Oil & Natural Gas Technology

DOE Award No.: DE-NT0005665

Quarterly Progress Report
(March – June 2010)

Source characterization and temporal variation of methane seepage from thermokarst lakes on the Alaska North Slope in response to Arctic climate change

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Prepared for:
United States Department of Energy
National Energy Technology Laboratory

August 31, 2010

Office of Fossil Energy

Source characterization and temporal variation of methane seepage from thermokarst lakes on the Alaska North Slope in response to arctic climate change

CONTRACT NO. NT0005665

QUARTERLY PROGRESS REPORT
Reporting Period: March. 1- June. 30, 2010

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Overall Summary

The goals of this research are to characterize the source, magnitude and temporal variability of methane seepage from two representative thermokarst lake areas within the Alaskan North Slope gas hydrate province and to assess the vulnerability of these areas to ongoing and future Arctic climate change. Work during the second budget period focused on conducting the group's field work for the second budget period and laboratory analyses of samples collected during field work conducted during the first and second budget periods (Figure 1). Field work during the second budget period has included conducting aerial surveys on the north slope of Alaska and

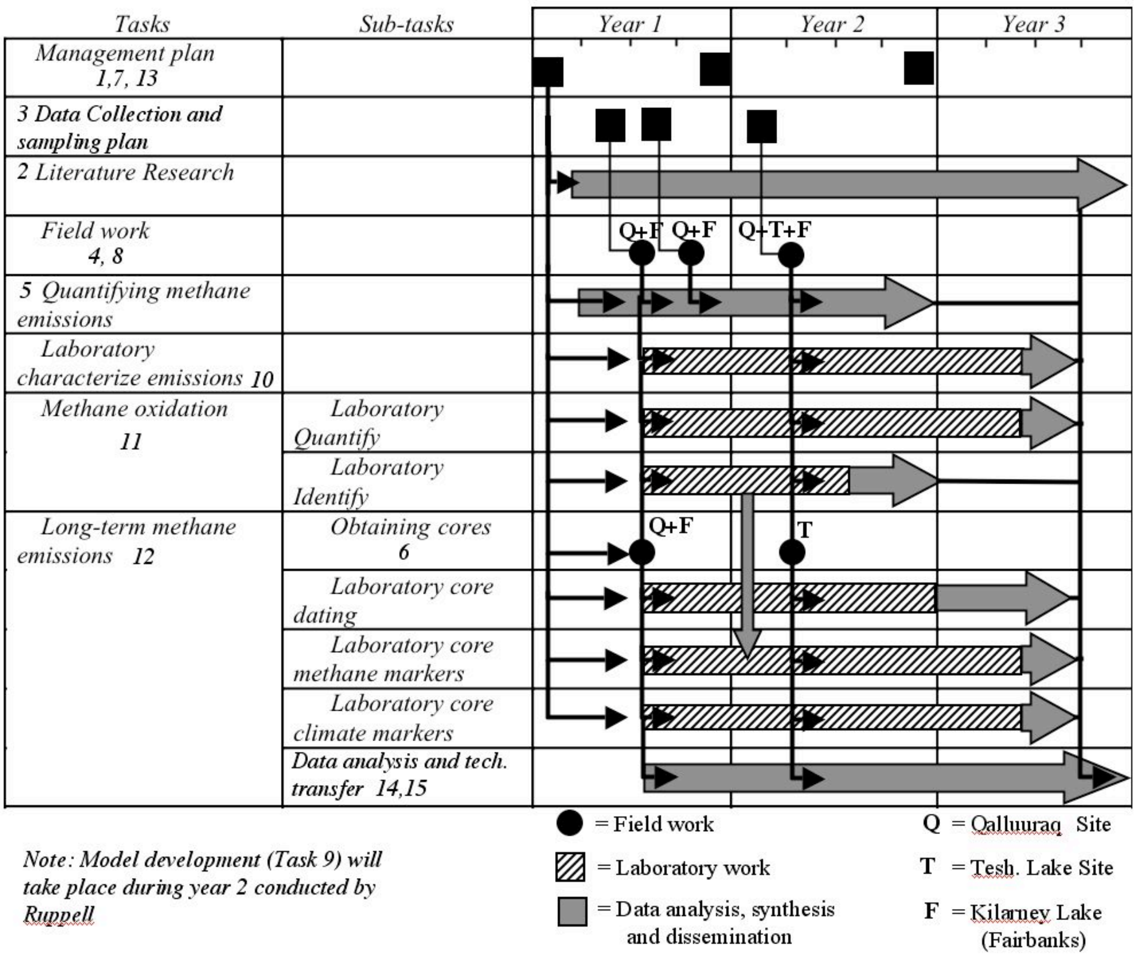

Figure 1: Project timeline as stated in the PMP.

then visiting and sampling at the lake we had observed to be emitting gas (Tesh. Lake) on the north slope. Field work in the second budget period has also included conducting further methane flux measurements at our lake in the area local to Fairbanks (Killarney Lake) and at the seep site in Lake Qalluuraq near the village of Atqasuk. The majority of the project's subsequent tasks (Figure 1) (including those for the remaining second budget and the third budget period) have required successful acquisition of samples to analyze from the proposed field locations and in all cases this has been achieved. With the subsequent successful acquisition of the samples during the field activities of the first and second budget periods the subsequent tasks have all been initiated. All of the project areas (Tasks) and co-pis are currently in the process of drafting manuscripts for submission to international peer reviewed journals. Figure 1 shows a summary timeline of the project tasks and detailed descriptions of progress related to each of these tasks are stated below.

