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## Final Report

### Field Exploration of Methane Seep Near Atqasuk

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## **Final Report**

### **Field Exploration of Methane Seep Near Atqasuk**

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Natural gas flare at Qalluuraq Lake seep near Atqasuk, Alaska, April 2008.

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## **ABSTRACT**

Methane (CH<sub>4</sub>) in natural gas is a major energy source in the U.S., and is used extensively on Alaska's North Slope, including the oilfields in Prudhoe Bay, the community of Barrow, and the National Petroleum Reserve, Alaska (NPRA). Smaller villages, however, are dependent on imported diesel fuel for both power and heating, resulting in some of the highest energy costs in the U.S. and crippling local economies. Numerous CH<sub>4</sub> gas seeps have been observed on wetlands near Atqasuk, Alaska (in the NPRA), and initial measurements have indicated flow rates of 3,000–5,000 ft<sup>3</sup> day<sup>-1</sup> (60–100 kg CH<sub>4</sub> day<sup>-1</sup>). Gas samples collected in 1996 indicated biogenic origin, although more recent sampling indicated a mixture of biogenic and thermogenic gas. In this study, we (1) quantified the amount of CH<sub>4</sub> generated by several seeps and evaluated their potential use as an unconventional gas source for the village of Atqasuk; (2) collected gas and analyzed its composition from multiple seeps several miles apart to see if the source is the same, or if gas is being generated locally from isolated biogenic sources; and (3) assessed the potential magnitude of natural CH<sub>4</sub> gas seeps for future use in climate change modeling.

## TABLE OF CONTENTS

DISCLAIMER .....	ii
ABSTRACT .....	iii
TABLE OF CONTENTS .....	iv
LIST OF FIGURES .....	v
LIST OF TABLES .....	vii
ACKNOWLEDGMENT .....	viii
INTRODUCTION .....	1
EXECUTIVE SUMMARY .....	4
EXPERIMENTAL .....	6
Objectives and Scope of Study .....	6
Study Area .....	7
Time Line and Summary of Work .....	8
RESULTS AND DISCUSSION .....	10
Task 1. Locate, identify, and map natural gas seeps within 40 km of the village of Atqasuk .....	10
Task 2. Estimate methane production rates from active seeps near Atqasuk .....	14
Task 3. Geochemical interpretation as inference of gas origin and quality .....	18
Task 4. Core lake to investigate possibility of establishing a long-term record of seep emission consistency .....	28
Task 5. Engineering assessment and demonstration of the development of seep methane for energy use in rural Alaska .....	31
Task 6. Education and outreach .....	33
CONCLUSIONS .....	35
REFERENCES .....	37
LIST OF ACRONYMS AND ABBREVIATIONS .....	42
APPENDIX A .....	43

## LIST OF FIGURES

Figure 1. Regional map of northern Alaska showing location of Atqasuk, a rural village surrounded by unconventional natural gas seeps. ....	8
Figure 2. Locations of the validated CH <sub>4</sub> seeps. ....	10
Figure 4. Flight path for 1-hour aerial survey for CH <sub>4</sub> seeps. ....	11
Figure 3. Convection associated with hotspots of methane bubbling maintains open holes in early winter lake ice, which are visible in aerial photographs as dark spots contrasted against white snow- and ice-covered lakes. ....	1
Figure 5. B1-b seeps as seen from the air in October 2008 (left). Qalluuraq Lake CH <sub>4</sub> seep. ....	12
Figure 6. Qalluuraq Lake Seep in October 2008 (left), January 2008 (middle), and August 2007 (right). ....	12
Figure 7. Thermal infrared photograph of Walter collecting gas from ice-sealed Lake Q seep in January 2008. White indicates the hottest temperature, emitted through thin ice cover over the seep. Photo by P. Anthony. ....	13
Figure 8. At individual seep sites, Walter and Whiteman measure water depth (left), count the number of seeps visible in open holes (other seeps are present but not visible beneath the snow) (middle), and collect gas using underwater bubble traps for laboratory analysis of gas constituents and geochemistry (right). ....	13
Figure 9. Amaqaruk Meade River seeps (B10). ....	14
Figure 10. Gas flow of ~3,000 ft <sup>3</sup> /day. ....	14
Figure 11. CH <sub>4</sub> seeps reported in the Atqasuk area shown as red stars (a). ....	16
Figure 13. Stable isotope $\delta^{13}\text{C}_{\text{CH}_4}$ and $\delta\text{D}_{\text{CH}_4}$ of methane in seep gases from Atqasuk (inside black box, colored circles) and other thermokarst lakes in Alaska and Siberia (outside box, dark green circles); based on Whiticar <i>et al.</i> 1986. ....	22
Figure 14. Molecular (Bernard Ratio) and stable carbon isotope characterization of natural gases, after Whiticar 1996. The concentrations of hydrocarbons and $\delta^{13}\text{C}_{\text{CH}_4}$ value of methane from the Lake Q B1-a and Amaqaruk seep suggest that the gas has become slightly enriched in $\delta^{13}\text{C}$ since 1996, with a potential increase in higher molecular-weight hydrocarbon concentrations. ....	23
Figure 15. Researchers investigated cutbanks in the Meade River. ....	24

Figure 16. After Schwamborn *et al.* (2000). Chirp and seismic data (1.5 to 11.5 kHz) collected in a thermokarst lake in Siberia reveal a 95-m thick thaw bulb (talik) beneath a shallow lake (left). A schematic (right, not shown to scale) showing potential CH<sub>4</sub> sources contributing to total emissions from lakes near Atqasuk: microbial CH<sub>4</sub> produced in thaw bulb sediments, coalbed CH<sub>4</sub>, thermogenic CH<sub>4</sub> from deep conventional hydrocarbons, and possibly dissociating CH<sub>4</sub> hydrates; courtesy of C. Ruppel. ....25

Figure 17. In April 2008, engineers Schmid and Johnson drilled through lake ice at regular intervals away from the seep to measure the lake bottom depth and probe for frozen vs. thawed sediments. ....27

Figure 18. Photo showing ice dome at seep center. ....28

Figure 19. The concept of using the remains of chironomids (aquatic insects) preserved in dated cores of lake sediments to track the long-term duration and consistency of methane emissions from a lake. ....29

Figure 20. A hotspot of biological activity at the seep site revealed living midge larvae (chironomids) whose radiocarbon age is 1,700 years! Stable isotopes of chironomids also confirmed that methane is making its way into the food web of these organisms. Researchers pick living chironomids from seep sediments (left). An example of a chironomid is shown (right). ....31

Figure 21. Dutch farmers dig shallow artesian wells in their yard, through which groundwater, rich in CH<sub>4</sub> generated from nearby peat bogs, rises to the surface. A sieve is placed at the top of the well casing, causing the water to de-gas as it sprays through the sieve. A heavy metal cap is placed over the top of the well, which allows adequate pressure to build to transport the gas from the wellhead to the house via an inexpensive, low-pressure hose. ....32

Figure 22. January 2008 Atqasuk community meeting to discuss the methane seep project (left). April 2008 local residents and UAF student at the Lake Q seep during the gas flare. ....34

Figure 23. Melissa Smith (UAF undergraduate student) demonstrating a lake sediment grab sampler for collecting lake bottom organisms from methane seep sites (left); Katey Walter (UAF faculty) introducing a methane bubble trap for capturing and collecting gas in lakes (middle); Tom Johnson (UAF staff) showing digital images to kindergarteners at Meade River School. ....34

## LIST OF TABLES

Table 1. Objectives, methods, and products for unconventional CH <sub>4</sub> seep research at Atqasuk. ....	6
Table 2. Number of seeps and estimated flux from observed seep fields near Atqasuk during 2008. ....	17
Table 3. Mixing ratios of CH <sub>4</sub> , CO <sub>2</sub> , N <sub>2</sub> , O <sub>2</sub> , and CH <sub>4</sub> , C <sub>2</sub> –C <sub>5</sub> hydrocarbons in gas seeps. ....	19
Table 4. Isotope values of methane ( $\delta D_{CH_4}$ and $\delta^{13}C_{CH_4}$ ) and $\delta^{13}C_{CO_2}$ in Atqasuk gas seeps. ....	20
Table 5. Physical and chemical properties of lake and river water at seep and non-seep sites near Atqasuk. ....	25

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## INTRODUCTION

Methane (CH<sub>4</sub>) in natural gas, a major energy source in the U.S., is used extensively on Alaska's North Slope, including the oilfields in Prudhoe Bay and the Barrow community. Smaller remote villages such as Atqasuk (population 300, ~550 miles NE of Fairbanks), however, depend on expensive imported diesel fuel for both power and heating, which makes the existence of natural gas seeps near their communities of significant interest as a potential energy source for local residents.

Huge reservoirs of CH<sub>4</sub> exist in the subsurface in Alaska (tens of trillions of cubic feet; Houseknecht and Bird 2006), contained both within and below permafrost. Subsurface CH<sub>4</sub> is found in association with thick peat, coal seams, gas hydrate formations, and petroleum deposits. In some areas, CH<sub>4</sub> seeps to the surface through permafrost. Macroseeps emerge as strong, discrete ebullition plumes through lakes, rivers, and in some cases, dry ground with and without oily sheens (Chapman *et al.* 1964; Burruss 1999; Decker and Wartes 2008). In contrast, microseeps may extend laterally kilometers from the source (Etiope 2004; Etiope *et al.* 2007). Recent analysis of atmospheric CH<sub>4</sub> indicates a much larger component of geologic CH<sub>4</sub> in the global atmospheric CH<sub>4</sub> budget than was previously estimated (Lassey *et al.* 2007). Globally, terrestrial seeps may contribute as much as 50–70 million tons of CH<sub>4</sub>, a potent greenhouse gas, per year (Etiope *et al.* 2007), or up to 10% of global sources, with a substantial proportion of these seeps located in the Arctic. There are critical gaps in our knowledge of CH<sub>4</sub> seeps in the Arctic and their potential for use as an energy source in remote villages, in particular:

- 1) The number of CH<sub>4</sub> seeps, their proximity to villages, and potential to serve villages for energy has never been thoroughly identified and mapped. Specific seeps have been recognized and described on the North Slope of Alaska from as early as 1923 (Burruss *pers. comm.*); however, the precise number of macroseeps, their proximity to communities, and the quantity and quality of gas potentially available to villages have not been well identified. Interest is increasing along with the rising cost of diesel fuel, currently ~\$6/gallon, widely used for heating and power generation in rural Alaska. Several seeps have been reported within a 25 km radius of the village of Atqasuk, in the

heart of the NPRA, but gas flow rates from these seeps have not previously been measured.

