Oil & Natural Gas Technology

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Quarterly Research Performance Progress Report (Period ending 06/30/2014)

Mapping Permafrost and Gas Hydrate using Marine CSEM Methods

Project Period (10/1/2012 – 09/30/16)

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TABLE OF CONTENTS

Page

EXECUTIVE SUMMARY

Last quarter was mainly spent planning the logistics for the 2014 field season, and working up an experimental plan for the field work in collaboration with USGS. This quarter we continued with these tasks, but also made some improvements to our transmitter and receiver systems based on tests carried out in the previous budget period. We carried out a full scale test off San Diego with 4 receiver instruments and source–receiver spacings of 250–1,000 m, with excellent results. We also designed and built the 4 moored, seafloor receivers that we plan to use in the 2014 field work. The student working on the project continued to develop skills in the processing and inversion of marine CSEM data over hydrate targets.

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

Planning for summer 2014 field season. The student working on the project, Peter Kannberg, met with Pat Hart and Carolyn Ruppel of the USGS while at the Gordon Research Conference on Gas Hydrate Systems in Galveston in late March (this was incorrectly reported as the International Conference on Gas Hydrates in the previous quarterly report), and discussed co-locating the marine EM lines with seismic lines and estimates of permafrost extent. During the current quarter we developed these conversations into a work plan for the summer 2014 Arctic field season (Figure 1). Since this will be our first time working out of Prudhoe Bay, we decided to locate our survey lines closer to dock for logistical reasons. (This turned out to be a good choice, since much of the area west of Prudhoe was ice-covered this year.)

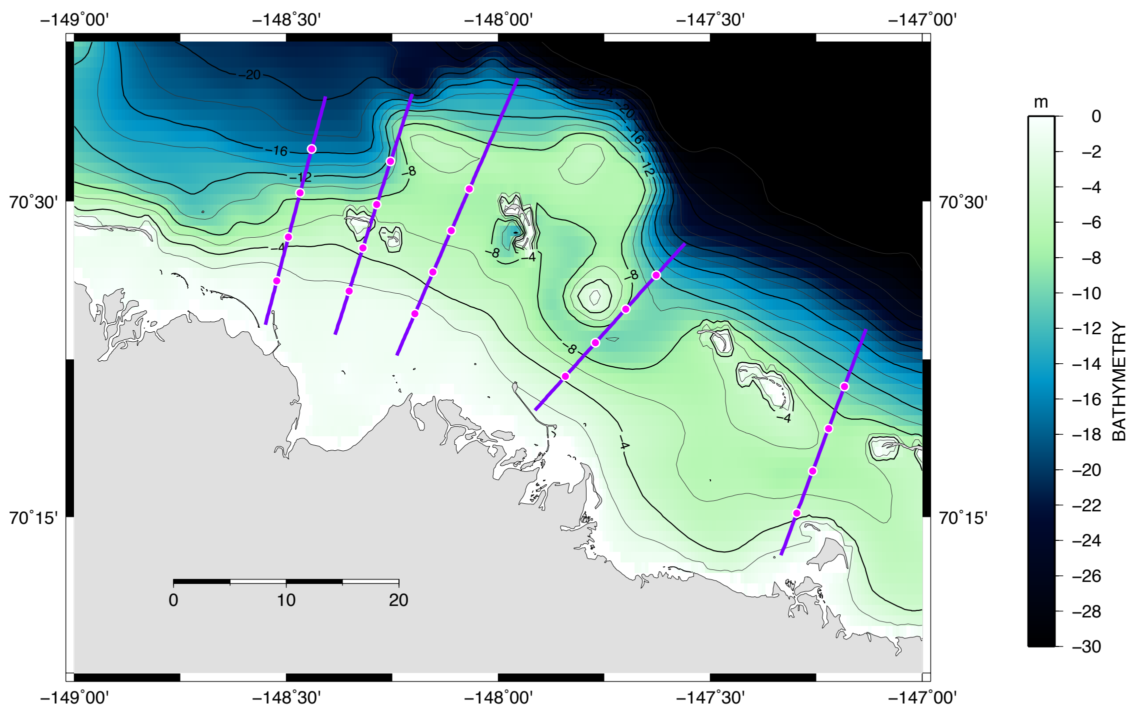

Figure 1. Planned survey for the 2014 field season. Based on the USGS seismic interpretations, permafrost is thought to extend out to about the 8 m bathymetry contour. Red dots represent moored seafloor receivers.

