The "Tree of Life"

Metabolic Pathways

Calculation Of Energy Yields

OCN 401 - Biogeochemical Systems

8/22/17

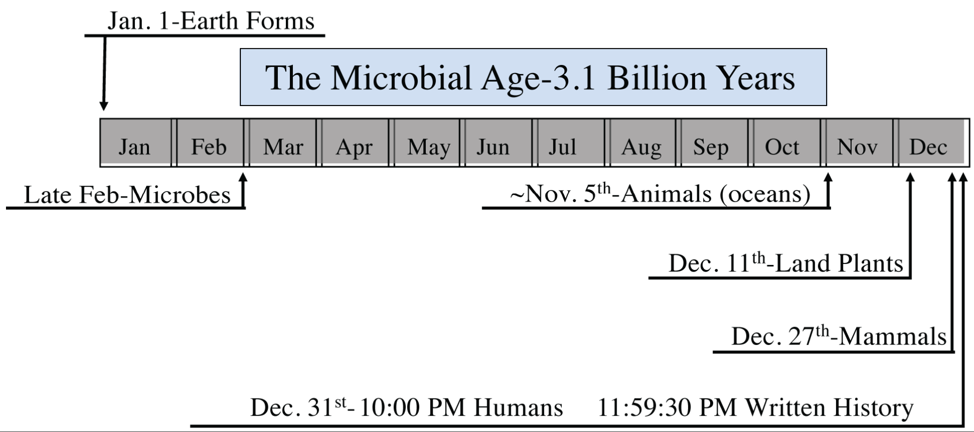
Reading: Schlesinger & Bernhardt, Chapters 1 & 2

Outline

1. Earth's history and the evolution of life
2. The "Tree(s) of Life"
3. Metabolic strategies by organisms
4. Linkages between reductions and oxidations (redox)
5. Calculation of energy yields

Some perspective

- The history of life on earth is overwhelmingly microbial
- The earth is ~4.5 billion yrs old,
  - microbes arose 3.8 billion years ago (bya)
  - animals-0.7 bya -- humans-0.001 bya

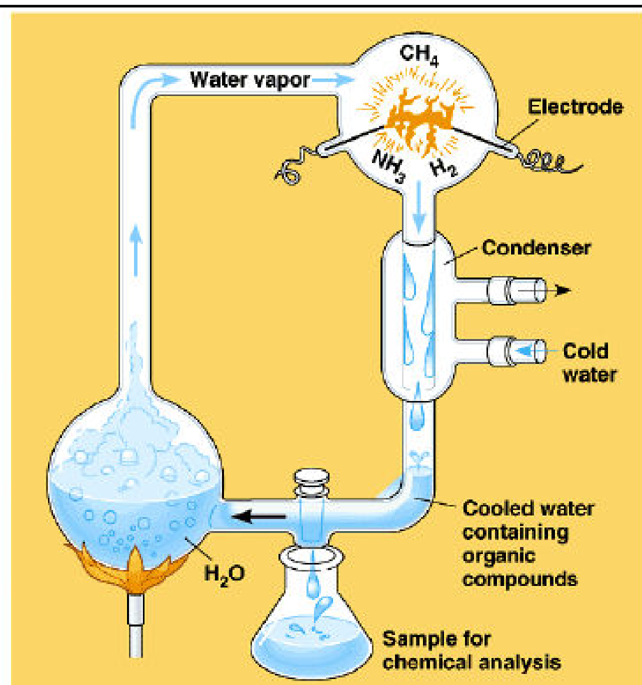


The Origin of Life?

