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כ"ד ל"ב כ"ד

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Identifying Putative Microbial Drivers of Methane Flux on Earth and Mars
 Methane plays a critical role in climate change on Earth and observations of methane on Mars may suggest the presence of life. Understanding the relationship between subsurface microorganisms and methane in the Arctic will help predict the influence of climate change on methane concentrations in permafrost environments and inform our understanding of methane on Mars. The following are required to assess methane-microbe relationships: i) diversity and metabolic potential; ii) physical architecture and spatial relationships between microorganisms and minerals, organic substances, and elements; iii) geochemical parameters of the environment. We will investigate three environments on Axel Heiberg Island: i) hypersaline cold spring hosted methane seeps (Colour Peak, Gypsum, and Wolf springs); ii) cryosols from polygonal terrain known to be both methane sources and sinks; and iii) glacial ice not known to be associated with methane release (Crown and White glaciers). We will test 4 prototype spectroscopy instruments to assess near surface methane in the atmosphere as well as mapping of organic molecules, minerals, and elements. Physical samples will also be acquired to assess the microbial community diversity and environmental geochemistry. Testing this instrumentation help with monitoring of remote ecosystems sensitive to environmental change and is also a crucial step in developing this instrumentation for future Mars missions.

- Can new spectroscopy instruments be used to detect methane emissions from natural methane seeps and map organics, minerals, and elements?
- What is the subsurface microbial community structure and near surface methane profile in each environment?
- Are subsurface microbial communities capable of oxidizing methane and how do they influence methane cycling?

Objective 1: Characterize the subsurface sediment-hosted microbial communities and their capacity for active methane oxidation demonstrating their significance to methane cycling.
Objective 2: Characterize the near surface methane establishing a local record of methane flux linked to microbial methane oxidation rates.

Field research (26/06/2023 – 31/07/2023) with active on Axel Heiberg Island based out of the McGill Arc3c Research Station (July 2 – 19). A pump will draw atmospheric samples into the methane spectrometer. The mapping spectroscopy instruments use non-destructive LEDs. The spectroscopy instruments pose no environmental hazards or risks. Manual scooping and sediment push cores (30-50 cm) will be used to collect <5 L of sediment. Manual syringes will be used to collect <2 L / spring of water from each site. Given the water refresh rate and seasonal re-modelling, no environmental damage or risk is anticipated. Hand coring will collect <3 meters of ice core and <1.5 m of cryosol. Given the low volumes and the summer glacial surface melt, no environmental damage or risk is anticipated. All instruments will operate using Li-ion batteries. Atmospheric, geochemical, and biological data will be stored on university servers, available on request. Published data will be publicly available through GitHub repositories or long-term databases such as NCBI. As funding for the project advances, we plan to hire local wilderness guides in addition to developing bi-directional outreach initiatives to share our science results with the Hamlet of Resolute Bay and other Nunavut residents through engaging with local SAO offices.

DΔΛNOC: French translation of description is only necessary if the affected community includes the City of Iqaluit.

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Personnel

Personnel on site: 2

Days on site: 18

Total Person days: 36

Operations Phase: from 2023-06-28 to 2023-07-21

$$\Lambda \subset \mathbb{N} \triangleleft \mathbb{N} \xrightarrow{\gamma} \sigma \triangleleft \mathbb{N}^b \supset \mathbb{C}$$
[illegible]

(staging, logistics base)			contains an operations building, the Martin Bergmann complex, and the Roy M. 'Fitz' Koerner Laboratory.		
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Information is not available			

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North Baffin

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Project transportation types

Transportation Type	ግብርናዊ ምርጫ ማሳሰቢያ ለጋራ ልማት ምርጫ ለጋራ ልማት ምርጫ ለጋራ ልማት ምርጫ ለጋራ ልማት ምርጫ	Length of Use
Air	Twin Otter charters (de Havilland Canada DHC-6 Twin Otter aircraft of Kenn Borek Air Ltd) from PCSP (Polar Continental Shelf Program, Resolute Bay) to MARS , helicopter charters (logistical support request submitted to PSCP) from MARS to sample sites	
Land	Hiking transport from MARS to gypsum Hill springs, and Crown Glacier	

Project accomodation types

Permanent Camp

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Λ⁵δ^c δ^aΓ²ξ^b δ²ξ^bCDσδ⁴γ⁵ξ^b Δ^cξ^bΓ²Π³Γ^c Δ^jCD^c, Γ^cδ²Q²Π^c, ξ^bξ^cLC^jξ^b, με^cΓ²δ^c δ^aΓ²Γ^cδ^a

