**METHANE DYNAMICS AND MICROBIAL COMMUNITIES IN SMALL, SEASONALLY ICE-COVERED ARTIC LAKES IN WESTERN GREENLAND: INSIGHTS INTO EARLY PLUVIAL PERIODS ON MARS.**

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**Introduction:** Recent measurements by Curiosity have not yet detected atmospheric methane on Mars [1]; however previous Earth-based telescopic observations of methane plumes [2,3,4] demand continued investigation into biogeochemical pathways for the origin and distribution of volatile hydrocarbons on Mars. On Earth, methane emissions are predominantly derived from thermal cracking of ancient organic matter in the deep subsurface or from microbial, methanogenic metabolisms in aquatic environments, including wetlands and lakes [5, 6, 7]. Isolated lacustrine depositional environments in craters were common features during early periods in Martian history [8]. The underlying permafrost and lack of through-going surface drainage would have allowed individual lakes to evolve distinct chemical signatures.

In order to assess the potential for putative microbial processes to be recorded in fine-grained sediments from Martian crater lakes, 4 small lakes (surface area < 1 $km^2$) within a narrow valley extending from the Russells Glacier to Sondre Stromfjord in Southwestern Greenland were examined during winter ice-cover. Lakes on the Martian surface would have become progressively colder over time, developing seasonal and perennial ice covers, similar to those found in Arctic environments. Bedrock at the study site is predominantly interlayered mafic and felsic gneiss with sparse cross-cutting, ultramafic alkaline dikes of about 1.5 m in thickness. There is a conspicuous, lenticular, oxide gossan containing sulfate minerals on a ridge at the east end of the study area. Here, we describe results from ice-covered conditions in April 2013, concentrating on aquatic chemistry combined with methane concentrations and isotopic compositions of methane through the water column of four lakes.

**Site Description:** The study area occurs between the head of the Sondre Stromfjord in Kangerlussuaq and the active terminal moraine of the Russells Glacier. The area is characterized by a Low Arctic continental climate [9], with continual permafrost <1 m below surface and low precipitation (<150 mm $yr^{-1}$). The mean annual air temperature is -6°C with peaks of +20°C in June to early August when mean temperatures are over +8°C. The study lakes are ice-covered from mid-September to mid-June. Due to minimal precipitation, the lakes are supplied with water mainly though contributions from the melting snowpack. Groundwater seepage is very limited due to negative precipitation-evaporation balance and presence of permafrost.

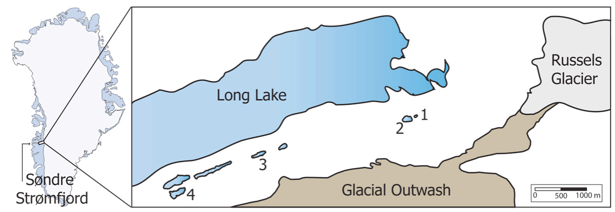


Figure 1. Lake location map. Lakes of focus for this study: 1) EVV Upper lake, 2) EVV Lower lake, 3) Potentilla lake, 4) South Twin lake

**Methods:** All samples were collected from the center of each lake though the ice in April 2013. Temperature, pH, dissolved oxygen, oxidation/reduction potential, and conductivity were measured using a YSI Data Sonde deployed at 0.5 m depth increments. Water was collected in Nalgene bottles though the water column using a submersible pump for further analysis. Ion concentrations were analyzed on a Dionex Ion Chromatograph 2000, and sulfide concentrations by precipitation of cadmium sulfide.

Dissolved methane was stripped in the field using a headspace-equilibrium technique [10] with a 1 L Erlenmeyer flask. Concentration of $CH_4$ was measured using a Los Gatos Research methane carbon isotope analyzer at the field station in Kangerlussuaq, Greenland. Carbon and hydrogen isotopes of $CH_4$ were measured on a Gas Chromatograph Combustion Isotope Ratio Mass Spectrometer fitted with a methane pre-concentrator at Indiana University.

**Results and Discussion:** During late winter under ~ 2 m of ice, the entire water column within each lake was anoxic. In three of the four lakes, the water column was isothermal, with little vertical variation in aquatic chemistry. In the lake closest to the ice margin (EVV Upper lake), visible black particulate matter was observable throughout the water column. A 40‰ offset in $\delta^{34}S$ of sulfate and sulfide indicates active microbial sulfate reduction [11], confirmed by occurrence of sulfate reducing bacteria using environmental genomics. In the other two lakes, there is no evidence of active sulfur cycling. In these lakes, methane concentrations and $\delta^{13}C$ are stable over the depth of the water column, averaging from 120 to 480 μM, with $\delta^{13}C_{CH4}$

values from -56‰ to -66‰, respectively. In addition, δD of $CH_4$ are stable, averaging -350‰.

In the deepest lake, Potentilla lake, vertical chemical and redox stratification was observed, despite being moderately isothermal and having dilute ionic chemistry. A horizon of purple sulfur bacteria was observed corresponding with a shift to reducing conditions. Methane concentrations increased with depth from <1 μM below the ice to 800 μM at the sediment/water interface. An inverse relationship was observed between $[CH_4]$ and $\delta^{13}C$ with $\delta^{13}C_{CH4}$ decreasing from -30‰ to -70‰ suggesting consumption of $CH_4$ [12]. Carbon and hydrogen isotopes of $CH_4$ display a positive linear relationship consistent with partial microbial oxidation [13]. Oxygen saturated waters at the onset of winter ice cover may have served as the principal electron acceptor for much of the winter period. Following deleption of oxygen, alternate anaerobic methane oxidation processes may have affected methane dynamics in this system.

**Implications:** Substantial variations in aquatic chemistry, methane dynamics, and microbial communities are observed in a series of small ice-covered Arctic lakes in Greenland. In the absence of through-going drainage systems, small lakes embedded in permafrost operate independently despite close proximity. Diversity observed among the lakes is due to variations in underlying geology. Lakes on Mars would also likely exhibit such variation. A better understanding on controls of aquatic chemistry, methane dyanimics, and microbial communities is therefore needed in order to accurately interpret future findings on Mars.

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