2) Spatial and temporal variability of production dynamics of natural gas seeps need to be characterized. Thorough flux measurements from arctic terrestrial seeps have never been made, although spot sampling and observations suggest that large (up to  $10^8$ -fold) differences in efflux can occur (von Fischer *et al.* 2007; Decker and Wartes 2008; K. Hinkel *pers. obsv.*; K. Walter *unpublished data*). The flux of CH<sub>4</sub> from discrete seeps needs to be measured and gas geochemical analysis used to inform climate modeling about the magnitude of CH<sub>4</sub> emissions from the seep-ridden landscape, and about the lateral extent of deep-sourced CH<sub>4</sub> seepage (macro- and microseeps) at the surface, for use in determining potential future drilling locations (i.e., beneath town).

3) The consistency of gas seepage is unknown, and efforts such as analysis of methane biomarkers in sediment cores may help to reconstruct the history, strength, and duration of CH<sub>4</sub> seepage over time scales of decades to millennia.

4) Technologies for capture and beneficial use of the CH<sub>4</sub> from natural seeps should be explored including (a) efficient, cost-effective means of transporting CH<sub>4</sub> to Atqasuk from distal seeps and/or (b) shallow drilling beneath Atqasuk if a significant reservoir is identified there, allowing potentially economical production of high-quality gas from a well; and (c) collection and utilization of seep CH<sub>4</sub>. A semi-permanent CH<sub>4</sub> collection and transport demonstration system should be designed and constructed to assess technical challenges associated with future use of seep CH<sub>4</sub> as an energy source. An engineering assessment should be conducted based on synthesis of new data about the quantity, location, quality, and production dynamics of seeps to determine the feasibility and cost-effectiveness of environmentally responsible development of CH<sub>4</sub> seeps as an alternative energy resource for Atqasuk.

Addressing these issues requires interdisciplinary science and engineering research to better characterize arctic CH<sub>4</sub> seeps and to assess opportunities for developing this potentially significant resource. In this study we used a combination of local knowledge, field measurements, aerial surveys, and laboratory analysis to locate and identify seeps within a 40 km radius of Atqasuk in order to provide background knowledge for future

work on the above-listed knowledge gaps and to provide an initial assessment of the potential for future development of the gas as an energy source.

An overview of the project objectives, methods, and products appears in Table 1 of the Experimental section.

## EXECUTIVE SUMMARY

The objectives of this study were to locate and identify natural gas seeps near the remote Alaskan village of Atqasuk and to evaluate the potential for environmentally responsible development of unconventional natural gas from seeps for local space heating and power generation. Research priorities included identifying and evaluating the quantity, quality, and location of natural seeps, as well as determining potential capture and transport mechanisms necessary for future resource development.

Methane (CH<sub>4</sub>) in natural gas is a major energy source in the U.S., and is used extensively on Alaska's North Slope, including the oilfields in Prudhoe Bay, the community of Barrow, and the National Petroleum Reserve, Alaska (NPRA). Smaller villages, however, are dependent on imported diesel fuel for both power and heating, resulting in some of the highest energy costs in the U.S. and crippling local economies. Numerous CH<sub>4</sub> gas seeps have been observed on wetlands near Atqasuk, Alaska (in the NPRA), and initial measurements indicated flow rates of 3,000–5,000 ft<sup>3</sup> day<sup>-1</sup>. Gas samples collected in 1996 indicated biogenic origin, although more recent sampling in this study indicated a mixture of biogenic and thermogenic gas. In this study, we (1) located seven seep fields and estimated the amount of CH<sub>4</sub> generated by them; (2) collected gas and analyzed its composition from multiple seeps several miles apart to see if the source is the same, or if gas is being generated locally from isolated biogenic sources, and identified the likely source of CH<sub>4</sub> (coal seams); (3) cored Qalluuraq Lake (Lake Q) to determine its basal age and potential for paleostudies using chironomid biomarkers; (4) evaluated the potential use of seep methane as an unconventional gas source for the village of Atqasuk; and (5) assessed the magnitude of natural CH<sub>4</sub> gas seeps for future use in climate change modeling.

We accomplished and learned the following: (1) Using a combination of local knowledge, aerial photography, and ground-based surveys, located ~10 large seep sites (7 were ground truthed) in the Atqasuk region; (2) Determined that the seeps have a mixed biogenic-thermogenic signature and likely have a coal seam origin; (3) Measured spatial/temporal variability of seep CH<sub>4</sub> fluxes using gas traps and flowmeters; (4) Determined the calibrated 11,500 ± 180 calendar years age of Lake Q, the thermokarst lake near Atqasuk with a very large seep, by radiocarbon dating the basal organic material in a sediment core; (5) Found that Atqasuk CH<sub>4</sub> seeps are biological hotspots, with evidence that CH<sub>4</sub> is fueling modern productivity based on depleted δ<sup>13</sup>C values and 1,700 radiocarbon-year age of living chironomids (midges), suggesting that these organisms can be used as an indicator of long-time records of gas generation and emission in these lakes; (6) Designed and built a capture system for flux measurements of large and small seeps, and flared the gas; and (7) Conducted an engineering and economic assessment for environmentally responsible development of unconventional CH<sub>4</sub> from seeps as an alternative energy source for the remote Alaskan village of Atqasuk. Our recommendation is that transporting gas from the seep sites to town is not cost-effective, but given the widespread distribution of seeps, there is the potential for shallow drilling of coal seams beneath the town.

Potential benefits of the project include reduction in the consumption of diesel fuel in Atkasuk both for power generation and home heating (approximately 500,000 gallons per year, current value of \$1.5–\$3 million per year), and better understanding of gas resources in the NPRA area, with potential larger markets. On the climate-change side, quantifying natural seeps to atmospheric CH<sub>4</sub> sources may change our understanding of the global balance between human and natural sources. Recent work revealed that seeps may contribute as much as 50–70 million tons of atmospheric CH<sub>4</sub> per year, or ~10% of global sources. Additionally, capture and use of CH<sub>4</sub> from seeps mitigates global climate change in two ways: Combusting CH<sub>4</sub>, a potent greenhouse gas (CH<sub>4</sub> is 25 times stronger than CO<sub>2</sub> on a per molecule basis), converts it to the weaker greenhouse gases, CO<sub>2</sub> and H<sub>2</sub>O; and use of local CH<sub>4</sub> reduces energy consumption associated with diesel usage and shipping to remote villages.

## EXPERIMENTAL

### ***Objectives and Scope of Study***

The overall objective of this effort was to assess the capacity for environmentally responsible development of unconventional natural gas from observed seeps near the remote Alaskan village of Atqasuk. Our objectives included quantifying the number, quality, origin, and location of seeps, designing capture mechanisms necessary for flow measurements, and assessing the potential future development of the gas as an energy source.

Questions we aimed to answer were these:

- What is the source of the large Qalluuraq Lake seep?
- What is the best way to look for other large seeps? How many seeps are there? What is their origin? What is their net production of methane?
- Is there enough gas from the Qalluuraq Lake seep and others to provide energy economically for the village of Atqasuk?
- Should gas be captured at the surface and transported above ground to town?
- Is drilling for shallow gas a good idea? Could wells be drilled in the village of Atqasuk, where it could be used, or is the lake with the largest seep, Qalluuraq Lake, the best drilling site?

Table 1. Objectives, methods, and products for unconventional CH<sub>4</sub> seep research at Atqasuk.

<b><i>Objectives</i></b>	<b><i>Methods</i></b>	<b><i>Products</i></b>
<i>Locate, identify, and map natural gas seeps within 40 km of the village of Atqasuk (Task 1)</i>	<b>Review of traditional knowledge</b> of Atqasuk residents to locate seeps	Town hall meeting and map of potential seep locations marked.
	Acquisition and analysis of low altitude <b>aerial photographs</b> and <b>thermal infrared</b> images to locate CH <sub>4</sub> seeps as open hole “hotspots” in early winter lake ice.	Map and aerial photographs showing seep locations.
	<b>Field validation</b> of seep identification by visiting seep sites located by above methods to measure fluxes, sample gas, measure limnology, and assess potential to service Atqasuk.	Database of flux and geochemistry for individual seeps and limnology of seep sites.

<i>Estimate methane production rates from active seeps near Atqasuk (Task 2)</i>	Short-term (minutes-hours) measurement of flux from small (<1 m) seeps in lakes and rivers using <b>underwater/under-ice bubble traps and other flowmeter technology</b> .	Data for fluxes from at least 5 individual seeps, seasonal measurements from the large seep.
<i>Provide geochemical interpretation to infer gas origin and quality (Task 3)</i>	<b>Geochemistry:</b> Measurement of mixing ratios, stable isotopes (D/H, <sup>13</sup> C/ <sup>12</sup> C) and <sup>14</sup> C-age of CH <sub>4</sub> , C <sub>2</sub> –C <sub>5</sub> hydrocarbons and CO <sub>2</sub> in field samples collected from seeps.	Inference of seep gas origin as thermogenic vs. biogenic, young vs. old.
<i>Core lake to investigate possibility of establishing a long-term record of seep emission consistency (Task 4)</i>	Extract sediment cores from thermokarst lakes to determine basal age of lake and to analyze <b>chironomid biomarkers in seep sediments</b> cores to assess their potential use as a record of the long-term (10–10 <sup>3</sup> yr) dynamics of CH <sub>4</sub> seepage from active seeps.	Basal age of thermokarst lake; isotopic signature of chironomid biomarkers; other evidence of origin and dynamics of methane seepage.
<i>Engineering assessment and demonstration of the development of seep methane for energy use in rural Alaska (Task 5)</i>	Design and install a <b>pilot CH<sub>4</sub> collection system</b> to collect and measure flux from 4 large seeps	Data on flow rate from large seep.
	Demonstrate use of CH <sub>4</sub> by flaring the gas.	Photographs and video of methane flare.
	Conduct a <b>feasibility study</b> including an economic analysis and engineering feasibility for providing unconventional CH <sub>4</sub> gas to Atqasuk residents.	Initial economic feasibility report as part of Final Report.
<i>Education and outreach (Task 6)</i>	Share research objectives, concepts, and project ideas with the K–12 public school and residents in the remote village, Atqasuk.	Four classroom visits at the Meade River Elementary School; field trip to seep site with 5 Atqasuk residents; 2 open town hall meetings in Atqasuk.
<i>Briefings/reports</i>	Synthesize and <b>publish</b> results.	Final Report; peer review publication.

