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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 24 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 hydrate within the pore spaces or containing hydrate veins or other inclusions 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 July 2012 through September 2012 efforts were made to prepare for the July cruise to MC118 to conduct a 3D resistivity survey. The following activities were performed:

- John Dunbar and graduate student Tian Xu took part in a July 12-20 cruise to MC118 in an attempt to collect a 3D resistivity data set over Woolsey Mound.

- During the deployment of the seafloor resistivity system the main instrument housing flooded and no data were collected.

- Subsequence efforts were made to salvage as much as possible of the instrument and assess the cost of repairs to the seafloor resistivity instrument.

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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
RF	Radio frequency
RS232	Electronics Industries Association common computer interface standard
ROV	Remotely operated vehicle
SSD	Station service device
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, installing 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 re-purposed 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 potential 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 to 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. Based on the results for the first phase, the second phase of the project involves reconfiguring DCR system for high-resolution 3D surveying of the methane vent area of MC118. The resulting data will 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, in 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.

Mats 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 24 of the project, from July 2012 through September 2012.

2.0 Results and Discussion

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

The main limitations of the reconnaissance survey conducted in Phase 1 of the project were that the array used was designed to image as much as 200 m below the seafloor, at the expense of near-bottom resolution, and the signal to noise ratio of the resulting data was relatively poor. The results of the Phase 1 survey indicated that the most interesting resistivity anomalies, suggestive of high concentration hydrate deposits, occur within 50 m of the seafloor. Hence, the goals of the DCR system reconfiguration for Phase 2 are to improve near-bottom resolution and to increase the signal to noise ratio. The main changes in the DCR system from the reconnaissance 2D survey configuration will be the addition of a new, shorter electrode array, with dedicated source and receiver electrodes. That is, unlike in the general-purpose reconnaissance survey array, the source and receiver assignments will be fixed throughout the survey. This makes it possible to use larger and more efficient copper electrodes connected by heaver-gauge wire for the sources and low-noise titanium electrodes for the receivers. An external, low-noise preamplifier will also be added to the front end of the cable to boost the signal level by a factor of at least 100, prior to entering the instrument housing. Together, these changes should dramatically increase the signal-to-noise ratio and shallow resolution over that achieved in the reconnaissance survey. All changes to the seafloor DCR system necessary for the Phase 2 survey were completed prior to this project quarter.

No resistivity data were collected during the July cruise to MC118. The resistivity system was operational while on deck, but communication with the instrument was lost on the way to the bottom. Upon retrieval, it was found that the main instrument housing had flooded. The failure was due to a pinched O-ring. Subsequent efforts to recover the system components were not successful, meaning that a new set of system cards will be required to make the instrument operational.

3.0 Milestone and budget tracking.

As of the end of Project Quarter 24, all the components of the reconfigured DCR system for Phase 2 were completed, tested, and an unsuccessful attempt was made to conduct a 3D survey at MC118. We have therefore reached Milestone 2.1 of the Research Management Plan. Since, insufficient funds remain in the project to repair the resistivity instrument, the Phase 2 survey of MC118 will not be completed.

Table 3.1. 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			

Table 3.1 continued.

Task/ Milestone	**Task/Milestone Description**	Phase II Duration - Start: 10/2006 End: 9/2009								Planned Start Date	Planned End Date	Actual Start Date	Actual End Date
		Project Year 4				Project Year 5							
		Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20				
Task 2.1	Reconfigure for 3D surveying									11/09	5/10	1/10	12/10
Task 2.2	Test of 3D DCR System									5/10	6/10	12/10	3/11
CMP 2.1	**Test of 3D DCR System Complete**			√◊						5/10	6/10	1/11	6/11
Task 2.3	3D DCR Survey of MC 118									5/10	3/11	7/12	7/12
CMP 2.2	**Completion of 3D Survey**						◊			3/11	3/11	Failed	
Task 2.4	Analysis of 3D DCR Data									6/10	7/11		
Task 2.5	Project Final Report									7/11	10/11		

Table 3.2. 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 3.2 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	202,134	202,134	202,134	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	66,785	61,880	66,318	66,407	66,086	64,765	48,342	47,063	42,663	40,443	10,757	10,757

Table 3.2 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	0	0	0	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												
Cumulative Baseline Cost	206,660	208,923	211,186	213,449	215,712	217,975	220,238	222,501	222,501	222,501	222,501	224,764
Actual Incurred Cost												
Federal Share	4693	2325	0	0	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
Cumulative Baseline Cost	200,596	205,184	207,447	209,710	211,973	214,236	216,499	218,762	218,762	218,762	218,762	221,025
Variance												
Federal Share	(4,693)	(2,325)	0	0	0	0	0	0	0	0	0	0
Non-Federal Share	0	0	0	0	0	0	0	0	0	0	0	0
Total Variance-Quarterly	(4,693)	(2,325)	0	0	0	0	0	0	0	0	0	0
Cumulative Variance	6,064	3,739	3,739	3,739	3,739	3,739	3,739	3,739	3,739	3,739	3,739	3,739

Table 3.2 continued.

