The objectives of these experiments will be to test the DCR method to determine its applicability in gas hydrate exploration, to collect baseline seafloor electrical data useful in the design of future commercial seafloor DCR systems, and to contribute to the fundamental understanding of gas hydrate systems at the MC 118 site.

- During October 2006 – December 2006 effort was concentrated on:
- Developing a detailed research management plan;
- Conducting a technology status assessment;
- Initial evaluation of multiple strategies for deploying the prototype seafloor DCR system.
- Initial evaluation of 56-electrode array designs.

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List of Acronyms and Abbreviations

BSR	Bottom simulating reflection
CSEM	Controlled source electromagnetic
DC	Direct current
DCR	Direct current resistivity
DGPS	Differential global positioning system
GOM-HRC	Gulf of Mexico-Hydrate Research Consortium
GPS	Global positioning system
MC 118	Mississippi Canyon Block 118
RS232	Electronics Industries Association common computer interface standard
4D	four-dimensional (three spatial dimensions and time)

1.0 Introduction

1.1 Project Background

One of several ongoing projects investigating the gas hydrate deposits on the northern Gulf of Mexico slope is being conducted by the Gulf of Mexico-Hydrate Research Consortium (GOM-HRC). This is a group of 15 academic institutions and various State and Federal agencies formed to conduct multi-disciplinary studies of hydrate systems in the northern Gulf of Mexico. The group has had funding from DOE (Project numbers DE-FC26-00NT40920, DE-FC26-02NT41628 and DE-FC26-06NT42877), NOAA, and the MMS since 2001 to establish a multi-sensor seafloor monitoring site at a natural gas hydrate location. The current work of the group is focused on Mississippi Canyon Block 118 (MC 118). Gas hydrate deposits at this site are believed to be derived from thermal gas actively migrating up deep-seated normal faults that intersect the seafloor.

To date GOM-HRC has conducted site reconnaissance by direct sampling from a deep submersible, gravity coring, multi-beam profiling, and deep-towed sub-bottom acoustic profiling. This work has established that there are both active and dormant gas vents at the site and that gas hydrate is exposed at the seafloor in the active vents. Recently disturbed sediments and open fissures in the seafloor indicate that there are dynamic processes occurring at the site. The group's near-future plans include the deployment of a seabed seismic array and pore-fluid samplers, bottom-towed P- and S-wave seismic profiling, and vertical array seismic profiling.

In spite of seismic work at the MC 118 site, the sub-bottom distribution of gas hydrates has not been determined. As is the case with most thermal hydrate deposits, the deposits at MC 118 are not associated with a clear bottom simulating reflection (BSR) signature. Electrical methods offer an alternate geophysical approach to determining the sub-bottom distribution of gas hydrates. Gas hydrate is essentially non-conductive. Hence, massive gas hydrate has high electrical resistivities (2 - 100 Ωm) and sediments with pore spaces partially filled with hydrate are more resistive (1– 2 Ωm) than surrounding sediments with saline pore fluids (≤ 1 Ωm). This resistivity contrast has been widely exploited to quantify downhole hydrate concentration levels from resistivity logs (e.g. Hyndman et al., 1999; Collett and Ladd, 2000; Lee, 2001).

To date, the only attempts to map the sub-bottom distribution of gas hydrates by electrical methods have been done on an experimental basis using the controlled source electromagnetic method (CSEM) (e.g. Edwards, 1997; Hyndman at al., 2001). The CSEM method involves the generation of low-frequency EM signals from a source instrument and the reception of the signals by separate receiver instruments. The CSEM systems used in gas hydrate experiments were scaled-down versions of systems used in exploration for conventional petroleum deposits at depths of 3 to 6 km. Petroleum CSEM systems are, in turn, scaled-down versions of systems used in academic studies to image the electrical properties of the ocean crust and upper mantle to depths of 10 – 12 km (MacGregor et al., 2001).

The current project will evaluate an alternative electrical method, the direct current resistivity (DCR) method, for gas hydrate exploration. The DCR method involves the injection of a direct current between two source electrodes and the simultaneous measurement of the electric potential (voltage) between two or more receiver electrodes. In applications in which electrical coupling to the environment is not a problem and large source-receiver offsets are not required, the DCR method provides subsurface information comparable to that produced by the CSEM method, but with much less sophisticated instrumentation. Because the receivers are simple electrodes, large numbers can be deployed at relatively low cost. Also, because of the inherent stability of voltage measurements, adaptation of DCR instruments for use in long-term site monitoring will not be as difficult as would be the case with CSEM instrumentation.