## Study Area

At elevations of only 15–25 m above sea level, the immediate Atqasuk area is characterized by low-lying tundra, wetlands, lakes, and the Meade River drainage, with few bedrock and coal outcrops.



Figure 1. Regional map of northern Alaska showing location of Atqasuk, a rural village surrounded by unconventional natural gas seeps.

### ***Time Line and Summary of Work***

**September 1996:** Qalluuraq Lake (Lake Q) Seep (B1-a) was sampled by ConocoPhillips.

**August 2007:** PI Katey Walter sampled gas from Lake Q seep for geochemical analysis.

**January 2008:** Walter and field assistants, Peter Anthony and Doug Whiteman (Atqasuk resident) measured gas flow from seep, equivalent to  $3,000 \text{ ft day}^{-1}$  under conditions of poor visibility,  $-46^{\circ}\text{C}$ , possible insufficient seal over the seep on ice. They discovered an abundance of midge larvae (chironomids) associated with the seep. The seep was photographed with digital and thermal infrared cameras. Researchers conducted a town hall meeting with Atqasuk residents, and 3 residents accompanied them to the field.

**April 2008:** PIs Walter and Witmer returned with several field assistants to the Lake Q seep under fair conditions ( $-7^{\circ}\text{C}$ ) and measured gas flow through seep during 3 days,  $\sim 5,000$  cubic feet per day. Researchers collected gas and lake sediments for radiocarbon dating and geochemical analyses. The chironomid community was sampled as a potential means for determining how long the seep has been active. The team attempted to measure thaw bulb thickness (at least 5.9 m), and measured the bathymetry and hydrology of an ice-free cavern associated with the Lake Q seep. A second seep (Amaqaruk, B10), located in the Meade River, was identified, measured ( $\sim 12$  cubic feet per day), and gas sampled for

geochemical analysis. Limnological parameters were measured at both seep sites. Researchers conducted a town hall meeting with Atqasuk residents, and 5 residents accompanied them to the field. Researchers visited 4 classrooms at the Meade River Elementary School with demonstration and instruction related to the CH<sub>4</sub> study.

**October 2008:** PI Walter conducted one hour of aerial surveys with field assistants Matt Nolan and Doug Whiteman over the Atqasuk area. They identified 10 potential seep sites from the air. Seven of the 10 sites have been ground truthed as actual CH<sub>4</sub> seeps. By November 2008, flow measurements were conducted and gases collected for geochemical analysis at 5 seep sites (B1-a, B1-b, B7, B9, B10).

## RESULTS AND DISCUSSION

### **Task 1. Locate, identify, and map natural gas seeps within 40 km of the village of Atqasuk**

Meetings with local residents suggested that 3 additional seeps could be found near Lake Q and the village of Atqasuk. GPS coordinates were recorded, and the suspected seep sites were marked on a map (Fig. 2). Subsequent efforts to locate these seeps in April–May 2008, even with local guides, produced only 1 additional seep (Amaqaruk Seep on the Meade River). Our effort and that of Atqasuk residents to locate additional seeps using snow machines took 6 full days (20+ person days).



Figure 2. Locations of the validated  $\text{CH}_4$  seep, Qalluuraq (Lake Q), and 3 additional suspected sites (white triangles) based on local knowledge of Atqasuk residents. The Amaqaruk Seep on the Meade River was located and measured in April 2008. Field-validated sites are indicated by red stars.

Quantifying  $\text{CH}_4$  emissions from arctic lakes is difficult due to the inaccessibility of the terrain, but a new technique has recently been developed that maps the locations of active seeps by surveying early winter lake ice (Walter *et al.* 2006, 2008a). As water freezes in lakes,  $\text{CH}_4$  bubbles are trapped in ice. The convection associated with strongly bubbling seeps (hotspots) prevents freezing, leaving open holes in lake ice (Fig. 3) that are easily identified in early winter aerial and remote sensing imagery as dark holes that contrast against white, snow-covered ice. Aerial photography has been used to quantify

CH<sub>4</sub> seeps in lakes over hundreds of kilometers of Siberian tundra (Walter *et al.* 2006), and it has potential for locating natural gas seeps on the North Slope. PI Walter attempted this new method for locating CH<sub>4</sub> seeps near Atkasuk in October 2008 by flying aerial surveys and searching for open holes in lake ice. Ten potential seep sites were identified during 1 hour of aerial surveying (Fig. 4). Survey time was limited by Frontier Airline's commercial flight schedule. Examples of seeps seen from air in winter and summer are shown in Figure 5.

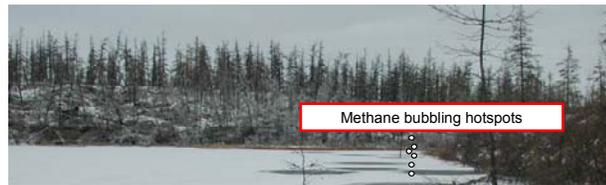


Figure 3. Convection associated with hotspots of methane bubbling maintains open holes in early winter lake ice, which are visible in aerial photographs as dark spots contrasted against white snow- and ice-covered lakes. Photo taken at a thermokarst lake in Siberia by K. Walter.

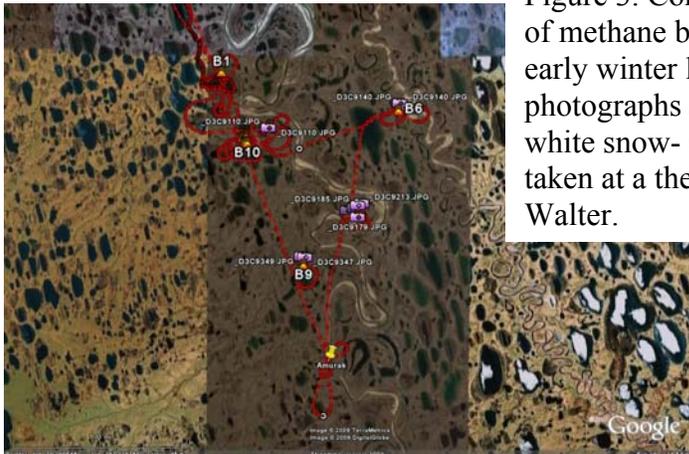


Figure 4. Flight path for 1-hour aerial survey for CH<sub>4</sub> seeps in October 2008. Observed potential seeps were photographed, and GPS coordinates were recorded. Approximate locations are marked as B1–B10 on the map.

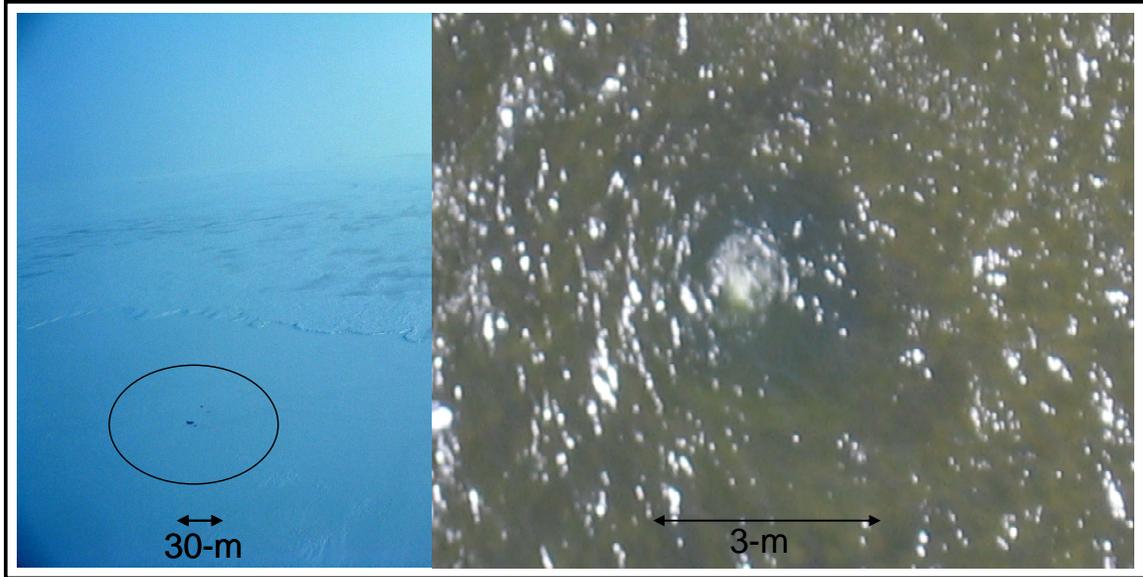


Figure 5. B1-b seeps as seen from the air in October 2008 (left). Qalluuraq Lake CH<sub>4</sub> seeps (B1-a) as seen from the air in August 2007 (right). Photo by K. Walter.

As of December 31, 2008, seven of the potential ten seep sites have been ground truthed. Gas flux has been measured at five sites, and samples collected for geochemical analysis. Photographs of several of the seeps, including gas-sampling efforts, are shown in Figure 6–Figure 9.



Figure 6. Qalluuraq Lake Seep in October 2008 (left), January 2008 (middle), and August 2007 (right). Photos by K. Walter.

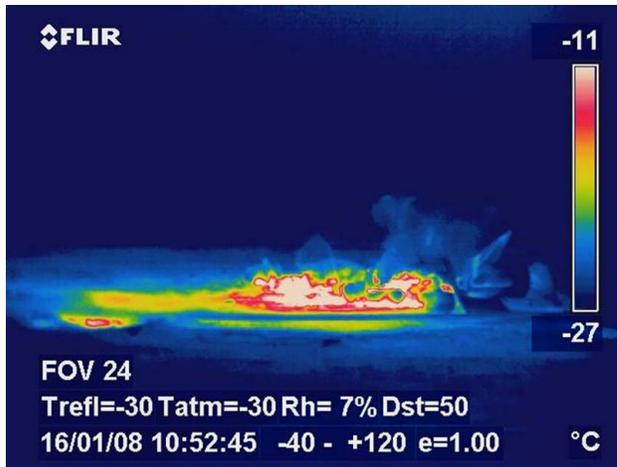


Figure 7. Thermal infrared photograph of Walter collecting gas from ice-sealed Lake Q seep in January 2008. White indicates the hottest temperature, emitted through thin ice cover over the seep. Photo by P. Anthony.



Figure 8. At individual seep sites, Walter and Whiteman measure water depth (left), count the number of seeps visible in open holes (other seeps are present but not visible beneath the snow) (middle), and collect gas using underwater bubble traps for laboratory analysis of gas constituents and geochemistry (right). Photos by D. Whiteman and K. Walter.



