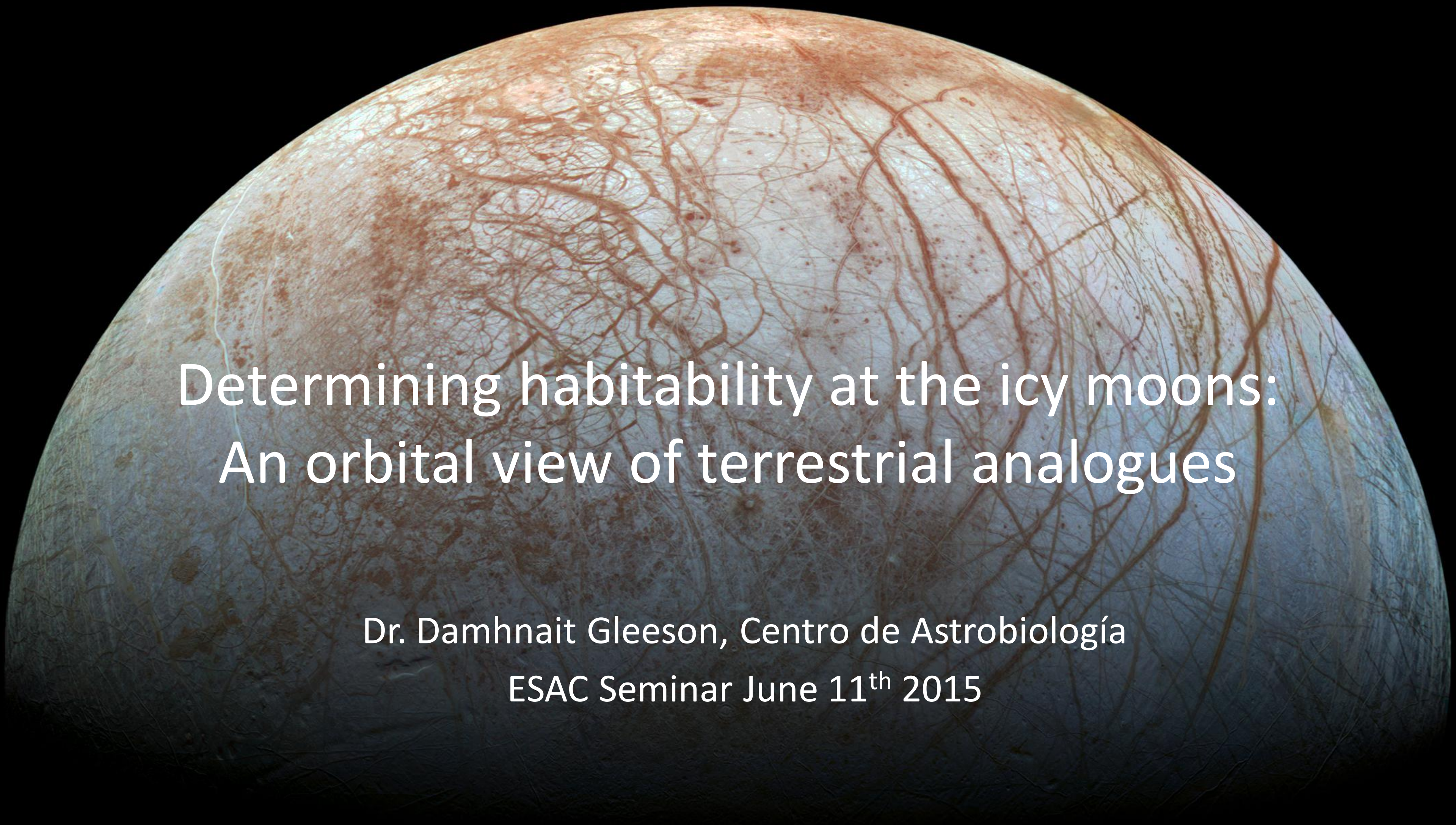


Determining habitability at the icy moons: An orbital view of terrestrial analogues

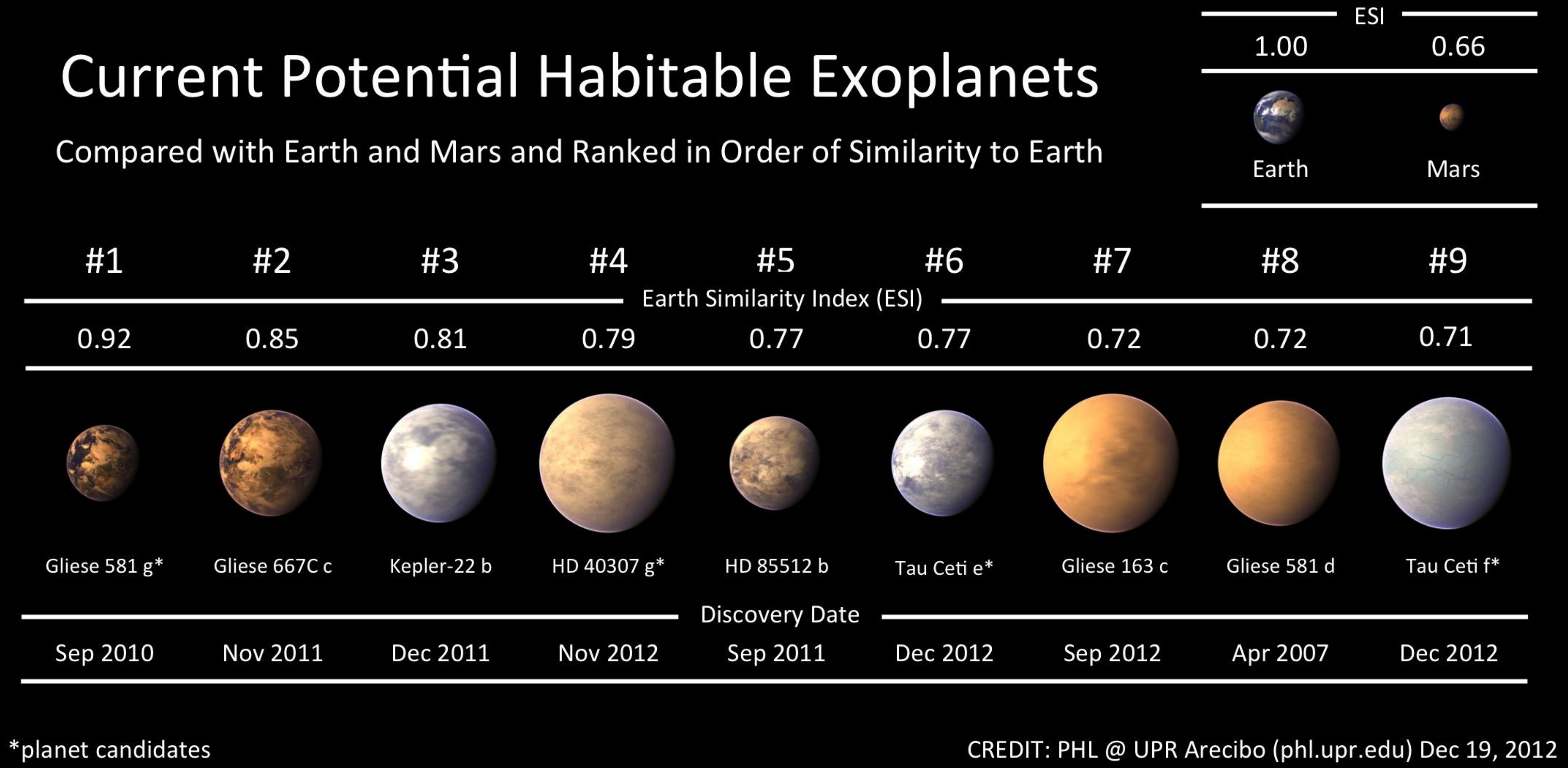
Dr. Damhnait Gleeson, Centro de Astrobiología

ESAC Seminar June 11th 2015

What does it mean to be habitable?

“Billions and billions of planets”, “17 billion Earths”, “15 New Planets Hint at "Traffic Jam" of Moons in Habitable Zone”, “Nearly Half of Sun-Like Stars May Have Earth-Like Planets”, “NASA'S Kepler Mission Discovers 461 New Planet Candidates”

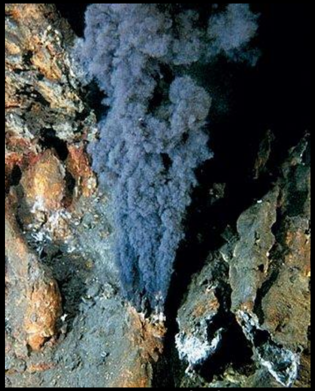
“Earth-like”


Current Potential Habitable Exoplanets
Compared with Earth and Mars and Ranked in Order of Similarity to Earth
ESI
1.00
0.66
Earth
Mars
#1
#2
#3
#4
#5
#6
#7
#8
#9
Earth Similarity Index (ESI)
0.92
0.85
0.81
0.79
0.77
0.77
0.72
0.72
0.71
Gliese 581 g*
Gliese 667C c
Kepler-22 b
HD 40307 g*
HD 85512 b
Tau Ceti e*
Gliese 163 c
Gliese 581 d
Tau Ceti f*
Discovery Date
Sep 2010
Nov 2011
Dec 2011
Nov 2012
Sep 2011
Dec 2012
Sep 2012
Apr 2007
Dec 2012
*planet candidates
CREDIT: PHL @ UPR Arecibo (phl.upr.edu) Dec 19, 2012

