An Arctic Analog to Europa: Signs of Life on the Ice

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Europa Lander Workshop - February 11th 2009

BEAR Team

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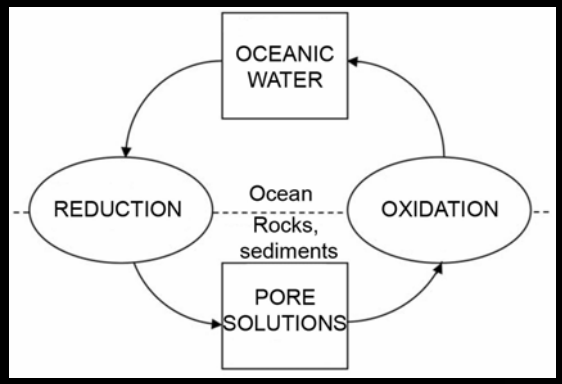
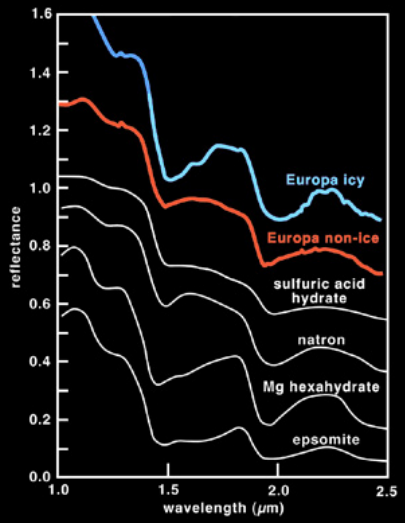
Europa's habitability

Ocean chemistry

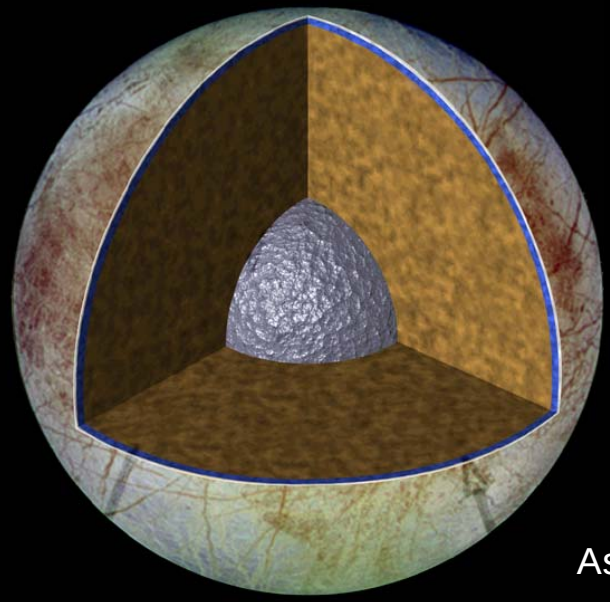


After Zolotov & Shock, 2004

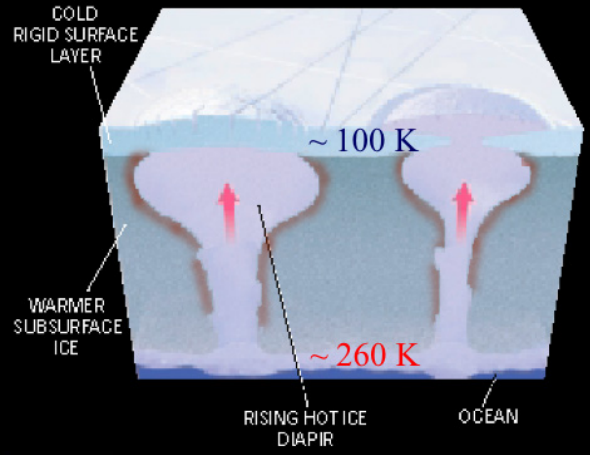
Sulfur-rich material



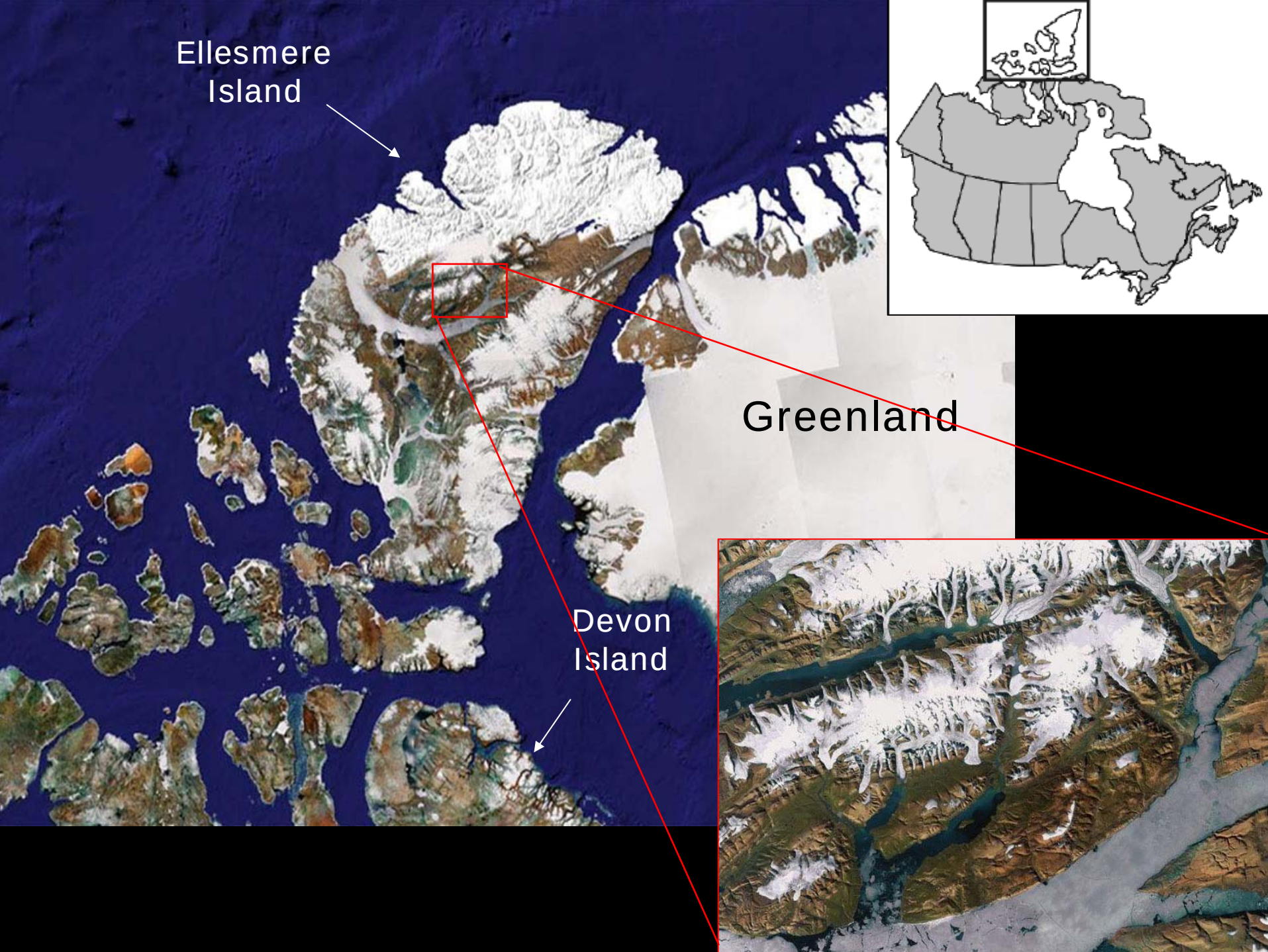
From McCord et al., 1998
and Carlson et al., 1999