Figure 9. Amaqaruk Meade River seeps (B10). Researchers found this naturally occurring, large, ice-free hole due to convection of gas seepage through 3.2-m deep water (left). Such open holes on lakes and rivers are a hazard to snow machine travelers who may not see the open water until it is too late. Poles and flags were placed adjacent to each of the seeps as an indicator of the seep location to warn snow machine travelers, thanks to the foresight of D. Whiteman. Walter measured gas flow ( $\sim 12 \text{ ft}^3 \text{ day}^{-1}$ ) with submerged bubble trap from 3 individual seeps (right). Photos by K. Walter and T. Johnson.

### ***Task 2. Estimate methane production rates from active seeps near Atqasuk***

We estimated the methane flux from active seeps near Atqasuk during several times of the year using underwater bubble traps (Figs. 8, 9) and gas flowmeters (Fig. 10).



Figure 10. Gas flow of  $\sim 3,000 \text{ ft}^3 \text{ day}^{-1}$  from seeps was measured in January 2008 (left) and of  $\sim 5,000 \text{ ft}^3 \text{ day}^{-1}$  in April 2008 (middle) using ice-cover to seal the seep and direct flow through a 1" ID pipe for direct flux measurement using an anemometer. Anemometer measurements were calibrated by flowmeter tests and visual reconstruction in a water tank in the laboratory (left). Photos by P. Anthony and K. Walter.

In January 2008, PI Walter led a small team of researchers (Walter, Anthony, Whiteman) to measure the flow rate of methane from the Lake Q seep (B1-a) near Atqasuk. These measurements were made under adverse conditions (-46°C, little daylight, in January), but the measurements seem to consistently indicate that the flow rate was approximately 3,000 cubic feet per day, and that the gas is methane. This flow rate is considerably higher than found on typical lakes where methane is produced from decaying vegetation on the bottom of the lake at a rate of less than 1 ft<sup>3</sup> day<sup>-1</sup> per seep (Walter et al. 2006). We calibrated the anemometer measurements using flowmeter tests and visual reconstruction in a water tank in the laboratory. Error was calibrated at 0.2%, better than nominal instrument precision.

In April 2008, a larger team (Walter, Witmer, Schmid, Johnson, Wooller, and Smith) returned to Atqasuk for a second expedition. The team worked at the Lake Q seep site (B1-1), ~6 miles out of town for 3 days, and at a site ~20 miles from town (Amaqaruk) on the Meade River for 1 day. The team collected samples of gas from seeps, measured seep flow rates, collected cores of sediments from the lake bottom, and measured ice thickness and other lake features associated with the methane gas seeps.

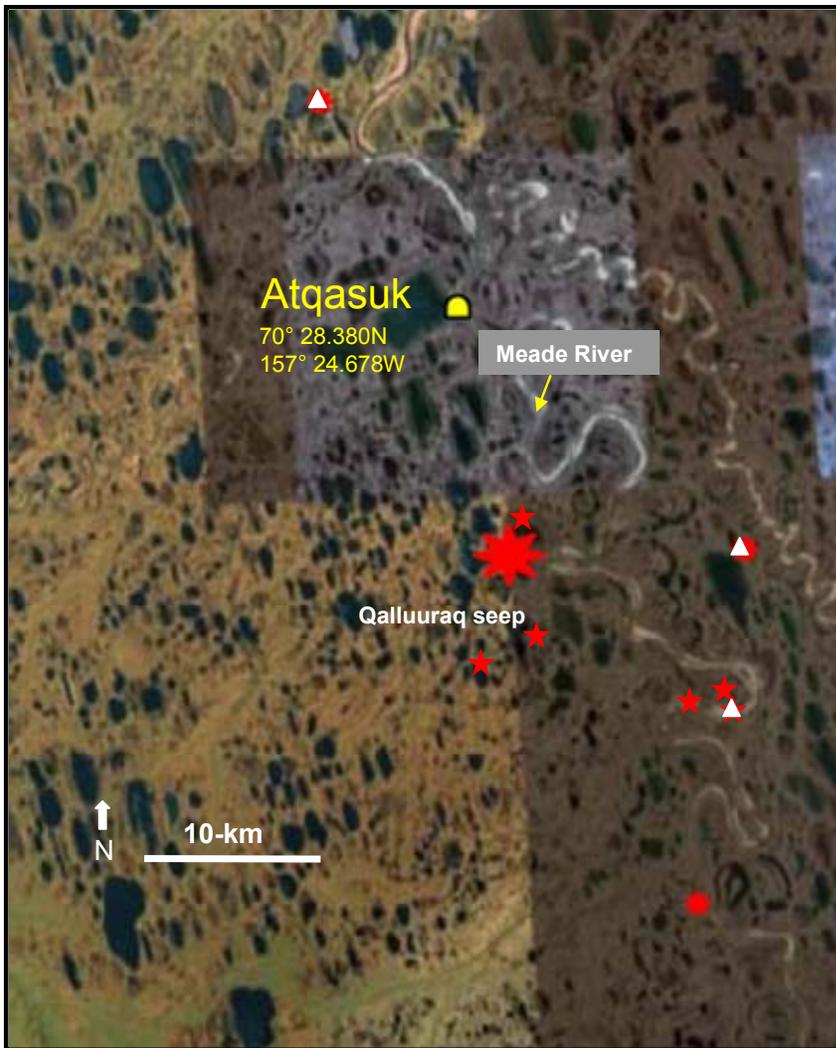


Figure 11. CH<sub>4</sub> seeps reported in the Atqasuk area shown as red stars (a). The Qalluuraq Lake seep is of interest as an energy source given preliminary measurements of high flow rates and CH<sub>4</sub> concentration.

In October 2008, PI Walter returned to Atqasuk to conduct aerial and ground surveys, accompanied by M. Nolan and D. Whiteman. Within the 1 hour of flying available using a small aircraft, 8 additional new potential seep sites were located, making a total of 10 for the small area surveyed (Fig. 11). Walter obtained GPS coordinates accurate to  $\sim\pm 250$  m from the low-flying aircraft, while Nolan shot aerial photos from the back of the aircraft. Investigators traveling by snow machine ground truthed seep sites during the subsequent 1.5 days. They visited 3 of the 8 new seep sites and confirmed that each had significant bubbling columns, and they obtained accurate ( $\pm 1$ – $5$  m) GPS coordinates for the seeps. They measured flow rate from 1 seep and

collected gas for geochemical analysis. Poor weather prevented further ground truthing during that trip. In November, Whiteman visited 3 additional seep sites and conducted measurements identical to those that Walter and he had conducted in October: that is, counted the number of bubbling columns, acquired accurate GPS coordinates, photographed the seep, and collected gas using gas bubble traps. Single seep sites contained as many as 68 individual bubbling columns, ranging in magnitude of flux (Table 2). Seven of the 10 seep sites have now been ground truthed. It is likely that there are numerous other methane seeps in this region. We expect that further flying time for aerial surveys would yield location and identification of more seep sites.

Table 2. Number of seeps and estimated flux from observed seep fields near Atqasuk during 2008.

Seep field site	Water Body Type	Observed number of seep	Gas seepage (L day <sup>-1</sup> )	Methane production (kg CH <sub>4</sub> yr <sup>-1</sup> )	Max water depth (m)
B1-a	Lake (Lake Q, main seep)	one large seep, +10 <sup>1</sup> to 10 <sup>2</sup> of small seeps	141,600	36,900	2.2
B1-b	Lake	at least 28 seeps	3,700	954	~2
B2	Lake	at least 58 seeps			
B5	Lake	at least 54 seeps			
B6	Lake	nothing verifiable			
B7	Lake	at least 64 seeps	14,000	3,625	1.3
B8	Meade River lead	nothing verifiable			
B8x	Meade River	nothing verifiable, probably sand bar			
B9	Lake	at least 3 seeps	560	129	1.5
B10 Amaqaruk	Meade River	3 seeps	540	125	3.2
Possibility	wetlands NW of Atqasuk	nothing verifiable, local knowledge source			

\*Seepage rates are minimum estimates because we observed innumerable seeps beneath the snow and ice that we were unable to feasibly count under the harsh field conditions.

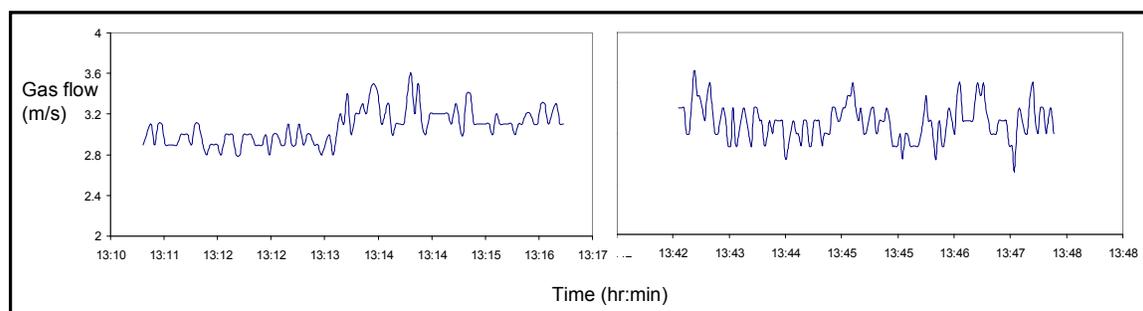


Figure 12. Flow data for the Lake Q B1-a seep on April 22, 2008.

Flow measured from the large Lake Q seep was considerably higher in April 2008 ( $3.0 \pm 0.0$  m/s,  $n=288$ , approximately 5,000 ft<sup>3</sup>/day) compared to the January 2008 flow measurements ( $2.0 \pm 0.1$  m/s, approximately 3,000 ft<sup>3</sup>/day). The difference could be real,

but the January 2008 measurements were conducted under extremely harsh conditions (-46°C and darkness), and therefore may not be as reliable as those conducted under warmer, brighter spring conditions. The stability of the short-term flow measurements in April suggests that over the course of several hours-days, flow velocity was consistently ~3 m/s. We recommend long-term flow monitoring of the seep to determine potential seasonal and interannual variability.

We measured seepage rates from multiple seeps in each of the seep fields and counted the number of seeps visible in the open-ice holes in October 2008. The number of seeps was multiplied by the measured seepage rates, and assuming consistent year-round seepage rates, we estimated annual emissions from the seep fields near Atqasuk (Table 1). Scaling emissions from measured seeps to the potential 10 seepage fields identified in October 2008, the total emissions from the seeps would be 6,200 ft<sup>3</sup> d<sup>-1</sup> (175,500 L d<sup>-1</sup>). This flow is considerably higher (>10,000 times) than that found in typical lakes where CH<sub>4</sub> is produced from decaying lake-bottom vegetation at less than 1 ft<sup>3</sup> day<sup>-1</sup> (Walter *et al.* 2006, 2008), and greater than the sum of 5 terrestrial natural petroleum seeps measured in the Ojai Valley, California (1,942 ft<sup>3</sup> day<sup>-1</sup>; Duffy *et al.* 2007). The source of this Lake Q CH<sub>4</sub> seep is thus of considerable interest.

