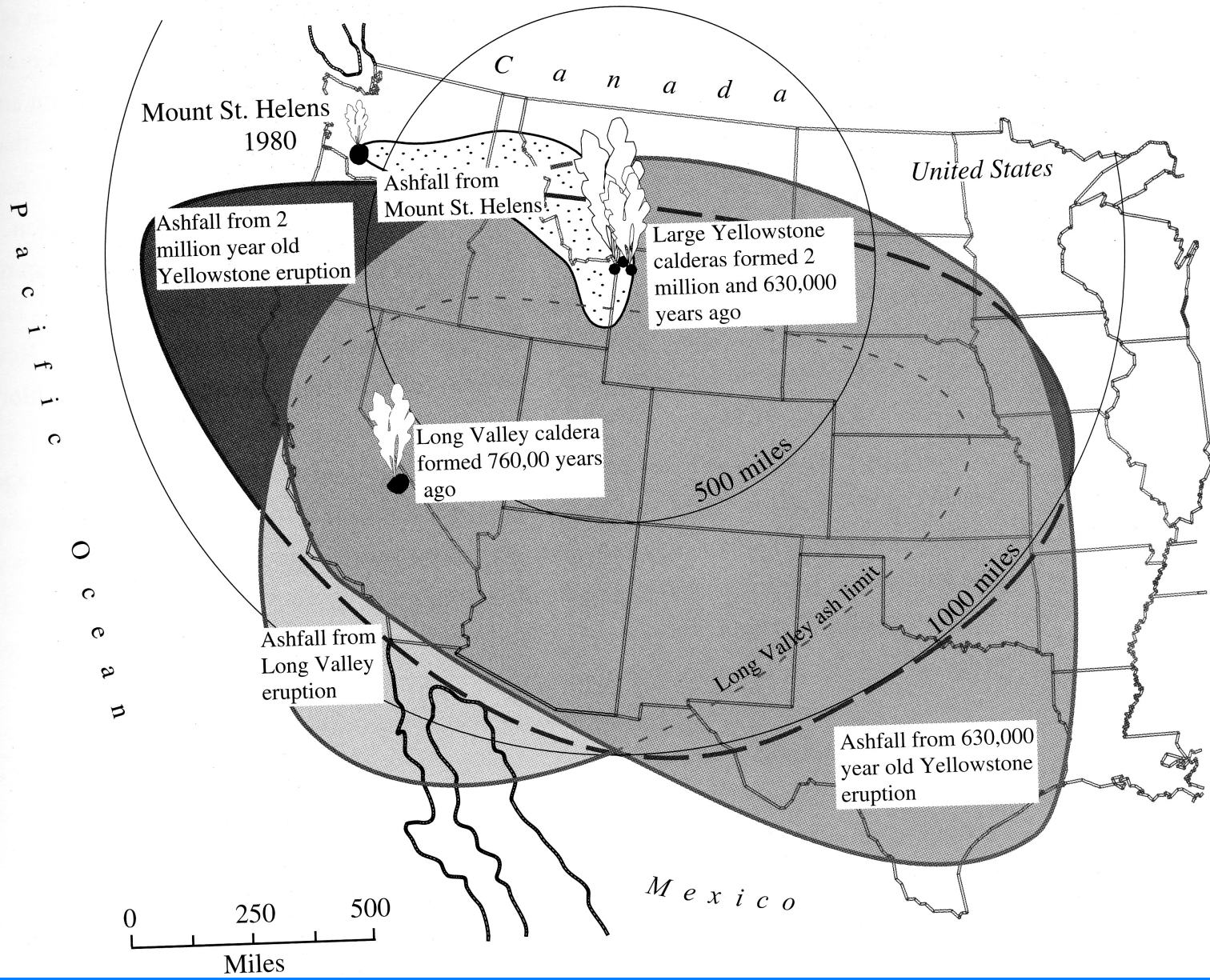


Lecture Outline

- Extremophiles
 - Yellowstone National Park
 - Lake Vostok
 - Atacama Desert
 - Deep Sea Hydrothermal Vents
 - Extremophile Types and Diversity
- Extremophiles' Roles in the Evolution & Origin of Terrestrial Life
- *D. Radiodurans* (hyper-poly-extremophile)
- Implications for Astrobiology

Limits of Life on Earth

- Archaea and bacteria can thrive in extreme environment (heat, cold, acidity, high pressure) and can use unusual energy source
- Distinguish between growth and survival (e.g., seeds, spores)
- Analogs for extraterrestrial environments
- Origin of life in extreme environments?



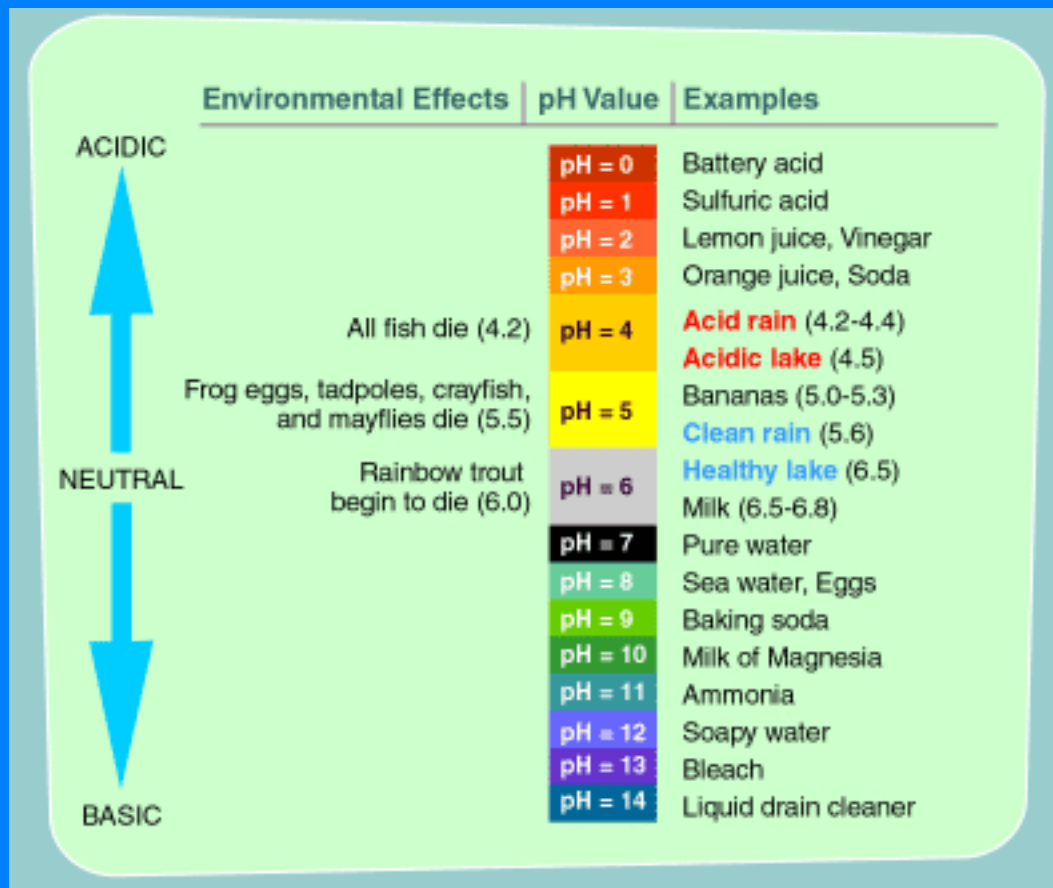
Origin of Yellowstone National Park





Figure 1 Congress Pool, Norris Geyser Basin, Yellowstone National Park, USA, where Tom Brock originally isolated *Sulfolobus acidocaldarius*. The average pH is 3 and the average temperature is 80 °C. Photo taken on 20 September 2000.