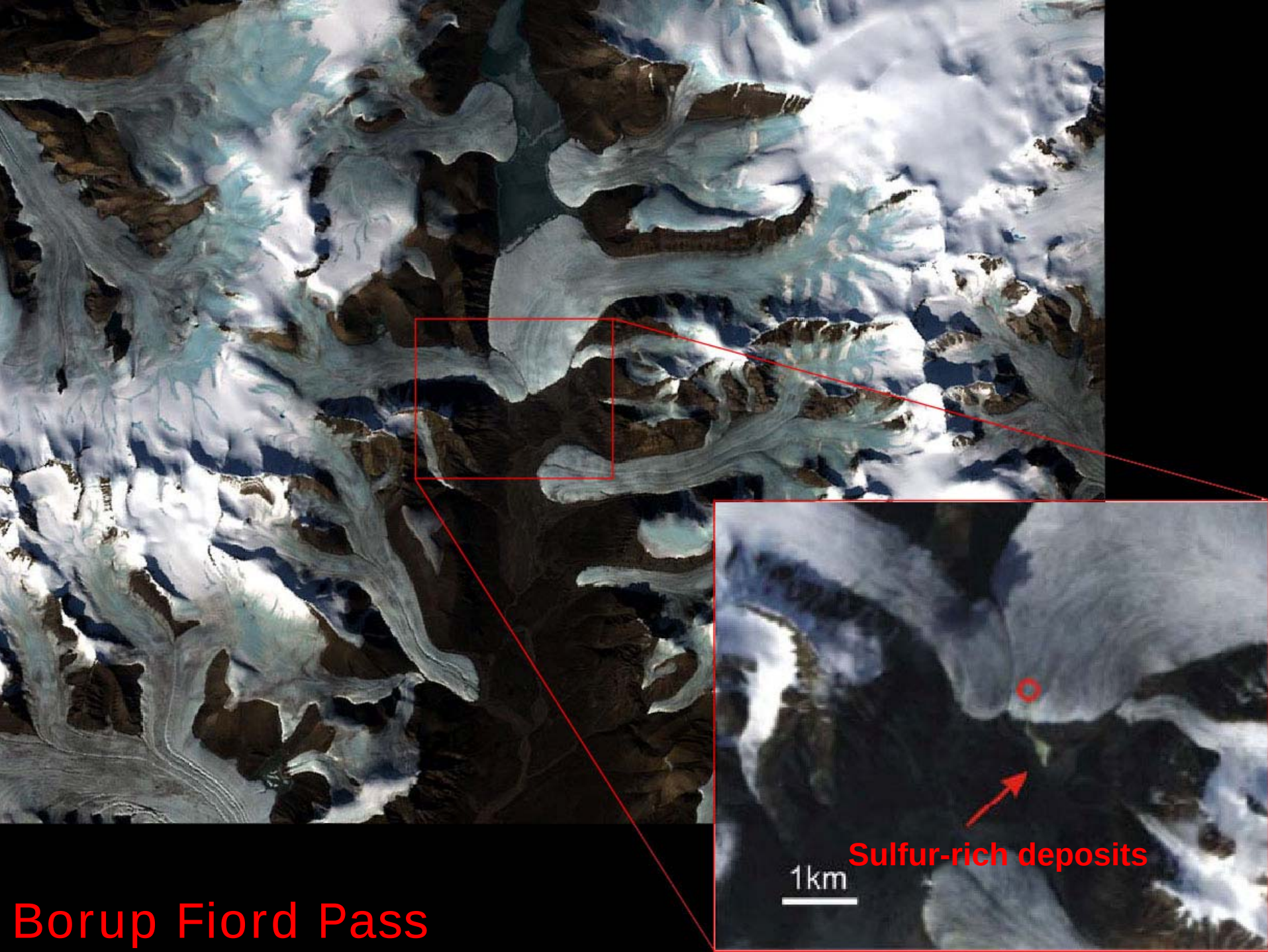


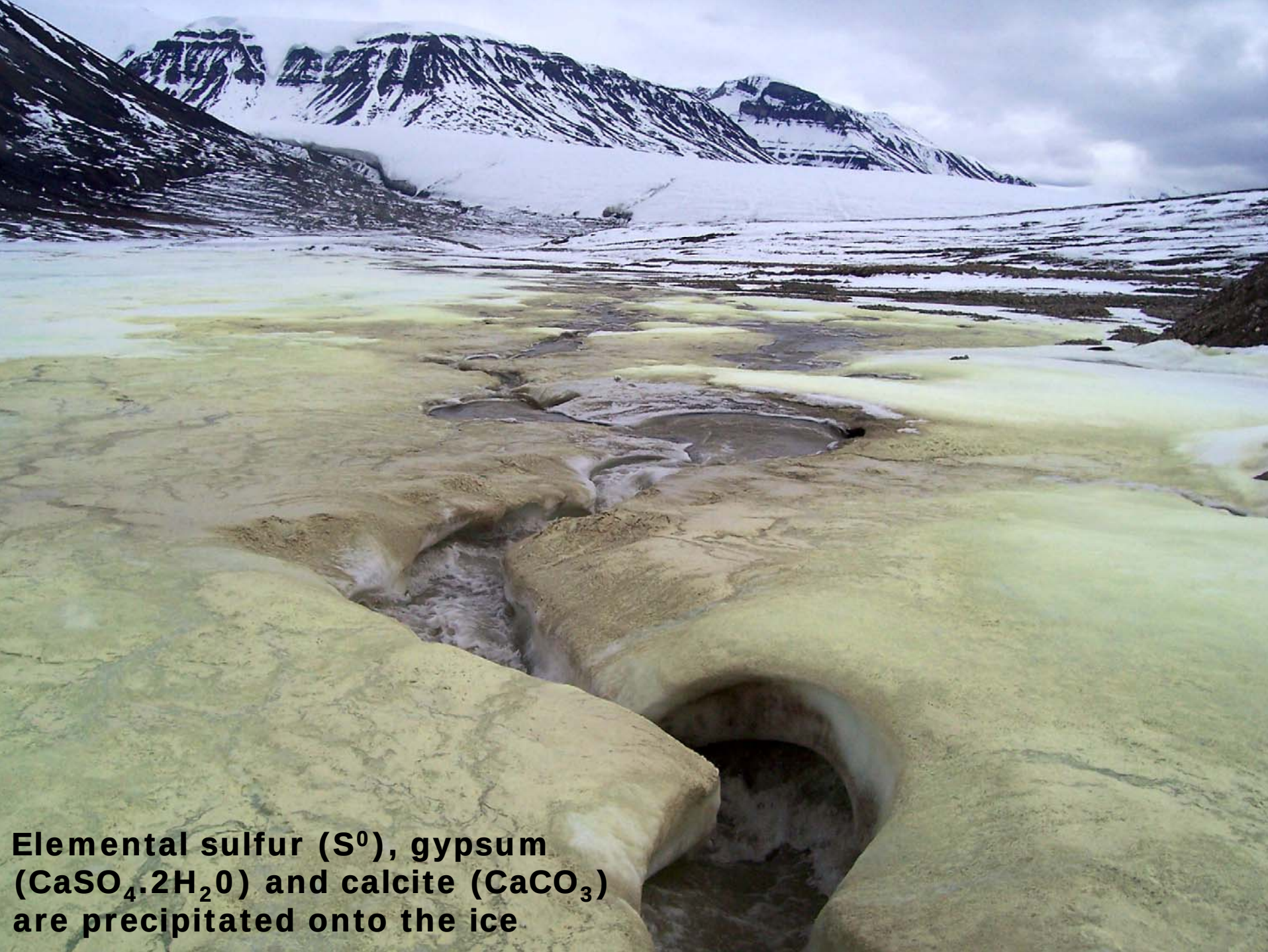
Mobile ice or partial melt



Association of sulfur-rich material with geologic features

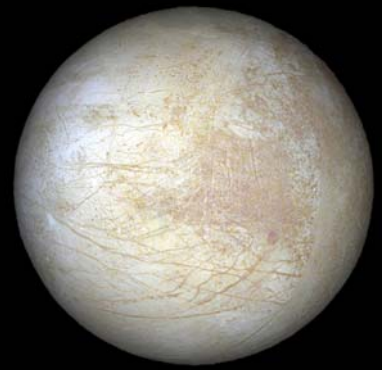

Ellesmere Island
Greenland
Devon Island


Sulfur-rich deposits
1km
Borup Fiord Pass



Elemental sulfur (S^0), gypsum ($CaSO_4.2H_20$) and calcite ($CaCO_3$) are precipitated onto the ice

Borup Fiord Pass as a Europa analog



	BORUP FIORD PASS	EUROPA
REMOTE SENSING	Sulfur-rich materials on ice	Probably a combination of sulfur-bearing materials and ice
ASTROBIOLOGY	Extreme environment hosting psychrophilic organisms which metabolize sulfur	Any life existing on Europa would operate at similar temperatures and could utilize similar metabolic pathways

Overview of the research

Objectives:

1. To utilize the field site as a spectral analog for Europa's non-ice materials, and to explore change detection strategies for a future Europa mission.

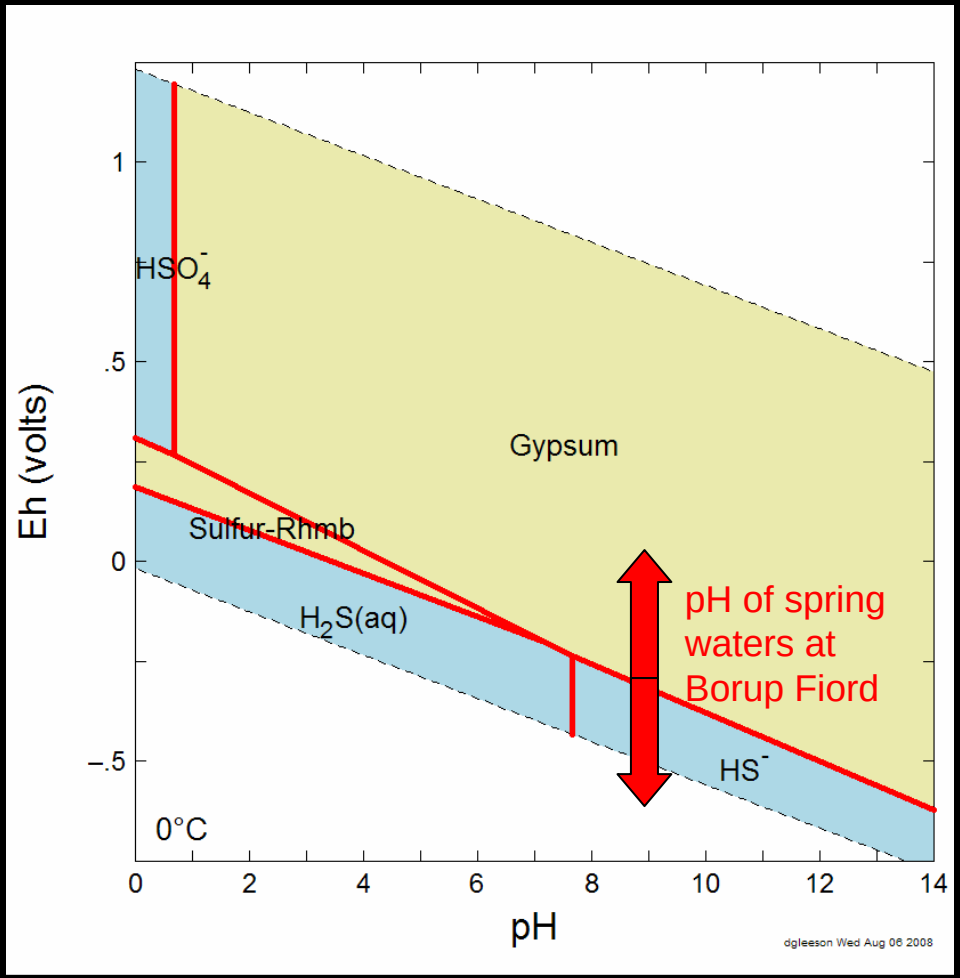
2. To investigate the geomicrobiology of the spring system, with the intention of furthering our knowledge of microbially mediated sulfur cycling in cold environments.

Approach:

1. Identify sulfur compounds on the ice in satellite imagery, and map their distribution. Then produce a sulfur classifier to run onboard EO1, allowing autonomous detections to be made and temporal coverage of the spring system to be obtained.

2. Carry out a series of targeted culturing experiments to search for active microbes in the system and compare successful cultures to community structure of field samples, identifying key players and their metabolic pathways.

S^0 as a biosignature

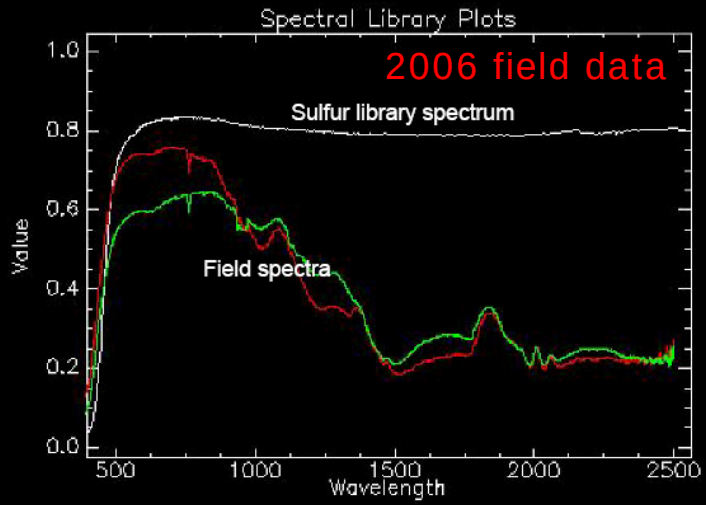


- Estimates of total sulfur in the system come from field measurements of sulfide and sulfate
- Sulfur-Rhmb (S^0) has a very narrow stability field
- Under environmental conditions (0° C and pH of 8-9), sulfur is predicted to be stable in the form of gypsum ($CaSO_4.2H_2O$) or HS^- depending on redox conditions

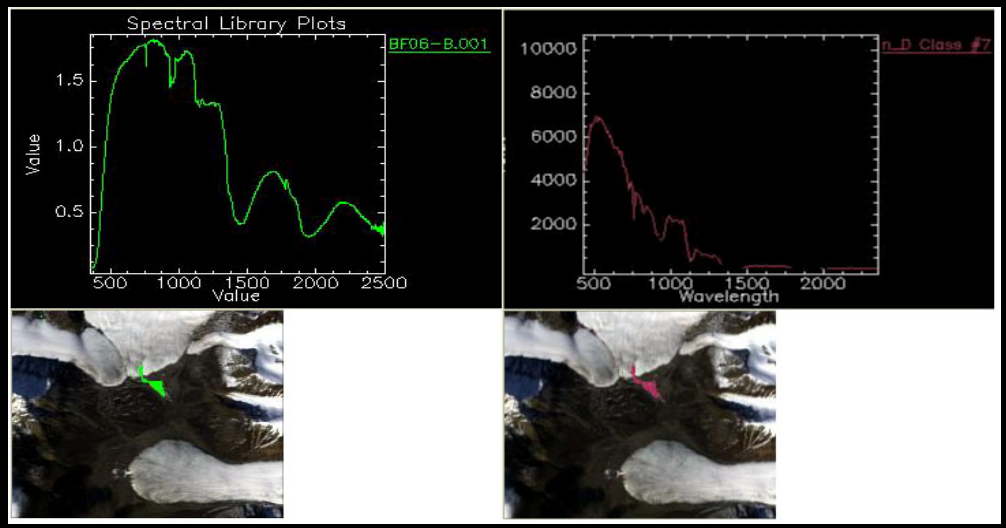
Identifying & mapping sulfur species

Collecting field data

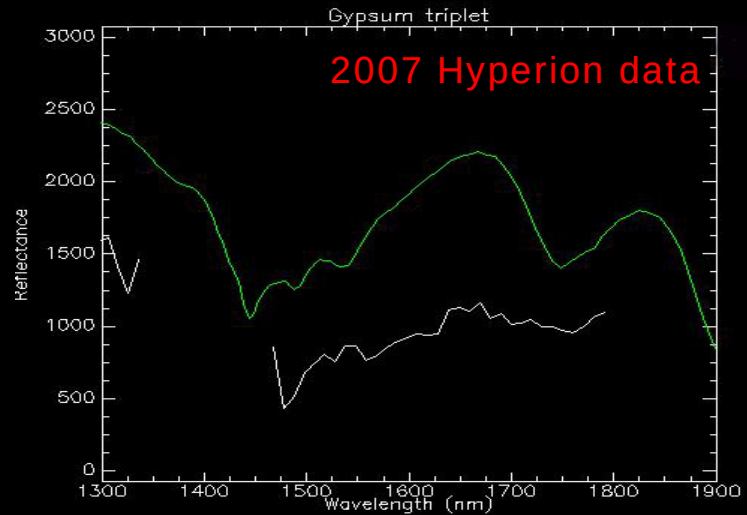
Mapping the deposits using spectral endmembers



