

Course Logistics

Instructors:

- Joe Vallino, Starr 330, x7648, jvallino@mbi.edu
- Julie Huber, Lillie 305, x7291, jhuber@mbi.edu
- Office hours: Tuesdays after lab.

TA:

- Stef Strebel, SES TA's office, email: [sstrebel@mbi.edu](mailto:ssstrebel@mbi.edu)

Schedule

- Class meets Tuesdays and Thursdays, 10:15 - 12:00, **Except weeks 8.5 – 10 (3- 10 Nov)**

Requirements

- Courses in first year chemistry, biology, and biochemistry (suggested).
- Readings. No required text. Recommended text: Madigan, Martinko and Parker (2000) *Brock Biology of Microorganisms*, 9th ed. Copies of *Brock* are on reserve. Can be purchased through Amazon.com (search ISBN: 0130819220)
- Problem Sets: Set of questions on reading and lab, **due Thursdays at beginning of class.**
- Lab participation.

Organization

- Combination of lectures and labs.
- 8 focus topics over 10 weeks.
- Lectures, problem sets, and answers available at: <http://ecosystems.mbi.edu/ses/MicrobialMethods>

Grading

- 80% Problem Sets (10% each)
- 20% Participation and laboratory technique (**use of lab notebook, etc.**)
- Final contingent on individuality of problem sets and class participation.

Course Objectives

- Introduction to microbial methods applicable to the study of ecosystems
 - State variables (i.e., concentration, abundance)
 - Processes (i.e., rates, fluxes)
- Introduction to microbial systems (or systems biology)
 - Diverse communities of microorganisms exhibiting some homeostasis.
- Introduction to microbial biogeochemistry
 - Chemistry that results from both biotic and abiotic processes.

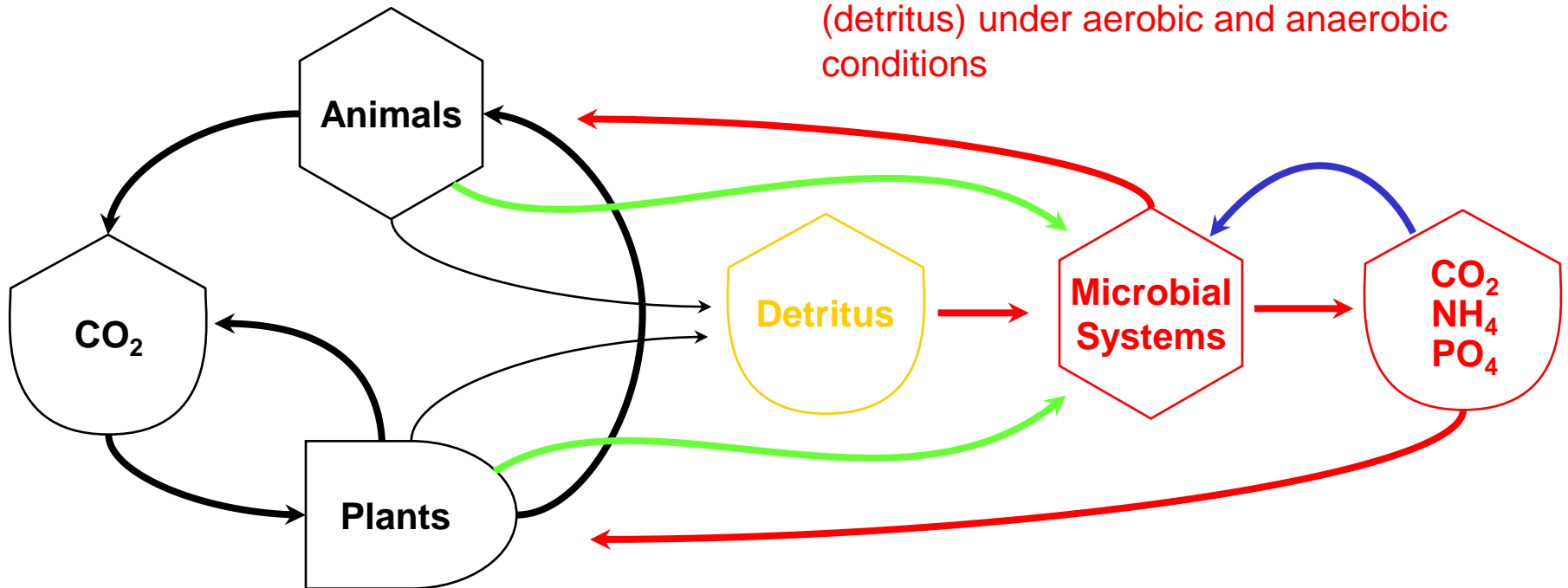
My Background and Research:

- Chemical and Biochemical Engineering (metabolic engineering).
- Modeling microbial dynamics
- Understanding and modeling of *whole system* biogeochemistry
- Living systems and nonequilibrium thermodynamics (“Systems Biology”)
- Transport modeling

The importance of microorganisms

You could probably remove all higher organisms without significantly altering the Earth's biogeochemistry or homeostatic properties.

Higher Trophic Levels Metabolically Simple

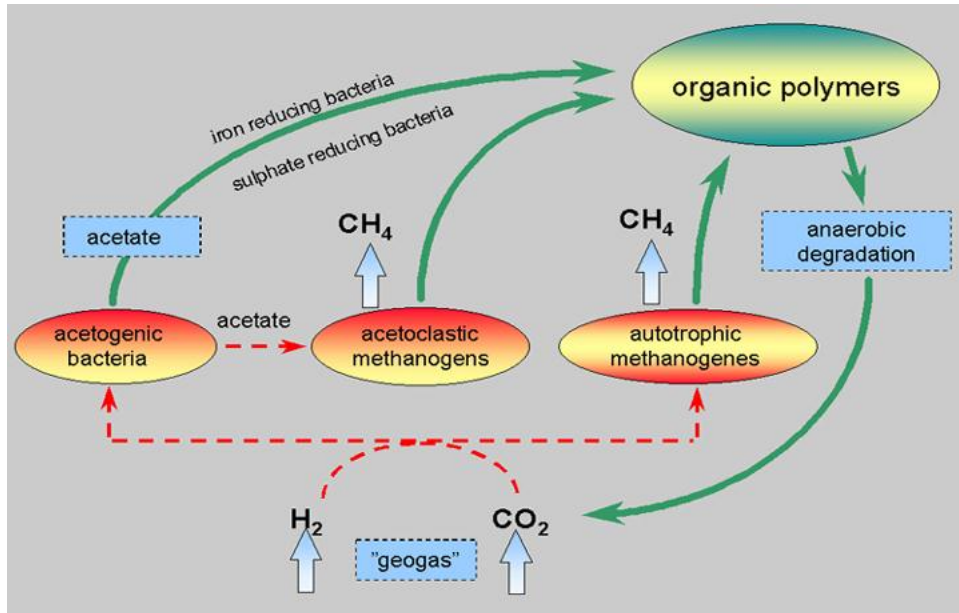


As well as being consumed by higher trophic levels, microbial systems also recycle many inorganic nutrients: N, P, S, Trace metals.

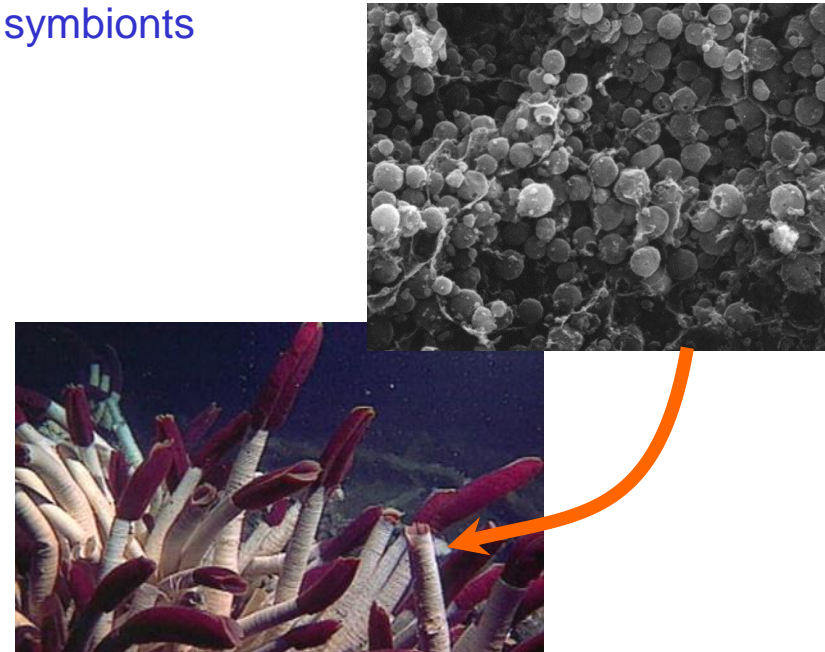
Deep Biosphere

Strong evidence now supports the presence of a biosphere living up to 1 km below the earth's surface. Bacteria in this deep biosphere have been found in even crystalline basalt rocks below marine sediments, and their biomass is on the order of that above the surface. This biosphere is driven by geogasses, and is similar to deep ocean vent ecosystems. Could also exist on other planets, e.g., Mars.

