Unity of Life

- All lifeforms on Earth have a common system. Examples:
  - universal usage of DNA to store genetic information
  - the ribosome technique of protein synthesis
  - proteins serve as enzymes and catalysts
  - the same 20 amino acids are always used, and only left-handed ones
  - a universal genetic code
  - DNA triplets coding for same amino acid
  - the use of proteins and lipids to make membranes
  - the use of the ATP-ADP cycle for chemical energy.
- The subsystems of life are highly interlocked.
  Proteins are needed to make enzymes, yet enzymes are needed to make proteins.
  Nucleic acids are needed to make proteins, yet proteins are needed to make nucleic acids.
- The common system is very complex.
  It must have been the result of an extended evolution. In evolutionary terms, it is very far from the original organisms.
- It is possible to construct detailed phylogenetic trees based either on morphology or molecular (genetic) data.

Conclusion: It must be that all organisms on Earth are descended from a single common ancestor.

Phylogeny and the Nature of the Common Ancestor

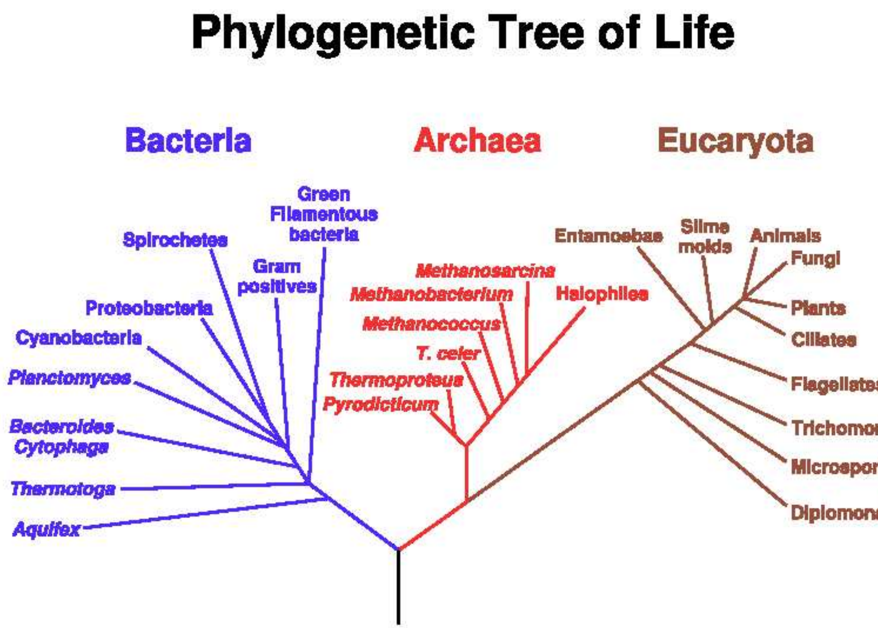
- Evolutionary distance = fractional genetic difference between organisms
- Phylogenetic tree = map of evolutionary diversification
- Three primary groupings or domains:
  - Archaea
  - Bacteria
  - Eucarya
- Most deeply diverging lineages in Bacteria and Archaea are thermophiles, suggesting that the common ancestor of all life was also.
  - Metabolize compounds rich in H, S and Fe
  - Utilize anaerobic (sulfur) photosynthesis to synthesize carbohydrates

    $2H_2S + CO_2 \rightarrow CH_2O + 2S + H_2O$

    and fermentation for respiration (energy release)

