Extent of Microbial Life in the Deep Biosphere

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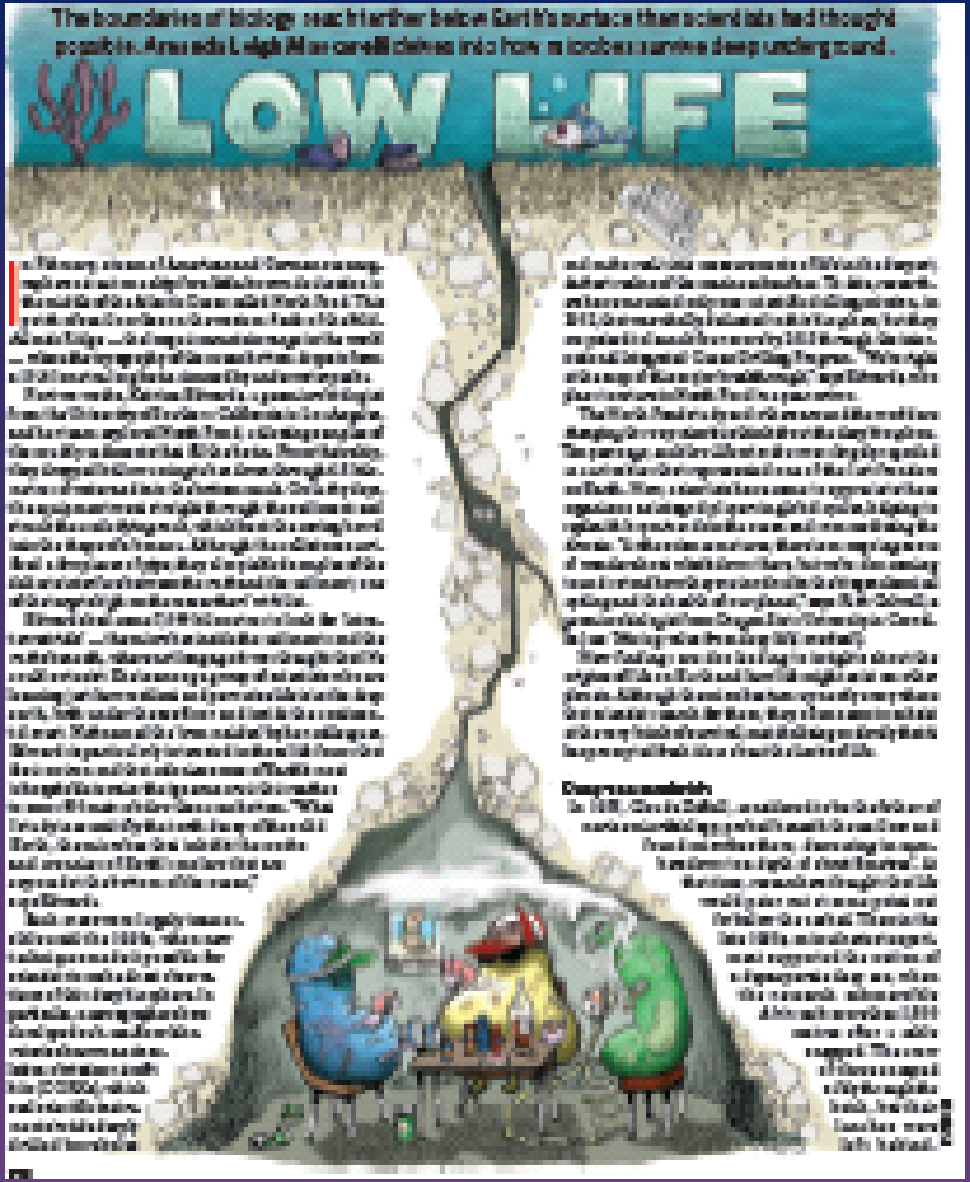
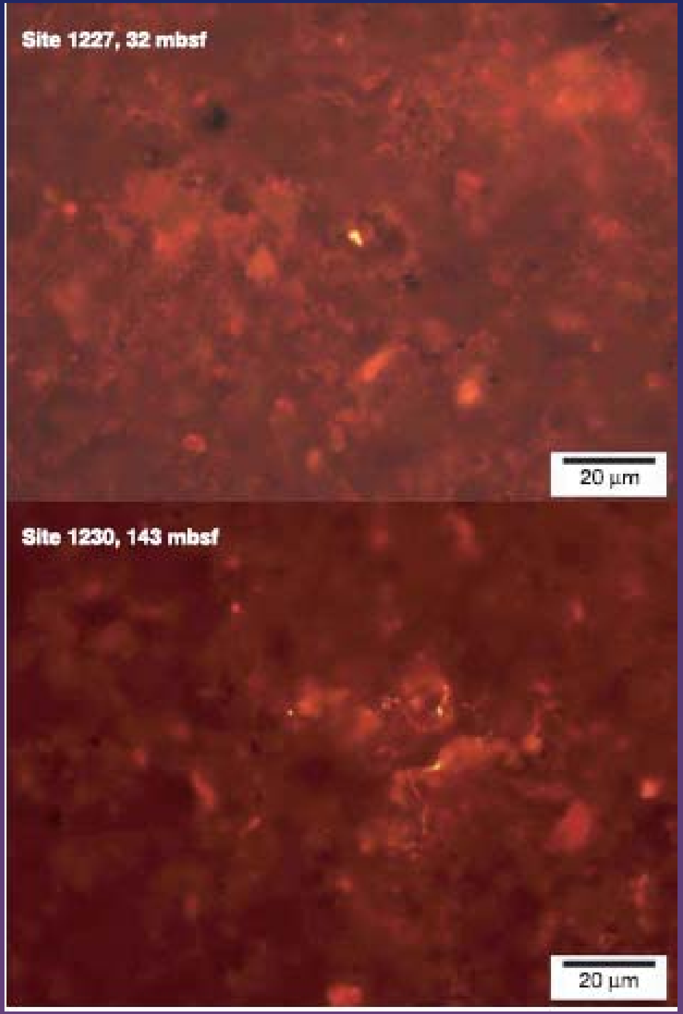
Will there be life at the bottom of the Mohole?



Mascarelli *Nature* 2008

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



Schippers*Nature*2005

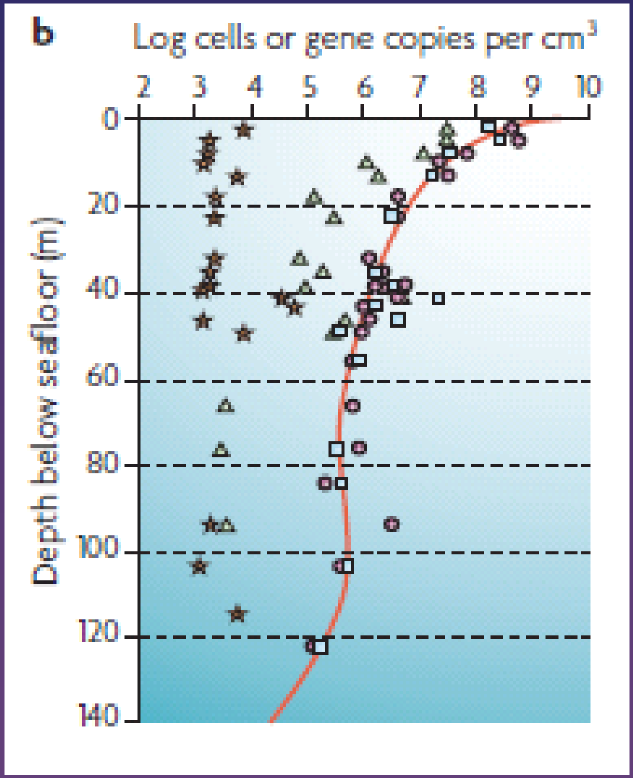
Advances in understanding the deep biosphere