Chemistry of the Deep Biosphere



Hydrothermal Vent Tubeworms and bacterial symbionts



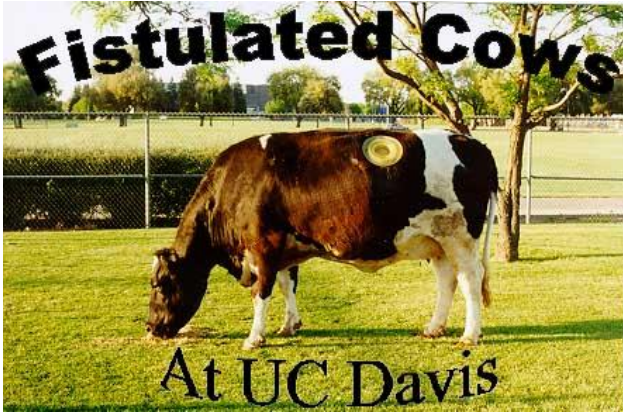
Kotelnikova, S. and Pedersen, K. 1998. Distribution and activity of methanogens and homoacetogens in deep granitic aquifers at Äspö Hard Rock Laboratory, Sweden. *FEMS Microbiology Ecology*, Vol. 26, 121-134.

N. R. Pace. A molecular view of microbial diversity and the biosphere. *Science* 276 (5313):734-740, 1997.

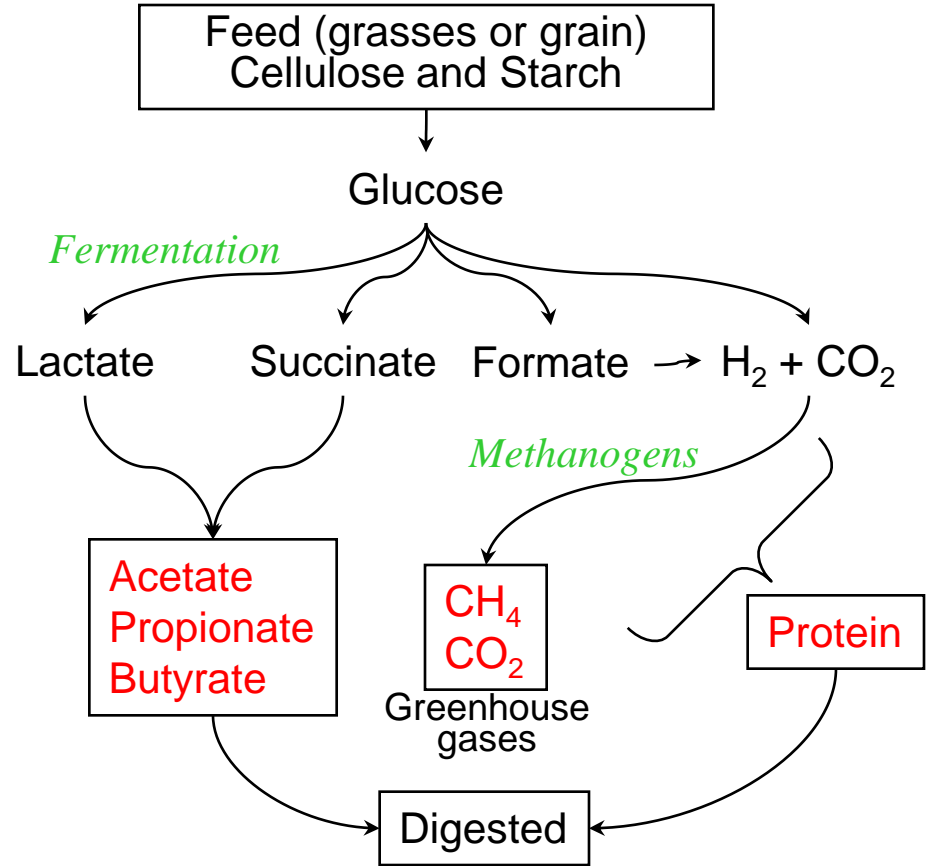
Roussel, E.G. et al. Extending the Sub-Sea-Floor Biosphere. *Science* 320 (5879): 1046, 2008.

Rumen Microbial Ecosystem

Complex *anaerobic* microbial system found in the rumen

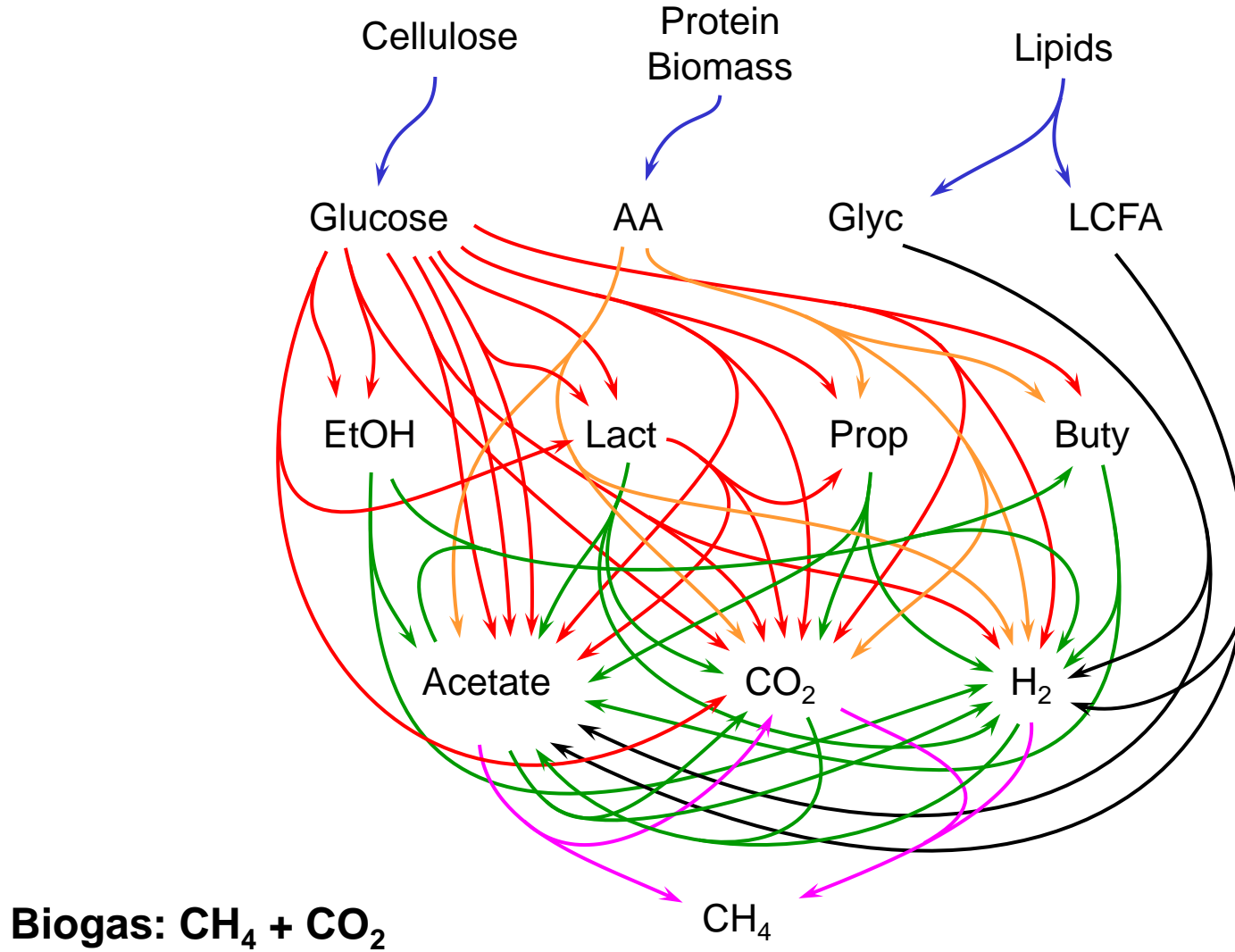


Similar systems found in termites



Reactions mediated by dozens of bacterial species, including protozoan grazers such as ciliates.

Diversity of Anaerobic Methanogenic Pathways



“Distributed Metabolic Network”

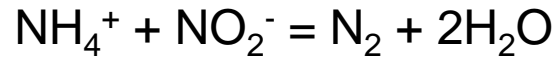
Chemical Potential Exploitation

H₂S oxidation by NO₃⁻

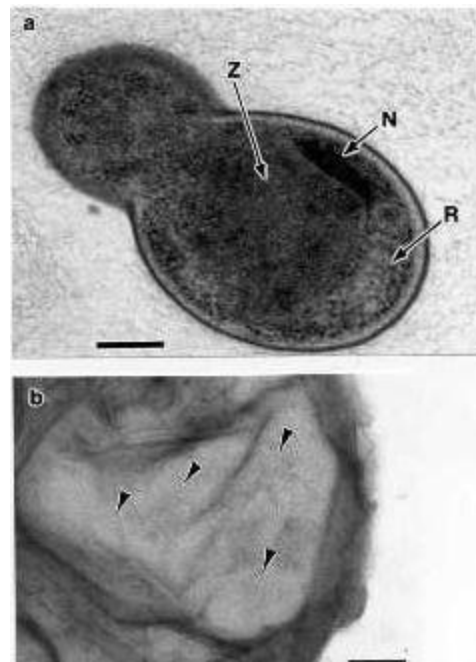
Schulz et al. 1999:
Thiomargarita namibiensis