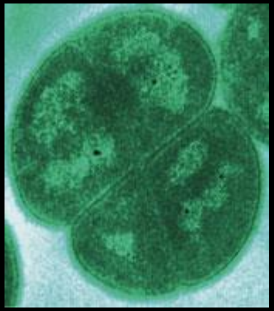
Earth life


Halophiles


Thermophiles


Piezophiles

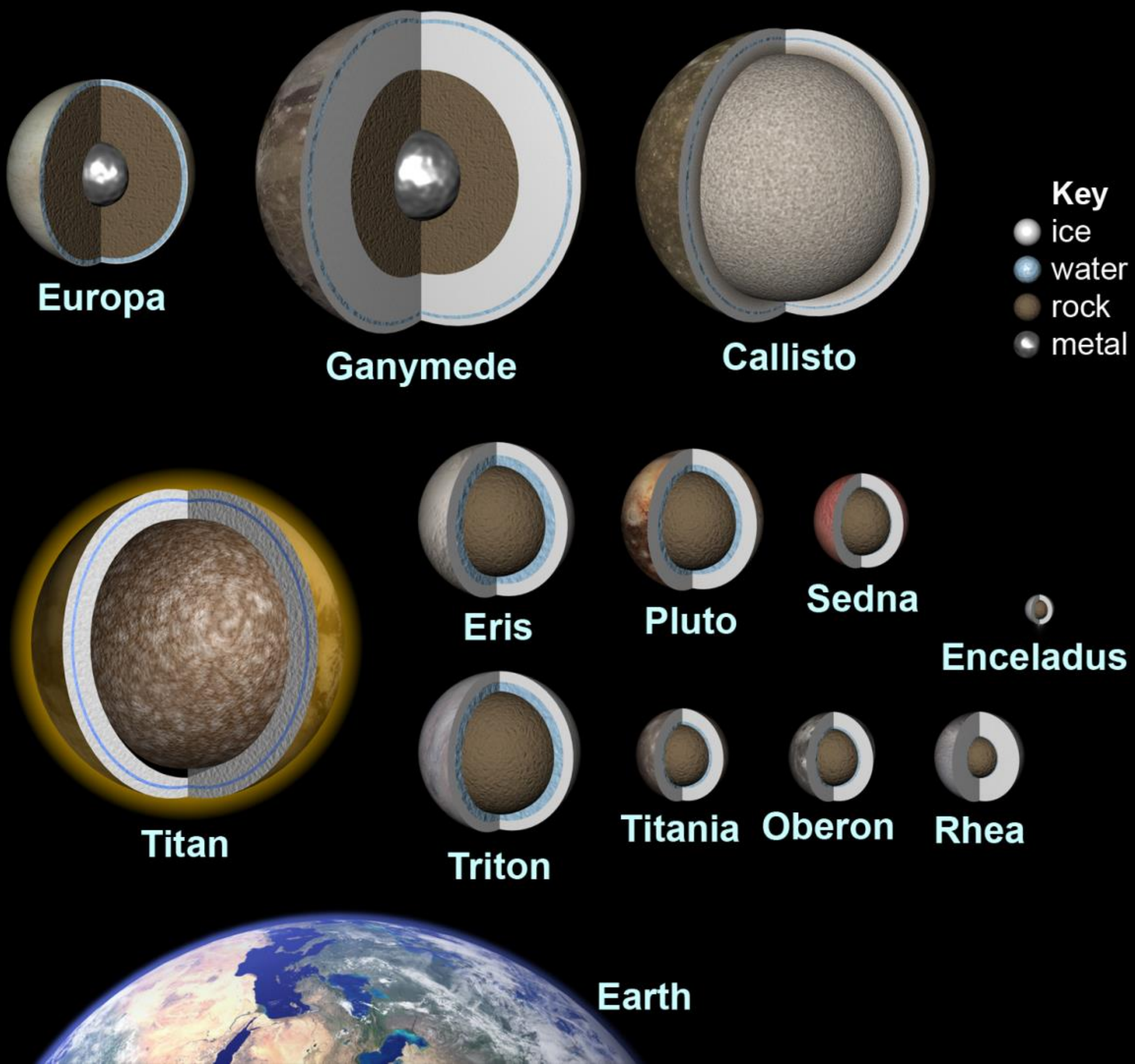

Psychrophiles


Polyextremophiles

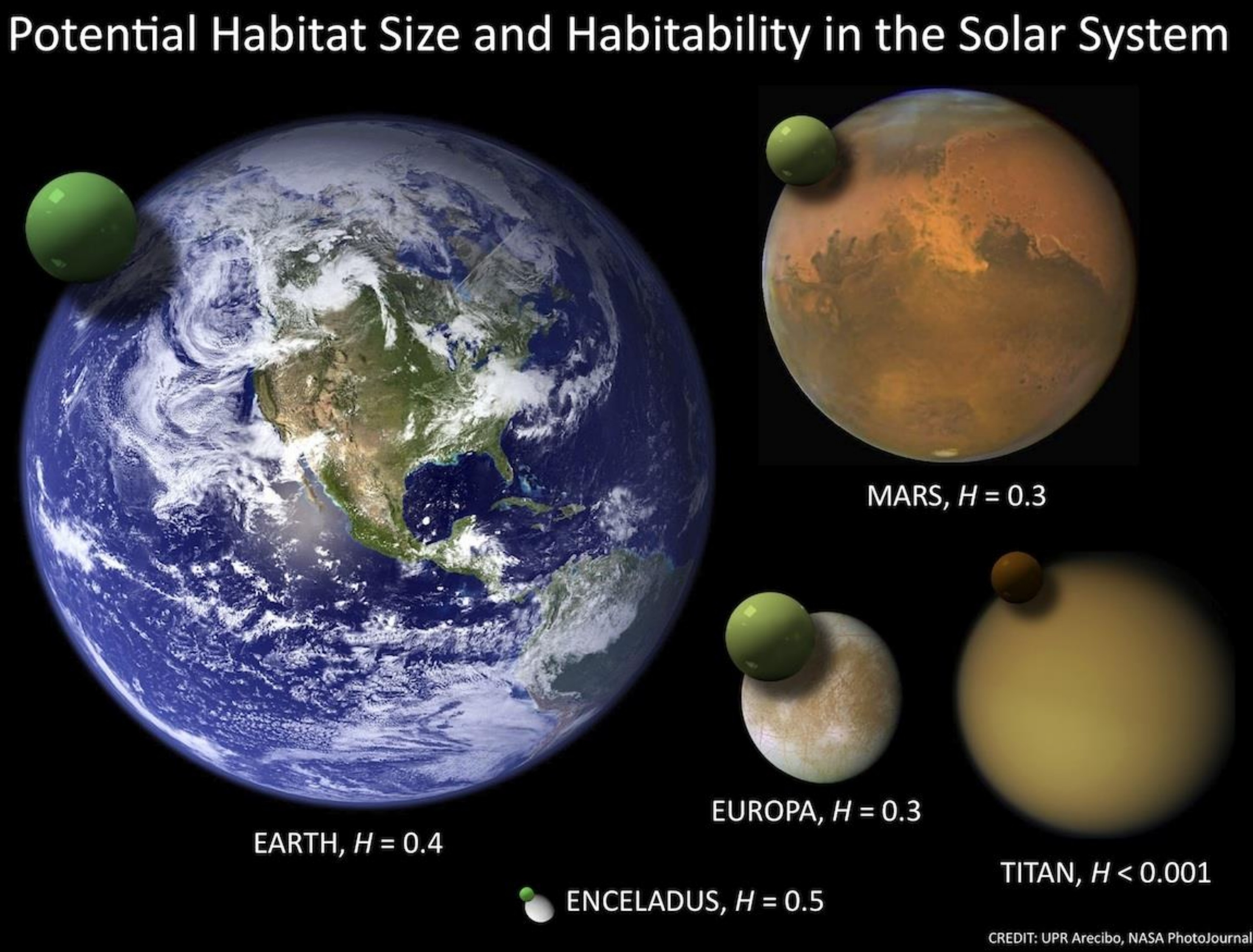
Essentials

1. Liquid H_2O
2. Biogenic elements
3. Solar or geochemical energy source

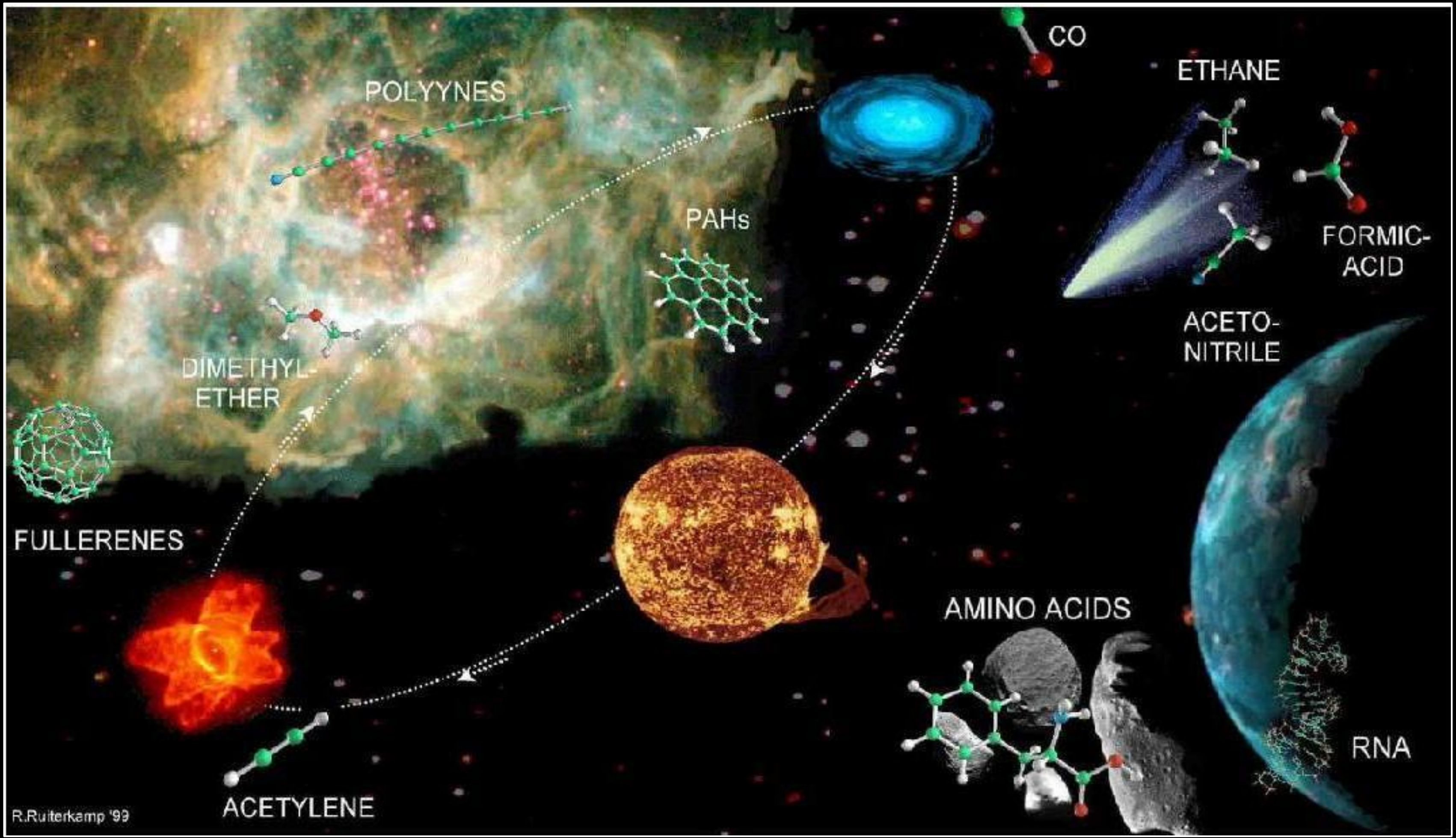
The presence of liquid water



Availability of liquid water

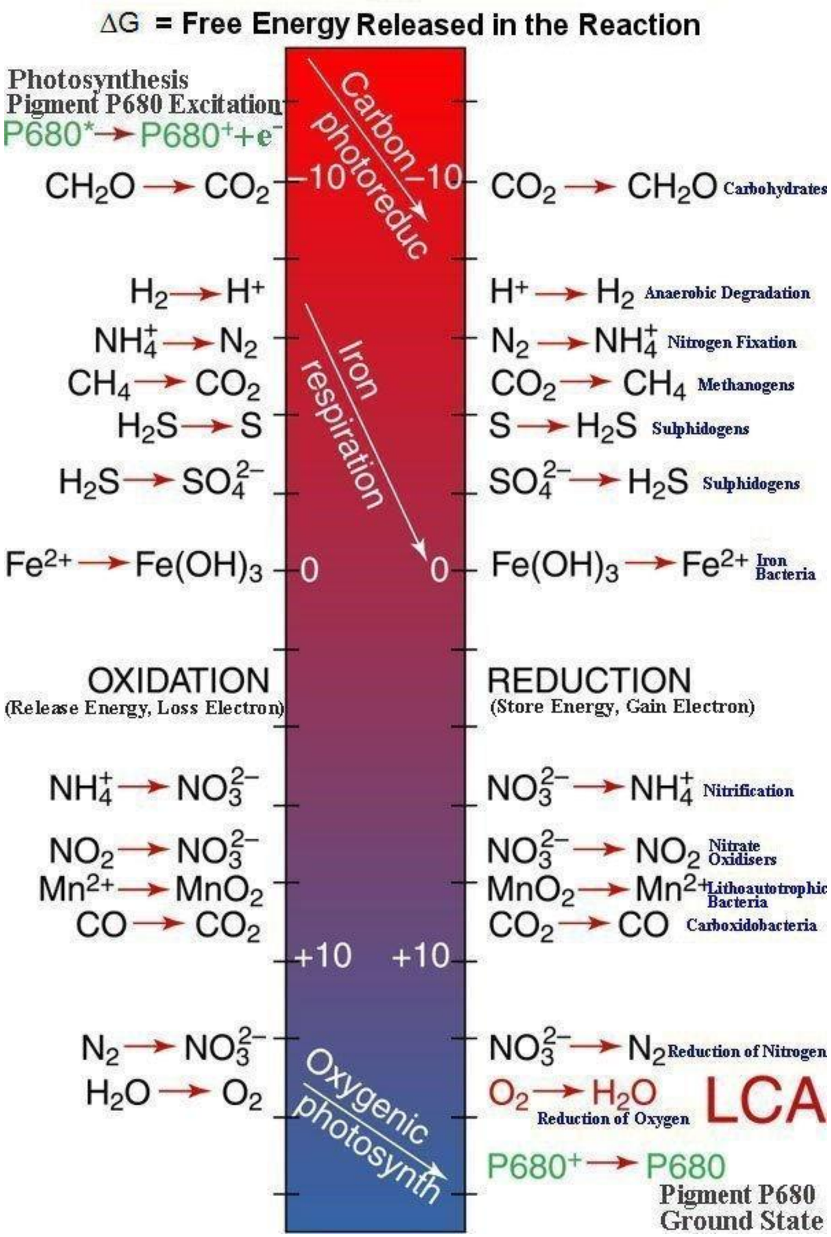


The presence of organics



Organics are formed in simple forms in the interstellar medium, in star-forming regions, and on dust grains. They are found in more complex forms in comets and meteorites up to amino acids and simple sugars. Organics have also been observed on the surfaces of moons and planets in our solar system.

