Oil & Natural Gas Technology

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Quarterly Research Performance Progress Report (Period ending 09/30/2014)

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 was spent planning the logistics and experimental layout for the 2014 field season, as well as making and testing some improvements to our transmitter and receiver systems. This quarter we carried out data collection offshore Prudhoe Bay between 15th and 21st July. Although sea ice had not retreated past the expected boundary of marine permafrost, we had a total of 5 days of data collection, 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 show 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.

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

Data collection in the 2014 field season.

We carried out a field campaign to collect marine EM data over sub-sea permafrost from the 16th to 22nd July on the R.V. Ukpik out of West Dock, Prudhoe Bay. The field crew consisted of Peter Kannberg (Ph.D. student working on the project), Dallas Sherman (Ph.D. student working in marine EM methods), Jake Perez (marine technician), and Steven Constable (P.I.). The vessel captain was Mike Fleming of Oceanic Research Services.

All our equipment was air freighted to Prudhoe Bay and could be carried in the bed of a single pickup truck rented in Prudhoe for the purpose (Figure 1A). The equipment included 4 surface towed electric field receivers with integrated GPS positioning systems (Figures 1B and 1C), 4 seafloor electric field receivers that could be deployed on moorings in up to 10 m water depth (Figure 1D), a small electric winch with 1,000 m of floating tow cable (Figure 1D), a 50 m transmitter antenna, two (one plus one spare) 60 amp EM transmitters, a conductivity-temperature-depth package integrated with a Contros methane sensor, and support gear.

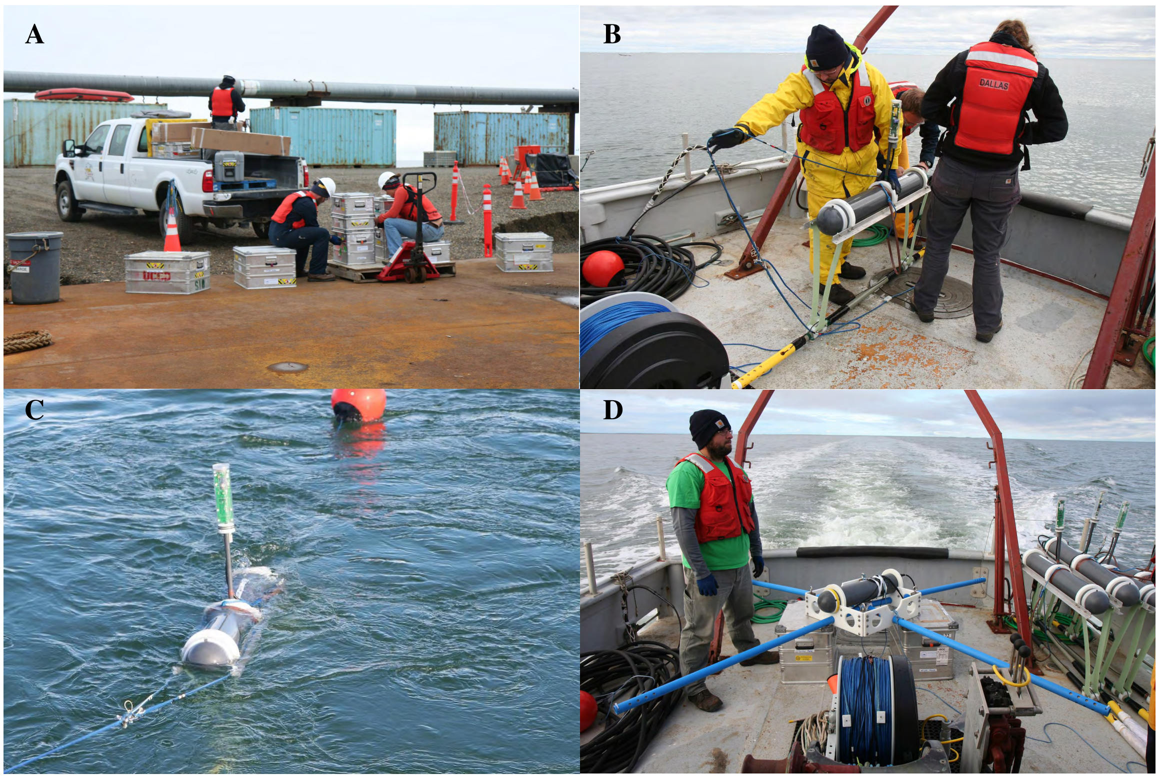

Figure 1. A: All our equipment is air freightable and fits into the back of a single pickup. B: Surface towed EM receiver being readied for deployment. C: Towed receiver in the water D: Seafloor instrument ready for deployment.