Anammox

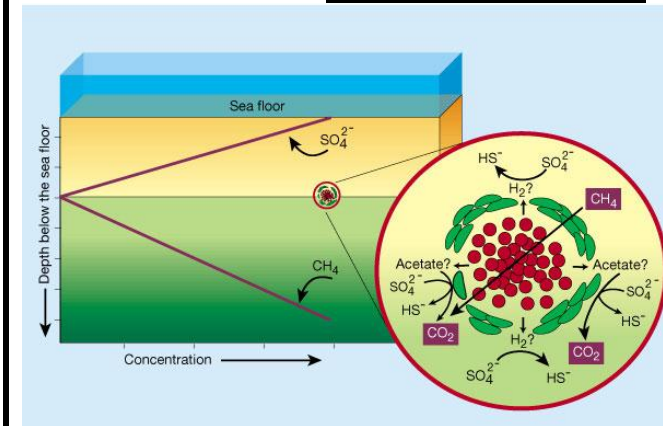
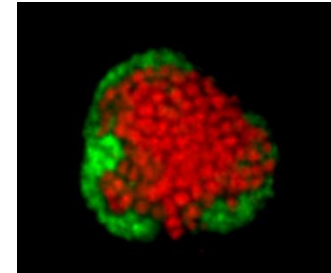


Strous et al. 1999:
Planctomycete

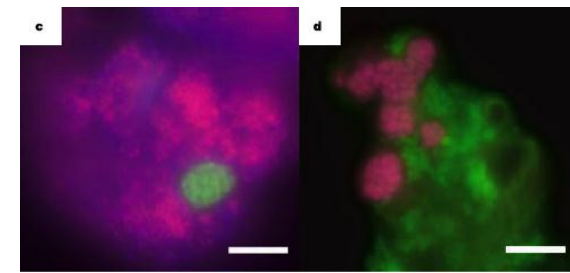
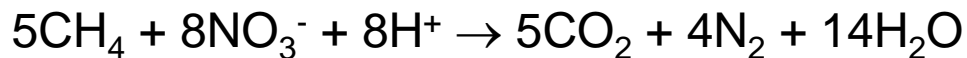


CH₄ oxidation by SO₄²⁻

Boetius et al. 2000:



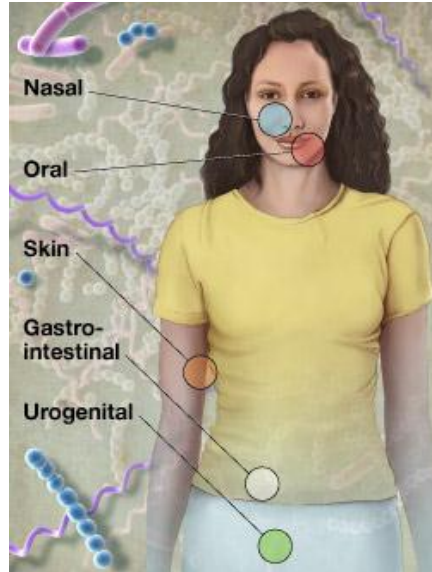
CH₄ oxidation by NO₃⁻ (Raghoebarsing et al. 2006)



Microbiome

See: Turnbaugh et al., *Nature* 449 (7164):804-810, 2007.

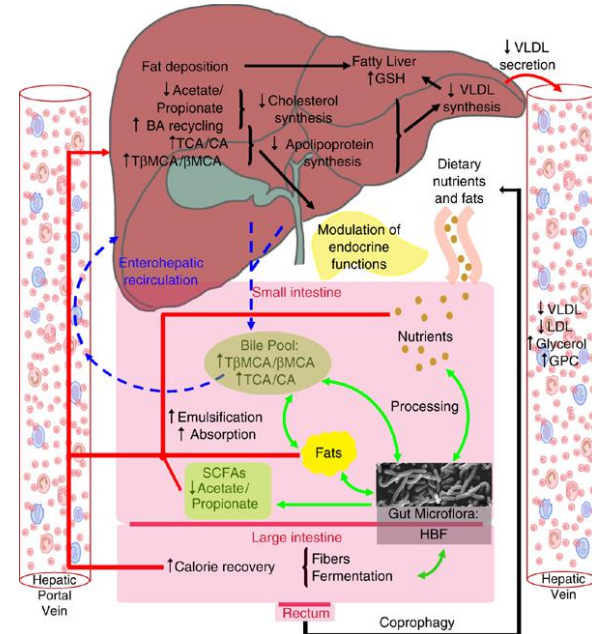
<http://nihroadmap.nih.gov/hmp/>



Remember,
You're a Donut



Microbe–mammalian metabolic interactions related to bile acid and lipid metabolism.



Martin et al. *Mol. Syst. Biol.* 3 (112):1-16, 2007.

Human:

- Somatic+germ Cells: ~10 Trillion
- Genome: 20,000 protein encoding genes

Intestinal microbiota:

- Cells: ~100 Trillion
- Metagenome: ~100x human

(Gill et al. *Science* 312 (5778):1355-1359, 2006.)



Bravo et al. (2011) Ingestion of *Lactobacillus* strain regulates emotional behavior and central GABA receptor expression in a mouse via the vagus nerve, *PNAS*, doi: 10.1073/pnas.1102999108

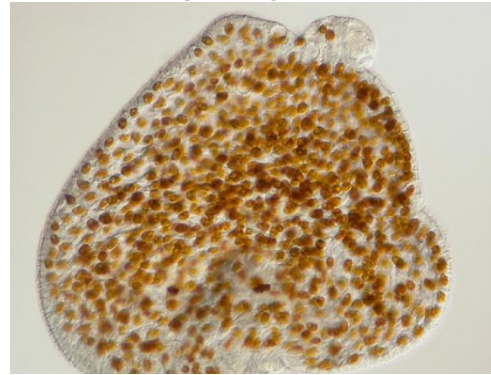
Other examples, Microbially-coupled Systems

Symbiosis and Endosymbiosis

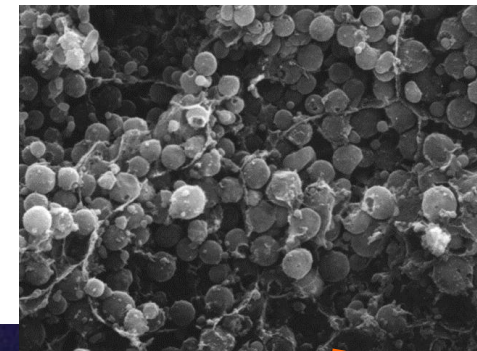
Lichen: Fungi+Algae



Dinoflagellates in flatworm



Sulfur bacteria in *Riftia*



Mycorrhizae



Caldwell et al. 1997: Biological systems develop with multiple levels of organization and multiple levels of proliferation.

Prokaryotic Differentiation

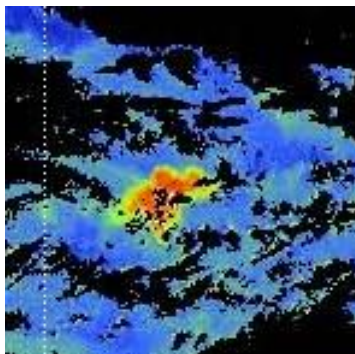
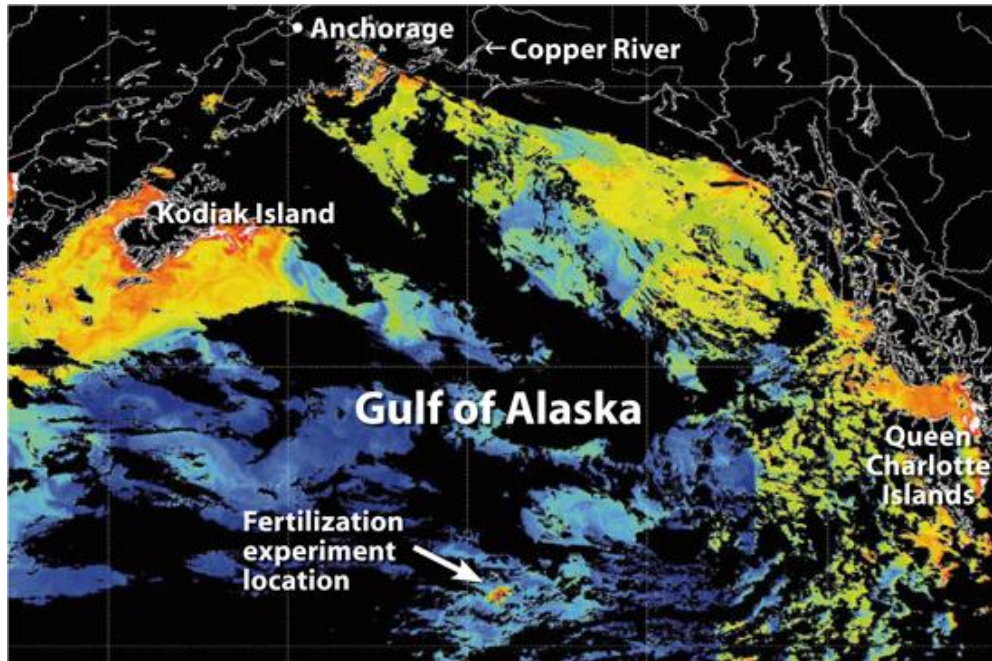
Cell-to-cell signaling compounds (such as N-acyl homoserine lactones) allow bacterial species to exhibit multicellular characteristics.

Ben-Jacob (1998) *Paenibacillus dendritiformis*



Geoengineering and Biofuels

Iron Fertilization?