•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 times



JorgensenNatRevMicro2007

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

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

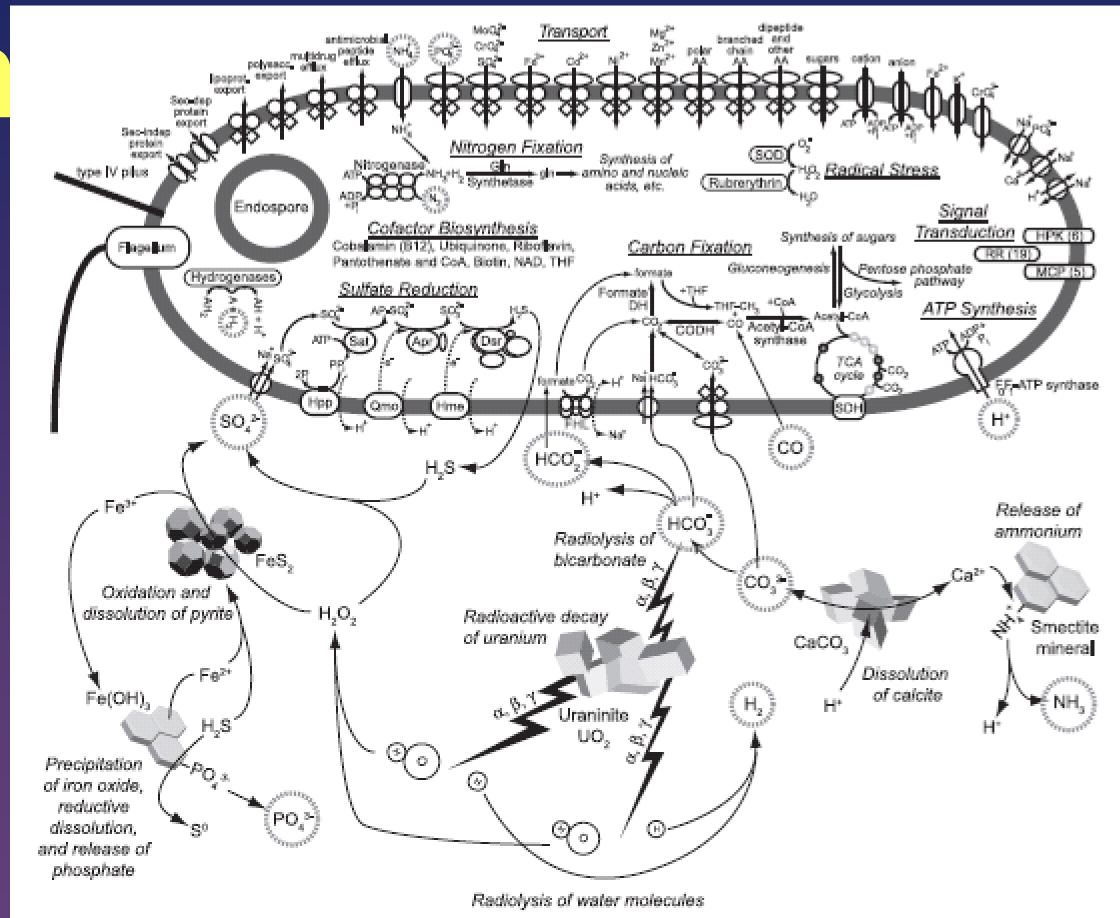
*The value or mean of the range discussed in the text.
†Based on the median generation time of *Prochlorococcus* (84).
‡Sum of the number of prokaryotes in cattle, sheep, goats, and pigs from Table 4.
§From ref. 85.

Whitman*PNAS*1998

Advances on the continen

•Äspo mine
•DOE work
•Chesapeake Bay
•Columbia River flood basalts

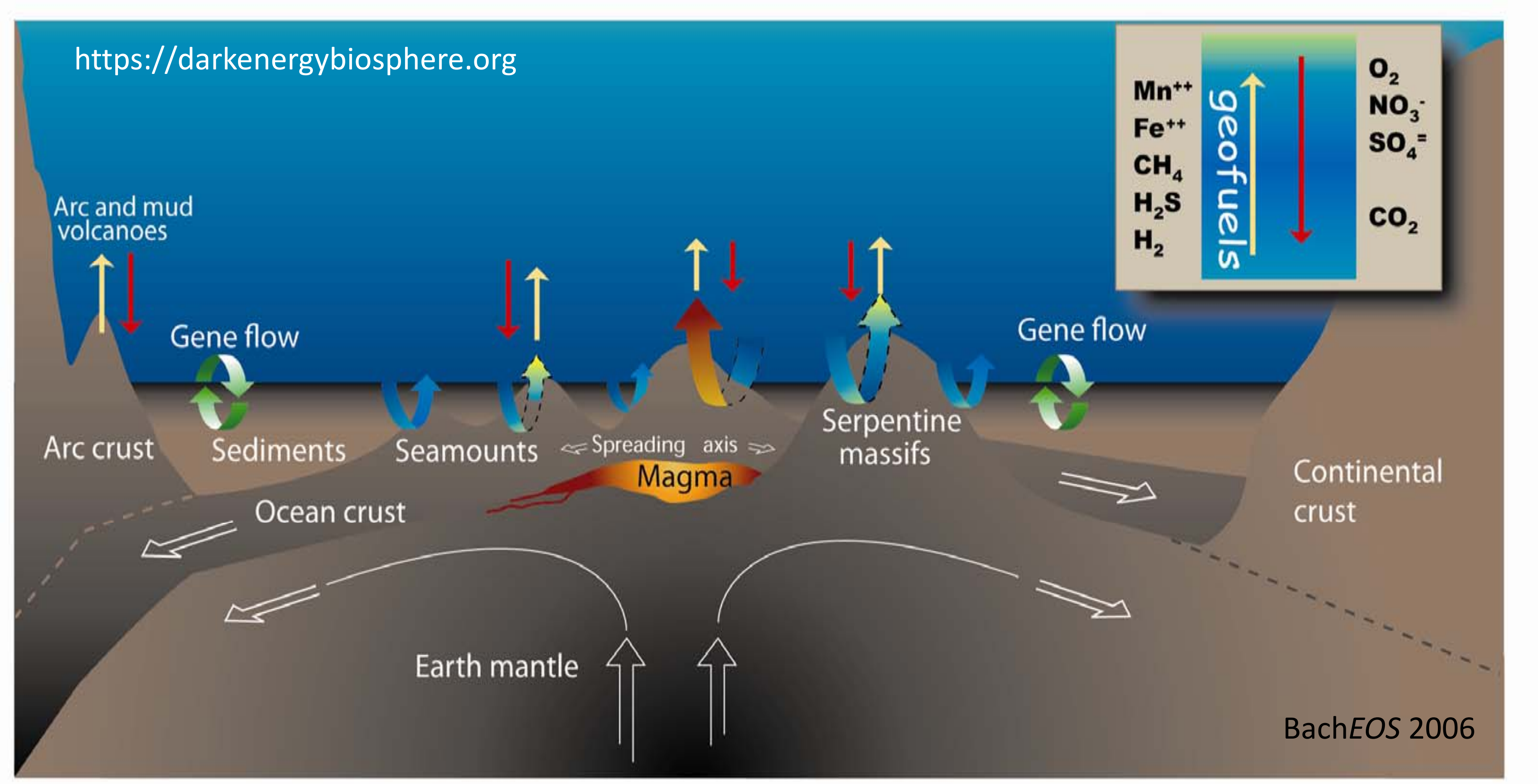
•Accessing sealed fault systems 2.8 km-4km below land surface in South African gold mines