pH scale





Nymph Creek

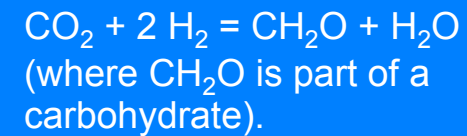


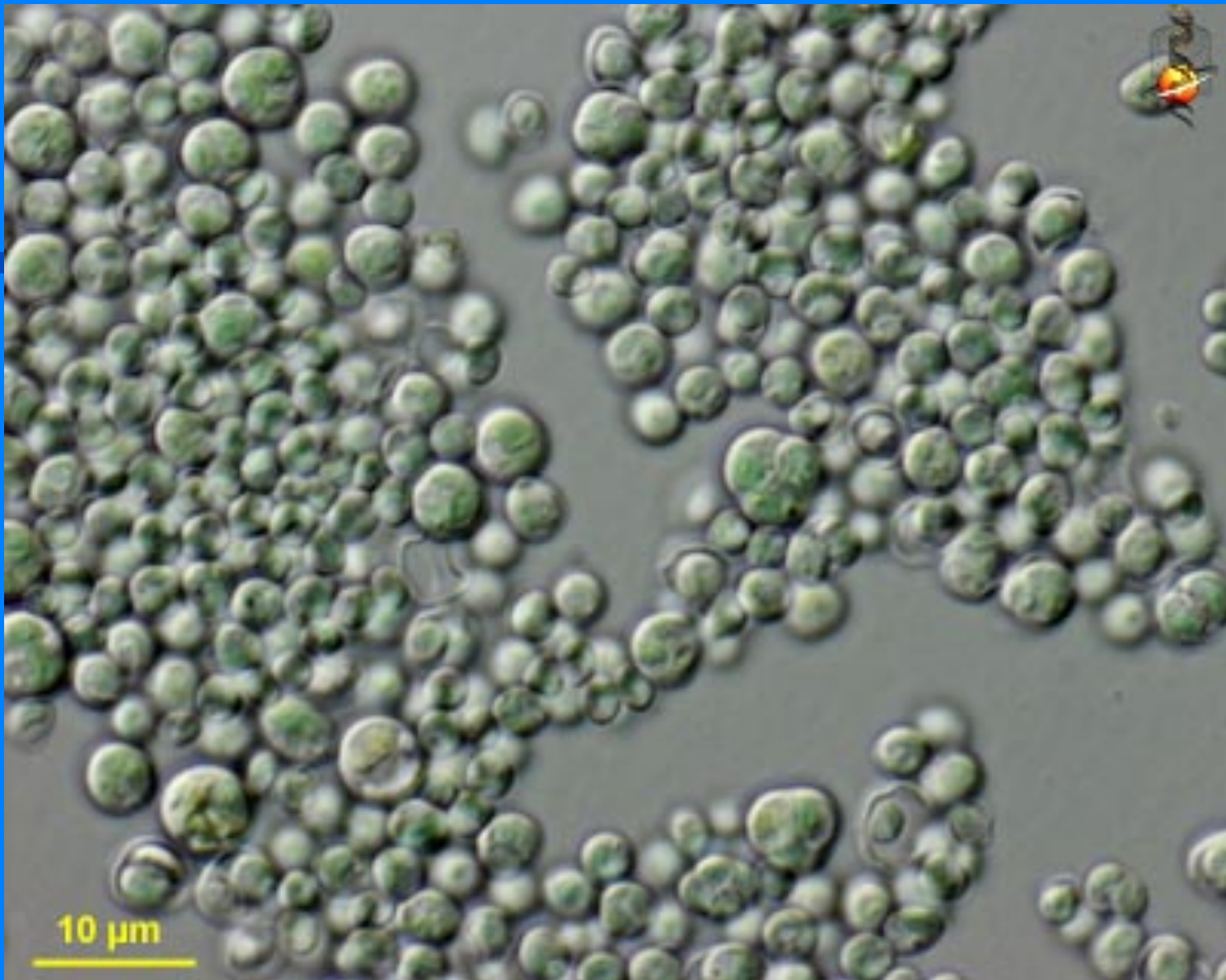
pH 3

Temperature 60 C

Rich in sulfur

Hydrogenobacter gets energy by reacting oxygen from the air with hydrogen gas and/or sulfide in the water. It uses the energy to make carbohydrate (sugar) from atmospheric carbon dioxide and hydrogen in the water:

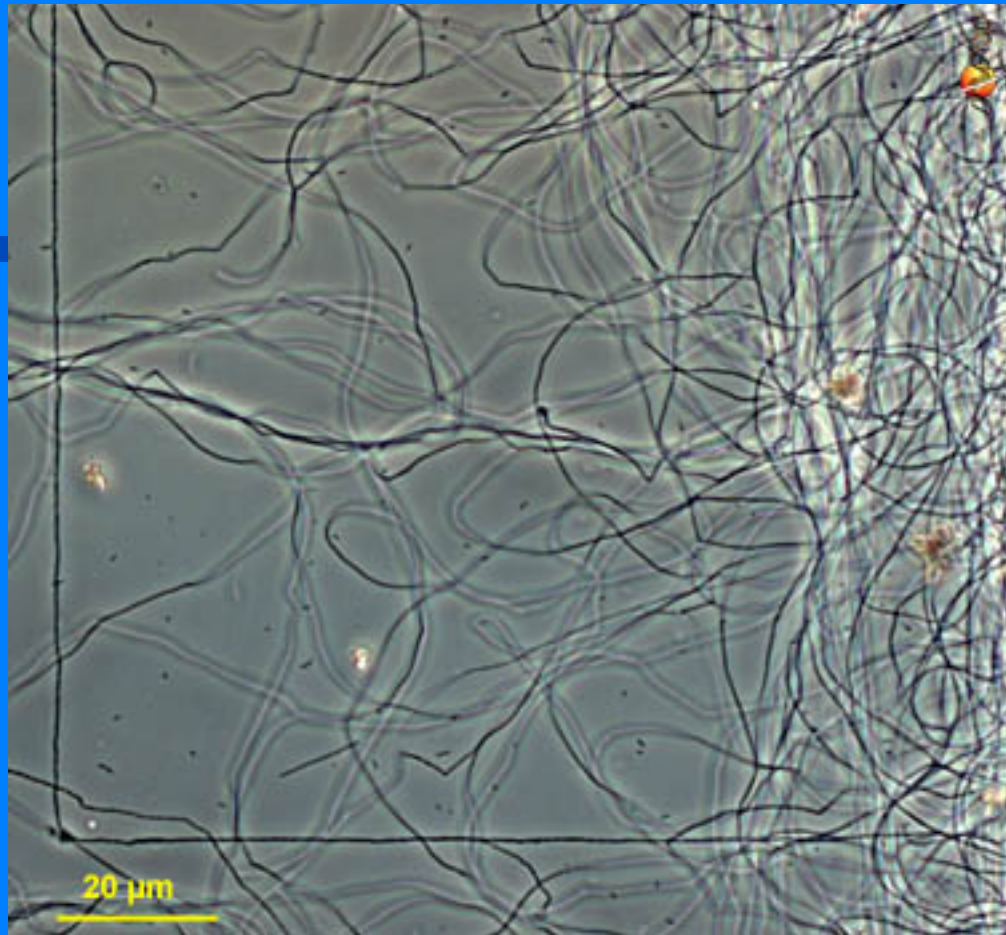




Nymph Creek flowing into Nymph Lake, Yellowstone National Park; green mat of *Cyanidium* (pH 3, 40 to 45°C)



Nymph Lake

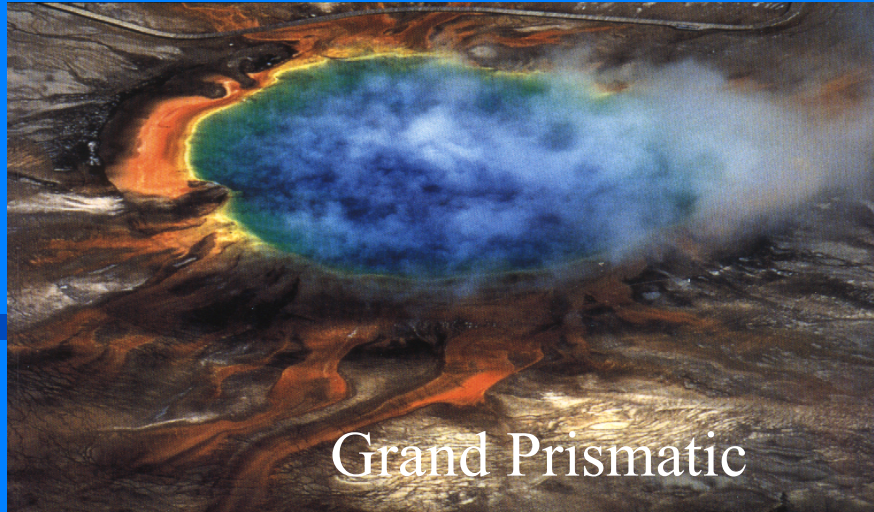


Hydrogenobacter acidocaldarius

Hyperthermophile ($T > 80\text{ C}$), $\text{pH} \approx 3$

H_2 metabolism, low nutrient tolerant

Hot springs in YNP, New Zealand & Australia + oil wells



Sulphobus: optimum T~80C

Minimum 60 C, maximum 90C. Lives by oxidizing sulfur which is abundant near hot springs

“Boiling Lake”

70 C

Filled with thermophiles

Orange “mats” of pigmented extremophiles (carotenoids)



Cyanobacterial mat at Grand Prismatic Springs, Midway Geyser Basin; the dark area is *cyanobacteria with scytonemin* (<45°C)

Adaptations of Thermophiles

- Similar to “ordinary” archaea and bacteria (DNA, same amino acids)
- Subtle differences:
 - Cell membranes are made of lipids that are more stable to high temperature
 - Additional enzyme (reverse DNA gyrase) causes DNA to fold up in a way that is more stable against heat

The absolute maximum temperature is around 150 C--- DNA breaks up very readily above this temperature

