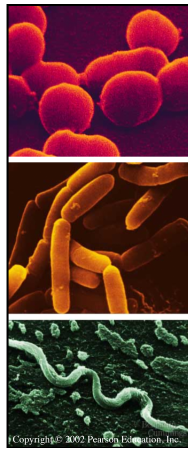
Class announcements

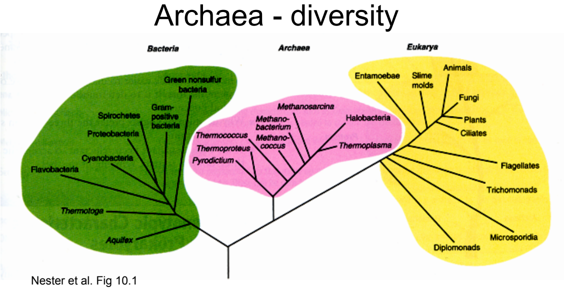
1. Today – I hope that we'll be able to use clickers
2. Today – phylogenetic tree homework due
3. Review sessions for first mid-term exam @
   Today, CSS (Computer/Space Science) room 2324, 12:30-2:00 pm
   Tuesday, 2/15, PLS1140 (where we hold the GAE's), 9:00-10:30 am
   Bring your questions!
4. Use the regular meeting time for your study group to prepare for first mid-term exam
5. Wednesday – first mid-term exam

Prokaryotic Diversity II - Coming attractions



- Evolutionary origins
- Basic features
- Bacteria – several major groups
- Bacteria - pathogenesis
- **Archaea – extremophiles**
- Metabolic diversity
- Bioenergetics – redox reactions
- Bioenergetics - electron transport chains
- Biogeochemical cycles

Archaea - diversity

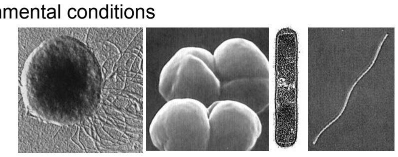


Nester et al. Fig 10.1

Hyperthermophiles - very high temperatures (optimal 80-106 °C)
Methanogens - methane producers
Halophiles - very high salinities (15 to 30% (w/v) NaCl)

Archaea - Diversity

- Primitive similarity with the Bacteria - prokaryotic cells, binary fission, circular chromosome, 70S ribosomes, flagella.
- Derived similarity with the Eukarya - shared features of more complex replication, transcription, and translation (e.g., several origins of DNA replication, several RNA ploymerases, histone proteins, met as start amino acid, etc.)
- Most distinctive feature - extremophiles often thriving in extreme environmental conditions



www.ucmp.berkeley.edu/archaea/archaeamm.html

Various archaeal species

Archaea - Cell walls


Salterns in south San Francisco Bay

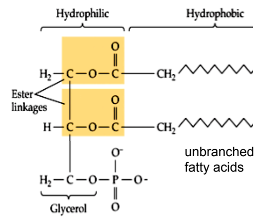

Hot spring in Yellowstone Park


Acidic mud volcano (pH < 3.0) in Yellowstone Park

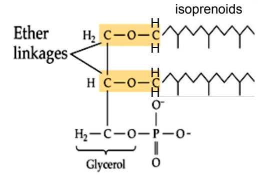
No peptidoglycan, diverse cell wall polymers correlate with extreme environments.

J. DiRuggiero

Prokaryotic lipids



Bacteria



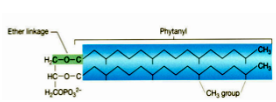
Archaea

J. DiRuggiero

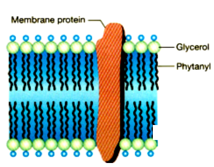
Prokaryotic membranes

J. DiRuggiero

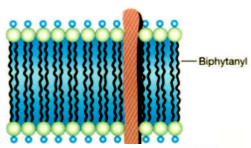
Bacteria – bilayer membranes



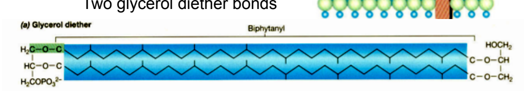
One glycerol diester bond



Hyperthermophilic archaea – monolayer membranes



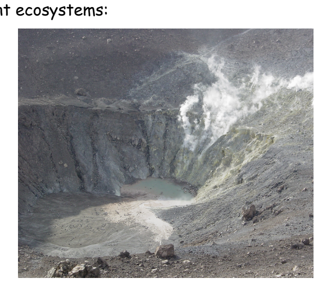
Two glycerol diether bonds



Hyperthermophile Habitats

High temperature environments encompass a wide variety of different ecosystems:

- Hot springs
- Alkaline hot springs
- Soda lakes
- Alaskan oil fields
- Sulfurous volcanic vents
- Deep sea hydrothermal vents



J. DiRuggiero

Hyperthermophile environments


Grand Prismatic Hot Spring, Yellowstone


Hot spring, Canada


Mud volcano, Yellowstone


Black smoker in deep sea vent

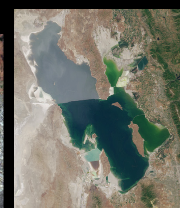
Halophile environments


Salterns, Great Salt Lake


Lake Natron, Tanzania


Salterns, Bonaire

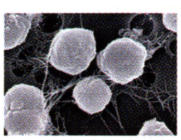

Salterns, San Francisco Bay

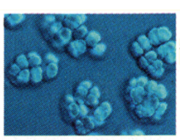

Great Salt Lake

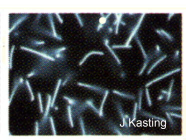
http://earthobservatory.nasa.gov/

Methanogens

- $2CO_2 + 6H_2$ ---> $(CH_2O)_n + CH_4 + 3H_2O$
- Strict anaerobes - very sensitive to O_2
- Principal producers of natural gas associated with oil reserves (e.g., *Archaeoglobus* has been isolated from a deep oil well growing at >80 °C.)
- Other habitats - swamps ("marsh gas") and animal guts
- Effective greenhouse gas
- Plausible role in Earth's early climate

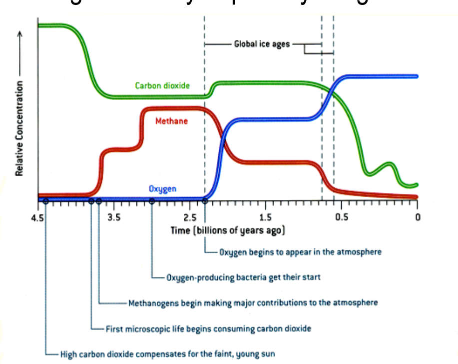

Methanococcales


Methanosarcinales



Methanopyrales

Geological history of prokaryotic gas exchange



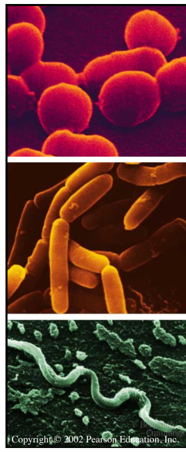
Kasting Sci. Am. 2004

Study questions for Archaea

1. Describe the three major groups of Archaea.

2. Describe the adaptations in the Archaea that seem to contribute to their ability to survive in extreme environments.

3. Support the claim that prokaryotic metabolism has profoundly affected the composition of atmospheric gases over geological time, and thus, this metabolism had transformed the Earth at several times in geological history.



Prokaryotic Diversity II - Coming attractions

- Evolutionary origins
- Basic features
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- Archaea – extremophiles
- **Metabolic diversity**
- Bioenergetics – redox reactions
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- Biogeochemical cycles

Metabolic Diversity - "Feeding Strategies"

All microbial metabolisms can be organized according to 2 principles:

I. **Carbon source** for synthesizing organic molecules:
   A. **Auto**trophic - simple molecules - CO_2, CH_4, CH_3OH, CO
   B. **Hetero**trophic - complex organic molecules

