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

Project Quarter 6 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 or containing veins filled with hydrate are more resistive than surrounding sediments with pore spaces filled with seawater. 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.

From January 2008 – March 2008:

- Two, 2m long, 2-electrode cables were test in a high-pressure chamber for electrical continuity prior to fabricating the full electrode array,
- Electronic components for the seafloor DCR system were assembled in the instrument pressure housing,
- 28 graphite electrodes were molded onto the 540 m long electrode array,
- The annual meeting of the Gulf of Mexico-Hydrate Research Consortium (GOM-HRC) was attended in Oxford Mississippi,
- A mixed dipole-dipole and inverse-Winner array configuration to electrically image the hydrate stability zone was designed and numerically simulated.

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List of Acronyms and Abbreviations

BSR	Bottom simulating reflection
CSEM	Controlled source electromagnetic
CRP	Continuous resistivity profiling
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
UNOLS	University-National Oceanographic Laboratory System
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 methane 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 shallow source – deep receiver seismic 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. An apparent bottom simulating reflection (BSR) beneath the vent area suggests that the base of the hydrate stability zone is approximately 200 m below the seafloor. 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.

Although hydrates are observed at the seafloor and an apparent BSR marks the apparent base of the hydrate stability zone at the site, the distribution of gas hydrates within the stability zone has not been determined. Attempts to image the sub-bottom within the methane vent region have not produced interpretable results. Electrical methods offer an alternate approach to mapping the concentration of hydrates within the stability zone. Gas hydrate is essentially non-conductive. Hence, massive gas hydrate has high electrical resistivities (100 Ωm) and sediments with pore spaces partially filled with hydrate are more resistive (2 to 100 Ωm) than surrounding sediments with saline pore fluids (≤ 1 Ωm). This resistivity contrast has been widely exploited to quantify downhole hydrate concentration 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, potentially resulting in higher resolution images of the hydrate distribution. Also, because of the low power of the source and 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.

In this project, 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 and a BSR underlying the site at a depth of approximately 200 m has been mapped. 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 than would be the case for a standalone experiment. 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 an inexpensive, yet 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 (CRP) 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 periodically re-profile a selected cross-section across the site 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 second quarter of the project, from January 2008 to March 2008.

2.0 Results and Discussion

2.1 Construction of the deep-sea, 28-electrode electrode array (Subtask 1.3.2)

Prior to this project quarter 576 m of gel-filled, 28-conductor marine cable with a central Kevlar strength member was delivered in early November, 2007. During this project period, Advanced Geosciences, Inc. of Austin TX (AGI) cut two, 2 m long segments from the cable and fabricated test segments. The segments are short versions of the 28-electrode, deep-sea cable, in that 2 electrodes were molded in place by the method that will be used to fabricate the full cable. These short cable segments were then tested in a pressure chamber at 3000 PSI. The results indicated that continuity between the electrodes and the connector was maintained while under pressure. There was loss of electrical isolation between the electrodes and internally exposed conductors. However, this appeared to be the result of leakage into the connector used to connect the test cables to the external monitoring equipment, and not due to leakage into the test cables.

The placement of the electrodes along the cable was predicated on two design constraints. The objective of the Phase 1 reconnaissance survey is to image resistivity variations within the expected hydrate stability zone from the seafloor to 200 m sub-bottom over a 1 km^2 region centered on the active methane vents. The objective of Phase 2 is to image sub-bottom resistivity changes over time along one cross section. This will be done by leaving the cable deployed on the seafloor in a fixed position and running the DCR system in an autonomous monitoring mode. The Phase 1 objective would best be achieved with variable electrode spacing, in which electrodes are spaced closer together at near offsets and further apart at far offsets. The Phase 2 objective would best be accomplished with uniformly spaced electrodes. A compromise would be to use a uniform electrode spacing of 20 m, but use a subset of the electrodes in multiple reads during the reconnaissance survey.