Progress Task 2.0 - Continuous Literature Research and Updating

A pdf reference library of related and relevant literature using the program "Papers" (see http://mekentosj.com/papers/) has been maintained. The USGS is continuing to compile hard-to-obtain North Slope reports from its own national libraries and working on the transfer of a North Slope gas chemistry database from the Central/Western Regions to the Woods Hole office.

Progress Task 3.0 – Develop Data Collection and Sampling Plan

The UAF/USGS team developed data collection and sampling plans to cover field activities occurring during the second budget period. These plans were designed to mimic those that were implemented during the first budget period.

Task 4.0 – Field-work progress in Alaska (Year 1)

Completed and reported on in previous submitted reports.

Task 5.0 – Quantifying the short-term variability in methane emissions (and Task 10.0 - Gas sources and methanogenesis)

Katey Walter Anthony (Co-PI) has continued long-term seep measurements on ebullition seeps at study sites in the Fairbanks area. Two masters students, Laura Brosius and Dragos Vas, each supported in part by this project, finished their masters degrees at UAF studying Killarney Lake and Goldstream Lake, and are in the process of drafting manuscripts to summarize the flux dynamics, mixing ratios and stable isotope compositions of biogenic seeps from the Fairbanks thermokarst lakes. At the Lake Qalluuraq site, Walter coordinated the installation of a heavy duty skirt to funnel a large fraction of the main seep ebullition through a flow meter (spring 2010), and recorded short- and long term average flow rates. Data are being processed for flow measurements on the large and small ebullition seeps at Lake Qalluuraq, and the ebullition gas contents (mixing ratios, stable isotopes, and radiocarbon dates). Field work is currently planned for Walter and a technician to visit (July 2010) the study sites at Tesh. Lake to collect gas samples and assess ebullition.

