Oil & Natural Gas Technology

DOE Award No.: DE-FE0010144

Quarterly Research Performance Progress Report (Period ending 12/31/2013)

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 finished construction of a extremely small but moderately powerful EM transmitter for use on this project, and carried out bench tests and software development. This quarter we finished construction of a towed EM receiver suitable for use on small vessels in shallow water, and tested the combined transmitter/receiver system offshore California. The transmitter/receiver system performance exceeded the design goals of this project. The student working on the project continued to develop skills in the 2D 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 mapping elsewhere.

Work accomplished during the project period

Construction and tests of shallow-water towed EM receiver. We designed, constructed, and tested a novel towed EM receiver system specifically adapted to shallow water operation from small vessels. A schematic illustration of the system is shown in Figure 1. The floating instrument housings, made of PVC, house the EM data logger and amplifiers and the navigation package of pitch, roll, heading, and GPS location. By logging the position of the instrument, rather than telemetering it back to the vessel, we will avoid the danger of electromagnetic interference with our EM recording system.

The sensor electrodes are held below the waterline at the ends of a rigid boom, about one meter below the surface. Prior experience tells us that much of the noise in towed systems comes from vibration and motion perpendicular to the tow direction, and rigid antennas generally have lower noise than towed arrays. The assembly is towed through the water using a strong, floating line.

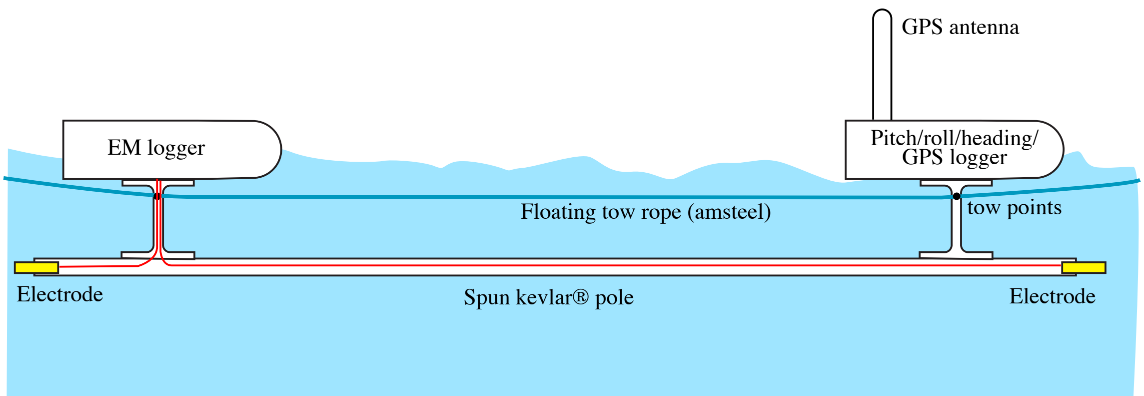

Figure 1. Schematic drawing of our towed EM receiver system.

In November 2013 we tested our transmitter and receiver system offshore San Diego using a small fishing vessel of similar size to the one we plan to use in the Arctic. Transmission current was initially 60 A from a 12 V lead-acid battery, which was close to exceeding our design maximum, so we reduced the length of one electrode to increase antenna resistance. Transmission current was then 55 A, dropping to 40 A as the batteries depleted. We then switched to using a compact DC power supply operating off the vessel's 110 VAC and transmitted 50 A with an input voltage of 10.7 VDC. These currents exceed our design goal of 40 A. We transmitted a broad-spectrum waveform with a fundamental frequency of 0.5 Hz. The antenna length was 50 m and the receiver was towed at an offset of 500 m.

Figure 2 shows processed, 60-minute stacks of the 3.5 Hz harmonic on the towed receiver. In the top panels (A and B) we show amplitude and phase data collected on a Vulcan system, our deep-towed receiver designed for deepwater hydrate mapping work. We towed a Vulcan behind our new receiver in order to get a comparison with a known, developed system.

In the lower panels (C and D) we show data from the new shallow-water system. The green data are from electrodes in the boom, as the instrument was designed. The pink data are from a pair of electrodes strapped to the boom supports, which were added as a test since the cable and logger system we were using had additional channels available. The dipole length of the test electrodes was a little shorter than the boom length, hence the small difference in amplitude, but the phase data are identical, as one would expect.

The gap in data was when we switched from battery to power supply. Being able to operate off the vessel's 12 V battery system provides an option that might be useful, but under normal circumstances we would operate off a power supply, which provides a more constant output voltage that is controllable. The output current on the antenna is monitored and logged.