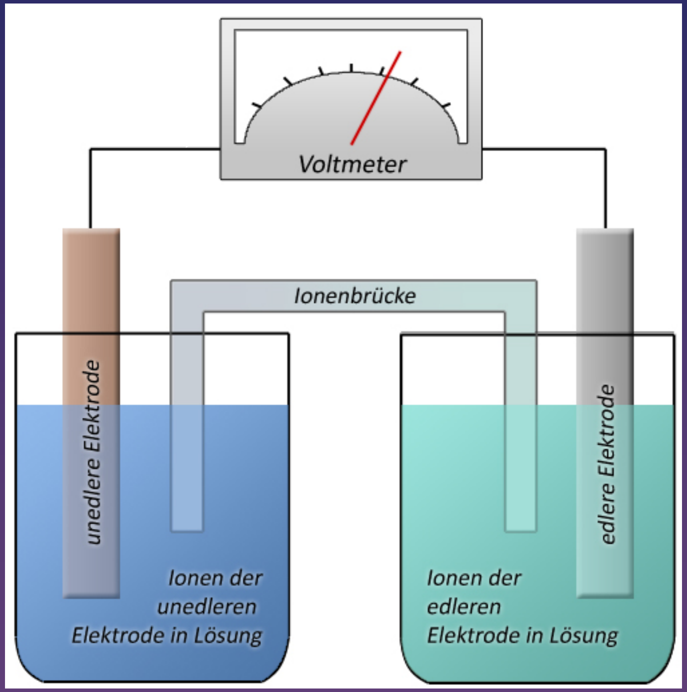
Chivian*Science*2008

"The Dark Energy Biosphere"

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*



How can life use geofuel energy



sugar	oxygen
sulfur	nitrate
hydrogen	oxygen
methane	sulfate

Electromotive force = Electrical Energy

Chemical affinity = Chemical Energy

Electrons

sugar + oxygen →
carbon dioxide + water
+ energy (ΔG)

Metabolic diversity

Gibbs free energy

$E_h° = -\Delta G_r° / nF$

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

- Happens at ***interfaces***
  - **H_2S/O_2**
  - **CH_4/SO_4**

Mix *Astrobiology* 2006

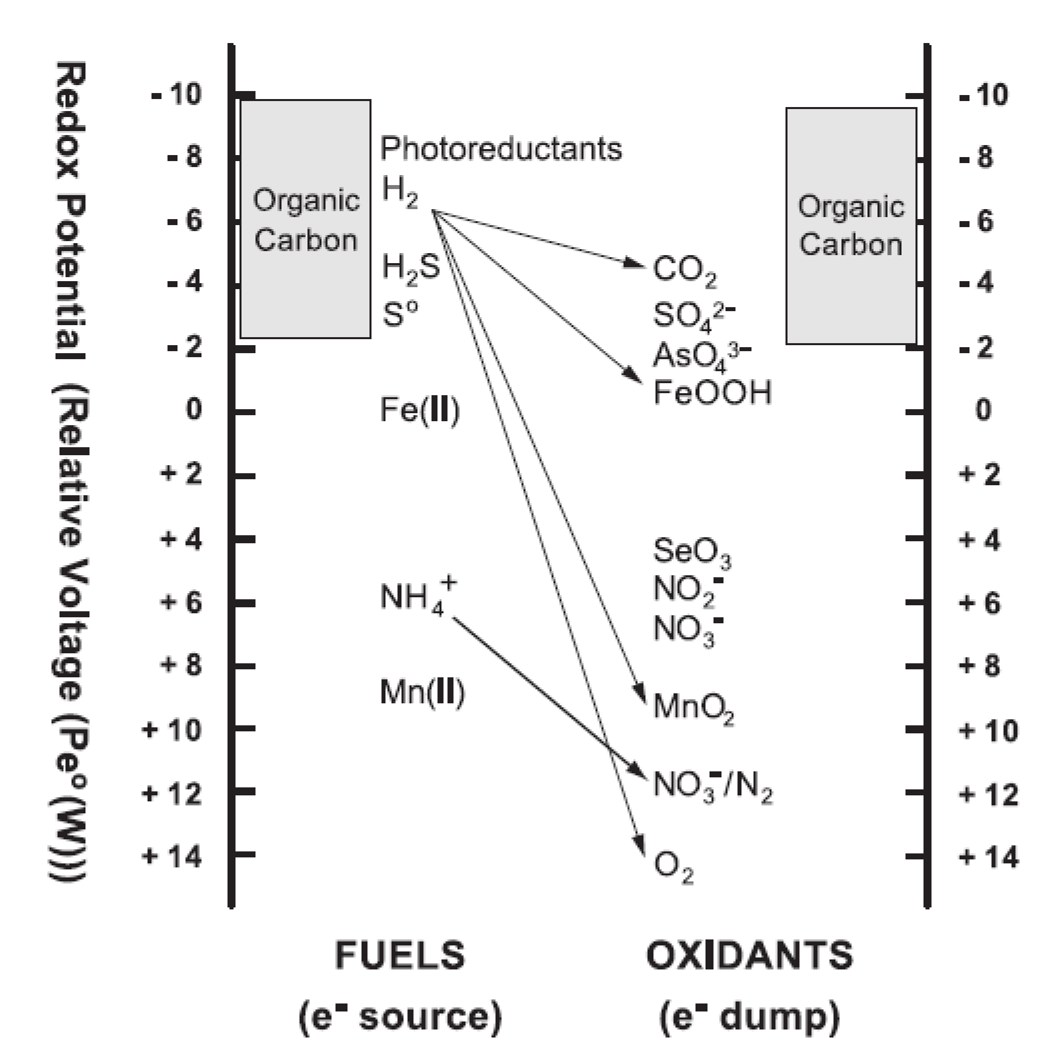


FIG. 6.5. Redox potentials and life.

DEB links to Carbon flow

•Life is Carbon, right?