Katey Walter Anthony's group has continued with the long-term seep flux monitoring using automated traps on the Fairbanks thermokarst lake. We have automated flux traps on 16 seeps which vary in magnitude of ebullition. The seeps also show seasonal differences, related to the depth in sediment at which methanogenesis occurs. During the past quarter we collected gas samples from the seeps and have recently received data on the gas concentrations and stable isotope composition of these seep gases. They all had high methane concentrations despite variable rates of emission. We are now analyzing the geochemical and isotope data. Flux data continue to be obtained, filling in gaps from previous summertime emissions. We are working on modeling the flux data to explain short-term and long-term variability in methane seep flux as a function of atmospheric pressure, temperature and permafrost thaw dynamics. In addition to direct measurement of seep fluxes, we also set up a LiCor 7700 in April 2010 to measure atmospheric methane content above the lake. We are in the process of analyzing data. In addition to Fairbanks work, Walter Anthony supervised flux measurements of the large seep at Lake Q with assistance from local resident, Doug Whiteman and UAF project technicians. Gas samples were received and will be mailed out for isotope analysis**.** Preliminary results suggested lower rate of gas flow through the collection skirt than Walter Anthony previously measured at the seep; however, the large skirt did not cover the peripheral seeps. We measured fluxes using smaller automated traps on some peripheral seeps as well, and fluxes from both sources will be added together.

Task 6.0 – Obtaining cores of lake sediment

All cores collected during the first budget period were reported in previous reports. All cores collected from Tesh. Lake in the second budget period are shown in Table 1 below. All of these cores are sufficient to conduct the remainder of the project work defined for the second budget period and the final budget period.

Table 1: Cores collected from Tesh. Lake during the second budget period.

Core Code	Purpose	Lake
WS-Paleo-A	Archive (material in reserve)	Tesh. Lake
WS-Paleo-B	Paleo (Task 8, 12)	Tesh. Lake
WS-BGC	Biogeochem (Task 7)	Tesh. Lake
WT-Paleo	Archive (material in reserve)	Tesh. Lake
East Tesh BGC	Biogeochem (Task 7)	Tesh. Lake

Task 7.0 – Revise PMP, if necessary Year 1.

The project is proceeding as proposed in the PMP.

Task 8.0 – Field-work in Alaska (Year 2)

A project meeting to discuss field-work logistics at Tesh. Lake took place via WEBEX hosted by USGS in the Spring of 2010 and was attended by Ben Jones (USGS collaborator), John Pohlman (USGS Co-PI), Ben Jones (USGS – collaborator), Matthew Wooller (UAF PI), Mary Beth Leigh (UAF Co-PI), Ben Gaglioti (UAF Graduate Student Research Assistant), Kevin Becker (German graduate student collaborator conducting organic biomarker analyses of sediments), and Dr. Marcus Elvert (German collaborator conducting organic biomarker analyses of sediments). Discussions focused on developing a field sampling plan (notably focused on coring lake sediments). The group planned and managed the logistics for fieldwork (winter 2010). Efforts during the second budget period focused on conducting the group's field work for the second budget period and laboratory analyses of samples collected during field work conducted during the first and second budget periods (Figure 1). The bulk of the projects efforts during the second budget period were directed at accomplishing one main field expedition during the spring of 2010 at Tesh. Lake. The primary aim of this field expedition was to collect samples that would be worked on throughout the remainder of the second budget period and into the third budget period. Fieldwork took place at Tesh. Lake between the 18th and the 26th April 2010 and involved Ben Jones, John Pohlman, Ben Gaglioti and Kevin Becker in the field. In all respects the field expedition to Tesh. Lake was a success and all samples were collected for the group's further activities. Additional field work activities are being coordinated by Katey Walter Anthony (UAF Co-PI), Ben Jones and Carolyn Ruppel (USGS PI) to be conducted during the remainder of the second budget period at Tesh. Lake (July 2010).

The primary objective of the 2010 fieldwork was to acquire the samples needed to conduct Tasks 5-8 during Phase II of the project. These include acquisition of samples of lake sediment for studying past methane emissions (Task 8), to conduct stable isotope probing (Task 7) and gas analyses and flux measurements (Task 5). All of the field objectives were successfully achieved. Cores of lake sediment were collected for studying past methane emissions (Task 8) and to conduct methane stable isotope probing (Task 7).

