NSF: Microbial Habitats Below Ice

Presented by: Dr. Jill Mikucki

April 25, 2012
Microbial Habitats Below Ice

NSTA Webinar
25 April 2012
Jill Mikucki – Dept. of Microbiology
The Earth’s biosphere is cold:

- 14% Polar
- 90% (by volume) cold ocean (<5°C)
- 20% of soil ecosystems are permafrost
- 10% of the Earth’s terrestrial surface is covered with glaciers
Examples of Icy Microbial Ecosystems

- Sea Ice
- Glacier ice
- Subglacial systems
- Ice-covered lakes
- Cryoconite holes
- Supraglacial streams
- Permafrost
- Cold marine sediments
- Other icy, dark systems- habitat detection

~70% of Earth’s fresh water
Question:
What is the biggest challenge for icy life?

A. Low temperatures
B. Energy resources
C. Liquid water
D. Ice crystals (freezing/thawing)
Biology of the cryosphere

Sea ice
Junge et al. 1998

Lake Vostok accretion ice
Priscu et al., Science 1999

Perennial lake ice
Priscu et al., Science 1998

8 Mya glacial ice
Bidle et al., PNAS 2007

Permafrost
Rivkina and Gilichinsky

Glacier beds
Sharp et al., AEM 1999

Cryoconite holes
Tranter et al.
Icy Microbial Worlds: Rock Ice and Water

Mikucki et al. 2011
Majority of the world’s ice is in Antarctica:
Antarctica’s subice world:

Diverse microbial habitat?!

Zina Deretsky – NSF
Antarctica’s subice world: ROCK

- Most common rocks in West Antarctica are volcanic
- East Antarctica is more varied with metamorphic and igneous rocks as well as modern rocks such as sandstone and limestones, coals and shales.

Subglacial topography and bathymetry of Antarctica

BEDMAP Consortium
European Ice Sheet Modeling Initiative
Scientific Committee on Antarctic Research.
Antarctica’s subice world:

What do we know about life in soils?

One gram of soil contains \(~10\) billion microorganisms and thousands of species (Torsvik et al., 1990)
Antarctica’s subice world: WATER

- Pressure from a (thick) ice sheet reduces the melting temperature
- Ice sheets insulate the base from extremely cold (surface) temperatures and retain heat
- Heat generated from friction (ice deformation and basal sliding) and geothermal heat from the Earth (~50 mW m\(^{-2}\))
- Water accumulates in topographic lows
Remote sensing: detecting Antarctica’s subice world

Airborne radio-echo sounding (RES)

- Strong reflections at ice-sheet base
- Echoes of constant strength along a track
- Flat topographic character

Siegert 2005; Bingham and Siegert 2007
Questions?
Research Questions in Polar Microbial Ecology:

1) Structure – who is living in these icy systems?
2) Function – what ‘ecosystem service’ do icy microbial communities provide?
3) What are the unique attributes of microbial species living in this extreme environment?
4) Are these microbes active in situ? Can we measure it?
5) Can we link microbial metabolism with both contemporary and ancient geochemistry and evolution?
Antarctic Subglacial Samples: What do we know so far?

Considering the size of a borehole...
Antarctic Subglacial Samples: Kamb Ice Stream

Lake Ellsworth
Lake Whillans
Lake Vostok
Kamb Ice Stream
Blood Falls

The Loner?
Kamb Ice Stream: an Antarctic subglacial sample

Sequences related to *Comamonas*, *Gallionella*, and *Thiobacillus*

An enrichment culture?

Lanoil et al. 2009
Kamb Ice Stream: an Antarctic subglacial sample

Sediment core from below the Kamb Ice Stream

1 sample:
Cells detected (10^7 cells gram^{-1})
Clones and isolates obtained

Joughin and Tulaczyk, 2002.
Antarctic Subglacial Samples: Lake Whillans

Lake Ellsworth

Kamb Ice Stream

Lake Whillans

Lake Vostok

Blood Falls

Up and coming
Polythermal subglacial outflow

Glacier Thermal Classifications:
- Temperate
- Polar
- Subpolar

Winter storage of subglacial melt can lead to anoxia

Some very brief points on hydrology:
The Whillans Ice Stream Subglacial Access Research Drilling (WISSARD) project:

Estimation of regional hydropotential

Helen Fricker - Scripps

www.wissard.org
The Whillans Clean Access Drill:
A hot water drill designed to filter drill water and UV-sterilize water and down-hole equipment

- After one passage through the system:
  - 4-log reduction in the total number of cells.
  - Of the cells remaining, >99.9% will be dead.
Question:
Melting of the meteoric ice from an overlying glacier provides the following to the subglacial environment:

A. Oxygen  
B. Carbon Dioxide  
C. Microbial cells  
D. All of the above  
E. None of the above
Antarctic Subglacial Samples: Lake Vostok

Lake Ellsworth
Lake Vostok
Kamb Ice Stream
Lake Whillans
Blood Falls

The Movie Star
Lake Vostok: the holy grail of subglacial lakes

Russians breach Lake Vostok

A ‘Lost World’ found
Lake Vostok is the largest lake beneath the Antarctic ice, sealed off for 15 million to 34 million years. It may contain unique lifeforms.