•Life is also catalysis

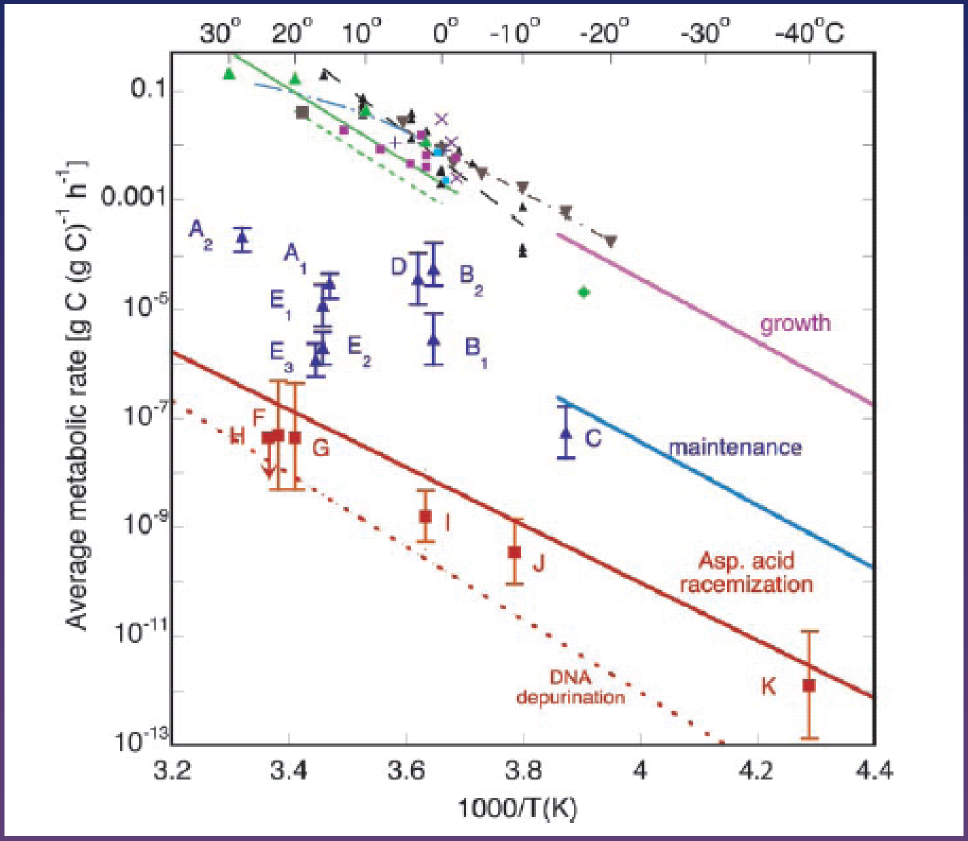
•We need to better understand microbial activities

-Hydrogen, methane, CO_2 (organic acids, CO, alkanes, etc.)

-N, P

-Fe, S

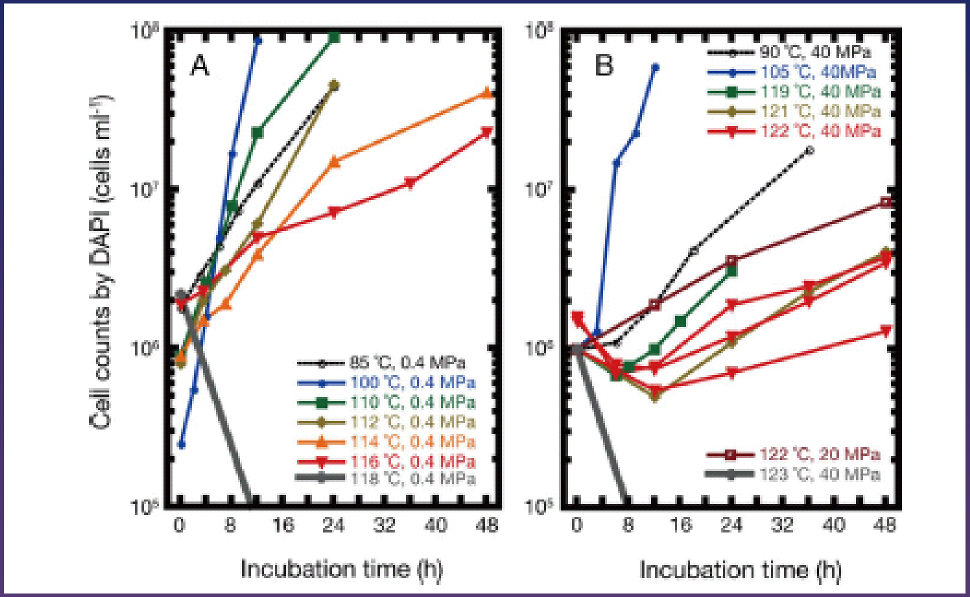
•We need to understand growth, survival, expiration, and diagenesis

