SULFUR / CARBONATE SPRINGS AND LIFE IN GLACIAL ICE.

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Introduction: Ice in the near subsurface of Mars apparently discharges liquid water on occasion [1]. Cold-tolerant microorganisms are known to exist within terrestrial glacial ice [2], and may be brought to the surface as a result of melting events. We are investigating a set of springs that deposit sulfur and carbonate minerals, as well as evidence of microbial life, on the surface of a glacier in the Canadian arctic.

Field Observations: *Geologic Setting.* The springs are located at 81°01'N, 81°35'W, near the northwest coast of Ellesmere Island. The sampling area is characterized by widespread glaciers and deep fiords. Outcrops in the sampling area include the Upper Carboniferous to Lower Permian Nansen formation (limestone, minor sandstone, siltstone and shale) and the Upper Permian Trold Fiord Formation (siltstone, sandstone, minor bioclastic limestone, conglomerate and chert) [3]. Permafrost with depths of 400 to 600 m has been documented on nearby Axel Heiberg Island [4].

Climate. The climate, as monitored at the Eureka meteorological station on Ellesmere Island, includes cold, dry winters and cool summers. The mean annual air temperature is -19.7°C (-36.1°C in January; +5.4°C in July), and seasonal extremes of -55°C and +20°C are not uncommon [4].

Samples: Sterile samples of spring water and associated solid deposits were collected from several locations during July, 2000. The springs are located on the surface of a glacier several hundred meters thick. All of the sites are typically characterized by large accumulations of yellow and white, or only white, minerals (Figure 1). A strong smell of H_2S was apparent during sampling. There is evidence for both active and past water discharge at these sites.

Water. Water temperatures are low (1 to 2°C), but higher than surface melt water (0.2°C). The spring waters have pH values of approximately 9 to 9.8, distinctly different from glacial melt water streams and pools without sulfur that have pH values of around 5.2. Total dissolved solids in the spring water range from approximately 200 to 300 mg/l, as compared to <1 mg/l for melt water elsewhere on the ice.

Solid Deposits. The solid samples were air dried and ground in an agate mortar and pestle for powder X-ray diffraction (XRD) analysis. The XRD patterns of all samples are nearly identical, and include peaks for abundant sulfur and calcite. Minor gypsum was identified following dissolution extraction.

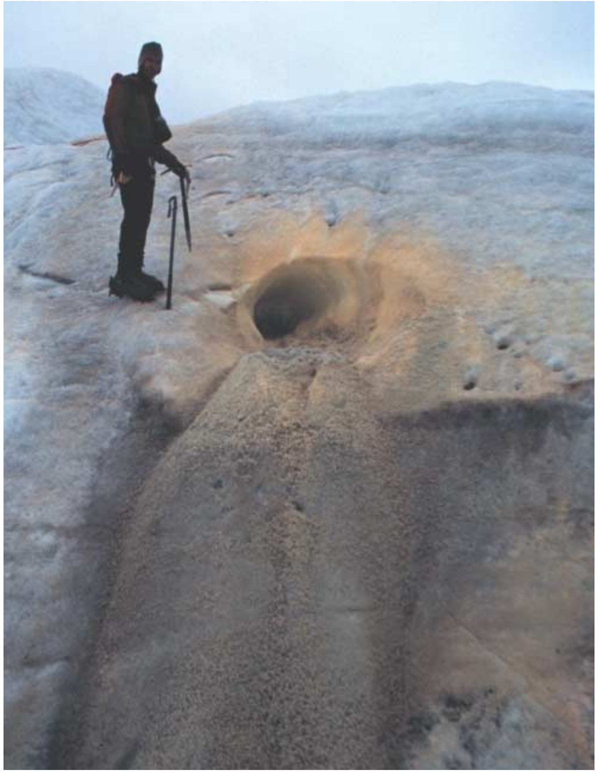

Figure 1. Channel in the ice with water discharge and the formation of a large mound of sulfur and calcite.

Dissolved / Suspended Solids. One water sample was passed thru a 0.2 μm filter by vacuum filtration. The filter was air dried and a portion was chromium-coated and mounted for analysis by a field emission scanning electron microscope (FE-SEM). Elemental abundances were determined using an energy-dispersive X-ray spectrometer operated in a windowless configuration, allowing detection of elements as light as carbon.

The FE-SEM analyses of solids filtered from the water detected numerous sub-spherical sulfur particles, generally 1 to 2 μm in diameter (Figure 2). A second population of 1 μm spheres are characterized by myriad radiating spikes. These spheres consist of Ca, P and O. The tentative mineral identification of apatite could not be confirmed by XRD, due to peak overlap.