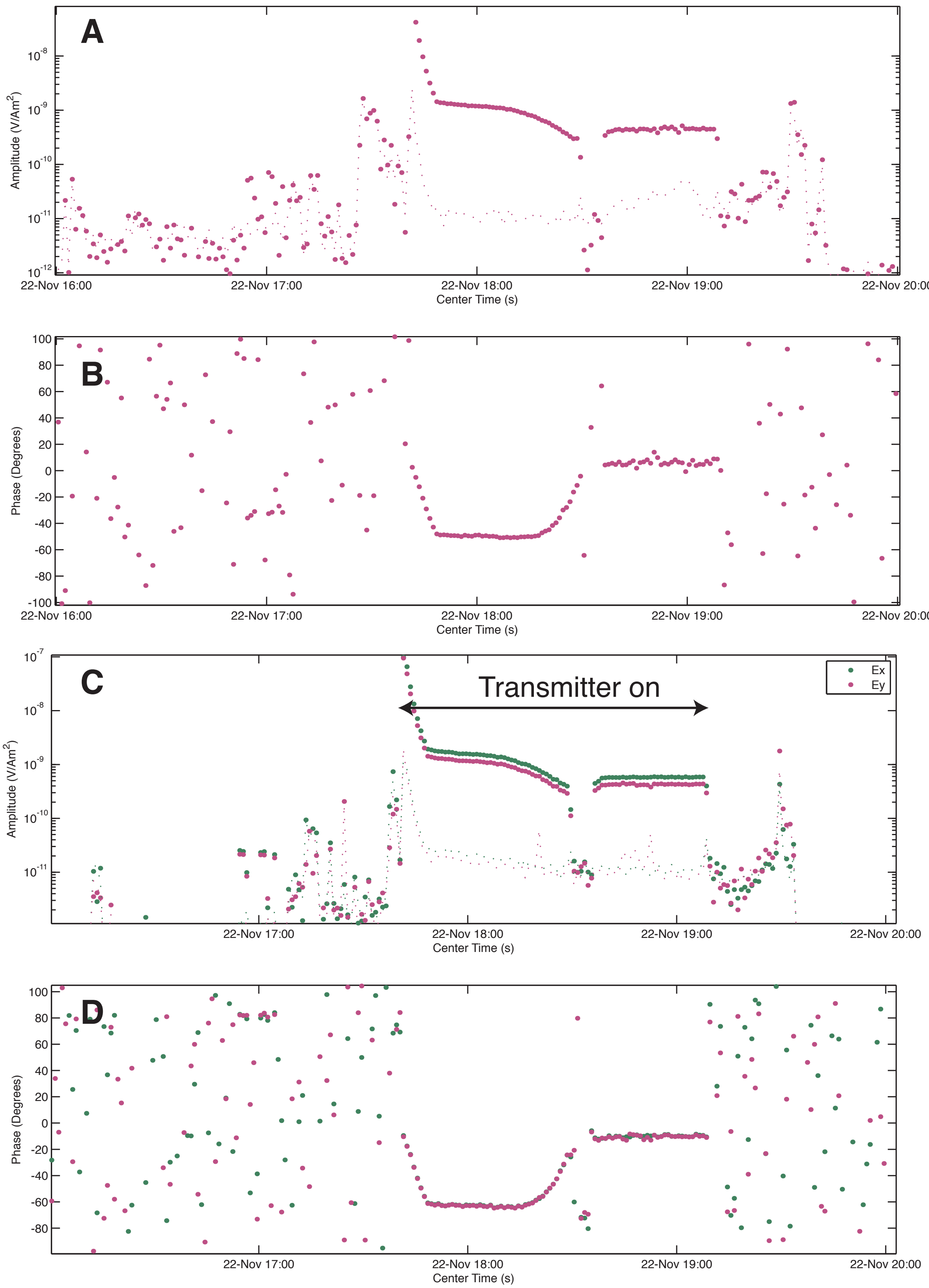

Figure 2. CSEM data collected on a Vulcan system, our deepwater towed receiver ('A' – amplitude and 'B' – phase) and our new surface-towed receiver ('C' – amplitude and 'D' – phase). The break in transmission is when we switched from battery power to a DC power supply. The broken line is the processing noise floor. The change in amplitude and phase with time is associated with the signature of the seafloor as we towed into deeper water.

The change in amplitude and phase with time is associated with the vessel's transit away from shore and into deeper water. It would have been desirable to carry out more tests in shallow water, but there was a lot of small boat traffic and lobster traps in the near-shore area. However, the transit from shallow to deep water provides nice evidence that our data are sensitive to the resistivity of the seafloor, which, of course, is the point of the exercise.