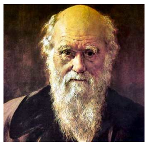
II. **Energy source** for electron transport and ATP synthesis:
   A. **Photo**trophic - light
   B. **Chemolitho**trophic - high-energy inorganic molecules
   C. **Chemoorgano**trophic - high-energy organic molecules

Metabolic Diversity

Nutritional mode	Energy source	Carbon source	Examples
Photoautotrophs	Light	CO_2	Several groups of photosynthetic B
Photoheterotrophs	Light	Organic compounds	Halophilic A
Chemoorgano-autotrophs	Organic compounds	CH_4	Methanotrophic B
Chemoorgano-heterotrophs	Organic compounds	Organic compounds	Most prokaryotes, inc. saprobes, parasites, and pathogens
Chemolitho-autotrophs	Inorganic compounds (S, N, Fe, H_2, etc.)	CO_2, etc.	Methanogenic A, sulfur oxidizing B, nitrifying B, iron-oxidizing B
Chemolitho-heterotrophs	Inorganic compounds (S, N, Fe, H_2, etc.)	Organic compounds	various B species

B = bacteria   A = archaea   See F. Table 28.3

Two hypotheses for the origin of life



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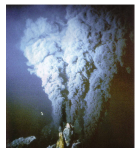


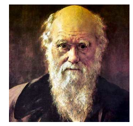
Journal du CNRS)

"The original spark of life may have begun in a **1) warm little pond**, with all sorts of ammonia and phosphoric salts, lights, heat, electricity, etc. present, so that a protein compound was chemically formed ready to undergo still more complex changes." - Charles Darwin in a letter to Joseph Hooker, 1871

2) Deep-sea hydrothermal vent

Clicker question: Which one do you think is the more likely site of the origin of life?

Be prepared for small group discussions about the origin of life



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Warm little pond

Journal du CNRS)

Deep-sea hydrothermal vent

1. Compare and contrast these two hypotheses about the site of the origin of life in terms of energy sources, molecule availability, and other physical and chemical features.

2. Construct arguments for favoring either one or both hypotheses.

Chemolithoautotrophs at deep-sea hydrothermal vents

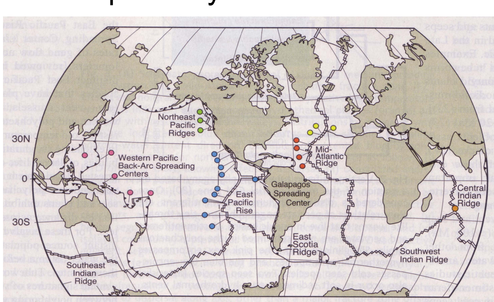


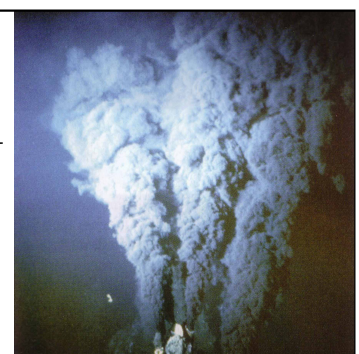
Fig. 1. Map of known hydrothermal vent biogeographic provinces and major mid-ocean ridges. Provinces: Pink, western Pacific; green, northeast Pacific; blue, East Pacific Rise; yellow, Azores; red, Mid-Atlantic Ridge; orange, Indian Ocean.

Dover et al. 2002

Black-smoker

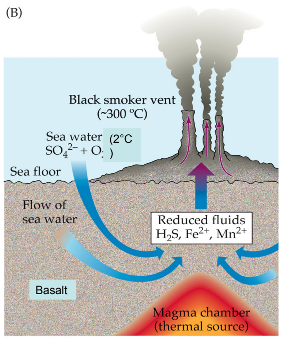
Black smoker emitting sulfide- and iron-rich fluid at 300°C.