An available energy source

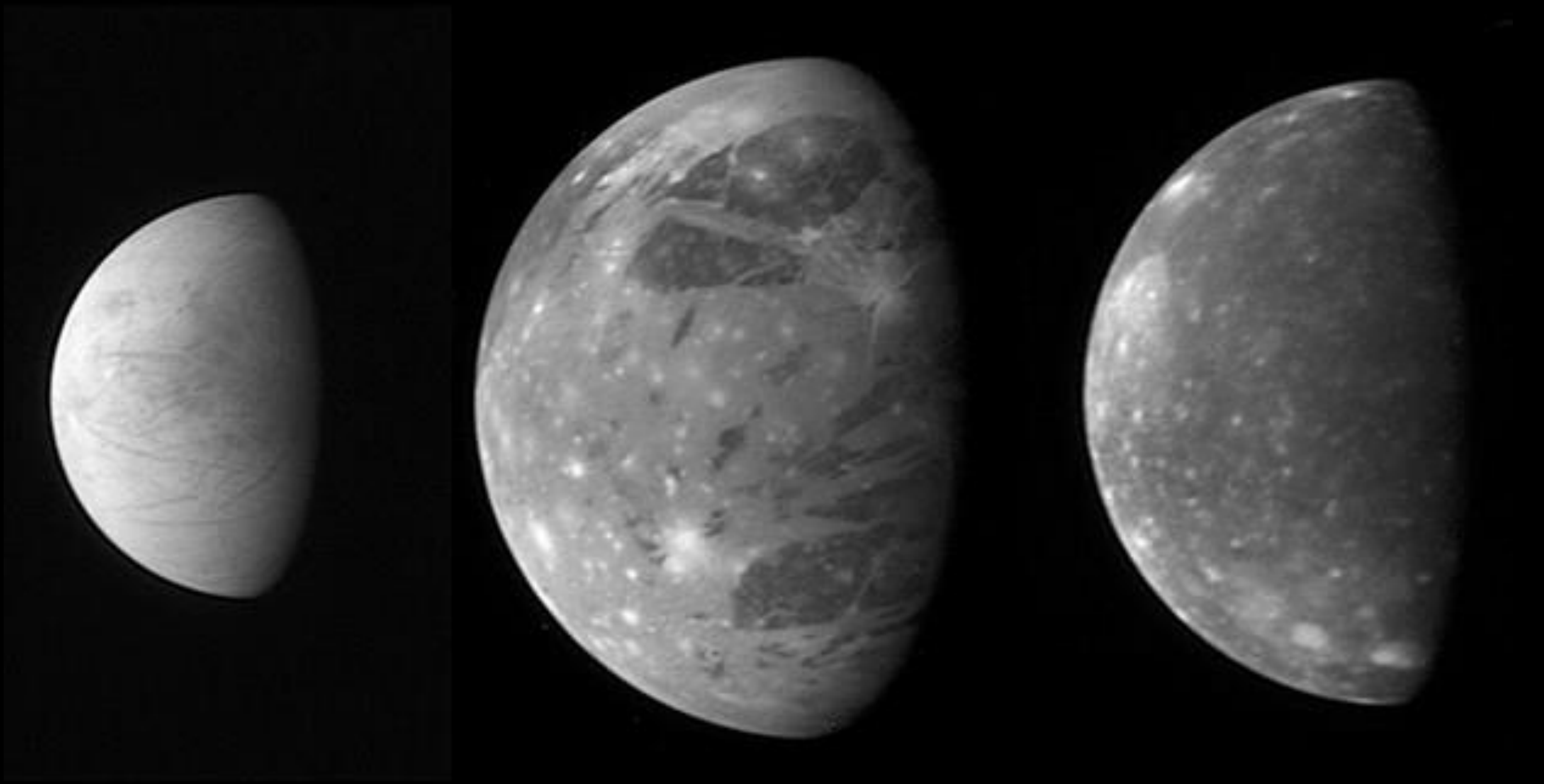


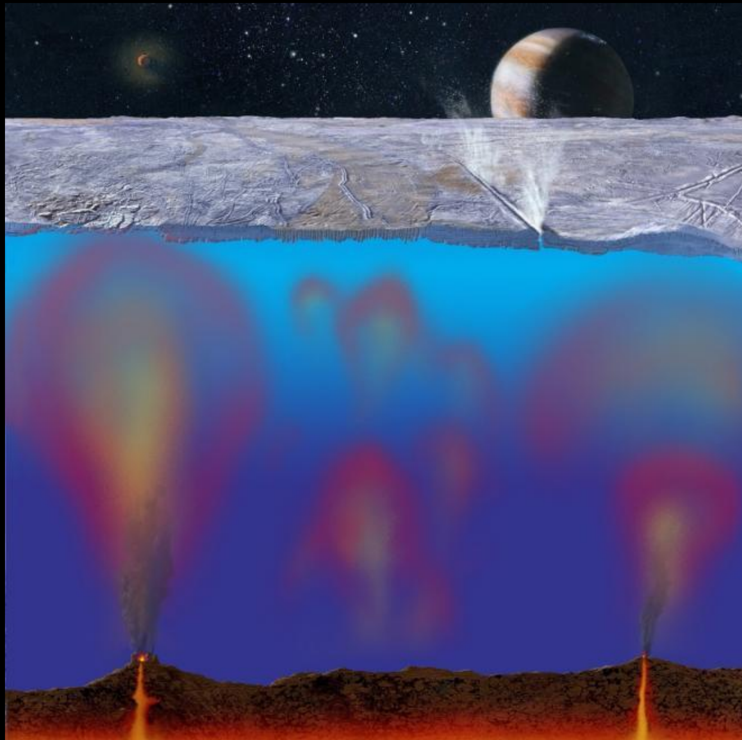
Redox reactions – The utilization of chemical energy in living systems involves the transfer of electrons from one reactant to another.

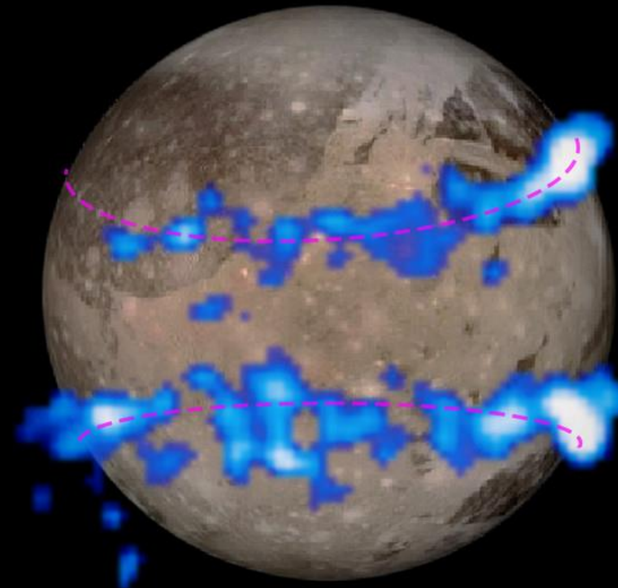
- **Phototropy**: electrons within chorophyll become energized by the absorption of light to more negative electron potentials
- **Chemoheterotroph**y: oxidation of organic compounds
- **Chemolithotrophy:** oxidation of reduced inorganic substrates in the environment

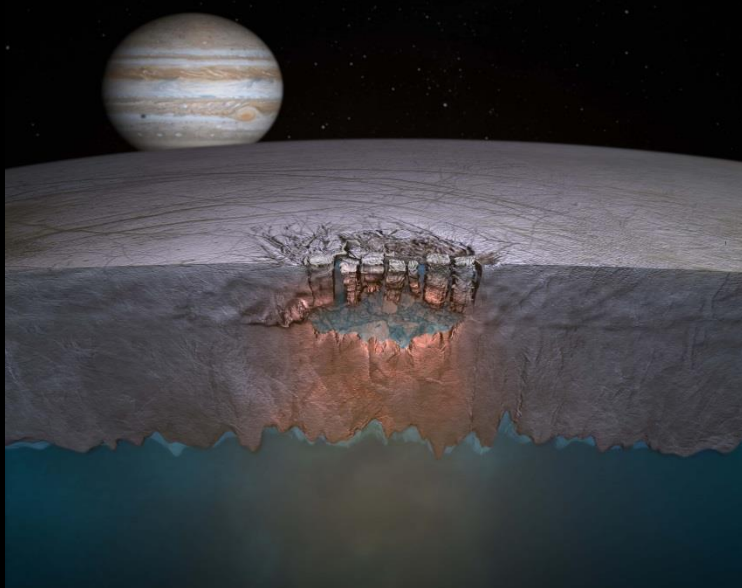
Do the icy moons of Jupiter meet these criteria for habitability?