We have been allocated vessel time 16–23 July, and this quarter the PI spent time planning the logistics of field work. This included Coast Guard notifications, packaging equipment for air freight, security access to BP's facilities at West Dock, accommodation, vehicle rental, integration of the vessel's echo sounder data into our data streams, personnel travel, etc.

Improvements to the instruments systems. We continued to make modifications to the field equipment based on the results of the tests we carried out late last year. This included the following:

i) Re-packaging the towed receiver system to reduce flex and vibration during use. The new design also improves handling at sea and packaging for shipping by air. Figure 2 shows the evolution of the instrument package. We integrated the two flotation packages into one, longer instrument case, and slightly shortened up the electric field dipole.

ii) Building a second, backup transmitter system for the field work, to provide full redundancy should this component fail. Our compact transmitter is shown in Figure 3. We also modified the transmitter so that the internal clock can be

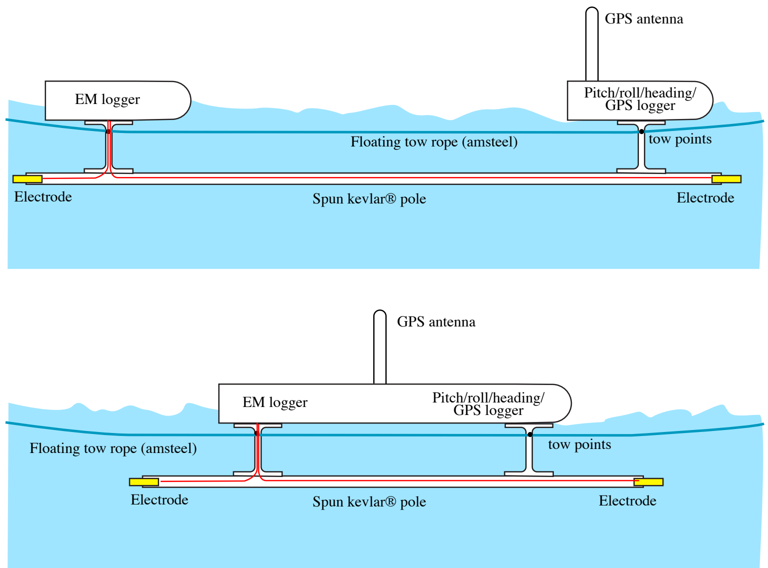

Figure 2. Sensor design concept tested in late 2013 (top panel) and design concept tested this quarter (bottom panel).

replaced with a 2 Hz GPS clock signal to provide drift-free, phase locked, operation. Input power can be provided by 12 V from the vessel, or more conveniently through a 120 VAC input to a 8–14 V DC power supply.

iii) Designing and building four moored seafloor electromagnetic field recorders, used in combination with our towed system to extend source–receiver offsets to several kilometers (Figure 3). These receivers can be broken down for transportation, and use the same logger and amplifier systems as the towed receivers.

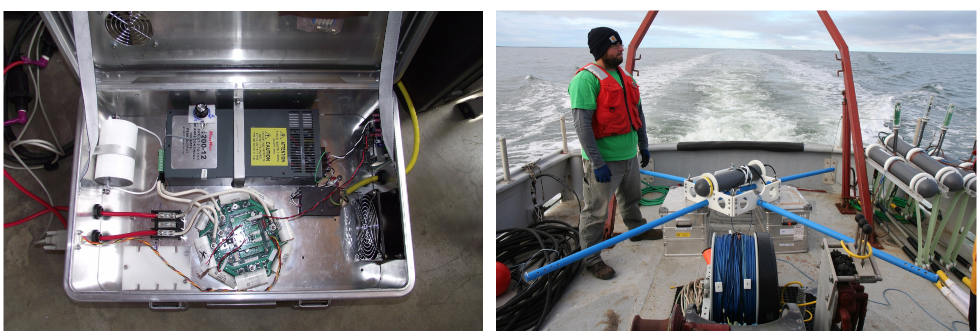

Figure 3. Our 20–50 amp transmitter system (left), housed in the smallest size Zarges box and only 60 cm wide. Our moored seafloor electric field recorder (right).