### ***Task 3. Geochemical interpretation as inference of gas origin and quality***

Distinguishing the source and origin of CH<sub>4</sub> from seeps is complicated by the numerous source and production pathways that can contribute to seep gas. The most widely employed approach for discriminating gas sources is based on the stable isotopic composition ( $\delta^{13}\text{C}$  and  $\delta\text{D}$ ) of CH<sub>4</sub> and the relative abundance of low molecular-weight hydrocarbons (Figs. 13 and 14; Schoell 1983, 1984; Faber 1987; Whiticar 1999). In general, “microbial” CH<sub>4</sub> is <sup>13</sup>C-depleted and contains a lower relative concentration of higher hydrocarbons (expressed as the Bernard ratio, C<sub>1</sub>/[C<sub>2</sub>+C<sub>3</sub>]) than “thermogenic” CH<sub>4</sub>. Microbial CH<sub>4</sub> synthesized by the carbonate reduction pathway tends to be more depleted with respect to <sup>13</sup>C and D than CH<sub>4</sub> from acetate fermentation. For thermogenic sources, further differentiation as either coal-bed CH<sub>4</sub> or natural-gas CH<sub>4</sub> is possible because humic organic matter (the source of coal-bed CH<sub>4</sub>) is generally more

<sup>13</sup>C-enriched than sapropelic organic matter (the source of conventional natural gas) (Whiticar 1996).

In mixed systems, differentiating gas sources using this approach is difficult. For example, in microbial systems where carbonate reduction dominates, the  $\delta^{13}\text{C}$  signature of the  $\text{CH}_4$  is controlled by the  $\delta^{13}\text{C}$  signature of the  $\text{CO}_2$  (Whiticar 1999). Therefore, accurate classification also requires analyzing the  $\delta^{13}\text{C}$  of the  $\text{CO}_2$  (Walter *et al.* 2008b; Pohlman *et al.* in prep). Further source distinction is possible using radiocarbon dating of terrestrial seep  $\text{CH}_4$ , because a large percentage of the microbial gas is derived from relatively young (e.g., <50 ka) organic matter (Walter *et al.* 2006, 2008b).

We measured mixing ratios of  $\text{CH}_4$ ,  $\text{CO}_2$ ,  $\text{N}_2$ , and  $\text{O}_2$ , and  $\text{CH}_4$ ,  $\text{C}_2\text{--C}_5$  hydrocarbons as well as stable isotopes (D/H,  $^{13}\text{C}/^{12}\text{C}$ ) and  $^{14}\text{C}$ -age of  $\text{CH}_4$  in field samples collected from seeps near Atqasuk.

Table 3. Mixing ratios of  $\text{CH}_4$ ,  $\text{CO}_2$ ,  $\text{N}_2$ ,  $\text{O}_2$ , and  $\text{CH}_4$ ,  $\text{C}_2\text{--C}_5$  hydrocarbons in gas seeps.

Field Date	Analyzer	Site	$\text{CH}_4$ (%)	$\text{CO}_2$ (%)	$\text{N}_2$ (%)	$\text{O}_2$ (%)	ethane (%)	$\text{C}_3+$ (%)	Bernard Ratio $\text{C}_1/(\text{C}_2+\text{C}_3)$
Sep. 1996	ConocoPhillips	Lake Q (B1-a)	93.1	0.3	4.4	2.1	0.0052	0.001	15,016
Apr. 23, 2008	UC Santa Barbara, D. Valentine	Lake Q (B1-a)	97.7	1.2	1.0	0.1	0.01 - 0.05*	0.005	1,915 - 8,880
Apr. 23, 2008	UAF, K. Walter	Lake Q (B1-a)	99.4	1.3	1.4	0.3		0.00020	
Apr. 24, 2008	UAF, K. Walter	Lake Q (B1-a)	98.5	1.3	2.6	0.6		0.00020	
Apr. 23, 2008	UC Santa Barbara, D. Valentine	Amaqaruk (B10)	$85.9 \pm 0.37$	$0.6 \pm 0$	$12.1 \pm 0.4$	$1.4 \pm 0$	0.01 - 0.05*	0.005	1,690 - 7,820
Apr. 23, 2008	UAF, K. Walter	Amaqaruk (B10)	88.4	0.4	10.8	2.6		0.00020	
Oct. 10, 2008	UAF, K. Walter	B1-b	97.1	0.2	5.3	1.9			

\*poor separation of ethane from large methane peak on gas chromatograph

The largest methane seep, Lake Q B1-a, in the study area had a methane concentration of 97.7–99.4% in 2007–2008 (Table 2). This is 6% higher than what ConocoPhillips measured 12 years earlier. In 2008, the smaller seep near Lake Q B1-a (B1-b) had a similar methane concentration (98.5%), whereas the more distant Amaqaruk (B10) seep on the Meade River had a lower methane concentration (85.5–88.4%). We attribute the difference to water depth and gas diffusion. Bubbles emitted through the Lake Q seep rise through ~2 m of water, whereas bubbles from the river seep rise through 3.2 m of water (Table 2). As bubbles rise from the sediments through the water column, air diffuses into the bubbles throughout the deeper water column at the river site, while  $\text{CO}_2$  and  $\text{CH}_4$  diffuse out along a concentration gradient.

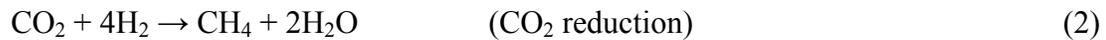
Note that we observed a strong H<sub>2</sub>S odor at the seep sites; however, H<sub>2</sub>S was not detected on the gas chromatograph. It was likely present, but subsequently oxidized in the sample bottles in the presence of a small amount of O<sub>2</sub> prior to analysis in the lab.

Table 4. Isotope values of methane ( $\delta D_{CH_4}$  and  $\delta^{13}C_{CH_4}$ ) and  $\delta^{13}C_{CO_2}$  in Atqasuk gas seeps.

Analyzer	Site	Field Date	$\delta^{13}C_{CH_4}$ (‰)	$\delta^{13}C_{CO_2}$ (‰)	$\delta D_{CH_4}$ (‰)
ConocoPhillips	Lake Q (B1-a)	Sep. 1996	-59.15		-248.6
Florida State, L. Brosius	Lake Q (B1-a)	July 25, 2007	-59.18	-27.71	-237.1 ± 0
Florida State, L. Brosius	Lake Q (B1-a)	Aug. 8, 2007	-58.58	-24.82	-235.9 ± 0.7
Florida State, J. Chanton	Lake Q (B1-a)	Aug. 12 2007	-56.9 ± 0.9	-39.5 ± 0.5	-231.5 ± 1.3
Florida State, J. Chanton	Lake Q (B1-a)	Aug. 12 2007	-53.5 ± 0.5	-39.3 ± 0.2	
Florida State, J. Chanton	Lake Q (B1-a)	Jan. 16, 2008	-57.24	-32.22	-228.85
Florida State, J. Chanton	Lake Q (B1-a)	Jan. 16, 2008	-57.22	-32.69	-229.91
Florida State, J. Chanton	Lake Q (B1-a)	Jan. 16, 2008	-57.35	-32.12	-230.26
Florida State, J. Chanton	Lake Q (B1-a)	Jan. 16, 2008	-57.34	-32.58	-229.11
Florida State, J. Chanton	Lake Q (B1-a)	Apr. 22, 2008	-57.45	-33.98	-228.13
Florida State, J. Chanton	Lake Q (B1-a)	Apr. 22, 2008	-57.39	-33.57	-228.53
Florida State, J. Chanton	Lake Q (B1-a)	Apr. 22, 2008	-57.27	-33.65	-227.39
Florida State, J. Chanton	Amaqaruk (B10)	Apr. 23, 2008	-56.68	-26.16	-236.77
Florida State, J. Chanton	Amaqaruk (B10)	Apr. 23, 2008	-56.77	-26.23	-236.50
Florida State, J. Chanton	Amaqaruk (B10)	Apr. 23, 2008	-56.73	-26.94	-236.24

### Methane production pathway

Methanogenesis is an ancient process that relies on relatively simple substrates—for example, carbon monoxide, carbon dioxide, acetate, formate, methylamine, methanol, and dimethylsulfide—that are produced by other metabolic processes (Conrad 1989). The two main pathways of bacterial methane production in anaerobic sediments are CO<sub>2</sub> reduction and acetate fermentation:



To estimate the relative proportion of these two major pathways of methanogenesis we calculated the apparent C fractionation factor ( $\alpha_C$ ) between CH<sub>4</sub> and CO<sub>2</sub> (Whiticar *et al.* 1986; Hornibrook *et al.* 2000). The  $\alpha_C$  is defined as

$$\alpha_c = \frac{(\delta^{13}C_{CO_2} + 10^3)}{(\delta^{13}C_{CH_4} + 10^3)}$$

where  $\delta^{13}C_{CO_2}$  and  $\delta^{13}C_{CH_4}$  represent the  $\delta^{13}C$  of CO<sub>2</sub> and CH<sub>4</sub> in bubbles, respectively. This estimation of  $\alpha_C$  is approximate because CH<sub>4</sub> and CO<sub>2</sub> are not related in the same way for the CO<sub>2</sub> reduction and acetate fermentation pathways; however,  $\alpha_C$  values have been utilized to differentiate between dominant pathways of methanogenesis in natural and artificial systems (Sugimoto and Wada 1993; Waldron *et al.* 1999b; Chasar *et al.* 2000a; Chanton *et al.* 2006; Prater *et al.* 2007). The CO<sub>2</sub> reduction pathway has a larger apparent C fractionation factor (Eq. 3,  $\alpha_C = 1.055$ – $1.090$ ) than acetate fermentation ( $\alpha_C = 1.040$ – $1.055$ ) (Whiticar *et al.* 1986).

The  $\alpha_C$  of gases from the Lake Q B1-a and Amaqaruk B10 seeps were 1.06, suggesting that if the methane is of biogenic origin, then it is produced via the CO<sub>2</sub> reduction pathway.

