Oil & Natural Gas Technology

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Quarterly Research Performance Progress Report (Period ending 6/30/2015)

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 tests to characterize the waveform from our transmitter, and showed results from an upgrade to the EM receivers to correct for clock drift in the logger time base.

This quarter we re-processed the data collected in 2014 in order to take into account a problem with the transmitter phase stability, a consequence of running the clock timing cables too close to the output cables in the small lab we used in the Prudhoe survey. We have built an improved transmitter system which will alleviate the problem, and we had the opportunity to tests these upgrades during a separately funded survey in the northern Sea of Cortez as part of a project to evaluate offshore geothermal energy resources.

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.

Work accomplished during the project period

Re-processing of 2014 data.

While our transmitter worked well on field tests off San Diego, during the 2014 Prudhoe Bay data acquisition we routed the wires from the GPS timing clock alongside the transmitter output wires to the antenna, and during the switching transients we missed timing pulses. This created a bad phase drift on the transmission signal, which was not taken into account during the initial processing. Because the phase can drift significantly over the 1-2 minute stacking window, stacked amplitudes were under-estimated, especially at higher frequencies. We have re-written the processing code to correct for the phase drift, and the results look good – consistent with the original processing but with much less dispersion at higher frequencies. An example from the 1,000 m instrument is shown in Figure 1.

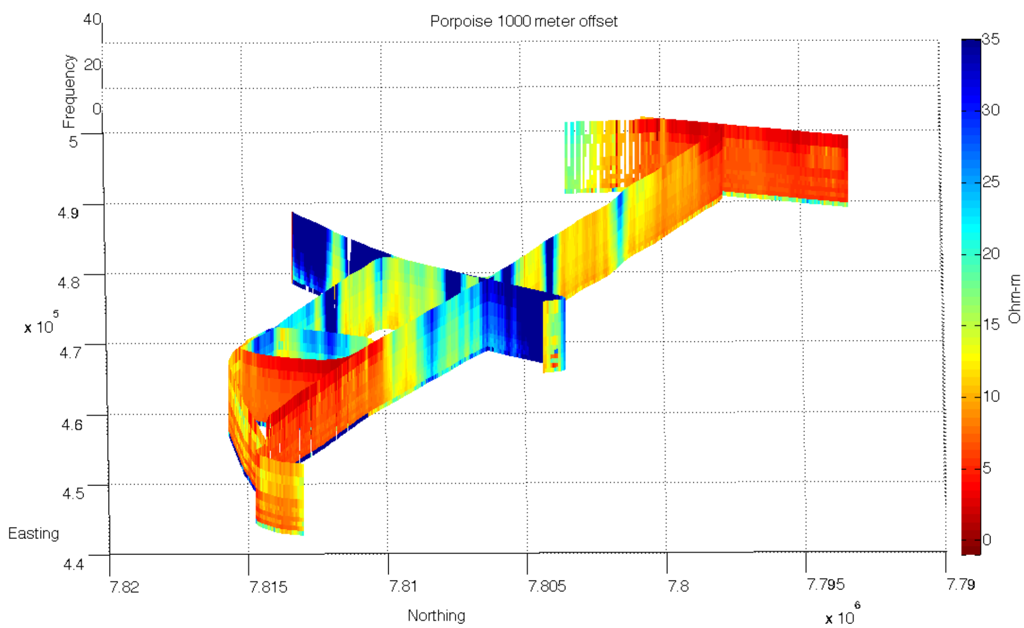

Figure 1. Apparent resistivity pseudosection for the 1000 m surface instrument, re-computed with a correction for transmitter phase drift. The vertical scale is frequency, with highest frequency "up".

New transmitter construction.

While our "suitcase"-style transmitter works very well, we did have the problem with the external GPS clock mentioned above, and it has other limitations. Early this year we obtained funding to join a Mexican project to study offshore geothermal energy prospects in the northern Sea of Cortez (Gulf of California), in relatively shallow water (less than 200 m deep). Based on the success of the 2014 Prudhoe Bay study, as well as the offshore San Diego tests, we decided to use the surface towed receiver array along with a new, bigger transmitter. We built a new 150 amp transmitter based on three TDK-Lambda 50 A power supplies, with improved switch-frame and control circuitry and an integrated GPS clock (no more long cables!). We carried out over 1,000 line-kilometers of survey for the geothermal project in May this year without a hitch. Unfortunately, this new transmitter was bigger, heavier, and more power hungry that we can easily use on the R.V. Ukpik in Prudhoe, so we have built a second, smaller unit based on a single power module (Figure 2) for use this year. We will take out "suitcase" transmitter as a backup, but the new transmitter tests well in the lab.

Figure 2. Our new 50 A transmitter system, with integrated GPS clock and improved power supply.

Planning for the 2015 field season.

The surprising result from last year, which holds up in the re-processing of the data described above, is that there is a large amount of lateral variability in the apparent resistivities. In Figure 1 we see resistivities varying by nearly an order of magnitude over distances of little more than a kilometer. This suggests that there will be more scientific value in increasing the data density rather than extending the survey further along shore. Of course, we need to extend the survey offshore in order to capture the presumed edge of the permafrost.

The experience we gained last year in learning the logistics associated with working in Prudhoe Bay have made this year relatively easy. We have our security clearance for the oilfields in hand, a later slot in the field season (to avoid ice), accommodation organized (we are going to overnight in Anchorage this year, rather than Deadhorse, where accommodation is tight and cannot be booked in advance), and as of the time of writing, our air shipment is on its way. Barring bad luck, we should have an excellent 2015 field season.

Training and professional development.

The new student working on this project, Dallas Sherman, has effectively taken over from Peter Kannberg, and both will be participating again in this year's field program.

Plans for next project period.

During the next project period we will collect and process data for the 2015 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	7/22/2014	Internal review	
Y2 data processing	9/30/2014	9/30/2014	Internal review	
Y3 data collection	9/1/2015			about to commence
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.

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:	Peter Kannberg
Project Role:	PhD student
Nearest person month worked:	1
Contribution to project:	Transferring data/code to Sherman
Funding support:	Institutional matching funds
Foreign collaboration:	No

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

Name:	John Souders
Project Role:	Engineer
Nearest person month worked:	1
Contribution to project:	Design/build new transmitter
Funding support:	This project
Foreign collaboration:	No

Name:	Jacques Lemire
Project Role:	Engineer
Nearest person month worked:	1
Contribution to project:	Prepare shipment for 2015 field work
Funding support:	This project
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		
Non-federal	$9,900	$109,096	$9,900	$118,996	$9,900	$128,896		
Total	$28,742	$437,107	$28,742	$465,849	$58,742	$524,591		
Actual cost:								
Federal	$6,397	$ 304,825	$35,075	$339,900	$72,796	$412,696		
Non-federal	$9,900	$109,096	$9,900	$118,996	$9,900	$128,896		
Total	$16,297	$413,921	$44,975	$458,896	$82,696	$541,592		
Variance:								
Federal	-$10,741	-$23,186	$16,233	-$6,953	$23,954	$17,001		
Non-federal	$0	$0	$0	$ 0	$0	$0		
Total	-$10,741	-$23,186	$16,233	-$6,953	$ 23,954	$17,001		