Field data vs. satellite data as endmembers

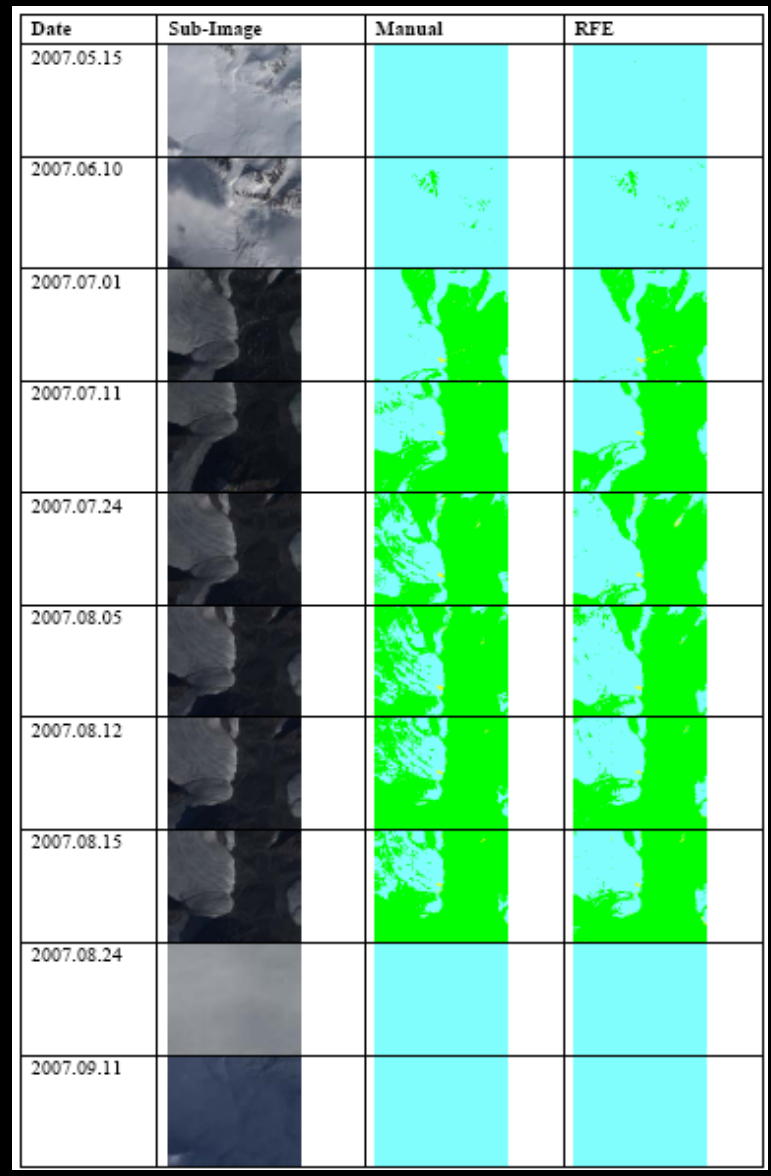


Identification of other S species

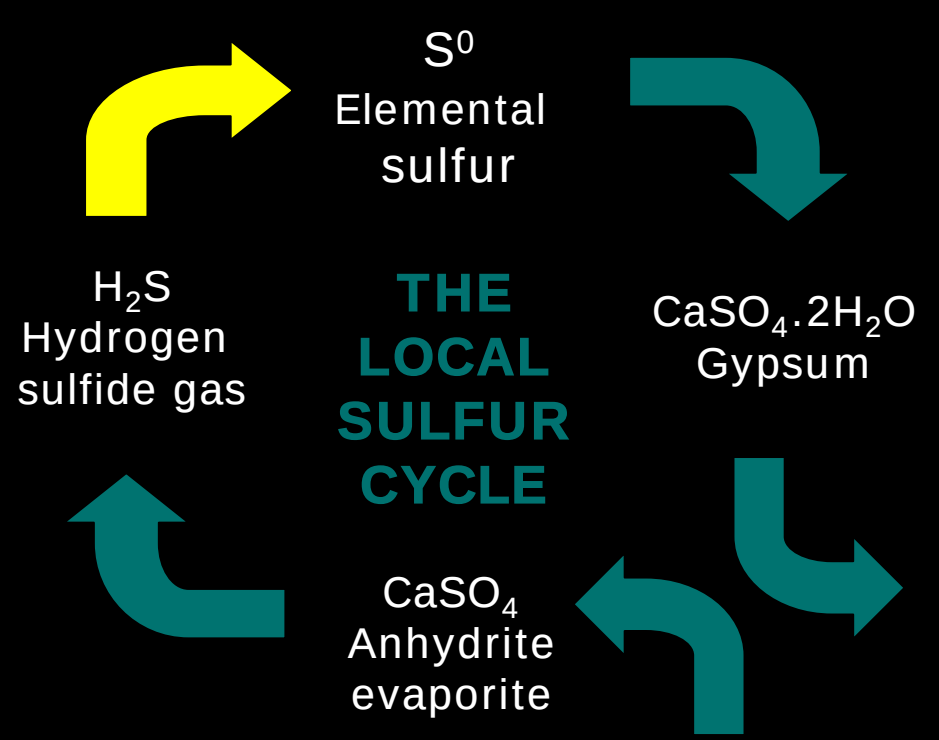


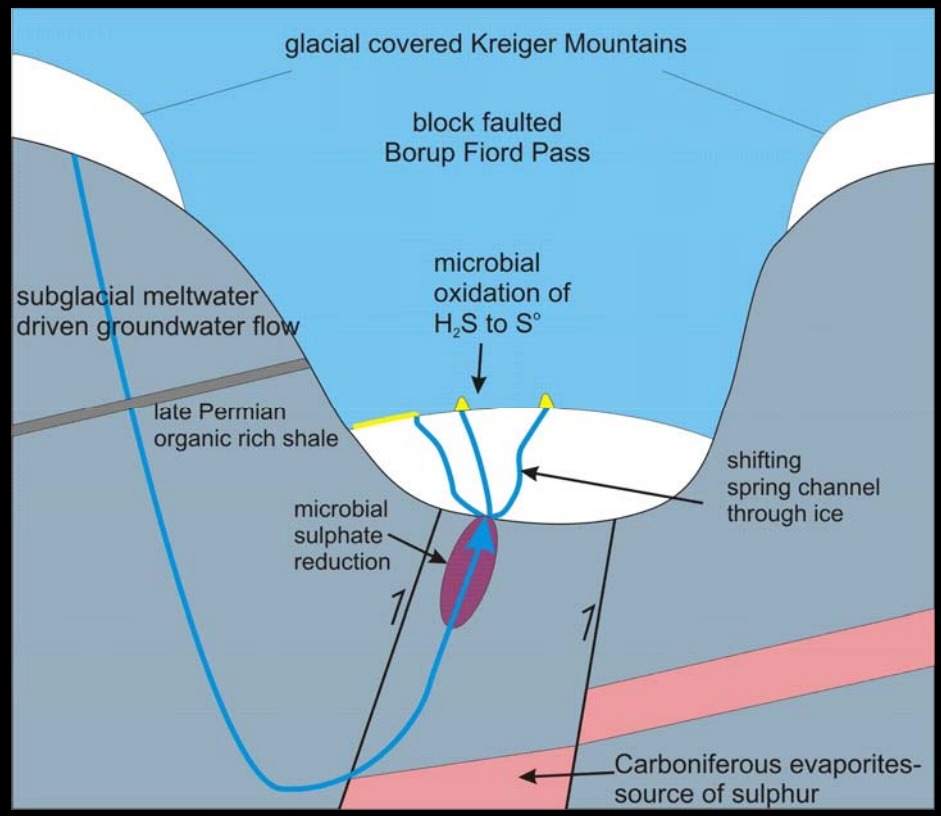
Change detection at Borup Fiord Pass

Satellite imagery of Borup Fiord Pass, Hyperion data from EO-1 and results from a sulfur classifier run onboard, after Castano et al, 2007