The Miller – Urey Experiment (1951)

Produced amino acids and other organic compounds

Couldn't happen under modern conditions.....oxidizing atmosphere attacks organic bonds



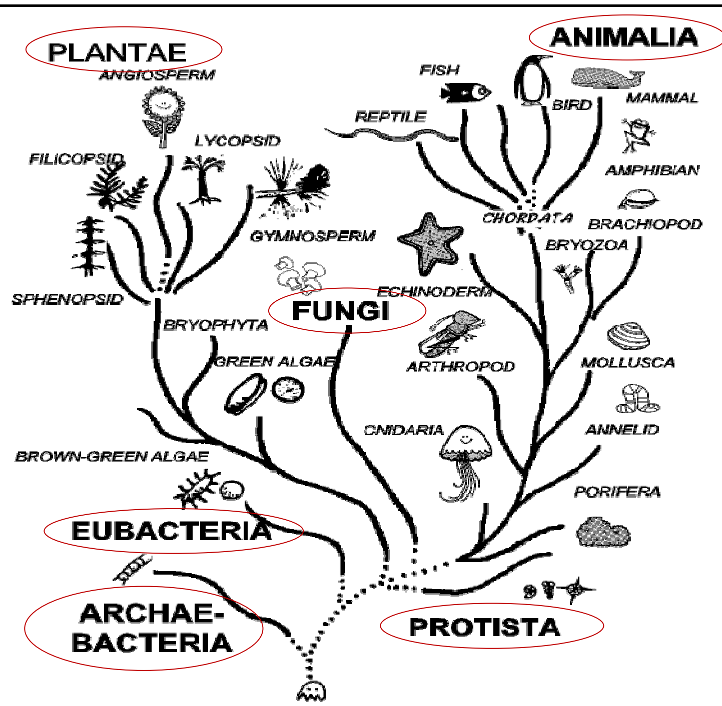
Other Possibilities

Interplanetary sources of organic matter - interplanetary dust particles, carbonaceous chondrites (meteorites) - a small amount of material, but may have a major catalytic effect, speeding the rate of abiotic organic matter synthesis

Clay minerals - may have aided in concentrating simple organics, making the assembly of complex organic compounds more favorable

Icy comets crashing into earth's atmosphere - can produce complex organics from simple inorganic compounds (water, ammonia, methanol, carbon dioxide) due to elevated temp and pressure

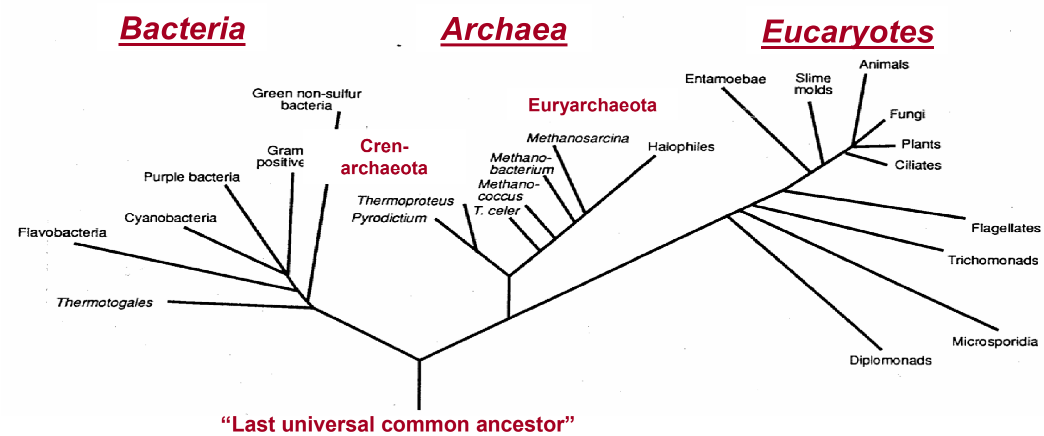
The Tree of Life – A Traditional Approach