    $2(CH_2O)_n \rightarrow nCH_4 + nCO_2 + \text{energy}$

  - Thrive in oxygen- and sunlight-free environments, like hydrothermal vents



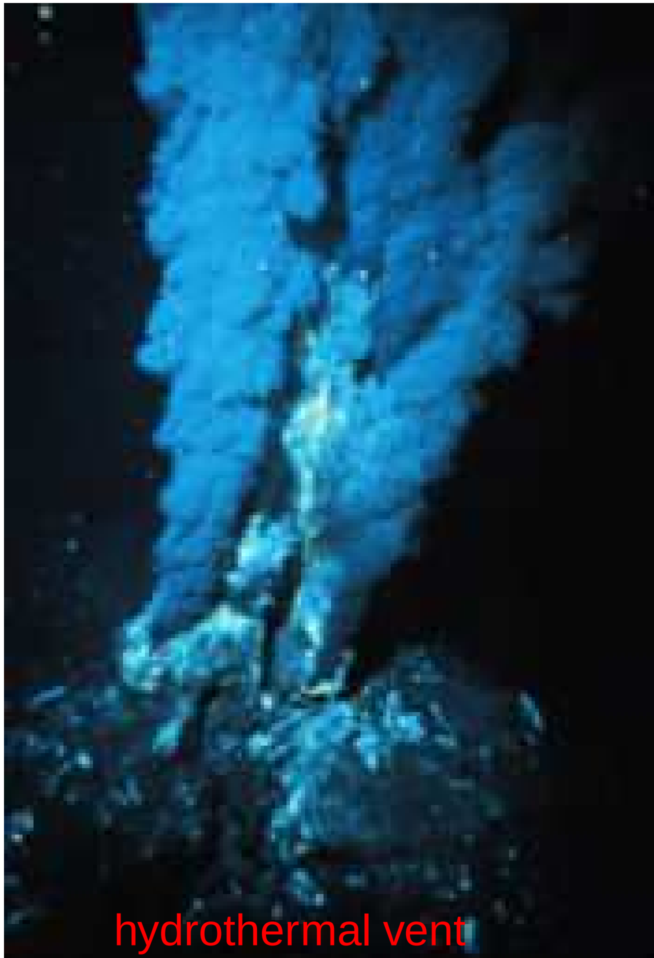
Eric Gaba, NASA Astrobiology Institute

Extremophiles

Organisms (mostly micro-organisms) that require extreme environments for growth
"Extreme" is a relative and anthropocentric term

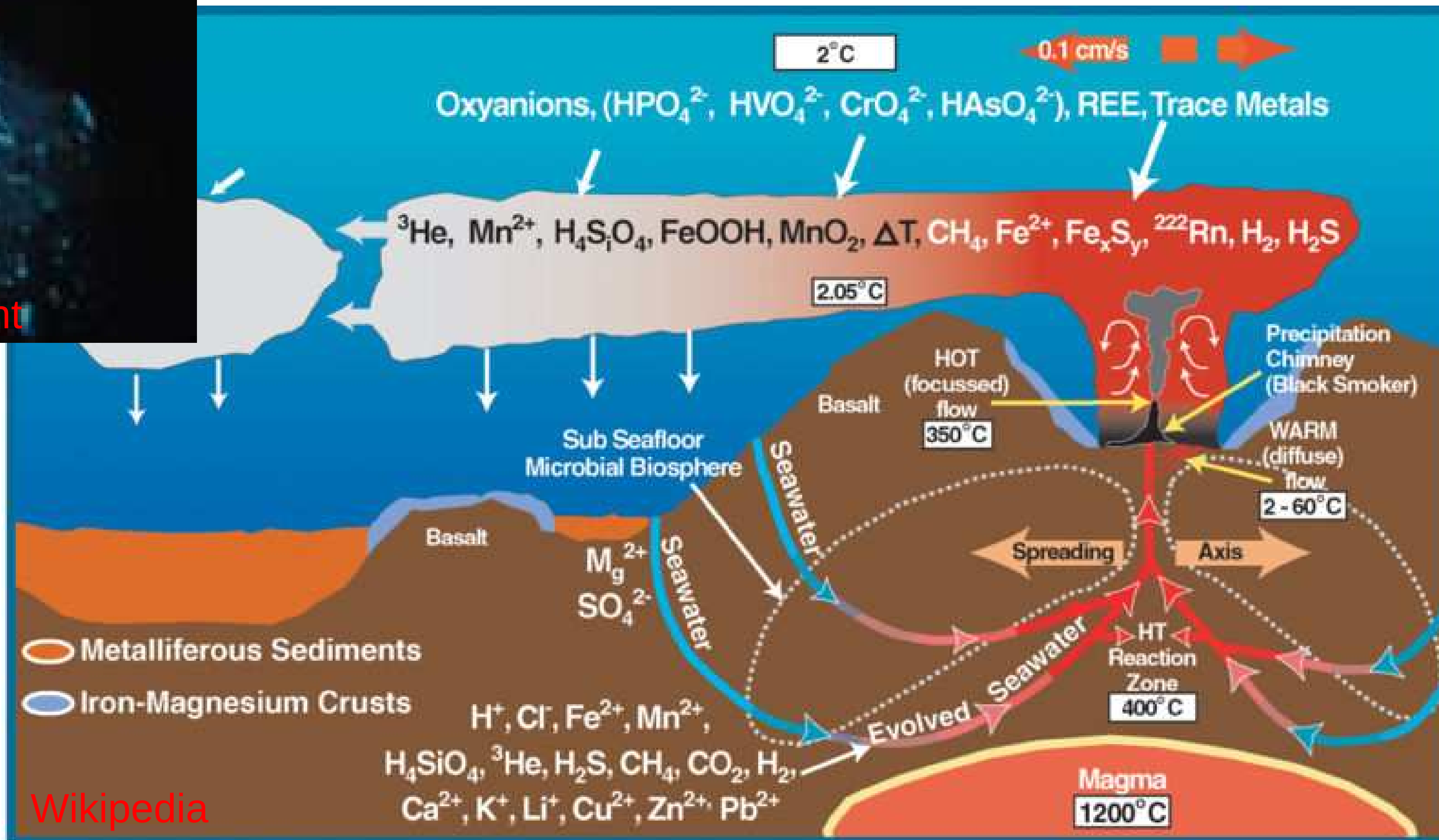
Some Examples:

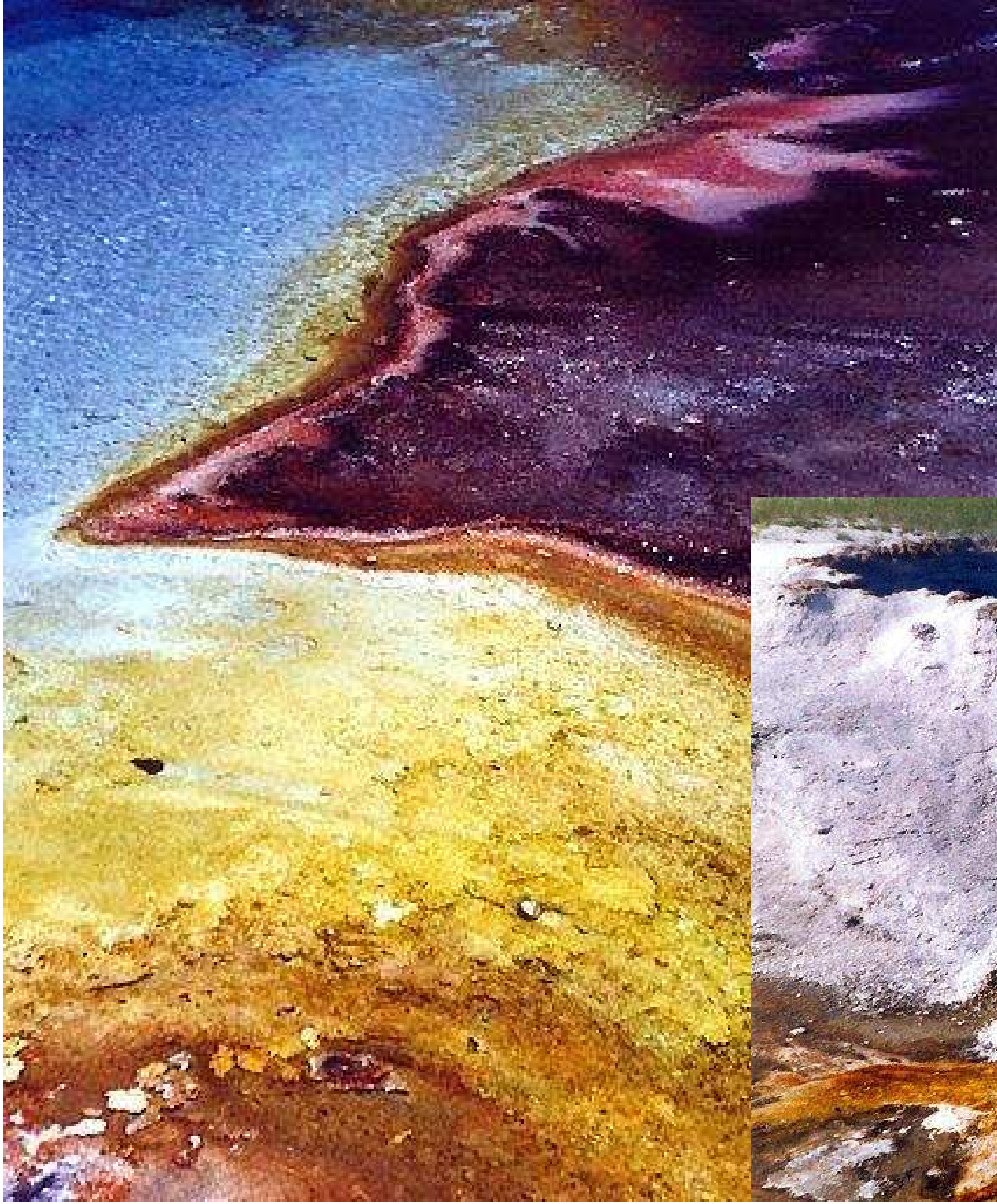
- Acidophile: optimal growth at pH values less than 3
- Alkaliphile: optimal growth at pH values above 10
- Endolith: live within rocks, or deep (a mile or more) underground; antarctic lichens
- Halophile: require high salt content
- Hyperthermophile: requires $T > 80^\circ$ C, up to 121° C; hydrothermal vents, hot springs, volcanos
- Hyper- or Hypo-baric: require high or low pressure; hydrothermal vents, cold seeps, high-altitude bacteria, bacteria recovered from lunar Surveyor III camera
- Lithoautotrophes: live in igneous rocks and utilize no organic products of photosynthesis or sunlight, need only CO_2, H_2O and H_2 to sustain themselves
- Oligotrophe: optimal growth in limited nutrient conditions
- Psychrophile: optimimum $T < 15^\circ$ C, maximum of 20° C
- Toxitolerant: can withstand high levels of benzene, radiation, etc.; Radio-resistant insects and bacteria, organisms living within metals or liquid hydrocarbons.
- Xerotolerant: capable of growth at low water activity, e.g., halophile or endolith; revived bacteria from stomachs of frozen mammoths and from fossilized amber, plant seeds from tombs.



