NAME: Damhnait Gleeson
PROJECT TITLE: Borup Fiord Europa Analog Investigation
PROGRAM: Lewis and Clark Fund for Exploration and Field Research in Astrobiology
DATE: awarded May 31st 2006

PROJECT REPORT

Figure 1 - Sulfur-covered glacial ice observed at Borup Fiord Pass, Ellesmere Island, in the Canadian High Arctic during the course of the 2006 field season.

Introduction

In advance of our 2006 field season, sulfur-rich springs and associated deposits of elemental sulfur, gypsum and calcite had been observed discharging onto a glacier at an isolated field site located at 81°01´N, 81°35´W, at the north end of Borup Fiord Pass on Ellesmere Island in the Canadian High Arctic (Figure 2). Intermittent odors characteristic of H_2S had also been noted in association with the springs. The presence of sulfur in three oxidation states indicated a complex series of redox reactions, suggesting biological mediation of the local geochemistry.

The Borup Fiord Pass site is of astrobiological interest for several reasons. The chemistry of Europa's non-ice surface material, 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 us the opportunity to apply the techniques of remote sensing to evaluate and enhance our ability to identify and map the distributions of sulfur materials on ice, in an area for which we have obtained ground truth.

From another perspective, if the connection between microbial communities present in the system and the local geochemistry could be established, the extensive deposits could effectively be viewed as biosignature, on a large enough scale to allow detection from orbital measurements. Understanding the complex biogeochemical system operating in this extreme environment could lend insights to possible microbiologic niches at icy moons such as Europa.

The initial source of the sulfur, and the mechanism for its production at the surface were two major questions to be answered in order to understand the system. The Otto Fiord Formation, an evaporitic anhydrite layer, had been suggested as the only source of sulfur in the area but further isotope analysis was required to confirm this as the origin. Biological mediation was proposed to explain the presence of sulfur under the environmental conditions present at the surface, whereby the sulfur would undergo reduction from anhydrite to H_2S and subsequent oxidation to the elemental sulfur observed on the ice. Limited microbial analyses of spring waters had shown the presence of some mesophiles and psychrophiles but failed to identify potential candidates for sulfur oxidation or reduction, which would provide evidence for this process.

In situ spectral measurements of the spring deposits were also necessary to provide ground truth for orbital observations, to allow identification of deposited materials and their distributions, and quantitative comparisons between orbital and ground measurements.

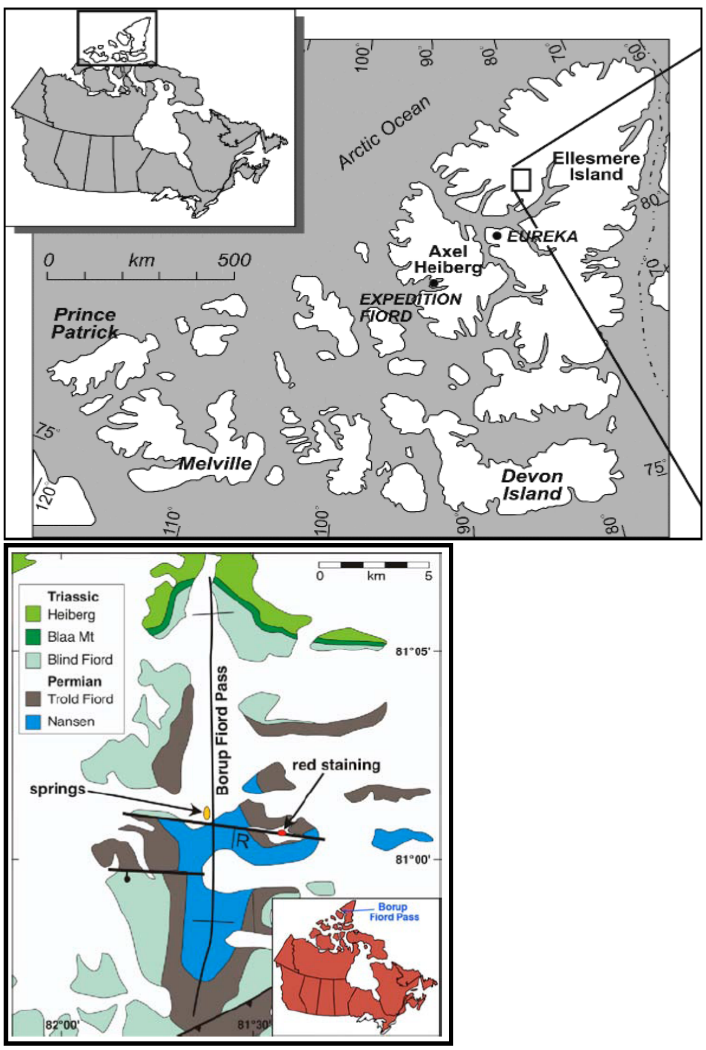

Figure 2 – Location of the field site and local geology of the area.