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OA-ICOS spectrometer	1	33.96 cm (L) x 22.45 cm (W) x 10.18 cm (H)	ABB Inc. GLA131 series microportable methane gas analyzer. This non-destructive spectroscopy instrument will be used to measure atmosphere methane concentrations near the surfaces at the indicated sampling sites. OA-ICOS (Off axis integrated cavity output spectrometer). The analyzer poses no electrical hazards and contains a class 1 laser protected with interlocks (laser cannot engage while instrument case is open. There is no stray laser light outside the instrument when engaged)
Jackery 500 Li-ion power station	1	30 x 19.2 x 24.2 cm	The Jackery power station (model Explorer 500) will be used to power the spectroscopy instruments during sampling. It will be recharged at the McGill Arctic Research Station. The power station has a capacity of 518.4 Wh (24Ah/21.6V). The power station will be transported back to PCSP following field use.
Mini drone	1	140x82x57 mm Folded 160x202x55mm Unfolded	DJI Mini SE Quadcopter Drone will be used to take arial photographs of the sampling sites on Axel Heiberg Is. The drone will not be used on Cornwallis Is. All drone flights will be undertaken in accordance with protocols at the McGill Arctic Research Station respecting all rules and regulations. Although this drone is under the weight limit requiring a licence (<249 g), all operators will have basics operations drone licence through Transport Canada.
sonic Anemometer	1	60.64 x 12.2 x 43.0 cm	The sonic anemometer is used to take measurements of windspeed and direction. It is a passive, non-destructive instrument.
Kovacs Mark II corer	1	7.25 cm x 1 m	Ice and cryosol cores will be acquired using a Kovacs Mark II corer (7.25 cm diameter) down to 50 cm. Cores are obtained manually by rotating the corer with a lever arm.
Multi-band spectral imager	1	10 cm x 7 cm x 8 cm	Multi-band spectral imager incorporating ultraviolet and visible multi-excitation and UV-VIS-NIR emission imaging to spatially detect and characterize organic matter (protein-like, humic-like, and pigments); determine coarse mineralogy;

			and detect select rare-earth elements. The imager will be deployed 75 mm above natural unprepared surfaces (e.g. rocks, ice). Data acquisition is non-invasive, using optical methods, with approximately 30 minutes required per acquisition.
Microscopic ultraviolet imager	1	20 cm x 20 cm x 40 cm	In situ microscopic ultraviolet imager incorporating simultaneous multi-spectral imaging for in situ excitation-emission spectroscopy. The UV microscopic imager will be placed on natural unprepared or sampled surfaces, and uses optical non-invasive methods to assess the presence and distribution of organic matter at 10s of microns spatial scales.
Down-hole probe	1	20 cm x 20 cm x 40 cm	The down-hole miniature probe will map and contextualize organic matter in the near subsurface down to a 20 cm depth using optical methods. The probe will be deployed in holes created by the Kovacs corer, and operated using a laptop computer.
lithium ion battery	4	19.5 x 14 x 2.6 cm	Goal zero sherpa 100 AV Power banks (94.7 Wh). One sherpa power bank will be used for emergency back up power for instruments, cameras, phones while at field sites. An additional 3 power banks will be used for powering the three in situ spectroscopy instruments in the field. All will be charged at the McGill Arctic Research Station and will be transported back to PCSP following field use.
push core (short)	1	7 x 30 cm	A cylindrical polypropylene push core tube will be used to take sediment samples within the springs. The core tube will be manually pushed into the sediment to a depth of ~ 30 cm.
push core (long)	1	7 cm x 50 cm	A cylindrical polypropylene push core tube will be used to take sediment samples within the springs. The core tube will be manually pushed into the sediment to a depth of ~ 50 cm.