However, without further information, the  $\alpha_C$  has limited diagnostic power, given that a host of factors such as environmental variability, temperature, substrate concentrations, available Gibbs free energies, and the possibility of mixed thermogenic sources leads to variability in  $\alpha_C$  (Valentine *et al.* 2004; Conrad 2005).

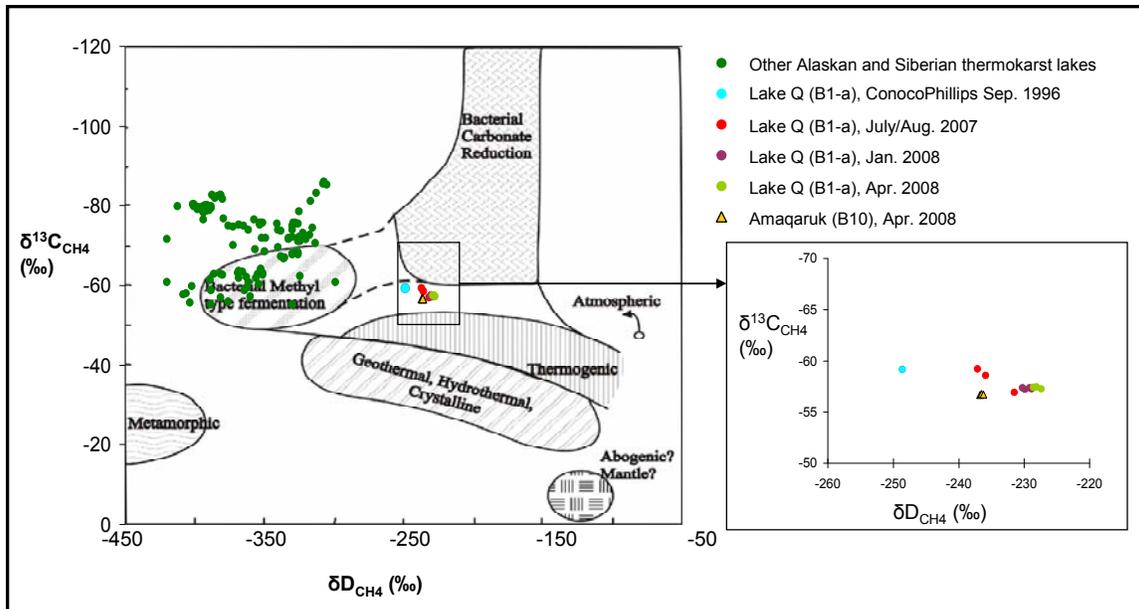


Figure 13. Stable isotope  $\delta^{13}\text{C}_{\text{CH}_4}$  and  $\delta\text{D}_{\text{CH}_4}$  of methane in seep gases from Atqasuk (inside black box, colored circles) and other thermokarst lakes in Alaska and Siberia (outside box, dark green circles); based on Whiticar *et al.* 1986.

Stable isotope ( $\delta^{13}\text{C}_{\text{CH}_4}$  and  $\delta\text{D}_{\text{CH}_4}$ ) data of methane from seeps near Atqasuk showed a mixed biogenic-thermogenic signature (Fig. 13). Samples collected from the large Lake Q (B1-a) site by ConocoPhillips in 1996 had a relatively larger contribution from biogenic methane, while samples collected in 2007 and 2008 had a progressively more thermogenically-enriched signature. One possibility is that there is a seasonal pattern to the isotopic composition, perhaps as a function of temperature-dependent biological processes; however, seasonal data from multiple years would be required to confirm this. In contrast, the majority of methane seeps in Alaska and Siberia measured by PI Walter outside the Atqasuk study region were of biogenic origin, providing a contrast to the more thermogenically anomalous Atqasuk seeps.

Preliminary radiocarbon data suggest that  $\text{CH}_4$  from the Atqasuk seeps is radiocarbon dead while, in comparison, seeps from other thermokarst lakes in Alaska and Siberia had  $^{14}\text{C}_{\text{CH}_4}$  ages ranging from modern to 43,000 years (Walter *et al.* 2006, 2008). Analytical errors in the Florida State Laboratory in August 2008 require re-running samples from this study for more precise error information. These analyses are underway. We expect to present publishable data by March 2009 for a peer-reviewed publication.



seams in the vicinity (or within the greater hydrocarbon migration fetch area) are sufficiently thermally mature to have sourced thermogenic gas (Kaba 2004; Strapoc *et al.* 2006).



Figure 15. Researchers investigated cutbanks in the Meade River. They found pieces of coal near both the Lake Q (B1-a) and Amaqaruk (B10) seeps.

Whatever its ultimate source, the gas might be escaping from a subsurface accumulation of finite areal extent and thickness. One possibility is that there is a shallow conventional sandstone reservoir with a structural or stratigraphic trap, whose top seal has been breached by erosion. Alternatively, free gas in a shallow sandstone reservoir might have been trapped and sealed by once-impermeable permafrost that has subsequently been intersected and compromised by the thaw bulb beneath the lake (Fig. 16). To date, geophysical techniques have rarely been used to describe the 3D characteristics of thermokarst lakes. Either ground-penetrating radar (GPR) or high-resolution seismic data should be capable of resolving such a free-gas interface, provided it occurs within the imaging range. Additional possibilities that should be evaluated include unconventional reservoir situations, such as ongoing desorption from a shallow coalbed  $\text{CH}_4$  accumulation or dissociation of a shallow gas hydrate accumulation (Praveen *et al.* 2008). Finally, the seep could simply represent the surface intersection of an active gas migration path, by way of either a permeable carrier bed (stratal migration) or a fault or fracture network (cross-stratal migration). Such a conduit may or may not be

connected to a leaking gas reservoir located at depth, well beyond the reach of erosion, permafrost thaw effects, or other near-surface processes.

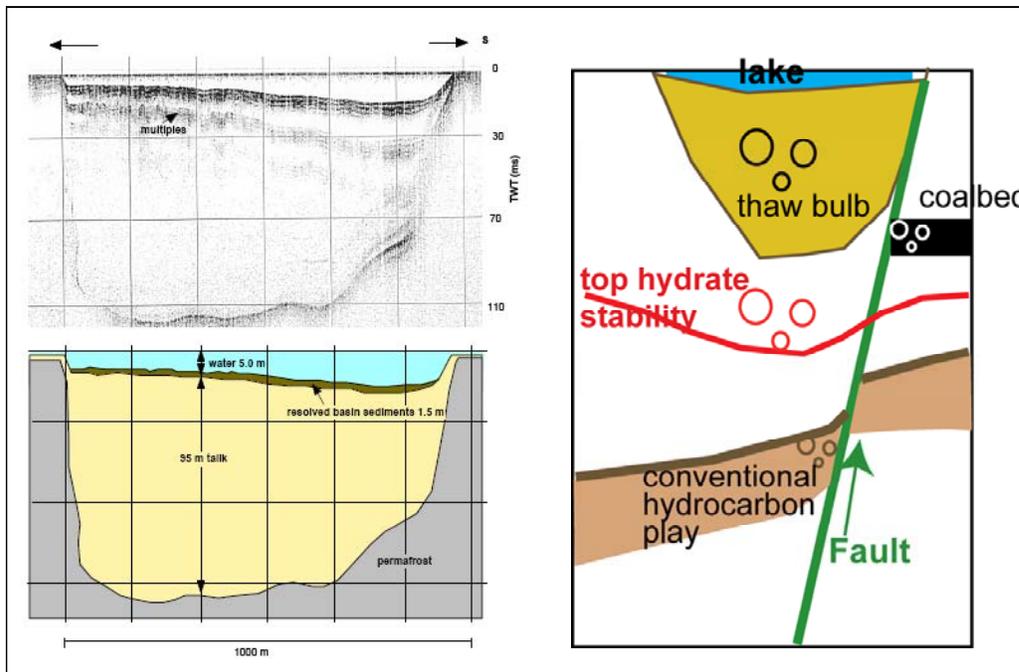


Figure 16. After Schwamborn *et al.* (2000). Chirp and seismic data (1.5 to 11.5 kHz) collected in a thermokarst lake in Siberia reveal a 95-m thick thaw bulb (talik) beneath a shallow lake (left). A schematic (right, not shown to scale) showing potential CH<sub>4</sub> sources contributing to total emissions from lakes near Atqasuk: microbial CH<sub>4</sub> produced in thaw bulb sediments, coalbed CH<sub>4</sub>, thermogenic CH<sub>4</sub> from deep conventional hydrocarbons, and possibly dissociating CH<sub>4</sub> hydrates; courtesy of C. Ruppel.

## Limnology

Limnological data were collected from the seep sites using a Hydrolab instrument (Table 5).

Table 5. Physical and chemical properties of lake and river water at seep and non-seep sites near Atqasuk.

Date	Site	Depth (m)	temp (°C)	pH	DO (mg/L)	DO (%)	SpC (ms/cm)	redox	salinity
2008-Apr-21	Lake-Q (B1-a)	0.5	-0.3	7.22	1.11-0.99	8.6-7.9	0.22-0.24	228	0.11
2008-Apr-21	Lake-Q (B1-a)	1.7	-0.3	6.94	1.15	11.3	0.16-.22	235	0.08
2008-Apr-21	Lake-Q 200m coring site	1.5	0.06	7.01	1.45	11.8	0.15	2.79	0.07
2008-Apr-23	Amaqaruk (B10)	3.2	0.78						

Water temperatures at the seep and non-seep (Lake Q 200 m coring) sites were near the freezing point of water. The river and lakes were still covered with ice in April, except where active seeps maintained open holes in lake ice. In some places, the open holes were hidden by thick overburden of soft snow and, as such, are a hazard to snow machine travelers.

Other parameters were surprisingly similar between the seep and non-seep site. The pH was slightly more acidic at the bottom of the seep than at the top of the water column. The oxygen content in both sites was low.

### **Thaw bulb determination**

We inserted a galvanized steel pipe to probe the thickness of the thaw bulb at the Lake Q (B1-a) site. At 5.9 m into the sediments, our probe hit an impenetrable layer, which most likely was permafrost. Geophysical measurements would be useful in further determining the thaw bulb dimensions of this lake as well as the subsurface sedimentary and tectonic features.

### **Bucket-hollow test**

One interesting observation made during ice-hole drilling to allow coring of lake bed sediment was that each time a new hole was made, the water level in the existing holes did not immediately rise to a level that would be expected for floating ice. Only after some time did the water approach near the surface. Also, it was noted that the further from the central flow area one drilled, the thicker the ice was, with ice forming to the bottom about 10 m from the center of the seep.

