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

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Project Quarter 14 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 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 2010 – March 2010:

- A summary of the results of Phase 1 of this project was presented by the Recipient at a DOE-sponsored conference on methane hydrates, held on the campus of Georgia Tech., Atlanta, Georgia. An expanded abstract as well as a poster based on this presentation was prepared for the SAGEEP meeting to be held April 11-15, 2010 in Keystone, Colorado.

- Work on reconfiguring the seafloor resistivity system for high-resolution 3D data acquisition began. The main change from the reconnaissance 2D survey configuration used in Phase 1 of the project will be the addition of new, shorter electrode array, with variably-space electrodes. In this quarter a preliminary design for the new array was completed and long-lead time materials for its construction were ordered. Experimental electrodes for the array were built using a variety of materials for testing purposes.

Table of Contents

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
ROV	Remotely operated vehicle
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 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 deployment of a seafloor seismic array, pore-fluid samplers, bottom-towed P- and S-wave seismic profiling, and vertical array seismic profiling.

Although hydrates are observed at the seafloor and a 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 map the distribution of hydrates seismically have not yet produced usable 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 hydrate blocks have 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).

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 electrical 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 (many kilometers) 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 at 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 as originally planned was to be conducted in two phases. The first phase involved the development of an experimental bottom-towed DCR system, configured for continuous resistivity profiling (CRP) on the seafloor. Once complete, the experimental system was used to conduct a reconnaissance survey of the methane vent area at the MC 118 site. The resulting data will be complimentary to seismic data, previously collected at the site and will help characterize the overall hydrate distribution at the site. Depending on the results for the first phase, the second phase of the project would involve reconfiguring DCR system for high-resolution 3D surveying of the methane vent area of MC118. The resulting data would be used to better constrain the 3D distribution of hydrate within the vent region of MC118.

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 and 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 that 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.

Markus Lagmanson and personnel of Advanced Geosciences, Inc. of Austin, Texas (AGI) will be the subcontractor in charge of fabricating 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 Markus 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 Quarter 14 of the project, from January 2010 through March 2010.

2.0 Results and Discussion

2.1. Reconfiguration of the DCR system for high-resolution 3D surveying

The main change in the DCR system from the reconnaissance survey configuration used in Phase 1 will be the addition of new, shorter electrode array, with variably-space electrodes. The array used in Phase 1 was designed for general use and initial testing. It is 1.1 km long, with 56 graphite electrodes evenly spaced 20 m apart. Graphite was chosen for the electrode material for its corrosion resistance during possible long-term deployments. The large number of electrodes and even spacing were chosen to permit automatic profiling with the array fixed on the seafloor and for flexibility in continuous resistivity surveying. The array intended for high-resolution 3D surveying will be designed for dedicated continuous profiling while the array is towed along the seafloor. It will have three dedicated source electrodes, two of which will be used at any one time. There will be 9 dedicated, low-noise potential electrodes. The potential electrodes will be variably spaced along array, with smaller spacings at near offsets and larger spacings at the far offsets, for a maximum source-receiver offset of 500 m. This will provide high spatial resolution in the first 50 m below the seafloor, while maintaining a maximum penetration of approximately 120 m achieved in Phase 1.

In this quarter, a preliminary design for the new array was completed and long-lead time materials for its construction were ordered. The cable connecting the elective electrodes in the array will contain 17 total conductors. The diameter of conductors to both source and receiver electrodes will be larger in the new array compared to those used in the reconnaissance array. This will reduce DC voltage loss along the cable and result in improved signal strength. The reconnaissance array contained 60 #26 gauge stranded copper conductors used to connect 56 electrodes that could be used interchangeably as source or receiver electrodes. In the new array, four of the conductors will be #16 gauge stranded copper and will be dedicated to driving source electrodes. Three of the four #16 gauge conductors will initially connected to a pair of source electrodes at the lead-end of the array and one at the trailing end of the array. This will allow the array to be used in either a dipole-dipole array configuration or in a gradient array configuration. The fourth #16 gauge conductor will be left as a spare in case one the active source conductors is damaged. The remaining 14 conductors will be #22 gauge stranded copper and will be used to connect 9 potential electrodes, variable spacing along the array, plus five spare conductors for future changes in electrode configuration or repair of damage. The array will have a maximum operating depth of 2000 m and a breaking strength of 4500 lbs. The raw underwater cable for this array has been ordered at a cost of $8,950, with an expected delivery date of June 3, 2010.

While useable data were collected in Phase 1 of this project, only proximately 50% of the data collected had sufficiently high signal to noise ratio to be productively analyzed.   The data that were used had higher noise levels than are typical for land resistivity surveys, with average noise levels between 5 and 10% of the signal strength. In Phase 2 the Recipient plans to improve the signal to noise ratio in three ways: (1) the total array length will be shorter and hence signal levels will be higher by virtue of smaller source-receiver offsets and less DC voltage loss along the cable; (2) the DC voltage losses along the cable will be further reduced by using larger diameter conductors; (3) a low-noise pre-amplifier will be added to the system in a separate, electrically isolated housing, which will amplify signal levels in the low-noise environment of the deep seafloor, prior to entering the instrument housing with its onboard sources of RF noise; and (3) low noise electrodes will be used. In this project quarter experimental electrodes were prepared composed of graphite, stainless steel, copper, brass, titanium, lead/lead chloride, and silver/silver chloride. In the next quarter the relative performance of these electrodes in terms of self-polarization will be tested in a low electrical noise environment of a doubly-shield Faraday cage within a doubly magnetically shielded laboratory. The electrode type used for the new array will be chosen based on performance, logistical considerations, and price.