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Other	fuel	0	0	0	Cubic ft	No additional fuel other than the fuel already cached and accounted for at the McGill Arctic Research Station will be used. All MARS fuel cached is accounted for in the MARS NIRB and associated licenses.
bleach	hazardous	1	5	5	Liters	for disinfecting equipment and laboratory space at MARS during biological sample

						processing. The capacity is 0.5 L, however the container capacity will not accept a decimal and millilitres is not an option for units of measure.
ethanol	hazardous	1	1	1	Liters	100% not denatured ethanol will be mixed with purified water to created 70% ethanol for disinfecting tools and laboratory space during biological sampling and sample processing.
BaCl ₂	hazardous	1	40	40	Liters	Barium chloride will be used to preserve samples for downstream measurement of sulfate concentrations using ICPMS in collaboration with the California Institute of Technology. The capacity is 40 mL, however the container capacity will not accept a decimal and millilitres is not an option for units of measure.
Zinc Acetate	hazardous	1	40	40	Liters	0.5 M Zinc Acetate will be used to preserve samples for downstream measurement of sulfide in collaboration with the California Institute of Technology. The capacity is 40 mL, however the container capacity will not accept a decimal and millilitres is not an option for units of measure.
bromobimane	hazardous	1	20	20	Liters	30 mM bromobimane will be used to preserved samples for downstream measurement of sulfur species in collaboration with the California Institute of Technology. The capacity is 20 mL, however the container capacity will not accept a decimal and millilitres is not an option for units of measure.
methansulfonic acid	hazardous	1	40	40	Liters	65 mM methansulfonic acid will be used with the bromobimane reagent to preserve samples for downstream measurement of sulfer species in collaboration with the California Institute of Technology. The capacity is 40 mL, however the container capacity will not accept a decimal and millilitres is not an option for units of measure
phosphoric acid	hazardous	1	10	10	Liters	45% phosphoric acid will be used to acidify samples for downstream measurement of dissolved inorganic carbon in collaboration with the California Institute of Technology. The capacity is 10 mL, however the container capacity will not accept a decimal and millilitres is not an option for units of measure
ferrozine reagent	hazardous	1	20	20	Liters	Ferrozine reagent (2 mM ferrozine dissolved in 6.5M ammonium acetate in 1N HCl) will be used to preserve samples for downstream measurement of iron species in collaboration with the California Institute of Technology. The capacity is 20 mL, however the container capacity will not accept a decimal and millilitres is not an option for units of measure
Lifeguard	hazardous	1	1	1	Liters	lifeguard (https://www.qiagen.com/us/products/discovery-and-translational-research/sample-collection-stabilization/rna/lifeguard-soil-preservation/) will be used to preserve samples for DNA extraction in Collaboration with the California Institute of technology.
paraformaldehyde	hazardous	1	40	40	Liters	paraformaldehyde will be used for fixing samples for microscopy and nucleic acid extraction in collaboration with the California

						Institute of Technology. The capacity is 40 mL, however the container capacity will not accept a decimal and millilitres is not an option for units of measure.
sodium hydroxide	hazardous	1	200	200	Liters	5M sodium hydroxide will be used to adjust the pH of non-hazardous buffer solutions for biological sample preparation as well as make pH standards to measure the pH of samples. The capacity is 200 mL, however the container capacity will not accept a decimal and millilitres is not an option for units of measure.

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0	Water will be retrieved by gas generator powered pumps at the MARS under NWB permit # 8WLC-MGU2324 held by MARS	Water will be retrieved from Colour Lake, McGill Arctic Research Station (MARS), Expedition Fjord, Axel Heiberg Island, Nunavut .

$$\Delta^b C d \subset \mu \sigma \Delta^a \sigma^a$$

$\Delta^{\circ} \text{G}_{\text{f}}^{\circ}(\text{C}_6\text{H}_6) = -123.4 \text{ kJ mol}^{-1}$

There is no environmental risk or impact predicted by the proposed studies. The spectroscopy instruments pose no environmental hazards or risks. Sediment cores: Sediment cores will be acquired using 30 cm or 50 cm polypropylene tubes that will be manually pushed into the sediment within the spring sites. Pore water will be extracted from the sediment in the core tube. Sediment will be subsected. As a result of the seasonal filling and re-modelling of the springs, no long term damage or environmental risk is expected. Cryosol cores: Cryosol cores will be collected using a Kovacs Mark II corer (7.25 cm diameter) down to 50 cm. Cores will be extracted from the borehole and imaged with non-destructive spectrometers. All three instruments acquire non-invasive measurements. No long term damage or environmental risk is anticipated due to the small sample size. Ice cores: Ice cores will be acquired using a Kovacs Mark II corer (7.25 cm diameter) down to 50 cm. Cores will be extracted from the borehole and imaged non-destructive spectrometers. All instruments acquire non-invasive measurements. Given the low volumes and the summer glacial surface melt, no environmental damage or risk is anticipated. Atmospheric samples: An Off-axis integrated cavity output spectrometer (OA-ICOS) will use a lithium ion battery to power an internal pump to draw air into the internal analytical chamber where a class 1 laser will analyze methane and carbon dioxide concentrations. The air is then passively released. Interlocks prevent the laser from engaging unless the instrument is sealed. There is no stray laser light when the instrument is sealed. The non-destructive nature of the instrument prevents any environmental risk or damage.