NOAA Ocean Explorer

NOAA Ocean Explorer





Yellowstone hot springs
Webshots channel: outdoors

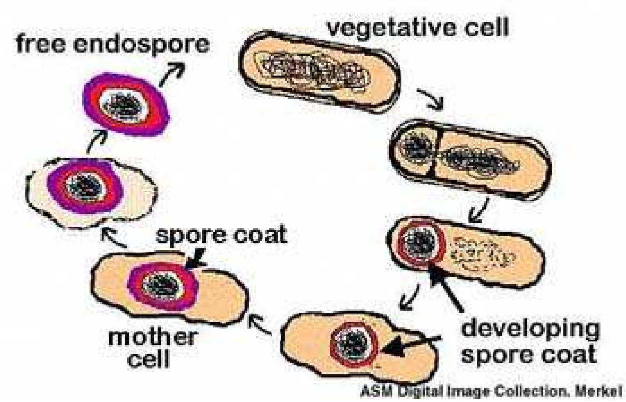
Adaptations to Extremes

Spores A reproductive structure that permits dispersal and survival for extended periods in unfavorable conditions. They form part of the life cycles of many plants, algae, fungi and single-celled eukaryotes.

Endospores A dormant, tough, non-reproductive structure produced by some bacteria and archaea, whose primary purpose is to ensure survival through periods of environmental stress. The parent cell copies its DNA and encloses the copy into a little cell (daughter) that is then surrounded by the material used to make cell walls, peptidoglycan. Another external sheath of proteins protects it. Harsh conditions wither or blast away the surrounding parent cell, leaving the endospore. They are resistant to

- ultraviolet and gamma radiation
- desiccation or extreme dryness
- lysozyme, an enzyme that damages bacterial cell walls
- temperature
- starvation
- chemical toxins