Lake Vostok is one of more than 280 subglacial lakes in Antarctica.

5 February 2012

An achievement 20 years in the making!
Lake Vostok: the holy grail of subglacial lakes

Technical feat in Ice Core Drilling

3769.3 meters
2.34 miles
“Data from cores drilled in polar ice sheets show a remarkable correlation between past glacial-interglacial temperature changes and the inferred atmospheric concentration of gases such as carbon dioxide and methane.”
Lorius et al 1990
Lake Vostok: the holy grail of subglacial lakes

345 m (1,130 ft) deep and 15,700 km$^2$ (6,000 sq mi) in area
Where the climate record disappears...

...a new microbial world is revealed!
Lake Vostok: the holy grail of subglacial lakes

- Cells are present
- Without sunlight, microbes may use iron and sulfur for energy

2.8X10³ – 3.6X10⁴ cells/mL (3590 m)
2X10² – 3X10² cells/mL (3603 m)

Priscu et al., Science 1999
Christner et al. (2006; and numerous references therein)
Questions?
Antarctic Subglacial Samples: Lake Ellsworth
Subglacial Lake Ellsworth:

Lake Ellsworth Consortium

- UK-wide Team configured for exploration
- Hot-water drilling will access the lake cleanly
- Probe will take measurements and samples
- Corer will collect sediments

www.geos.ed.ac.uk/ellsworth

Glaciologists use explosive devices to conduct a seismic survey of Lake Ellsworth. Scientists can determine the depth, length, width and position of subglacial lakes from seismic waves caused by the explosions. Copyright BAS.
Lake Ellsworth

• Geophysics survey completed:
  Lake is 10 km long; ~160 m deep; >2 m of soft sediments on the floor

Siegert 2005; Bingham and Siegert 2007
Question:
Why get excited about 2 m of sediment at the bottom of Lake Ellsworth?

Raise your hand to volunteer to answer.

1.

2.

3.
Emerging themes in Subglacial Processes:

Antarctica’s subice biosphere:

~5 Pg of carbon in Antarctic subglacial environments

*Estimate from Priscu et al. 2008*

Iron and sulfur cycling- energetically important in the subglacial environment

Hydrology, bedrock lithology and preglacial ecosystem are key factors in determining subglacial microbial community structure
Emerging themes in Subglacial Processes:

**Antarctica’s subice biosphere:**

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Antarctic Subglacial Samples: Blood Falls

A model system
How does HYDROLOGY, BEDROCK and PREGLACIAL SYSTEM influence the subglacial ecosystem?
Location of Blood Falls, Taylor Glacier, Antarctica
The Blood Falls System

GLACIER ICE

SUBGLACIAL BRINE

BEDROCK

Flux Out

Artwork: Zina Deretsky
Characteristics of discharge: Cold, Salty and Reduced

Chloride = 1375 mM [2.5 X seawater]
Sulfate = 40 mM
Total Iron = 3.8 mM [97% Fe(II)]
DIC = 55 mM
Measureable Organic Carbon = 450 μM C
Dissolved inorganic Nitrogen = 94 μM [100% NH₃⁺]
Eh (reduction potential) = 90 mV
pH = 6.2
Temp = -5.2 °C
Subglacial biology should leave its footprint in the brine:

- Nucleic Acids
- Cells
- Carbon substrates
- Metabolic substrates
- Major Ions

Genetic instructions for metabolic activity
Fractionation in the elements involved in redox chemistry
The organisms themselves (with some luck)
Subglacial Life: Bacteria in Blood Falls
Nucleic Acids:
16S rRNA gene diversity can provide a metabolic ‘compass’

Mikucki and Priscu AEM (2007)
Nucleic Acids:
16S rRNA gene diversity can provide a metabolic ‘compass’

Majority of clones and isolates are related to organisms from cold marine environments-similar to marine sediments (i.e. Ravenschlag et al 1999)

Mikucki and Priscu AEM (2007)
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Chemoautotrophy:

Organisms that use inorganic (carbon dioxide) carbon for cellular carbon, and obtain their energy by oxidizing inorganic substances.
Subglacial carbon dynamics: evidence for chemoautotrophy

Labeled substrate incorporation experiments:

- **Measureable metabolic activity**
- **Subglacial volcanic lake (3.3 nmol C liter$^{-1}$ d$^{-1}$)**
  - *Gaidos et al. (2004)*
- **Ice-covered Antarctic lakes in Winter**

Mikucki et al. in prep
Subglacial carbon dynamics: evidence for chemoautotrophy

• Diversity of the RUBISCO genes in Blood Falls
  a key enzyme in the Calvin Cycle

• The Calvin cycle is a biochemical route for CO₂ fixation in many autotrophs

Mikucki et al. in prep
Subglacial carbon dynamics: multiple lines of evidence for chemoautotrophy

- Clone (16S rRNA gene) – a metabolic compass
  *Housekeeping genes*: required for the maintenance of basic cellular function
- Metabolic activity – labeled substrate incorporation
- Genes involved in specific metabolic process (Rubisco)
Subglacial carbon dynamics: multiple lines of evidence for chemoautotrophy

- Clone (16S rRNA gene) – a metabolic compass
  *Housekeeping genes*: required for the maintenance of basic cellular function

- Metabolic activity – labeled substrate incorporation

- Genes involved in specific metabolic process (Rubisco)

Questions?
Question:
Why would chemoautotrophic production in the subglacial environment be important?