We had been allocated vessel time 16–23 July, which was the first leg of the R.V. Ukpik for the 2014 field season. Our position early in the season was largely a consequence of being first-time users of the vessel – other groups had made long-term arrangements with the vessel operators – but we were advised that the edge of the sea ice should have retreated past the expected edge of the permafrost by then. However, through a combination of bad luck and being so early in the season, the edge of the sea ice was approximately near the expected edge of the permafrost during most of our operations. We had already decided to reduce the field work by one day because of difficulty in getting flights out of Prudhoe, and this turned out to be a good move because on our demobilization day the ice came into the edge of the bay and was easily visible from shore. This does highlight the fact that ice conditions are not simply a function of time in the season, but can be very variable. Nevertheless, the field program allowed us to collect an extensive data set to the expected edge of the permafrost, and was a valuable test of the new equipment (described in the last quarterly report). Next year we will request time later in the season, carry the extra day of shiptime over, and should be able to extend the current data set into deeper water.

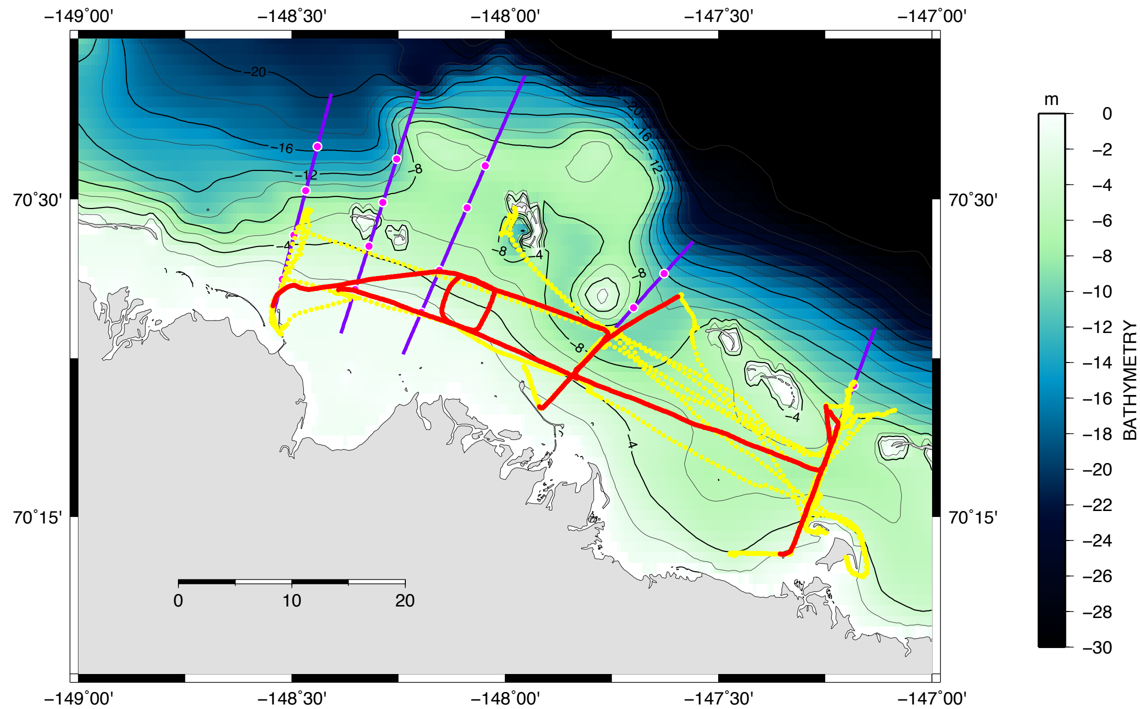

Figure 2. Survey lines planned for the 2014 field season (purple lines). Based on the USGS seismic interpretations, permafrost is thought to extend out to the 8 m bathymetry contour. Red lines show actual data collection, limited by the extent of sea ice. Yellow dots show the vessel tracks for the entire survey, associated with reconnaissance for ice conditions and seafloor receiver deployment and recovery.

