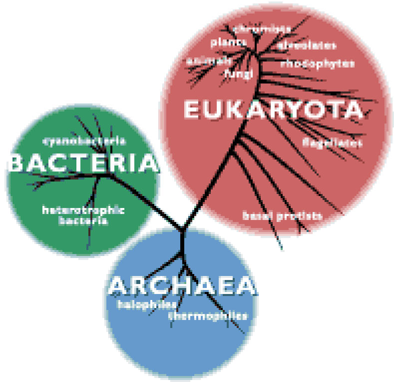
Introduction to the Archaea

Life's extremists. . .



The Domain Archaea wasn't recognized as a major domain of life until quite recently. Until the 20th century, most biologists considered all living things to be classifiable as either a plant or an animal. But in the 1950s and 1960s, most biologists came to the realization that this system failed to accomodate the fungi, protists, and bacteria. By the 1970s, a system of Five Kingdoms had come to be accepted as the model by which all living things could be classified. At a more fundamental level, a distinction was made between the prokaryotic bacteria and the four eukaryotic kingdoms (plants, animals, fungi, & protists). The distinction recognizes the common traits that eukaryotic organisms share, such as nuclei, cytoskeletons, and internal membranes.

The scientific community was understandably shocked in the late 1970s by the discovery of an entirely new group of organisms -- the Archaea. Dr. Carl Woese and his colleagues at the University of Illinois were studying relationships among the prokaryotes using DNA sequences, and found that there were two distinctly different groups. Those "bacteria" that lived at high temperatures or produced methane clustered together as a group well away from the usual bacteria and the eukaryotes. Because of this vast difference in genetic makeup, Woese proposed that life be divided into three domains: Eukaryota, Eubacteria, and Archaebacteria. He later decided that the term Archaebacteria was a misnomer, and shortened it to Archaea. The three domains are shown in the illustration above at right, which illustrates also that each group is very different from the others.

Further work has revealed additional surprises, which you can read about on the other pages of this exhibit. It is true that most archaeans don't look that different from bacteria under the microscope, and that the extreme conditions under which many species live has made them difficult to culture, so their unique place among living organisms long went unrecognized. However, biochemically and genetically, they are as different from bacteria as you are. Although many books and articles still refer to them as "Archaebacteria", that term has been abandoned because they aren't bacteria -- they're Archaea.

Archaeans include inhabitants of some of the most extreme environments on the planet. Some live near rift vents in the deep sea at temperatures well over 100 degrees Centigrade. Others live in hot springs (such as the ones pictured above), or in extremely alkaline or acid waters. They have been found thriving inside the digestive tracts of cows, termites, and marine life where they produce methane. They live in the anoxic muds of marshes and at the bottom of the ocean, and even thrive in petroleum deposits deep underground.

Some archaeans can survive the dessicating effects of extremely saline waters. One salt-loving group of archaea includes Halobacterium, a well-studied archaean. The light-sensitive pigment bacteriorhodopsin gives Halobacterium its color and provides it with chemical energy. Bacteriorhodopsin has a lovely purple color and it pumps protons to the outside of the membrane. When these protons flow back, they are used in the synthesis of ATP, which is the energy source of the cell. This protein is chemically very similar to the light-detecting pigment rhodopsin, found in the vertebrate retina.

Archaeans may be the only organisms that can live in extreme habitats such as thermal vents or hypersaline water. They may be extremely abundant in environments that are hostile to all other life forms. However, archaeans are not restricted to extreme environments; new research is showing that archaeans are also quite abundant in the plankton of the open sea. Much is still to be learned about these microbes, but it is clear that the Archaea is a remarkably diverse and successful clade of organisms.