www.msnucleus.org

A Modern Approach

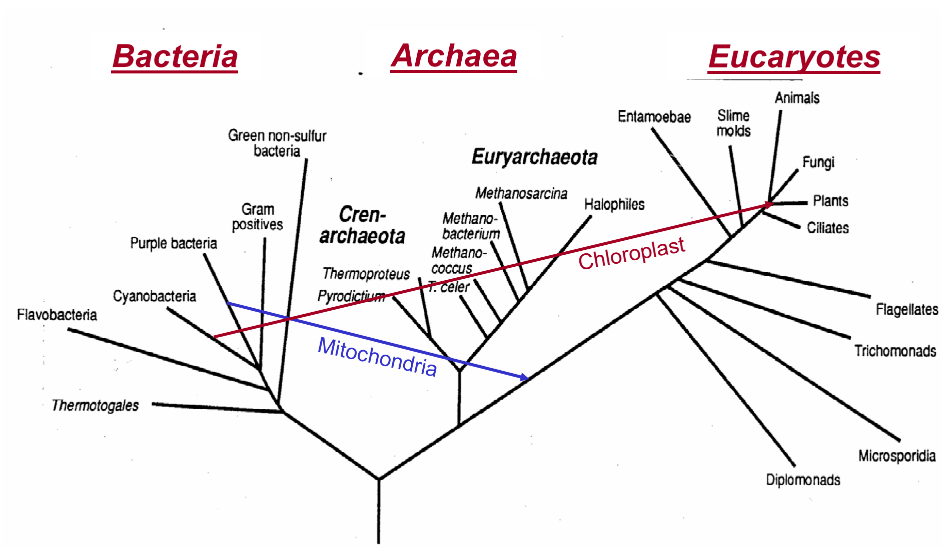
Determined from sequencing of ribosomal RNA (as opposed to morphology and physiology)



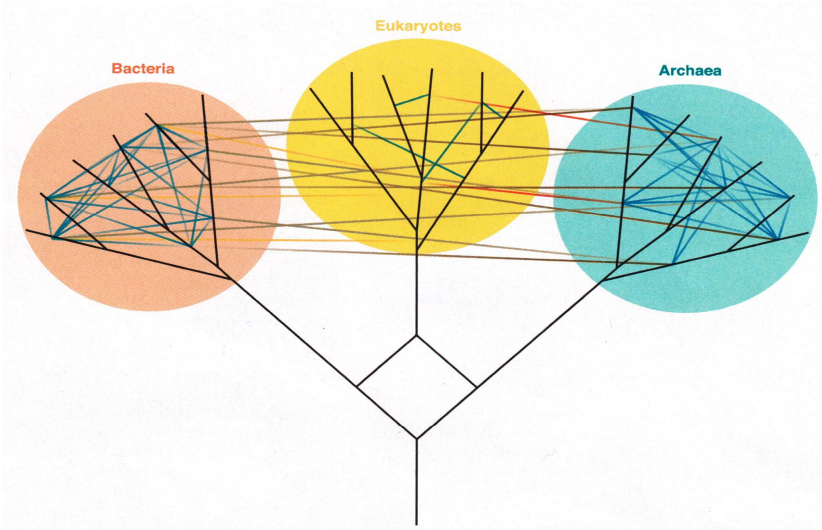
Archaea – most "primitive", commonly live in extreme environments

Modified from Chan et al. (1997)

A further complication -- *endosymbiosis* due to *lateral gene transfer*:



The New Paradigm??



A schematic of a tree of life capturing both vertical lines of descent and lateral lines of gene transfer. Eukaryotes are shown to have evolved through a fusion/symbiosis between archaea and bacteria, consistent with many hypotheses on eukaryotic origins. Together a tree of life that captures the vertical lines of descent and the lateral lines of gene transfer would offer a more comprehensive evolutionary story of the biodiversity of life. Branch lengths in this representation do not represent time.

Swithers & Katz 2013

Metabolic Strategies for Sustaining Life

We can classify organisms by function -- how they obtain **energy** and **cell-carbon**:

1. Method of energy generation (reactions that convert ADP to ATP):
   - Photosynthesis -- *Phototroph*
     - *e.g.*: Oxic photosynthesis: $6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2 + ATP$
   - Oxidation/reduction of inorganic compounds -- *Lithotroph (Chemotroph)*
     - *e.g.*: Ammonia oxidation: $NH_4^+ + 1\frac{1}{2}\ O_2 \rightarrow NO_2^- + 2\ H^+ + H_2O + ATP$
   - Oxidation of organic compounds -- *Organotroph*
     - *e.g.*: Glucose oxidation: $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + ATP$
2. Carbon source:
   - Carbon dioxide -- *Autotroph*
   - Organic compounds -- *Heterotroph*

Metabolic Strategies - Examples

Photoautotrophs

Green plants — Most algae

Cyanobacteria — Some purple and green bacteria

Lithoautotrophs (Autolithotrophs)

