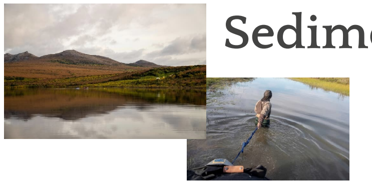

Sediment characteristics and economic potential of large methane seeps in Esieh Lake, NW Alaska

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Abstract

My thesis evaluates lake sediment characteristics and how they have been affected as large geologic methane (CH4) seeps formed in Esieh Lake (informal name), a lake in Northwest Alaska. I provide extensive background of the lake, including a synthesis of studies and reports that characterize the geology around this lake which, to date, contains the largest known CH4 seeps in the Arctic. In addition to providing background information on Esieh Lake and characterizing the lake's sediments, I evaluate the economic potential for the CH4 seeps and compare flux values to natural gas projects which were previously completed in Alaska and Canada. The evidence suggests the possibility that CH4 seeps initiated in Esieh Lake sometime within the last century via an explosive event that formed large pockmarks in the lake bottom. Rapid expansion of the seep field occurred between 1952 and 1972. Seepage continued after the blowout event and is still present today, albeit at a more quiescent stage. An economic evaluation of the seep as an energy source found that the capital cost for infrastructure to transport gas to a nearby community resulted in high energy costs, higher than the current cost of electricity in Noatak from imported diesel. However, if infrastructure capital costs were not a factor, then the cost of electricity for Noatak using Esieh Lake seepage as natural gas, would be much lower that current electricity costs. Through existing technologies, Esieh Lake is not economically viable as a resource but as technology progresses, developing a very small-scale gas resource may become a viable option.

Introduction

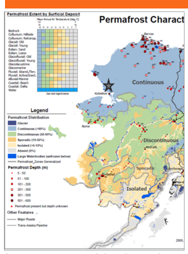


Figure 1: Jorgensen et al. (2008) permafrost map of Alaska. Esieh Lake location is designated by a grey star.

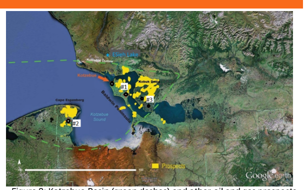


Figure 2: Kotzebue Basin (green dashes) and other oil and gas prospects relative to Esieh Lake (blue star north of basin).

Figure 3: Aerial view of Esieh Lake's open ice, indicators of year-round gas emissions. Photo by Janelle Sharp.

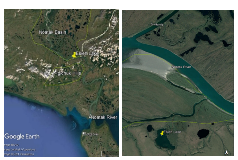


Figure 4: Esieh Lake's location relative to Noatak Basin (A) and the Noatak River (B).

Permafrost in the Arctic is a significant topic due to its potential to release large amounts of carbon into the atmosphere as it thaws. Both biotic and abiotic methane (CH_4) are released from permafrost-related traps, including cryosphere caps and terrestrial CH_4 hydrate. In aquatic environments, gas release is visible through bubbles known as seeps, which can be sampled to determine carbon sources and hydrocarbon concentrations. These seeps might provide energy to nearby rural communities, offsetting energy costs.

In 2016, a community outreach program coordinated by NANA Regional Corporation investigated possible oil and gas shows in the NANA Region. Community members provided locations and notes, which were used to analyze satellite imagery and identify methane seeps. Aerial surveys confirmed these locations, and ground truthing prioritized areas like Esieh Lake (figures 2, 3, and 4), where large seeps kept the ice open year-round (figure 3). Historically, the region's oil and gas potential has been of interest, with assessments identifying prospects in the Kotzebue Basin (figure 2). Additionally, recent geophysical studies funded by NANA aimed to explore development potential in the Kobuk Delta.

Methodology

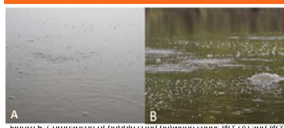


Figure 5: Comparison of bubble sized between seeps W1 (A) and W2 (B). W1's seeps, while covering a larger surface area of the lake, were much smaller than those at W2.

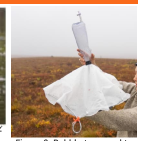


Figure 6: Bubble trap used to test for flammable gas.

To reach Esieh Lake for each field event, we took a charter boat from Kotzebue up the Noatak River. Depending on water levels, the boat was able to bring us to the lake shore, or we has a "field hand" help us haul gear. Zodiacs and pack rafts were used during each event. The first field event in fall 2017 involved paddling to seeps identified via remote sensing. The initial seep, named W1 for "Wow 1," had soap sud-sized bubbles, while the second, W2, had much larger, boiling-like bubbles (figure 5). Later investigations used a fish-finder to map the bathymetry of the lake.

