## Extent of Microbial Life in the Deep Biosphere



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Will there be life at the bottom of the **Mohole?** 

The boundaries of biology sear interther below East Masurtace than scient ists had thought populsis. Analysis Leigh Mas carelli cleves into how microbes survive deep underground.

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#### needles in the haystack, that you are seeding with more needles



SchippersNature2005

#### 

•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



JorgensenNatRevMicro2007

# Advances in understanding the deep

• Biased Sward 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

	Population	Turnover time,	Cells/yr,
Habitat	size	days	$ imes 10^{29}$
Marine heterotrophs			
Above 200 m	$3.6  imes 10^{28}$	16*	8.2
Below 200 m	$8.2 imes10^{28}$	300*	1.1
Marine autotrophs	$2.9 imes10^{27}$	1.5†	7.1
Soil	$2.6  imes 10^{29}$	900*	1.0
Subsurface	$4.9  imes 10^{30*}$	$5.5 \times 10^{5*}$	0.03
Domestic mammals	$4.3  imes 10^{24}$ ‡	1§	0.02

\*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 PNAS1998

#### **Advances on the**

Aspo 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



#### Chivian Science 2008

**"The Dark Energy** Ligit seeptembere is only indirectly coupled, if coupled at all, to photosynthetic processes at the Earth's surface. Instead it is *chemotrophic* 



#### How can life use geofuel energy



Electromotive force = **Electrical Energy** Chemical affinity = Chemical Energy Electrons sugar + oxygen  $\rightarrow$ carbon dioxide + water

### Metabolic



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

 Happens at *interfaces* H<sub>2</sub>S/O<sub>2</sub> CH<sub>4</sub>/SO<sub>4</sub>



### **DEB links to Carbon flow**

•Life is Carbon, right?

•Life is also catalysis

•We need to better understand microbial activities

> -Hydrogen, methane, CO<sub>2</sub> (organic acids, CO, alkanes, etc.) -N, P -Fe, S



PricePNAS2004

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

### **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 Oger Biochem 2006

•Cell survival and activity to >1GPa pressures

•Certainly many "common" organisms can <u>survive</u> 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





Fig. 5 Kinetics of ethanol production in the DAC as a function of pressure to 100 MPa

Picard Extremo2007

### Ties between energy and

HOEHLER



HoehlerAstrobiology2007

#### Energy, cont.



your average deep-sea hydrothermal vent...

#### Energy, cont.

...and your average deep-sea sediment

JorgensonNatRevMicro2007

## Fluid circulation

#### KanazawaWorkshopReport

•How deep do fluids circulate?

•How continuous is the circulation?

•hydrology and microbiology are intimately linked!



## Radiogenic production of chemical disequilibria

•Radiogenic  $H_2$  production •Splitting water with  $\alpha$ ,  $\beta$ ,  $\gamma$ radiation produced from radioactive decay

•Low biomass, energy poor regimes

-South Pacific Gyre -S. African crustal aquifer



D'HondtPNAS2009

### 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





OrcuttGeomicroJ2010

## S/N in biological systems

600

•Deep sequencing techniques are allowing us to thoroughly document microbial diversity

•Very similar to the problems for organic geochemistry

sample 3 bact Number of OTUs (3% distance) 128 yrs) 500 sample 4 bact 400 245 yrs). sample 1 bact (34 yrs) 300 ample 2 ba sample 3 arch sample 1 arch (128 yrs) (34 yrs) sample 2 arch 200 (43 yrs) ample 4 arch (1245 yrs) 100 0 5000 10000 15000 20000 25000 30000 35000

Number of tag sequences

Brazelton PNAS2010

•We have to weight the costs/benefits of anticontamination measures

# 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



S1] Schematic illustrating the geological, hydrothermal, chemical and biological relationships within the Lost City Hydrothermal Field. Fluids migrating into the maxii interact with olivine-rich ultramafic rocks at temperatures up to 200°C. This process results in the generation of pH 9-11 fluids, rich in methane, hydrogen and hydrocarbons. Aragonite, acidite and bruckie are deposited to form chirmeys as the metal-poor, 40-91°C hydrothermal fluids mix with cold seawater. The warm porous interiors of the chirmeys hast dense biofilms dominated by a single philyotype related to Methanoscarcinales. Surprisingly, animal communities are mostly limited to meiofaume, <12 cm in size that are dominated by gastropods and amphipods, a variety of polycheetes, and rare biolayles. Image produced in collaboration with the Center for Environmental Visualization, University of Washington, USA. Martin*NatRevMicro* 2008



#### Serpentinite O<sub>2</sub>, CO<sub>2</sub>, Orgs (photo) H<sub>2</sub>, CH<sub>4</sub>, S alkanes, Orgs (chemo) ??? **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.)