In terms of signal to noise the results are excellent. The noise floor of the system, measured both as the processing noise (broken lines) and the amplitudes immediately after transmitter turn-off, is around 10^{-11} V/Am^2, or ten times smaller than the milestone target of 10^{-10} V/Am^2. The signal to noise ratio is around 100, or 1% error in the data, which is lower than typical errors introduced by navigation and geometry. The amplitude and phase stability of the new system is slightly better than the Vulcan system, so the design shows some improvement over the existing technology, and the packaging is designed to be lighter both for shipping and deployment by hand (the components shown in Figure 1 come apart and will be assembled on site).

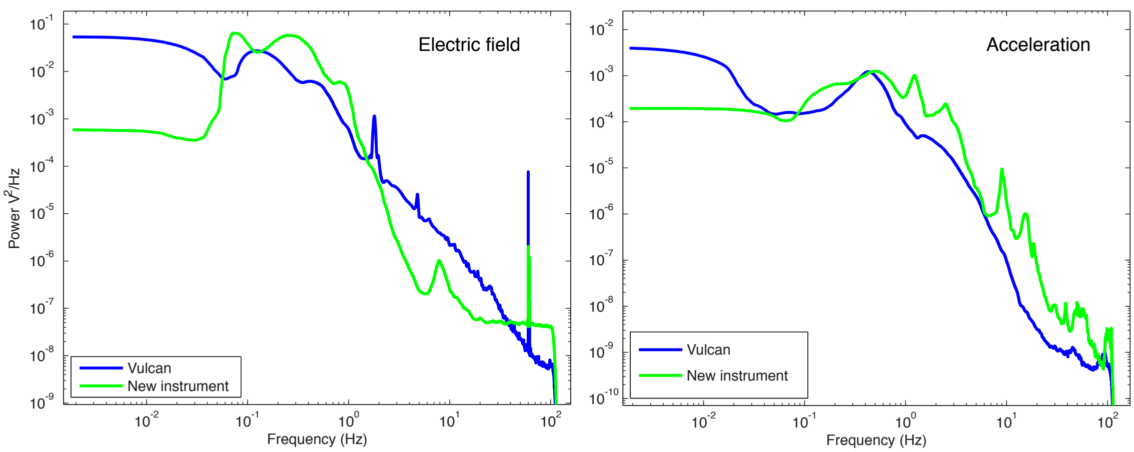

Figure 3. The left panel shows electric field spectra of the Vulcan and the new instrument. In the critical band around 10 Hz, the new instrument is significantly quieter. The narrow peak at 60 Hz is powerline noise. The right panel shows acceleration spectra from the two instruments (units are 600mV/g).

Further insight into the noise performance can be gained by taking spectra of data immediately after transmitter turn-off (Figure 3). The electric field spectra show that the new instrument is quieter than a surface-towed Vulcan in the 1–40 Hz band. The proposal model studies showed that our peak sensitivity to target permafrost structure is likely to be around 10 Hz, so the noise improvement is centered on the band of most interest. Both instruments carry onboard accelerometers, sampling at the same rate as the electric field. The shape of the acceleration spectra follows that of the electric field, suggesting that this is the major source of noise. The new instrument recorded higher overall accelerations than the Vulcan, but it appears that electric field noise couples into acceleration in the new instrument less effectively, possibly because of different instrument geometries.

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 at Hydrate Ridge and San Nicolas Basin.

Peter has submitted an abstract for the International Conference on Gas Hydrates 2014 meeting.

Plans for next project period.

During the next project period we will continue to test and refine the towed receiver system, and develop field plans for the project summer field season.

Table 1: 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	
Harrison Bay data collection	9/1/2014			
Harrison Bay data processing	9/30/2014			
Camden Bay data collection	9/1/2015			
Camden Bay 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 abstracts were 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.

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

Due to delay associated with commitments to two other large ocean-going projects, we revised the date of the second Milestone to December 6, 2013. This is still in good time to be ready for the 2014 field season. We have also extended the Project/Budget period 1 to December 31 2013 for similar reasons.

BUDGETARY INFORMATION

Table 2a: Spend profile

	Budget Period 1								
baseline	10/1/12 – 12/31/12								
	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								
	Q4		Q1		Q2		Q3		
	Q4	Cum. Total	Q1	Cum. Total	Q2	Cum. Total	Q3	Cum. Total	
Baseline cost:									
Federal	$0	$121,742							
Non-federal	$0	$59,589							
Total	$0	$181,331							
Actual cost:									
Federal	$18,959	$106,960							
Non-federal	$11,486	$59,589							
Total	$30,445	$166,549							
Variance:									
Federal	$18,959	-$14,782							
Non-federal	$11,588	$0							
Total	$30,445	-$14,782							