A total of 5 cores of sediment were collected from Tesh. Lake (Table 1). GPS coordinates were taken at each location. The cores ranged in length from ~70cm to 569cm (considerably longer than the cores taken during the first budget period) and are to be dedicated to sample analyses related to future project tasks (e.g. Task 7, 8 and 12). Magnetic susceptibility measurements were made on the majority of the Paleo cores and samples have already been sub sampled from the cores for radiocarbon dating. Limnological characteristics were measured at Tesh. Lake using a YSI. All of the Biogeochem cores were subsampled during the field work for Biogeochemical analyses (Kevin Becker, Marcus Elvert, Mary Beth Leigh, Ruo He and John Pohlman) and pore water chemistry (Pohlman). Water was collected from the site locations with water present for oxygen and hydrogen isotope analyses, POC (particulate organic carbon) stable isotopes (C and N), DIC (dissolved inorganic carbon) stable isotopes (C and O). Photos and videos were taken throughout the fieldwork.

Task 9.0 – Model Development

Carolyn Ruppel (co-PI) is proceeding to build standard Matlab-based numerical models and COMSOL multiphysics-based 2D and potentially 3D models to explore how geologic structures, hydrologic conditions, surficial climate forcing, the permafrost and gas hydrate zones, and the thaw bulb interact and account for gross spatial patterns of methane emission (e.g., at thermokarst lake boundaries, from specific parts of the thaw bulb). Geophysics data obtained during the first budget period (Qalluuraq Lake) is being processed and Ruppel is proceeding to enhance the data set available from Tesh. Lake during fieldwork planned for July, 2010.

Task 10.0 – Gas sources and methanogenesis

Described above (see task 5).

Task 10.0 and 11.0 –Methane oxidation in Alaskan thermokarst lakes (Characterization and quantification of aerobic methane oxidation by microorganisms)

Water and sediment samples were collected from Qalluuraq Lake and Killarney Lake in May 5-15 and July 8-18, 2009. Four sampling sites, LQ-BGC, LQ-CM, LQ-GPS and LQ-WEST, were set in Qalluuraq Lake, of which LQ-BGC was a methane seepage site, LQ-GPS was away from LQ-BGC, LQ-CM was far away from LQ-BGC, LQ-WEST was a site with some methane seepage. Three sampling sites, KIL-S, KIL-NW, KIL-NNE, were set in Killarney

Lake. Water samples of approximately one liter each were taken from the top, middle and bottom depths at each sampling site. Water temperature, dissolved oxygen and pH at different sampling depths at each site were measured in situ using a YSI meter. Core samples were used for the collection of sediment and sediment-water interface microbial samples. Holes were drilled in freshly extracted cores to collect water within 1 cm at the top of sediment-water interface. After cores were split, sediment samples were collected every 2 cm from the top 15 cm sediment and then every 5 cm for the remaining length of the core. The sediment samples were immediately placed in a plastic freezer bags, which were closed and all free air were removed. Samples were homogenized in the bag and then a subsample was frozen for direct molecular studies. Sediment samples in the plastic bags were kept at 4^oC for methane oxidation incubations and SIP experiments.

Methane oxidation potentials of water and sediment samples were detected using microcosm incubations at 4°C, 10°C and room temperature (22±1°C). Methane concentrations in microcosms were monitored using gas chromatography with a flame ionization detector during incubation. Substantial CH_4 utilization was detected in many microcosms. The highest methane oxidation potentials were observed in the sediment samples from LQ-WEST and LQ-CM, followed by the sediment samples from Killarney Lake, the least were those from LQ-BGC and LQ-GPS. For water samples, the highest methane oxidation potentials occurred in the samples from the bottom of Killarney Lake. There was no detectable methane consumption in the water samples from Qalluuraq Lake, except for the LQ-BGC (seep) sampling site.