Slow growth of bacteria in thermafrost down to -20C

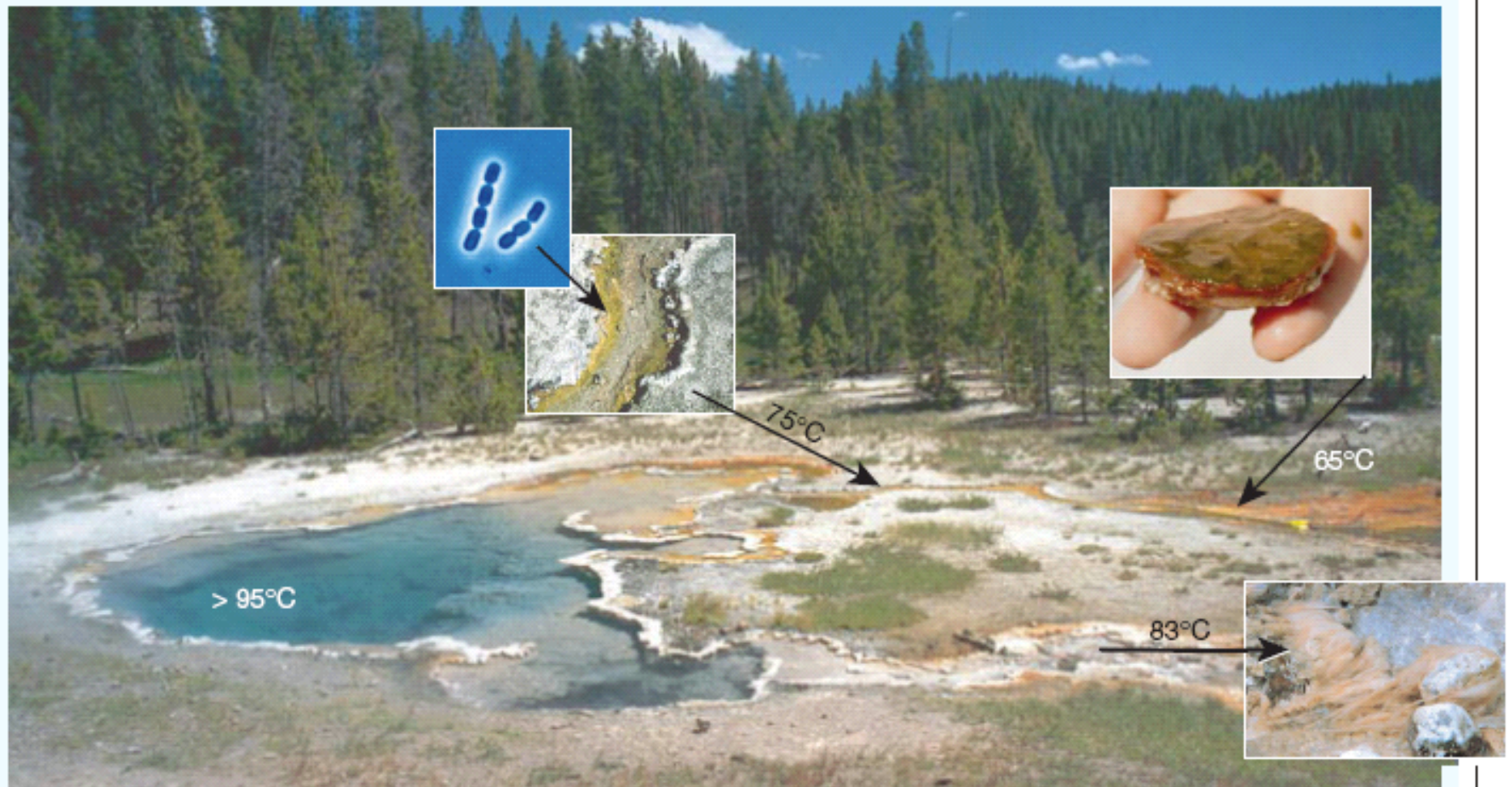
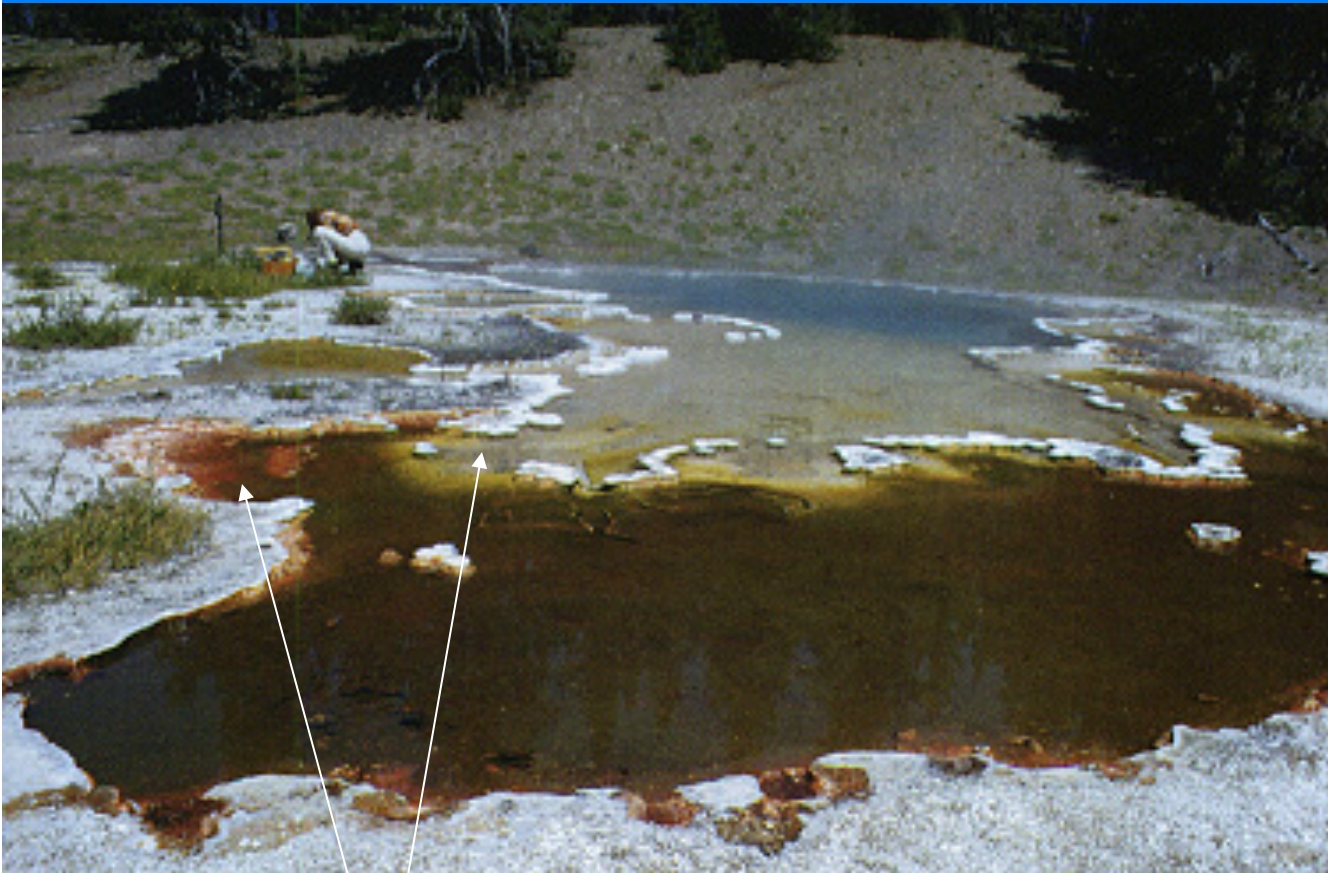


Figure 2 Octopus Spring, an alkaline (pH 8.8–8.3) hotspring in Yellowstone National Park, USA, is situated several miles north of Old Faithful geyser. The water flows from the source at 95°C to an outflow channel, where it cools to a low of 83°C. About every 4–5 minutes a pulse of water surges from the source raising the temperature as high as 88°C. In this environment the pink filamentous *Thermocrinis ruber* thrives (lower right). Where the water cools to $\leq 75^\circ\text{C}$, growth of photosynthetic organisms is permitted. The inset on left shows the growth of a thermophilic cyanobacterium, *Synechococcus*, tracking the thermal gradient across the channel. At 65°C a more complex microbial mat forms with *Synechococcus* on the top overlaying other bacteria, including species of the photosynthetic bacterium *Chloroflexus* (upper right). The yellow object at 65°C was part of an experimental set-up. Photo taken on 4 July 1999.

YNP-Octopus Spring
(White Creek area)



Microbial mat. The principal organism in the thin top dark-green layer is *Synechococcus* (center photomicrograph) and the orange bottom layer is *Choroflexus* (right).



Thermus aquaticus (Taq) Polymerase discovered at YNP (1965)

Figure 7 Mushroom Spring, Yellowstone National Park, USA, where Tom Brock isolated *Thermus aquaticus*, the organism from which Taq polymerase was obtained.

Molecule of the Year
(1988)

Nobel prize: Kary
Mullis (1993)



World market now = US\$(few x 10⁸) and growing

Atacama

- Driest place on Earth: 1mm rain/year
- Some regions have not had rain in recorded history
- Life lives off of volcanic gas and in salt lakes



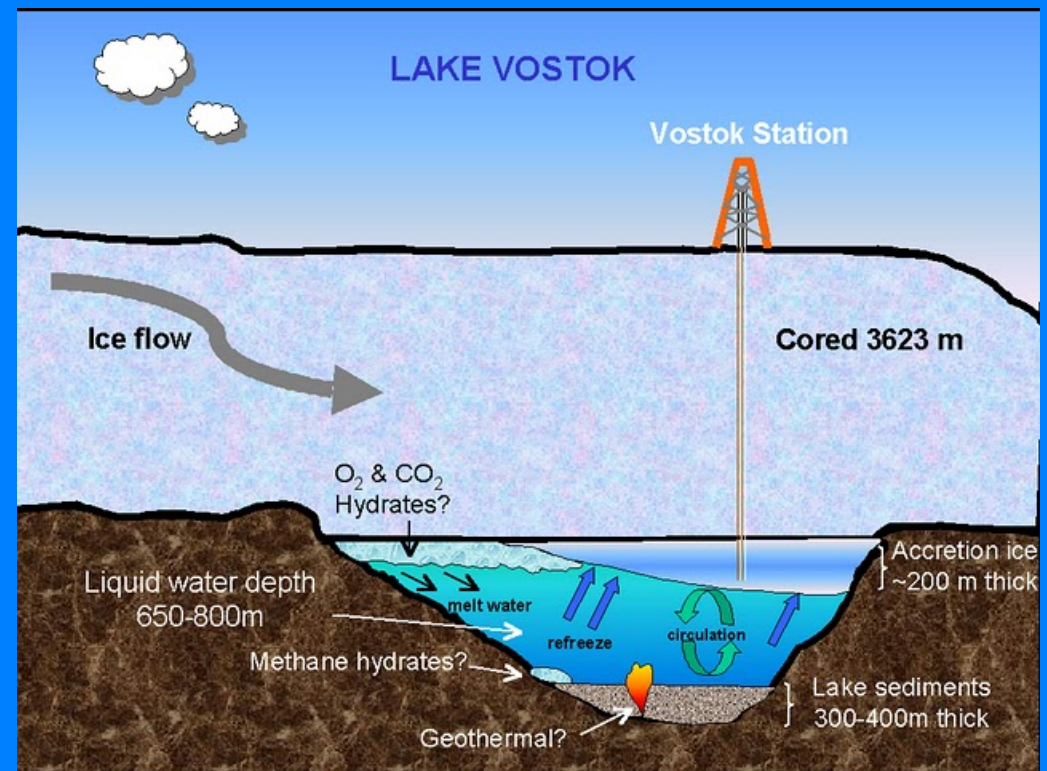
Cave Slime

- live on the ceilings and walls of caves where there are high levels of hydrogen sulfide
- breaking down the hydrogen sulfide in the rock and converting it to sulfuric acid.
- causing the cave to grow larger.
- Phlegm balls are gooey mats made up of cave slime secretions.