3.0 Milestone and budget tracking.

As of the end of Project Quarter 14, Phase 2 was within budget and on time. However, the June 3, 2010 delivery date for the raw cable for the new electrode array will delay the completion of the DCR system modifications to Quarter 16. This will not influence the overall project schedule, because no cruises are planned to the field site (MC118) between the original completion date in late Quarter 15 and late Quarter 16. In Quarter 14, expenditures of Federal funds were as follows: $7,000 in graduate student stipends, $889 for gradient student insurance, $1,468 for travel, $555 in conference registration fees, $1,134 for fabrication of experimental electrodes, and $8,950 for 650 m of raw 17-conductor high pressure cable.

Table 1: Revised Project Milestones. Grey shaded quarters indicate period of activity, by the end of which the milestones occur. The √ symbols indicate the quarter in which project tasks/subtasks were completed. The X symbols indicate tasks not completed because of technical problems and associated milestones not met. The ◊ symbols indicate the time of go/no-go decisions at Critical Path Milestones. Grey-shaded quarters indicate originally planned period of activity and milestones. Red-shaded quarters indicate originally planned period of activity and milestones.

Task/ Milestone	**Task/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					
Task 1	Research Management Plan	√												10/06	12/06	10/06	11/06	
Task 2	Technology Status	√												10/06	12/06	11/06	12/06	
Task 3	Adaptation of DCR system																	
Subtask 3.1	DCR system components		√											1/07	6/07	1/07	3/07	
Subtask 3.2	Deep-Sea electrode array						√							1/07	5/07	4/07	3/08	
Subtask 3.3	Assembly of DCR system						√							5/07	6/07	4/08	5/08	
Task 4	Test of Bottom-towed system						X	System Repair						2/07	3/09	5/09	5/09	
CPM 1	**DCR system test successful**				◊		X				√◊			2/09	3/09	5/09	5/09	
Task 5	Bottom-towed survey													3/09	6/09	6/09	6/09	
CPM 2	**Completion of DCR survey**					◊						√◊		6/09	6/09	6/09	6/09	
Task 6	Analysis of DRC data												√	8/09	9/09	8/09	8/09	
Task 7	Project Final Report													9/09	9/09			In progress

Table 2: Expenditures by project month.

Baseline Reporting Quarter	YEAR 1: Starting 10/06 Ending 9/07											
	Q1			Q2			Q3			Q4		
	10-6	11-06	12-06	1-07	2-07	3-07	4-07	5-07	6-07	7-07	8-07	9-07
Baseline Cost Plan												
Federal Share	0	0	0	3,305	30,000	15,000	54,288	0	17,695	0	0	2,971
Non-Federal Share	2,263	2,263	2,263	14,995	2,263	2,263	2,263	2,263	0	0	0	14,995
Total Planned	2,263	2,263	2,263	18,300	32,263	17,263	56,551	2,263	17,695	0	0	17,966
Cumulative Baseline Cost	2,263	4,526	6,789	25,089	57,352	74,615	131,166	133,429	151,124	0	0	169,090
Actual Incurred Cost												
Federal Share	0	0	0	2,310	5,210	1,145	(914)	4,404	5,104	38,324	1,791	892
Non-Federal Share	2,263	2,263	2,263	14,995	2,263	2,263	2,263	2,263	0	0	0	14,995
Cumulative Baseline Cost	2,263	4,526	6,789	24,094	31,567	34,975	36,324	42,991	48,095	86,419	88,210	104,097
Variance												
Federal Share	0	0	0	995	24,790	13,855	55,202	(4,404)	12,591	(38,324)	(1,791)	2,079
Non-Federal Share	0	0	0	0	0	0	0	0	0	0	0	0
Total Variance-Monthly	0	0	0	995	24,790	13,885	55,202	(4,404)	12,591	(38,324)	(1,791)	2,079
Cumulative Variance	0	0	0	995	25,785	39,640	94,842	90,438	103,029	64,705	62,914	64,993

Table 2 continued.