The field expedition

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Our four person team visited the Borup Fiord Pass site during 16 days in June and July of 2006. This field expedition revealed extensive sulfur deposits in association with multiple channels originating with one main source on the southern portion of the glacier (Figure 3). Yellow to brownish deposits covered an area of many thousand square meters on the southern slope of the glacier and the outwash plain at its toe. Older more brownish deposits at greater distance from the yellow deposits surrounding observed channels were revealed as snow melted. This suggested that the springs had been operational over the course of the winter and had probably changed position during that period. The springs themselves were operating at hugely inflated rates (~2 gallons/second) in comparison to previous years, likely connected with the large quantities of meltwater being generated all over the glacier as snow cover retreated.

Figure 3 - Top left: view from initial helicopter flyover, top right: walking through sulfur deposits up onto the glacier. Bottom left: yellow sulfur deposits alongside a channel, bottom right: spring source.

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 measurements were collected by an ASD FieldSpecPro field spectrometer and fell into one of three categories: spectra of materials of interest to use as spectrally pure endmembers for subpixel analysis of hyperspectral satellite imagery collected by the Hyperion instrument aboard EO-1, grid measurements across the sulfur-rich outflow plain for qualitative comparison with those orbital measurements, and aerial measurements obtained from helicopter to provide an intermediate level of resolution.

The reflectance spectra of the endmember materials were obtained using illumination from a probe attached to the field spectrometer, increasing the resolution of these spectra over the other spectra taken by increasing their signal-to-noise ratio. Some of the collected spectra are shown in Figure 4 below, alongside examples of materials for which spectra were collected. The grid spectra were obtained using natural illumination on a reasonably clear day. Occasional clouds overhead did lead to noticeable spikes in the data corresponding to water absorptions at around 1.1 and 1.4 microns. It was necessary to collect aerial spectra in radiance mode as reference could not be made to a reflectance standard. A five degree fore-optic was used to reduce the field of view, again to increase signal-to-noise ratios of the returned spectra.

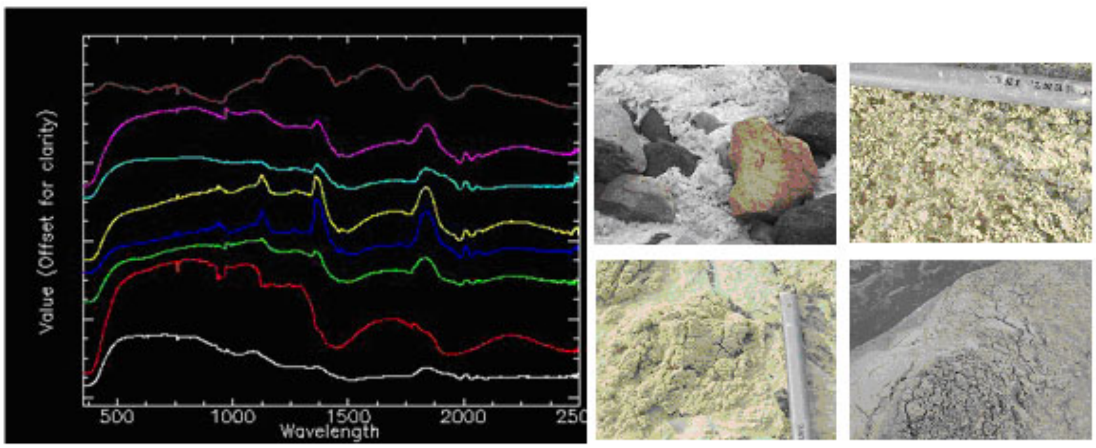

Figure 4 – Field-derived endmembers

Continuing 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 trace ion and isotopic analyses of the springs are expected to be returned shortly.

Laboratory culturing experiments have been set up under environmental conditions similar to those in the field, which were inoculated with returned samples. The preliminary results seem to show sulfur production via both oxidation from FeS and reduction from $Na_2S_2O_3$. Sequencing of DNA extracted from returned and cultured samples is underway to determine the microbes present in the system.

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. 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. Mapping the deposit distributions has been achieved using a sulfur-rich spectrally pure pixel as the endmember spectrum, allowing sub-pixel analysis of Hyperion imagery to be carried out based on the concept that each pixel spectrum is made up of a linear combination of endmember spectra with contributions owing to their areal coverage within the pixel.

Progress is being made towards understanding and characterizing the springs and deposits of Borup Fiord Pass but much work remains to be done before we can fully understand the true significance of this unique site, both as an analog to Europa and as an extreme abode for life which possesses a surface geochemical expression of the type that we hope to recognize on other planetary bodies as the search for life continues.