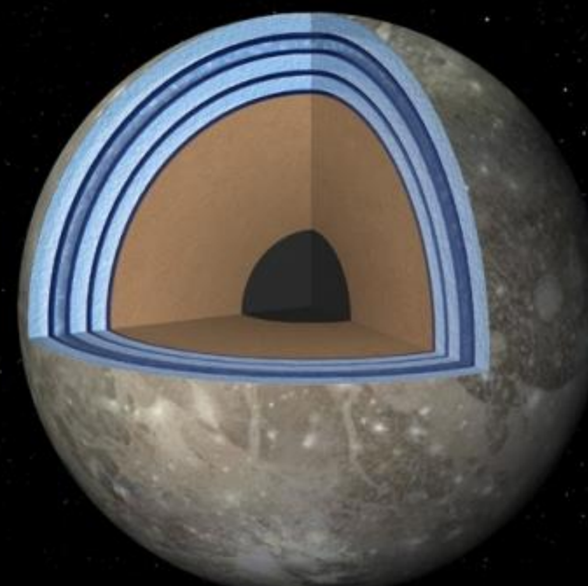
Ocean worlds





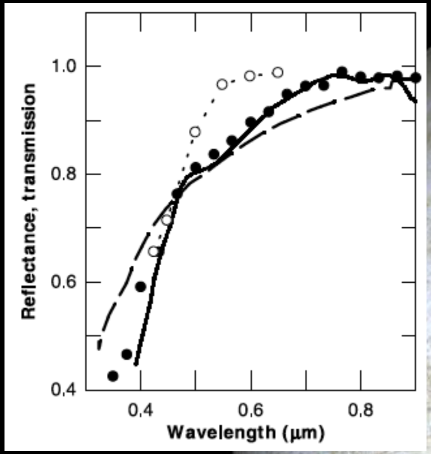






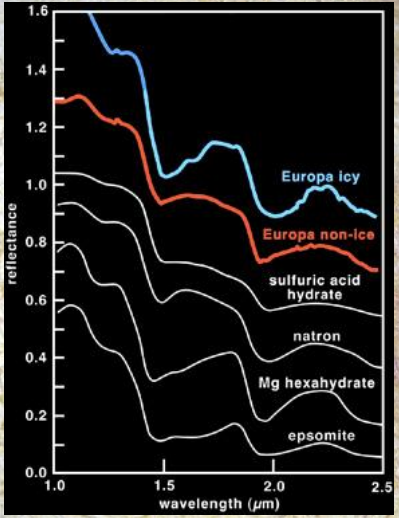
Composition of the oceans

Visible



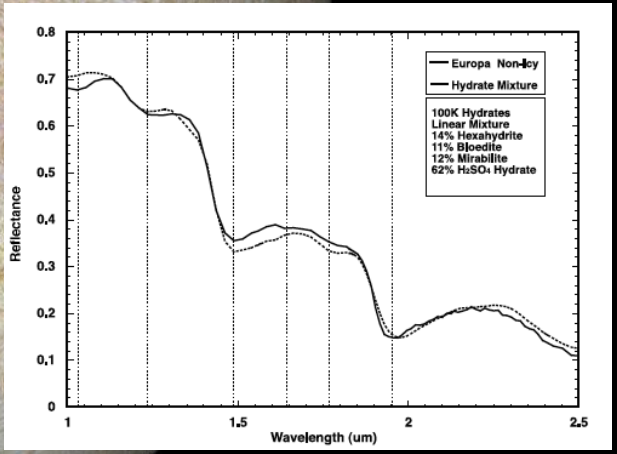
Carlson et al. 1999

IR models



Carlson et al. 1999
McCord et al 1998

IR bes



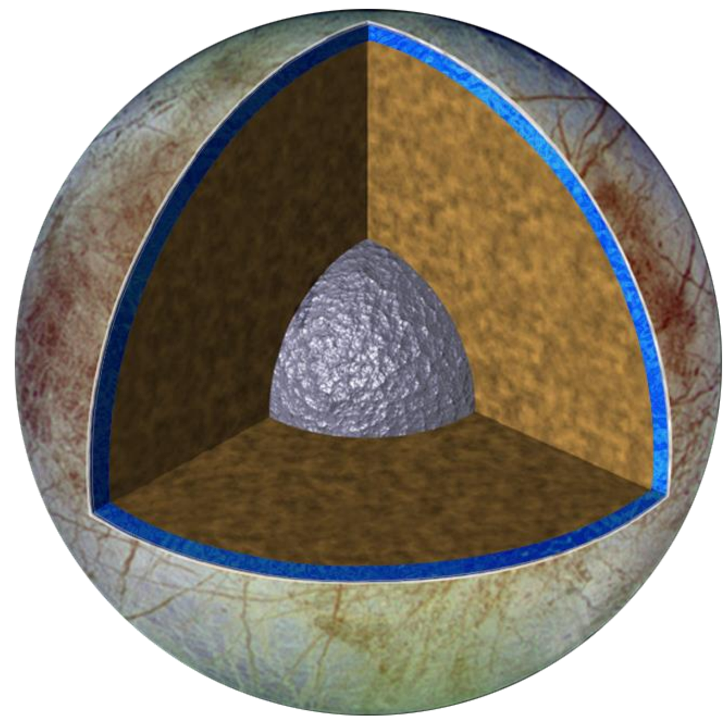
Dalton 2007

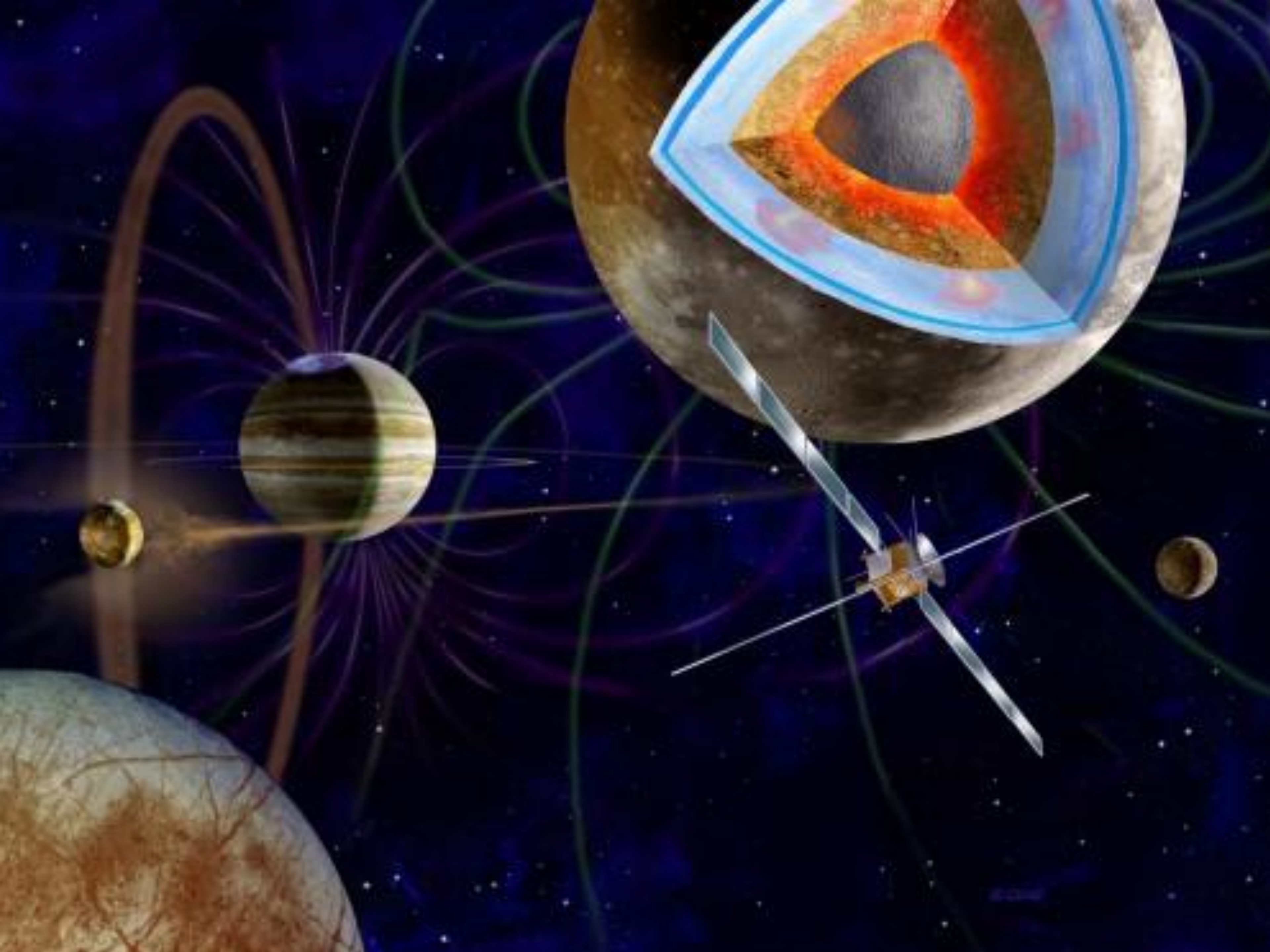
Organics and energy sources

- Surface of the ice
  - Oxidants produced by irradiation include O_2, SO_2, H_2O_2 & CO_2
  - Carbon compounds in meteorites include amino acids and simple sugars
  - Pierazzo & Chyba 2002, delivery of biogenic elements to Europa
  - Generation of organics from irradiation of ices (Hudson & Moore 1999)

- Ice layer
  - Geologic surface features point to convective activity
  - Potential melt zones within plumes or along ice grain boundaries
  - Giant lakes!

- Water-rock interface
  - Fischer-Tropsch reactions (McCollom 1999)
  - Hydrothermal vents provide high temperatures and reduced fluids
  - Serpentinization could generate H_2





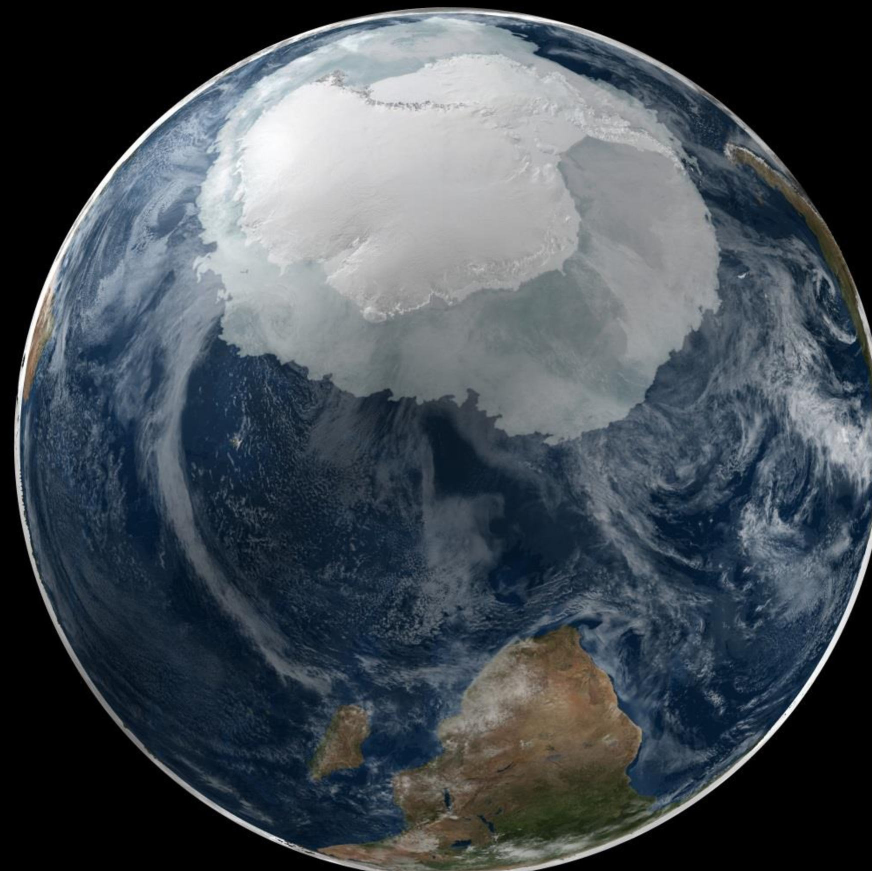
JUICE has the capabilities to build up a picture of habitable niches using synergistic observations:

- RIME will deliver data on the presence of liquid areas in the near subsurface
- SWI will explore thermophysical properties of the icy surfaces
- JANUS and GALA will provide information on surface structures resulting from endogenic activity which could deliver materials to the surface
- MAJIS and UVS will probe the composition of extruded surface materials that may reflect the chemistry of liquid zones, and directly search for actively venting surface features

The JUICE instrument payload has the capacity to provide data on the presence, location, connectivity and chemistry of habitable niches within the ice shells.

How can we prepare for this mission?

Earth: Arctic and Antarctic views




Borup Fiord Pass, Ellesmere Is.

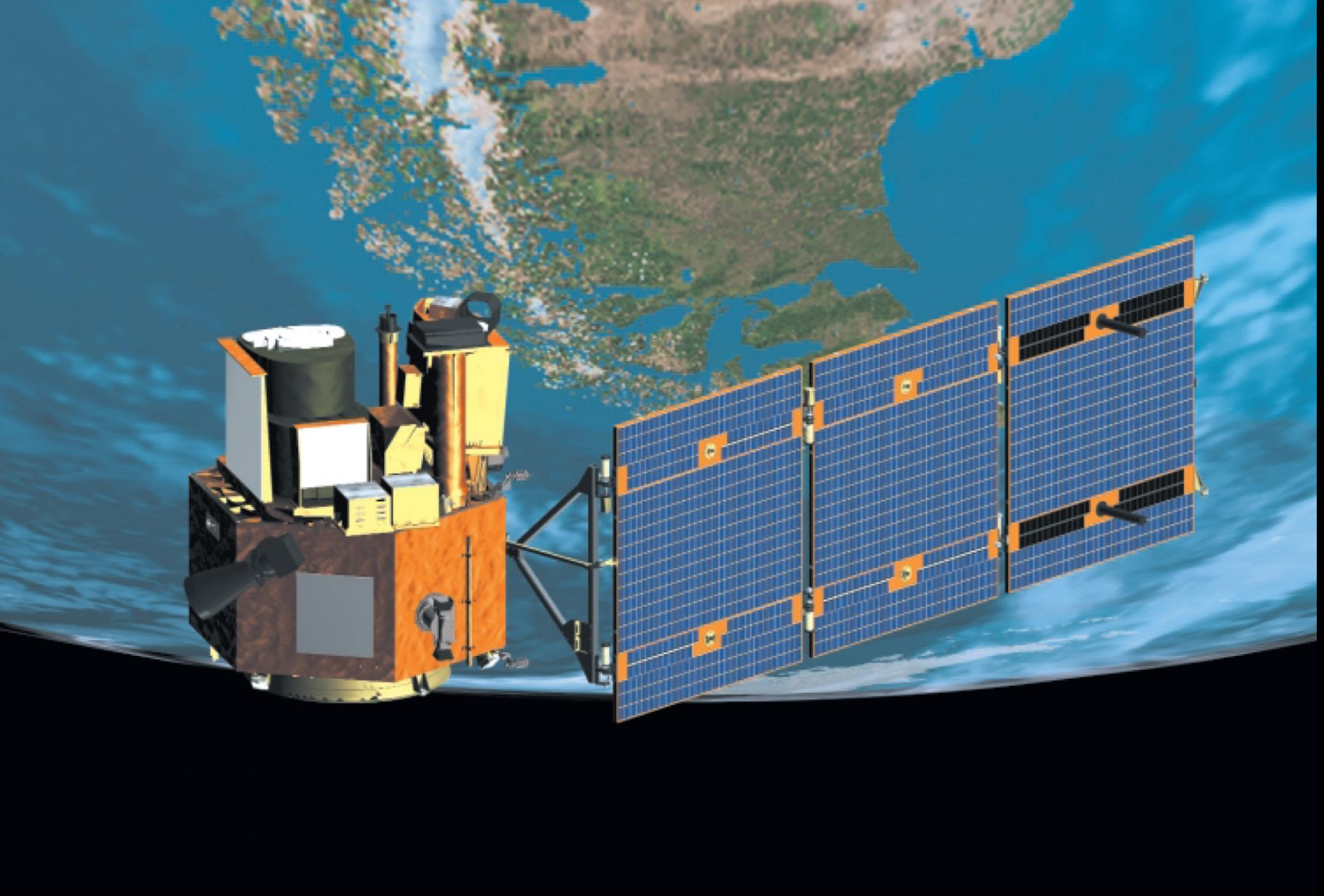
Blood Falls, Taylor Valley

Analogue approach

1. Establish habitability profile of the site; geochemistry, microbiology, etc.

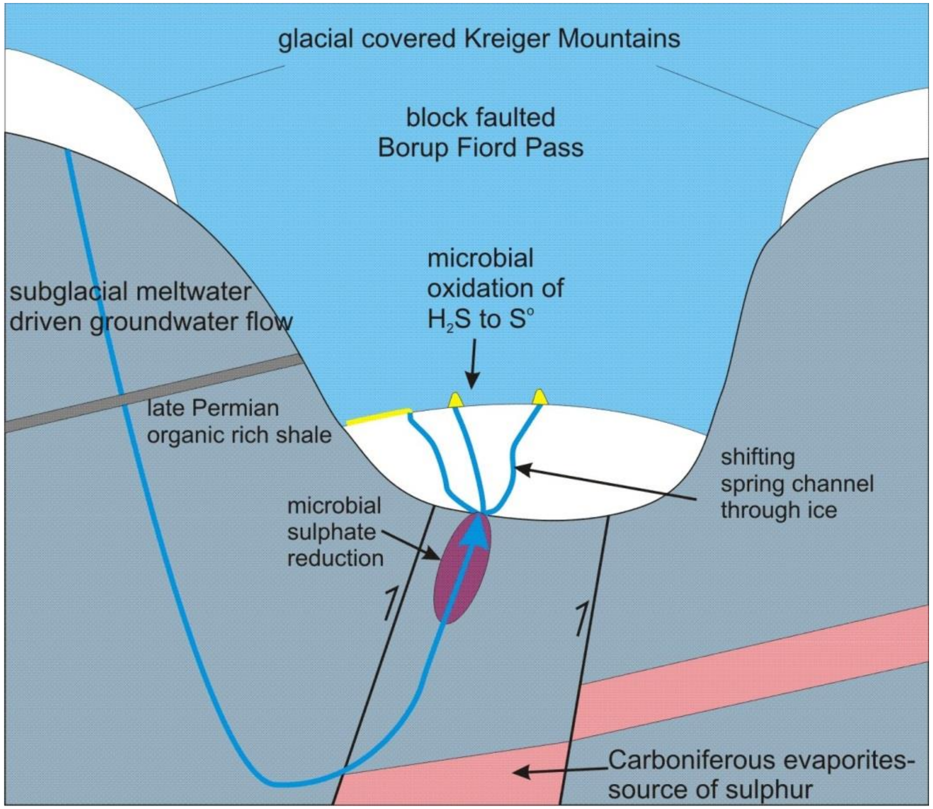
2. Carry out satellite investigations using Vis-NIR hyperspectral data:
   - Atmospheric correction
   - Spectral polishing
   - Data reduction
   - Extraction and identification of spectral endmembers
   - Linear unmixing to derive subpixel information
   - **Detect and map minerals within the scene**