The Recipient will evaluate the DCR method for gas hydrate applications at the MC 118 site. Because of the previous work done by GOM-HRC, the MC 118 site will make an ideal laboratory for this purpose. Massive gas hydrate blocks have been observed outcropping on the seafloor. Hence, there is no doubt that the site contains gas hydrate. The ongoing work of GOM-HRC will provide a range of auxiliary data with which sub-bottom conditions can be independently constrained and the DCR results can be evaluated. In addition, infrastructure at the site, such as a site-wide power source and facilities for mass data storage and routine data recovery, will make long-term monitoring experiments using DCR instruments much easier. For these reasons, work on the current project will be coordinated with that of GOM-HRC, results from the project will be presented at GOM-HRC meetings, and data generated will be freely shared with GOM-HRC members.

1.2 Project Objectives

The current project is a pilot study, the over arching objective of which is to evaluate the DCR method for future use in commercial gas hydrate exploration and exploitation. To this end, a prototype seafloor DCR system will be developed and used to conduct experiments at the MC 118 site. The intent is not to develop a system that is optimized for collecting data in a production mode, but rather to develop a flexible system that can be used to conduct multiple experiments. The objectives of these experiments will be to test the DCR method to determine its applicability in gas hydrate exploration, to collect baseline seafloor electrical data useful in the design of future commercial seafloor DCR systems, and to contribute to the fundamental understanding of gas hydrate systems at the MC 118 site.

1.3 Project Phases

The project will be conducted in two phases. The first phase will involve the development of an experimental bottom-towed DCR system, configured for continuous resistivity profiling on the seafloor. Once complete, the experimental system will be used to conduct a reconnaissance survey of the methane vent area at the MC 118 site. The resulting data will be complimentary to previously collected seismic data and will help characterize the overall site. The second phase of the project will involve reconfiguring and deploying the bottom-towed DCR system for long term, static operation on the seafloor. In this mode, the system will be programmed to re-profile a selected cross-section across the site multiple times per day for an initial period of one year. The data will be stored within the mass data storage unit at the site and retrieved on a semiannual basis, along with the other monitoring data at the site. The resulting data will be used to quantify changes in subsurface gas hydrate distribution over time.

1.4 Research Participants

Three institutions will contribute directly to the project. John Dunbar and his graduate students at Baylor University, Department of Geology, Waco, Texas will develop the geophysical specifications for the experimental DCR system, participate in the initial testing and offshore experiments with the system, process and interpret the resulting DCR data, and report the results of the project in national meetings and peer-reviewed journals. Dunbar will also have overall management responsibility for the project. For the purposes of identification in this document, work done or primarily led by John Dunbar along with his graduate students will be referred to collectively as work done by the Recipient.

Paul Higley and personnel at Specialty Devices, Inc. of Wylie, Texas (SDI) will be the subcontractor in charge of assembling the experimental DCR system and will take the lead in conducting the offshore operations. SDI is an industrial member of GOM-HRC and has been the prime subcontractor for the development and deployment of much of their seafloor instrumentation. Work done for the project by Paul Higley and his employees will be referred to collectively as work done by SDI.

Mats Lagmanson and personnel of Advanced Geosciences, Inc. of Austin, Texas (AGI) will be the subcontractor in charge of producing the electronics for the experimental DCR system. AGI is a leading manufacturer of commercial DCR systems used in near-surface geophysics on land and shallow marine applications. Work done by Mats Lagmanson and his employees will be referred to collectivity as work done by AGI.

1.5 Purpose of this report

The purpose of this report is to document the research results during the initial project period, from October 2006 to December 2006.

2.0 Results and Discussion

2.1 Research Management Plan

During this first reporting period a detailed research management plan was developed and submitted. The main decision point in the plan occurs at the end of Phase 1. This point will be reached by the end of Quarter 6, in March 2008. If the DCR method can be shown to unambiguously delineate gas hydrate deposits in MC 118, then the project should proceed to Phase 2. If not, DOE will decide if the results are promising enough to justify continuing the project.