Baseline Reporting Quarter	**YEAR 2: Starting 10/07 Ending 9/08**											
	Q5			**Q6**			**Q7**			**Q8**		
	10-7	11-07	12-07	1-08	2-08	3-08	4-08	5-08	6-08	7-08	8-08	9-08
Baseline Cost Plan												
Federal Share	2,971	2,971	5,930	3,068	0	0	0	0	0	0	0	0
Non-Federal Share	2,263	2,263	2,263	2,263	2,263	2,263	2,263	2,263	0	0	0	2,263
Total Planned	5,234	5,234	8,193	5,331	2,263	2,263	2,263	2,263	0	0	0	2,263
Cumulative Baseline Cost	174,324	179,558	187,751	193,082	195,345	197,608	199,871	202,134	0	0	0	204,397
Actual Incurred Cost												
Federal Share	1,179	7,876	1,492	2,979	1,321	1,321	16,423	1,279	4,400	2,220	29,686	0
Non-Federal Share	2,263	2,263	2,263	2,263	2,263	2,263	2,263	2,263	0	0	0	2,263
Cumulative Baseline Cost	106,539	116,678	120,433	125,675	129,259	132,843	151,529	155,071	159,471	161,691	191,377	193,640
Variance												
Federal Share	1,791	(4,905)	4,438	89	(1,321)	(1,321)	(16,423)	(1,279)	(4,400)	(2,220)	(29,686)	0
Non-Federal Share	0	0	0	0	0	0	0	0	0	0	0	0
Total Variance-Monthly	1,791	(4,905)	4,438	89	(1,321)	(1,321)	(16,423)	(1,279)	(4,400)	(2,220)	(29,686)	0
Cumulative Variance	66,784	61,879	66,317	66,406	65,085	63,764	47,341	46,062	41,662	39,442	9,756	9,756

Table 2 continued.

Baseline Reporting Quarter	**YEAR 3: Starting 10/08 Ending 9/09**											
	Q9			**Q10**			**Q11**			**Q12**		
	10-8	11-08	12-08	1-09	2-09	3-09	4-09	5-09	6-09	7-09	8-09	9-09
Baseline Cost Plan												
Federal Share												
Non-Federal Share	2,263	2,263	2,263	2,263	2,263	2,263	2,263	2,263				2,263
Total Planned												
Cumulative Baseline Cost												
Actual Incurred Cost												
Federal Share	4693	2325	0									
Non-Federal Share	2,263	2,263	2,263	2,263	2,263	2,263	2,263	2,263				2,263
Cumulative Baseline Cost												
Variance												
Federal Share	(4,693)	(2,325)	0	0	0	0	(300)	0	(693)	0	0	0
Non-Federal Share	(2,263)	(2,263)	(2,263)	(2,263)	(2,263)	(5,137)	0	(330)	0	(2,263)	(2,263)	(2,263)
Total Variance-Quarterly	(6,956)	(4,588)	(2,263)	(2,263)	(2,263)	(5,137)	(300)	(330)	(693)	(2,263)	(2,263)	(2,263)
Cumulative Variance	2,800	(1,788)	(4,051)	(6,324)	(8,577)	(13,714)	(14,014)	(14,344)	(15,037)	(17,300)	(19,563)	(21,826)

Baseline Reporting Quarter	YEAR 4: Starting 10/09 Ending 9/10											
	Q13			Q14			Q15			Q16		
	10-9	11-09	12-09	1-10	2-10	3-10	4-10	5-10	6-10	7-10	8-10	9-10
Baseline Cost Plan												
Federal Share				3,000	5,000	11,500	2000	2000	4,000	7,500	10,000	9,000
Non-Federal Share	2,263	2,263	2,263	2,263	2,263	2,263	2,263	2,263				2,263
Total Planned												
Cumulative Baseline Cost												
Actual Incurred Cost												
Federal Share	0	0	0	3,060	4,550	11,858						
Non-Federal Share	2,263	2,263	2,263	2,263	2,263	2,263	2,263	2,263				2,263
Cumulative Baseline Cost												
Variance												
Federal Share	0	0	0	(60)	450	(358)						
Non-Federal Share	0	0	0	0	0	0						
Total Variance-Quarterly	0	0	0	0	0	0						
Cumulative Variance	(21,826)	(21,826)	(21,826)	(21,886)	(21,436)	(21,794)						

Baseline Reporting Quarter	YEAR 5: Starting 10/10 Ending 9/11											
	Q17			Q18			Q19			Q20		
	10-10	11-10	12-10	1-11	2-11	3-11	4-11	5-11	6-11	7-11	8-11	9-11
Baseline Cost Plan												
Federal Share	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	10,000	5,000	5,000	1,560
Non-Federal Share	2,263	2,263	2,263	2,263	2,263	2,263	2,263	2,263				2,263
Total Planned												
Cumulative Baseline Cost												
Actual Incurred Cost												
Federal Share												
Non-Federal Share												
Cumulative Baseline Cost												
Variance												
Federal Share												
Non-Federal Share												
Total Variance-Quarterly												
Cumulative Variance												

4.0 Plans for the next quarter

In Quarter 15 of the project, the Recipient will complete preparations for the final electrode array assemble prior to the delivery date for the raw high-pressure cable. This will involve testing candidate electrode types for self-potential noise in a low electrical noise environment, selection of the final electrode type, and fabricating the electrodes to be used in the array construction. It will also be necessary to finalize the locations of the electrodes along the array. The electrode configuration will be selected base on finite element forward and inverse modeling of different candidate electrode configurations to test their ability to image hydrate-related resistivity anomalies similar to those found in the Phase 1 reconnaissance survey. The Recipient will also purchase and test an 8-channel, low-noise, pre-amplifier circuit board for use inline between the electrode array and the DCR instrument.

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