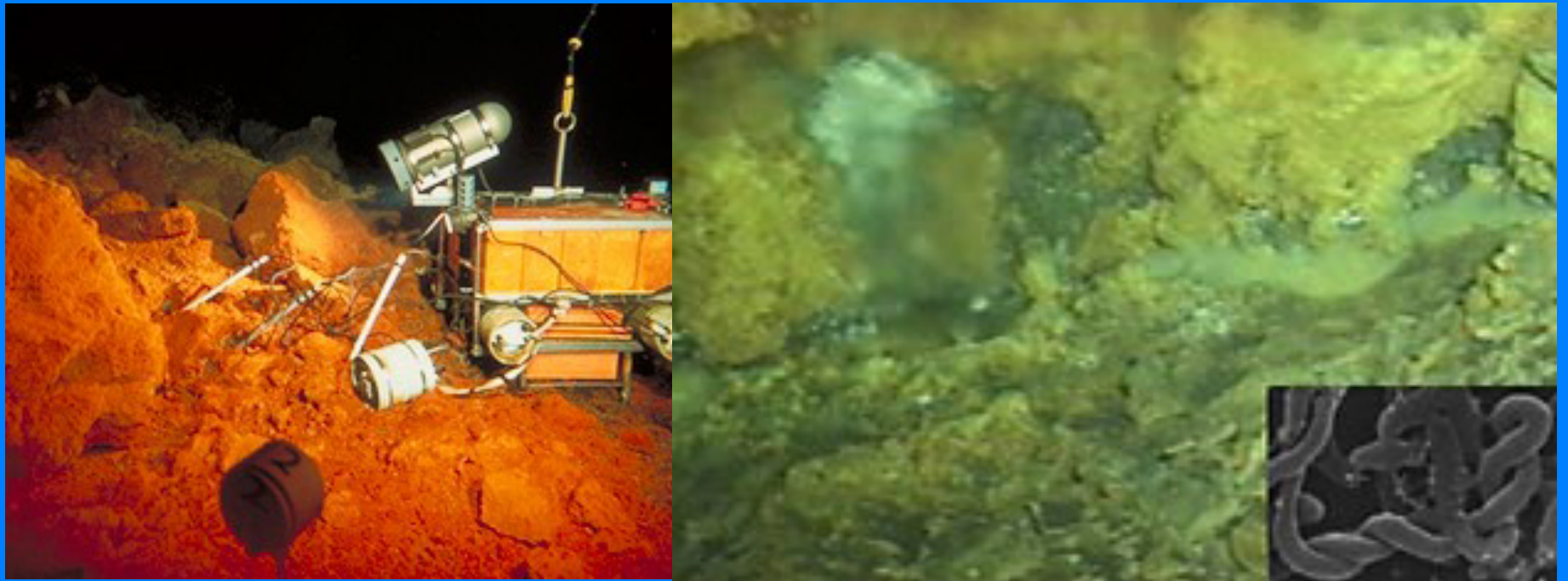


Lake Vostok

- Largest subglacial lake (water isolated for ~10 Myr)
- Similar to Europa and Encedelus
- Total darkness/Oxygen rich
- “Deep Biosphere”
- Cores reveal *Hydrogenophilus themoluteolus* (geothermal vents)

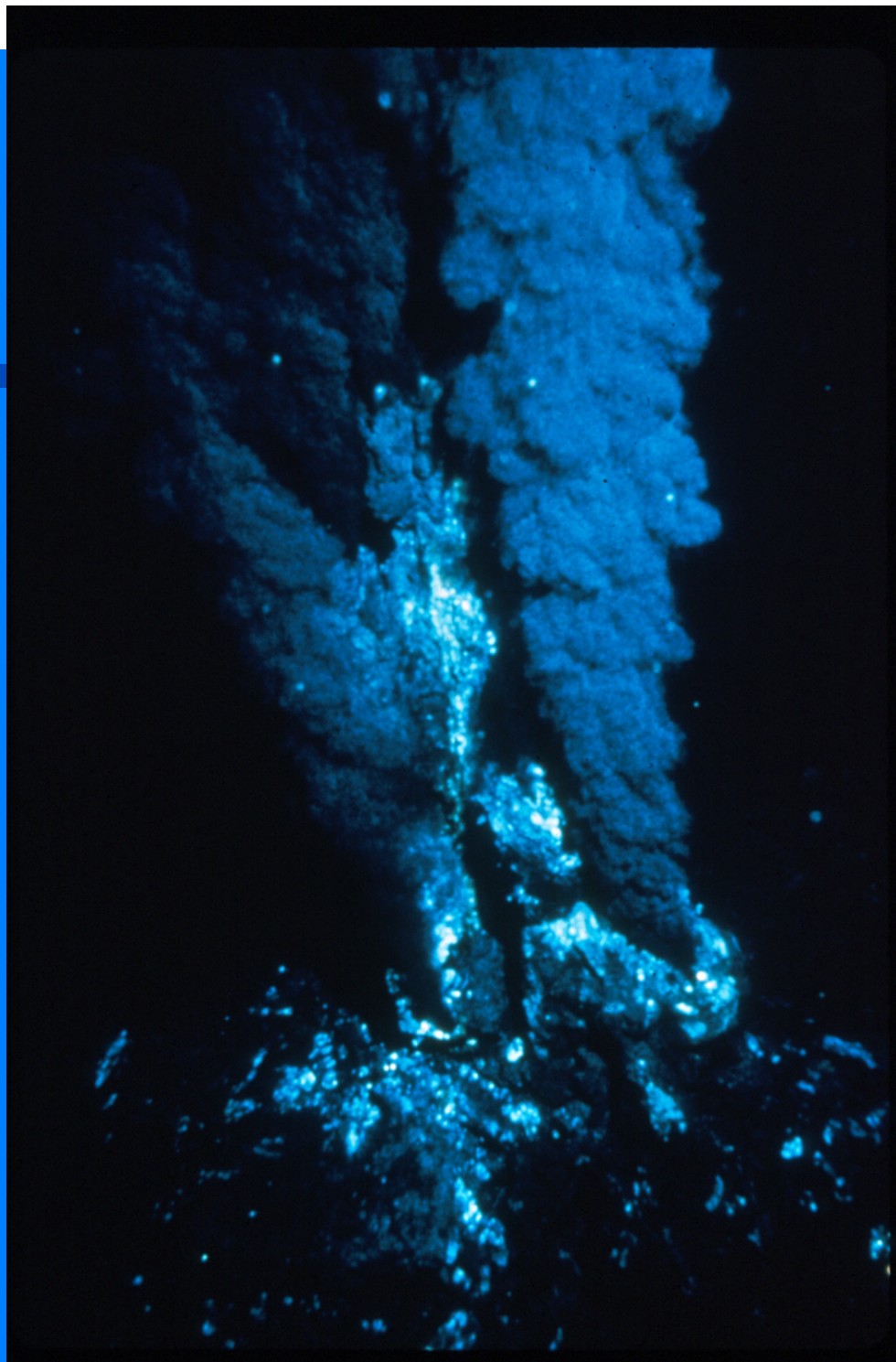


Life in deep sea hydrothermal vents



Analogs of Yellowstone

Early Mars? Europa?