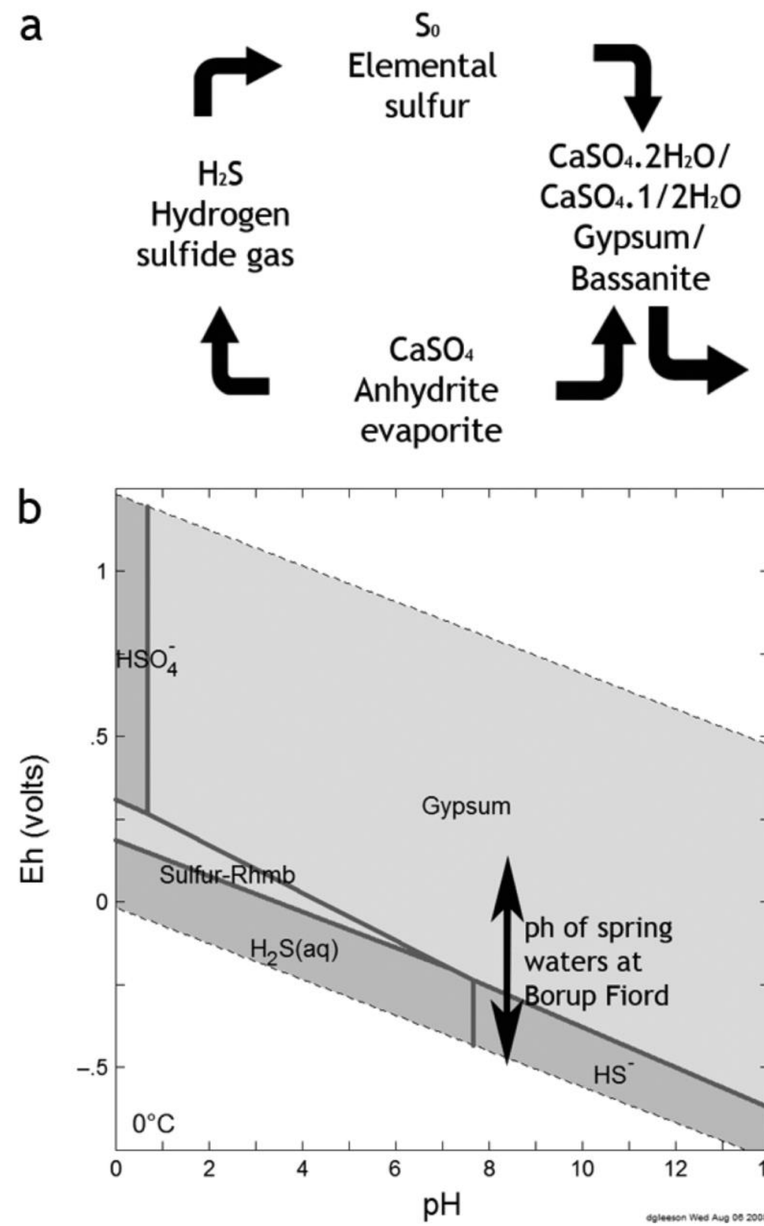
3. Determine the overlap between the two datasets



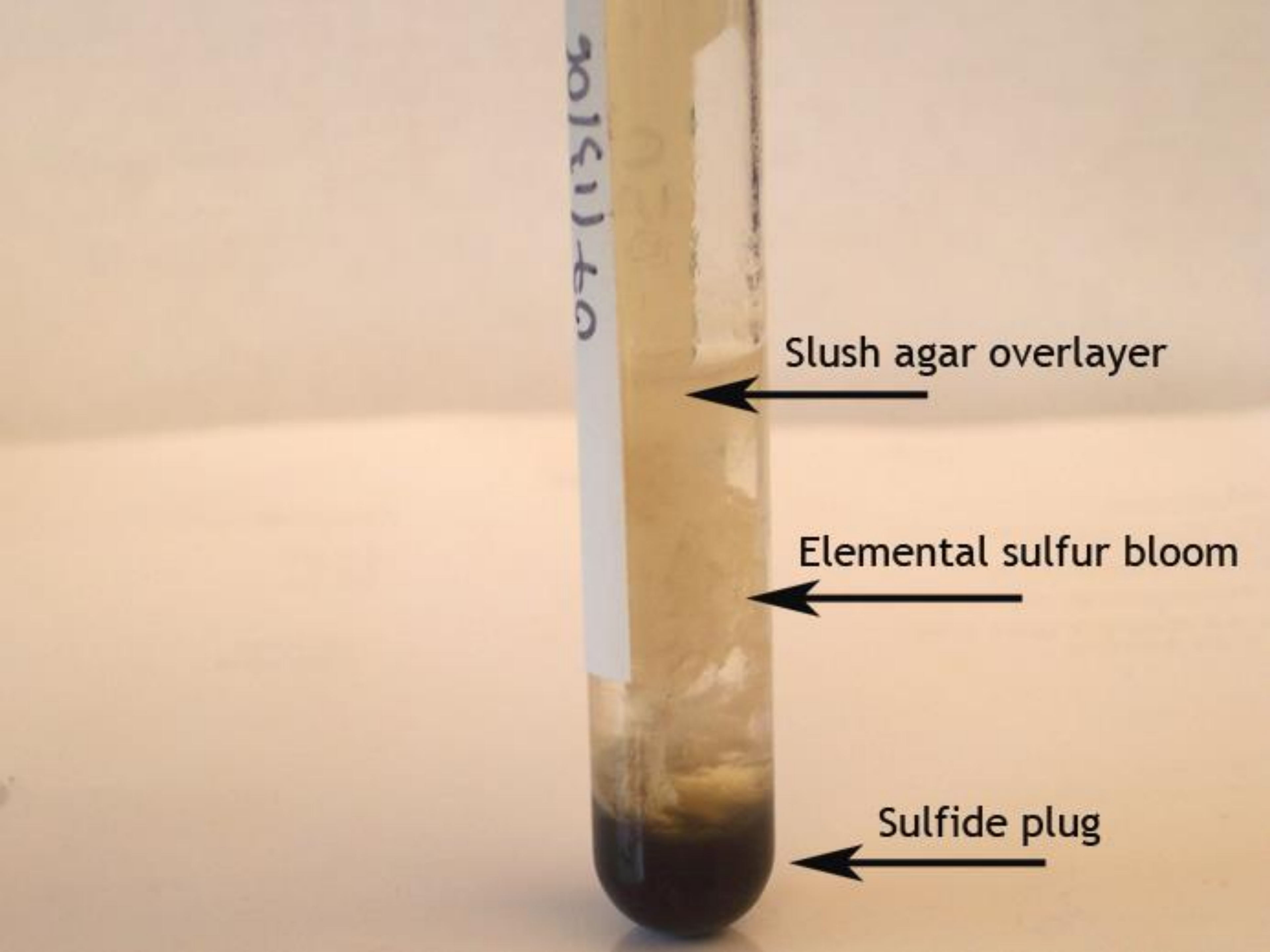
Hyperion instrument on Earth Observing - 1

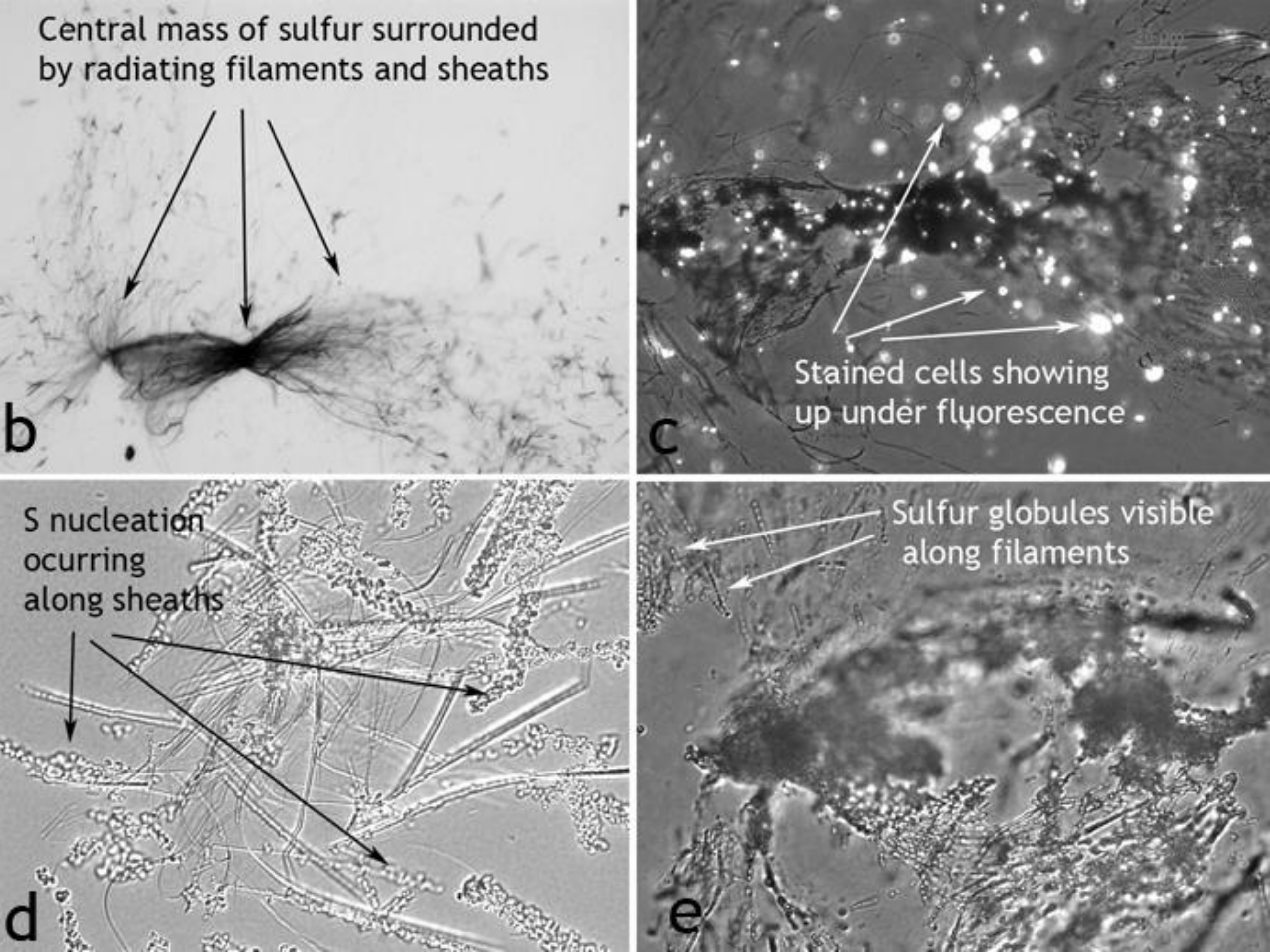
Borup Fiord Pass model





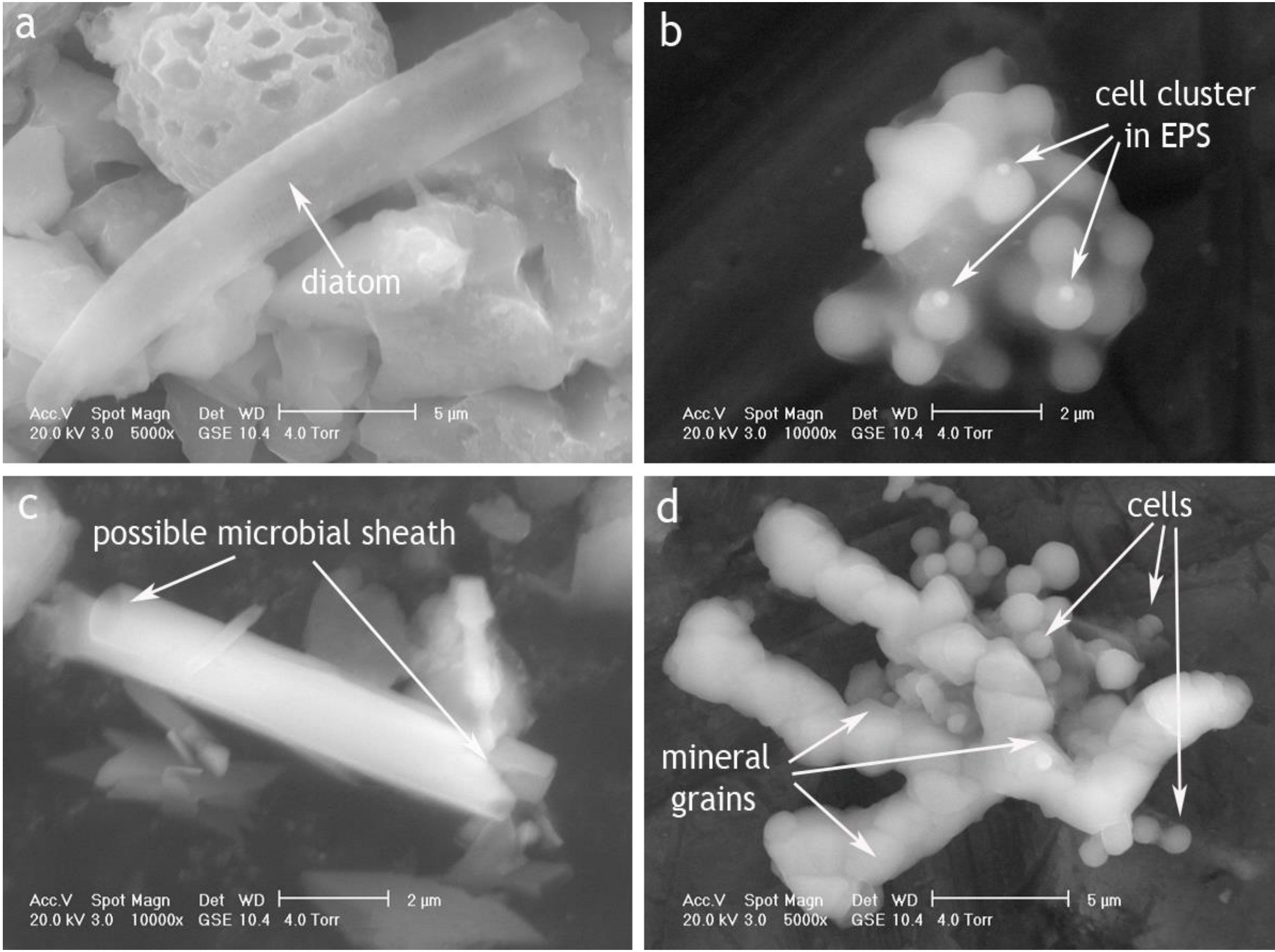
- Reduced sulfur reaches the surface during periods of glacial recharge
- Sulfide is oxidized to sulfur resulting in yellow staining on ice