Additional Information

SECTION A1: Project Info

SECTION A2: Allweather Road

SECTION A3: Winter Road

SECTION B1: Project Info

SECTION B2: Exploration Activity

SECTION B3: Geosciences

SECTION B4: Drilling

SECTION B5: Stripping

SECTION B6: Underground Activity

SECTION B7: Waste Rock

SECTION B8: Stockpiles

SECTION B9: Mine Development

SECTION B10: Geology

SECTION B11: Mine

SECTION B12: Mill

SECTION C1: Pits

SECTION D1: Facility

SECTION D2: Facility Construction

SECTION D3: Facility Operation

SECTION D4: Vessel Use

SECTION E1: Offshore Survey

SECTION E2: Nearshore Survey

SECTION E3: Vessel Use

SECTION F1: Site Cleanup

SECTION G1: Well Authorization

SECTION G2: Onland Exploration

SECTION G3: Offshore Exploration

SECTION G4: Rig

SECTION H1: Vessel Use

SECTION I1: Municipal Development

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The proposed sampling sites are not proximal to protected environments (i - xi) or other protected areas. By nature of the delicate permafrost environment (continuous, ~600m thick) and receding glaciers, the study sites may be considered a general sensitive area. There will be no infrastructure required for the proposed project outside of the use of the existing facilities at the McGill Arctic Research Station (MARS). Unique landscapes under study include 3 hypersaline perennial cold spring methane seeps (Colour Spring, Gypsum Springs, and Wolf Spring, also known as Lost Hammer Spring). Subpermafrost groundwater flow through carboniferous evaporites in areas of diapiric uplift feed these springs. While a definitive water source for these springs is unknown, multiple sources have been proposed including recharge from Colour Lake, and sub-surface saline brines from the extensive subsurface and surficial diapirism in the Expedition Fjord area. The differing geochemistry of the spring suggests multiple hydrogeological sources. Two Glacier sites, White and Crown Glacier are also proposed. Colour Lake, proximal to MARS provides fresh water and may comprise a potential recharge source for the springs. Additional information from Pollard, W., Haltigin, T., Whyte, L., Niederberger, T., Andersen, D., Omelon, C., Nadeau, J., Ecclestone, M., and Lebeuf, M. 2009. Overview of analogue science activities at the McGill Arctic Research Station, Axel Heiberg Island, Canadian High Arctic. *Planetary and Space Science* 57: 646-659; Climate: Polar desert conditions characterized by cold, dry winters and cool summers are predominant in the region. The nearest long-term meteorological records are from Eureka, which reveal a mean annual air temperature (MAAT) of -19.7°C , mean monthly temperatures of -36.1°C and $+5.4^{\circ}\text{C}$ for January and July, respectively, and minimum air temperatures frequently reaching -55°C . Periodic meteorological records are available for Expedition Fjord over the past 47 years, with a more complete record for Colour Lake available since 1992 displaying a MAAT of -15.5°C (Andersen et al., 2008). Recent data from a broader network of automatic weather stations for the Expedition Fjord area indicate MAAT's as much 2–3 $^{\circ}\text{C}$ cooler than the Colour Lake site depending on setting. Annual precipitation at Eureka consists of approximately 64 mm total, of which 60% falls as snow (Pollard and Bell, 1998). Though long-term precipitation values are not available for Expedition Fjord, it is assumed that the totals are somewhat greater than those measured at Eureka likely due to a rain shadow effect caused by the mountain range on the eastern Axel Heiberg Island that blocks precipitation systems from reaching Ellesmere Island (Edlund and Alt, 1989). Earlier research near Expedition Fjord suggests a mean annual accumulation of 371 mm of water equivalent on the nearby Mueller ice cap (Muller 1963). Geology: Axel Heiberg Island is situated within the Sverdrup Basin (Hoën, 1964; Thorsteinsson and Tozier, 1970), a northeasterly striking sedimentary trough covering an area of approximately 3,13,000 km² (Pollard et al., 1999). Near the head of Expedition Fjord, where the M.A.R.S. camp is located, peaks rise to a maximum of approximately 2000 m ASL. Asymmetrical ridges resulting from breached anticlines are characterized by steep scarp faces angled 70–80° and dip slopes of 25–35°. Though piercement structures can create somewhat regular and symmetrical slope features, the area is dominated by 'serrated' profiles resulting from gypsum weathering and anhydrite outcrops along with resistant volcanic sills and dikes. The island is characterized by a series of evaporite diapirs that have been revealed by erosion over the past tens of thousands of years. The diapirs were formed by the upward intrusion of Upper Paleozoic evaporites and often appear as large domed structures cored by rock salt (Stephenson et al., 1992). The Carboniferous evaporites are comprised of an upper anhydrite layer up to 500 m thick with limestone interbeds overlying a lower layer of rock salt (Stephenson et al., 1992). Seven perennial spring sites have been identified on Axel Heiberg Island (Pollard et al., 1999; Andersen et al., 2008). The discharge temperatures are between -4 and $+12^{\circ}\text{C}$ and flow rates vary from <1 to 30–40 l/s. Discharge is typically mineralized with varying amounts of dissolved salts that depress their freezing temperature. The springs derive their dissolved salts from the underlying evaporates and their location most often can be linked to a nearby diapir. Permafrost/geomorphology: Permafrost is defined as any ground material that stays below 0°C for at least two consecutive years (van Everdingen, 2002). The depth of permafrost at the M.A.R.S. camp is estimated to be 400–500 m based on surface temperature and regional heat flow patterns. Approximately 60 km from M.A.R.S., the thickness of permafrost observed in an exploration well (oil and gas) was greater than 400 m, a value consistent with other exploration wells in the region that revealed permafrost depths 400–600 m (Taylor and Judge, 1976). The thin seasonally thawed active layer atop the permafrost typically measures 40–60 cm in thickness. Quaternary sediments of fluvial, deltaic, marine, and glacial origins comprise the surficial deposits, with tussock microtopography dominating lower wet areas and poorly sorted circles and stripes evident at mid-elevations while bedrock dominates higher elevations. Several characteristic permafrost landforms are widespread throughout the region, including several small pingos at Middle Fjord, icing blisters and mounds in the Expedition River floodplain, and extensive polygonal terrain and ice wedge development in fluvial and colluvial deposits. Ground ice is also widespread with ice bonded permafrost occurring in unconsolidated materials, buried glacier ice occurring in most moraines, and bodies of intrasedimental ice occurring beneath fine-grained marine deposits.