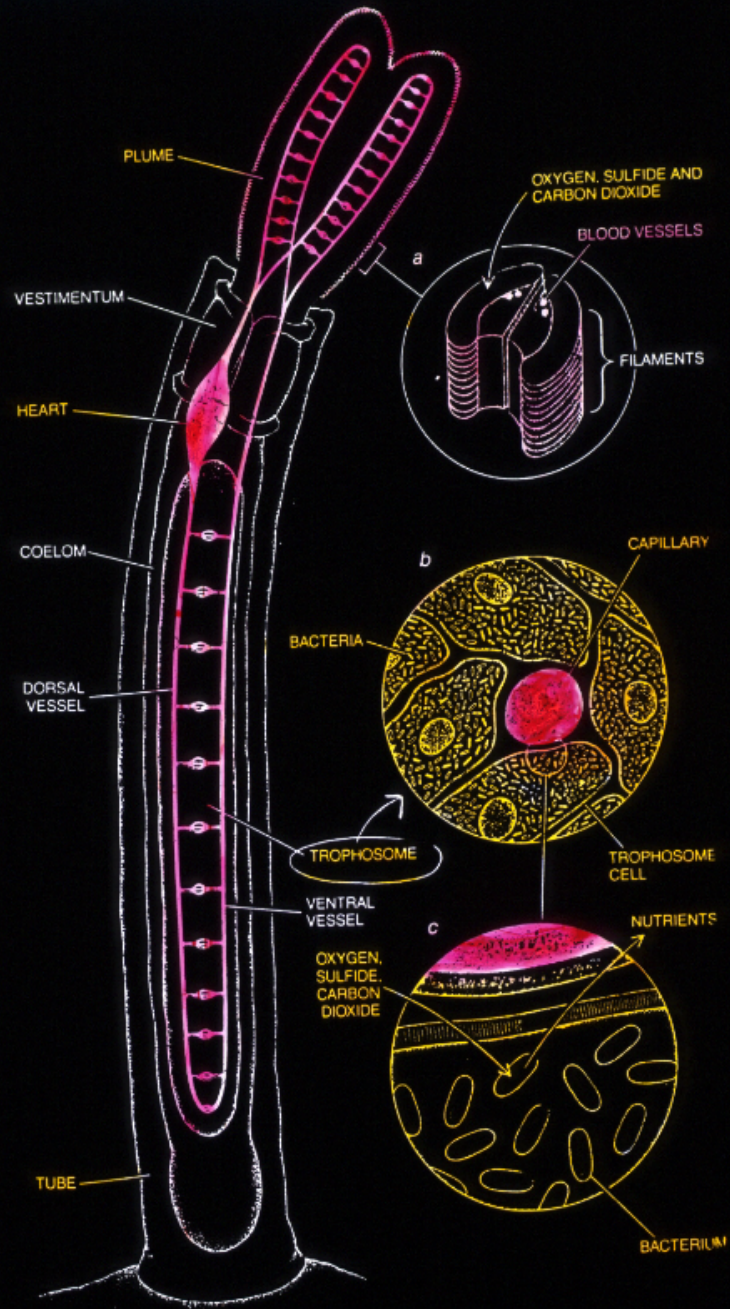








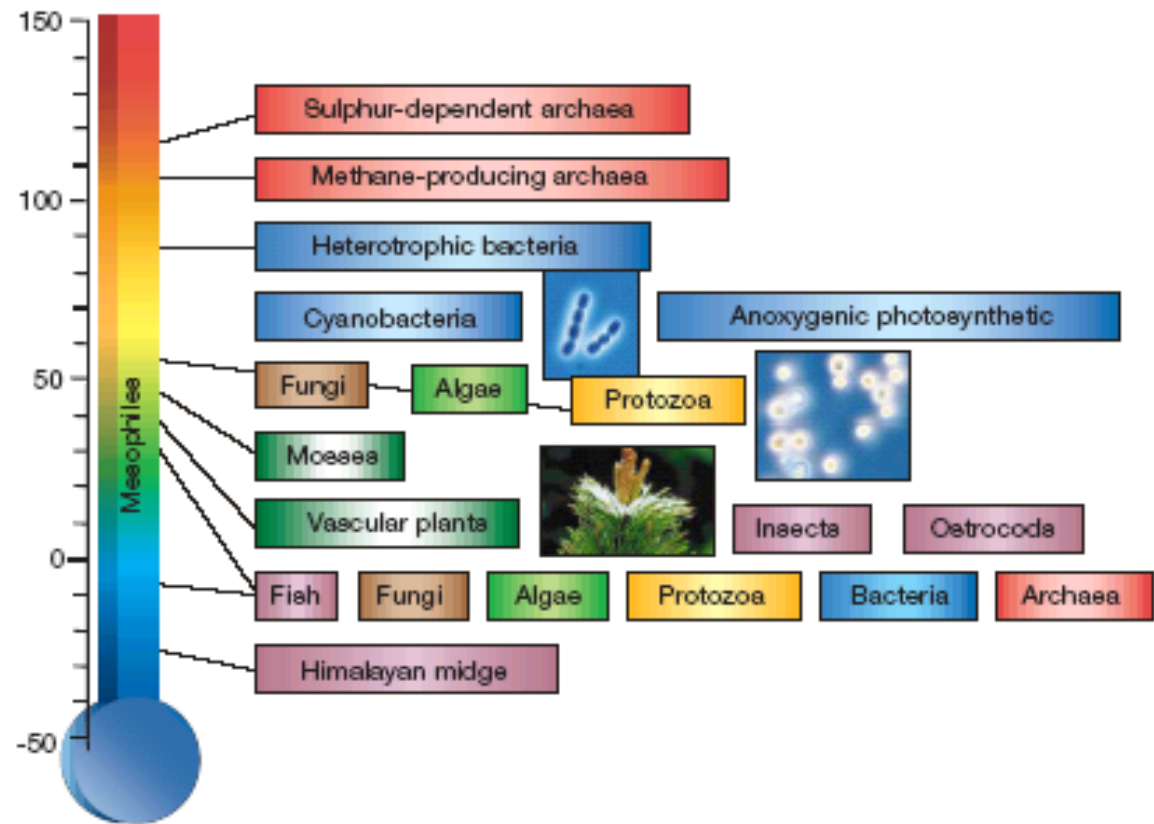
ANATOMY OF RIFTIA PACHYPTILA - THE VENT TUBE WORM



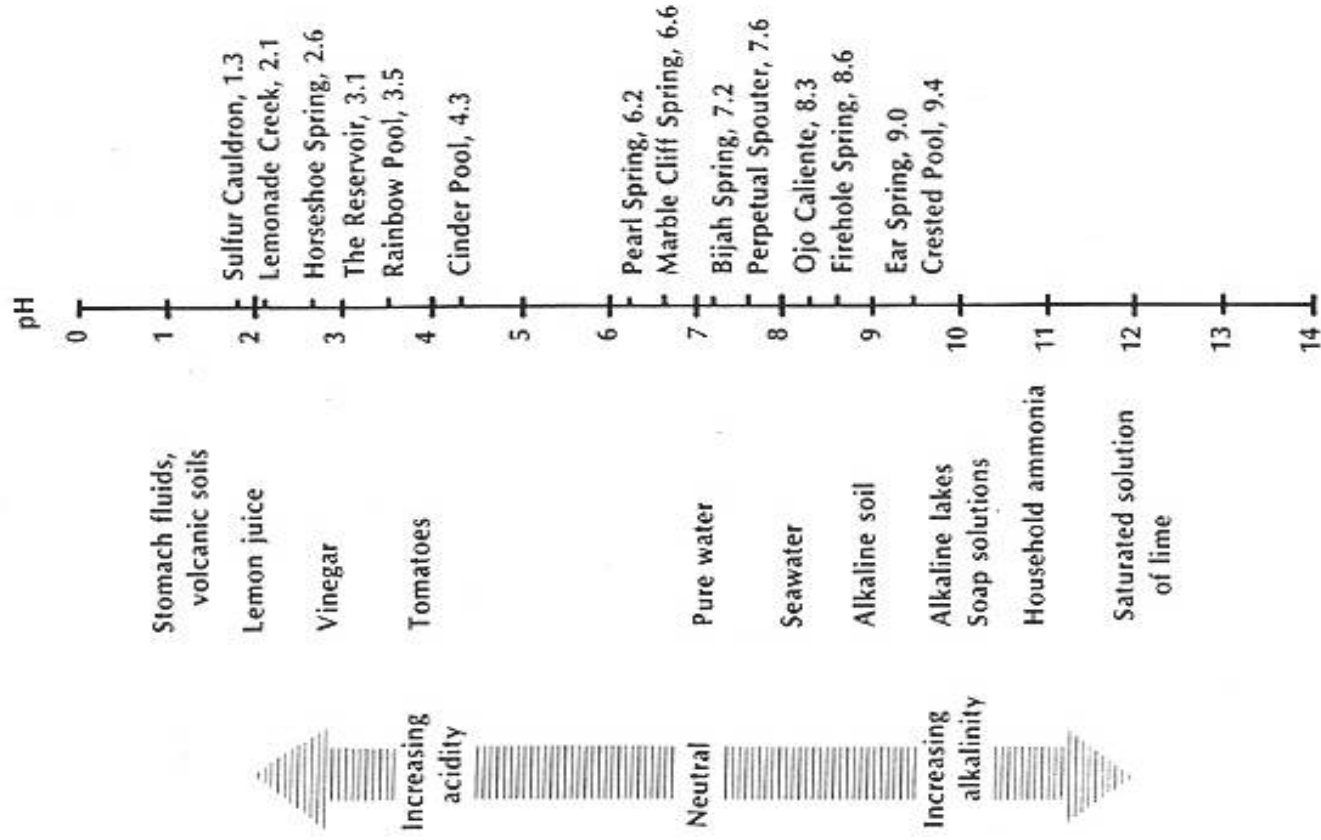
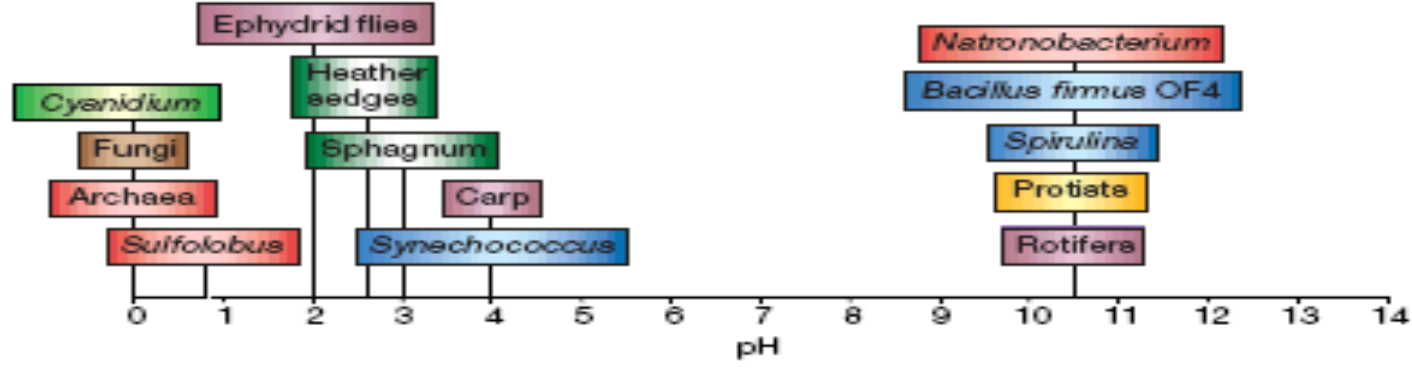
Current Record Holding Hyper-thermophile

Pyrodictium Pyrolobus - growth at the highest temps in culture, 110-113°C. Metabolism by H₂/S₀, growth on surfaces of sulfur globs in a mineral salts mixture under several atmospheres of H₂ and CO₂. A hard country!

Figure 3 Temperature limits for life. The highest and lowest temperature for each major taxon is given. Archaea are in red, bacteria in blue, algae in light green, fungi in brown, protozoa in yellow, plants in dark green and animals in purple.



own pH limits for life are
 , algae in light green,
 plants in dark green



Extremophile Classifications (plus hyper- & poly- types)

- (An)aerobes: with(out) free oxygen
- Thermophiles: high temperature
- Psychrophiles: low temperature
- Acidophiles: low pH
- Alkalophiles: high pH
- Halophiles: salty
- Barophiles (Piezophiles): high/low pressure
- Xerophiles: dry
- Oligotrophs: scarce nutrients
- Endoliths: within solids (rock)
- Radiation tolerant: high ionizing radiation



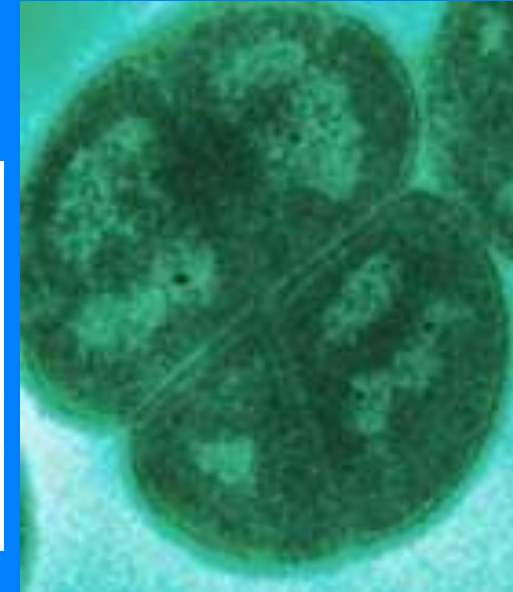
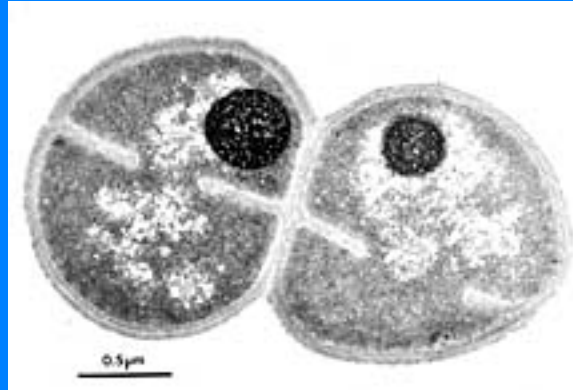
The Goldilocks Fallacy

Just how perfect does the environment have to be
for life to exist?