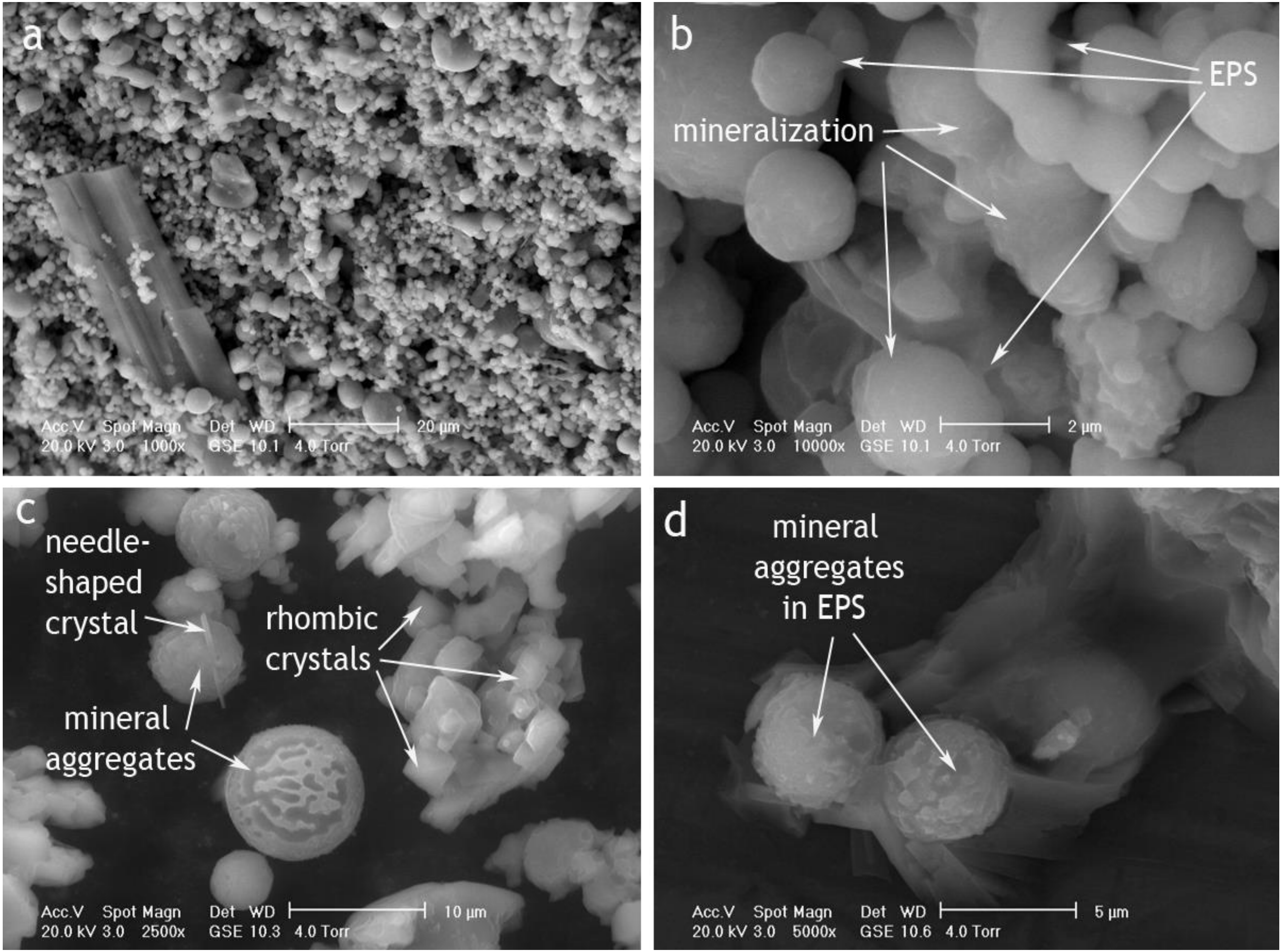

Slush agar overlayer
Elemental sulfur bloom
Sulfide plug



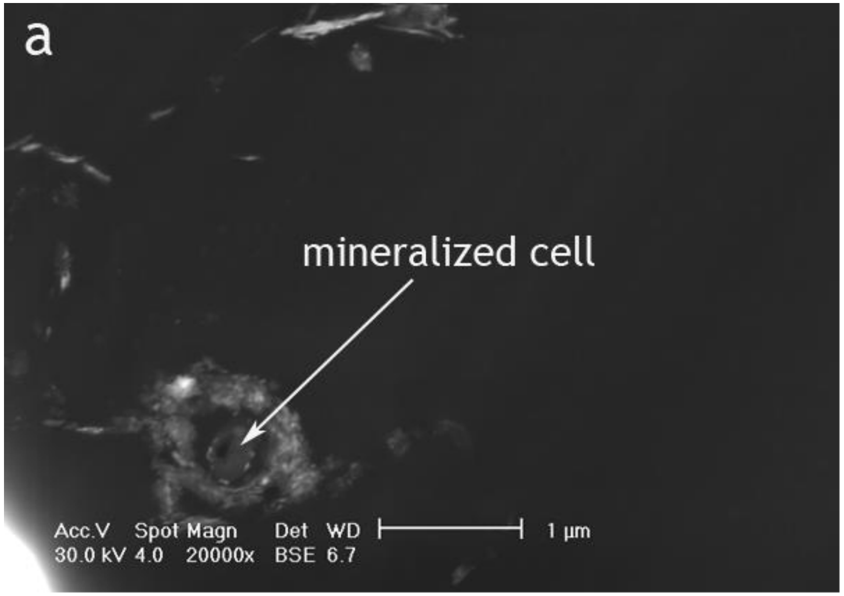
Central mass of sulfur surrounded
by radiating filaments and sheaths
b
Stained cells showing
up under fluorescence
c
S nucleation
ocurring
along sheaths
d
Sulfur globules visible
along filaments
e

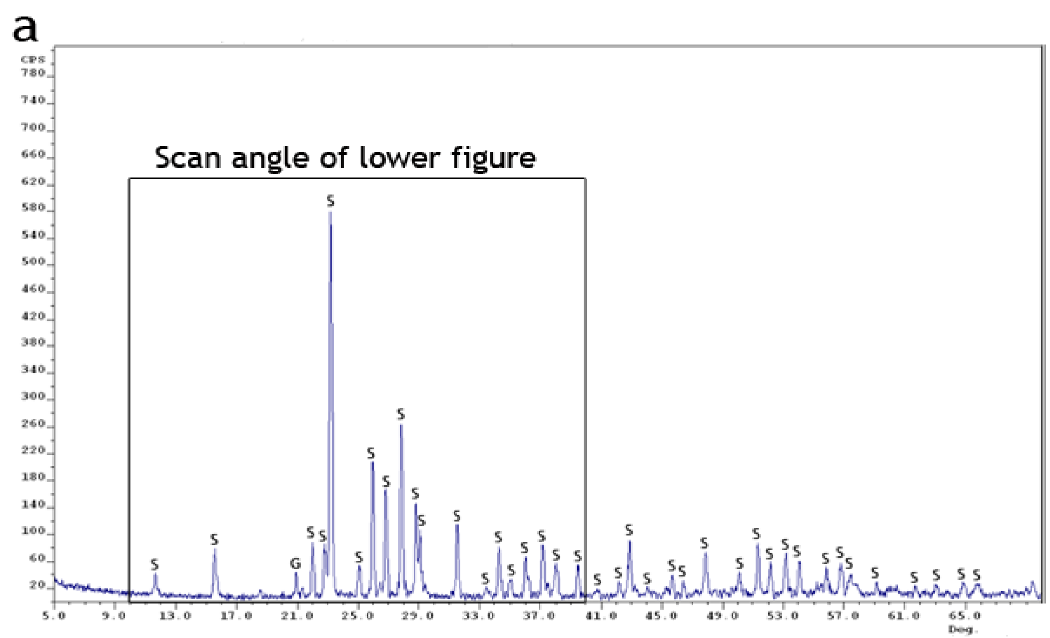
Gleeson et al 2011, *Geobiology*

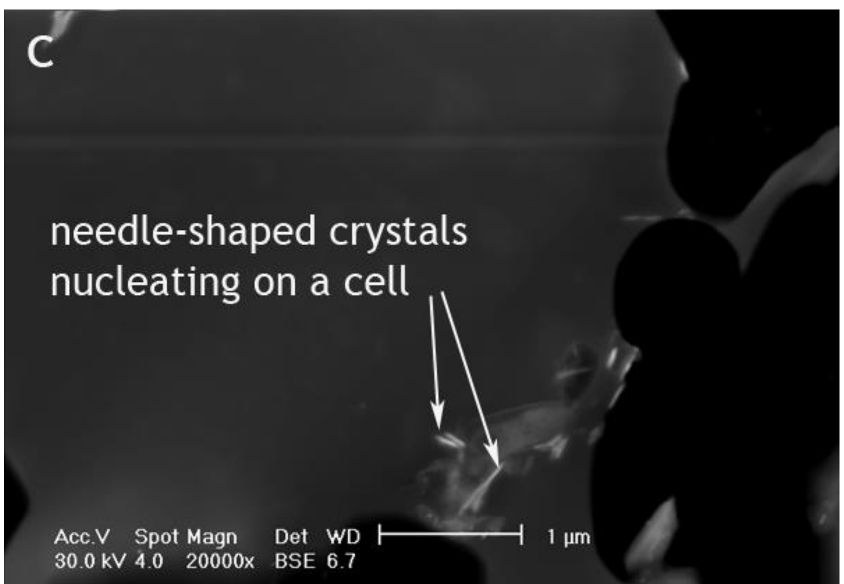

a
diatom
Acc.V Spot Magn Det WD 5 µm
20.0 kV 3.0 5000x GSE 10.4 4.0 Torr
b
cell cluster
in EPS
Acc.V Spot Magn Det WD 2 µm
20.0 kV 3.0 10000x GSE 10.4 4.0 Torr
c
possible microbial sheath
Acc.V Spot Magn Det WD 2 µm
20.0 kV 3.0 10000x GSE 10.4 4.0 Torr
d
cells
mineral
grains
Acc.V Spot Magn Det WD 5 µm
20.0 kV 3.0 5000x GSE 10.4 4.0 Torr

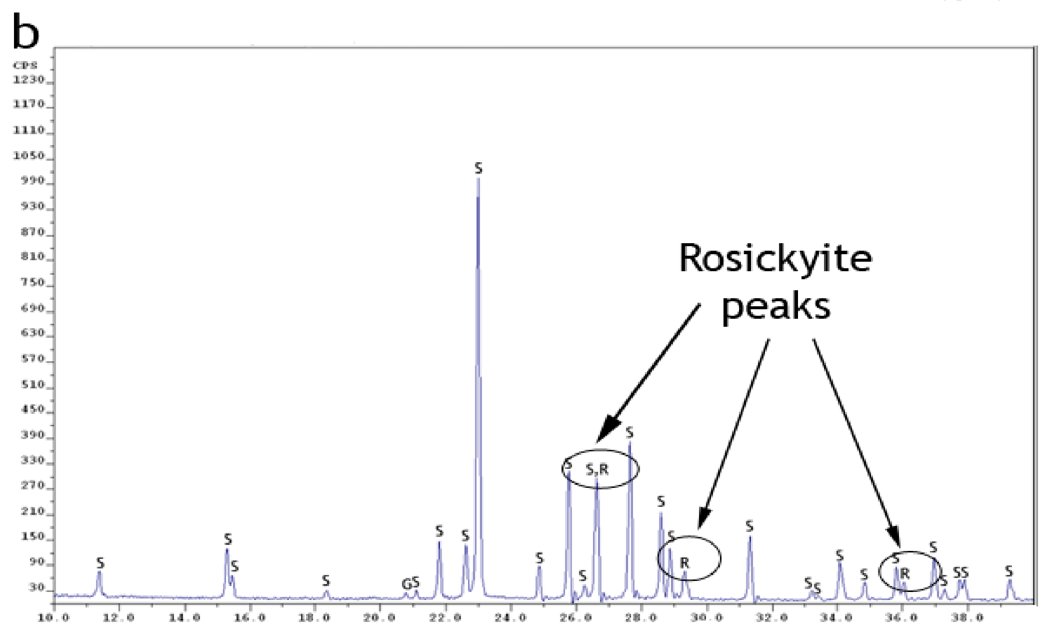

a
Acc.V Spot Magn Det WD 20 µm
20.0 kV 3.0 1000x GSE 10.1 4.0 Torr
b
EPS
mineralization
Acc.V Spot Magn Det WD 2 µm
20.0 kV 3.0 10000x GSE 10.1 4.0 Torr
c
needle-shaped crystal
rhombic crystals
mineral aggregates
Acc.V Spot Magn Det WD 10 µm
20.0 kV 3.0 2500x GSE 10.3 4.0 Torr
d
mineral aggregates in EPS
Acc.V Spot Magn Det WD 5 µm
20.0 kV 3.0 5000x GSE 10.6 4.0 Torr

