Oil & Natural Gas Technology

DOE Award No.: DE-FE0010144

Quarterly Research Performance Progress Report (Period ending 12/31/2015)

Mapping Permafrost and Gas Hydrate using Marine CSEM Methods

Project Period (10/1/2012 – 09/30/16)

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EXECUTIVE SUMMARY

Last quarter we carried out the 2015 data collection off Prudhoe Bay, using a newly built transmitter and other instrument upgrades, and processed the data to psuedosections. This quarter we started to prepare the data for inversion, correcting the phases using the newly acquired GPS timing signals collected on the receivers. We presented the preliminary results of the work at the Fall American Geophysical Union Meeting.

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, although our receiver array is now 1,000 m long. The 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, and most recently offshore geothermal exploration.

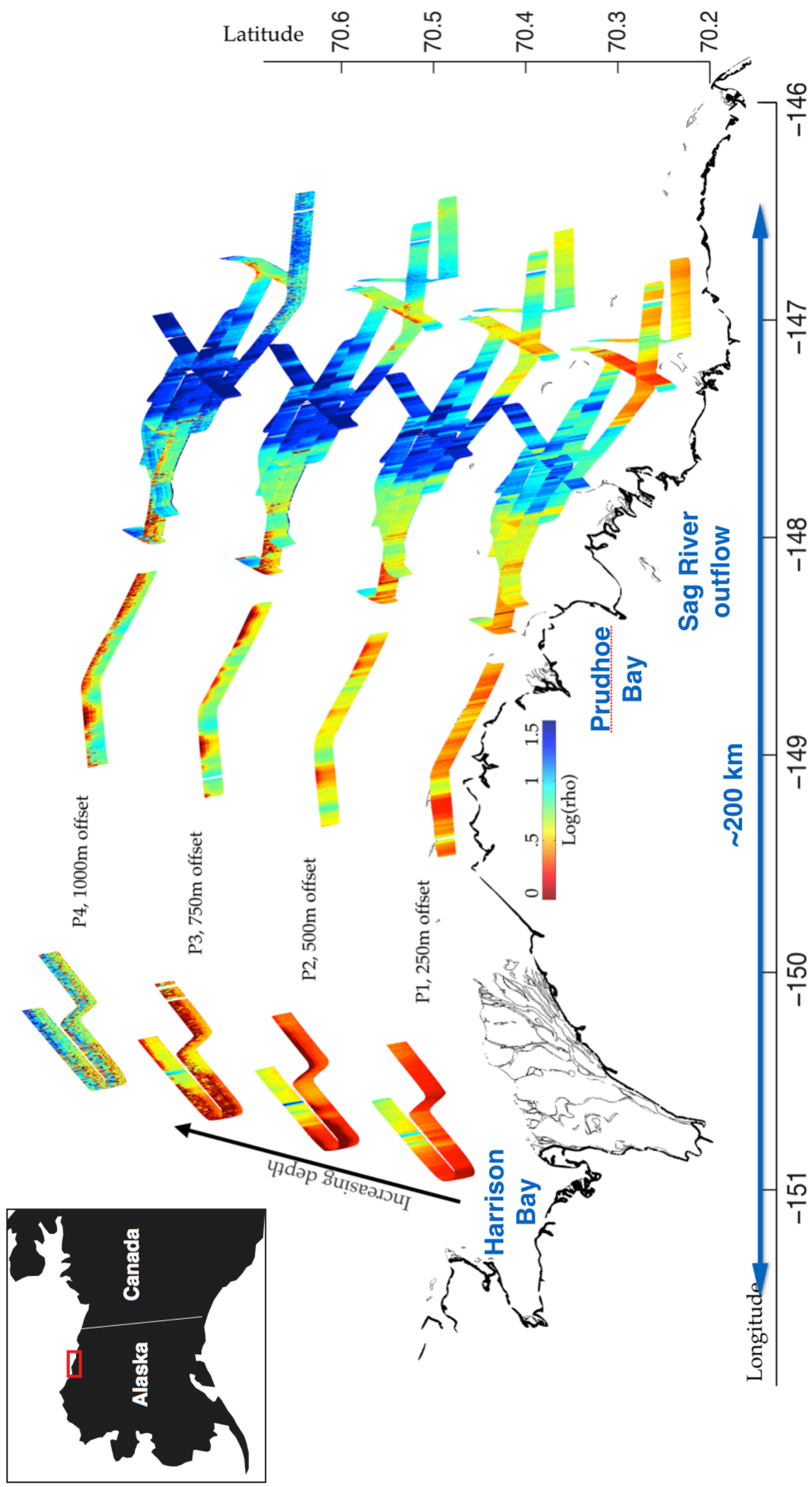

Figure 1. Apparent resistivity pseudosections of 2015 data collected on all four receivers. The resistivity scale is logarithmic, from 1 Ωm to 30 Ωm.

Work accomplished during the project period

Preparing data files for inversion.

Last quarter we processed the 2015 amplitude data to pseudosection form. The results are presented again in Figures 1 and 2, in particular to show the excellent year to year correlation in the results (Figure 2).

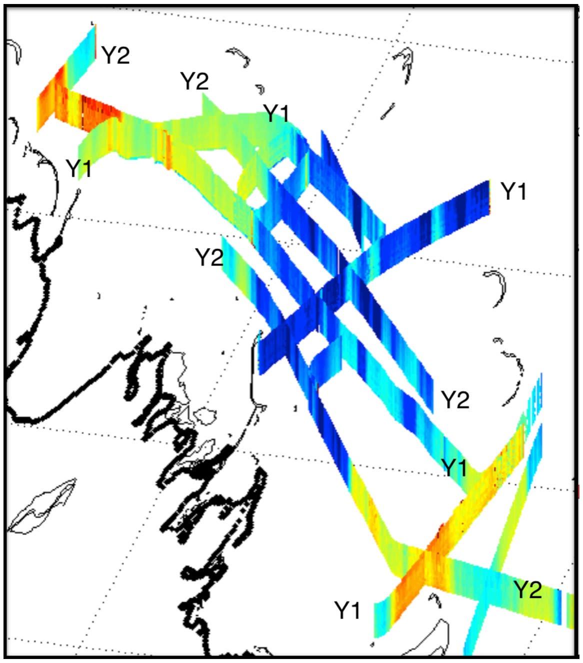

Figure 2. Apparent resistivity pseudosections in the region of the Sag River outflow, marked by the year collected to emphasize the year to year agreement in the data.

The pseudosections are based on electric field amplitudes, while inversions will include phase. Last year we had issues with the phase stability of the transmitter, but for 2015 the transmitter was rebuilt to correct this problem. In addition, we included an extra channel of data on the towed receivers which digitized a 1 Hz signal from the GPS receiver we use for navigation. We have processed those data up in order to correct the phase for clock drift in the receivers. This processing uncovered a previously unknown 2.5 ms timing error in the receiver instruments, which is fixed and independent of clock drift.

We have started to conduct inversions of the data but are still in the process of debugging aspects of the data processing and inversion file generation. Bear in mind that all of our processing, data management, and inversion codes are written in-house because of the novel nature of our data collection system, and so this is far from a turn-key operation.

AGU presentation.

The student working on the project, Dallas Sherman, made a presentation at the fall meeting of the American Geophysical Union.

Training and professional development.

Dallas Sherman, PhD student, is now the student working on this project.

Plans for next project period.

During the next project period we will invert the combined 2014 and 2015 data sets, and start writing up the results for publication.

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	7/7/2015	Internal review	
Y3 data processing	9/30/2015	9/1/2015	Internal review	
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.

AGU 2015 Fall Meeting: Resistivity structure of the Del Mar methane seep, Peter Kannberg and Steven Constable.