Heat, rock and water. What more could you ask?

Life could be common in the Universe?

A hyper-poly-extremophile Eukaryot: *Deinococcus radiodurans*

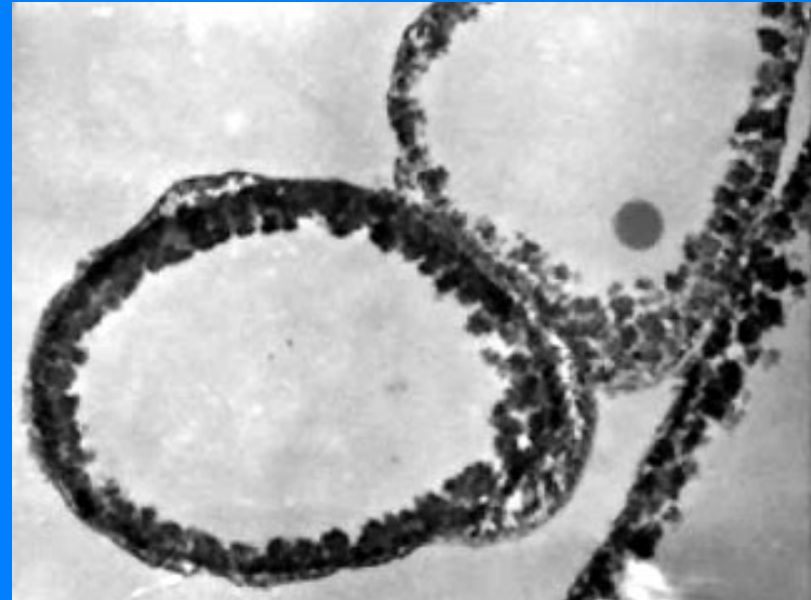


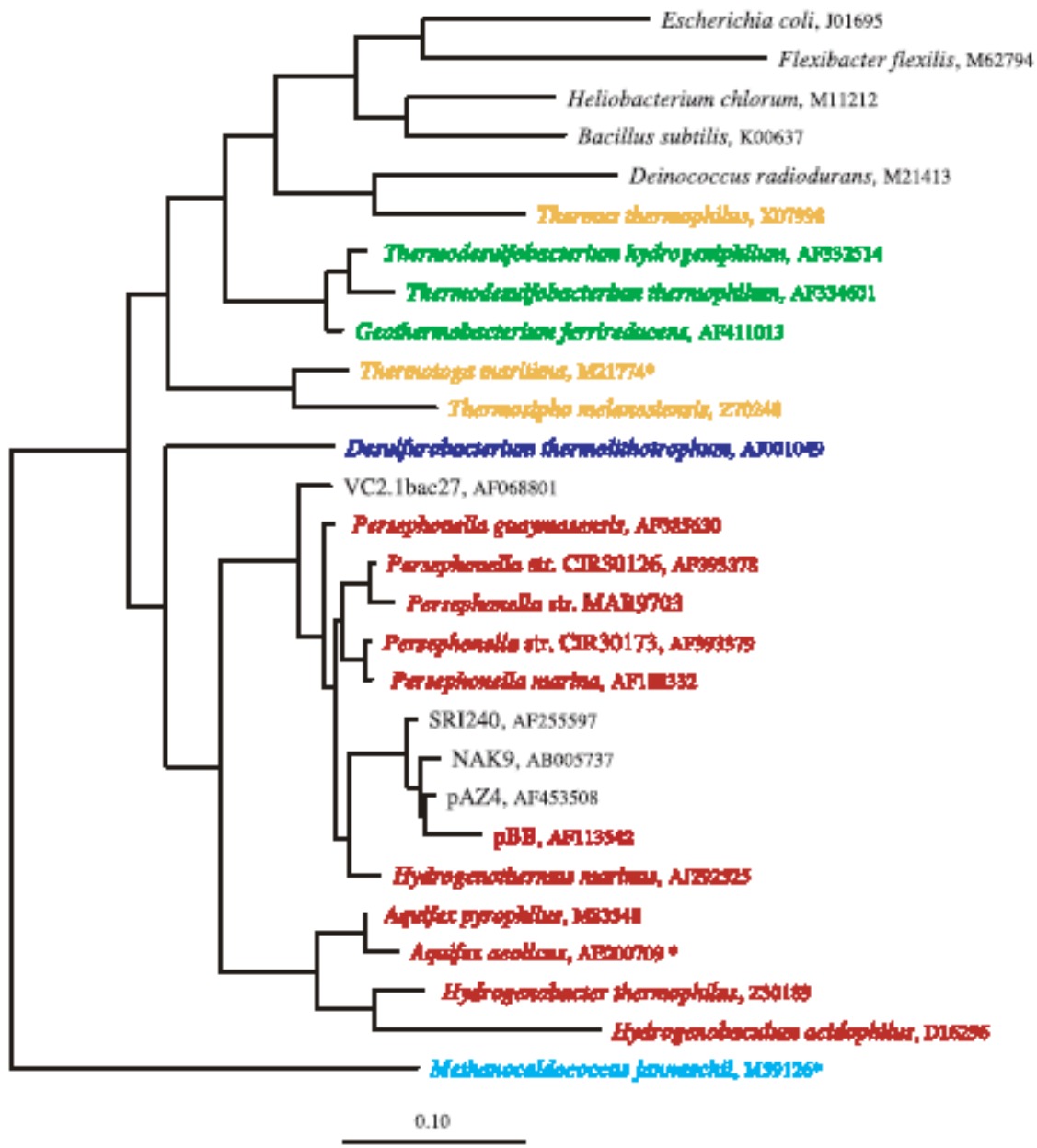
Resistant to radiation (UV to γ -rays), cold, vacuum, dormancy, oxidative damage, extreme desiccation, wide ranges of pH etc.

Uses multiple, redundant copies of its DNA and enzymes which carry out error checking and repair of its genetic material.

Radiotrophic Fungi

- Discovered in 2007 as black mold growing inside Chernobyl Power plant
- Melanin containing fungi grow faster in environments where radiation is 500 times normal
- Highly melanized fungi are found on the space station





Black = nonthermophiles or 16S rRNA sequences from the environment.

Thermophilic Bacteria

Green = SO_4^{2-} or Fe^{3+} reducers

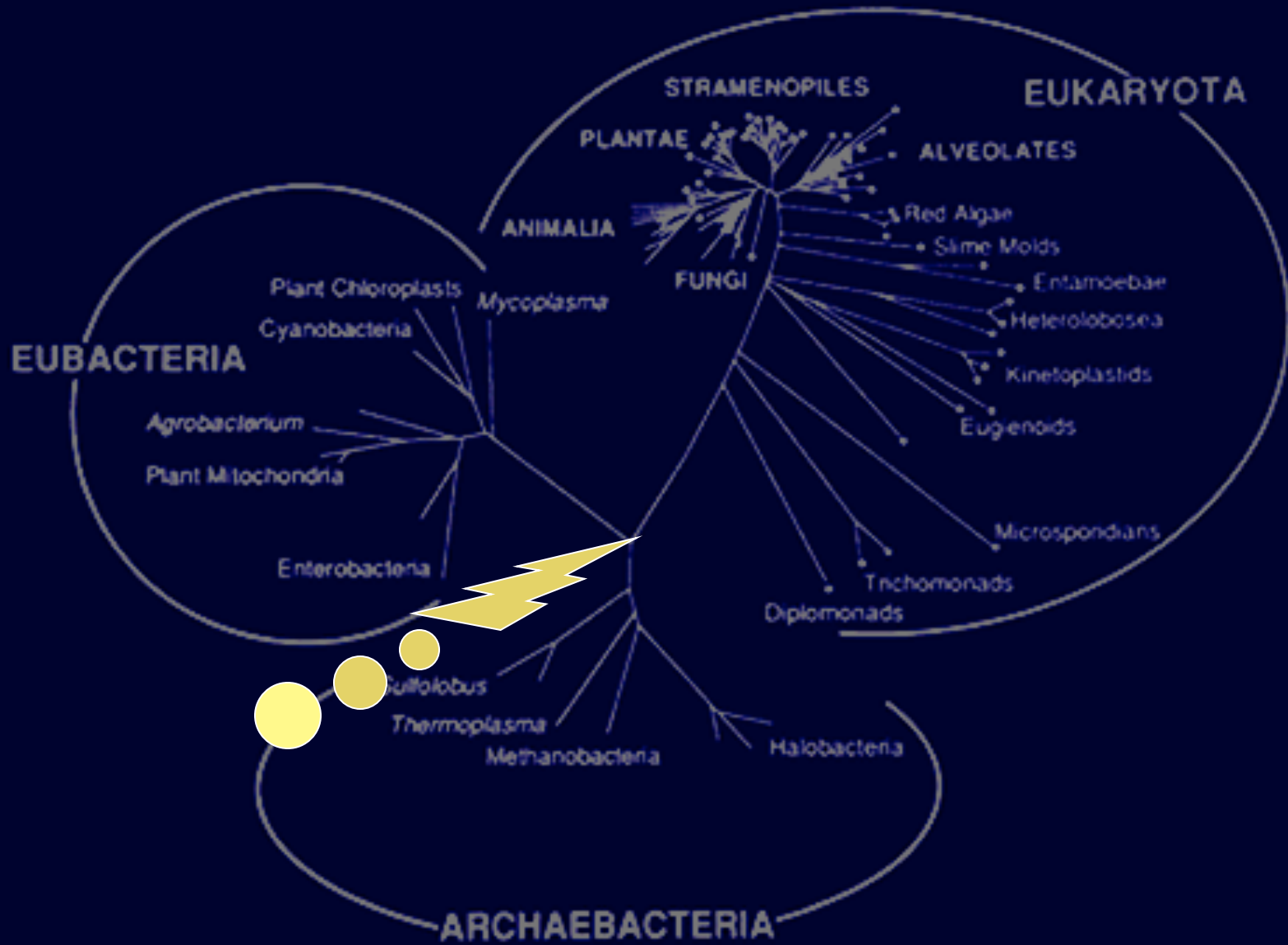
Yellow = heterotrophs

Blue = chemolithoautrophic and

heterotrophic S^0 reducers

Red = organisms using Knallgas reaction ($\text{H}_2 + \frac{1}{2} \text{O}_2 \Rightarrow \text{H}_2\text{O}$)