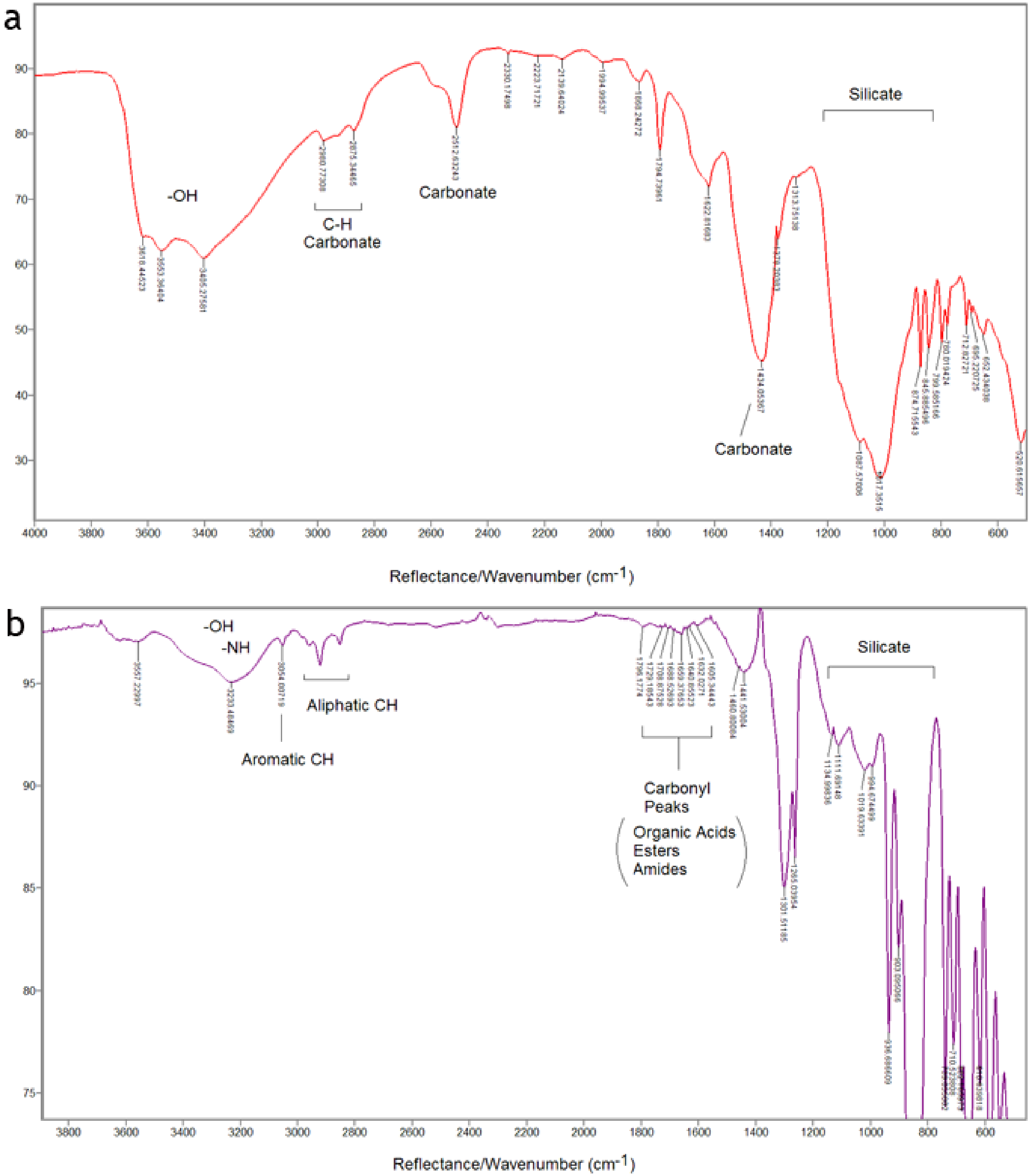
Mineralogy and potentially biogenic sulfur phases