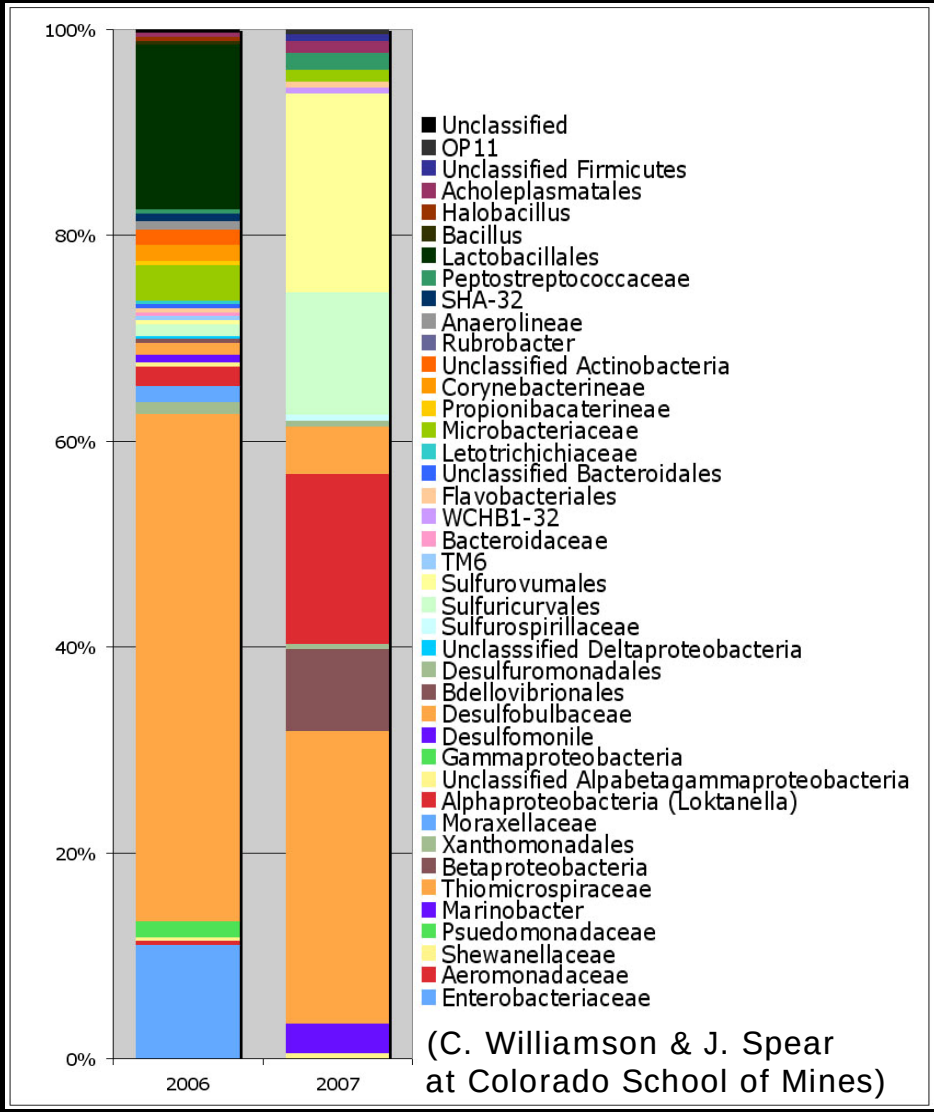


An hypothesized model of the system



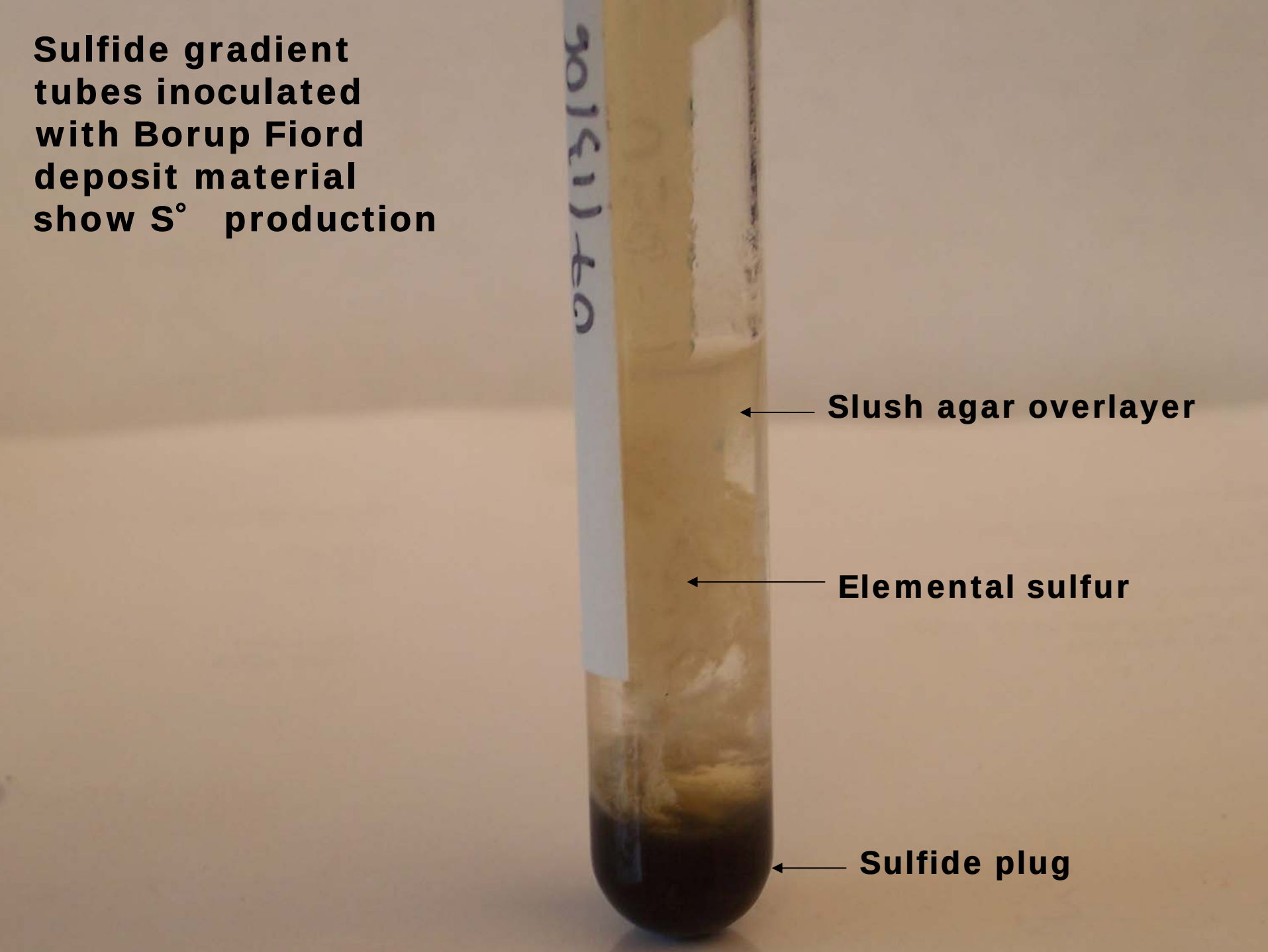


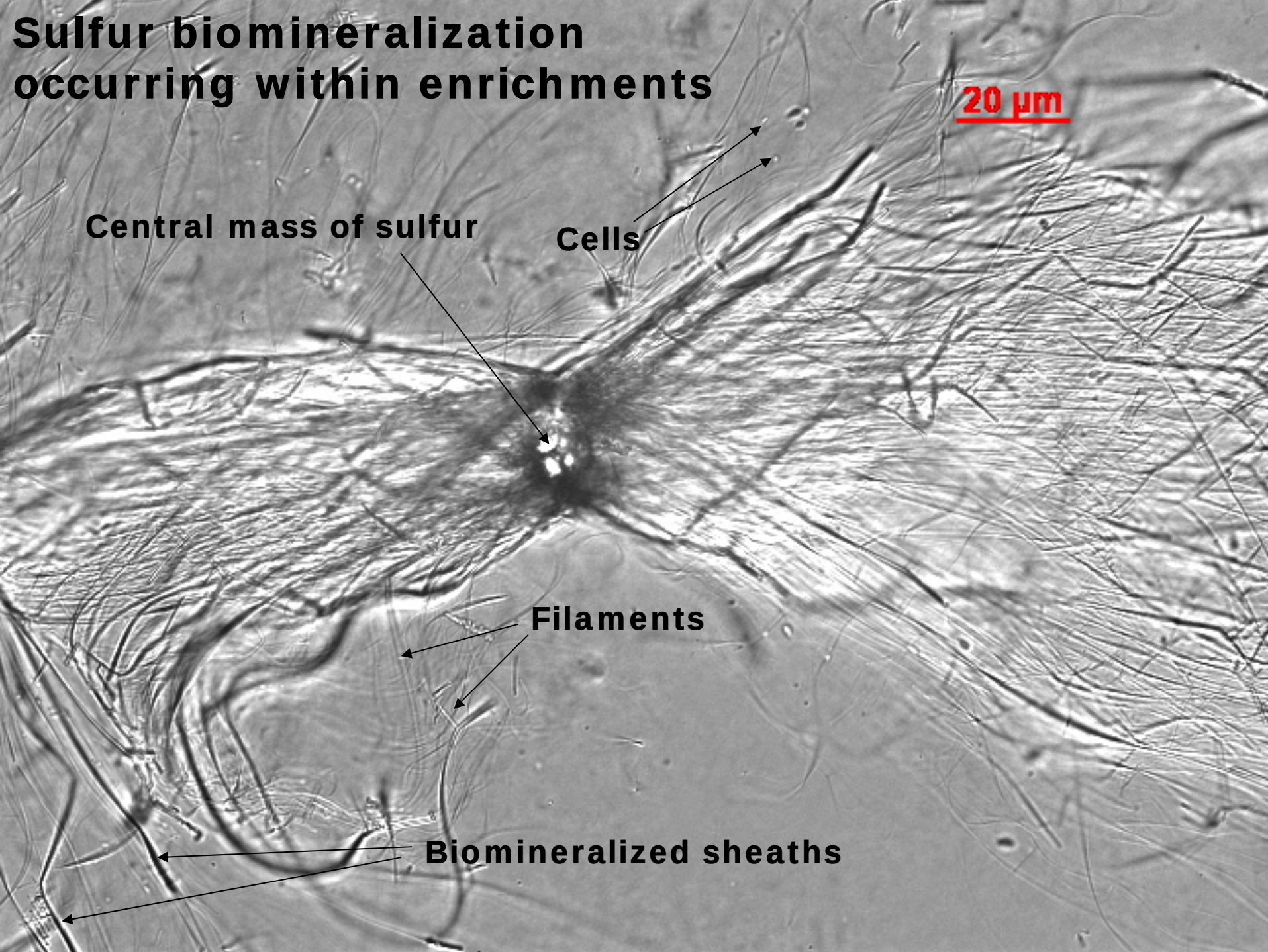
Environmental microbial diversity

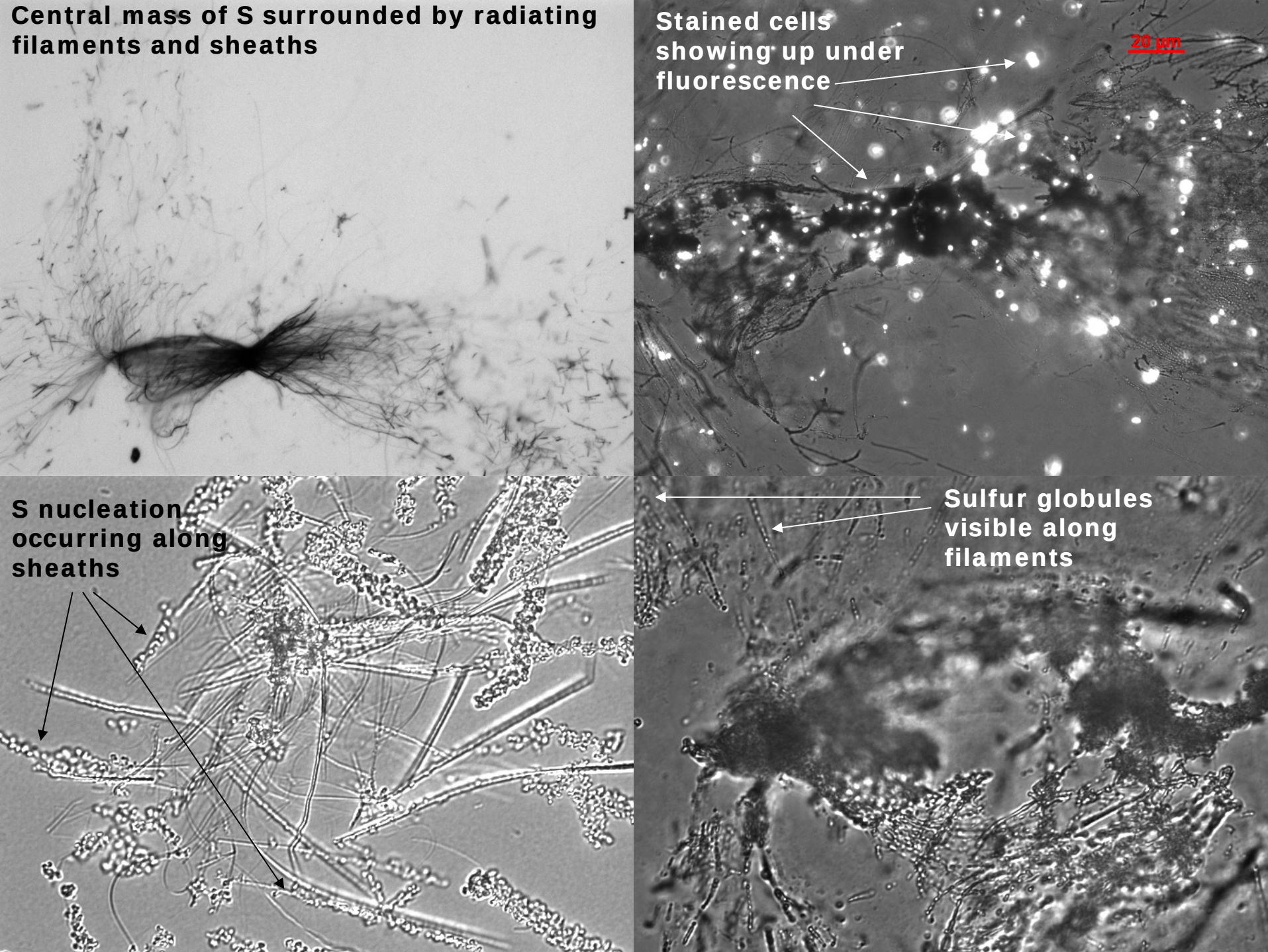


(C. Williamson & J. Spear at Colorado School of Mines)

