# Oil & Natural Gas Technology

**DOE Award No.: DE-FE0010144**

# Quarterly Research Performance Progress Report (Period ending 9/30/2015)

# Mapping Permafrost and Gas Hydrate using Marine CSEM Methods

**Project Period (10/1/2012 – 09/30/16)**

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**Office of Fossil Energy**

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## EXECUTIVE SUMMARY

Last quarter we were about to carry out the 2015 data collection off Prudhoe Bay, using a newly built transmitter and other instrument upgrades. This quarter the data collection went ahead as planned and was highly successful, and we have processed the new data through to apparent resistivity pseudosections. This satisfies Milestones E and F. Although we went to the Arctic later in the season this year, sea ice was still a problem and limited how far offshore we could collect data. In response to this we extended our survey alongshore, and collected data in Harrison Bay, crossing the seismically identified permafrost boundary several times. Our results so far indicate that there is not a strong electrical resistivity signature associated with the seismic identification of permafrost, but rather the highest resistivity signal is associated with the outflow of the Sag River, which is consistent with some models of permafrost preservation.

## 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

### *2015 data collection.*

We carried out the 2015 data collection from 28th July to 7th August this summer. Our equipment included an upgraded transmitter system that was designed to address some of the issues with drifting phase that we had last year, as well as a modification to the receivers that allowed us to log the timing signal from the receiver GPS masts. Both these upgrades worked extremely well. Although we managed to get ship time later in the season this year, sea ice was still a problem, and limited our ability to collect data in deeper water. The ice was, in fact, more of a problem this year than in 2014, so it is clear that picking the time to carry out field work is not a complete solution. However, given the high degree of lateral variation we saw in the 2014 data, our plan was to infill the 2014 lines anyway, and we supplemented this by extending the survey to the east and west of the 2014 area. Taking opportunistic advantage of the weather conditions, we also collected one day of data in Harrison Bay, where we were able to cross the seismically identified edge of permafrost several times.

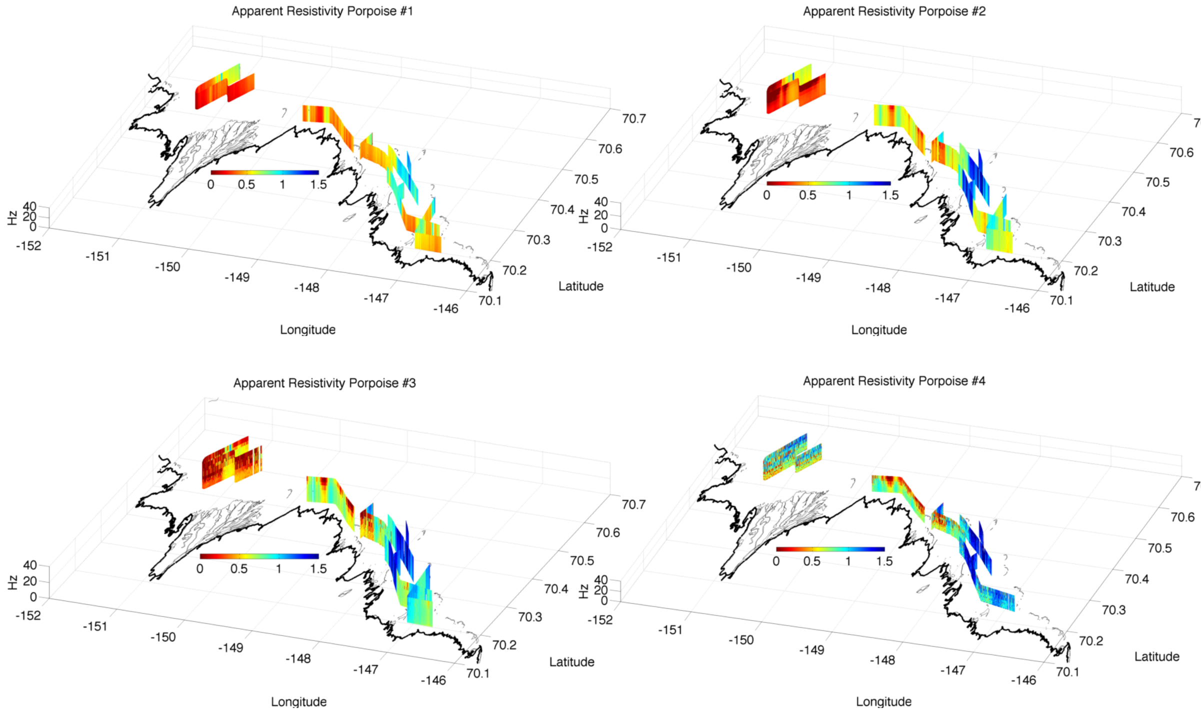

Figure 1. Apparent resistivity pseudosections of 2015 data collected on all four receivers. The resistivity scale is logarithmic, from 1 Ωm to 30 Ωm.