Sky Blue = methanogens

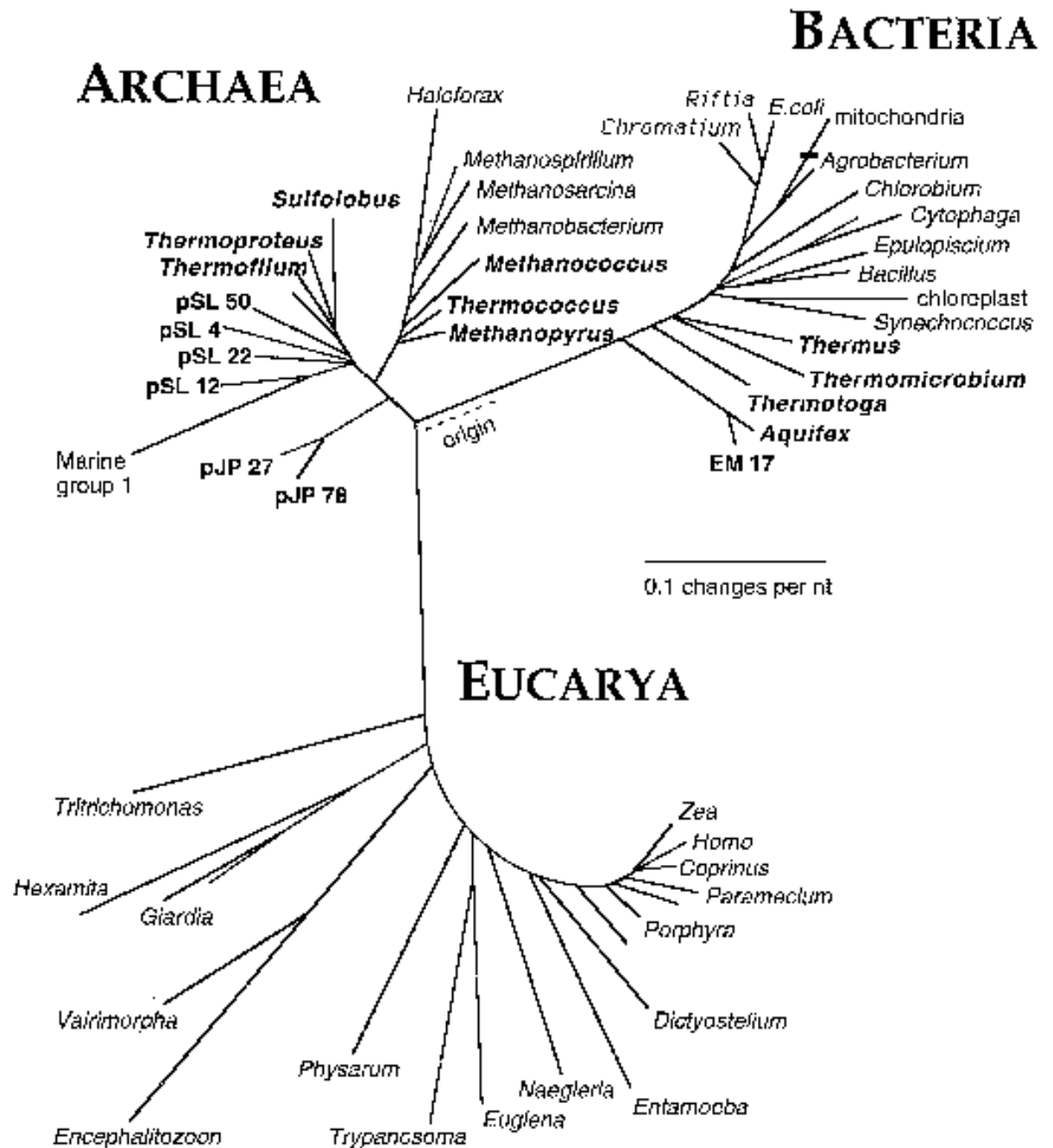


from Patterson and Sogin, in "The Origin and Evolution of the Cell" World Scientific (1992)

Tree of Life:

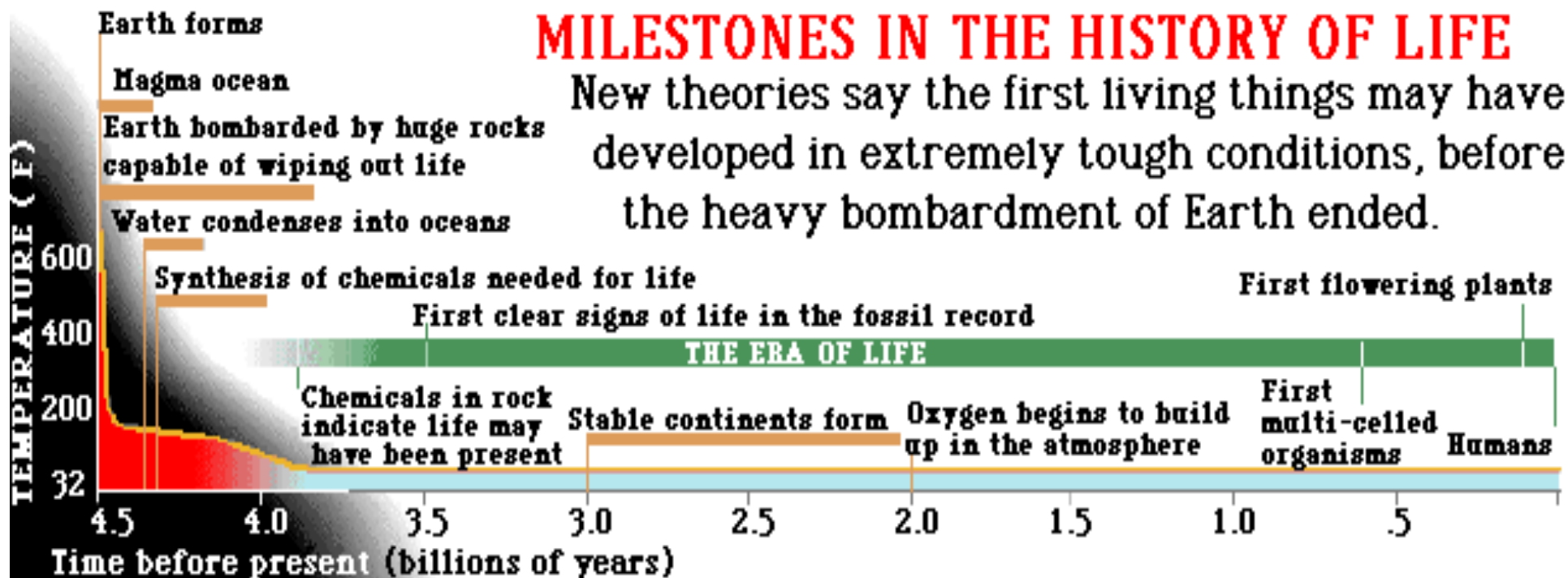
Map of Genetic Similarities/ differences

Evolution in action!

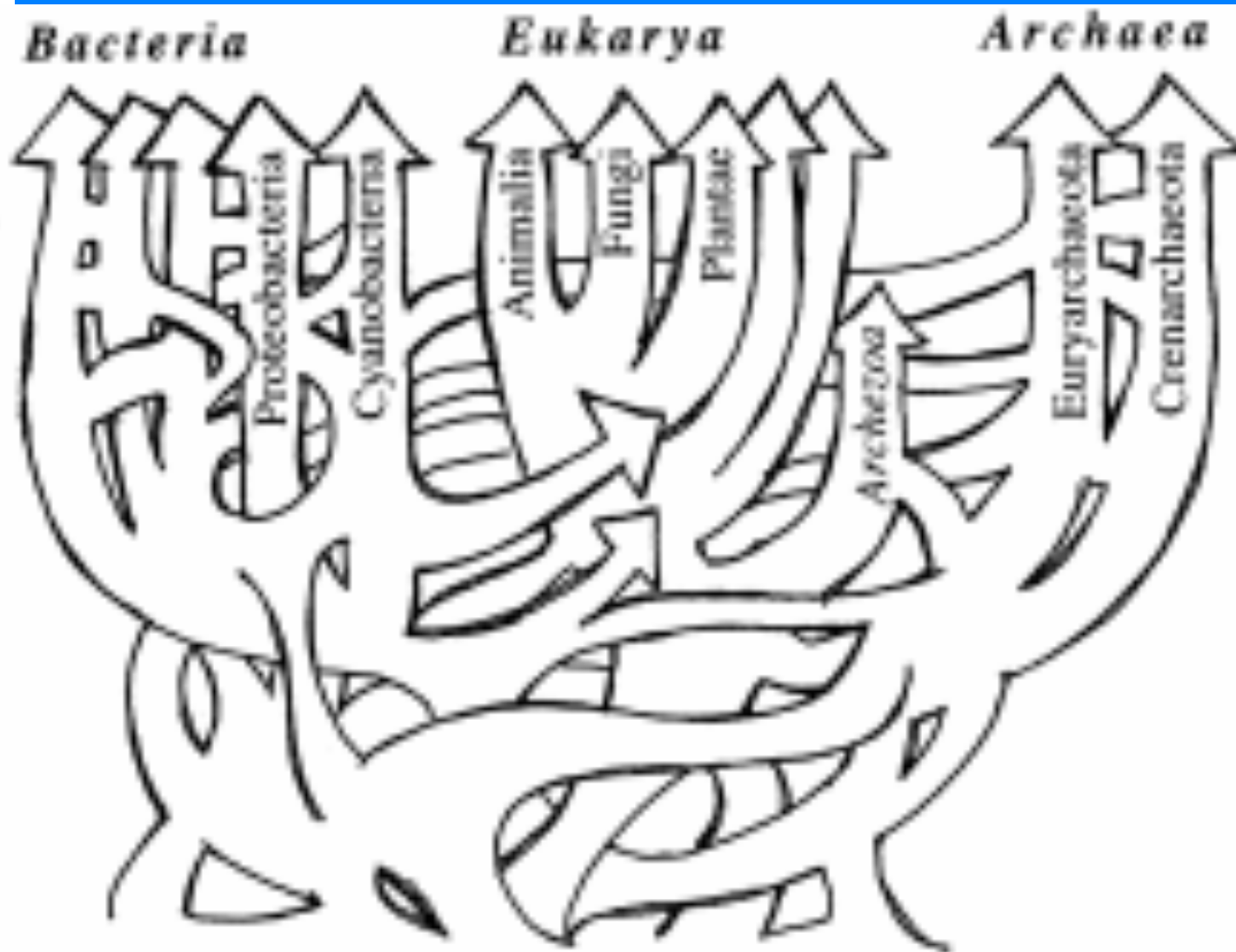


MILESTONES IN THE HISTORY OF LIFE

New theories say the first living things may have developed in extremely tough conditions, before the heavy bombardment of Earth ended.