Methane oxidizing bacteria: $CH_4 + O_2 \rightarrow CO_2 + 4H^+ + 4e^-$

Hydrogen oxidizing bacteria — Iron oxidizing bacteria

Nitrifying bacteria: $NO_2^- + ½\,O_2 \rightarrow NO_3^-$

Photoheterotrophs

Most purple and green non-sulfur bacteria — Some algae

Some cyanobacteria

Lithoheterotrophs (Heterolithotrophs)

Sulfide oxidizing bacteria

Organoheterotrophs

Animals — Most bacteria — Fungi — Protozoa

Linkages Between Oxidations and Reductions

$CH_2O \equiv$ generic organic matter

These are the most common redox reactions; many others are possible

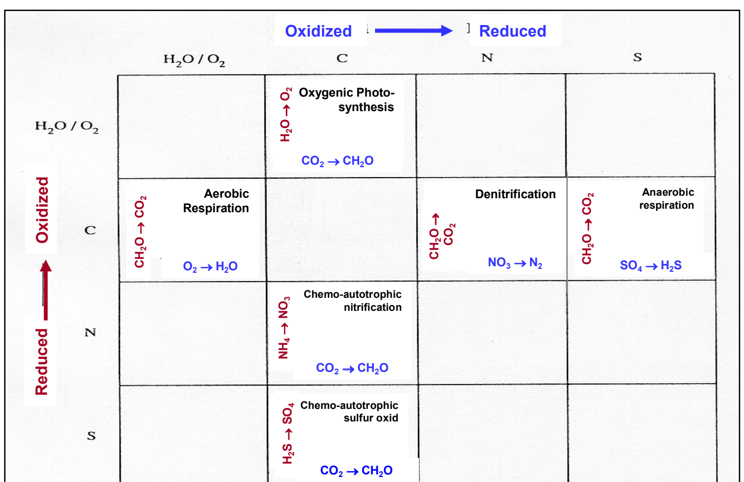


Figure 2.8 Metabolic pathways that couple oxidations of C, N, and S on the Earth's surface. For each pathway, the constituent at the top is transformed from an oxidized form obtained from the environment to a reduced form, released to the environment. At the same time, the constituent at left is transformed from a reduced form to an oxidized form. Modified from Schlesinger (1989).

In this course we will see that global biogeochemical cycles are driven by transformations of substances between oxidized and reduced forms in different environments

Calculation of Energy Yields

Consider this general reaction:

$$aA + bB \rightarrow cC + dD$$

The free-energy change of the reaction at "standard state" can be calculated as:

$$\Delta G_r^\circ = (cG_C^\circ + dG_D^\circ) - (aG_A^\circ + bG_B^\circ)$$

where G_X° is the free energy of formation for a product or reactant "X" at standard state (which can be looked up)

Standard state:	1 atm pressure
	25°C
	Concentrations = 1 mole/kg

- If $\Delta G_r^\circ < 0$, then the reaction proceeds spontaneously as written (at standard state)
- If $\Delta G_r^\circ > 0$, then the reaction proceeds spontaneously in the opposite direction as written (at standard state)
- If $\Delta G_r^\circ = 0$, then the reaction is at equilibrium and will not proceeds spontaneously in either direction (at standard state)

Thus, ΔG_r° is a powerful tool to predict if a reaction will occur!

However, we are commonly interested in conditions other than standard state....

We calculate the *in-situ* ΔG_r using this equation:

$$\Delta G_r = \Delta G_r^{\circ} + RT \ln \frac{[C]^c [D]^d}{[A]^a [B]^b}$$

In-situ

Standard state

R = ideal gas constant = 1.987 cal °K^{-1} mol^{-1} = 8.31 J °K^{-1} mol^{-1}

T = °K

[ ] = concentration

Thus, using the same criteria used on the previous slide, we can predict whether a reaction will occur under real-world conditions!

Next Class:

"Atmospheric deposition, atmospheric models"

This will begin our investigation of biogeochemical systems on Earth:

- Atmosphere
- Terrestrial systems
- Aquatic systems
    - Lakes
    - Streams and rivers
    - Estuaries
    - Oceans