Oil & Natural Gas Technology

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Quarterly Research Performance Progress Report (Period ending 12/31/2014)

Mapping Permafrost and Gas Hydrate using Marine CSEM Methods

Project Period (10/1/2012 – 09/30/16)

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Office of Fossil Energy

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Last quarter we carried out data collection offshore Prudhoe Bay, amounting to more than 100 line km of survey from the west edge of Prudhoe Bay to 50 km east of Prudhoe Bay. Apparent resistivity pseudosections showed near-seafloor resistivities consistent with water saturated sediments, increasing at depth to resistivities consistent with permafrost. The many cross-line ties are extremely consistent, showing the data quality to be very good. There is considerable lateral variation in apparent resistivity, indicative of structure in the permafrost. This quarter we have spent time fine tuning the navigation and calibration data in preparation for full 2D inversion of the data. We have also involved a Masters student (Thomas Martin) in the inversion of data collected off San Diego last year as an engineering test of the towed EM system. The results are excellent, and clearly show the offshore extension of buried river channels associated with onshore drainage systems. We have started the planning for the 2015 field season, and have ship time planned starting 30 July.

The Ph.D. student who has been working on this project to date (Peter Kannberg) has also been involved in several other gas hydrate studies, and has been advised by his exam committee to concentrate on data sets collected offshore California. While he will continue to be involved with the collection and publication of the permafrost data, we have decided to rotate in a second student (Dallas Sherman) to carry the inversions of these data forward. Dallas has been involved in many aspects of this project to date (instrument tests, 2014 data collection) and has extensive experience working with marine EM data, and so this should allow us to stay on schedule in spite of the increasing demands on Peter's time.

ACCOMPLISHMENTS

Major goals of project

Permafrost underlies an estimated 20% of the land area in the northern hemisphere and often has associated methane hydrate. Numerous studies have indicated that permafrost and hydrate are actively thawing in many high-latitude and high-elevation areas in response to warming climate and rising sea level. Such thawing has clear consequences for the integrity of energy infrastructure in the Arctic, can lead to profound changes in arctic hydrology and ecology, and can increase emissions of methane as microbial processes access organic carbon that has been trapped in permafrost or methane hydrate dissociates. There has, however, been significant debate over the offshore extent of subsea permafrost.

Our knowledge of sub-seafloor geology relies largely on seismic data and cores/well-logs obtained from vertical boreholes. Borehole data are immensely valuable (both in terms of dollar cost and scientific worth), but provide information only about discrete locations in close to one (vertical) dimension. Seismic data are inherently biased towards impedance contrasts, rather than bulk sediment properties. In the context of mapping offshore permafrost and shallow hydrate, seismic methods can identify the top of frozen sediment through the identification of high amplitude reflections and high-velocity refractors but simple 2D seismic surveys do little to elucidate the bulk properties of the frozen layers, particularly the thickness. However, permafrost and gas hydrate are both electrically resistive, making electromagnetic (EM) methods a complementary geophysical approach to seismic methods for studying these geological features. Deep ocean EM methods for mapping gas hydrate have been developed by both academia and industry, but the deep-ocean techniques and equipment are not directly applicable to the shallow-water, near-shore permafrost environment. This project addresses this problem by designing, building, and testing an EM system designed for very shallow water use, and using it to not only contribute to the understanding of the extent of offshore permafrost, but also to collect baseline data that will be invaluable for future studies of permafrost degradation.

We will use the new equipment to carry out a pilot project to map the contemporary state of subsea permafrost on part of the U.S. Beaufort inner shelf, reoccupying seismic lines acquired in 2010 to 2012. We will combine the interpretation of EM data with seismic data through a no-cost collaboration with Carolyn Ruppel of the USGS. Modeling suggests that a 500 m long EM array will be adequate to sense the top of permafrost in many of the areas where the USGS has completed mapping. The 500 m towed array will be supplemented by the deployment of 2 to 4 seafloor recorders that will be retrieved after the cruise so that nothing remains in the area. The use of a small number of seafloor recorders will allow us to collect data at larger offsets, providing insight into deeper structure.

We are exploiting the close association of hydrate and permafrost at high latitudes, and in particular their common response to changing climate. By using a second geophysical method to supplement seismic data, we will be able to better map the current extent of permafrost and so better understand the impact of past sea level rise on the hydrate stability field, and provide a critical baseline for studies which target the effects of current climate change.