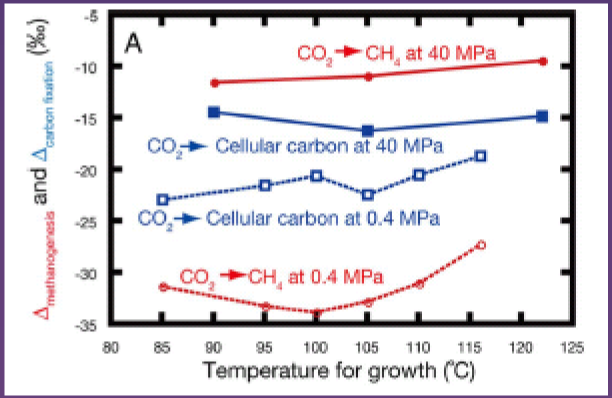


Price *PNAS* 2004

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

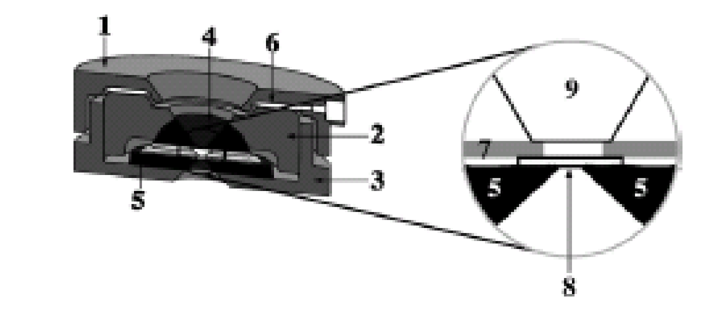
Oger *Biochem* 2006

•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



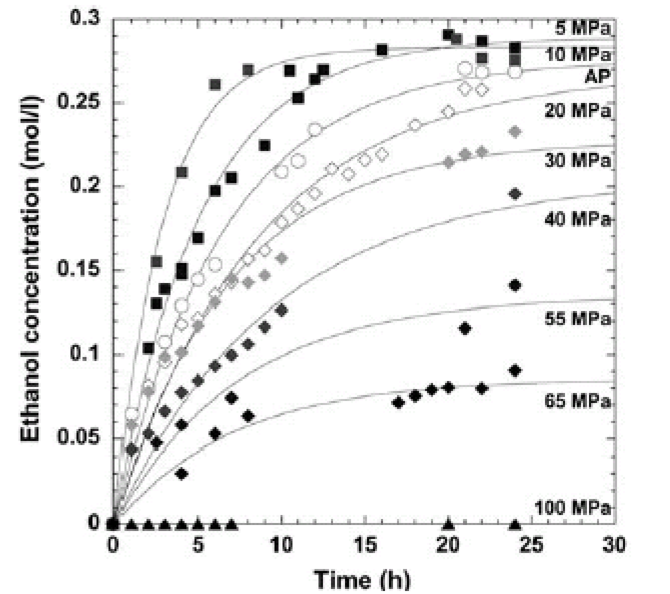
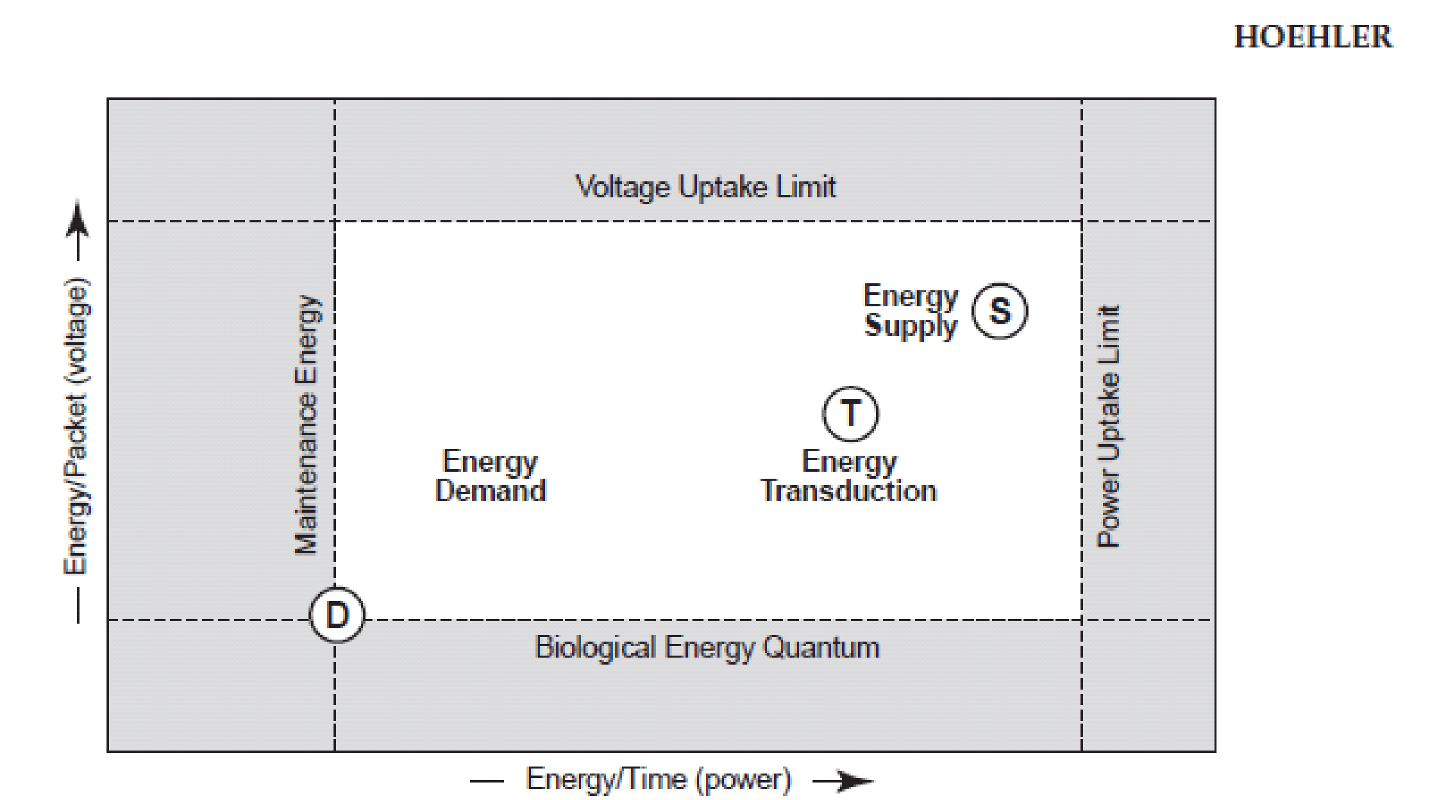


Fig. 5 Kinetics of ethanol production in the DAC as a function of pressure to 100 MPa