Further tests of the towed receiver system. On the 14th May we carried out further full-scale tests of our towed transmitter and receiver systems. We extended the source–receiver offset to 1,000 m (last year's tests only used the 500 m offset as proposed, but the good signal to noise ratios we obtained encouraged us to extend this). We towed the system in 5-6 m of water north of the Scripps campus parallel to shore.

Figure 4 shows the data collected during this test, overlaying electric field amplitudes on half-space resistivity calculations in order to obtain apparent resistivities. Most of the data lies at 2-3 Ωm resistivity, except at the outflows of the two lagoons – San Dieguito Lagoon on the left and Los Penasquitos Lagoon on the right – where apparent resistivity drops to 1 Ωm or less. We infer the low apparent resistivities are associated with buried offshore river channels, which provides good qualitative indication that our system is working.

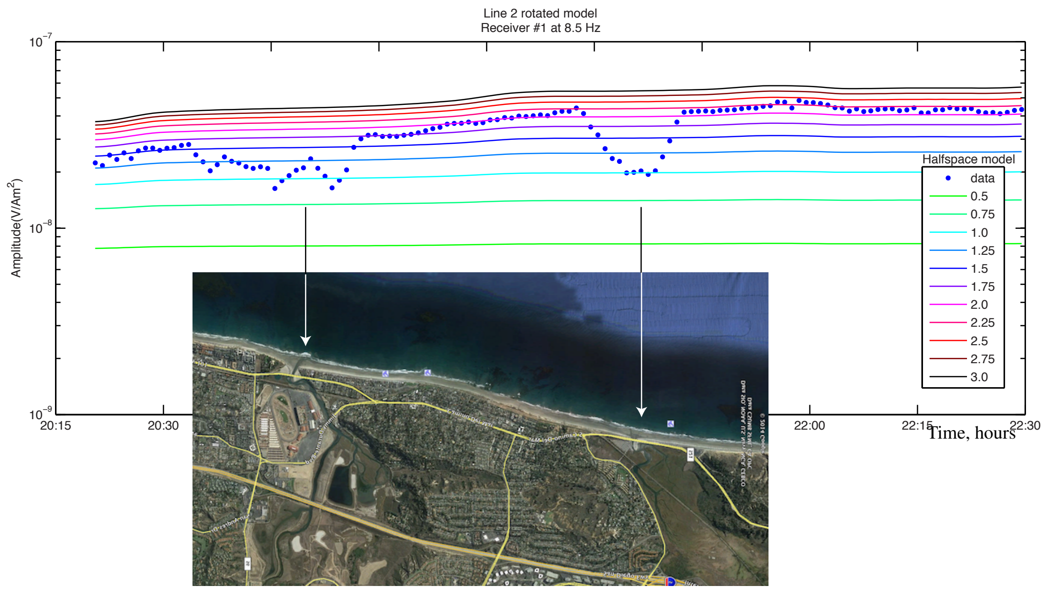

Figure 4. Electric field amplitudes (blue dots) at a frequency of 8.5 Hz from the 250 m receiver during the May 14 San Diego tests. Colored lines are amplitudes computed from half-space models of various resistivities, which may be used to estimate apparent resistivity from the electric fields. We infer that the low apparent resistivities are associated with buried offshore river channels. Since we were steaming south while these data were collected, north is to the left on the map.

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 2014 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, funded by BOEM, and also in the mobilization of a project to collect data offshore Japan, to be carried out in August.

Plans for next project period.

During the next project period we will collect data offshore Pruhhoe Bay for the 2014 field season.

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			scheduled for July 2014
Y2 data processing	9/30/2014			
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.

American Geophysical Union abstracts. The following 2012 abstracts were relevant to this and past DoE funded research:

> *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.*
>
> *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.*
>
> *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.*

The following 2013 AGU abstract is relevant to this and past DoE funded research:

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

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

CHANGES/PROBLEMS

None.

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*		
Non-federal	$11,486	$59,589	$3,247	$62,836	$36,360	$99,196		
Total	$30,445	$166,549	$15,249	$181,798	$180,444*	$362,242*		
Variance:								
Federal	$18,959	-$14,782	$1,414	-$13,368	-$16,050	-$29,418		
Non-federal	$11,486	$0	-$6,652	-$6,652	$21,506	$19,300		
Total	$30,445	-$14,782	-$5,238	-$20,020	$5,456	-$14,563		

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