Many features in common with Eukarya :
genes encoding protein: replication, transcription, translation
Features in common with Bacteria:
genes for metabolism
Other elements are unique to Archaea:
-unique tRNA gene structure
-capable of methanogenesis
Like bacteria archaea are highly diverse with respect to morphology, physiology, reproduction, and ecology. Best known for growth in anaerobic, hypersaline, pH extremes, and high-temperature habitats. Also found in marine arctic temperature and tropical waters

Archaeal Taxonomy:

Five major physiological and morphological groups:

Table 20.1 Characteristics of the Major Archaeal Physiological Groups

Group	General Characteristics	Representative Genera
Methanogenic archaea	Strict anaerobes. Methane is the major metabolic end product. S^0 may be reduced to H_2S without yielding energy. Cells possess coenzyme M, factors 420 and 430, and methanopterin.	*Methanobacterium* (E)[1] *Methanococcus* (E) *Methanomicrobium* (E) *Methanosarcina* (E)
Archaeal sulfate reducers	Irregular Gram-negative staining coccoid cells. H_2S formed from thiosulfate and sulfate. Autotrophic growth with thiosulfate and H_2. Can grow heterotrophically. Traces of methane also formed. Extremely thermophilic and strictly anaerobic. Possess factor 420 and methanopterin but not coenzyme M or factor 430.	*Archaeoglobus* (E)
Extremely halophilic archaea	Rods, cocci, or irregular shaped cells that may include pyramids or cubes. Primarily chemoorganoheterotrophs. Most species require sodium chloride ≥1.5 M, but some survive in as little as 0.5 M. Most produce characteristic bright-red colonies; some are unpigmented. Neutrophilic to alkalophilic. Generally mesophilic; however, at least one species is known to grow at 55°C. Possess either archaerhodopsin or halorhodopsin and can use light energy to produce ATP.	*Halobacterium* (E) *Halococcus* (E) *Natronobacterium* (E)
Cell wall-less archaea	Pleomorphic cells lacking a cell wall. Thermoacidophilic and chemoorganotrophic. Facultatively anaerobic. Plasma membrane contains a mannose-rich glycoprotein and a lipoglycan.	*Thermoplasma* (E)
Extremely thermophilic S^0-metabolizers	Gram-negative staining rods, filaments, or cocci. Obligately thermophilic (optimum growth temperature between 70–100°C). Usually strict anaerobes but may be aerobic or facultative. Acidophilic or neutrophilic. Autotrophic or heterotrophic. Most are sulfur metabolizers. S^0 reduced to H_2S anaerobically; H_2S or S^0 oxidized to H_2SO_4 aerobically.	*Desulfurococcus* (C) *Pyrodictium* (C) *Pyrococcus* (E) *Sulfolobus* (C) *Thermococcus* (E) *Thermoproteus* (C)

1 Indicates phylum; *E, Euryarchaeota, C, Crenarchaeota*

Two phyla currently accepted on Bergey's Manual:

1-*Euryarchaeota*

2-*Crenarchaeota*

Archaeal Metabolism:

Great variation among the different archaeal groups,some are chemolithotrophs, Organotrophy, autotrophy, and phototrophy have been observed, some have the ability to synthesize methane

Phylum *Crenarchaeota*: Some are acidophiles, Many are sulfur-dependent, Most are extremely thermophilic, hyperthermophiles (hydrothermal vents), Most are strict anaerobes, Include organotrophs and lithotrophs (sulfur-oxidizing and hydrogen-oxidizing), Contains 25 genera two best studied are *Sulfolobus* and *Thermoproteus*.

Genus *Thermoproteus:*

Long thin rod, bent or branched, Thermoacidophiles,grow at temperature from70–97 °C,some species are acidophiles with optimum pH value between 3-4,while other are neutrophils.

Anaerobic metabolism, lithotrophic on sulfur and hydrogen, organotrophic on sugars, amino acids, alcohols, and organic acids using elemental sulfur as electron acceptor, Autotrophic using CO or CO2 as carbon source.

They are found in hot springs and other aquatic habitat rich in sulfur.

Phylum Euryarchaeota:

Consists of many classes, orders, and families, often divided informally into five major groups:1 -methanogens2-halobacteria 4-thermoplasms 5-extremely thermophilic S0-metabolizers 5-sulfate-reducers

1-**Methanogens:**

All methanogenic microbes are Archaea, called methanogens: produce methane

Methanogenesis: last step in the degradation of organic compounds, occurs in anaerobic environments, e.g., animal rumens, anaerobic sludge digesters, within anaerobic protozoa, 26 genera, largest group of cultured archaea, differ in morphology, 16S rRNA sequence, cell walls chemistry and structure, membrane lipids and other features.