AGU 2015 Fall Meeting: Surface towed CSEM systems for shallow water mapping, Joanna Sherman, Steven Constable, and Peter Kannberg.

AGU 2015 Fall Meeting: Water and electricity do mix: Studying plates, petroleum, and permafrost using marine electromagnetism, Steven Constable (invited Bullard Lecture).

The following papers acknowledge this or past DoE funded research:

Du Frane, W., L.A. Stern, S. Constable, K.A. Weitemeyer, M.M. Smith, and J.J. Roberts, 2015. Electrical properties of methane hydrate + sediment mixtures. *Journal of Geophysical Research*, 120. doi:10.1002/2015JB011940.

Weitemeyer, K., and S. Constable, 2014. Navigating marine electromagnetic transmitters using dipole field geometry. *Geophysical Prospecting*, **62**, 573–593, doi: 10.1111/1365-2478.12092.

Du Frane, W.L., L.A. Stern, K.A. Weitemeyer, S. Constable, J.C. Pinkston, J.J. Roberts, 2011. Electrical properties of polycrystalline methane hydrate. *Geophysical Research Letters*, **38**, doi:10.1029/2011GL047243.

Weitemeyer, K.A., S. Constable, S. and A.M. Trehu, 2011. A marine electromagnetic survey to detect gas hydrate at Hydrate Ridge, Oregon. *Geophysical Journal International* , **187**, 45-62.

Weitemeyer, K., G. Gao, S. Constable, and D. Alumbaugh, 2010. The practical application of 2D inversion to marine controlled-source electromagnetic sounding. *Geophysics*, **75**, F199–F211.

Weitemeyer, K., and S. Constable, 2010. Mapping shallow geology and gas hydrate with marine CSEM surveys. *First Break*, **28**, 97–102.

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:	Dallas Sherman
Project Role:	PhD student
Nearest person month worked:	3
Contribution to project:	Processing 2014 data
Funding support:	This project, federal plus matching funds
Foreign collaboration:	No

CHANGES/PROBLEMS

No changes or problems to report at this time.

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	$18,842	$328,011	$18,842	$346,853	$48,842	$395,695	$111,322	$507,017	
Non-federal	$9,900	$109,096	$9,900	$118,996	$9,900	$128,896	$9,900	$138,796	
Total	$28,742	$437,107	$28,742	$465,849	$58,742	$524,591	$121,222	$645,813	
Actual cost:									
Federal	$6,397	$ 304,825	$35,075	$339,900	$72,796	$412,696	$104,030	$516,726	
Non-federal	$9,900	$109,096	$9,900	$118,996	$9,900	$128,896	$9,900	$138,796	
Total	$16,297	$413,921	$44,975	$458,896	$82,696	$541,592	$113,930	$655,522	
Variance:									
Federal	-$10,741	-$23,186	$16,233	-$6,953	$23,954	$17,001	-$7,292	$9,709	
Non-federal	$0	$0	$0	$ 0	$0	$0	$0	$0	
Total	-$10,741	-$23,186	$16,233	-$6,953	$ 23,954	$17,001	-$7,292	$9,709	

Table 2d: Spend profile

	Budget Period 4								
baseline	10/1/15 – 12/31/15		1/1/16 – 3/31/16		4/1/16 – 6/30/16		7/1/16 – 9/30/16		
	Q4		Q1		Q2		Q3		
	Q4	Cum. Total	Q1	Cum. Total	Q2	Cum. Total	Q3	Cum. Total	
Baseline cost:									
Federal	$18482	$525,499							
Non-federal	$9,900	$148,696							
Total	$28,382	$674,195							
Actual cost:									
Federal	$8,810	$525,536							
Non-federal	$9,900	$148,696							
Total	$18,710	$674,232							
Variance:									
Federal	-$9,672	$37							
Non-federal	$0	$0							
Total	-$9,672	$37							