One of the core access holes was expanded to allow passage of a 5-gal plastic bucket, and water was deliberately removed until the water level dropped approximately 16 in. About 225 gal of water had been removed to reach this point. A camera was inserted in the access hole, and several photographs were taken, until it was recognized that the gas in the cavity was likely a combustible mixture in a somewhat confined area, creating a possible safety issue if a spark were generated. This examination revealed that the top of the cavity was dome shaped.

After approximately 75 min, the water level rose to just below the surface of the ice, indicating that water was infiltrating from the unfrozen layer of lake sediments.



Figure 17. In April 2008, engineers Schmid and Johnson drilled through lake ice at regular intervals away from the seep to measure the lake bottom depth and probe for frozen vs. thawed sediments.



Figure 18. Photo showing ice dome at seep center.

**Task 4. Core lake to investigate possibility of establishing a long-term record of seep emission consistency**

The sustainability of harnessing CH<sub>4</sub> from seeps as a source of energy depends to some extent on the duration of CH<sub>4</sub> emissions from seeps. Several related questions arise including the following: Do tundra seeps emit CH<sub>4</sub> over time scales of decades or millennia? Do tundra seeps turn on and off? If so, over what time scales? By looking at the stable carbon isotope ( $\delta^{13}\text{C}$ ) composition of the remains of chironomids (small aquatic insects) preserved in radiocarbon-dated sediment cores from the seep sites, it is possible to determine the time scales and periodicity of CH<sub>4</sub> emissions from the active seeps near Atqasuk (Fig. 19). Chironomids, which are ubiquitous and numerous in lakes, carry a CH<sub>4</sub> signature because they feed on CH<sub>4</sub>-oxidizing bacteria.  $\delta^{13}\text{C}$  analysis of modern chironomids and their chitin-rich head capsules, which are well-preserved in lake sediment cores, have shown that these samples serve as an excellent chemical biomarker of whether CH<sub>4</sub>-derived C formed part of their diets (e.g., Grey 2006; Kankaala *et al.* 2006; Eller *et al.* 2007; Deines *et al.* 2007a,b; Wooller *et al.* 2007). This is because CH<sub>4</sub>

has a negative  $\delta^{13}\text{C}$  signature:  $\delta^{13}\text{C} = -57\text{‰}$  at the Lake Q seep, and as negative as  $-80\text{‰}$  at other lake bubbling sites (Walter *et al.* 2008) relative to plant-derived organic matter in Alaska (e.g.,  $\delta^{13}\text{C} \sim -27\text{‰}$ ; Wooller *et al.* 2007c). Instances where the  $\delta^{13}\text{C}$  of the chironomids is lower than the total organic carbon (TOC) and less than  $-35\text{‰}$ , will be taken to indicate that  $\text{CH}_4$ -derived carbon composed the diet of past chironomids and that  $\text{CH}_4$  was being emitted at the lake sites.

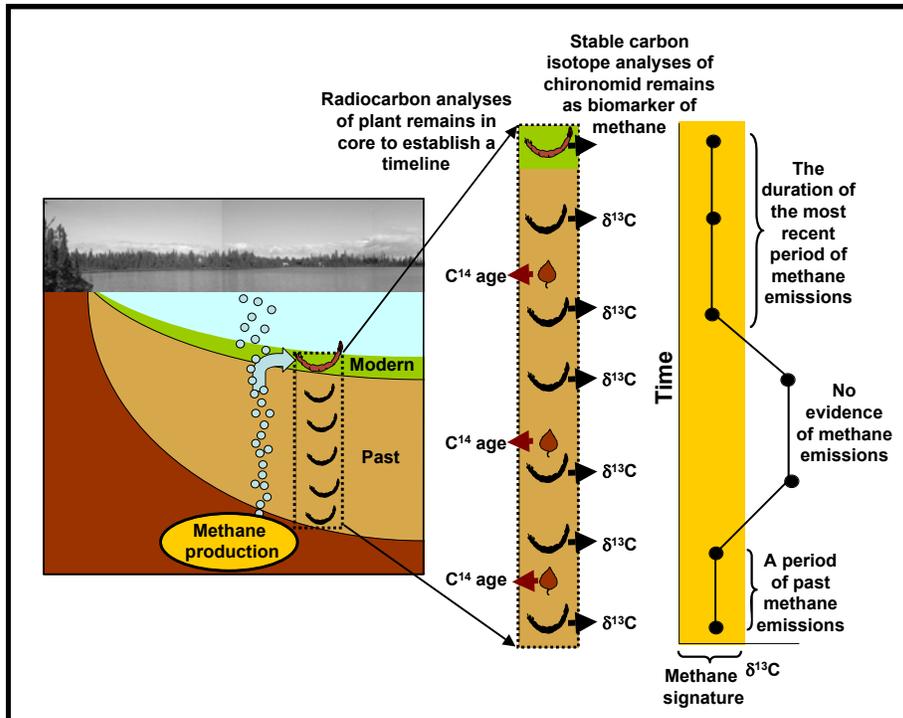


Figure 19. The concept of using the remains of chironomids (aquatic insects) preserved in dated cores of lake sediments to track the long-term duration and consistency of methane emissions from a lake.

In April 2008, we obtained a lake sediment core 200 m away from the seep site to avoid disturbance of anomalous sediment deposition associated with strong seepage. We dated the age of the lake (i.e., its date of formation) using radiocarbon dating (accelerator mass spectrometry [AMS]) of plant and algal remains preserved in the bottom of the core. Plant fossils were removed from samples of the sediment taken from the bottom and top of the core and analyzed for stable isotopes and/or radiocarbon age. Chironomids living at the seep site were collected in January and April 2008 (Fig. 20), and also were

radiocarbon dated using AMS dating. Calibrated dates are presented here in calendar years before present (cal yrs BP), using standard published protocols (Stuiver *et al.* 1998). We did **not** date the remains of aquatic insects preserved in the core, because if CH<sub>4</sub>-derived carbon formed part of the organism's past diet, the organism will have retained the old age of this prior CH<sub>4</sub>. Previous results from sediment taken at sites north of the Brooks Range in Alaska (Oswald *et al.* 2003; Eisner 1991; Eisner and Peterson 1998; Eisner and Colinvaux 1992; Hinkel *et al.* 2003) indicate that simply acquiring a 1m core from our study sites is likely to yield a temporal record >1,000 years, considerably longer than the modern climate data recorded for arctic Alaska. We were pleased to learn that the age of Lake Q, or its date of formation, is **11,500 ± 180** cal yrs BP. This age and the observed stratigraphy seem consistent with other sites in the region (Eisner 1991).

Our data suggest that carbon energy derived from seep methane is being transferred to modern organisms living in the seep environment. Stable C isotope values of modern benthic invertebrates (live chironomid larvae) from the large Lake Q (B1-a) seep, which is known to be emitting methane with a δ<sup>13</sup>C value of -57‰), were as low as -45 per mil. This level is considerably lower than the δ<sup>13</sup>C of the total organic carbon content of the sediment (-30‰) and is in keeping with values that have been taken to indicate consumption of biomass derived from methane oxidation in other lake systems (i.e., Grey *et al.* 2005). Radiocarbon analysis of these **live** chironomid larvae from the same seep also produced a <sup>14</sup>C “age” of **1,760 years**, which supports the role of “old” methane in the diet of these modern benthic invertebrates. A <sup>14</sup>C “age” of 1,300 years has also been recorded for a diving duck that feeds on chironomids in lakes of northern Alaska (Schell 1998, *pers. comm.*). The old age of the lake core and the isotopic results of modern chironomids living at the seep site suggest that there is the potential for preservation of a great (long) temporal record of environmental change and CH<sub>4</sub> emissions from Lake Q.



Figure 20. A hotspot of biological activity at the seep site revealed living midge larvae (chironomids) whose radiocarbon age is 1,700 years! Stable isotopes of chironomids also confirmed that methane is making its way into the food web of these organisms. Researchers pick living chironomids from seep sediments (left). An example of a chironomid is shown (right). Photos by K. Walter.

### ***Task 5. Engineering assessment and demonstration of the development of seep methane for energy use in rural Alaska***

Natural gas is a common fuel in many areas of the U.S., and is currently used for both space heating and electrical power generation. Developing CH<sub>4</sub> from local seeps could be of tremendous benefit to rural residents, replacing extremely expensive diesel fuel (now close to \$6 per gal for residential customers in Atqasuk) with locally available fuel. Some existing examples of tapping CH<sub>4</sub> from local sources for small-scale applications provide models for the Atqasuk project. In the Netherlands, CH<sub>4</sub> has been extracted from groundwater for more than a century and is used for cooking and space heating (Stuurman 2001). This has reduced or eliminated the need for purchasing fuel oil for a number of Dutch farmers. The systems are simple and low-tech, allowing the farmers to maintain their own systems and use the gas very near the well (Fig. 21). The well owner is also the gas consumer, and is thus responsible for all hardware installation and safety.



Figure 21. Dutch farmers dig shallow artesian wells in their yard, through which groundwater, rich in  $\text{CH}_4$  generated from nearby peat bogs, rises to the surface. A sieve is placed at the top of the well casing, causing the water to de-gas as it sprays through the sieve. A heavy metal cap is placed over the top of the well, which allows adequate pressure to build to transport the gas from the wellhead to the house via an inexpensive, low-pressure hose.

The estimated BTU content of  $\text{CH}_4$  produced by the large Lake Q (B1-a) seep is approximately 3–5 MMBTU per day, which may be adequate to heat a modest greenhouse, cultural center, or existing cabins near the lake. Initial calculations and discussions with local gas companies indicate that conventional buried pipe installation would not be economic for a single seep, but perhaps other ways could be devised for this small-scale system. According to the local Fairbanks Natural Gas Company, buried plastic pipe would likely cost approximately \$200,000 per mile to install, or \$1.2 million for the pipe alone. Additionally, since the gas leaving the ground is saturated with water vapor, this could freeze inside the pipe unless removed at the seep site, requiring additional hardware. Also, a compressor would be needed at the lake site to move the gas to town. A simple NPV calculation is included in Appendix A, showing that the value of

the gas is approximately \$157,000, considerably less than the cost of moving the gas to the village. The relatively small quantity of CH<sub>4</sub> available (the single seep of 5,000 ft<sup>3</sup> day<sup>-1</sup>) represents only about 5% of the energy consumed by the electrical generators in the village.