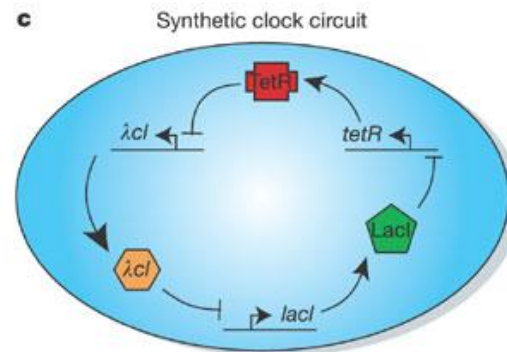
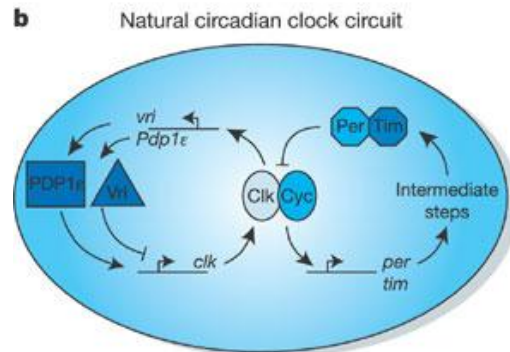
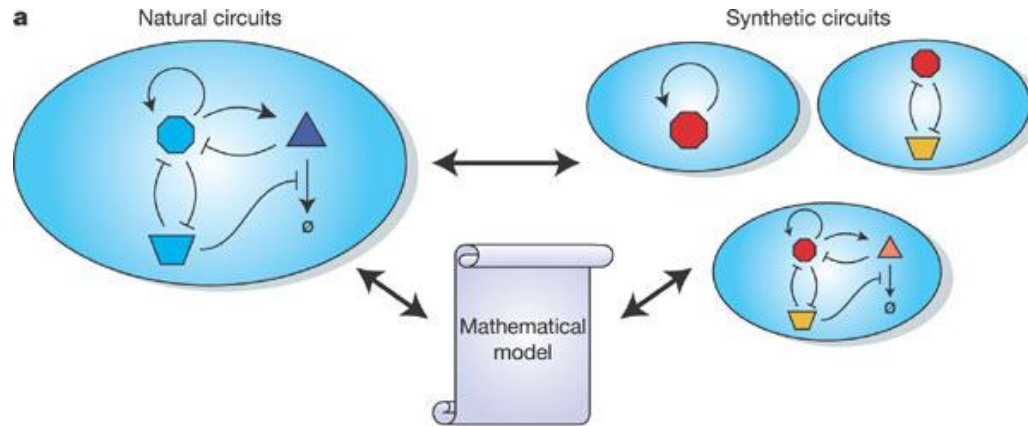


Oceanus, 46 (1) 2008
<http://www.whoi.edu/oceanus/>

Biodiesel from Algae



Synthetic Biology



David Sprinzak and Michael B. Elowitz
Nature 438, 443-448 (24 November 2005)

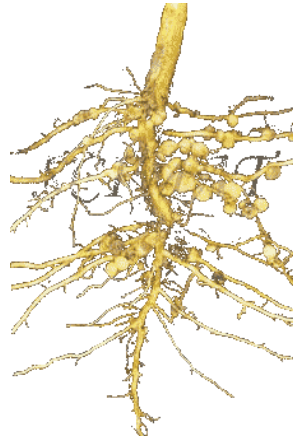
See recent issue of *Science* (2 Sept 2011)
<http://www.sciencemag.org/site/special/syntheticbio>

Other Important Microbial Processes

- Nutrient cycling under aerobic and *anaerobic* conditions.
- Removal of excess nitrogen via nitrification and denitrification in eutrophic systems.



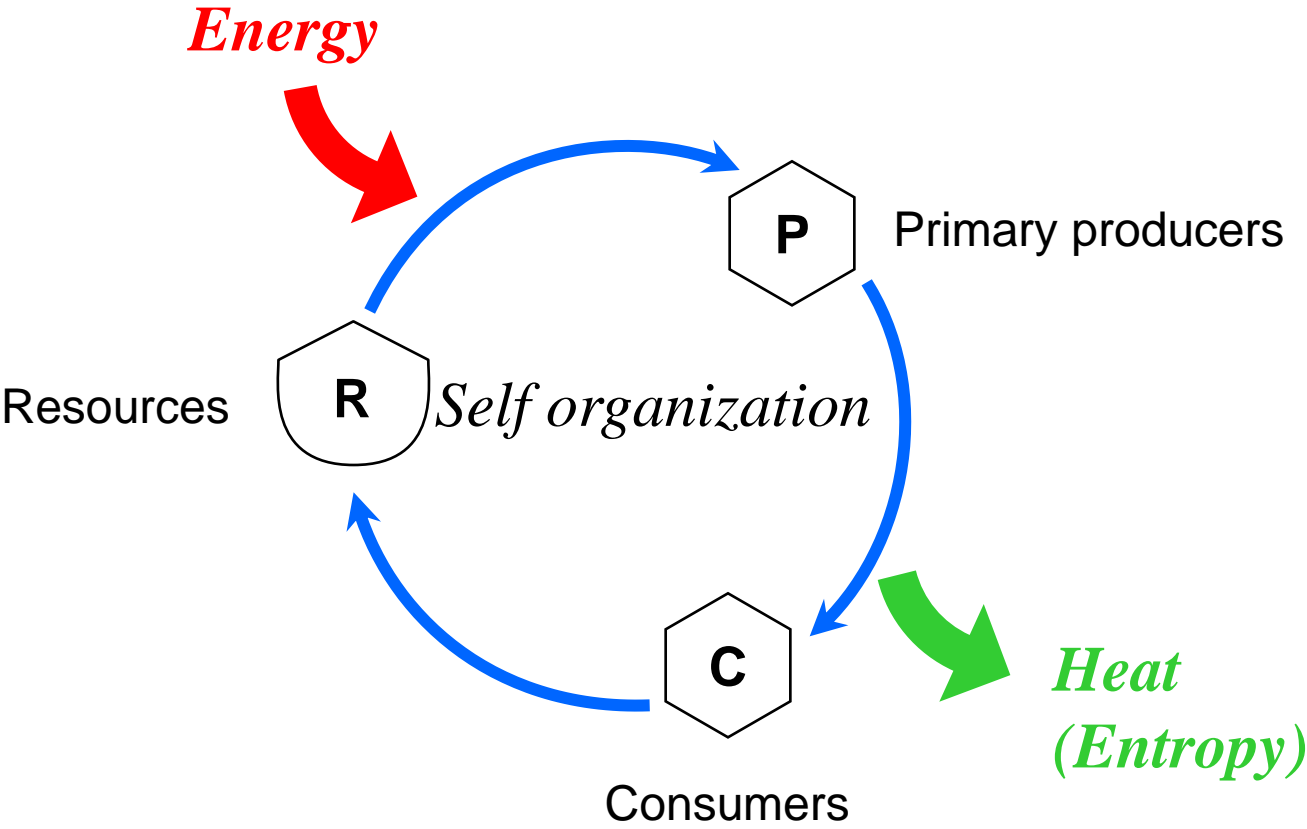
- Fixation of N_2 gas into organic N, especially in root nodules via symbiosis with bacteria, such as *Rhizobium*.



- Remediation of toxic substances (bioremediation or natural attenuation).
- Almost all biomass and processes in the oceans are dominated by microbes.
- Largest organism on Earth is a fungus (*Armillaria ostoyae*; honey mushroom).
- Major sources and sinks for atmospheric trace greenhouse gasses (CH_4 , N_2O).
- Cycling of iron ($\text{Fe}^{3+} \Leftrightarrow \text{Fe}^{2+}$), Manganese ($\text{Mn}^{4+} \Leftrightarrow \text{Mn}^{2+}$) and other metals.
- Cause of many diseases, especially in 3rd world countries.
- Very high “species” abundance, current estimate of 10^7 species in 10 g of soil.

Microbial Systems as Model Ecosystems

Closed Systems (such as Earth)



Course Focus

Microbiology

Study of small, mostly single cell, living organisms

Public Health

- Pathogens
- Clinical
- Immunology
- Viruses



Laboratory Techniques

- Isolation
- Cultivation
- Identification

Function

- Biochemistry
- Molecular genetics
- Physiology

Applied Microbiology

- Biotechnology
- Industrial microbiology
- Food (beer, wine, cheese, soy sauce)
- Extraction of metals from ores
- Biofuels, Geoengineering

Origin of Life

- Diversity
- Phylogeny

Microbial Ecology

- In Natural Environments
- Biodiversity
- Organismal relationships
- Biogeochemistry

See American Society of Microbiology: www.asm.org

Microbial Ecology

To study the relations of organisms to one another and to their physical surroundings (i.e., environment).

Key Differences from clinical microbiology

- Communities of organisms, not isolated laboratory monocultures.
- Interaction with environment.