The plan to achieve the phase 1 objective with a uniformly spaced electrode array is to make alternating readings of the cable with a dipole-dipole configuration and an inverse-Wenner configuration. The dipole-dipole configuration provides the maximum vertical resolution at the expense of penetration depth. The inverse-Wenner configuration provides maximum penetration at the expense of resolution. Using the two configurations together provides some of the advantages of both. For the dipole-dipole configuration, electrodes 2 and 4 will be used as the current injection points and electrodes 6, 7, 9, 11, 14, 18, 23, and 28 will be used to form 8 potential pairs with offsets from 60 to 520 m. These measurements will image to a depth of 100 m sub-bottom with 8 resistivity readings. The second reading will then be made with the inverse-Wenner configuration, in which electrodes 10 and 19 are used as current injection points and voltage will be measured between electrode pairs 6-23, 5-24, 3-26, and 1-28. These data will be used to image the region between 100 and 200 m sub-bottom with 4 resistivity readings. To test this design a finite element model of a 200 m-thick hydrate layer was built and used to compute a synthetic resistivity profile, using alternating dipole-dipole and inverse-Wenner arrays (Figure 2). The inversion results indicate that the combination of arrays is sufficient to image subtle resistivity variations (1 to 2 Ohm-m) to a depth of 200 m sub-bottom.

Tom fabricate the electrode array, AGI molded 28 graphite electrodes onto the high pressure cable at a uniform spacing of 20 m. A mechanical coupling to the cable was attached to the Kevlar strength member and molded in place 30 m in front of the first electrode. The result is a 570 m-long cable with a 540 m active section. The 30 m lead-in section was added to make it possible to tow the instrument above the seafloor and yet have all the electrodes on the seafloor. The electrode array has been shipped to Impulse Enterprises to have the electrical connector attached to the leading end. This will complete the electrode array.