2.2 Technology Status Assessment

Also during this first reporting period, a technology status assessment was completed and submitted. This assessment identifies two competing technologies for mapping sub-bottom hydrate distributions. The first is seismic tomography, in which seismic travel times from a wide range of offsets are inverted to produce sub-bottom velocities (Bunz et al., 2005; Carcione et al., 2005). Biot-type models are then used to predict the relationship between the seismic velocities and the properties of the sediment matrix, gas hydrate and pore fluids. The second competing technology is CSEM. For hydrate investigations, CSEM systems, consisting of a single source and a series of receivers, have been linked in a linear array by a cable and towed along the bottom from a survey ship. Initial experiments with CSEM demonstrated the value of electrical methods in characterizing sub-bottom hydrate distribution (Edwards 1997). However, extending current CSEM systems to achieve high-resolution, and 3D and 4D coverage would be more complex and expensive than would be the case using the DCR method.

2.3 Evaluation of strategies for deploying the seafloor DCR system

The project as envisioned by the Recipient is a proof of concept experiment/demonstration. As such, it was designed to be relatively low cost, given the objectives. In Phase 1 of the project, a prototype seafloor DCR system will be developed and used to conduct a reconnaissance survey of the methane vent area in MC 118. DCR systems are composed of an electrode array and a controlling electronics module. The deep water (~ 1 km) and low resistivity (0.5 – 1 Ωm) of the deep-sea environment at the MC 118 requires that the electrode array must be deployed on or near the seafloor in order to injected electric current to useful depths into the sub-bottom. To keep costs as low as possible, the prototype instrument will be built from components from an existing commercial DCR system produced by AGI. This system is normally used in land and shallow marine surveys for mining, environmental, and engineering applications.

For the reconnaissance survey task there is a choice between deploying the DCR system control on the seafloor in a pressure housing or on the surface vessel and connecting it to the electrode array through a multi-conductor tow-cable. The seafloor deployment strategy offers potential performance advantages and is more easily adapted for use in the long-term monitoring effort in Phase 2. Also, surface deployment would require the construction of a special, multi-conductor tow cable, approximately 1.5 km in length. Hence, seafloor deployment is the preferred strategy.

The main obstacle to seafloor deployment of the DCR control module obtaining a pressure housing for the electronic components. An 8-channel AGI DCR system for a 56-electode array has four major subcomponents: 1 transmitter board, measuring 27 x 20 cm, 2 switch boards with 28 switches per board, measuring 23 x 15 cm each, and an 8-channel receiver board, measuring 36.3 x 23 cm. Glass spheres are a low cost non-corrosive type of housing that are widely used to place electronics in the deep-sea environment. However, the receiver board is too large to fit into the largest commercially available glass sphere pressure housing, which has an inside diameter of approximately 36 cm. Also, because the receiver board is multi-layered, it cannot be easily cut or otherwise modified.

A workable solution to the problem of housing the DCR control module has been provided by Ocean Innovations, LLC. of La Jolla, California. Ocean Innovations offers a line of semi-custom instrument pressure housings, based on aluminum cylindrical tubes, with a range of wall thicknesses and inside diameters. The inside tube length can be cut to an arbitrary specification. For the AGI system components, they designed a 25.4 cm inside diameter, 50.8 cm long, cylindrical housing with a wall thickness of 1.3 cm, which gives the housing an operating depth of approximately 1 km (Figure 1). For the long deployment in Phase 2, the housing would be protected from corrosion by electrically isolating stainless steel end-cap hardware from the aluminum hull and attaching sacrificial anodes. One penetration would be made in the housing though the non-opening end-cap to supply power, a RS232 control link, and the attachment to the 56-electrode streamer. At an approximate price of $6,000, the housing can be purchased within budget, at a fraction of the cost of either re-designing the receiver board to fit a glass sphere or building a new, multi-conductor two cable.