Stable isotope probing (SIP) experiments were conducted to identify the microbial populations active in methane oxidation in sediment samples. Sediment samples were incubated with ^{13}CH or ^{12}CH (control) in the laboratory under both aerobic and anaerobic conditions. The incubation was continued until a series of specific quantities of CH_4 has been oxidized. When target oxidation extents were reached, the SIP samples were harvested and frozen for later analyses of the identity and community structure of methane oxidizing microorganisms. DNA was extracted from the sediment SIP samples and subjected to isopycnic centrifugation using cesium trifluoroacetate gradients and fractionated using established methods. DNA distributions in the series of fractions from both ^{13}C-incubated samples and control (^{12}C- incubated) samples were determined using quantitative real time polymerase chain reaction (RTm-PCR) with universal bacterial 16S rRNA primers. Substantial quantities of ^{13}C-DNA were detected in many samples. ^{13}C-DNA-containing fractions were subjected to community profiling using terminal restriction fragment length polymorphism (T-RFLP). Preliminary results indicate methane-oxidizing bacteria are diverse in the lake sediments and community structure varies with sediment depth. Methanotrophs have been successfully cultivated from water samples taken from different lake depths using enrichment cultures with methanotroph medium. 14 methanotrophs have been isolated, and sequencing is in progress. DNA was extracted from the culturable methanotrophs, and the community structure and diversity of culturable methanotrophs was analyzed using T-RFLP of bacterial 16S rRNA. Methanotrophs cultivated from lake water appear to be largely different consortia from those detected in sediments by SIP. T-RFLP profiles obtained are in progress compared over incubation time courses and among the study sites using existing software for microbial community statistics analysis and comparisons.

Task 12.0 – Establishing a long-term record of the variability in methane emissions in relation arctic climate change

Subtask 12.1 – Establishing the depositional chronology of lake sediments

A detailed chronology of lake sediments from Qalluuraq Lake (the lake containing a large methane seep) has been established and the basal age of a core named Lake Q West is < ~12,000 calendar years old (calibrated using Calib 5.0) (Gaglioti and Wooller). Chronologies have also been established using the radiocarbon dates produced from samples taken from cores at Terrapin and Coffee lakes, which are being used as control sites to compare with the Lake Q West core. In both of these other lakes the basal ages of the cores taken from these sites are >6,000 calendar years old and therefore will provide good comparative data. The chronologies constructed for all of these cores are providing an excellent temporal framework to examine changes in methane emissions using markers of methane preserved in the lake sediments (described below). Samples have already been taken from the Tesh. Lake core.

Subtask 12.2 – Establishing a long-term record of past methane emissions using chemical markers of methane preserved in lake sediments

Samples have been taken along the length of Lake Q West core and the cores from Terrapin and Coffee lakes. The samples from Lake Q West have been analyzed for biomarkers of past methane emissions and oxidation (chironomid and total organic carbon isotope analyses – Gaglioti and Wooller and organic biomarkers – Pohlman, Becker and Elvert). Chironomid and total organic carbon isotope analyses have also been completed on the core from Terrapin Lake. Sediment samples from Coffee Lake have been prepared, submitted and analysis completed for total organic carbon and the final stages of preparation of samples for chironomid analyses are completed. Significant fluctuations in the records of past methane derived carbon are evident from Lake Q West and Terrapin Lake and we are currently examining how these changes relate to past changes in arctic climate (e.g. temperature). Samples have already been taken from the Tesh. Lake core.

Subtask 12.3 – Establishing a long-term record of past climate using chemical markers of climate preserved in lake sediments

Samples have been taken along the length of the Lake Q West for analysis of the oxygen isotope composition of chironomids, which are to be used to examine whether the isotopic composition of the lake water has changed in the past. This information can subsequently be used to infer past changes in climate (e.g. temperature, precipitation). These analyses have been completed and significant changes are documented. These data are being synthesized relative to all of the data produced as part of Task 12.

Subtask 12.4 – Synthesizing and comparing long-term records to evaluate the influence of past climate on methane emissions

The data are currently in the process of being synthesized by the group.

Task 13.0 – Revise PMP, if necessary

The project is proceeding as proposed in the PMP and is anticipated to proceed as proposed in the PMP in the third budget period.

Task 14.0 – Data Analysis

In year 3, the UAF Team will continue to analyze data collected during the year 1 and 2 field site visits using the approach and methodology defined in the Tasks above.

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