An alternative to tapping the resource at the seep sites may be to drill a test hole adjacent to or within the Atqasuk community itself. It is known that the general area is gas-prone (it is inside the boundaries of the NPRA) and that shallow coal seams exist (the village is located at the site of the Mead River coal mine, a shallow mine used to supply coal to Barrow for whaling ships). Thus it seems likely that the seep may be associated with deeper gas. If this seep can be shown to be related to either coal deposits or a deeper gas source, drilling for gas in or near the village may be feasible. Providing a usable gas utility in the village would require significant additional input for permitting, site selection, exploratory drilling, production well drilling, well completion, and establishing a distribution system.

Further work should more clearly identify the engineering challenges that must be overcome before the Atqasuk community can economically utilize the resource. In addition, optimal resource use should be assessed in terms of technical challenges and economic feasibility based on our work.

### ***Task 6. Education and outreach***

Outreach in the village consisted of a town hall meeting in January 2008 (Fig. 22), and then 2 town hall meetings in April (on the first evening of the field trip) that lasted for 2 hours. Thirty-five village residents, representing more than 10% of the village population, including mayor Jimmy Nayukok, turned out for the meeting. At the April meeting, we discussed results from Walter's January 2008 field work as well as the present trip's research project objectives, and received important feedback including traditional knowledge and questions and interest from the residents. Between 1–5 local residents accompanied our team to the field for each trip.



Figure 22. January 2008 Atqasuk community meeting to discuss the methane seep project (left). April 2008 local residents and UAF student at the Lake Q seep during the gas flare.

In April 2008, we visited the Meade River School of Atqasuk (Fig. 23). Our project team members divided into three groups in separate classrooms and gave demonstrations about our research project. They showed students the methane bubble traps that we use to capture gas, an example of lake sediment cores, aquatic insects and fish from the lakes, videos of the bubbling seeps, and thermal infrared photography for imaging the seeps. Roughly 30 students from junior high and high school grades visited our stations and engaged in the demonstrations. We stayed for lunch with the teachers and students, and continued to demonstrate science materials in the hallways with interested parents and teachers for 2 hours after lunch. It was an enjoyable experience for all.



Figure 23. Melissa Smith (UAF undergraduate student) demonstrating a lake sediment grab sampler for collecting lake bottom organisms from methane seep sites (left); Katey Walter (UAF faculty) introducing a methane bubble trap for capturing and collecting gas in lakes (middle); Tom Johnson (UAF staff) showing digital images to kindergarteners at Meade River School.

## CONCLUSIONS

(1) Flow from the large Lake Q seep was  $\sim 5,000 \text{ ft}^3 \text{ day}^{-1}$ , measured in April 2008, exceeding the approximation from January 2008, when measurements were conducted in extreme cold temperatures ( $-46^\circ\text{C}$ ) and darkness. Seep rates from the Atqasuk seeps are huge in comparison with typical biogenic seeps from other arctic thermokarst lakes. Seven seeps have been measured in the Atqasuk area with an estimated net emission of  $>6,200 \text{ ft}^3 \text{ day}^{-1}$ . Gas is  $>98.5\%$  methane.

(2) At the conclusion of this project, all seeps that have been visited by these investigators are SE of Atqasuk within 30 km of the community. Researchers were thrilled to find so many new methane seeps (up to 10) within the brief 1-hour period of aerial surveys and following a day of ground searching during the preceding year. Local knowledge, based on the experience of igniting methane seeps, suggests that more seeps have been identified NW of Atqasuk. This shows the abundance of methane in the region and suggests a high probability for this resource to occur beneath the town of Atqasuk as well.

(3) The Atqasuk region is known for its coal strata. Coal particles were found near two of the seeps. Isotopic values suggest a mixed biogenic-thermogenic source of methane. It is likely that methane seeps have a coalbed origin.

(5) Methane seeps near Atqasuk are a hotspot for biological activity. Stable isotope and radiocarbon ages of living chironomids (midges), lake sediment organic matter, and seep methane suggest that seep methane is an energy source for the modern organisms. Age determination of the thermokarst lake, Lake Q, where the large seep (B1-a) occurs, of  $11,500 \pm 180 \text{ cal yrs BP}$  suggests that sediments in this lake may be studied for a long record of the consistency and availability of methane from the seep.

(6) The large Lake Q (B1-a) seep could provide enough energy to fuel 5–6 homes or a large community building; however, it is not likely that this seep would provide significant energy for Atqasuk because it is too far away to justify the cost of the pipe. Although the economic value of seep is not likely to justify any infrastructure in town, it

could be used more locally near the seep site. The abundance of seeps near Atqasuk and their high methane content indicate likely drilling success in coal seams near town. Drilling below town might be the best way of supplying the community with natural gas energy.

### **Impacts and Benefits**

The potential impact and benefits of developing methane from seeps near Atqasuk include reducing Atqasuk's consumption of diesel for power generation and home heating (~500,000 gal/yr, current value of \$1.5–\$3 million/yr); and understanding gas resources better, in particular unconventional gas in the NPRA area, with potential larger markets. Also, in terms of climate change, quantifying natural seep contribution to atmospheric CH<sub>4</sub> improves understanding of the global balance between human and natural sources. Use of CH<sub>4</sub> as energy will mitigate climate change, because burning CH<sub>4</sub> converts it to CO<sub>2</sub> and H<sub>2</sub>O, considerably weaker greenhouse gases (IPCC 2007), minimizing the destructive effect of CH<sub>4</sub> in the atmosphere.

### **Publication**

We are targeting publication of results of this study in the *Journal of Geophysical Research (JGR)*, *Biogeosciences*, with a submission goal of March 2009.

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## LIST OF ACRONYMS AND ABBREVIATIONS

AMS	Accelerator mass spectrometry
ANS	Alaskan North Slope
BTU	British thermal unit
C	Carbon
C <sub>1</sub> -C <sub>5</sub> hydrocarbons	Alkanes and alkenes consisting of 1-5 C atoms
<sup>13</sup> C	Stable C isotope, also expressed as <sup>13</sup> C/ <sup>12</sup> C or δ <sup>13</sup> C
<sup>14</sup> C	Radioactive C isotope, also expressed as δ <sup>14</sup> C
CH <sub>4</sub>	Methane
CO <sub>2</sub>	Carbon dioxide
D	Deuterium, stable isotope of Hydrogen, also expressed as D/H or
δD	
GPS	Global positioning system
H	Hydrogen
H <sub>2</sub> S	Hydrogen sulfide
INE	Institute of Northern Engineering
N	Nitrogen
NPRA	National Petroleum Reserve- Alaska
O	Oxygen
UAF	University of Alaska, Fairbanks
WERC	Water and Environmental Research Center (UAF)

## APPENDIX A

### Appendix A Calculation of economic value of methane for Atqasuk from Lake Q Calculation of economic value of methane for Atqasuk

3000	cubic feet per day methane (estimated)
992	BTU per cubic foot for pure methane (estimated) (higher heating value)
2976000	BTU per day
2.976	MMBtu per day
1086.24	MMBtu per year from methane source
239593	Gallons diesel fuel used for power generation in Atqasuk (2006 PCE report)
136000	BTU per gallon, higher heating value
32584.648	MMBtu diesel fuel used per year
3.33%	Fraction of total diesel need in Atqasuk
\$3.23	Cost of diesel fuel in Atqasuk (2006 PCE report)
\$25,798.20	Total value of diesel fuel displaced by methane source

#### Calculation of flow rates

3000	cubic feet / day (estimated)
20	gallon garbage bag
0.13367	cubic feet per gallon
2.6734	Cubic feet per bag
2.083333333	Calculated rate of flow in cubic feet per minute
1.283232	Minutes needed to fill garbage bag
76.99392	Seconds to fill garbage bag

#### Total carbon flow

3000	cubic feet per day methane (estimated)
28.31	liters per cubic ft
22.4	liters per mole
3791.517857	moles per day
16	grams per mole
60.66428571	Kg methane per day
0.75	Carbon weight in Methane
45.49821429	Kg carbon per day
16606.84821	Kg carbon per year

#### Water in gas calculations

3000	cubic feet per day methane (estimated)
3305	cubic feet per pound of water at 32 F
0.907715582	Pounds per day water vapor number of days below freezing
200	freezing
181.54	pounds of water that can freeze in lines

Energy use per household

3068257	Total kW-hrs sold in Atqasuk
0.8	Fraction to households
2454605.6	Total kW-hrs sold to households
57	Households in Atqasuk
43063.25614	Annual household electrical consumption
3588.604678	Monthly household electrical consumption

Conversion of velocity measured to flow rate

0.78	Square inches pipe diameter
2	meter / sec measured flow rate
39	Inches per meter
78	inches
60.84	Cubic inches per second
1728	Cubic inches per ft <sup>3</sup>
3650.4	Cubic inches per minute
2.1125	Cubic Feet per minute
1440	Minutes per day
3042	Cubic feet per day

Diesel plant calculations

\$3.23	Cost of diesel fuel per gallon
95	Number of Kw-hrs per household per day
58	Number of households in the village
\$1,000	Cost of diesel plant, per installed kW
6.00%	Cost of capital in percent
5	Years expected lifetime of diesel plant
20.00%	O&M cost, % of investment per year
3	Peak factor, above average electrical usage
14.17	kW-hrs per gallon
2.00%	Diesel price annual increase
1.00%	Load increase

2011150	Total kW-hr generated per year
229.5833333	Average load on generator
688.75	Total generator size
\$688,750	Cost of diesel generator (installed)
\$163,506.77	Cost of diesel generator capital per year
\$32,701.35	Estimated O&M

141930	Total gallons of diesel fuel
\$458,434.33	Cost of diesel fuel per year
\$654,642.46	Total cost of diesel plant per year
\$0.33	Cost of electricity for existing diesel plant

Diesel plus Lake Q gas

\$3.23	Cost of diesel fuel per gallon
95	Number of Kw-hrs per household per day
58	Number of households in the village
\$1,000	Cost of diesel plant, per installed kW
6.00%	Cost of capital in percent
5	Years expected lifetime of diesel plant
20.00%	O&M cost, % of investment per year
3	Peak factor, above average electrical usage
14.60824742	kW-hrs per gallon (This is how you add renewables)

\$157,746	Capital of renewable
6.00%	Cost of Capital, in percent
20	Years expected lifetime
\$13,753.03	Annual capital cost
8.00%	O&M, % of capital cost
\$14,853.27	Total annual cost of renewable system

2011150	Total kW-hr generated per year
229.5833333	Average load on generator
688.75	Total generator size
\$688,750	Cost of diesel generator (installed)
\$163,506.77	Cost of diesel generator capital per year
\$32,701.35	Estimated O&M
137672.2301	Total gallons of diesel fuel
\$444,681.30	Cost of diesel fuel per year
\$655,742.70	Total cost of diesel plant per year
\$0.33	Cost of electricity

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