Figure 1 shows apparent resistivity pseudosections of the data collected this year. Noise levels were a little higher this year for reasons we do not yet fully understand, but the data quality is still very good. The successful 2015 data collection meets the goals of Milestone E.

### *Merged pseudosections.*

Figures 2–5 shows merged data from the receiver instruments, presented as apparent resistivity pseudosections, for both years. The year to year consistency is excellent. We have verified the high resistivities associated with the outflow of the Sag River, and extended the survey along 120 km of coastline, as well has collecting 3 lines of data in Harrison Bay to the east. The high degree of lateral variability in the apparent resistivities is quite astonishing, and totally inconsistent with our simplistic understanding of permafrost structure when we started this project. Our initial goals were to identify the offshore extent of the permafrost and estimate its depth and thickness, assuming it to be a fairly uniform layer. Our data show that the real world is much more complicated than this.

Processing the 2015 data meets the goals of Milestone F.

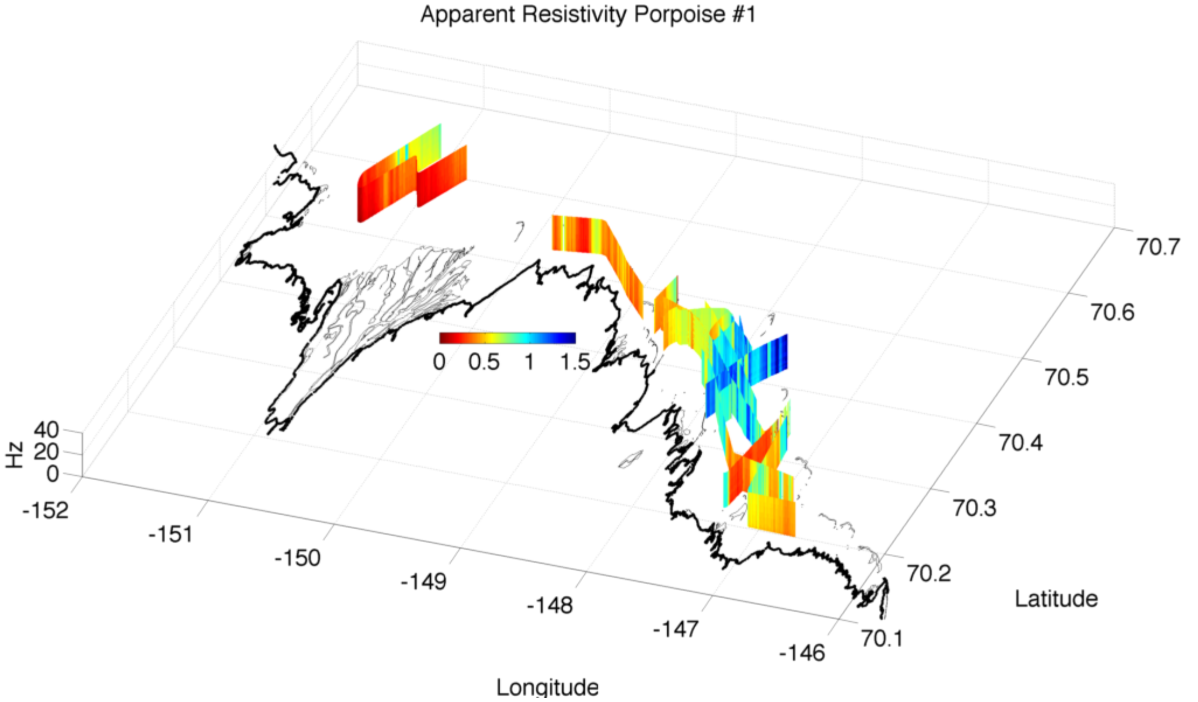

Figure 2. Data from the 250 m receiver, as apparent resistivity pseudosections merged from both years. The resistivity scale is logarithmic, from 1 Ωm to 30 Ωm.

## Training and professional development.

Dallas Sherman, who is now the student working on this project, and Peter Kannberg, who worked on the 2014 data collection, both participated in the 2015 data collection, and together made many of the day to day decisions on where to collect data.

