BIOGEOCHEMICAL AND SPECTRAL CHARACTERIZATION OF A SULFUR-RICH GLACIAL ECOSYSTEM AND POTENTIAL ANALOG TO EUROPA

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Introduction and relevance: Borup Fiord Pass, in the Canadian High Arctic, is home to sulfur-rich springs abundant in microbes, which discharge onto the surface of glacial ice, releasing H_2S and forming deposits of native sulfur, gypsum and calcite [1]. The presence of sulfur in three oxidation states indicates a complex series of redox reactions, and preliminary investigations support the hypothesis of biological mediation of the sulfur chemistry.

Figure 1 - Sulfur-rich deposits on the ice, observed during the 2006 field season. Foreground scale is ~10m across the image.

The Borup Fiord Pass site is of particular astrobiological and planetary interest for several reasons. The chemistry of Europa's non-ice surface material [2, 3], possibly representative of the composition of its subsurface ocean, may be paralleled by the sulfur-rich chemistry of the supraglacial deposits. At a minimum the juxtaposition of ice and sulfur chemistry provides a valuable opportunity to evaluate and enhance our ability to identify and map the distribution of sulfur minerals on ice by reference to ground truth, allowing us to test remote sensing and in-situ techniques for application to Europa. From another perspective, if the connection between microbial communities present in the system and the local geochemistry is established, the extensive deposits can effectively be viewed as biosignature on a large enough scale to allow detection from orbital measurements. In addition, understanding the complex biogeochemical system operating in this extreme environment could lend insights to possible microbiologic niches at icy moons such as Europa.

Here we present our initial efforts to understand the biogeochemical processes which have led to the deposition of these sulfur-rich materials on the ice, and investigate how well these materials can be characterized by use of remote sensing techniques.

Field and Remote Sensing measurements: A field expedition to Borup Fiord Pass was undertaken June-July 2006 to investigate the complex biogeochemistry of the site, and to provide ground truth for spectroscopic analyses of hyperspectral satellite imagery of the area.

Geochemical measurements obtained at spring sample sites included temperature, flow rates, pH, Eh, dissolved oxygen, and sulfide and sulfate contained within the spring waters. Sampling was also carried out on solid deposits for later laboratory analysis of major and trace ions and isotopic compositions. Biological samples for the same sample sites were obtained and preserved for culturing, microscopy and microbiological analysis.

Spectral reflectance measurements were collected by an ASD FieldSpecPro field spectrometer. Higher resolution field spectra of the sulfur-rich materials were obtained using illumination from a probe attached to the field spectrometer, increasing signal-to-noise ratios for these spectra, while many hundred more spectra were collected using natural illumination on a clear day.

Hyperspectral imagery of the site from the Hyperion instrument on EO-1 were obtained in a similar timeframe to the fieldwork.

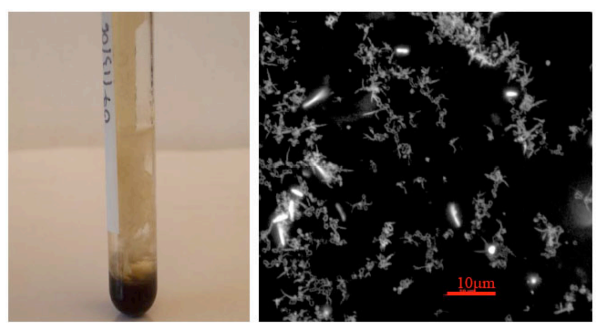

Figure 2 - FeS gradient tube (left) made with an artificial seawater medium shows rapid and abundant formation of S^0 when inoculated with sulfur-rich sample BF06-05A. Fluorescence microscopy (right) confirms the presence of microbial cells (bright rods) growing in the new S^0 deposits. No S^0 was formed in abiotic controls.

Analyses: Preliminary geochemical analyses of the spring waters have shown them to be high in salts, containing large amounts of sulfate (1786 mg/L). The results of these analyses were utilized to design targeted culturing experiments to determine which microorganisms mediate the biogeochemical transformation of sulfur, and their varied modes of metabolism in this extreme environment. These culturing experiments were set up under environmental conditions similar to those in the field and were inoculated with returned samples. The experiments were designed to select for psychrophilic sulfide-oxidizing bacteria that could produce S^0, as observed on the ice. Rapid growth and elemental sulfur deposition was observed in the gradient tubes (Figure 2) at temperatures of 4˚C as sulfide in FeS was oxidized while abiotic controls showed no S^0 production. The only carbon source provided was CO_2, suggesting potentially autotrophic growth.