To initially determine if the seeps possibly emitted methane, a plastic tent-like trap (figure 6) was used to collect gas, which was then tested with an open flame. The gas ignited, confirming flammable gas presence, and was sampled for isotopic analysis. In later seasons, Dr. Frederic Thalasso used a mobile dynamic chamber to measure methane flux around the lake (figures 7 and 8), finding variable emissions but constant ebullition at W1 and W2.

The thaw channel was mapped by Sullivan, et al. (2021) using TEM and Ground Penetrating Radar transects.

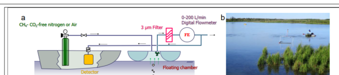


Figure 36. Methane flux measurements made with a mobile dynamic chamber. Panel a is a schematic of the method; panel b is a photograph of Frederic Thalasso conducting the measurements in the W2 gas field in August 2018. Photo: Katey Walter Anthony.

Figure 8: Dr. Thalasso and Philip Hanke measuring methane flux across lake surface in August, 2018.

Results

Site	Sampe ID	CH_4	CO_2	O_2	N_2	$\delta^{13}C$-CH_4	stdev	δD-CH_4	stdev	Radiocarbon Age	Age Err
		%	%	%	%	‰	‰	‰	‰	Yrs BP	
W1	KW1159.1	72.9	0.0	5.1	20.8	-72.68	0.180	-287.77	0.254	49,500	1,200
W2	KW1160.1	83.4	0.0	2.7	13.4	-70.77	0.484	-289.71	1.966	> 52,000	1,900

Table 1: Esieh Lake seeps W1 and W2 gas composition values, stable isotope values, and radiocarbon ages (Walter Anthony et al., 2019).

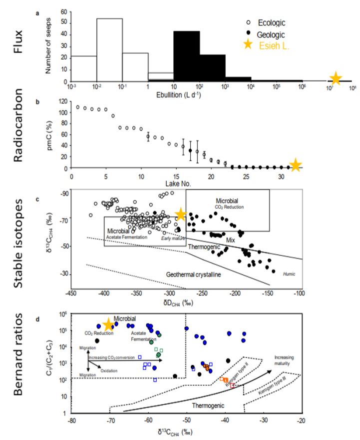


Figure 9: Esieh Lake flux (a), radiocarbon signature (b), stable isotopes (c), and Bernard ratios (d) compared to other lakes, studied by Walter Anthony et al. (2019), in Alaska.

Table 12. Esieh Lake CH_4 emissions estimated using a mobile dynamic chamber.

	All lake	W1	W2	Beaver	Rest of the lake
Area (m^2)	85141	14578	5241	1224	64099
% Total Area	100.00%	17.12%	6.16%	1.44%	75.29%
Mean flux ($g/m^2.d$)	128	218	1,238	314	13
Std. Dev.	558	441	1,711	218	108.404
Min flux	0.000	0.000	0.000	0.104	0
Max flux	23,721	6,689	23,721	988	366
Total emission (T/d)	10.88	3.18	6.49	0.38	0.83
% Total emission	100.0%	29.2%	59.6%	3.5%	7.6%

Lab analysis revealed that methane (CH_4) is the dominant component of the ebullition at both seeps in Esieh Lake (table 1). Compared to other lakes studied by Katey Walter Anthony, Esieh Lake's flux values are at the top of the range, surpassing both geologic and ecologic seeps (figure 9, Walter Anthony et al. 2019). Stable isotope values and radiocarbon ages suggest the gas originates from fossil microbial sources, possibly from coal beds or other fossil sedimentary deposits (Walter Anthony et al. 2019). Thalasso et al. (2020) measurements indicate Esieh Lake has the highest methane emissions ever recorded from natural gas seeps in the Arctic, at 10.9 tons CH_4 per day, equivalent to 506 Metric Million British Thermal Units per day, or 3,641.84 gallons of diesel per day.

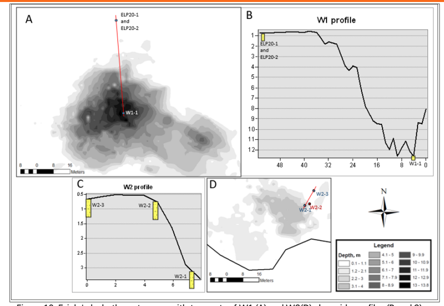


Figure 10: Esieh Lake bathymetry map with transects of W1 (A) and W2(D) alongside profiles (B and C) which show depth of each seep and compare sediment columns collected for each seep.

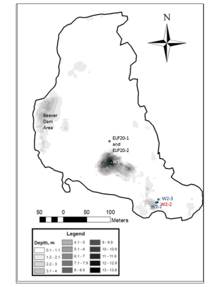


Figure 11: Esieh Lake bathymetry map and sediment core locations.