## 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.

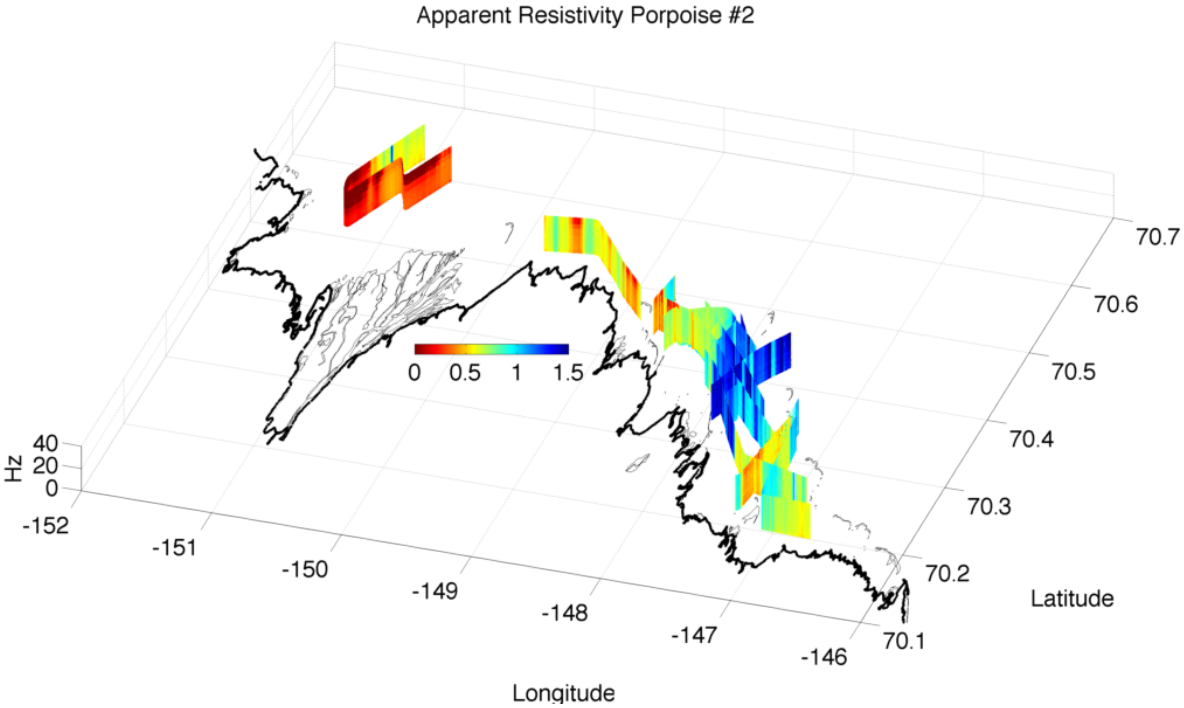

Figure 3. Data from the 500 m receiver, as apparent resistivity pseudosections merged from both years. The resistivity scale is logarithmic, from 1 Ωm to 30 Ωm.