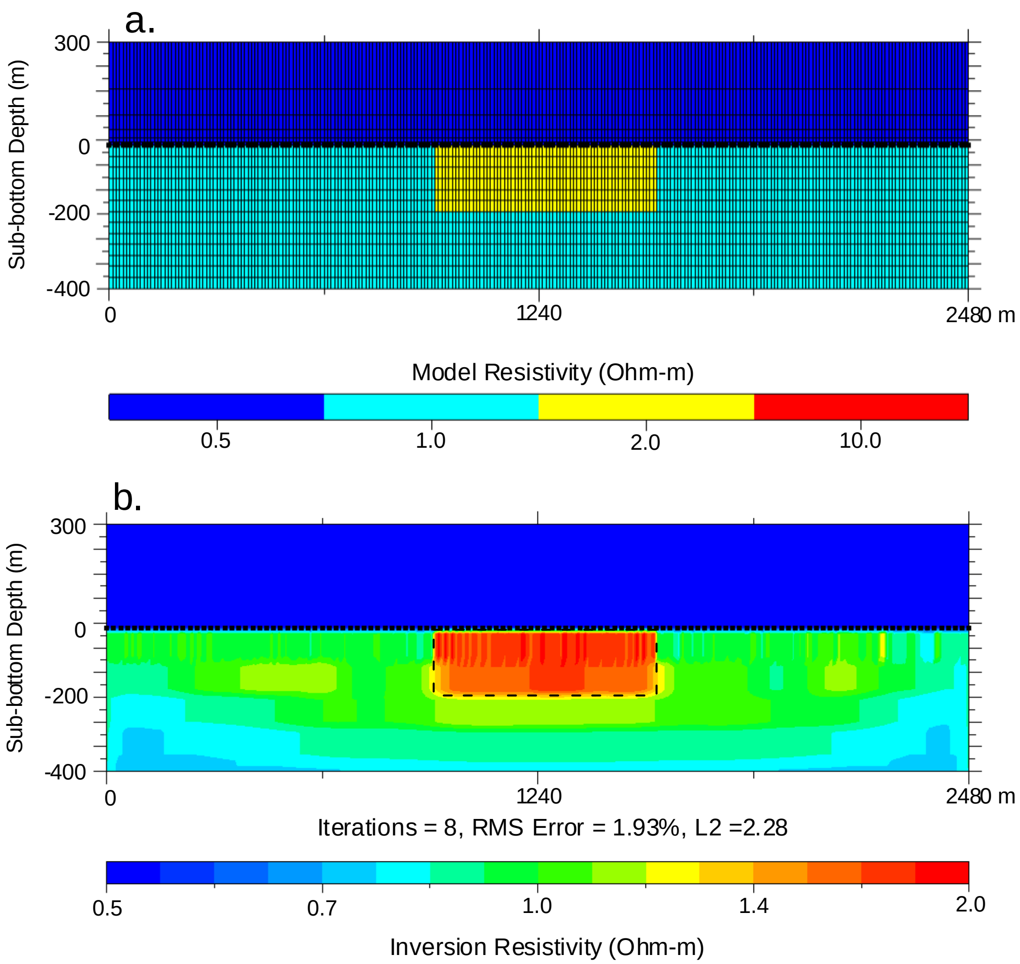

Figure 1. Numerical simulation of mixed dipole-dipole and inverse-Wenner arrays. (a) Hypothetical model of a 200 m-thick hydrate zone of 2 Ohm-m embedded in 1 Ohm-m sediment. (b) Inverted section produced from a 2480 m synthetic profile of mixed dipole-dipole and inverse-Wenner array readings. The dashed rectangle superimposed over the inverted section indicates the extent of the target region in part (a).

2.2 Construction of DCR system components (Subtask 1.3.1)

During this project quarter, AGI completed the mounting of the DCR system components in the pressure housing (Figure 2). The DCR system is normally powered by a 12 Volt battery that supplies a peak current of 17 amps. For the Phase 1 reconnaissance survey the options for power sources are a specially constructed oil-filled battery pack or drawing power from the main battery of the SDI ROV. The disadvantage of a special battery pack is the cost of construction, plus the added weight on the ROV. The disadvantage of using the ROV battery is that it supplies power at 150 Volts, which will have to be stepped down to 12 volts. Power options for the Phase 2 fixed monitoring are, again, a special battery pack or the seafloor observatory battery, which will supply power at 48 volts. The decision was made to power the system with the existing ROV and seafloor observatory batteries, which will require the addition of a 150 Volt to 12 Volt

DC-to-DC converter for use with the ROV and a 48 volt to 12 Volt converter for use with the seafloor observatory battery. The 150-12 Volt converter will be mounted in the instrument pressure housing for the Phase 1 reconnaissance survey and then replaced with the 48-12 Volt converter for fixed monitoring in Phase 2. This solution to the power problem completes the instrument fabrication.