Our work will not only expand our geophysical tool-kit but also expand our understanding of the geological and hydrological systems associated with gas hydrate. Instrumentation and analytical methods developed for this project can be easily applied for future permafrost and hydrate mapping elsewhere, and also other applications such as groundwater exploration and engineering studies associated with near-shore infrastructure development.

Work accomplished during the project period

Inversion of test data collected in Q2 2014.

Last quarter (Q3 2014) was very busy for us, involving the data collection for the 2014 field season and the processing and initial interpretation of the data sets for this DoE project. We were also involved in a large project to collect marine EM data over a hydrate prospect for the Japanese government (see http://www.oceanfloorgeophysics.com/news-releases.html), which represents a direct application of instrumentation and techniques developed under previous DoE funding. To some extent this quarter has involved working at a more deliberate pace to ensure that we have accurate navigation solutions, instrument calibrations, etc., prior to committing computer time to inversions.

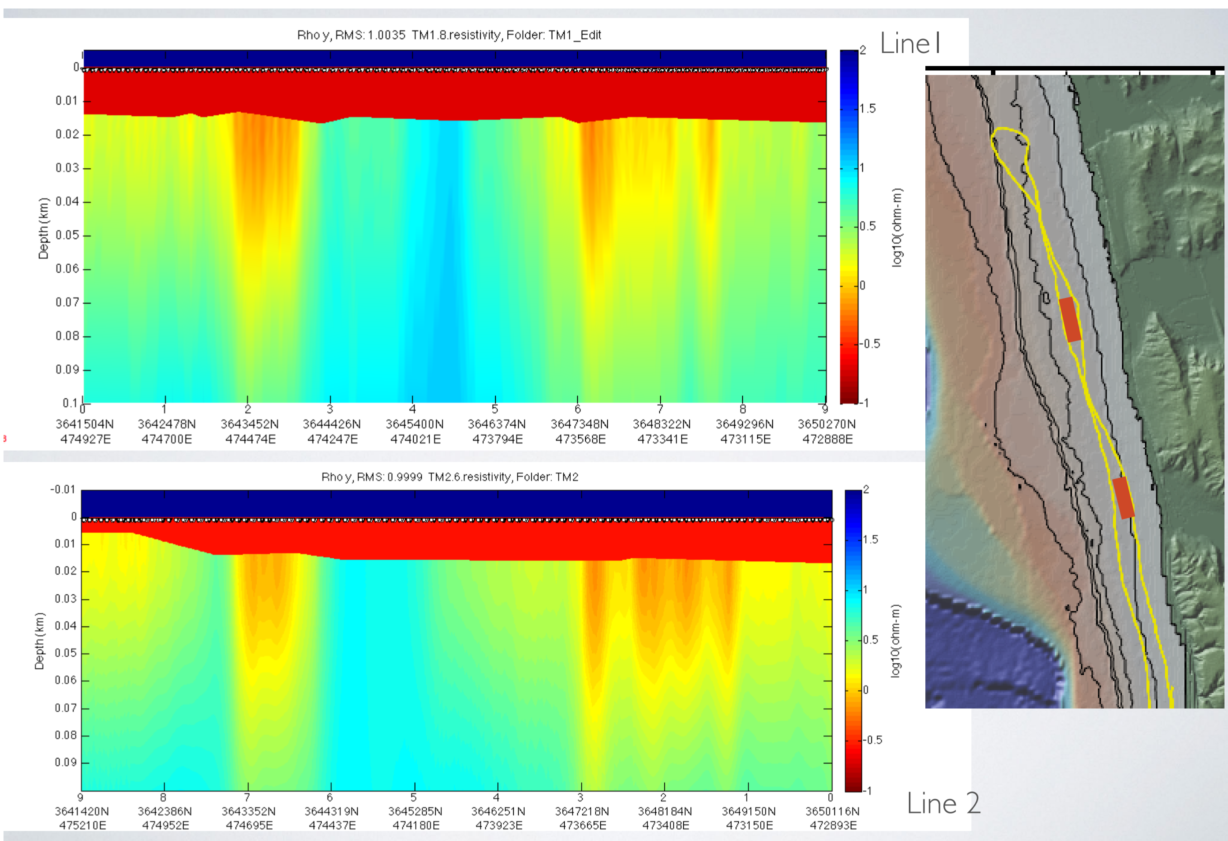

Figure 1. Inversions of data collected offshore San Diego last quarter as an engineering test of our systems: south to north tow (line 1) and north to south tow (line 2), along with location of tow lines north of La Jolla, California (right-hand inset). The locations of the Los Penasquitos Creek outflow (south) and San Dieguito River outflow (north) are shown in red, and are coincident with the 200 m deep conductive regions in the inversions.