Challenges

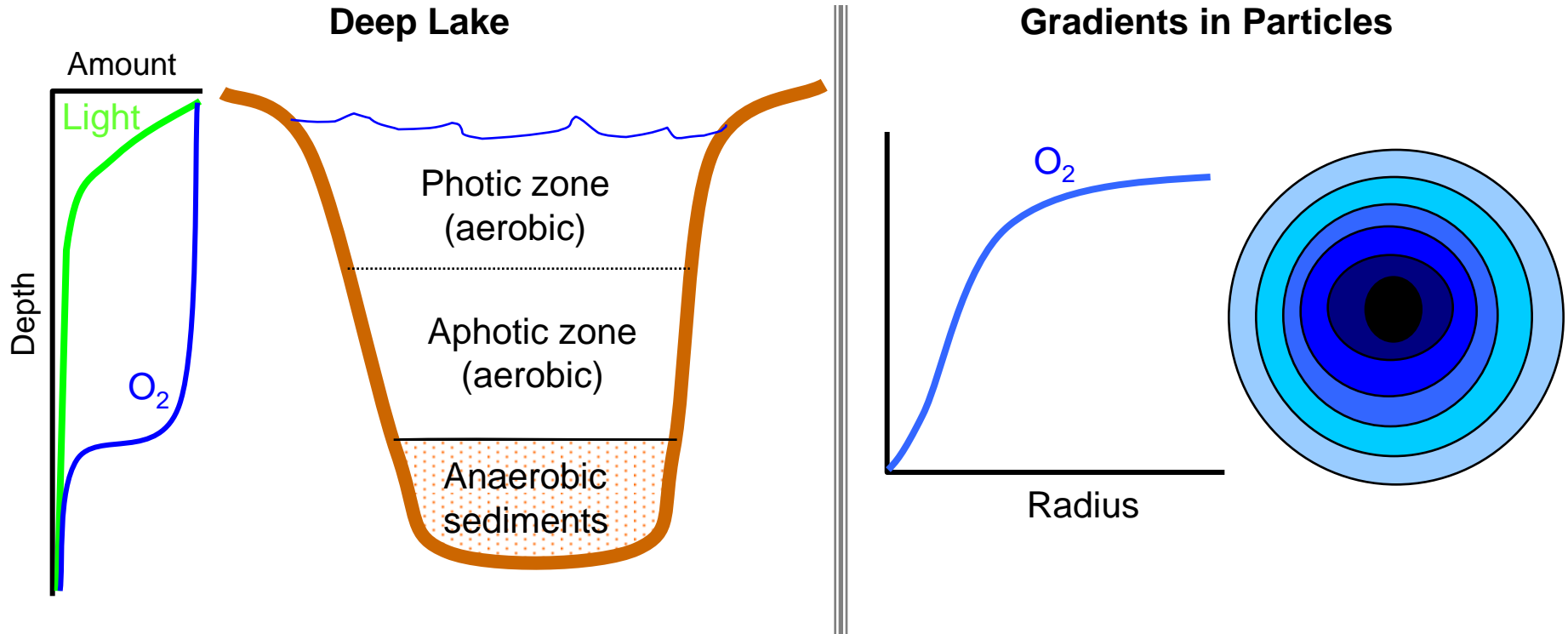
- Must work with low concentrations of nutrients and organisms
- Most clinical laboratory techniques do not work in the field.

Objectives

- Identify organisms present (biodiversity) and their interactions: predator-prey, **syntrophy**, **symbiosis**, etc.
- Identify new pathways (e.g., SO_4^{2-} oxidation of CH_4)
- Identify processes and measure rates, such as primary production, nitrification, methanogenesis, etc.
- Develop models for understanding and prediction (both qualitative and quantitative).

Habitats and biogeochemistry

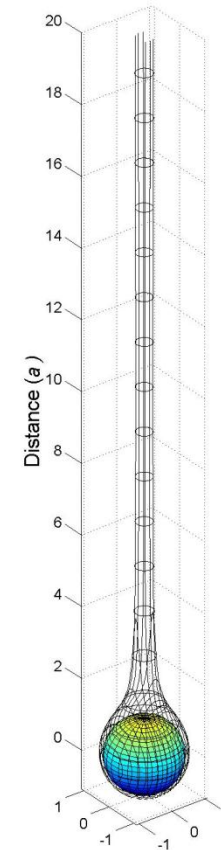
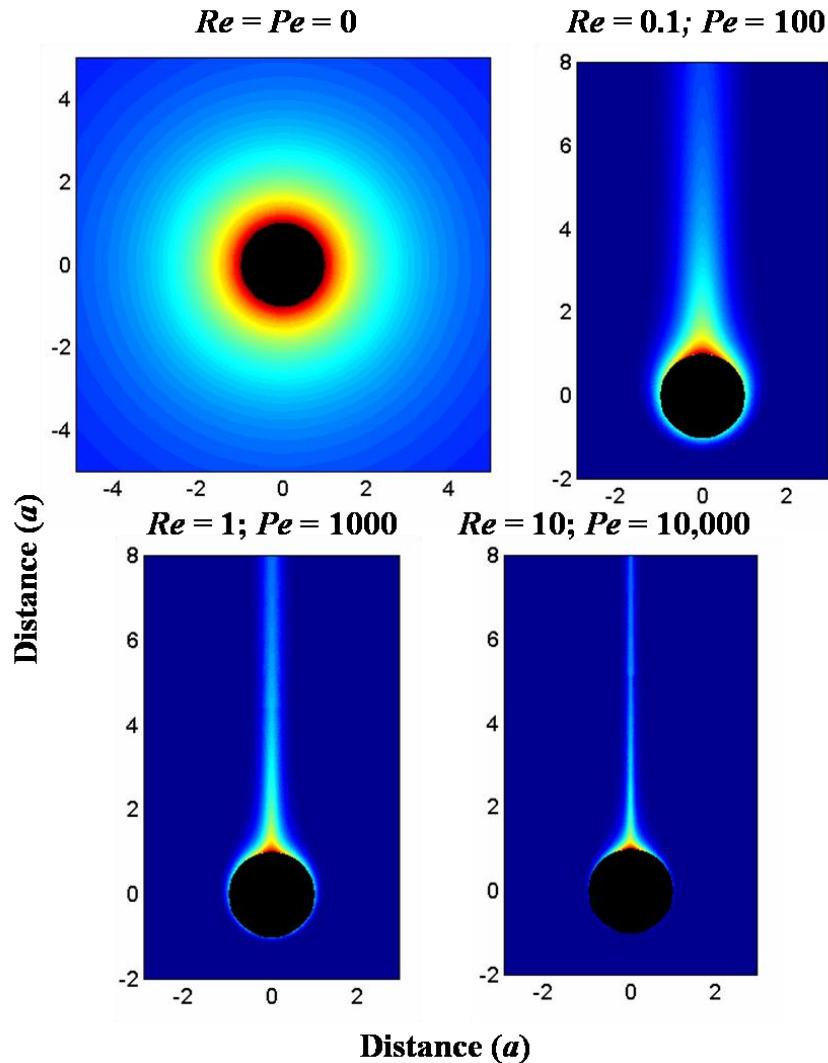
The world is not “well-mixed”, so that sources and sinks of matter and energy produce gradients and microenvironments. Microbial communities develop as a function of resource availability.



These gradient dominated environments often can not be duplicated in the lab, so research must be conducted in the field.

Examples: Hot springs, Deep sea vents, hyper-saline, and anoxic environments.

Organic Matter Around Sinking Particle

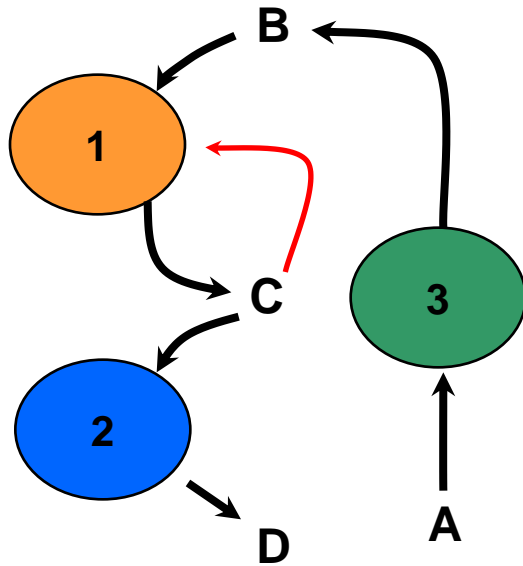


KIØRBOE et al. Fig. 7

(Kiørboe et al 2000)

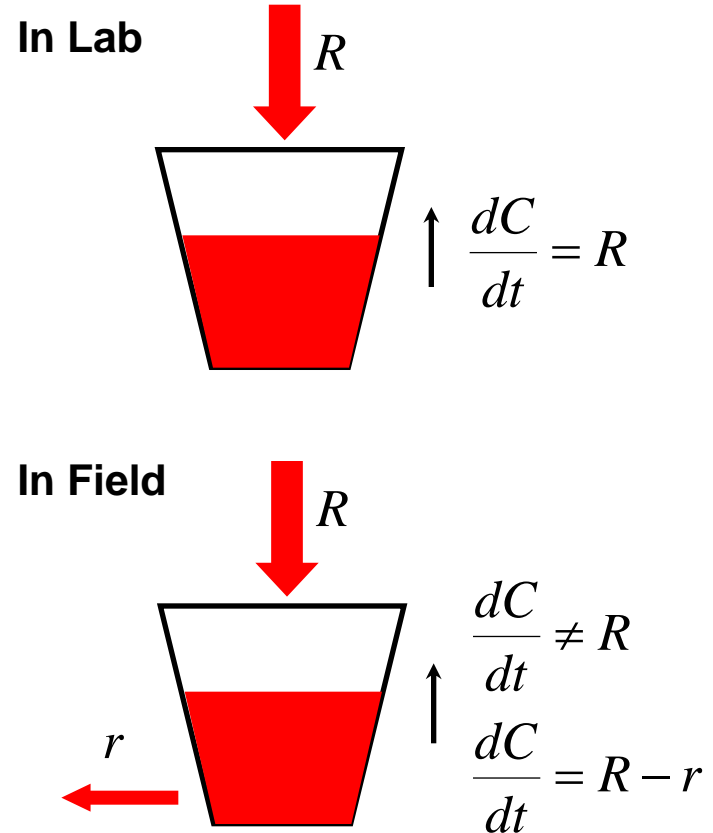
Works in the lab, but not in the field

Syntrophy
Nutrient cycling



Contained systems will often quickly diverge from true system.