*Raise your hand to volunteer to answer.*

1. 

2. 

3. 
Nucleic Acids:
16S rRNA gene diversity can provide a metabolic ‘compass’

Majority of clones and isolates are related to organisms from cold marine environments—similar to marine sediments (i.e. Ravenschlag et al 1999)

Clones and isolates potentially involved in iron/sulfur cycling

Mikucki and Priscu AEM (2007)
• All bacteria require S for amino acid construction; many acquire their S from SO$_4^{2-}$ (Assimilatory)

• Sulfate Reducing Bacteria (SRBs) use SO$_4^{2-}$ as an electron acceptor during energy generation (Dissimilatory)
Bacterial Sulfur requirements

Phylogenetic relationships of functional genes can reveal metabolic tendencies

Amplification of gene fragments of the APS reductase gene from subglacial brine genomic DNA.

Related to dissimilatory genes for sulfur metabolism

Mikucki et al. (2009)
Future Directions:

Grow isolates and enrichments under simulated ‘in situ’ conditions – tease out the physiology and couple that work with ‘omics’ approaches
Ecosystem Dynamics Below Taylor Glacier:

Net iron-reducing - S cycled catalytically as an electron shuttle

**Genes**

Phylotype involved?

**Reduced C**

**Oxidized C**

\[ ^{14}\text{C-Bicarb} \Rightarrow \text{RUBISCO} \Rightarrow \text{Reduced C} \Rightarrow \text{APS-reductase} \Rightarrow \text{SO}_4 \Rightarrow \text{SO}_3 \Rightarrow \text{Org S} \Rightarrow \text{S}_{int} \Rightarrow \text{Fe(III)} \Rightarrow \text{Fe(III) bedrock minerals} \Rightarrow \]

**Subglacial Microbial Consortia**

- Desulfocapsa sp.
- Thiomicrospira sp.
- Geopsychrobacter sp.
- Desulforomas sp.
- Marinobacter and Flavobacter sp.?
Questions?
Other subglacial niches:

Almost 400 documented subglacial lakes in Antarctica (Siegert et al. 2005, 2011)

NASA map by R. Simmon, based on data from the RADARSAT-1 Antarctic Mapping Project, T. Scambos, C. Shuman, and M. J. Siegert
Antarctica:
A window into the past and extraterrestrial worlds
Life in the Universe?
N = 1
Where are we in Earth’s Life History? Perspective!

http://www.news.wisc.edu/15317
Image by Andree Valley
What About Earth’s Past? Neoproterozoic Snowball Earth

- A global glaciation event approximately 650 million years ago
- Evidence for glaciers at the tropics
Banded Iron Formations:

In Blood Falls reduced iron builds up under ice...

Analogous Environments: life on other planets?

Europa: 15% water based on density

Possible liquid water layer up to 300 km thick
“Chaos terrain”

Evidence for subice water
Enceladus

- One of the brightest objects in our solar system
  ~100% reflection
- Geologically active; extremely cold surface (-330°F)
- Hot spot for life?

http://saturn.jpl.nasa.gov/
Volcanic Plumes on Enceladus

**Cryovolcanism:** simple organic molecules and other ‘life essentials’?

CH$_4$, H$_2$O, NH$_3$, HCN, H$_2$, K- and Na- Salts
A connection between ice and life
Glacial Environments are Players in Earth’s Biogeochemical Cycles

Hodgson et al. 2008
### Why study the subice biosphere?

- Microbial metabolism enhances the rates of subglacial weathering reactions
- Organisms in subglacial habitats live in cold, dark isolation (unique adaptation/acclimation)
- Sediments in subglacial lakes - a repository of materials that reflect Antarctica’s climatic history
- Icy environments offer modern analogs for past ecosystems on Earth and putative ecosystems on icy exobiological targets
- We still know very little about the function of icy ecosystems on Earth
Additional Education Resources about Antarctic Subglacial Lakes and the Cryosphere

• US Subglacial Lake Project (Lake Whillans)
  – *Follow the research team in the field November 2012-February 2013*
  – [http://www.wissard.org](http://www.wissard.org)

• British Subglacial Lake Project (Lake Ellsworth)

• National Snow Ice Data Center
Questions?? Looking for Additional Resources?

WISSARD Education and Outreach Coordinator:

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