Deep-sea hydrothermal vents



(Journal du CNRS)

Cross section of a deep sea hydrothermal vent



Chemolithoautotrophic prokaryotes

Sulfur-oxidizing bacteria

$2H_2S + CO_2 \rightarrow (CH_2O)_n + 2S + H_2O$

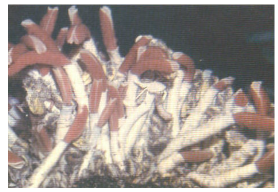
Methanogenic archaea

$6H_2 + 2CO_2 \rightarrow (CH_2O)_n + CH_4 + 3H_2O$

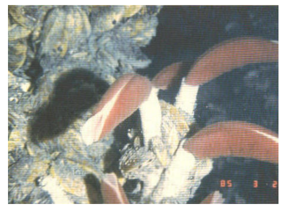
Is heat acting as the source of metabolic energy for these organisms?

Microbial Life Fig. 24.17

Vent communities



Giant tube worms showing the sheath (white) and plume (red) of the worm body.
Mussel beds and elemental sulfur deposits



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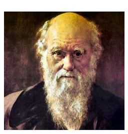
Small group discussion about the origin of life



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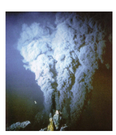

Journal du CNRS)

Warm little pond

Deep-sea hydrothermal vent

1. Compare and contrast these two hypotheses about the site of the origin of life in terms of energy sources, molecule availability, and other physical and chemical features.

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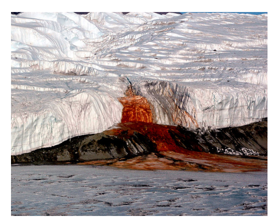
Other examples of “strange” microbial ecosystems

Blood falls in Antarctica



Bacteria live 400 m beneath glacier in sea water trapped 1.5 MYA at -5 C.

No light, no O_2, no nutrients except SO_4^{2-}

Complex chemical cycle – microbial SO_4^{2-} reduction is coupled to inorganic soluble Fe^{2+} oxidation -> Fe_2O_3 (rust)

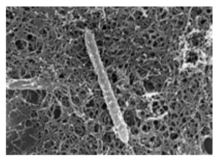
Other examples of “strange” microbial ecosystems

“Radiation-feeding”, subterranean prokaryotes

Intact ecosystems of 1 or a few prokaryotes- 3 to 25 M year old?!

Often several km below the surface – temps of 60 C or more

Division rate – once every 300 years or more



Candidatus desulforudis from S. African gold mine

Uranium radiation splits H_2O in H_2 and H_2O_2 (H peroxide)
H peroxide reacts with iron pyrite to release SO_4^{2-}
Prokaryotes use H_2 and SO_4^{2-} to generate energy

Possible model for underground life in our Solar System!

Diversity lectures - Summary

- Ecological - very diverse habitats
- Morphological - L’s shapes (coccus, bacillus, spirillum), other - filament, colony, polymorph
- Structural - gram-positive vs. gram-negative bacteria, Archaea vs. Bacteria - different cell wall and membrane components
- Metabolic - different energy and carbon sources, chemoautotrophs in deep-sea vent communities pathogens - evolutionary perspectives (LGT)

Prokaryotic Bioenergetics I - All That Jazz about Redox Reactions

- Evolutionary origins
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- Bacteria – several major groups
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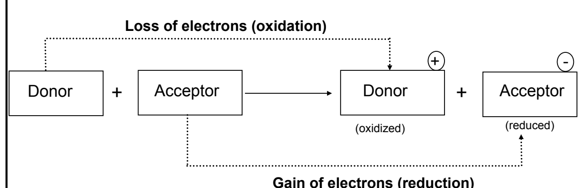
Reduction-oxidation (redox) reactions



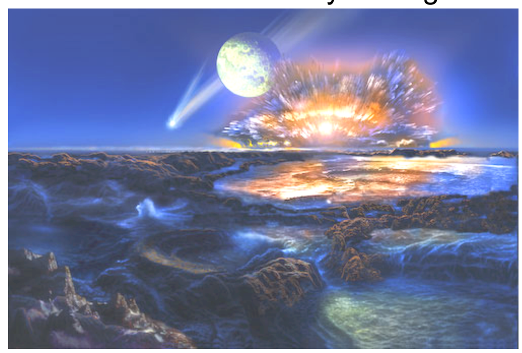
LEO says “GER”