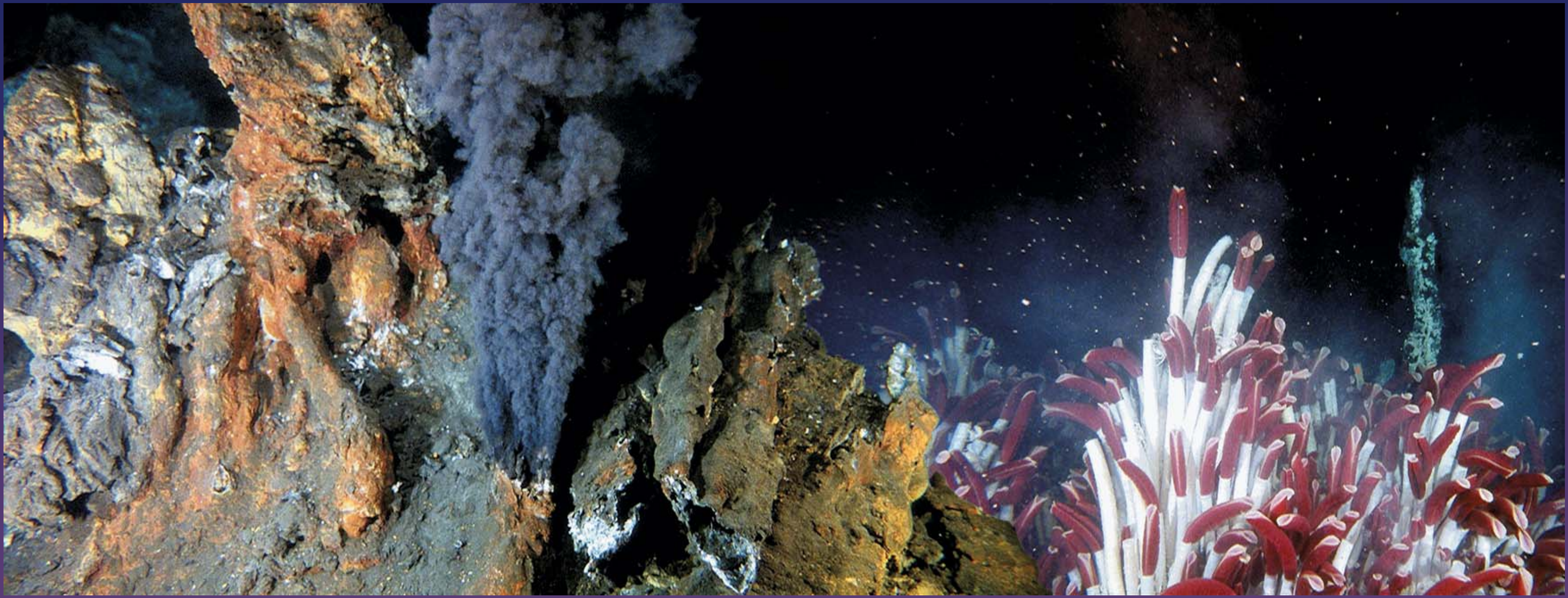
Picard *Extremo* 2007

Ties between energy and limits



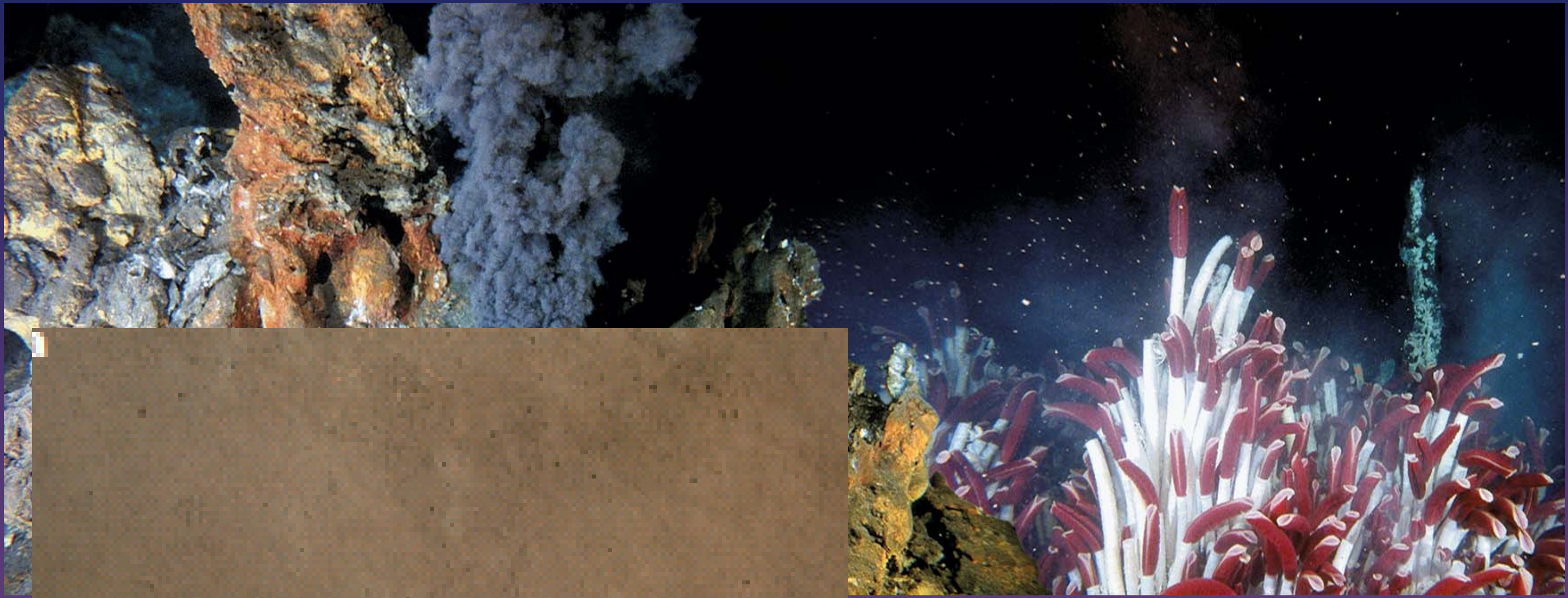
Hoehler *Astrobiology* 2007

Energy, cont.



your average deep-sea hydrothermal vent…

Energy, cont.