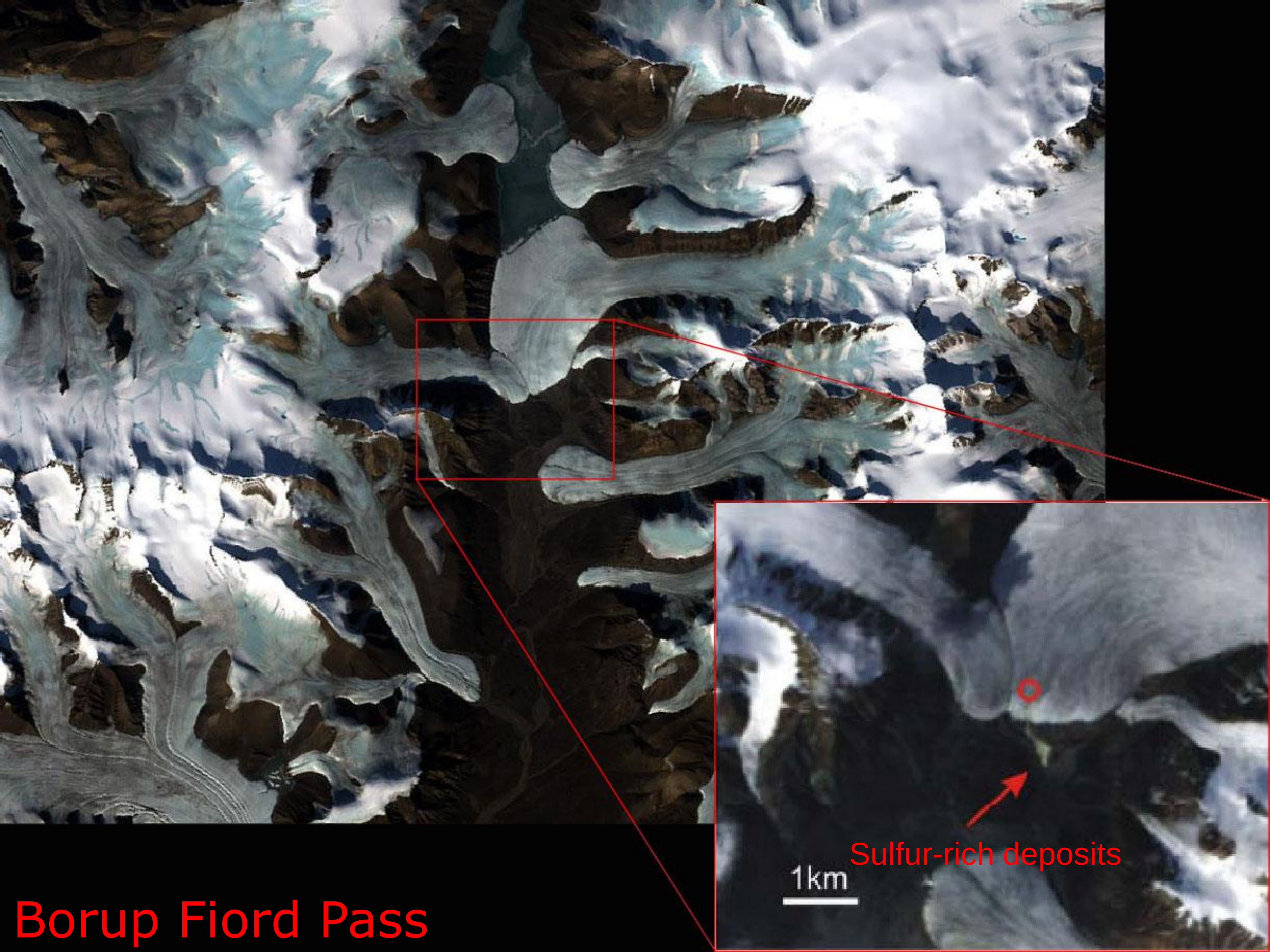




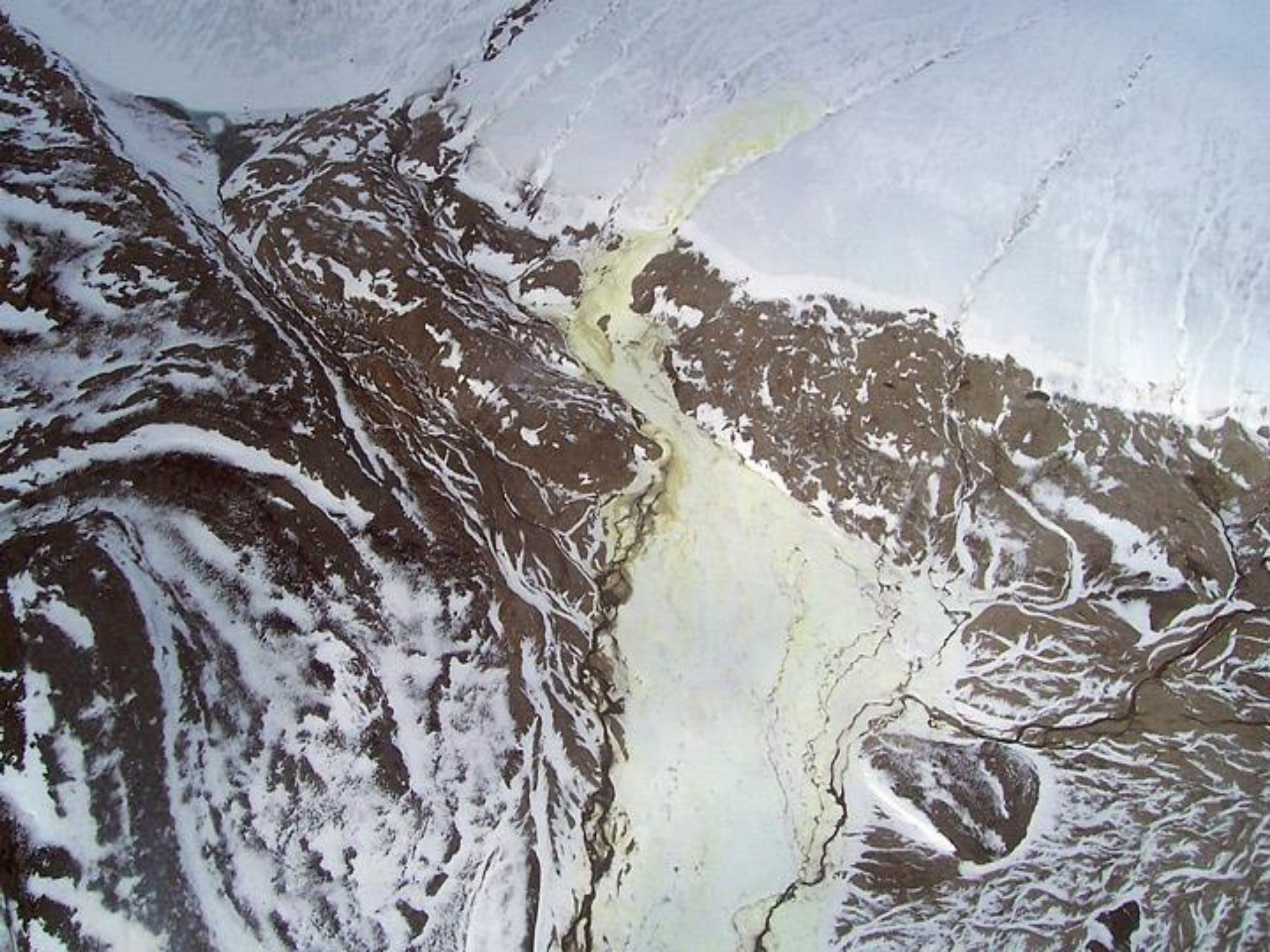




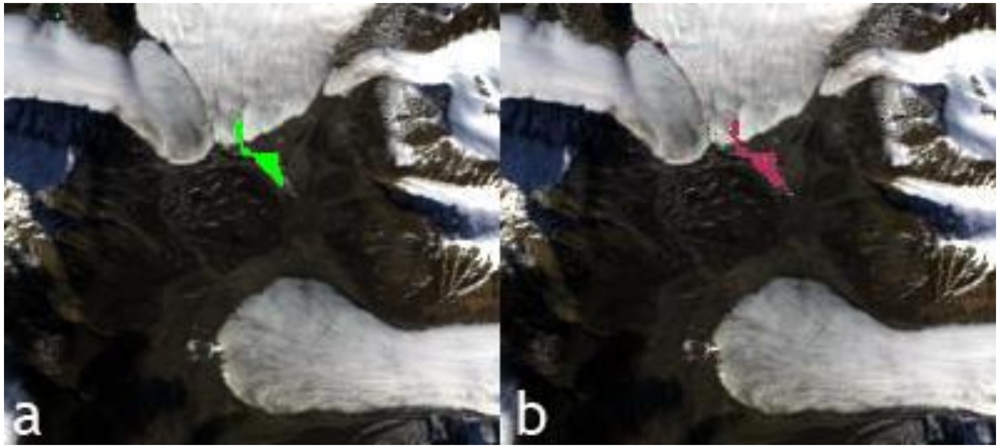
Gleeson et al 2012, *Astrobiology*

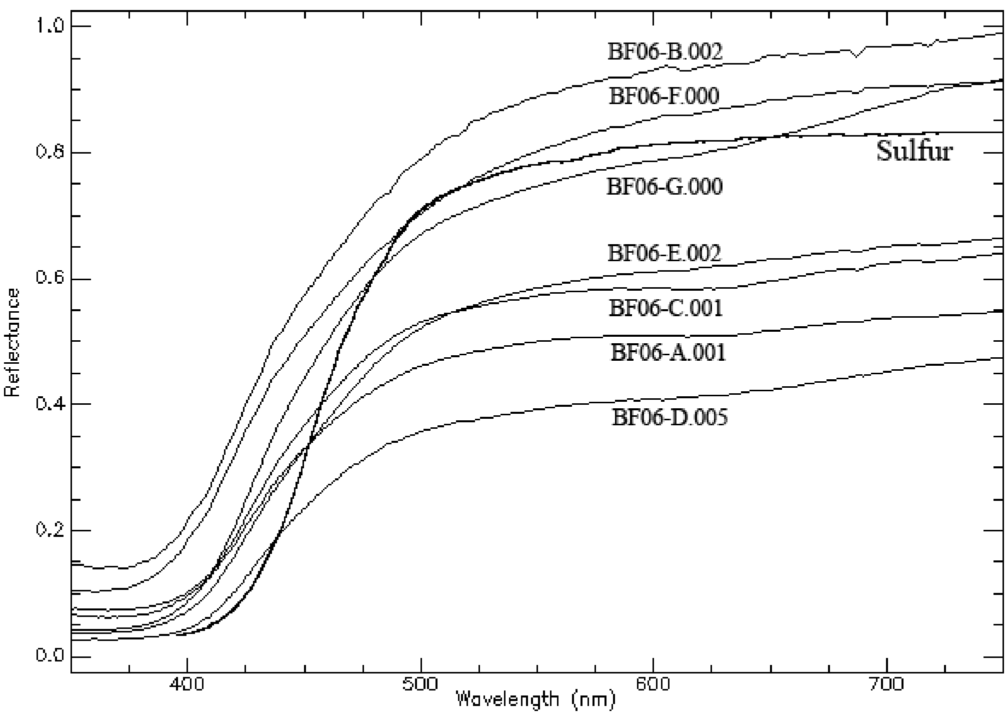


Borup Fiord Pass

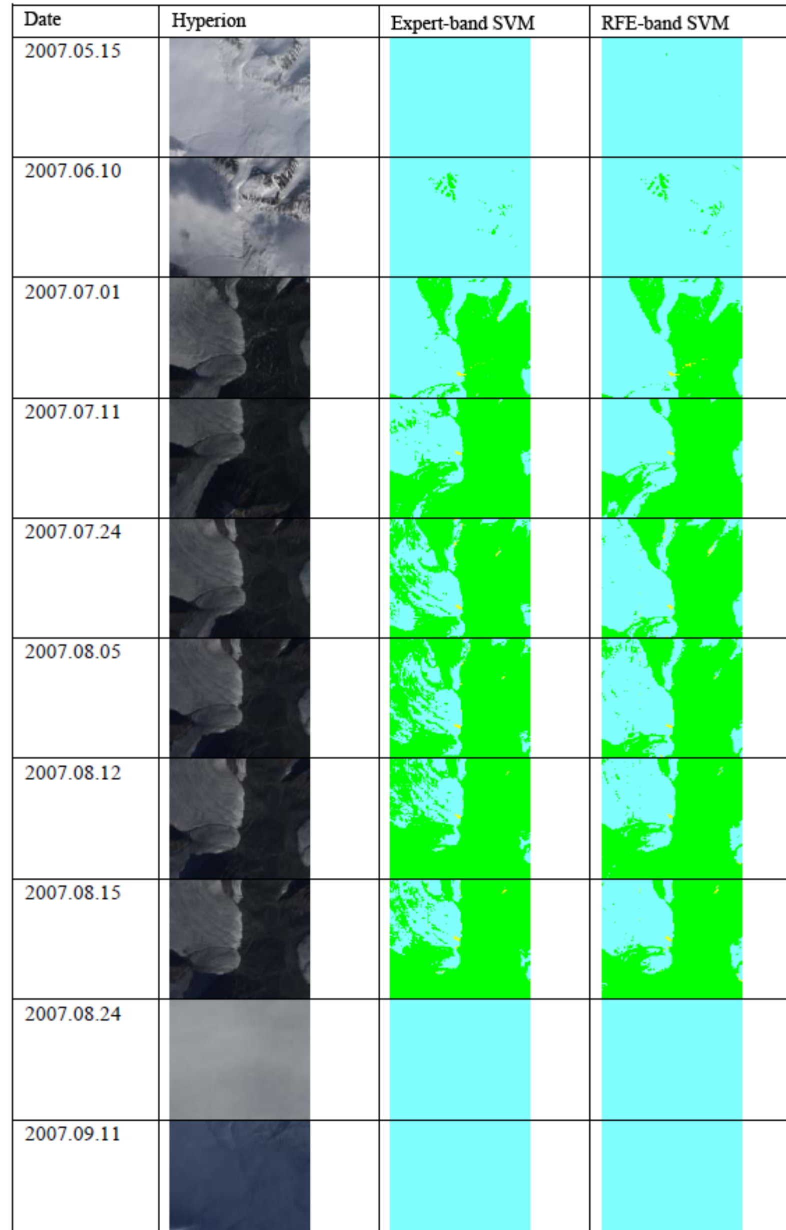


Mapping sulfur in Hyperion data

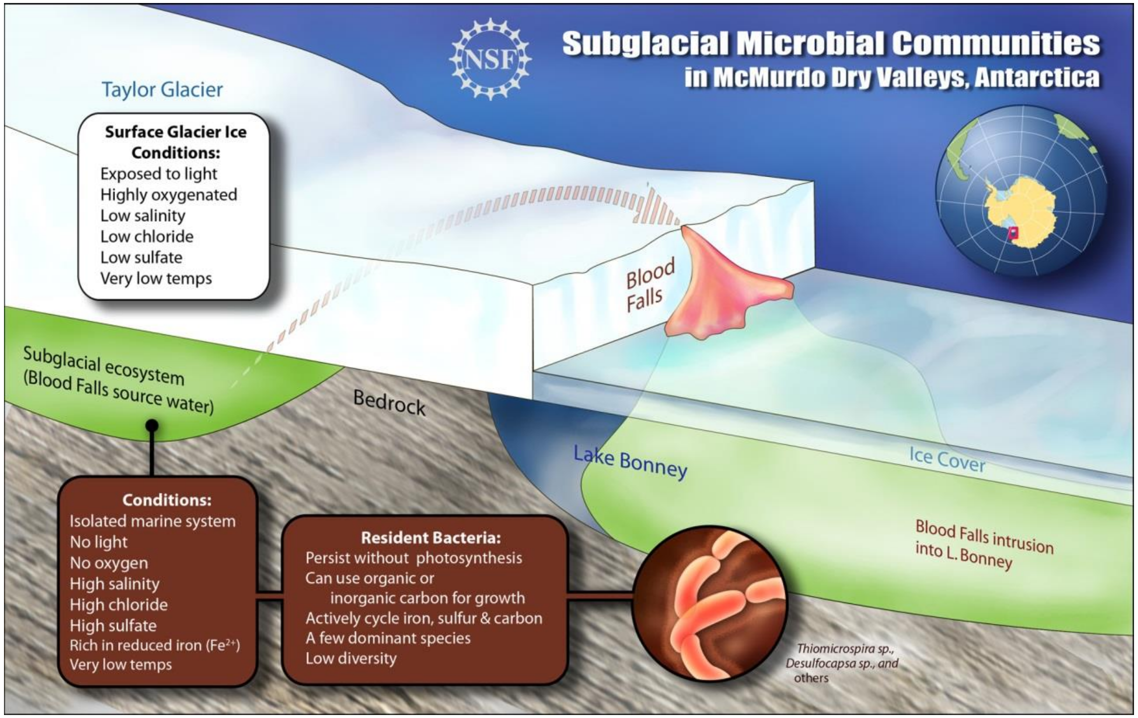




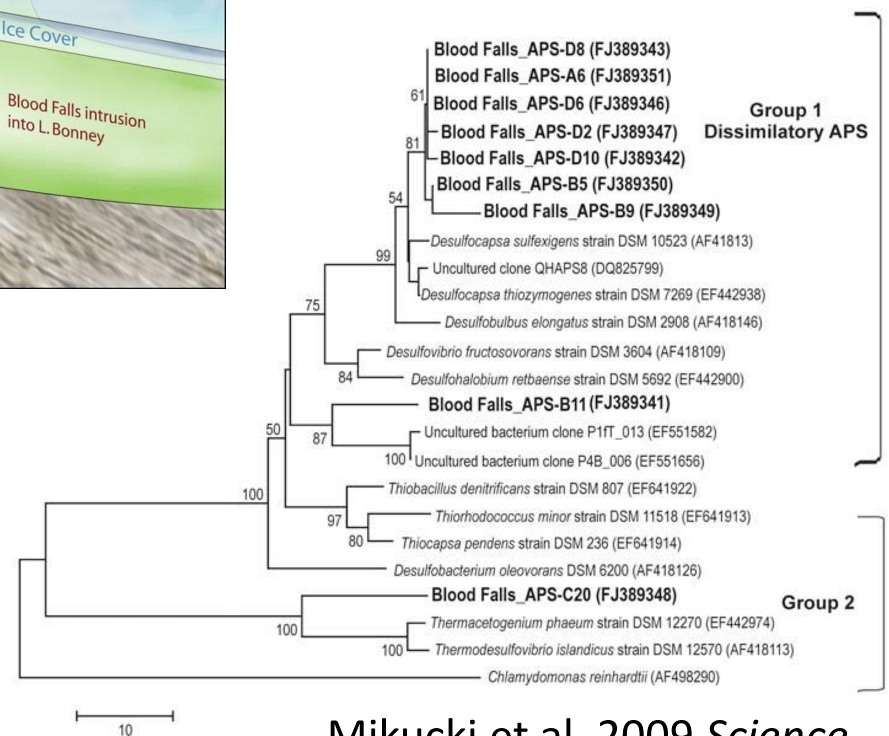
Gleeson et al 2010, *Remote Sensing of Environment*



Blood Falls model

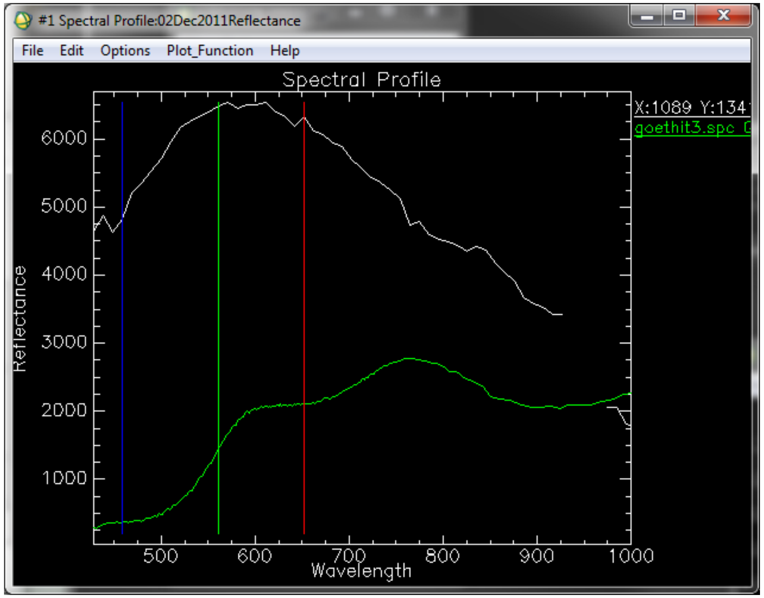


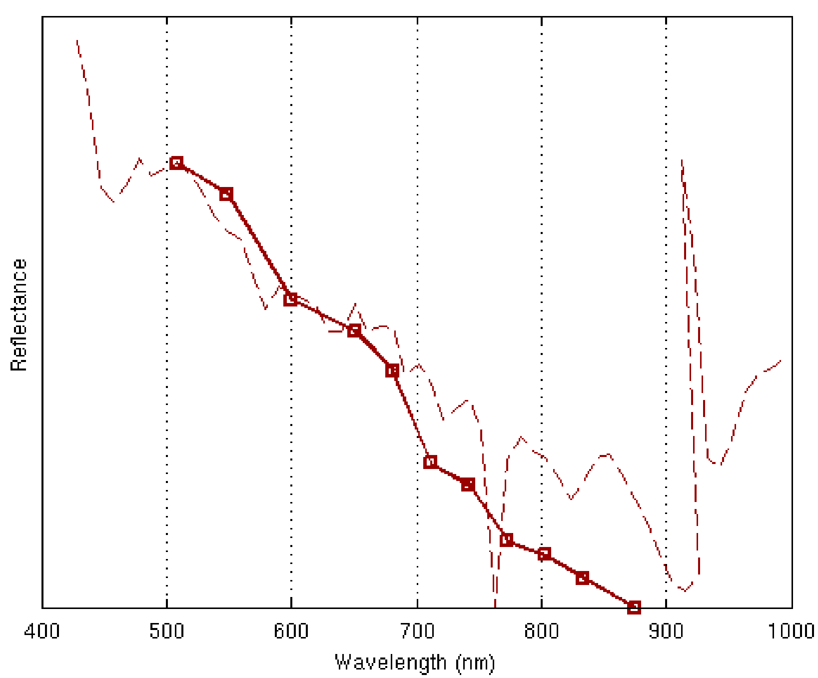
- Autocatalytic sulfur and iron cycle
- Sulfate reducers dominate the community
- Reduced iron is released and oxidized resulting in red staining



Mikucki et al. 2009 *Science*

Mapping iron in Hyperion data





Thompson et al. 2013

How could these analogue studies inform our view of the icy moons of Jupiter?

Questions

- Can we detect and characterise known hydrological systems in hyperspectral datasets of remote locations on the basis of mineralogical deposits derived from outflow?
- Can we detect and characterise new outflow or spring sites in terrestrial hyperspectral datasets by searching for analogous deposits?
- Can we search within existing planetary hyperspectral datasets (NIMS and VIMS) for comparable mineralogical indicators of potentially habitable systems?
- Can the results obtained provide a framework to facilitate habitability assessments during upcoming ESA missions?

Other sites of interest

Conclusions

- Exploring how these mineral deposits are expressed in hyperspectral satellite data allows us to:
  - detecting the presence of ice and permafrost-based hydrological systems
  - broadly characterize the composition of the fluids
  - probe the habitability of the systems
- Studying terrestrial analogues via satellite can help prepare us for habitability investigations of the icy moons

Acknowledgements

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- Thanks to Steve Chien, the EO-1 team and the Machine Learning group at JPL
- Thanks to Patrick Martin at ESAC, Vicente Ruiz at Isdefe and other colleagues at CAB