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The project has no predicted impacts on endemic species or habitats. The microbial community of the springs is dominantly sustained by chemolithoautotrophic primary production performed by sulfur-oxidizing bacteria consistent with sub-surface microbial communities. Of interest is recent data suggesting that archaea known to oxidize methane in the subsurface in the absence of oxygen may be present in the spring sediments of Wolf Spring. Our proposed work is aimed at confirming the microbial community's ability to oxidize methane. From personal documentation during the 2023 summer field season, the area of study appears to be comprised of diverse microhabitats with numerous arthropod species, insects including pollinating bees, an abundance of lichens, willow, and Arctic wildflowers. Wildlife known to be in the area from previous research trips include, muskox, Arctic fox, Arctic hare, ermines, and in coastal areas, the possibility of polar bears. Birds include Snow buntings, long-tailed Jaegers, and rock Ptarmigans.

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There are no current settlements or residents on Axel Heiberg Island.

Miscellaneous Project Information

It is anticipated 4 types of waste will be generated: 1) human waste human waste will be handled according with the regulations set by the McGill Arctic research station (MARS). Minimal environmental impact is expected. Solid waste will be incinerated while liquid waste will be transport to the PCSP Resolute Facility 2) combustible non hazardous waste Combustible non hazardous waste will be minimal and present little environmental risk. All combustible waste will be incinerated at MARS 3) non-combustible non hazardous waste Non combustible, non hazardous waste will be carried out of the field and transported directly to the PSCP Resolute Facility 4) hazardous waste Minimal potentially hazardous waste in the form of preservatives for sediment samples will be transported in in small (<25 mL) quantities using secondary and tertiary containment. All waste including all transportation and containment materials will be transported back to York University and disposed of according to University protocols. A pump will draw atmospheric samples into the methane spectrometer. The mapping spectroscopy instruments use non-destructive LEDs. The spectroscopy instruments pose no environmental hazards or risks. Manual scooping and sediment push cores (30-50 cm) will be used to collect <5 L of sediment. Manual syringes will be used to collect <2 L / spring of water from each site. Given the water refresh rate and seasonal re-modelling, no environmental damage or risk is anticipated. Hand coring will collect <3 meters of ice core and <1.5 m of cryosol. Given the low volumes and the summer glacial surface melt, no environmental damage or risk is anticipated. All instruments will operate using Li-ion batteries.