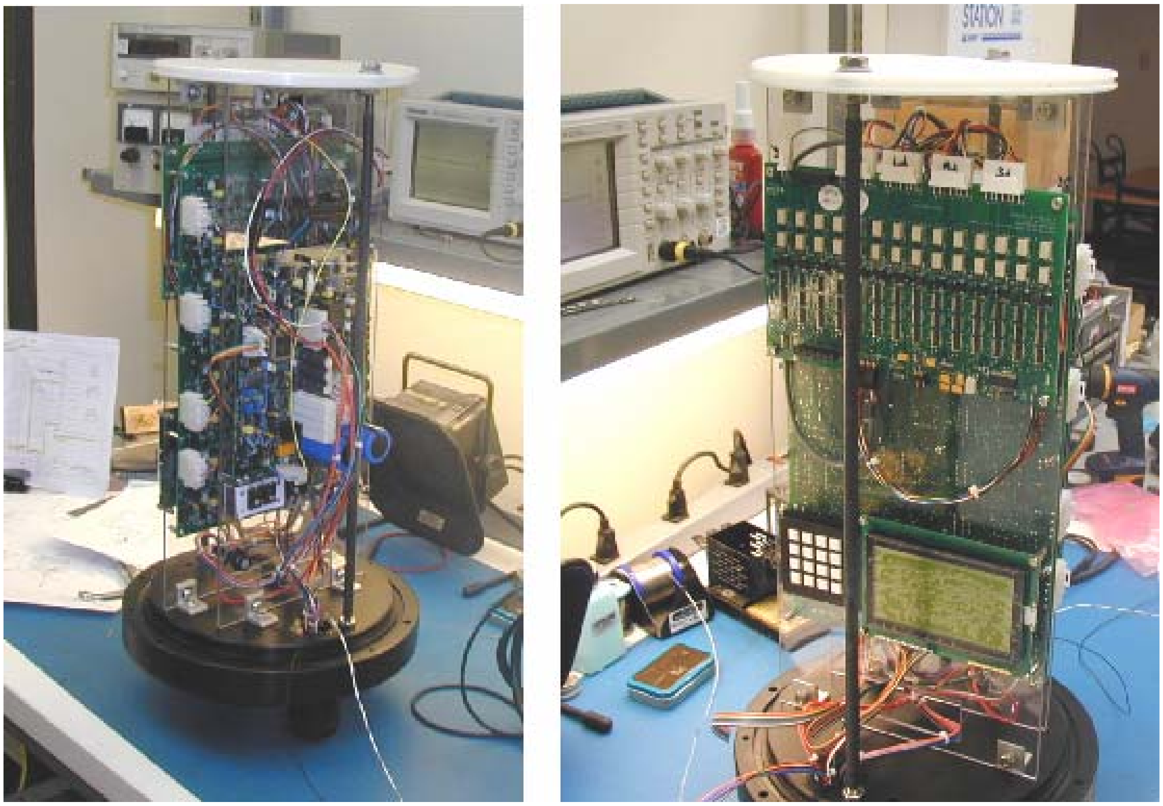

Figure 2. DCR system circuitry assemble onto pressure housing instrument tray.

3.0 Milestone and budget tracking.

As of the end of project the project period 6, the technical progress continuous to be approximately two quarters behind the original schedule (Table 1). However, approximately 95% of Subtask 1.3, adapting an engineering DCR system for deployment on the deep seafloor, has completed within budget (Table 2). The charges to the Federal Share of the budget in this quarter were associated with the cost of the purchase of mating connectors to the through-hull connectors in the instrument housing ($2,261.50), purchase of 28 graphite electrodes and molding them onto the cable ($10,520.00), graduate student support ($3,300) and travel for Dunbar to Oxford Mississippi to attend the annual meeting of GOF-HRC ($660.54). The project is currently within budget, but the schedule as shifted approximately two quarters, due to delays associated with the electrode array redesign in second quarter. Even with this delay, we are on schedule for conducting the Phase 1 reconnaissance survey on the first available cruse in mid May to early June, 2008.

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	1/07		
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 Er**		
	Q1	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**	**Q10**	**Q11**
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	14,4
Non-Federal Share	8,358	8,358	8,358		8,358	6,904	6,904		7,215	7,215	7,2
Total Planned	10,760	62,691	68,421	12,638	12,562	40,119	33,524	21,492	21,710	21,710	21,7
Cumulative Baseline Cost	10,760	73,451	141,872	154,510	167,072	207,191	240,715	262,207	283,917	305,627	327,3
Actual Incurred Cost											
Federal Share	1,874.11	52,658.74	41,497.20	5,497.51	692	16,742.04					
Non-Federal Share	16,716.00	8,358.00	8,358.00	8,358.00	8,358.00	8,358.00					
Cumulative Baseline Cost	18,590.11	79,606.85	121,105.05	134,960.56	144,010.00	169110					
Variance											
Federal Share	527.89	1,674.26	18,565.80	7,140.49	3,512.00	16472.96					
Non-Federal Share	(8,358.00)	0	0	(8,358)	0	(1,454)					
Total Variance-Quarterly	(7,830.11)	1,674.26	18,565.80	(1,217.51)	3,512.00	15,018.96					
Cumulative Variance	(7,830.11)	(6,155.85)	12,409.95	11,192.44	14,704.44	29,723.36					

4.0 Plans for the next quarter

In the project quarter 7, we plan to complete the adaptation of the DCR system for use on the GOM-HRC May-June cruse to MC118. After the connector is molded onto the electrode array by Impulse Enterprises, Inc., the complete DCR system will be tested in a brackish water reservoir (Lake Whitney). Three activities are scheduled for the cruse upcoming May-June cruse. First, previously deployed instruments will be recovered. Next, the data-retrieval mooring for the seafloor observatory will be deployed. Then, in the time remaining, the DCR reconnaissance survey for this project will be conducted.

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