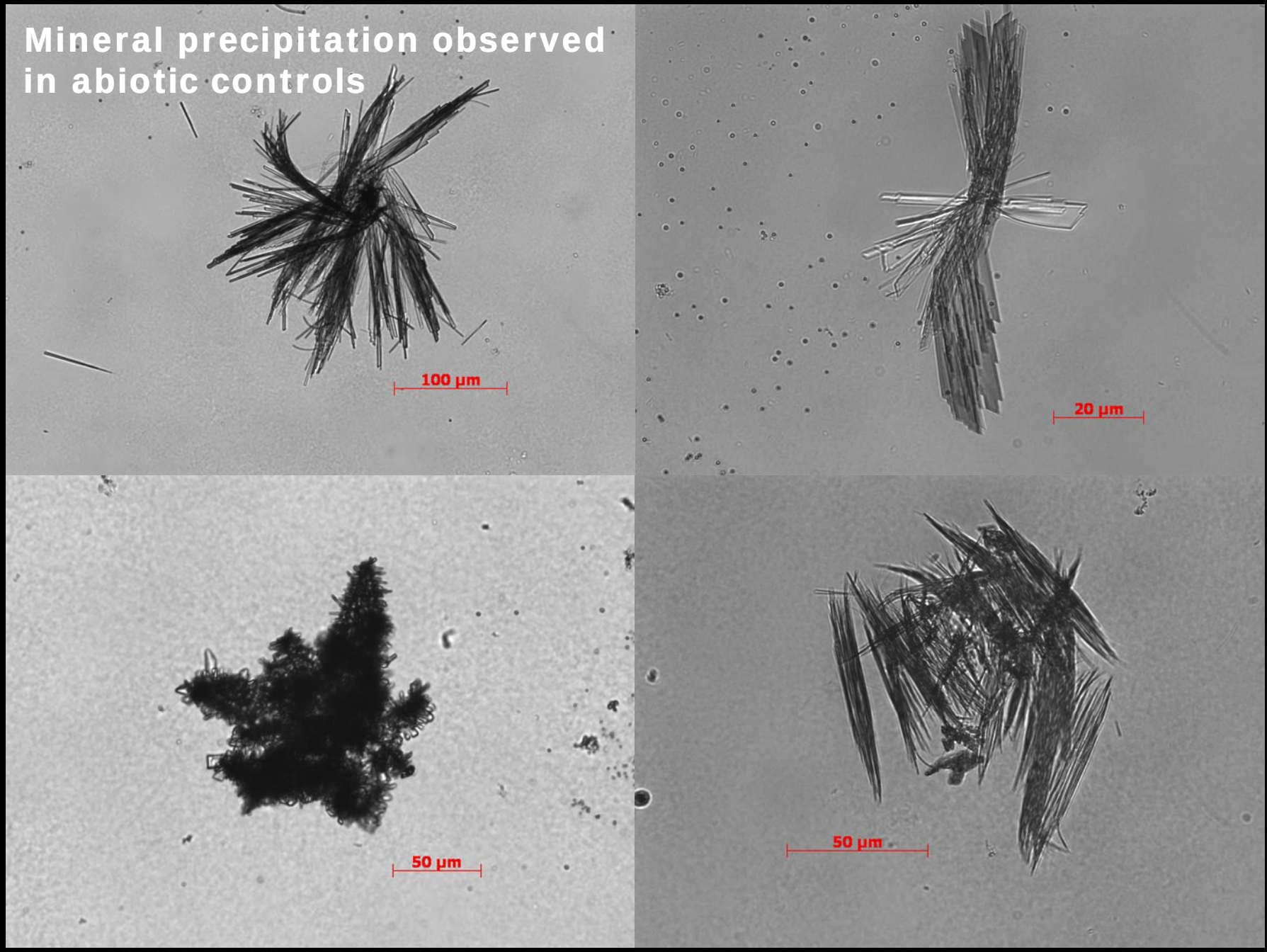
- Diverse but not greatly so
  - subzero temperatures
  - dominant sulfur-chemistry
- Candidates for sulfur-cyclers include:
  - *Thiomicrospira arctica*
  - *Loktanella salsilacus*
  - Deltaproteobacteria
  - Epsilonproteobacteria


Sulfide gradient tubes inoculated with Borup Fiord deposit material show S° production
Slush agar overlayer
Elemental sulfur
Sulfide plug

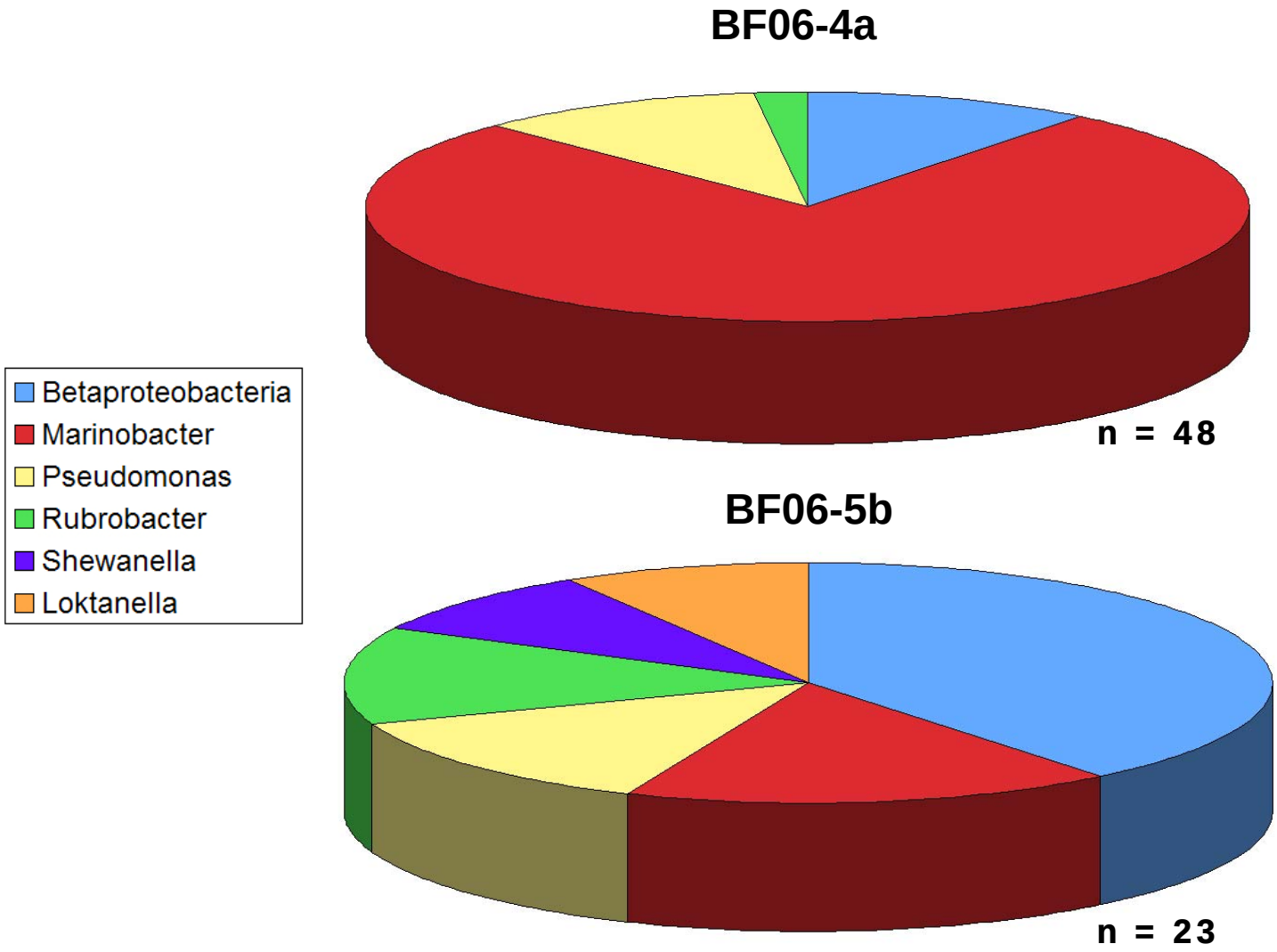

Sulfur biomineralization occurring within enrichments
20 µm
Central mass of sulfur
Cells
Filaments
Biomineralized sheaths

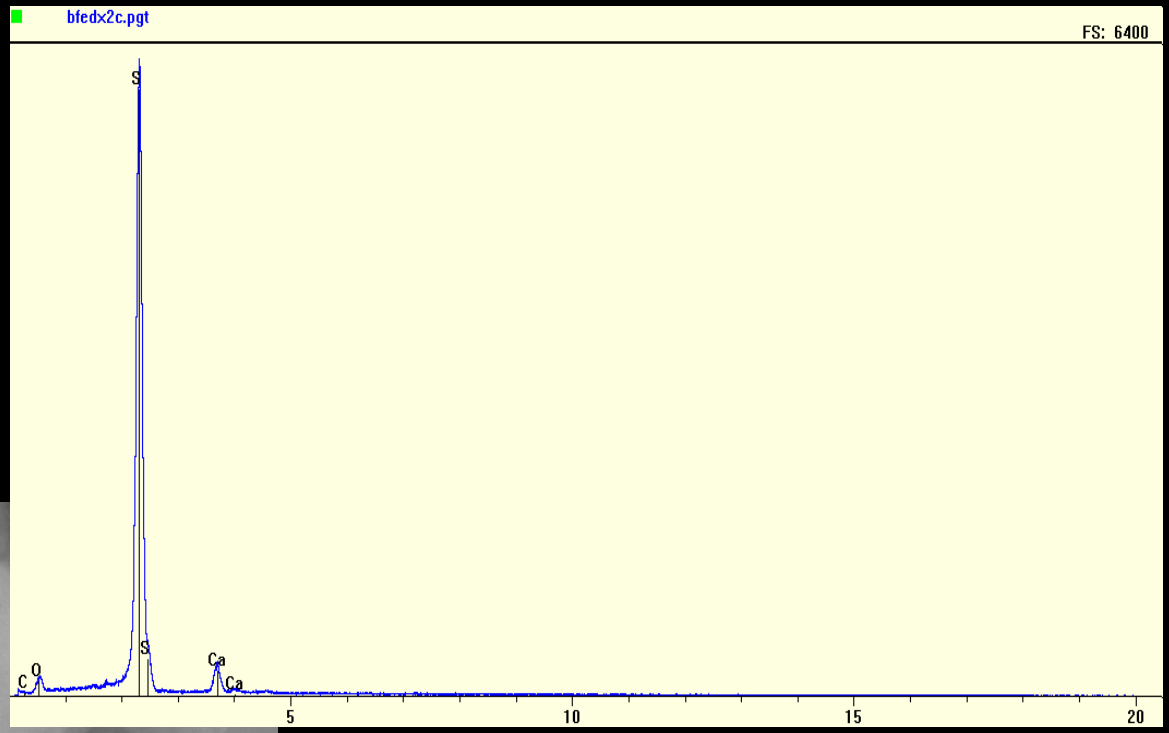

Central mass of S surrounded by radiating filaments and sheaths
Stained cells showing up under fluorescence
20 µm
S nucleation occurring along sheaths
Sulfur globules visible along filaments