Lab versus field measurements



Finally, concentrations of compounds in natural systems are often at the limit of detection!

⇒ ***New methods often produce new understanding...Paradigm Shifts***

How small are we talking?

Microbiology: Requires a microscope to study \Rightarrow \sim 1 mm or less

Plankton: Net movement dependent on flow field.

Phyto: Autotrophic

Nekton: Move independent of flow field.

Zoo: Heterotrophic

Femtoplankton: 0.02 - 0.2 μm

- Mostly viruses

Picoplankton: 0.2 - 2 μm

- Bacteria, cyanobacteria

Nanoplankton: 2 - 20 μm

- Flagellates, dinoflagellates

Microplankton 20 - 200 μm

- Diatoms, ciliates.

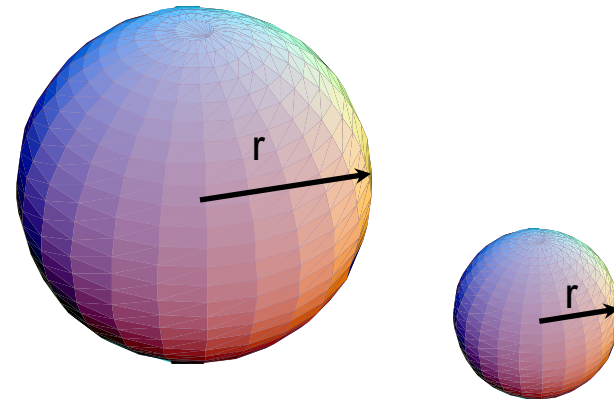
Mesoplankton > 200 μm

- Zooplankton (copepods)

Bacteria: 0.2 μm - 1000 μm (1 mm)

- Typically 1 - 2 μm culture, or < 1 μm natural environments.

Surface area to volume



$$\text{Surface area: } 4 \pi r^2$$

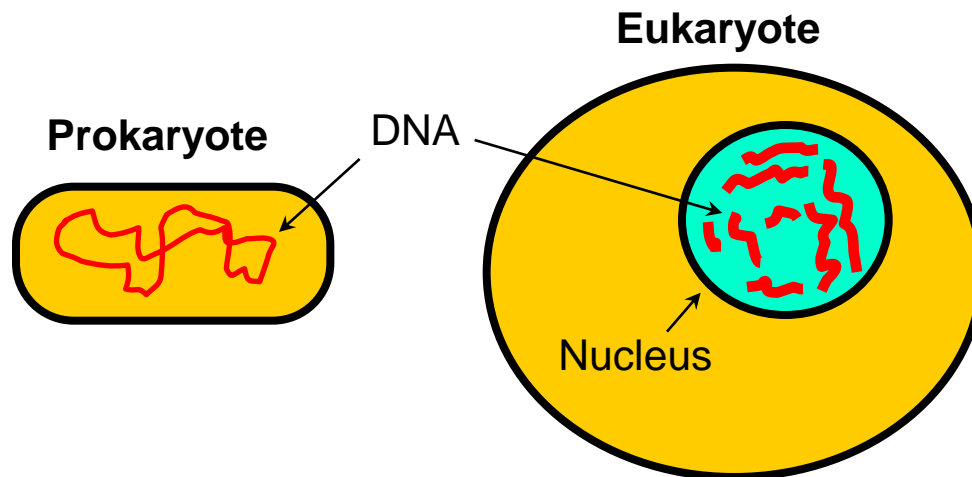
$$\text{Volume: } \frac{4}{3} \pi r^3$$

$$\text{SA/V} = \frac{3}{r}$$

Prokaryotes and Eukaryotes

Two general classes of cells:

- **Prokaryotes:** Most primitive cell. Lack internal organelles and nucleus. DNA is single molecule (no chromosomes) aggregated in the *nucleoid*, although plasmids can also be present. Reproduction occurs by simple division. Almost a synonym for bacteria.
- **Eukaryotes:** Typically larger cells that contain a nucleus with DNA organized into chromosomes. Organelles, such as mitochondria or chloroplast, are usually present. Usually contain two copies of genes (diploid) and division occurs by mitosis. Example eukaryotes:
 - *Algae:* Phototrophic, single cells (or colonies).
 - *Fungi:* Heterotrophic single (yeast) or multicellular (molds, mushrooms) with cell wall.
 - *Protozoa:* Single cells lacking rigid cell wall, heterotrophic.
 - *Metazoans:* Plants (phototrophic) and animals (heterotrophic) (cell differentiation).



Note, there are some (Norm Pace) that feel Prokaryote is an antiquated (and incorrect) definition

Five Kingdoms (old Phylogeny)

Animalia

- Multicellular
- Organs
- No cell wall
- Ingests nutrition
- Nervous system
- Has locomotion

Plantae

- Multicellular
- Cellulose cell walls
- Photosynthetic nutrition
- No nervous system
- No locomotion

Fungi

- Most multicellular
- Chitin cell walls
- Absorbs food
- No nervous system
- No locomotion

Protista

- Most unicellular or simple multicellular
- Some have cell walls
- Absorbs food, ingests or photosynthesizes
- No nervous system
- Locomotion in some

Monera

- Most unicellular, some colonial
- Cell walls of polysaccharides
- Absorbs food, chemosynthesizes or photosynthesizes
- No nervous system
- Locomotion in some

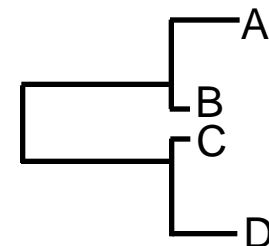
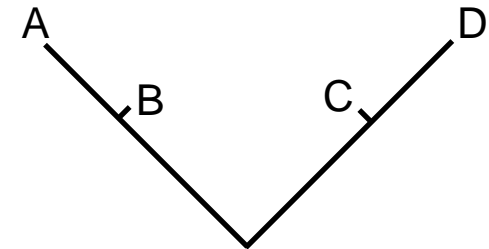
Phylogeny from DNA sequences

Methodology

- Compare DNA sequences of different organisms
- Closer DNA sequences are to each other, closer the evolutionary distance separating the organisms.
- Use DNA of ribosomal RNA (rRNA), since all organisms have rRNA and rRNA's are evolutionarily stable.

Example

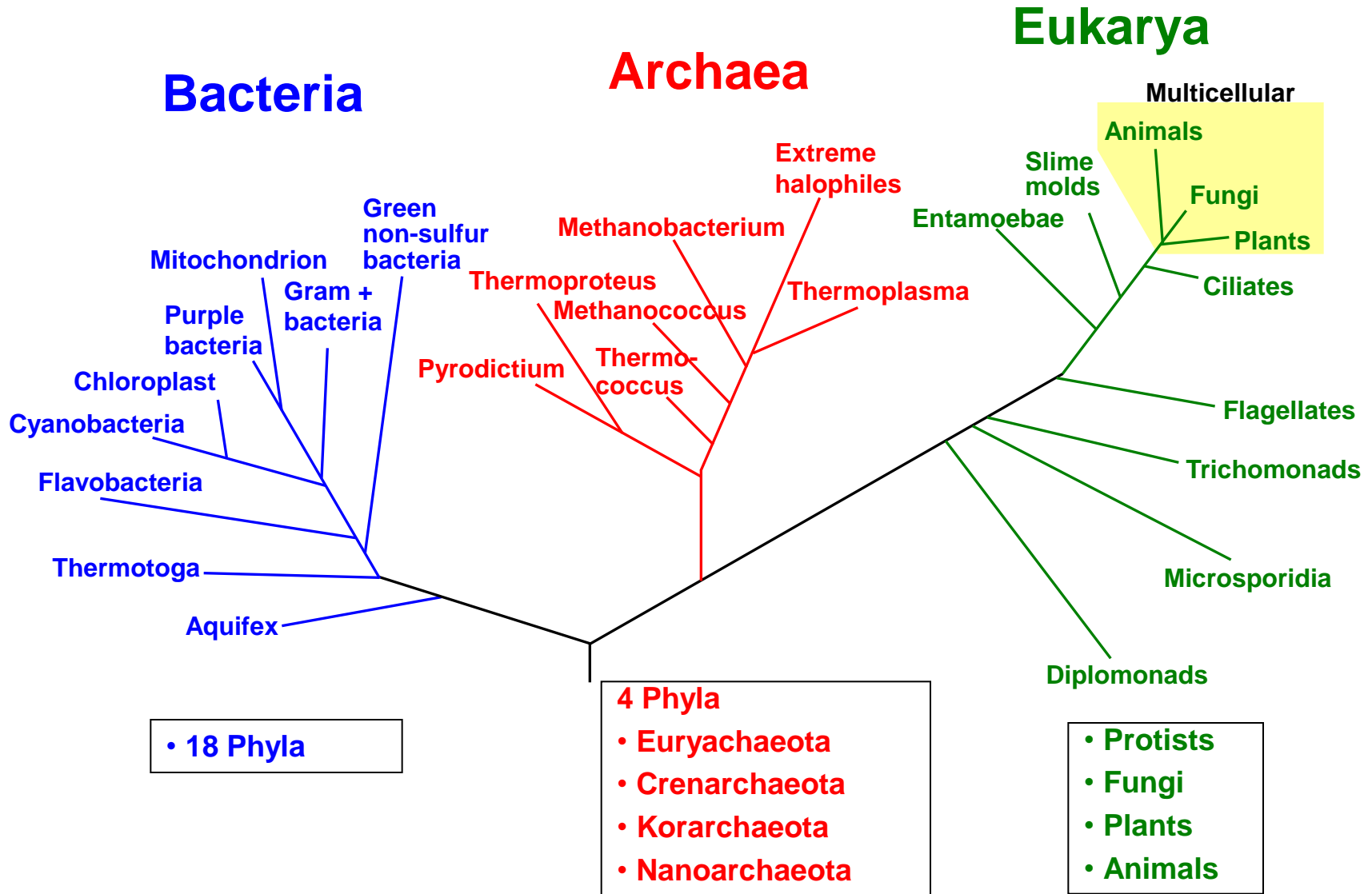
	Evolutionary distance (base pairs)
AACGTCGAAA (Organism A)	A → B 1
AACCTCGAAA (Organism B)	A → C 4
AGGCTAGAAA (Organism C)	A → D 5
	B → C 3
AGGCTAGTAA (Organism D)	B → D 4
	C → D 1