Parallel experiments targeting heterotrophic sulfate-reducing bacteria, which may be the source of H_2S produced from gypsum-derived sulfate, were also attempted, but the samples had not been appropriately preserved under anoxic conditions to successfully initiate the robust growth of sulfate-reducing bacteria in the laboratory. Preliminary sequencing of DNA extracted from returned samples has indicated the presence of known groups of sulfate-reducing microorganisms (e.g. classes of delta-Proteobacteria), while a small fraction of the total sequences do not correspond with any in the public databases (Figure 3).

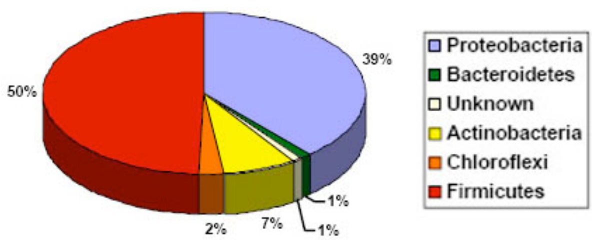

Figure 3 - Pie chart showing broadly-defined microbial community composition for a sulfur-rich sample (BF06-04a) collected in the summer 2006 field sampling. A small fraction of the total sequences do not correspond with any in the public databases.

The main spectral signatures emerging from the hyperspectral imagery of the area of interest are those of ice and sulfur. There may also be evidence for the bound water contained within gypsum in certain of the field spectra (Figure 4). Interpretation of the field spectra is aided by high resolution laboratory spectra of samples returned from the field.

Comparisons between satellite and in-situ spectral measurements taken across a grid are ongoing. Subpixel mapping of the distributions of the deposits has been achieved using both sulfur-rich spectrally pure Hyperion pixels, and certain of the field spectra collected in-situ as endmember spectra, and similar results are found for both.

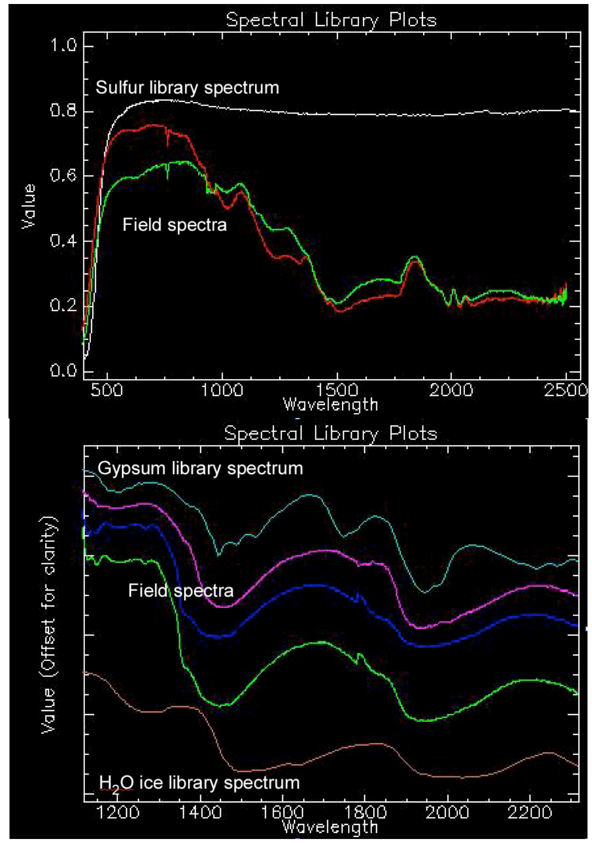

Figure 4 - Top: Field spectra match the sulfur curve in the 400-500 nm range. Bottom: Offsets in the shape and location of water absorption bands in the field spectra relative to those of the H_2O ice may be evidence for the bound water within gypsum.

Preliminary conclusions: Spectral analyses of the site have detected elemental sulfur on the ice from hyperspectral satellite imagery obtained from orbit, consistant with field spectra and geochemical analyses. While efforts are continuing to refine our spectral identifications and mapping of the spring deposits, the successful remote detection of these S^0-rich deposits, out of equilibrium with their environment, is of interest.

Preliminary evidence for microbial mediation of the sulfur transformations in this environment has been provided by our culturing experiments. Further exploration of the varied modes of metabolism which may exist in this extreme environment is necessary, via both further culturing experiments and DNA analyses. Much work remains to be done before we can fully understand the significance of this unique site, both as an analog to Europa, and as an extreme ecosystem, with a remotely detectable surface geochemical expression.

References: [1] Grasby, S.E. et al., (2003) *Astrobiology,* 3, 583-596. [2] McCord T.B. et al, (1998) Science, Vol. 280, 1242-1245. [3] Carlson R.W. et al., (1999) Science, Vol. 286. no.5437, 97-99.