Anthrax, botulism, tetanus



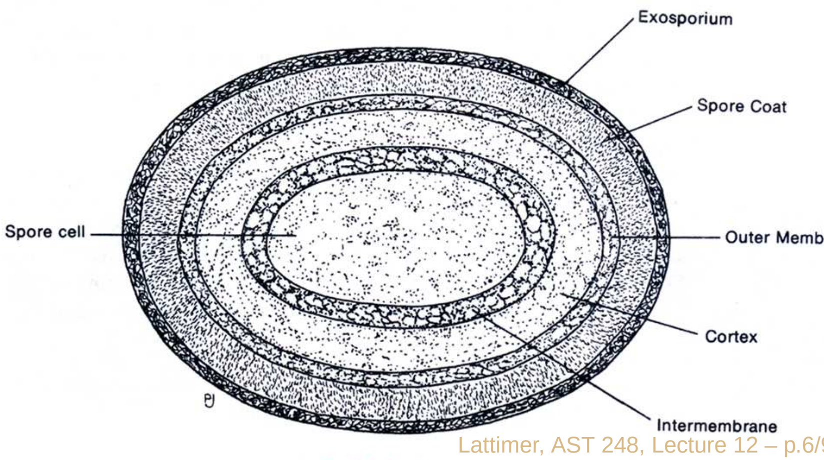


Fig. 8.1. Endospore

Exospores These form outside by growing or budding out from one end of a cell.

Cysts Thick-walled structures that protect bacteria from harm, but not as durable.

Source	Application
Psychrophiles	
alkaline phosphatase	molecular biology
proteaeses, lipases, cellulases, amylases	detergents
lipases, proteases	cheese manufacture, dairy products
polyunsaturated fatty acids	food additives, dietary supplements
varios enzymes	modifying flavors
b-galactosidase	lactose hydrolysis in milk products
ice-nucleating proteins	artificial snow, ice cream
ice-minus microorganisms	frost protectants for sensitive plants
various enzymes (e.g. dehydrogenases)	biotransformation
various enzymes (e.g. oxidases)	bioremediation, environmental biosensors
methanogens	methane production
Hyperthermophiles	
DNA polymerases	DNA amplification by PCR
proteases, amylases, a-glucosidase	baking, brewing
pullulanase and xylose/glucose isomerases	production from keratin
alcohol dehydrogenase	chemical synthesis
xylanases	paper bleaching
lenthionin	pharmaceutical
s-layer proteins and lipids	molecular sieves
oil-degrading microorganisms	surfactants for oil recovery
sulfur oxidizing microorganisms	bioleaching, coal waste gas desulfurization
hyperthermophilic consortia	waste treatment and methane production

Implications

- Extreme environments on present-day Earth were commonplace on the early Earth.
- For the first billion or more years after life arose on the Earth, only extremophiles could have survived.
- Total mass of extremophiles may well exceed those of ordinary lifeforms today.
  - Humans 100 MT
  - Domesticated animals 700 MT
  - Crops 2 BT
  - Bacteria 2 BT
  - Fish 1–2 BT
  - Archae 2+ BT
- Phylogenetic arguments reinforce the notion that extremophile organisms are the most primitive; hence they did not adapt to their present extreme environments, rather, ordinary life adapted or evolved from them.
- The fact that extremophiles can survive such a broad range of conditions suggests life may be possible outside of the “habitable zone” commonly envisioned.

Earliest Geologic Records of Life

Microfossils and Chemofossils

- 3.85 Gyrs (Akilia Island, Greenland; chemofossils, not universally accepted)
- 3.4–3.5 Gyrs (North Pole and Onverwacht, Australia, the so-called Warawoona finds; bacteria-like microfossils apparently fossilized cells of filamentous organisms, not universally accepted)
- 3.2 Gyrs (Fig Tree, S. Africa)
- 2.6–2.7 Gyrs (Eastern Transvaal, S. Africa; fossilized remnants of microbial mats, identified by relative abundances of H, C, N, O and P; oldest evidence of life on land, requiring ozone layer and O_2 in atmosphere)

Isotopic evidence (chemofossils) more reliable than shape (microfossils), but still controversial

C^{12}/C^{13} = 120 in fossilized material, same as in present-day living matter

C^{12}/C^{13} = 99 in non-living matter on Earth

Corroborating evidence:

- Depleted C^{13} has been found in other 3.8 Gyr-old rocks in other locations.
- Isotopic ratios of other elements, such as Fe, N and S, are also present in ratios characteristic of living, as opposed to never-living, material.