EXPLORING ICELANDIC SUBGLACIAL VOLCANOES AS ANALOGS TO HABITATS ON MARS

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Introduction: The search for life elsewhere in the Solar System has led to subsurface environments in cold and icy planets and satellites. Mars' surface appears sterile and hostile to Earth-like life, but its crust is ice-rich [1-5] and liquid water has been episodically mobilized over the planet's history [6-8], in some cases by volcanic heat [9-12]. Denied sunlight, subsurface life requires chemical sources of energy [13]. On Earth, chemical energy is available in geothermal systems where gases and reactions of water with volcanic rocks create chemical disequilibrium. Volcanism that melts ice may provide chemical energy [14-15]. One energy source is hydrogenotrophic methanogenesis ($CO_2+4H_2 \rightarrow CH_4+2H_2O$), an ancient metabolism carried out by some anaerobic archaea. CO_2 and H_2 are evolved from magmas and the weathering of mafic rocks [16]. CH_4 is a potential biomarker because it is inert, insoluble, and detectable at ppb concentrations, although it also has an abiotic origin [17]. There are reports of CH_4 in the martian atmosphere [18-21].

Glacial and volcanic landforms in Iceland are compared with features on Mars [22-25] and since 2002, we have studied Icelandic volcanic subglacial lakes. The Vatnajökull ice cap hosts three such lakes (Fig. 1) that fill as volcanic heat melts the overlying ice, and episodically drain in floods (*jökulhlaups*) [26]. The Grímsvötn caldera contains a 20 km^2 lake (Fig. 2) and two <5 km^2 Skaftá lakes lie 300 m beneath melt-formed depressions (cauldrons) in the ice surface (Fig. 3). The objectives of our studies are to describe the microbial communities in these environments, determine their sources of energy and nutrients, and evaluate potential biomarkers for application on Mars.

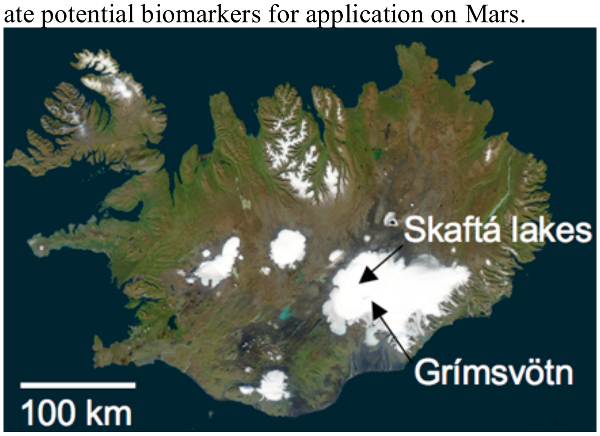

Figure 1. Location of the Grímsvötn and Skaftá lakes under the Vatnajökull ice cap, Iceland.

Figure 2. The Grímsvötn caldera, 5 km across. The bare ground at the rim is the result of geothermal heat.

Figure 3. Western Skaftá cauldron, 1 km across.

Methods: *Borehole drilling:* Hot water drilling is used for speed and using superheated water minimizes the potential for significant biological contamination of the lake and samples. The drilling system of the Icelandic Meteorological Office (Figs. 4 and 5) incorporates features that minimize contamination of drilling targets [27]. Clean snow is melted in a closed-loop glycol heat exchanger, filtered of large (>10μm) particles, UV-treated, and heated to 145ºC under pressure. The drilling protocol includes cleaning the internal system with 70% EtOH before operation, using snow upwind of the site, and discarding the uppermost meter of snow. Tests show that water at the drill exit contains no detectable (<1 ml-1) viable cells (i.e., colony forming units on dilute agar media) and direct counts of 8×10^3 total cells ml-1 (DAPI DNA stain) [27]. The system can drill through 300m of pure ice in 24hr. *Sampling*: To sample lake waters we used a custom mechanically triggered sampler [28] and an electrically-triggered 1L borehole fluid sampler (Mt. Sopris 2FSA-1000). Samplers are cleaned of organics and sterilized with NaClO prior to insertion into the borehole. Each 1L sample was partitioned into for geochemistry, DNA extractions, cell counts, and cultivation experiments.

Figure 4. Hotwater drilling system shown deployed behind the 4WD vehicle transporting it over the ice.

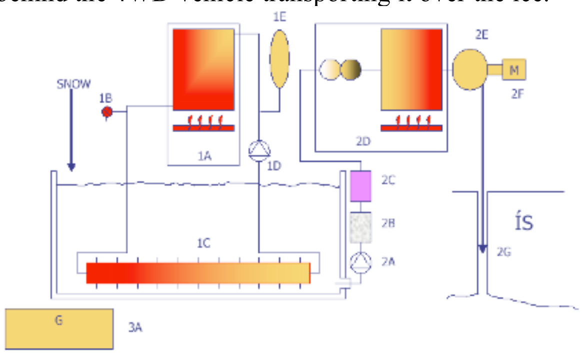

Figure 5. Schematic of the hotwater drilling system.

Results: Lake water chemistry is the product of mixing of glacial melt, hydrothermal fluid, and volcanic gases, and the low-temperature alteration of basalt (Fig. 6). We documented viable, endemic bacterial communities in all three lakes [29-30] and, with a previous study of Grímsvötn [30], described water chemistries ranging from oxic to anoxic/sulfidic. Notably, we failed to detect archaea in either Skaftá lake (we did not analyze for archaea in Grímsvötn). In contrast to other anoxic settings where archaeal methanogens are abundant [31-33], the Skaftá lakes are dominated by relatives of homoacetogenic bacteria that convert CO_2 and H_2 to acetate (CH_3COOH) and compete with methanogens for H_2 [34-26].

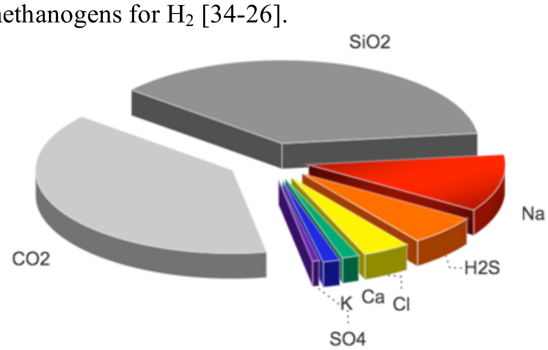

Figure 6. Average distribution of solutes in the eastern Skaftá lake waters. The TDS was 270 mg L^{-1}.

Our detailed analyses of the eastern Skaftá lake show that the community is homogeneously distributed in the water column and the same major groups are present in both the west and east lakes ([30] and Fig. 7).

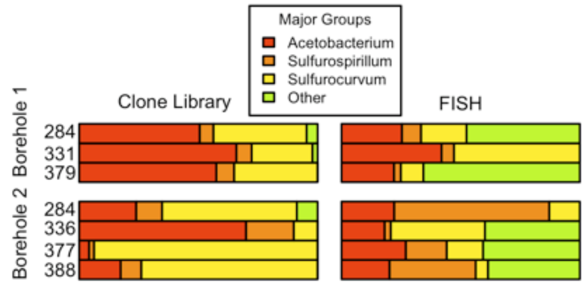

Figure 7. Microbial community composition in the eastern Skaftá lake: Distribution in DNA clone libraries and fluorescent in situ hybridization counts in samples from different depths (in m) and two boreholes.

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