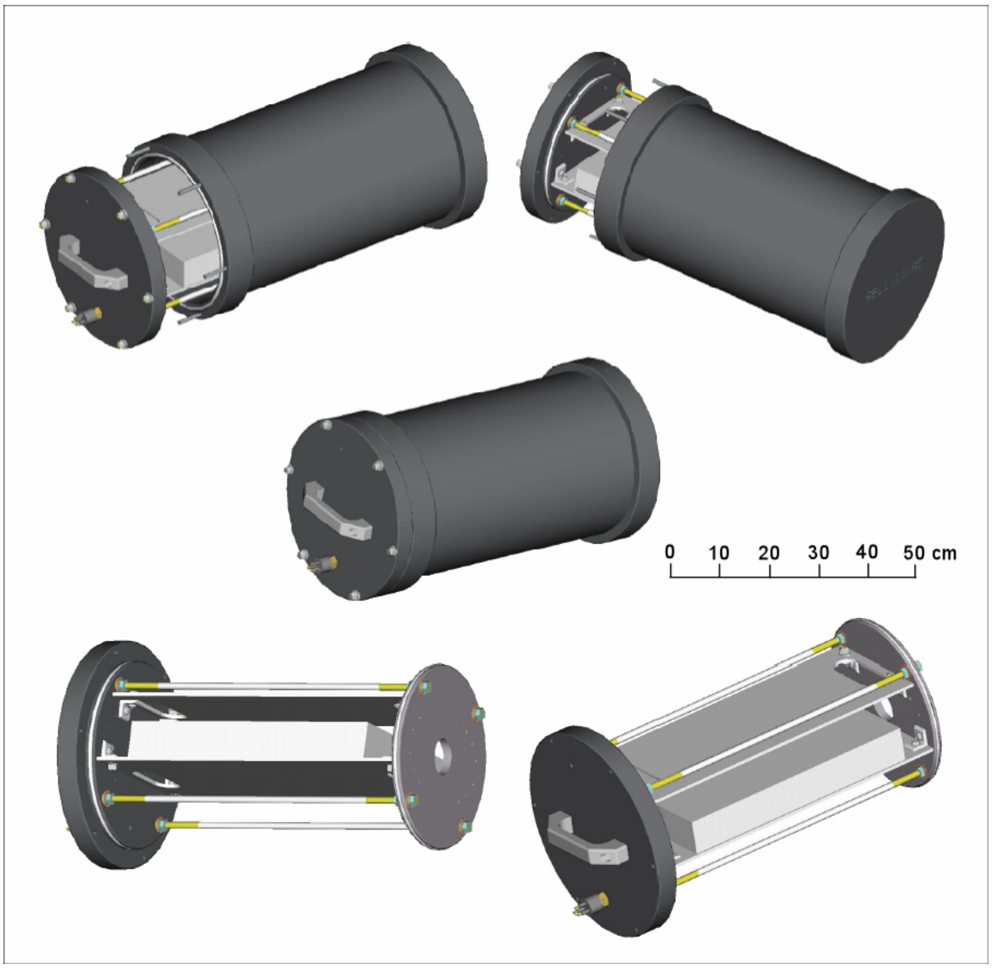


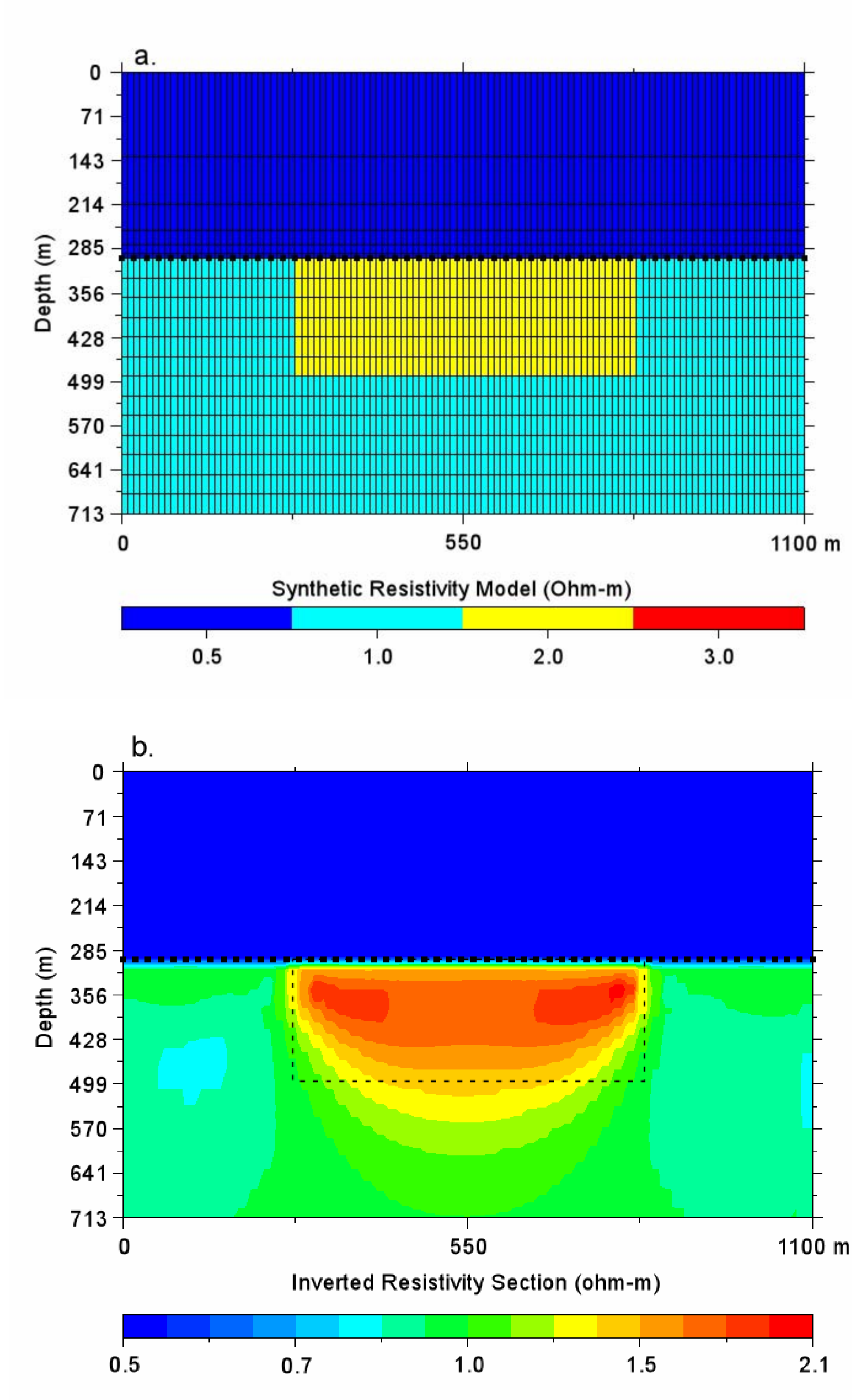
Figure 1. Proposed pressure housing design from Ocean Innovations, LLC., La Jolla, California. The inside diameter is 25.4 cm, length 50.8 cm, hull thickness 1.3 cm. The rectangular box shown in the housing is the approximate maximum dimensions of the AGI 8-channel receiver board. The housing is shown without the penetration through the non-opening end-cap**.**

2.4 Electrode array design for the seafloor DCR system

The dimensions and number of electrodes in the electrode array control the depth of investigation and the vertical resolution of DCR systems. For a fixed number of electrodes there is a tradeoff between electrode spacing for resolution and maximum offset for penetration. For the dipole-dipole array configuration normally used in continuous towed profiling, the maximum depth of penetration is approximately 20% to 25% of the maximum electrode offset, whereas the vertical resolution is approximately one-half the horizontal electrode spacing. Other electrode patterns, such as pole-dipole, produce depths of investigation of approximately 50% of the maximum electrode offset, at the expense of less vertical resolution. The design object is to investigate as deeply into the potential hydrate stability zone as practical with sufficient resolution to determine the vertical and horizontal distribution of hydrates at the MC 118 site. Hydrates are known to exist at the seafloor, but their sub-bottom distribution is unknown. Hydrates may exist only near the seafloor, they may exist at high concentrations down to a proposed base of the stability zone of approximately 400 m, or they may occur at variable concentration within that zone. An additional consideration is that the same array will be used in both Phase 1, for the towed reconnaissance survey and for Phase 2, for the fixed monitoring experiment.

The ideal array design would be one of sufficient length to image clearly to 400 m depth and with sufficient numbers of electrodes spaced sufficiently close together to resolve thin hydrate beds. However, increasing the array length and number of electrodes has cost implications and budget limitations will require some compromise. One such compromise would be to use an array of 56 electrodes, spaced at 20 m intervals, for a total length of 1100 m and to drive the array with a combination of dipole-dipole and pole-dipole electrode configurations. This combination should provide vertical resolution on the scale of 10 m in the upper 200 m of the proposed hydrate stability zone and penetration to the base of the proposed stability zone, albeit at lower resolution.