Phylogenetic Tree (Three Domains)

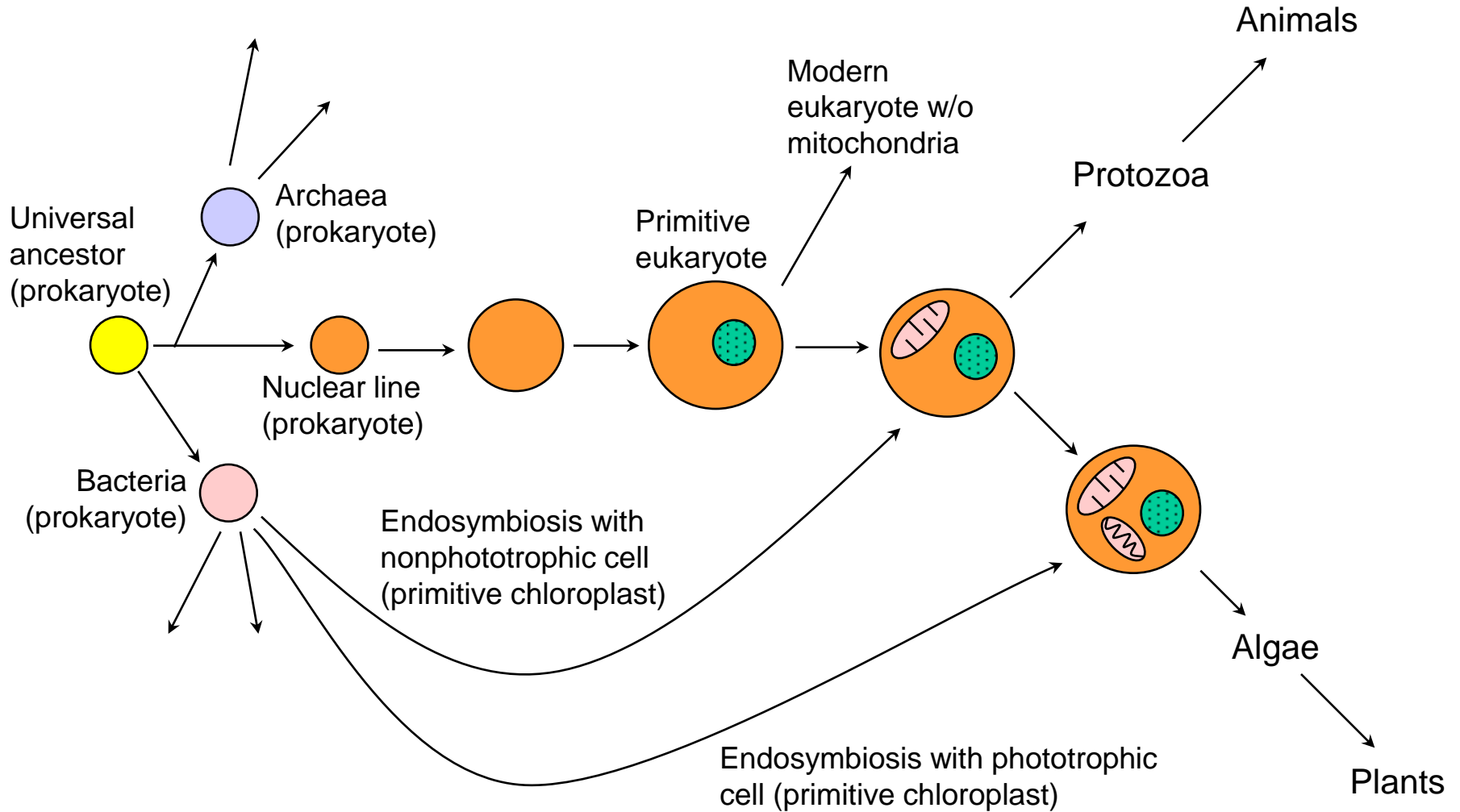
Based on 16s or 18s rRNA sequences

Carl R. Woese



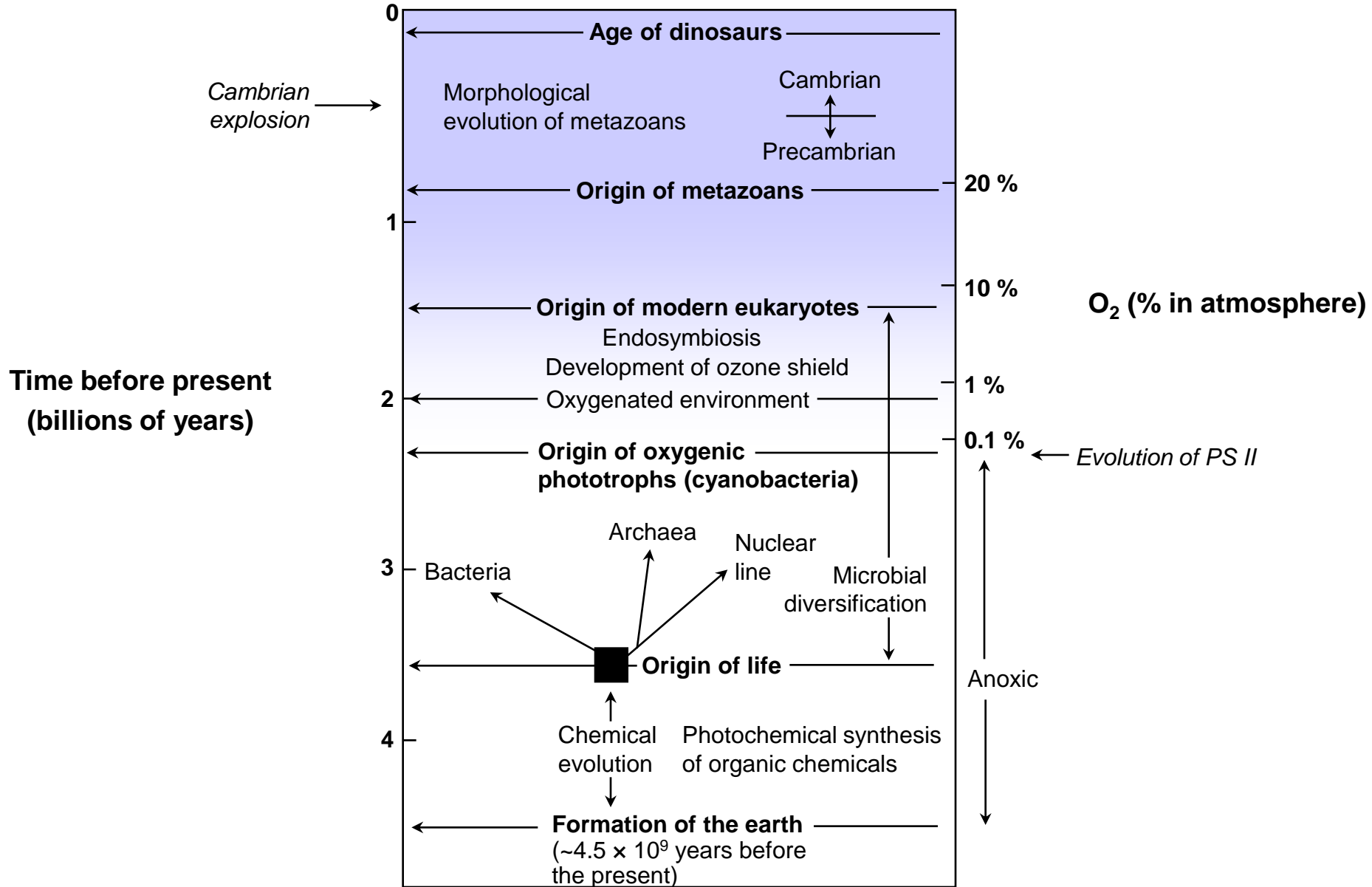
Endosymbiosis

Evolution of modern eukaryotic cells.