Biofilm. The sulfur and apatite (?) particles are partially enmeshed in a carbon-rich webbing fractions of a micrometer thick (Figure 2). This material matches the morphology and composition of the extracellular polymeric substance (EPS) produced by many microorganisms. In nature the EPS envelops microbial cells and detrital particles in a three dimensional, water-rich structure known as a biofilm [5]. Upon drying and exposure to the FE-SEM vacuum, EPS characteristically dehydrates and shrinks to a web-like structure such as that shown in Figure 2.

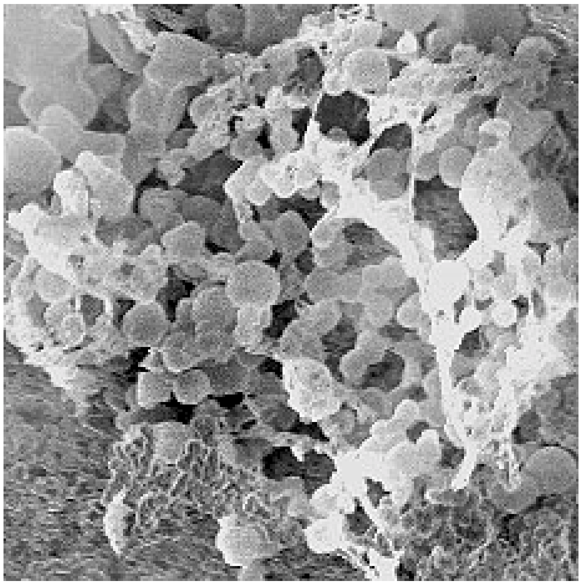

Figure 2. 1 to 2 µm sulfur particles in EPS from filtered sample; secondary electron image, 3 keV.

The FE-SEM images also show micrometer-scale, carbon-rich spheroids, which may be microbial cells. Further examination will be required to confirm the presence of microorganisms in these samples.

Discussion: *Hydrology.* Relative to more temperate locales, springs are rare in the Canadian arctic. A site on Axel Heiberg Island contains perennial springs in permafrost that form travertine deposits [4]. Also, seasonal "spring" discharges have been observed near the toes of glaciers at other localities. In these cases discharge occurs for only a matter of days and there are no associated precipitates.

Meltwater within glaciers moves through complex under-ice plumbing systems. Ice melted at the surface can move into the plumbing system through vertical cracks and pipes. In addition, ice can be melted at the base of the glacier by geothermal heat.

Water discharges onto glaciers occur because the under-ice plumbing is all connected. As the melting season advances the hydraulic head increases as the melt line advances up glacier. Surface discharges are fed by ice-enclosed streams, in which the water sometimes moves at very high speeds. In some cases the water coming out of the springs carries a high load of solids because it has run at or close to the bed.

Mineralogy. These springs may be expressions of a low-grade hydrothermal system (currently undetected) beneath Ellesmere Island. Hot spring water passing through hundreds of meters of glacial ice would be strongly cooled, but might still maintain a temperature slightly above freezing, as in the present case.

Sulfur-rich hot springs that precipitate calcite are common in Yellowstone, the Valle Grande, and thermal areas of Italy [6]. At Yellowstone the rising sulfur-rich water becomes saturated with $CaCO_3$ as it passes through a limestone horizon. Bedrock exposed closest to the Canadian springs contains Carboniferous and Permian limestone [3]. A reverse fault ~1 km south of the springs has abundant sulfide mineralization. This, and thick evaporite deposits in the underlying Otto Fiord Formation, are the likely sulfur sources.

Microbiology. FE-SEM examination of material filtered from one water sample revealed extensive EPS and possible microbial cells. Microorganisms were also reported in the spring water discharging from permafrost on Axel Heiberg Island [4]. In both cases, further investigation will be required to determine if the microorganisms are living within the spring plumbing systems or only at the points of surface discharge.

Bacteria can survive subfreezing (and even cryogenic) temperatures. Viable spore-forming bacteria (*Bacillus* and *Actinomycetes* species) have been recovered from glacial ice [2]. If cold-tolerant microorganisms exist in glacial meltwater they will be brought to the surface wherever that meltwater discharges.

Implications: The glacial springs of the Canadian arctic are useful terrestrial analogs to the channels and seeps issuing from beneath frozen strata on Mars. These glacial springs demonstrate that mineral-rich water can move through, and discharge from, solid ice. Liquid water, even at near-freezing temperatures, can support microbial life and bring evidence of that life to the surface.

References. [1] Malin, M.C. and Edgett, K.S. (2000) *Science 288,* 2330-2335. [2] Christner, B.C. et al. (2000) *Icarus 144,* 479-485. [3] Otto Fiord (1972), Geol. Surv. Canada, Geological Map 1309A. [4] Pollard, W. et al (1999) *Can. J. Earth Sci. 36*, 105-120. [5] Westall, F. et al. (2000) *JGR, 105,* 24,511-24,527. [6] Allen, C.C. et al (2000) *Icarus 147*, 49-67.