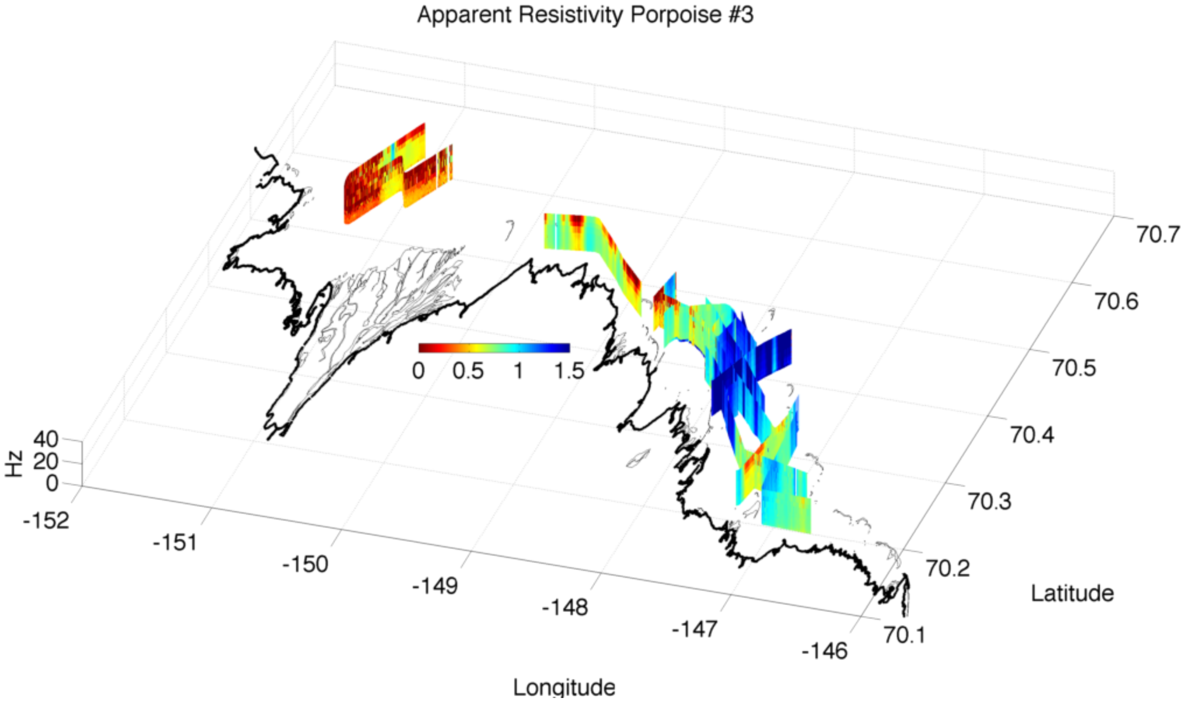

Figure 4. Data from the 750 m receiver, as apparent resistivity pseudosections merged from both years. The resistivity scale is logarithmic, from 1 Ωm to 30 Ωm.

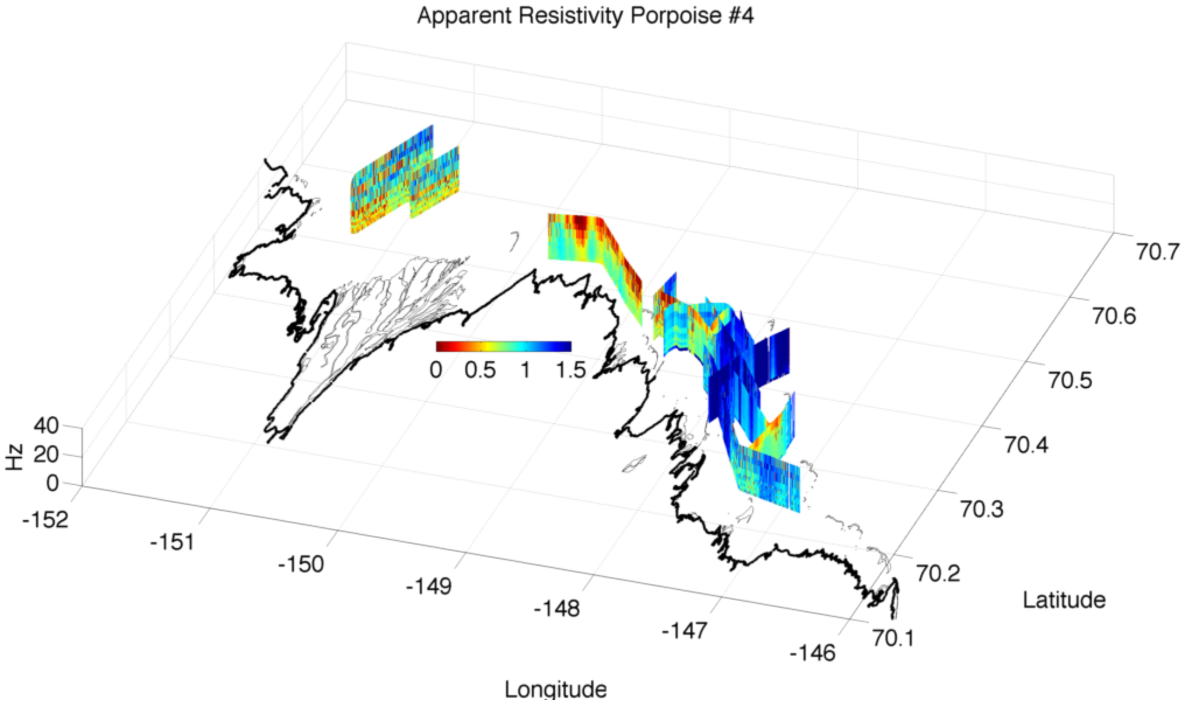

Figure 5. Data from the 1,000 m receiver, as apparent resistivity pseudosections merged from both years. The resistivity scale is logarithmic, from 1 Ωm to 30 Ωm.

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.

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 |

## 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 |