Geophysical studies at Esieh Lake included TEM and Ground Penetrating Radar (GPR) transects, which revealed that sub-permafrost gas seepage is linked to a thaw bulb. Methane is released from a sub-permafrost trap, resulting in strong, continuous flux at seep locations W1 (maximum depth of 13.8 m, figure 10 A and B, and figure 11) and W2 (maximum depth 3.4 m, figure 10 C and D, and figure 11). GPR data showed sediment rims around the seeps (figure 10 B and C), indicating material accumulation and ejection, possibly from a sudden seep initiation. Sediment cores (figure 10, B and C) from these rims were analyzed to date the initial ejection and identify periods of flux changes, but dating was unsuccessful. However, bulk identifiers (figure 12) suggest possible correlations between sediment layers and flux changes over time.

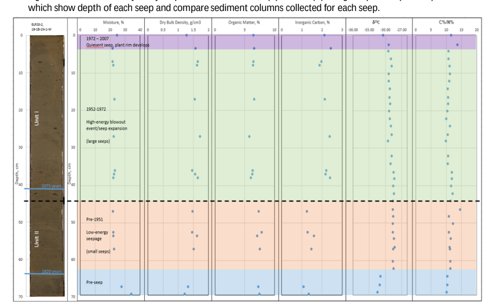


Figure 12: Sediment core ELP20-2, taken from the edge of W1, show sharp changes in bulk identifiers within Unit II (70.3-65 cm, highlighted in blue) and possibly indicate the lake's state before seepage began. Increased δ13C during the transition from pre-seep to seepage (blue to orange) suggests a shift from macrophyte-dominated inputs to terrestrial carbon mixing and redeposition during seep formation. Trash layers with woody terrestrial carbon, enriched in δ13C, were disturbed, mixed, and redeposited during gas eruption and pockmark formation. Radiocarbon ages of woody material from W1's pockmark support this. Increased CMM between orange and green transitions is attributed to pockmark formation and sediment expulsion, mobilizing carbonate-rich minerals from beneath Esieh Lake. Higher CMM concentrations in W2 pockmark sediment near the lake edge and an active thermokarst slump suggest additional erosion and deposition of carbonate-rich sediments. Future research should include more age dating and quantitative grain-size analysis to test the discharge-energy interpretation.

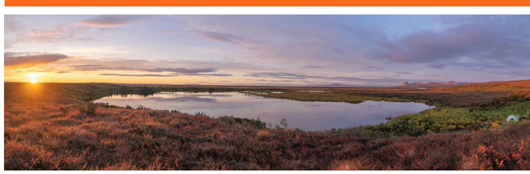
	Energy Needs/yr	Opex/yr	Capital cost	$/KwH in Noatak
Noatak	1,470,226.39 kW-hr	--	--	$0.91
Esieh Lake with Capex*	--	$3 MM/year	$75 MM*	$7.55

	Energy Needs/yr	Opex/yr	Capital cost	$/KwH in Noatak
Esieh with Capex paid by grants	--	$3 MM/year	$80,000	$2.11

Table 3: Economic evaluation of the cost to integrate a natural gas system for Noatak, Alasksa. *Capital cost includes well and a 25-mile pipeline.

Despite substantial CH4 concentrations and high flux values, development is limited by the site's remote location, 30 km northwest of the nearest community, making it uneconomical for the NANA Region. The total annual capital cost to develop infrastructure for natural gas over 10 years is $11,085,030 per year, resulting in an electricity cost of $7.55 per kWh, much higher than the $0.91 per kWh for diesel in Noatak, AK (table 3). With federal grants, the cost could drop to $2.11 per kWh. Capture and transport methods would need to be developed to remove moisture, condense, and store gas at or near the site, then transport it by small-scale boat or ice road. The community would need to convert its energy sources to natural gas and remain flexible in case the gas supply depletes.

Conclusion



Esieh Lake is the largest known methane seep in the Arctic, releasing 10.9 tons of CH_4 per day. Seep W2, closer to the lake shore, emits larger amounts of methane compared to the deeper seep W1. Geophysical studies indicate a through-going talik has created a channel-like release mechanism for deep-sourced methane, likely from coal decomposition in the Kotzebue Basin. However, the exact location and quantity of remaining methane, as well as the initiation date of the seep, remain unknown. Historical imagery shows the seepage expanded significantly between 1952 and 1972 before stabilizing.

While Esieh Lake is not currently a viable economic energy source through traditional methods, future technological advances could enable the harnessing of methane emissions for local community use. The work at Esieh Lake enhances our understanding of terrestrial methane seeps, highlighting the potential for small-scale energy development. As permafrost dynamics continue to change, new seeps may emerge, offering opportunities for innovative energy solutions. For the NANA Region, future technologies could transform Esieh Lake into a valuable resource.

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