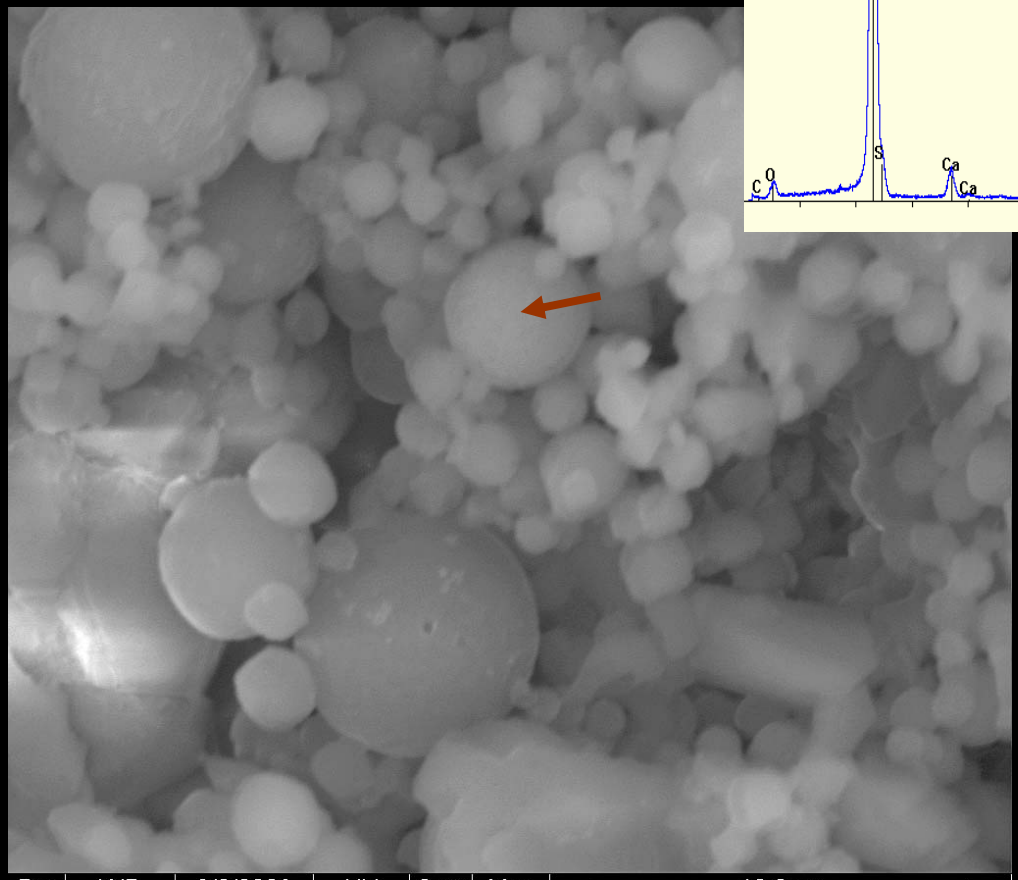
Mineral precipitation observed in abiotic controls



16s rRNA sequences from stable consortia within the enrichments







Det	WD	9/2/2008	HV	Spot	Mag	10.0µm
LFD	13.9 mm	4:24:50 PM	20.0 kV	4.5	5000x	test

Conclusions from Borup Fiord Pass

- Strong evidence for microbial mediation of the extensive sulfur-rich deposits at Borup Fiord Pass has been provided by experiments targeting microbes engaged in S^0 production, which are producing biomineralized sulfur-structures.

- These seasonal sulfur-rich deposits can be detected and monitored autonomously over the course of the season using strategies which are being developed for future Europa missions.

- Despite differences in temperature and radiation environment, the deposits at Borup Fiord Pass are the nearest terrestrial field analog we have to the “non-ice” materials at Europa, and our study of this analog site will inform efforts to identify these materials and investigate their potential to contain biosignatures.

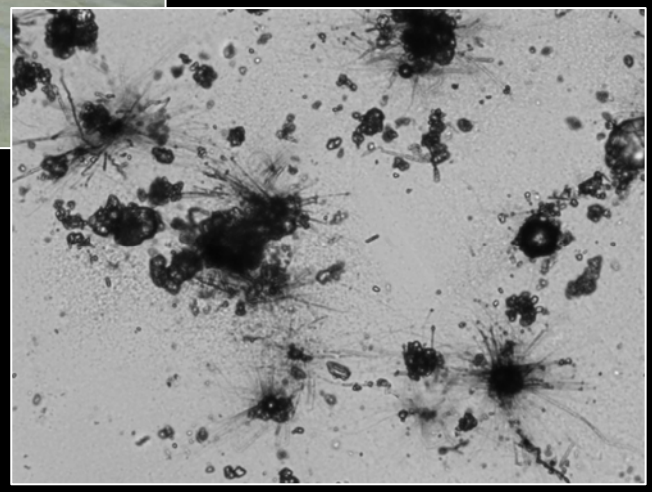
Open questions/future work

- Is the microbially induced S^0 distinguishable from abiotically produced sulfur?
- What is the preservation potential of these deposits and the biomineralized structures within them?
- What biosignatures would be generated under simulated Europa conditions?
- Are temperatures and mixing effects affecting the shapes and locations of absorption features?

Implications for a Europa lander

Sulfur-rich deposits could be used to narrow the search for biosignatures

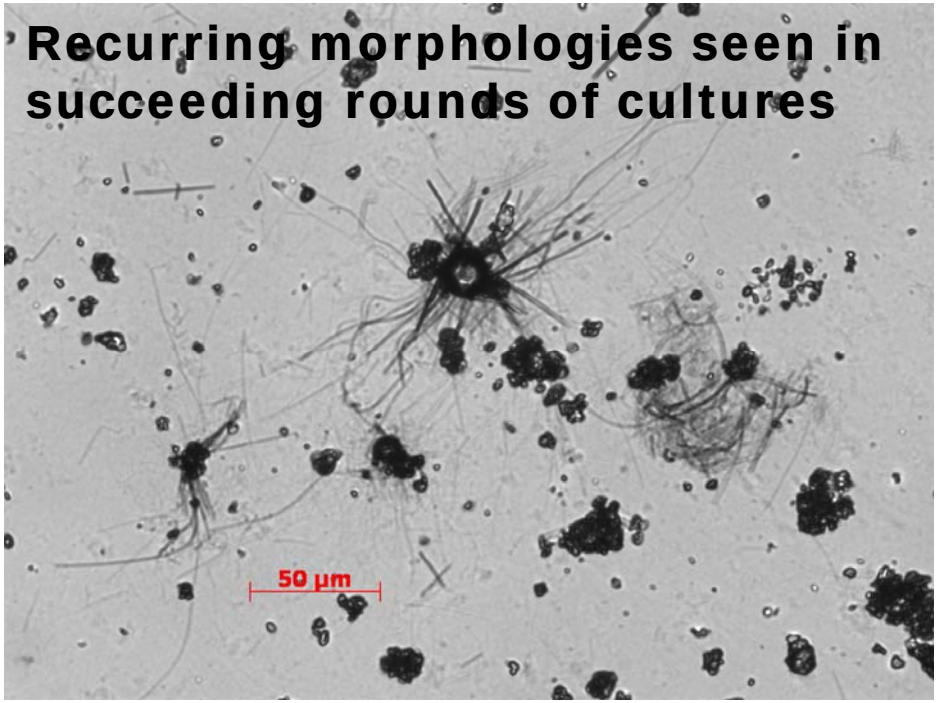
Microscopic imager would be necessary to distinguish morphological biosignatures

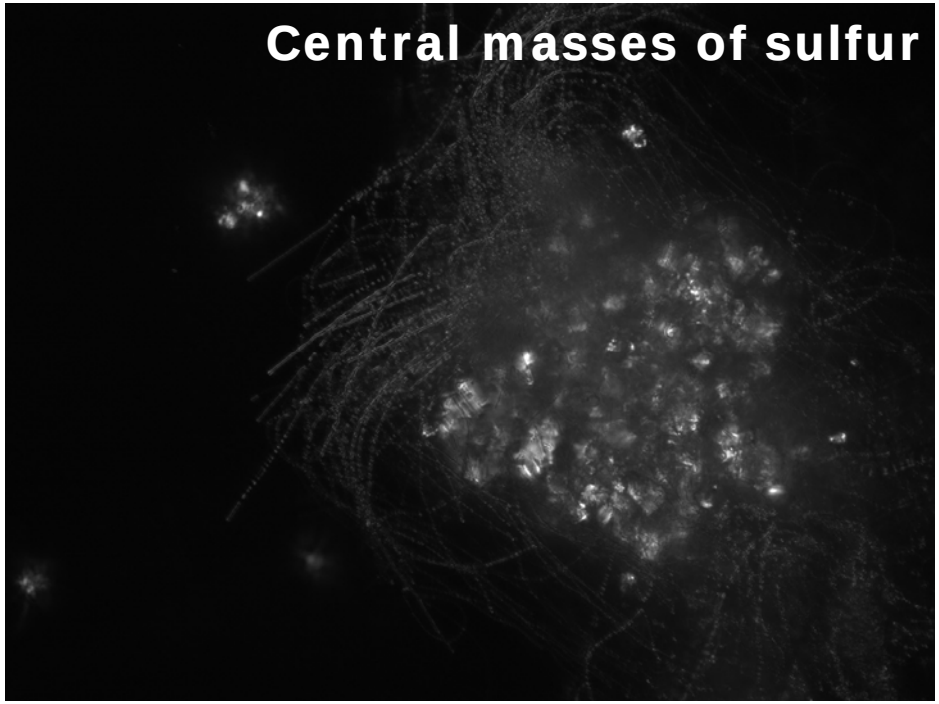


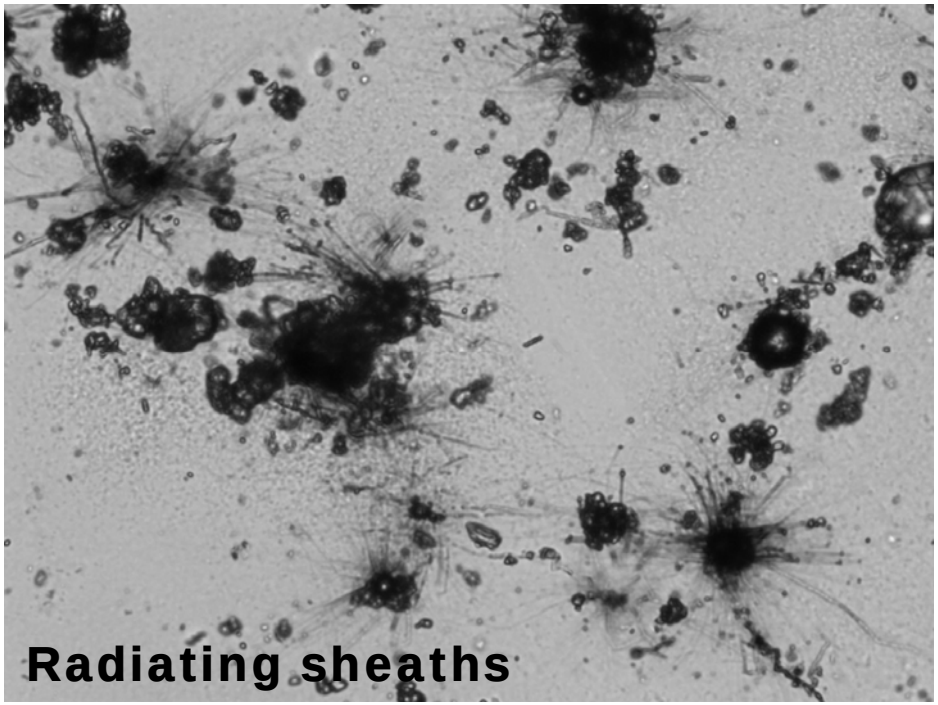
Thanks to:

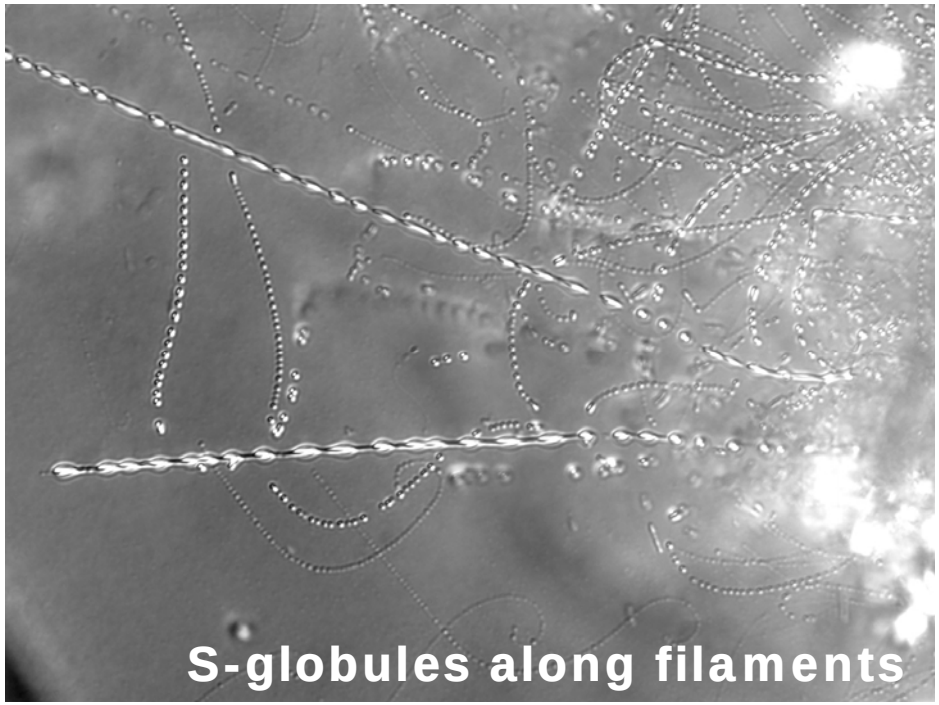
- Canadian Polar Continental Shelf project
- The Planetary Society
- Lewis & Clark Fund for Exploration and Field Research in Astrobiology