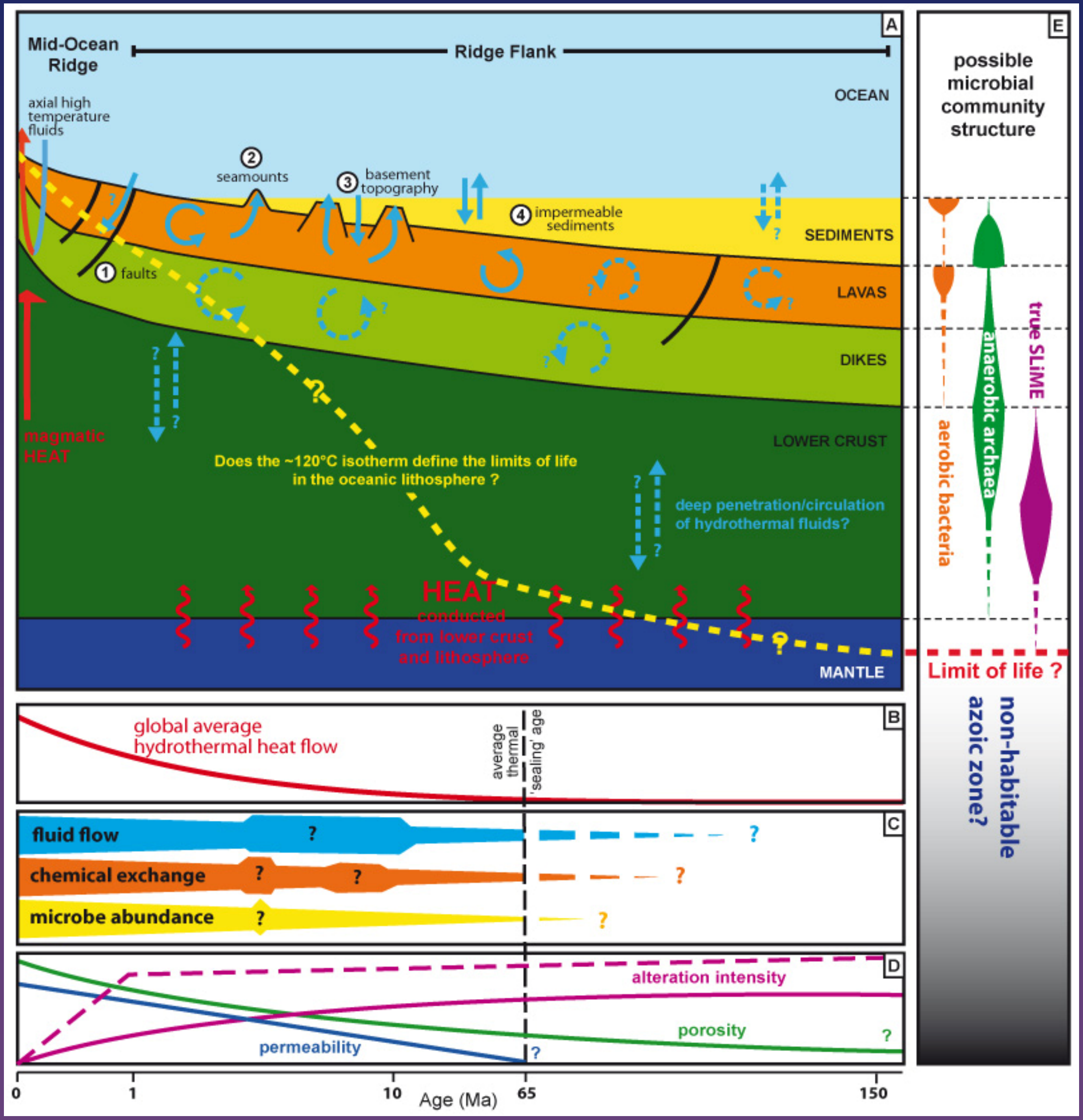
…and your average deep-sea sediment

Jorgenson*NatRevMicro*2007

Fluid circulation

KanazawaWorkshopReport

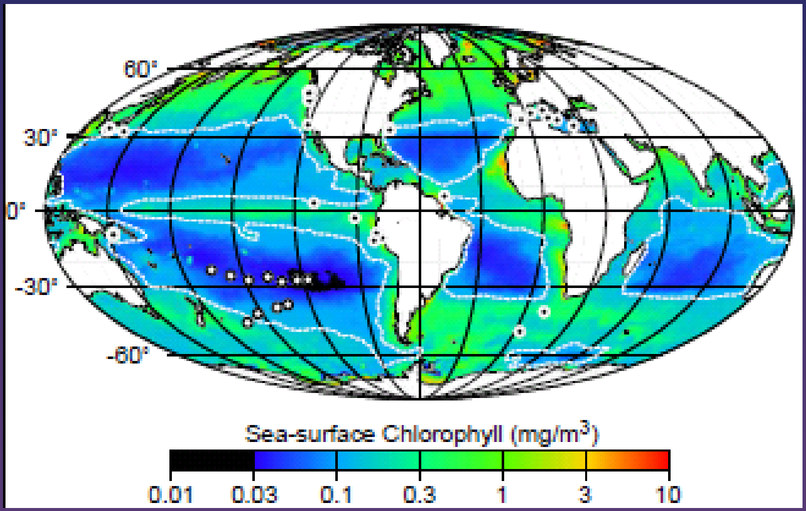
- How deep do fluids circulate?
- How continuous is the circulation?
- hydrology and microbiology are intimately linked!



Radiogenic production of chemical disequilibria

- Radiogenic H_2 production
- Splitting water with α, β, γ radiation produced from radioactive decay

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



D'Hondt *PNAS* 2009

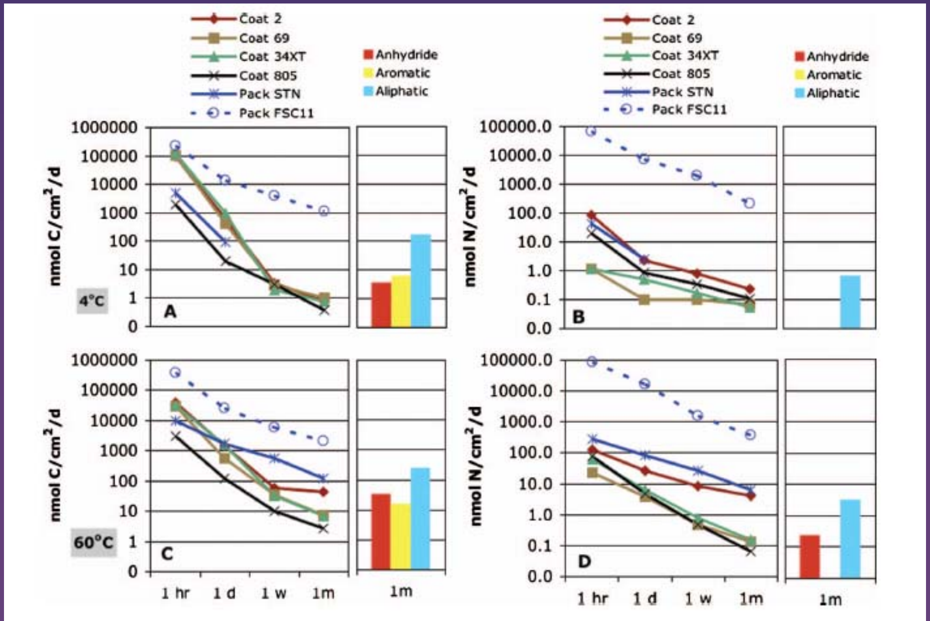
Take home point #1

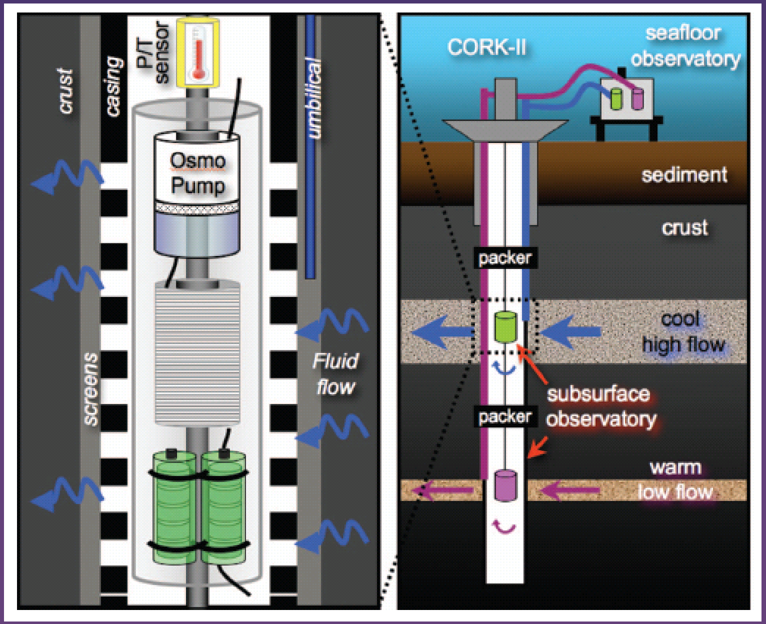
- Drilling through the crust provides an opportunity to explore the continuum from life to non-life, to explore the connectivity and flow between deep and surface chemical reservoirs