In order to gain some experience inverting the novel data we are collecting for this project (surface-towed EM for shallow targets), we had a Masters student (Thomas Martin, supervised by Kerry Key) work on the data collected during a test cruise described in the Q2 2014 report. The results (Figure 1) are very encouraging. Previously, we had noticed reduced electric field amplitudes as we towed our system across the outflows of Los Penasquitos Creek (south) and the San Dieguito River (north), but Thomas Martin's inversions have quantified these observations as 1 km wide, 50 m deep regions where the electrical conductivity is about an order of magnitude higher than the surrounding rocks and sediment. The results are particularly impressive when converted to porosity, using Archie's Law with an exponent of 2 (Figure 2). The 15% porosity contour probably represents bedrock (Torry Sandstone), which outcrops on the seafloor between the two river outflows. The 40% contours probably represent paleo-channels filled with high porosity infill.

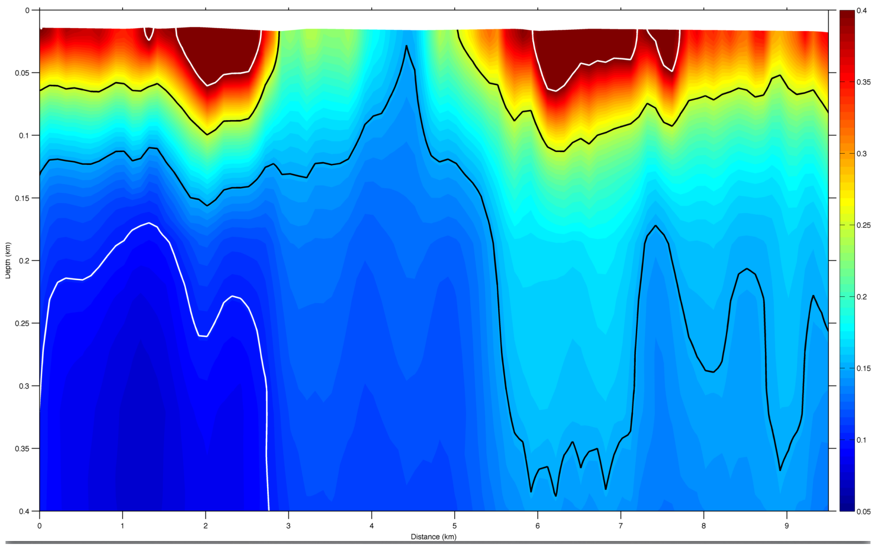

Figure 2. Line 1 inverted conductivity converted to porosity using Archie's Law. Contours are at 10% (white line on blue), 15%, 25%, and 40% (white line on red). Note the large vertical exaggeration.

These inversion results demonstrate that the instrument system designed and built under this current project also has application to offshore groundwater exploration. We have been funded by a University of California Shipfunds grant to carry out a student project to extend this study to an area of inferred offshore groundwater near the San Diego harbor, and also funded by the National Science Foundation to use this equipment offshore Martha' Vineyard on the US east coast.

The inversion of these engineering test data provided good experience for the inversion of the Prudhoe Bay data, but also highlighted the need to obtain a better characterization of the output current from our system. The data inverted were from three towed receivers at ranges of 250 m, 500 m, and 750 m, and frequencies of 1.5, 3.5, 6.5, 11.5, and 18.5 Hz, with a 5% noise floor. Amplitude data were fit to a RMS of 1.0, but we could not simultaneously fit the phase data. We have since discovered that this is a characteristic of our output current waveform, and shown that we need to modify our transmitter in order to characterize the whole waveform, and not just RMS output current as was done for the offshore San Diego test and the Prudhoe Bay test. We will make these modifications, and the results should be applicable to the earlier data sets.