Prokaryotic Bioenergetics: All That Jazz about Reduction-Oxidation (Redox) Reactions

1. Redox reactions transform almost the physical and chemical energy entering organisms into useful forms of biological energy.
2. Redox reactions are often used to transform the available molecules from the environment into useful metabolites.
3. An integrated biological perspective of redox reactions is:

Biomolecules	Organism	Environment
Catalysts/enzymes ETC's	Nutritional strategies e.g., photoautotrophy, chemolithoautotrophy	Biogeochemical cycles e.g., N and S cycles

Imagine you were the first life form on Earth 4.3 billion years ago



www.cosmographica.com

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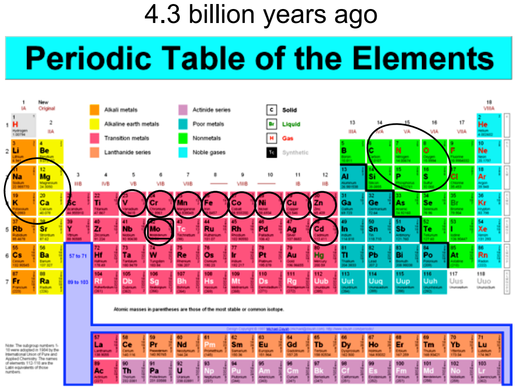

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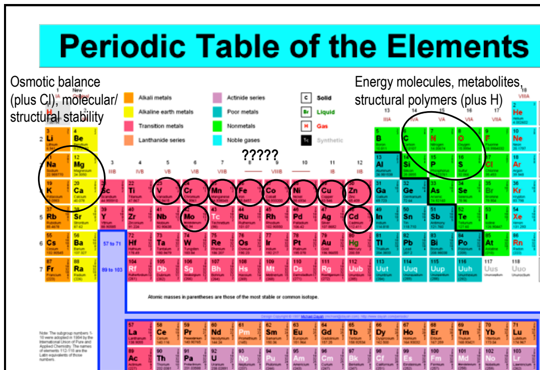
Periodic Table of the Elements



http://www.dayah.com/periodic/Images/periodic%20table.png

Basic Chemistry of Transition Metals

Several or more stable oxidation states
Effective inorganic catalysts
Formation of complex ions composed of more than one atom

e.g., Fe ions: 2 oxidation states - Fe^{2+}, Fe^{3+}
Mn ions: 7 oxidation states - Mn^{1+}-Mn^{7+}
Mo ions: 8 oxidation states - Mo^{2-}, Mo^{1-}, Mo^{1+}-Mo^{6+}

Some examples of transition metals in biology

Element	Enzyme/protein	Reaction/process
Iron (Fe)	Cytochromes	Electron carrier in ETC's
	Catalase	$2H_2O_2 \longrightarrow 2H_2O + O_2$
	Hemoglobin	Oxygen carrier
Copper (Cu)	Cytochrome oxidase	$4H^+ + 4e^- + O_2 \longrightarrow 2H_2O$
	Hemocyanins	Oxygen carrier
Zinc (Zn)	Carbonic anhydrase	$CO_2 + H_2O \rightleftharpoons H^+ + HCO_3^-$
	Alcohol dehydrogenase	$C_2H_5OH \longrightarrow C_2H_4O + 2H^+$
Molybdenum (Mo)	Nitrogenase	$N_2 \longrightarrow 2NH_3 + H_2$
	Nitrate reductase	$2NO_3^- \longrightarrow 2NO_2^-$
Vanadium (V)	Nitrogenase	$N_2 \longrightarrow 2NH_3 + H_2$
Manganese (Mn)	Water-splitting complex	$2H_2O \longrightarrow 4H^+ + 4e^- + O_2$
Cadmium (Cd)	Carbonic anhydrase	$CO_2 + H_2O \rightleftharpoons H^+ + HCO_3^-$
Nickel (Ni)	Hydrogenases	$H_2 + X_{ox} \rightleftharpoons 2H^+ + X_{red}$