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Table 20.2 Selected Characteristics of Representative Genera of Methanogens

Genus	Morphology	% G + C	Wall Composition	Motility	Methanogenic Substrates Used
Order *Methanobacteriales*					
Methanobacterium	Long rods or filaments	32–61	Pseudomurein	–	$H_2 + CO_2$, formate
Methanothermus	Straight to slightly curved rods	33	Pseudomurein with an outer protein S-layer	+	$H_2 + CO_2$
Order *Methanococcales*					
Methanococcus	Irregular cocci	29–34	Protein	+	$H_2 + CO_2$, formate
Order *Methanomicrobiales*					
Methanomicrobium	Short curved rods	45–49	Protein	+	$H_2 + CO_2$, formate
Methanogenium	Irregular cocci	52–61	Protein or glycoprotein	–	$H_2 + CO_2$, formate
Methanospirillum	Curved rods or spirilla	47–52	Protein	+	$H_2 + CO_2$, formate
Order *Methanosarcinales*					
Methanosarcina	Irregular cocci, packets	36–43	Protein sometimes with polysaccharide	–	$H_2 + CO_2$, methanol, methylamines, acetate

Methanogenic archae : strict anaerobes that obtaine energy through the synthesis of methane . they have several coenzymes and cofactors that are involved in methanogenesis. ATP production linked with methanogenesis

Ecological and Practical Importance of Methanogens:

1-Important in wastewater treatment

2-Can produce significant amounts of methane that can be used as clean burning fuel and energy source

3- Methane is greenhouse gas absorbs radiation and is more potent than CO2,and may contribute to global warming

4-an oxidize iron ,contributes significantly to corrosion of iron pipes

5- Can form symbiotic relationships with certain bacteria, assisting carbon/sulfur cycling

2-Halobacteria:

Order *Halobacteriales*; 17 genera in one family, *Halobacteriaceae*

Extreme halophilic archaea (halobacteria), are aerobic, respiratory, chemoheterotrophs with complex nutritional requirements that require at least 1.5 M NaCl, cell wall disintegrates if [NaCl] < 1.5 M, growth optima near 3–4 M NaCl,found in habitats such as salterns and salt lakes.

Strategies to Cope with Osmotic Stress:

1- Increase cytoplasmic osmolarity by accumulating small organic molecules called **compatible solutes.**

2-use antiporters/symporters to increase concentration of KCl and NaCl to level of external environment

3-Acidic amino acids tend to be located on the surface of the folded proteins ,where they attract cataions,which form a hydrated shell around the protein, thereby maintaining its solubility.

e.g., *Halobacterium salinarium (H. halobium):* Has unique type of photosynthesis,

not chlorophyll based, uses modified cell membrane (contains bacteriorhodopsin) absorption of light by bacteriorhodopsin.

3-Thermoplasms: Archaea in the class *Thermoplasmata* are thermoacidophiles that Lack cell walls.

Genus *Thermoplasma:* Thermoacidophiles; grow in refuse piles of coal mines at 55–59°C, pH 1–2,these piles contains large amount of pyrite(FeS)which is oxidized to sulfuric acid by chemolithotrophic bacteria.As a result the piles become very hot and acidic.This an ideal habitat for this archaea.

Genus *Thermoplasma* Cell structure: shape depends on temperature, may be flagellated and motile,although they lack cell wall cell membrane strengthened by diglycerol tetraethers, lipopolysaccharides, and glycoproteins their DNA is stabilized by association with archaeal histones that condense the DNA into nucleosome-like structures .

4-Extremely Thermophilic S0-Reducers:

Class *Thermococci;* one order, *Thermococcales* One family containing three genera, *Thermococcus, Paleococcus, Pyrococcus* These archeae are:Motile by flagella, Optimum growth temperatures 88–100°C, Strictly anaerobic, Reduce sulfur to sulfide

5-Sulfate-Reducing *Euryarchaeota*: class Archaeoglobi; order Archaeoglobales; one family with one genus, Archaeoglobus

***Archaeoglobus* spp.:**contain irregular coccoid cells with cell walls consist of glycoprotein subunits, extremely thermophilic (optimum 83°C), isolated from marine hydrothermal vents,they are lithotrophic or organotrophic,can reduce sulfate, sulfite, or thiosulfite to sulfide,some species possess some methanogen coenzymes.