We are evaluating the penetration and resolution of proposed array designs by forward finite element modeling resistivity measurements for different array configurations and hypothetical hydrate distributions. The forward modeled resistivity measurements are then inverted to determine how well the hypothetical hydrate distribution could be resolved. To date we have considered the response of dipole-dipole arrays of different lengths for a 200 m thick hydrate layer (Figures 2). In the coming weeks we will conduct forward modeling experiments with other hypothetic hydrate distributions and electrode patterns before deciding on a final array design.



a.
Depth (m)
0
71
143
214
285
356
428
499
570
641
713
0
550
1100 m
Synthetic Resistivity Model (Ohm-m)
0.5
1.0
2.0
3.0
b.
Depth (m)
0
71
143
214
285
356
428
499
570
641
713
0
550
1100 m
Inverted Resistivity Section (ohm-m)
0.5
0.7
1.0
1.5
2.1

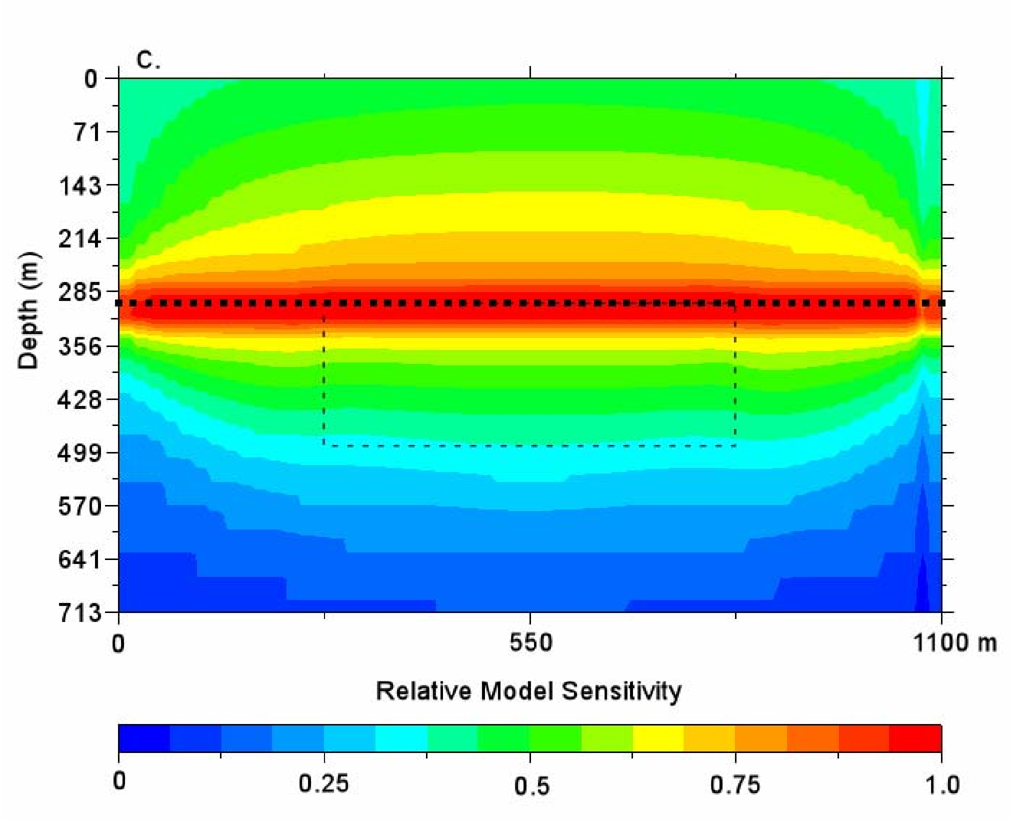


Figure 2. Forward finite element model for an 1100 m long, 56-electrode DCR array. (a) Resistivity distribution associated with a hypothetic 200 m thick, low saturation, hydrate layer. (b) Inverted resistivity section based on synthetic data from the model shown in (a). The rounded edges of the inverted model are typical of potential field inversions. (c) Relative sensitivity of the inversion versus position in the model section. The inversion sensitivity to variations in resistivity at a depth of 100 m below bottom is half of that associated with variations at the seafloor. At a depth of 200 m sub-bottom, the sensitivity is down to approximately one-third that of variations at the seafloor.