Student worked on data processing and interpretation skills. See "training and professional development" below.

Training and professional development.

The PhD student funded by this project, Peter Kannberg, continues to work on processing and inversion of hydrate data sets collected on other projects, as well as the experimental design for the 2015 Arctic field season. He was involved in the planning and execution of a project to collect data over BSRs in the Santa Cruz Basin in late June 2014, funded by BOEM, and also in the mobilization of a project to collect data offshore Japan, which was carried out in August 2014 with his participation. He carried out the survey design for the 2014 Prudhoe Bay survey and participated in the data collection.

During Peter's PhD qualifying exam in November last year, his committee recommended concentrating on only the San Nicolas and Santa Cruz Basin hydrate data sets for his thesis work. Fortunately, we have another senior student in our group, Dallas Sherman, who is looking for a second project and we have all agreed that she can step in to take over the Prudhoe Bay permafrost project. Dallas has experience at inverting (deep) towed EM data, and so we will not lose time to retraining. Peter will stay involved in the work, and participate in the 2015 data collection, so he won't lose his investment in this project. Indeed, it is likely that publications with his name on them will come out sooner this way.

Meanwhile, we have provided Masters student Thomas Martin with a data set to work on that would otherwise have languished. He has results that are more than sufficient for his Masters thesis, and are probably publishable. And, based on a talk given about this work, he was just offered an industry job with Rock Solid Images.

Plans for next project period.

During the next project period we will continue to work on inverting the 2014 field data, and begin to make detailed plans for the 2015 field season. We plan to carry our experiments to better characterize the transmitter output waveform.

Milestone status report.

Milestone Title	Planned Completion Date	Actual Completion Date	Verification Method	Comments on progress
Equipment design approved	5/1/2013	5/1/2013	Internal review	
Equipment passes tests	12/6/2013	12/1/2013	Internal review	delayed one quarter
Y2 data collection	9/1/2014	7/22/2014	Internal review	
Y2 data processing	9/30/2014	9/30/2014	Internal review	
Y3 data collection	9/1/2015			
Y3 data processing	9/30/2015			
Publications(s) submitted	4/12016			
Publications(s) accepted	9/302016			

PRODUCTS

Project Management Plan. The revised Project Management Plan was accepted on 19 November 2012.

The following abstracts are relevant to this and past DoE funded research:

AGU 2012 Fall Meeting: Mapping methane hydrate with a towed marine transmitter-receiver array, Peter K. Kannberg; Steven Constable, presented in *GP33A. Advances in Electromagnetic Induction: From the Near Surface to the Deep Mantle III Posters.*

AGU 2012 Fall Meeting: Mapping marine gas hydrate systems using electromagnetic sounding, Steven Constable; Karen A. Weitemeyer; Peter K. Kannberg; Kerry W. Key, presented in *OS34A. Marine and Permafrost Gas Hydrate Systems III.*

AGU 2012 Fall Meeting: Electrical conductivity of lab-formed methane hydrate + sand mixtures; technical developments and new results, Laura Stern; Wyatt L. Du Frane; Karen A. Weitemeyer; Steven Constable;

Jeffery J. Roberts, presented in *OS43B. Marine and Permafrost Gas Hydrate Systems IV Posters.*

AGU 2013 Fall Meeting: Hydrates in the California Borderlands: 2D inversion results from CSEM towed and seafloor arrays, Peter Kannberg, Steven Constable, and Kerry Key.

AGU 2014 Fall Meeting: Hydrates in the California Borderlands revisited: Results from a controlled-source electromagnetic survey of the Santa Cruz Basin, Peter Kannberg and Steven Constable.

Gordon Conference Abstract, 2014: Hydrates in the California Borderlands: Results from controlled-source electromagnetic surveys, Peter Kannberg, Steven Constable, and Kerry Key.