Likely complexity of evolution (more like a tangle of vines than a tree!)



Horizontal and descending limbs as well as vertical ascending ones!

Implications for Astrobiology

- Extremophiles demonstrate that life can adapt to a surprisingly wide range of environmental conditions
- Very primitive/simple extremophiles near root of phylogenetic tree (of life) suggest origin of life in one or more extreme environments or ...
- Dispersal of extremophiles throughout the tree suggest that evolution may be complex & “tangled”
- Panspermia - speculative possibility that microbes colonized Earth after originating elsewhere

Panspermia

- Advocated by “crazies”
- Rate of Mars \leftrightarrow Earth is fairly rapid
- Current rate of Earth bombardment is very low

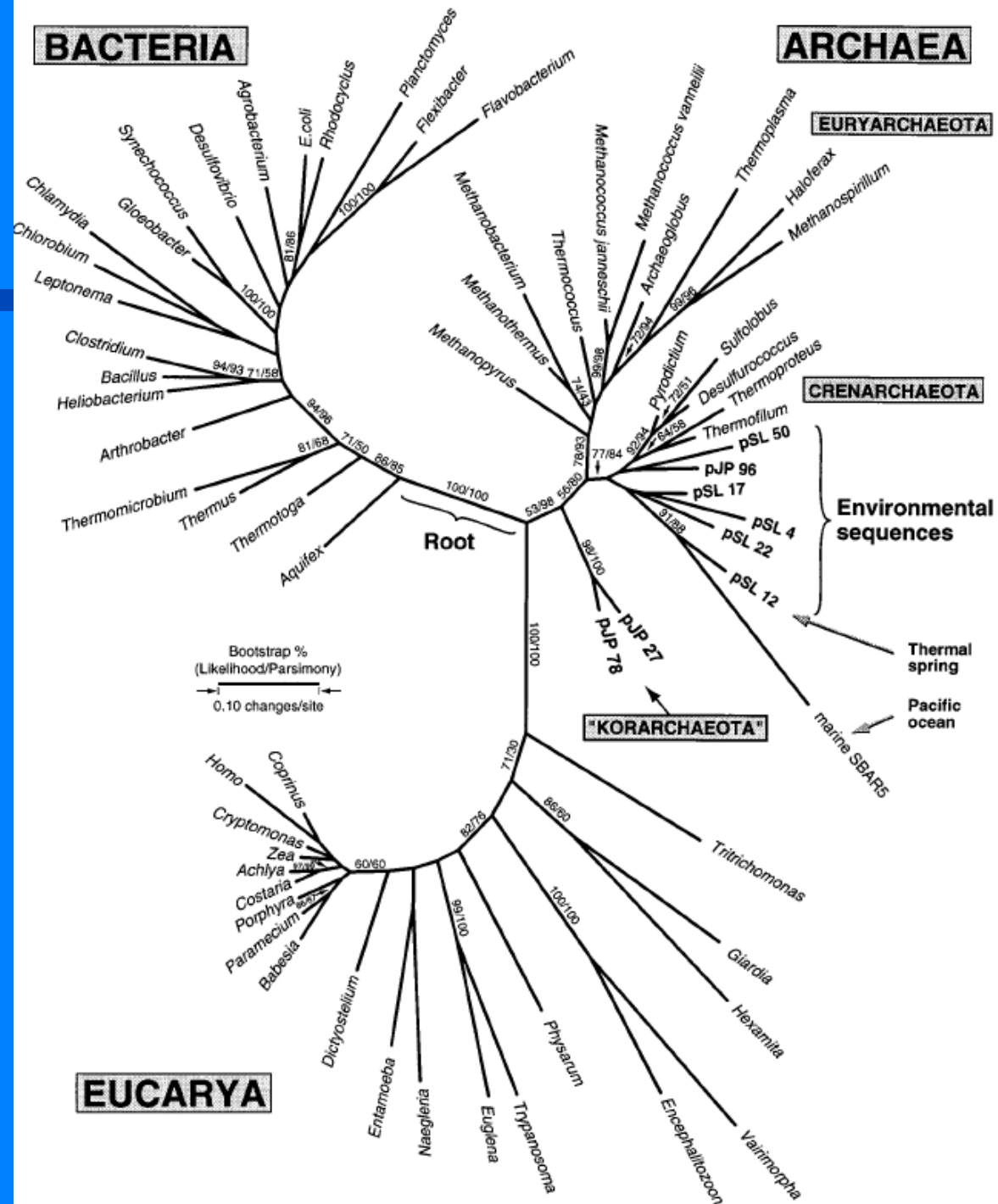
Lithopanspermia

- Sun formed in an open cluster of 1000s of stars
- During the early bombardment, there was fairly rapid transfer of materials between neighboring systems

Lithopanspermia

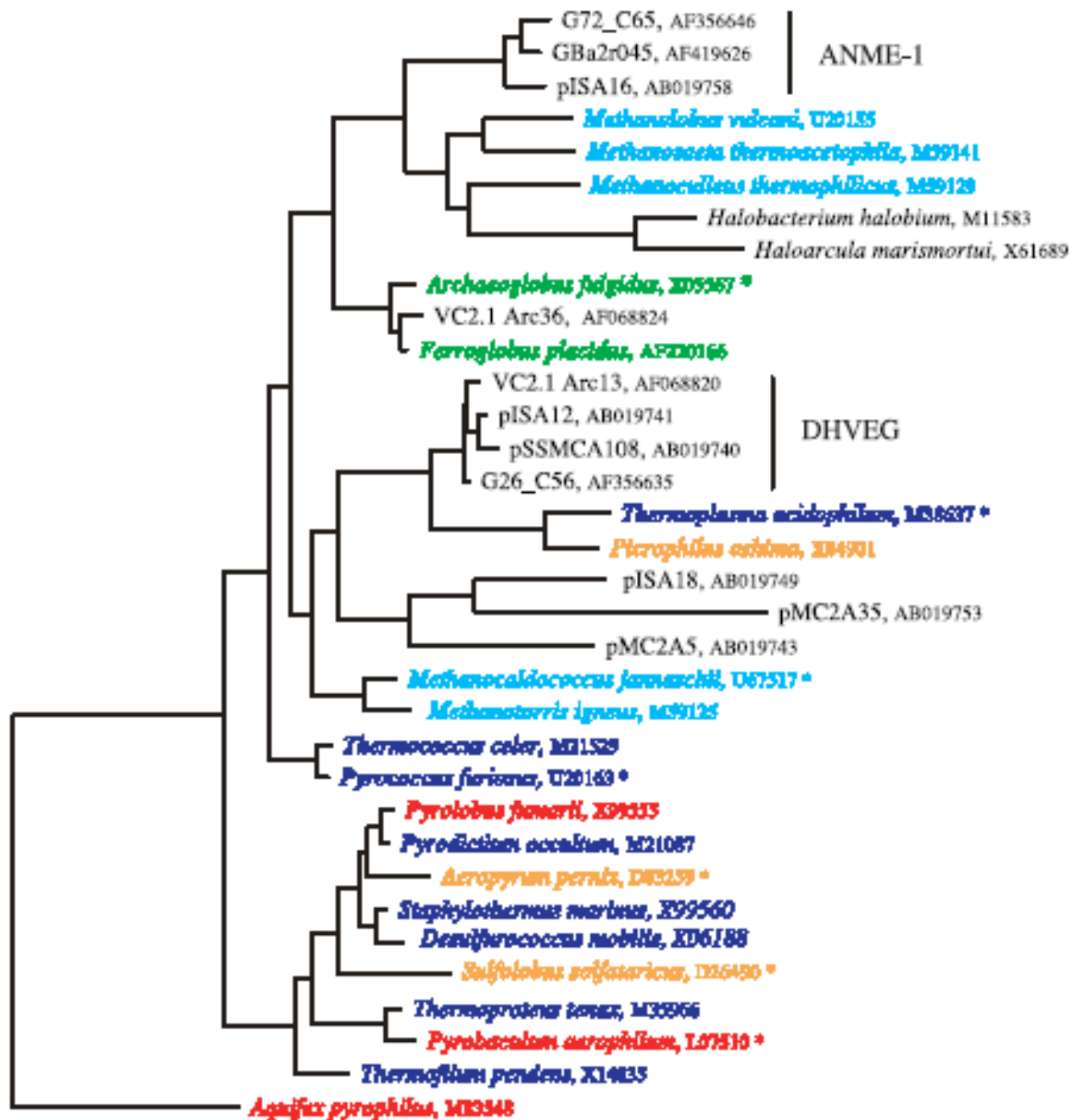
- Sun formed in an open cluster of 1000s of stars
- During the early bombardment, there was fairly rapid transfer of materials between neighboring systems

A few sediment samples from Obsidian pool yielded 86 novel lineages, 32 within the *Archaea* and 54 within the *Bacteria*



Comets and Lithopanspermia

- Protoplanetary disk is made of cometary material
- Comets are dirty iceballs. Habitable?
- Comets are transferred between systems at a rapid rate



0.10