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	0	0	0	7,500	7,500	7,500	7,500	7,500	7,500	5,000	5,000	5,000
Non-Federal Share	2,263	2,263	2,263	2,263	2,263	2,263	2,263	0	0	0	2,263	2,263
Total Planned	2,263	2,263	2,263	9,763	9,763	9,763	9,763	7,500	7,500	5,000	7,263	7,263
Cumulative Baseline Cost	227,027	229,290	231,553	241,316	251,079	260,842	270,605	278,105	285,605	290,605	297,868	305,131
Actual Incurred Cost												
Federal Share	0	0	0	2,500	5,499	2,750	12,742	1,682	7,465	4,977	0	0
Non-Federal Share	2,263	2,263	2,263	2,263	2,263	2,263	2,263	0	844	0	2,263	2,263
Cumulative Baseline Cost	223,288	225,551	227,814	232,577	240,339	245,352	260,357	262,039	270,348	275,325	277,588	279,851
Variance												
Federal Share	0	0	0	5,000	2,001	4,750	(5,242)	5,818	35	23	5000	5000
Non-Federal Share	0	0	0	0	0	0	0	0	(844)		0	0
Total Variance-Quarterly	0	0	0	5,000	7,001	11,751	(5,242)	576	(233)	(210)	0	0
Cumulative Variance	3,739	3,739	3,739	8,739	10,740	15,490	10,248	16,066	15,257	15,280	20,280	25,280

Table 3.2 continued.

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	0	0	0	0	20,000	10,000	10,000	5,000	10,650	0	0	0
Non-Federal Share	2,263	2,263	2,263	2,263	2,263	2,263	2,263	0	0	0	2,263	2,263
Total Planned	2,263	2,263	2,263	2,263	22,263	12,263	12,263	5,000	10,650	0	2,263	2,263
Cumulative Baseline Cost	307,394	309,657	311,920	314,183	336,446	348,709	360,972	365,972	376,622	376,622	378,885	378,885
Actual Incurred Cost												
Federal Share	0	0	0	511	20,000	10,232	10,000	12,000	12,360	0	3,000	0
Non-Federal Share	2,263	2,263	2,263	2,263	2,263	2,263	2,263	2,263	0	0	0	0
Cumulative Baseline Cost	282,114	284,377	286,640	289,414	311,677	324,172	336,435	350,698	363,058	363,058	366,058	366,058
Variance												
Federal Share	0	0	0	(511)	0	(232)	0	(7,000)	(1,710)	0	(3,000)	0
Non-Federal Share	0	0	0	0	0	0	0	0	0	0	0	0
Total Variance-Quarterly	0	0	0	(511)	0	(232)	0	(7,000)	(1,710)	0	(3,000)	0
Cumulative Variance	25,280	25,280	25,280	24,769	24,769	24,537	0	17,537	15,827	15,827	18,827	18,827

Table 3.2 continued.

Baseline Reporting Quarter	**YEAR 6: Starting 10/11 Ending 9/12**											
	Q21			**Q22**			**Q23**			**Q24**		
	10-11	11-11	12-11	1-12	2-12	3-12	4-12	5-12	6-12	7-12	8-12	9-12
Baseline Cost Plan												
Federal Share	0	0	0	0	0	0	0	0	0	0	0	0
Non-Federal Share	0	0	0	0	0	0	0	0	0	0	0	0
Total Planned	0	0	0	0	0	0	0	0	0	0	0	0
Cumulative Baseline Cost	378,885	378,885	378,885	378,885	378,885	378,885	378,885	378,885				
Actual Incurred Cost												
Federal Share	0	0	0	0	0	0	0	0	2000	1200		
Non-Federal Share	0	333	0	0	0	0	0	0	0	0		
Cumulative Baseline Cost	366,058	366,391	366,391	366,391	366,391	366,391	366,391	366,391	368,391	369,591		
Variance												
Federal Share	0	0	0	0	0	0	0	0	(2000)	(1200)	0	0
Non-Federal Share	0	(333)	0	0	0	0	0	0	0	0	0	0
Total Variance-Quarterly	0	(333)	0	0	0	0	0	0	(2000)	(1200)	0	0
Cumulative Variance	18,827	18,494	18,494	18,494	18,494	18,494	18,494	18,494	16,494	15,294	15,294	15,294

4.0 Plans for the next quarter

During Quarter 25, a portion of the seafloor resistivity system will be repaired and a final report for the project will be written.

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