PARTICIPANTS AND OTHER COLLABORATING ORGANIZATIONS

Name:	Steven Constable
Project Role:	PI
Nearest person month worked:	1
Contribution to project:	Management, scientific direction
Funding support:	Institutional matching funds
Foreign collaboration:	Yes
Country:	United Kingdom
Travelled:	No

Name:	Peter Kannberg
Project Role:	PhD student
Nearest person month worked:	3
Contribution to project:	Development of analysis tools
Funding support:	Institutional matching funds
Foreign collaboration:	No

Name:	Thomas Martin
Project Role:	Masters student
Nearest person month worked:	3
Contribution to project:	Inversion of test cruise data
Funding support:	None required
Foreign collaboration:	No

CHANGES/PROBLEMS

Student participation in the project is evolving in order to commit sufficient resources to keep the project on schedule.

BUDGETARY INFORMATION

Table 2a: Spend profile

	Budget Period 1							
baseline	10/1/12 – 12/31/12		1/1/13 – 3/31/13		4/1/13 – 6/30/13		7/1/13 – 9/30/13	
	Q4		Q1		Q2		Q3	
	Q4	Cum. Total	Q1	Cum. Total	Q2	Cum. Total	Q3	Cum. Total
Baseline cost:								
Federal	$49,969	$49,969	$33,192	$83,161	$19,810	$102,971	$18,771	$121,742
Non-federal	$9,897	$9,897	$9,897	$19,794	$9,897	$29,692	$29,897	$59,589
Total	$59,866	$59,866	$43,089	$102,955	$29,707	$132,663	$48,668	$181,331
Actual cost:								
Federal	$19,027	$19,027	$8,160	$27,187	$17,444	$44,631	$43,370	$88,001
Non-federal	$10,874	$10,874	$9,514	$20,388	$3,500	$23,888	$24,215	$48,103
Total	$29,901	$29,901	$17,674	$47,575	$20,944	$68,519	$67,585	$136,104
Variance:								
Federal	-$30,942	-$30,942	-$25,032	-$55,974	-$2,366	-$58,340	$24,599	-$33,741
Non-federal	$977	$977	-$383	$594	-$6,379	-$5,804	-$5,682	-$11,486
Total	-$29,964	-$29,964	-$25,415	-$55,380	-$8,763	-$64,144	$18,917	-$45,227

Table 2b: Spend profile

	Budget Period 1		Budget Period 2					
baseline	10/1/13 – 12/31/13		1/1/14 – 3/31/14		4/1/14 – 6/30/14		7/1/14 – 9/30/14	
	Q4		Q1		Q2		Q3	
	Q4	Cum. Total	Q1	Cum. Total	Q2	Cum. Total	Q3	Cum. Total
Baseline cost:								
Federal	$0	$121,742	$10,588	$132,330	$160,134	$292,464	$16,705	$309,169
Non-federal	$0	$59,589	$9,899	$69,488	$14,854	$84,341	$14,854	$99,196
Total	$0	$181,331	$20,487	$201,818	$174,988	$372,360	$31,559	$408,365
Actual cost:								
Federal	$18,959	$106,960	$12,002	$118,962	$144,084*	$263,046*	$35,382	$298,428
Non-federal	$11,486	$59,589	$3,247	$62,836	$36,360	$99,196	$0	$99,196
Total	$30,445	$166,549	$15,249	$181,798	$180,444*	$362,242*	$35,382	$397,624
Variance:								
Federal	$18,959	-$14,782	$1,414	-$13,368	-$16,050	-$29,418	$18,677	-$10,741
Non-federal	$11,486	$0	-$6,652	-$6,652	$21,506	$19,300	-$14,854	$0
Total	$30,445	-$14,782	-$5,238	-$20,020	$5,456	-$14,563	$3,823	-$10,741

* = estimate, includes ship time liened for 2014 field work.

Table 2c: Spend profile

	Budget Period 3								
baseline	10/1/14 – 12/31/14		1/1/15 – 3/31/15		4/1/15 – 6/30/15		7/1/15 – 9/30/15		
	Q4		Q1		Q2		Q3		
	Q4	Cum. Total	Q1	Cum. Total	Q2	Cum. Total	Q3	Cum. Total	
Baseline cost:									
Federal Non-federal Total	$18,842 $9,900 $28,742	$328011 $109096 $437107							
Actual cost:									
Federal Non-federal Total	$6,397 $9,900 $16,297	$ 304825 $109096 $413921							
Variance:									
Federal Non-federal Total	-$10,741 $0 -$10,741	-$23186 $0 -$23186							