Will there be life at the bottom of the Mohole?
needles in the haystack, that you are seeding with more needles
Advances in understanding the deep biosphere

- Ocean drilling has allowed us to document life from the upper few centimeters to 100’s of meters to >1 km below the seafloor.

- Archaea are more abundant than Bacteria in deep sediments.

- Cells may persist at average growth rates which defy our understanding of microbial physiology!
  
  - 100’s – 1000’s of yrs average doubling time

Jorgensen Nat Rev Micro 2007
Advances in understanding the deep biosphere

• Biased toward studies of subseafloor sediments, which have allowed us to extrapolate global estimates

• Recent work is expanding our knowledge and understanding of subseafloor biomes

Table 7. Annual cellular production of prokaryotes in various habitats

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Population size</th>
<th>Turnover time, days</th>
<th>Cells/yr, $\times 10^{29}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine heterotrophs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Above 200 m</td>
<td>$3.6 \times 10^{28}$</td>
<td>16*</td>
<td>8.2</td>
</tr>
<tr>
<td>Below 200 m</td>
<td>$8.2 \times 10^{28}$</td>
<td>300*</td>
<td>1.1</td>
</tr>
<tr>
<td>Marine autotrophs</td>
<td>$2.9 \times 10^{27}$</td>
<td>1.5†</td>
<td>7.1</td>
</tr>
<tr>
<td>Soil</td>
<td>$2.6 \times 10^{29}$</td>
<td>900*</td>
<td>1.0</td>
</tr>
<tr>
<td>Subsurface</td>
<td>$4.9 \times 10^{30*}$</td>
<td>$5.5 \times 10^5*$</td>
<td>0.03</td>
</tr>
<tr>
<td>Domestic mammals</td>
<td>$4.3 \times 10^{24}$</td>
<td>1§</td>
<td>0.02</td>
</tr>
</tbody>
</table>

*The value or mean of the range discussed in the text.
†Based on the median generation time of Prochlorococcus (84).
‡Sum of the number of prokaryotes in cattle, sheep, goats, and pigs from Table 4.
§From ref. 85.

Whitman PNAS 1998
Advances on the continents

- Åspö mine
- DOE work
- Chesapeake Bay
- Columbia River flood basalts

- Accessing sealed fault systems 2.8 km-4km below land surface in South African gold mines
Life in the deep biosphere is only indirectly coupled, if coupled at all, to photosynthetic processes at the Earth’s surface. Instead it is chemotrophic.

https://darkenergybiosphere.org
How can life use geofuel energy

Electromotive force = Electrical Energy

Chemical affinity = Chemical Energy

sugar + oxygen \rightarrow carbon dioxide + water + energy (\Delta G)
Metabolic diversity

Gibbs free energy

\[ E_h^\circ = -\Delta G_r^\circ / nF \]

• Microorganisms have evolved the capability of almost any reaction which yields free energy and has relatively slow kinetics

• Happens at **interfaces**
  - \( \text{H}_2\text{S/O}_2 \)
  - \( \text{CH}_4/\text{SO}_4 \)

**FIG. 6.5.** Redox potentials and life.
DEB links to Carbon flow

• Life is Carbon, right?

• Life is also catalysis

• We need to better understand microbial activities
  - Hydrogen, methane, CO₂ (organic acids, CO, alkanes, etc.)
  - N, P
  - Fe, S

• We need to understand growth, survival, expiration, and diagenesis

Price PNAS 2004
Temperature limits to life

• Deep-sea vent microbes have been shown to grow to at least 122° C

• Anecdotal evidence that life may survive to ~150 °C, or more...

• Pressure and temperature effects are cooperative

Takai PNAS 2008
Pressure limits to life

• Cell survival and activity to >1GPa pressures.

• Certainly many “common” organisms can survive 600 MPa or so pressure.

• Recent studies have begun to show that activities of surface adapted organisms can be suppressed at much lower pressures.

• And that retaining in situ pressures can impact the biology.
Ties between energy and limits
your average deep-sea hydrothermal vent...
Energy, cont.

...and your average deep-sea sediment

JorgensonNatRevMicro2007
Fluid circulation

• How deep do fluids circulate?

• How continuous is the circulation?

• hydrology and microbiology are intimately linked!
Radiogenic production of chemical disequilibria

• Radiogenic H₂ production
• Splitting water with α, β, γ radiation produced from radioactive decay

• Low biomass, energy poor regimes
  - South Pacific Gyre
  - S. African crustal aquifer

D’Hondt PNAS 2009
Take home point #1

• Drilling through the crust provides an opportunity to explore the continuum from life to non-life, to explore the connectivity and flow between deep and surface chemical reservoirs
CONTAMINATION!

- The interfaces are likely the most interesting, but also the most difficult to recover

- If you are going to make a borehole, to case a borehole, and to pump drilling fluids— you will perturb the system over biologically relevant time scales

Orcutt GeomicroJ 2010
S/N in biological systems

- Deep sequencing techniques are allowing us to thoroughly document microbial diversity.

- Very similar to the problems for organic geochemistry.

- We have to weight the costs/benefits of anti-contamination measures.

Brazelton PNAS 2010
Ophiolites and analogue systems

• Provide the opportunities to develop the technologies and the approaches for drilling, core recovery, and analysis
  - Where predicted technologically challenges can be tackled (e.g. temperature)
  - Analytical challenges (e.g. low biomass, surface contamination)
  - Where mantle rocks can be accessed near surface
Lost City Vent Field

MartinNatRevMicro2008

Kelley, Nature (2001)

Schematic illustrating the geological, hydrothermal, chemical and biological relationships within the Lost City Hydrothermal Field. Fluids moving into the crust interact with siliceous ultramafic rocks at temperatures up to 300°C. This process results in the generation of pH 9–11 fluids, rich in methane, hydrogen and hydroxyl ions. Argonite, calcium carbonate is deposited to form chimneys with metal-rich (Cu-Au) hydrothermal fluids mixing with cold seep water. The warm porous interiors of the chimneys host dense biofilms dominated by a single phototrophic clade related to Methylacidiphilum strain. Surprisingly, animal communities mostly limited to metalloids, <2-2 km wide, that are dominated by gastropods and amphipods, a variety of polyphyletic, and rare microbes. Image produced in collaboration with the Center for Environmental Visualization, University of Washington, USA.
Serpentinite

H₂, CH₄, alkanes, Orgs (chemo)

O₂, CO₂, Orgs (photo)

Tablelands Ophiolite Complex
Newfoundland, Canada
Microbiology in drillholes

• “Biologists” care about cell biology, biochemistry, evolution, and ecology

• You can relatively confidently provide seismic data and rocks— but what if there is no life below a few hundred meters?

• How do you engage the microbiological community to be involved in a decade-long project with no definitive promise of samples?
So the answer is???

• We won’t really know until we look

• Like with space exploration, a tangible outcome of this work will be the technological achievements and advancements

• Other outcomes could be new bio-technologies, information on biodiversity, evolution, and the global carbon cycle

• The “community” should also foster the development of microbiological studies that complement the overarching goal of reaching the mantle (e.g. IODP/COL, NSF/DEBI, DCO, NASA, etc.)