Figure 2 shows the planned profiles, along with the actual tows that were limited by ice extent. We collected over 100 line kilometers of data and covered much of the expected permafrost area from the western edge of Prudhoe Bay to Tigvariak Island, 50 km to the east. Table 3 shows gives the daily log of events. With a single vessel operator on board we were limited to 12 hours of work per day, but this resulted in 6 to 10 hours of towing, depending on transits and seafloor instrument deployments/recoveries.

The instrument systems generally performed very well. Every receiver instrument collected data as programmed, and noise levels were low. The exception was seafloor instruments that were moved when ice caught the float and continued to drift, dragging the instrument with it. We could not operate the transmitters at design output current of 30-60 amps because some interaction with the vessel power (110 VAC generated by an inverter) caused the reset of the micro-controller, but the transmitters worked well at 20 amp output, which we determined in the field to produce adequate signal to noise ratios using the 50 m transmitter antenna. Receivers were towed at 250, 500, 750, and 1,000 m behind the vessel. We transmitted a 1 Hz waveform-D, which has a broad spectrum of odd harmonics, and were able to process data up to 13 Hz at the full 1,000 m offset.

A Contros methane sensor was towed alongside the vessel during all operations, but the data did not show any variation. We are skeptical that it was functioning correctly.

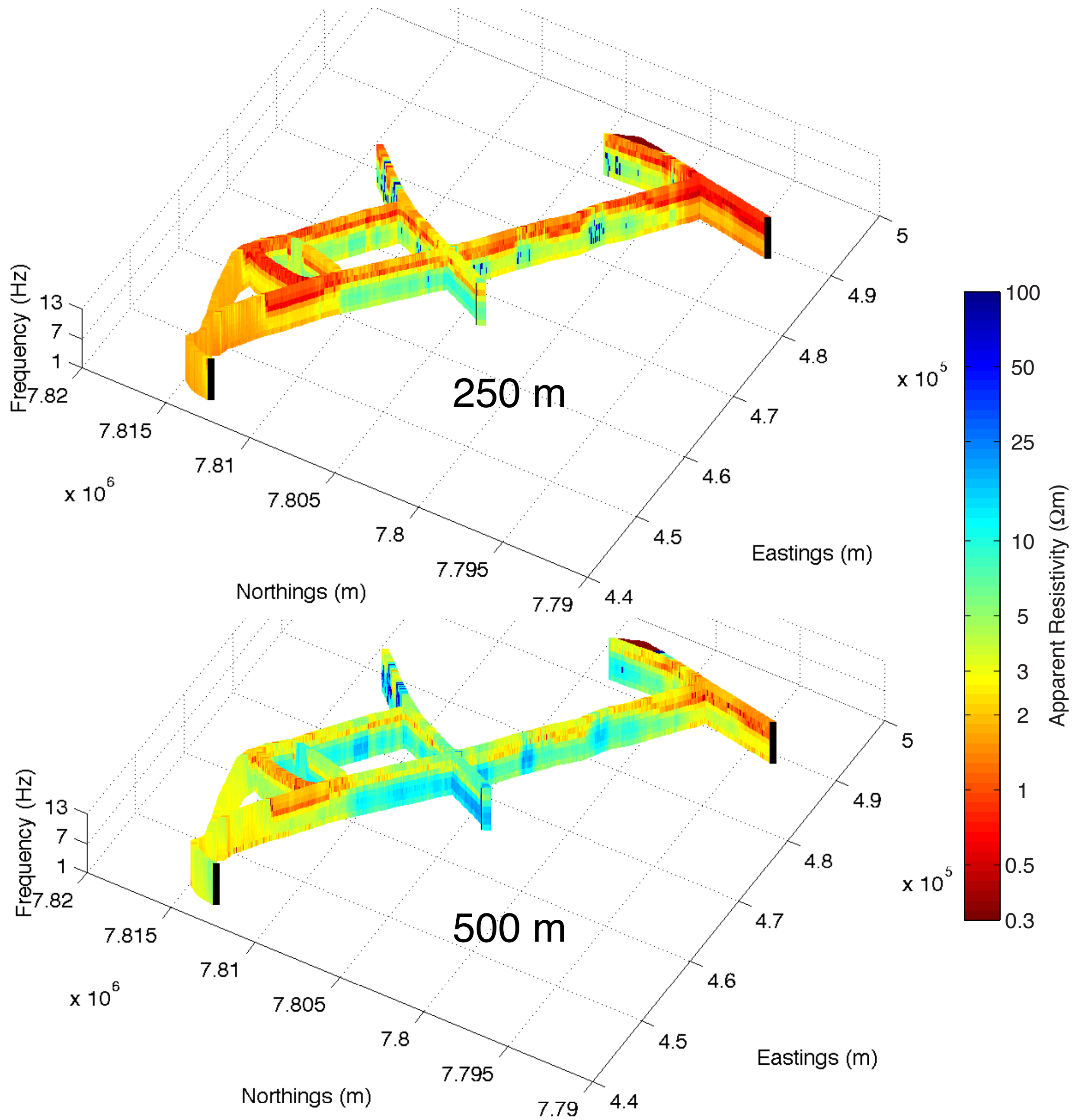

Figure 3. Apparent resistivity frequency pseudosections for towed receivers at ranges of 250 and 500 m.

The first step in processing is to stack the data into one minute windows and Fourier transform at each transmission frequency to obtain an amplitude and phase. Data are normalized by the transmission current and phase at each frequency, and then merged with vessel position, water depth, and water conductivity for modeling. We had established beforehand that the vessel's depth sounder would export depth, time, and position as a NEMA string on a serial line in the small laboratory, and so we logged this throughout the survey. We towed a conductivity, temperature, depth (CTD) package alongside the vessel which was also logged and time stamped, and occasionally lowered to the seafloor to