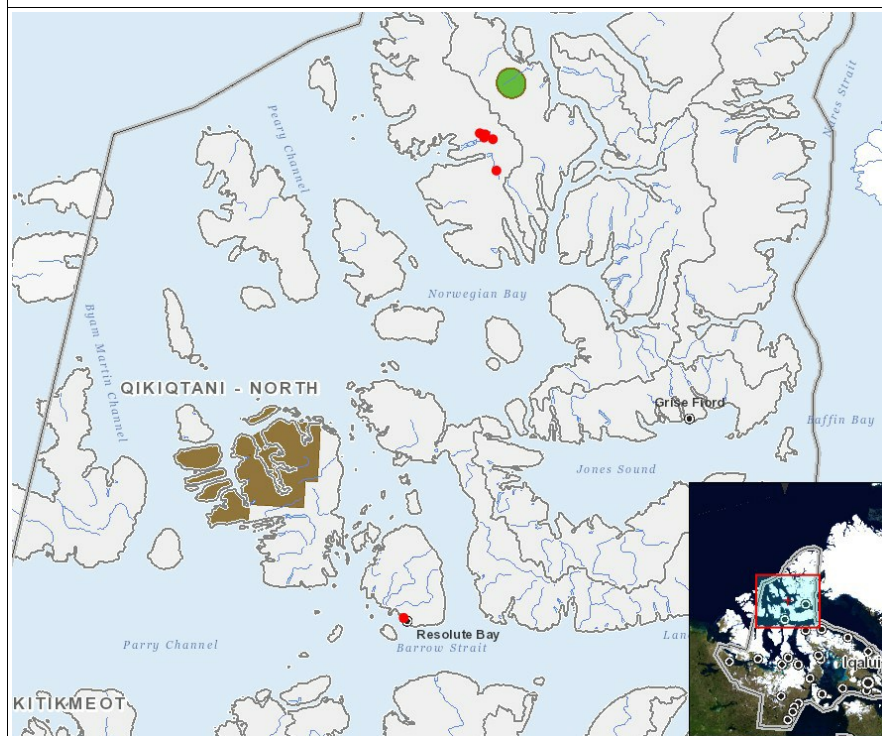
Cumulative Effects

No cumulative effects on the environment are predicted or anticipated.

Impacts

$\Delta^{\frac{1}{6}} \sigma^{\frac{1}{6}} r^C$ $\Delta^{\frac{1}{6}} \sigma^{\frac{1}{6}} r^C$

[illegible]
$$(P = \langle b \rangle \langle b \rangle \langle a \rangle \langle p \rangle \langle n \rangle \langle d \rangle \langle a \rangle \langle b \rangle \langle c \rangle, N = \langle b \rangle \langle b \rangle \langle b \rangle \langle d \rangle \langle c \rangle \langle d \rangle \langle a \rangle \langle b \rangle \langle c \rangle \langle c \rangle \langle d \rangle \langle \Gamma \rangle \langle d \rangle \langle \Gamma \rangle \langle b \rangle \langle c \rangle \langle d \rangle \langle a \rangle \langle b \rangle \langle \Gamma \rangle \langle c \rangle \langle a \rangle, M = \langle b \rangle \langle b \rangle \langle b \rangle \langle d \rangle \langle c \rangle \langle d \rangle \langle a \rangle \langle b \rangle \langle c \rangle \langle c \rangle \langle d \rangle \langle \Gamma \rangle \langle d \rangle \langle \Gamma \rangle \langle b \rangle \langle c \rangle \langle d \rangle \langle a \rangle \langle b \rangle \langle c \rangle \langle a \rangle, U = \langle b \rangle \langle d \rangle \langle \Gamma \rangle \langle L \rangle \langle a \rangle \langle b \rangle \langle \Gamma \rangle \langle c \rangle \langle b \rangle)$$



List of Project Geometries

- 1 point McGill Arctic Research Station (field base camp)
- 2 point Polar Continental Shelf Program Resolute Facility (staging, logistics base)
- 3 point White Glacier (science site)
- 4 point Gypsum Hill Spring (science site)
- 5 point Wolf Spring (aka Lost Hammer, science site)
- 6 point Colour Peak Spring (science site)
- 7 point Crown Glacier (science site)