3.0 Milestone and budget tracking.

The first project quarter (October to December, 2006), no Critical Path Milestones were reached (Table 1). However, the two initial project tasks of producing a research management plan and a technology status assessment report were completed (Table 2). The only charges to the Federal Share of the budget in this quarter were associated with travel to consult with AGI. Because SDI was busy preparing for and conducting offshore operations, we did not visit them. As a result charges to the Federal Share were 22% less ($527.89) than planned. In contrast, the charge to the Non-Federal Share was twice that originally budgeted. This was not unexpected, because the original budget did not include time to for the first two tasks, plus preparation for the project kickoff meeting.

Table 1: Critical Path Project Milestones. Grey shaded quarters indicate period of activity, by the end of which the milestones occur.

Task/ Subtask	Critical Path Project Milestone Description	Project Duration - Start: 10/2006 End: 9/2009												Planned Start Date	Planned End Date	Actual Start Date	Actual End Date	Comments
		Project Year 1				Project Year 2				Project year 3								
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12					
1.4	Test of Bottom-towed system													4/07	9/07			
1.5	Bottom-towed survey													7/07	12/07			
2.1	Semi-autonomous operation													4/08	6/08			
2.4	Monitoring system deployment													7/08	12/08			
2.6	Analysis of monitoring data													10/08	9/09			

Table 2: Other Project Milestones. Grey shaded quarters indicate period of activity, by the end of which the milestones occur. Check marks indicate Milestones that have been completed.

Task/ Subtask	Critical Path Project Milestone Description	Project Duration - Start: 10/2006 End: 9/2009												Planned Start Date	Planned End Date	Actual Start Date	Actual End Date	Comments
		Project Year 1				Project Year 2				Project year 3								
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12					
1.1	Research Management Plan	√												10/06	12/06	10/06	12/06	
1.2	Technology Status	√												10/06	12/06	10/06	12/06	
1.3	Adaptation of DCR system													1/07	6/07			
1.6	Analysis of bottom-towed data													10/07	3/08			
1.7	Phase 1 Topical Report													1/08	3/08			
2.2	Reconfiguration for monitoring													4/08	6/08			
2.3	Test of DCR monitoring system													7/08	9/08			
2.5.1	Data retrieval cruse 1													10/08	3/09			
2.5.2	Data retrieval cruse 2													1/09	6/09			
2.7	Final Report													7/09	9/09			

Table 3: Expenditures by project quarter.

Baseline Reporting Quarter	YEAR 1: Starting 10/06 Ending 9/07				YEAR 2: Staring 10/07 Ending 9/08				YEAR 3: Starting 10/08 Ending 9/09			
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
Baseline Cost Plan												
Federal Share	2,402	54,333	60,063	12,638	4,204	33,215	26,620	21,492	14,495	14,495	14,495	19,714
Non-Federal Share	8,358	8,358	8,358		8,358	6,904	6,904		7,215	7,215	7,215	
Total Planned	10,760	62,691	68,421	12,638	12,562	40,119	33,524	21,492	21,710	21,710	21,710	19,714
Cumulative Baseline Cost	10,760	73,451	141,872	154,510	167,072	207,191	240,715	262,207	283,917	305,627	327,337	347,051
Actual Incurred Cost												
Federal Share	1,874.11											
Non-Federal Share	16,716.00											
Cumulative Baseline Cost	18,590.11											
Variance												
Federal Share	527.89											
Non-Federal Share	(8,358.00)											
Total Variance-Quarterly	(7,830.11)											
Cumulative Variance	(7,830.11)											

4.0 Plans for the next quarter

There is a lot of work planned for the second quarter of the project. It will start with placing orders for the electronic components for the DCR system and the pressure housing in the first month (January, 2007). Both of these items have two-month lead times. In February we will settle on a design for the electrode array and place that order. Then in March, we should receive the components and housing and SDI can begin the assembly of the instrument package. The Electrode array will then arrive in April in time for field-testing in May, 2007.

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