Lynn Margulis et al. are still developing this evolutionary process

Evolution of life and atmospheric O₂

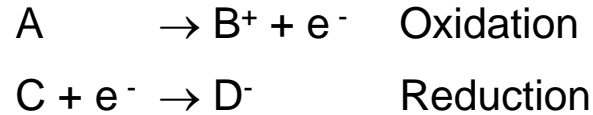


Redox Reactions and Energy Production

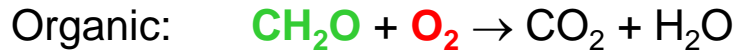
Gibbs Free Energy:



Reduction-oxidation (redox) reactions



Aerobic Respiration; Examples:



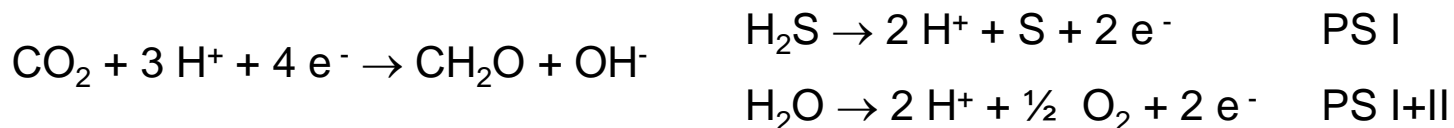
Anaerobic Respiration; Examples:



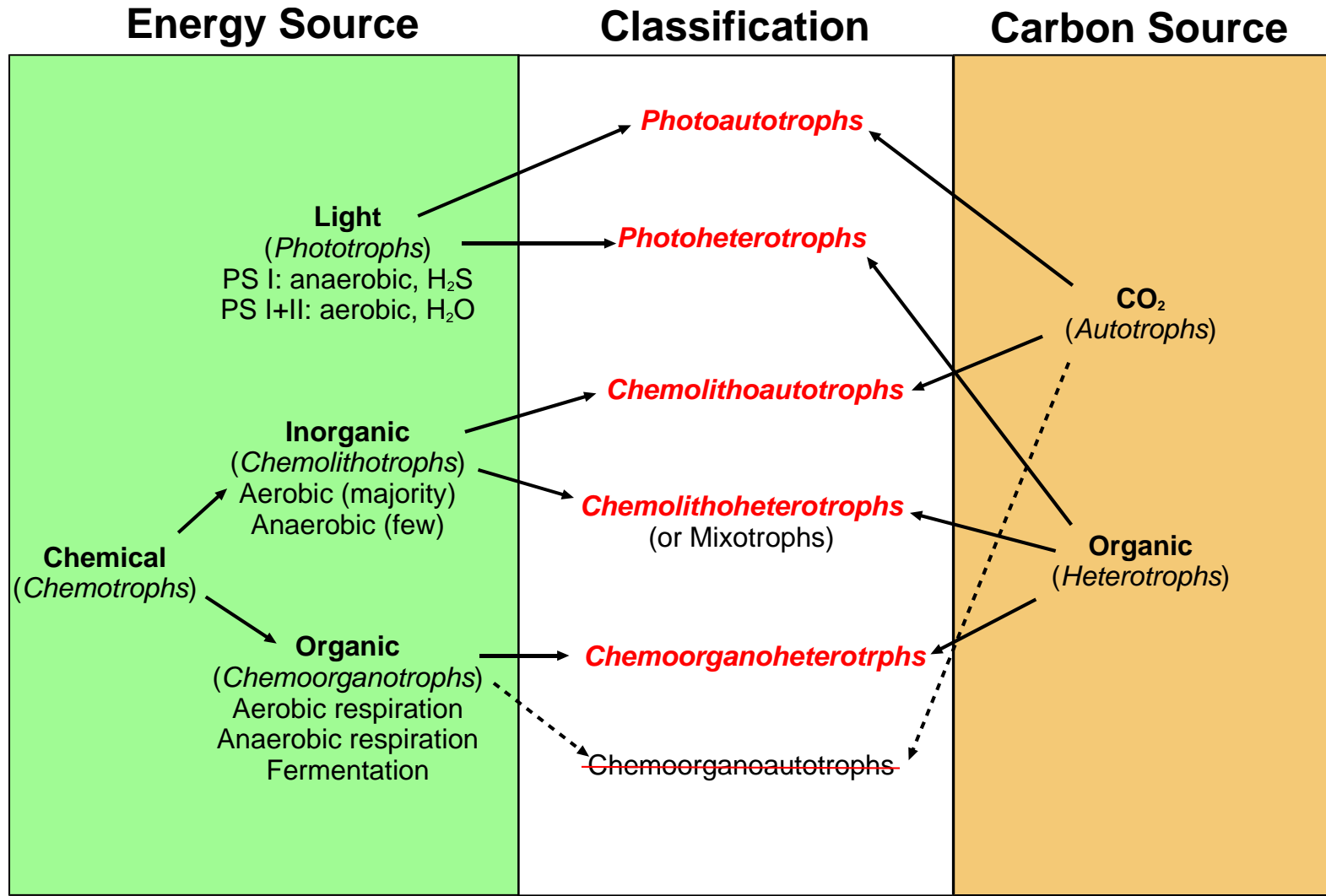
Fermentation; Example:



Autotrophy



Metabolic Classification of Life

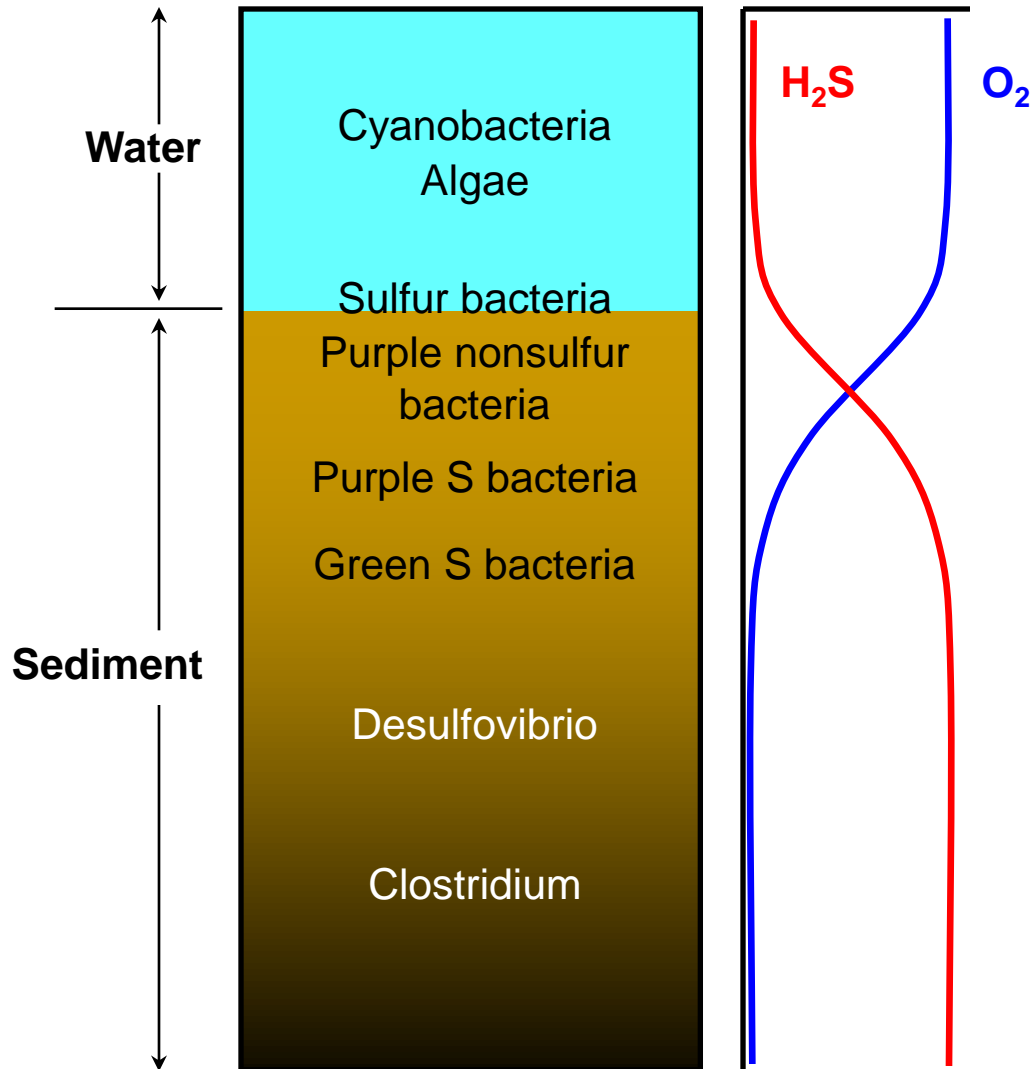


Course Overview

Lab and Lecture Topics:

- 1. Introduction** Background information and setup of Winogradsky columns.
- 2. Bacterial Abundance** Techniques to determine bacterial densities (plate and direct counts) (Huber).
- 3. Bacterial Production** Measurement of bacterial growth rates using ^{14}C .
- 4. Enzyme Assays** Technique to measure activity of extracellular enzymes.
- 5. Chemolithotrophy** Use Winogradsky columns to study microbial biogeochemical diversity.
- 6. Bacterial Grazers** Microbial loop concept and determination of the bacterial consumption rate by predators.
- 7. PCR Technique** Polymerase chain reaction (Huber).
- 8. Bacteria-Phyto. Comp.** Examine competition between bacteria and phytoplankton for inorganic nutrients.

Winogradsky Column



Sediment supplements:

- $CaCO_3$
- $CaSO_4$
- Carbon source

All five major metabolic groups will develop

- Sulfate reduction
- S oxidation
- Fermentation
- Photosynthesis PS II
- Photosynthesis PS I
- Methanogenesis
- Nitrification
- Denitrification?

**** Wear shoes that can get muddy for next Thursdays Lab ****