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





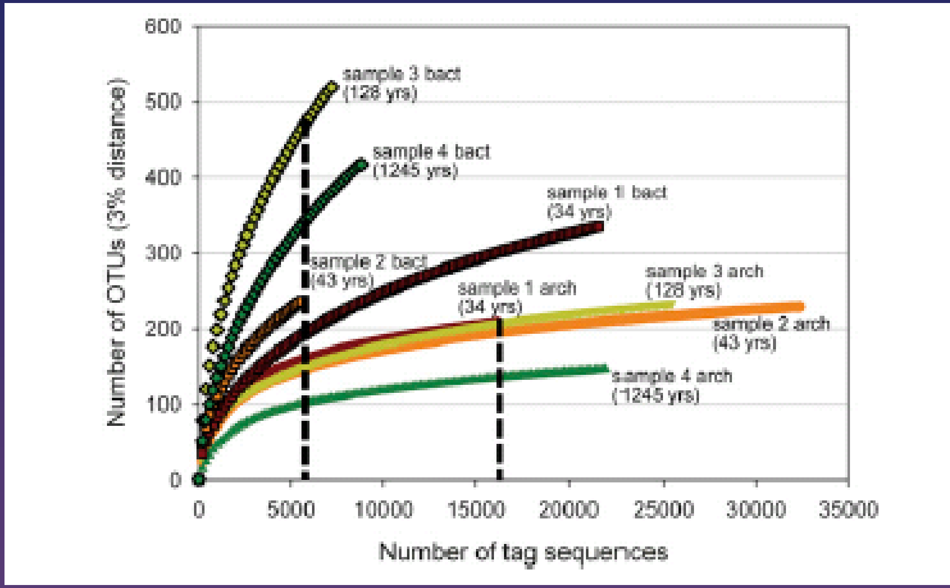
OrcuttGeomicroJ2010

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

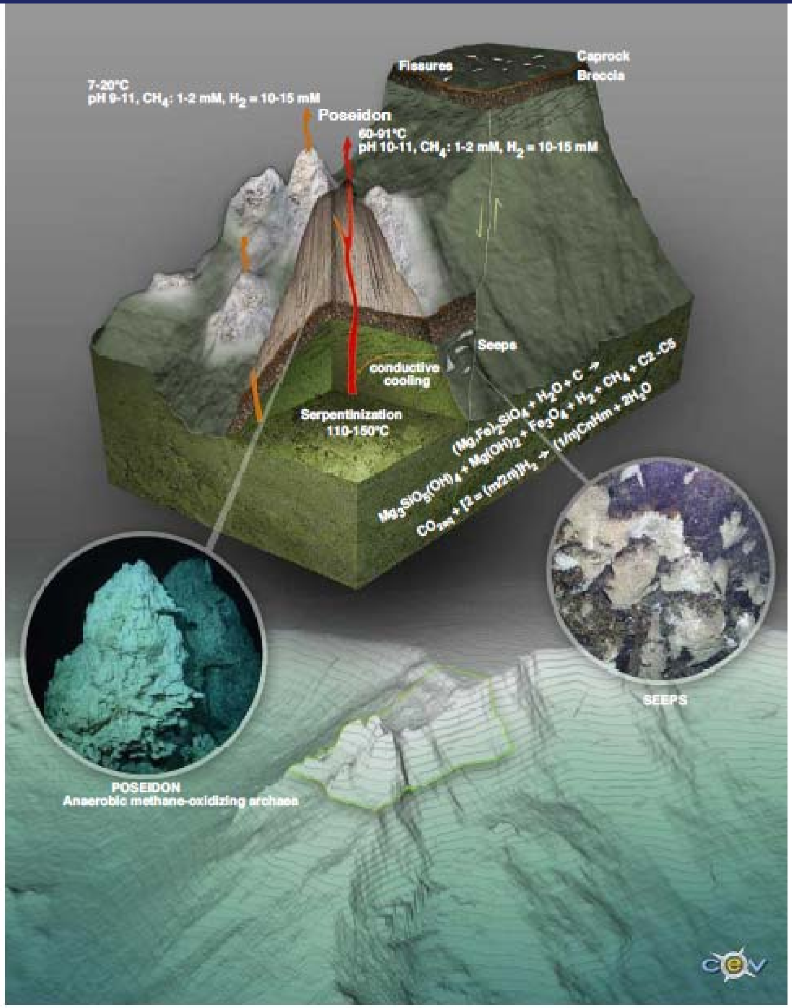
•Provide the opportunities to develop the technologies and the approaches for drilling, core recovery, and analysis

-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

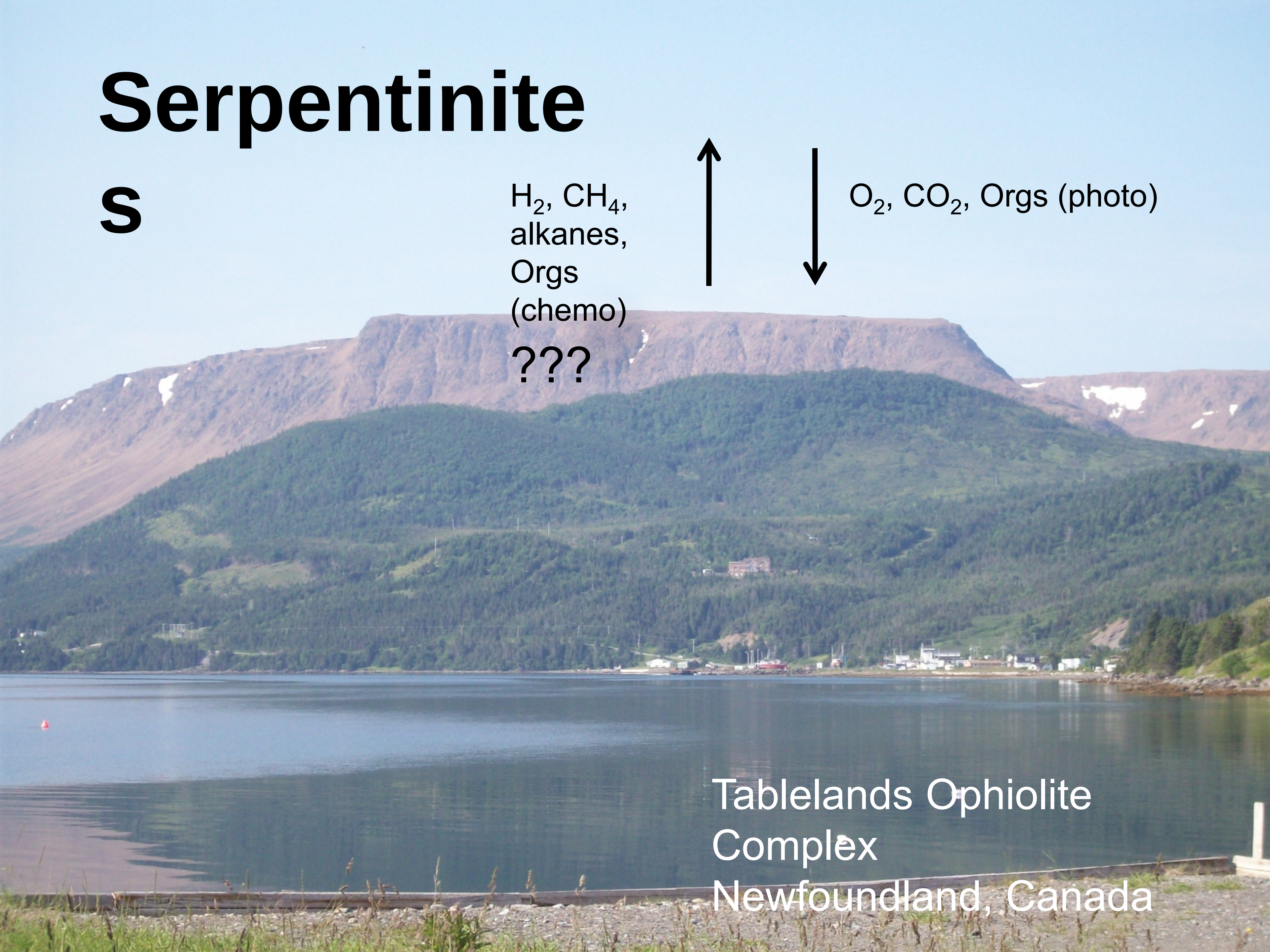


S1 | **Schematic illustrating the geological, hydrothermal, chemical and biological relationships within the Lost City Hydrothermal Field.** Fluids migrating into the massif interact with olivine-rich ultramafic rocks at temperatures up to 200°C. This process results in the generation of pH 9-11 fluids, rich in methane, hydrogen and hydrocarbons. Aragonite, calcite and brucite are deposited to form chimneys as the metal-poor, 40-91°C hydrothermal fluids mix with cold seawater. The warm porous interiors of the chimneys host dense biofilms dominated by a single phlyotype related to Methanosarcinales. Surprisingly, animal communities are mostly limited to meiofauna, < 1-2 cm in size that are dominated by gastropods and amphipods, a variety of polychaetes, and rare bivalves. Image produced in collaboration with the Center for Environmental Visualization, University of Washington, USA.

MartinNatRevMicro 2008

Kelley, *Nature* (2001)

Serpentinites



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.)