- NASA Astrobiology Institute Director’s Discretionary Fund

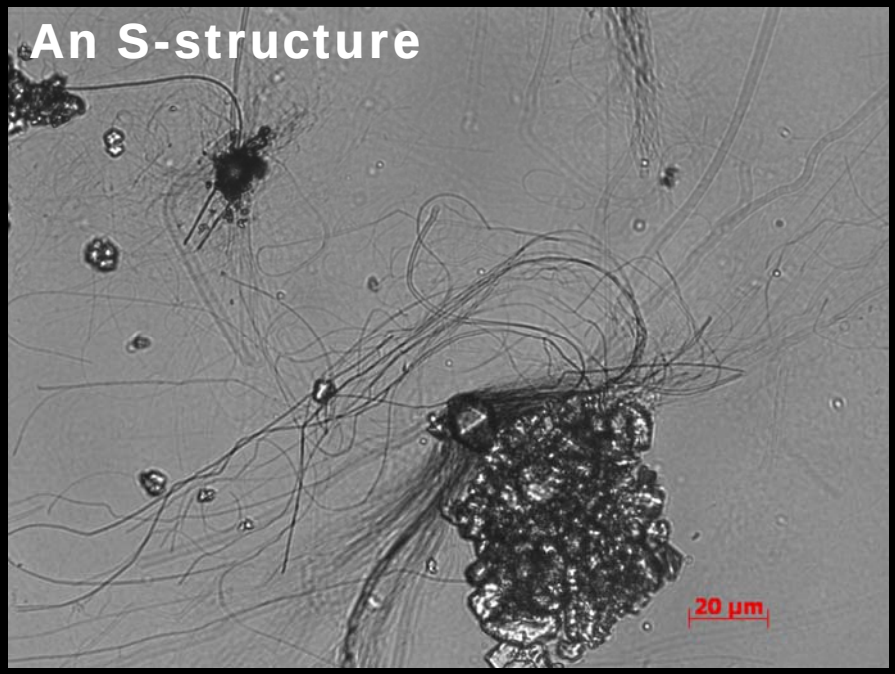

Recurring morphologies seen in succeeding rounds of cultures
50 µm


Central masses of sulfur

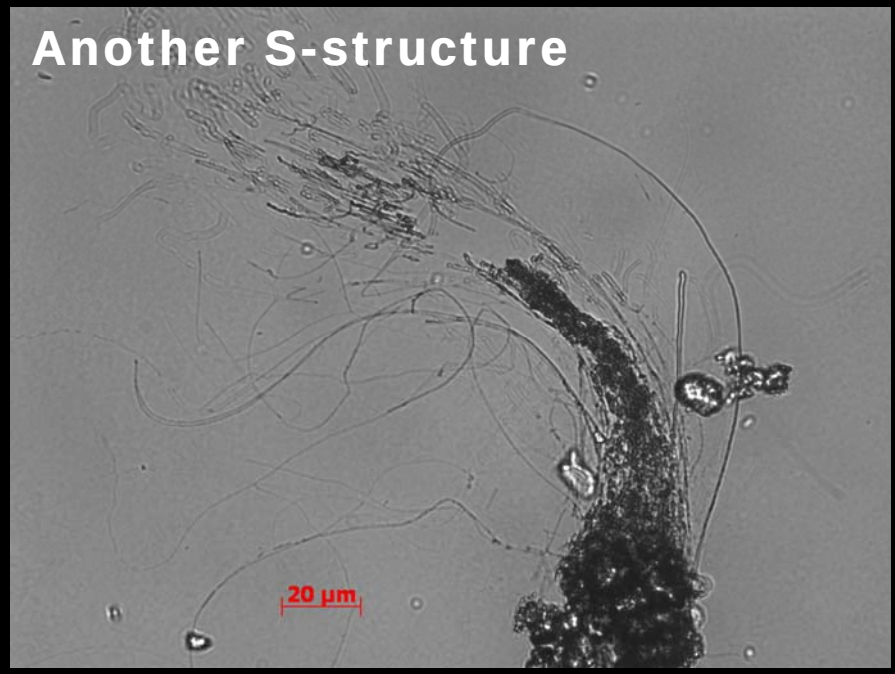

Radiating sheaths


S-globules along filaments

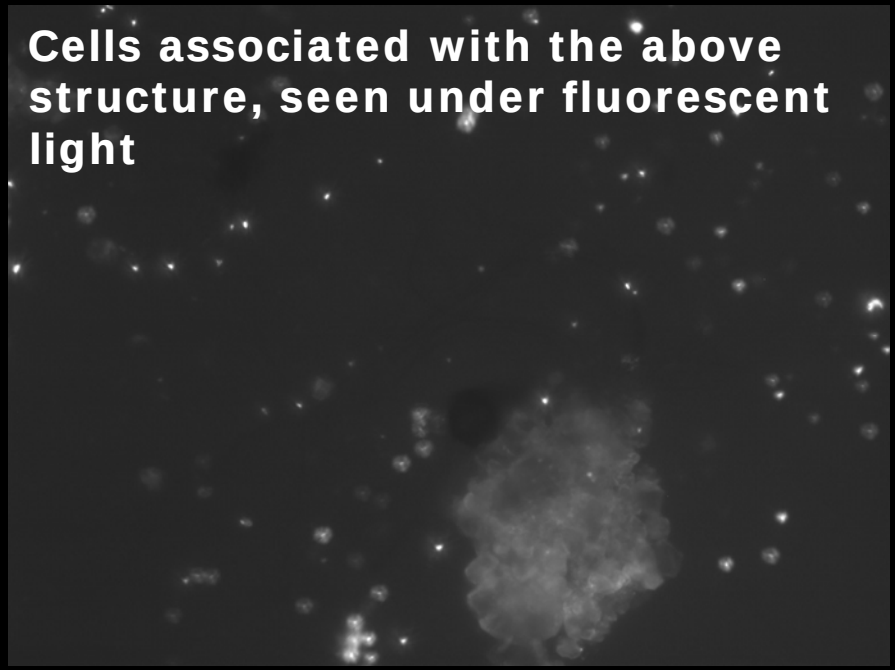
An S-structure



Another S-structure



Cells associated with the above structure, seen under fluorescent light



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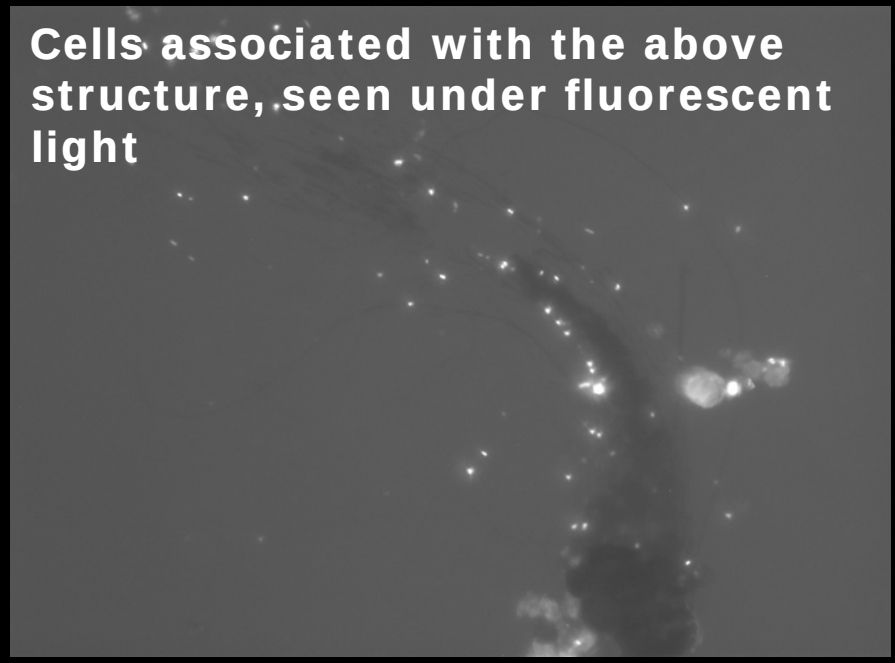
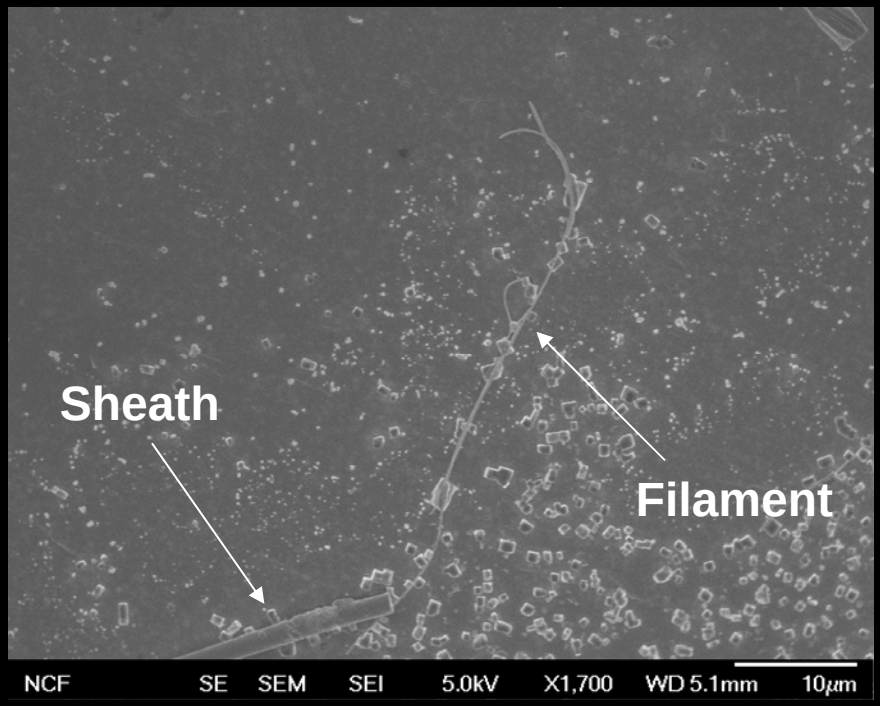
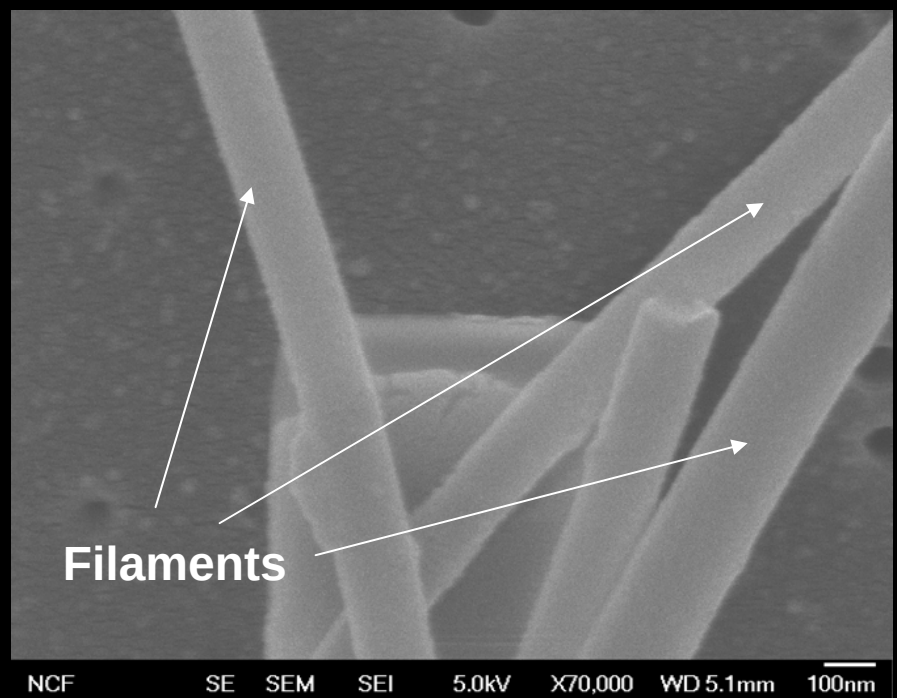



Sheath
Filament
NCF SE SEM SEI 5.0kV X1,700 WD 5.1mm 10μm

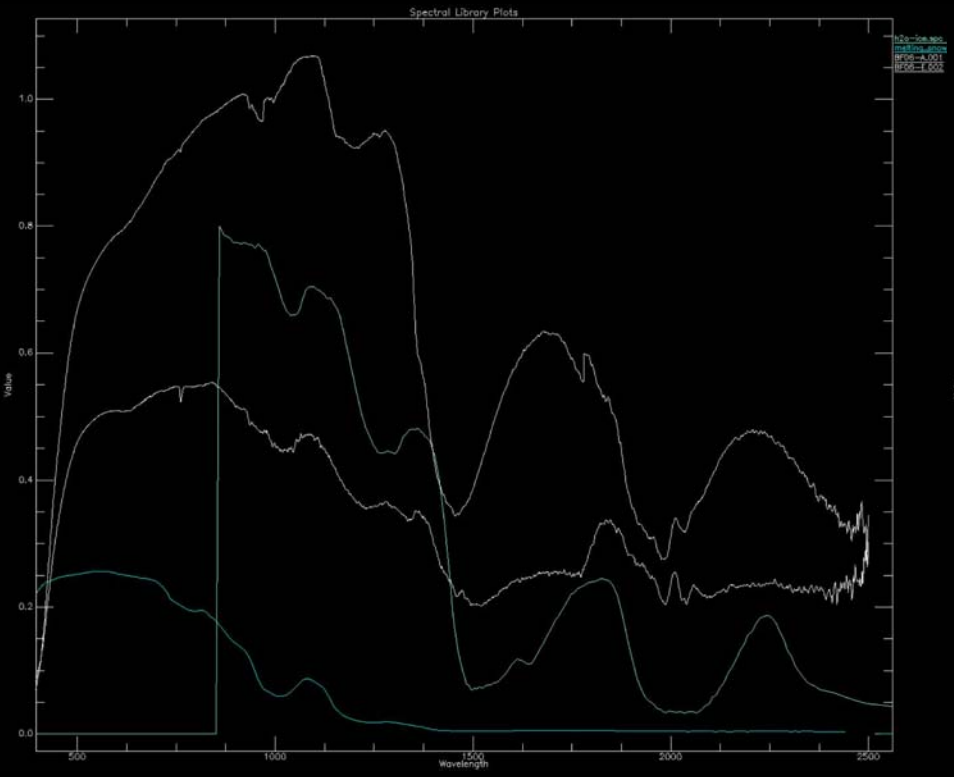

Sheath
NCF SE SEM SEI 5.0kV X8,500 WD 5.1mm 1μm


Filament with salt crystals
NCF SE SEM SEI 5.0kV X8,500 WD 5.1mm 1μm

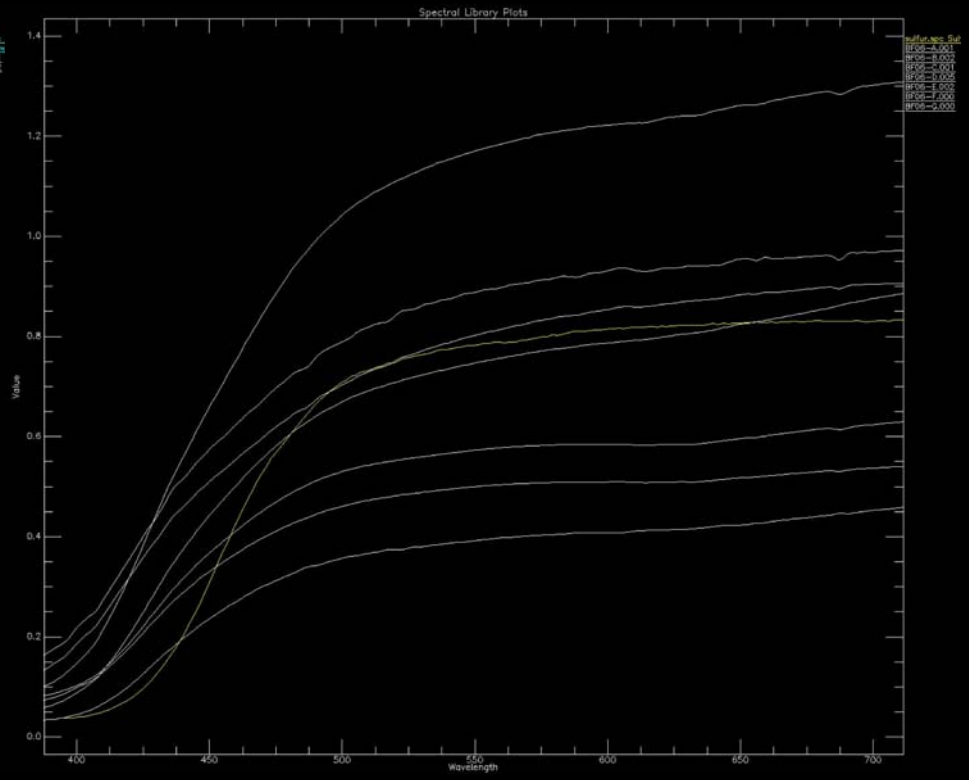

Filaments
NCF SE SEM SEI 5.0kV X70,000 WD 5.1mm 100nm

Field spectra from Borup Fiord

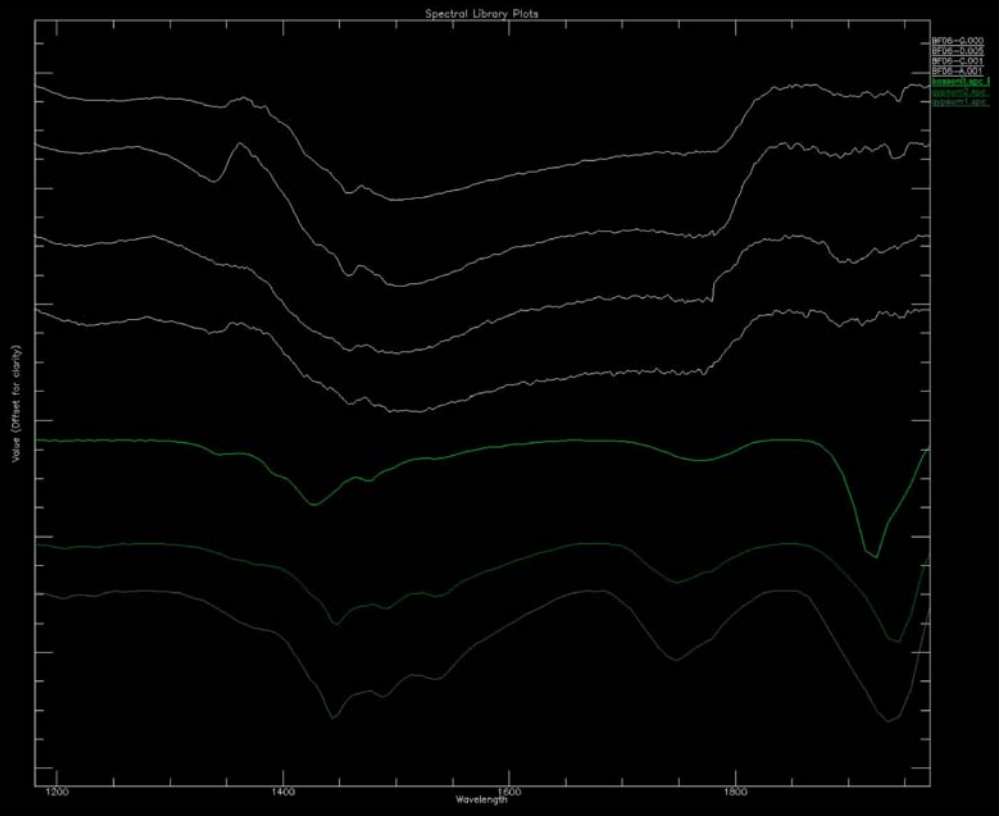
Ice & snow



Elemental sulfur



Sulfates in the deposits



Gypsum
($CaSO_4.2H_2O$)

Bassanite
($CaSO_4.1/2H_2O$)