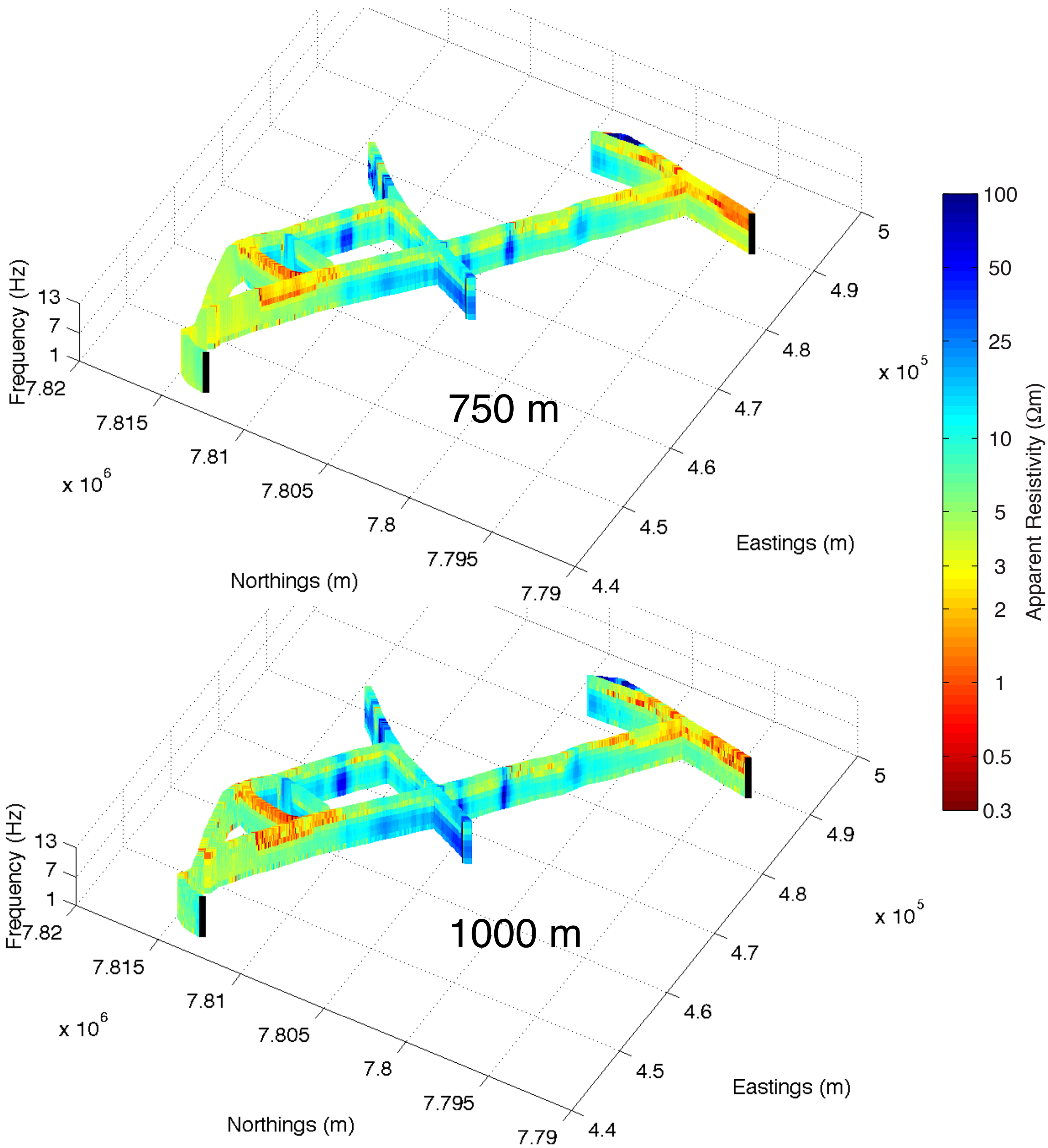

Figure 4. Apparent resistivity frequency pseudosections for towed receivers at ranges of 750 and 1,000 m.

obtain vertical conductivity profiles.

Figures 3 and 4 show apparent resistivity pseudosections computed as a function of frequency for the 4 towed receiver instruments. The assumption is that the lower frequency energy propagates deeper into the seafloor, and data associated with the longer offsets propagate more deeply as well. Generally speaking, resistivity is seen to increase with depth both as a function of frequency and source–receiver offset. Near-surface resistivities are about 1 Ωm, which is consistent with water-saturated sediments, increasing to nearly 100 Ωm at depth. The larger resistivities are consistent with those expected of permafrost. The ties between crossing lines are *extremely* good, and are an indication of the high quality of the data.

A substantial amount of lateral structure is evident in the data showing that the permafrost is far from uniform. Rather than interpret this at this stage, the next step will be to invert the data using 2D inversion code which is currently being modified to work with towed data such as these.

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, which was carried out in August with his participation. He carried out the survey design for the 2014 Prudhoe Bay survey and participated in the data collection. He processed the data and computed the apparent resistivities presented in this report.

Plans for next project period.

During the next project period we will invert the towed receiver data, and begin to incorporate data from the seafloor instruments.

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.

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. We are now back onto the original schedule for the project, having made up the one quarter delay in developing the new instrumentation. We have only a $10,741 carry-over into budget period 3.

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 3: Daily log.

15 July	Field crew arrives Prudhoe Bay. Rent vehicle and collect equipment from air freight
16 July	Move to West Dock and mobilize R.V. Ukpik
17 July	Push off 06:30. Deploy 4 seafloor receivers on line 5. Tow line 5
18 July	Deploy sites 1 and 2 on line 4. Tow line 4
19 July	Deploy sites 1 and 2 on line 5. Tow parallel to shore
20 July	Deploy sites 3 and 3.5 on line 5. Tow line 5
21 July	Tow line 3. Recover all gear
22 July	Demob vessel, dispatch air freight, return vehicle, fly crew to Anchorage