MICROBIAL DIVERSITY
Understanding the Archaea: best-known orders and genera, and notes about their characteristics

1. Phylum Euryarchaeota: This is the best-known phylum of Archaea. This phylum includes the halophiles, methanogens, and some hyperthermophiles, as well as some very poorly known hypothermophiles (grouped under the 'Marine ENV' lineage on the Archaea tree).

Archaeoglobales: the *only sulfate-reducer* among the Archaea, capable of reducing SO_4^{-2} to H_2S. These are *hyperthermophiles,* with optima around 83°C. Although they are *methanogens* (see below), they are not closely related to the other methanogenic groups and *lack a variety of genes needed for methanogenesis* - so how they make methane is not year clear.

Archaeoglobus

Halobacteriales: best-known genera are *extreme halophiles,* flourishing at >9% NaCl (most require 12-23%, and some can live at up to 32%, the saturation point). Those with *Natrono* in their names are *haloalkiphiles*, flourishing under highly salty and alkaline conditions (pH 9-11) in so-called soda lakes. The Halobacteriales *are non-motile, stain Gram-negatively, reproduce by binary fission, do not form resting stages (spores), are obligate aerobes, are chemoorganotrophs, and have very high GC content in their genomes (up to 71%).* They harbor large plasmids. *Halobacterium* is well known for its *remarkable DNA repair abilities*. Several members of the order are capable of *light-mediated synthesis of ATP* - which sounds like photosynthesis, but it's not (there's no chlorophyll involved). Under conditions of low aeration, they produce the protein bacteriorhodopsin, which they can insert into their membranes. This is coupled with a carotenoid-like molecule called retinal. Together, these molecules allow anaerobic photoautotrophy in *Halobacterium.*

Halobacterium
Halococcus
Haloferax
Halorhabdus
Natronococcus
Natronobacterium

Methanobacteriales (methanogens; see Methanosarcinales, below)

Methanothermobacter

Methanococcales (methanogens; see Methanosarcinales, below)

Methanococcus

Methanomicrobiales (methanogens; see Methanosarcinales, below)

Methanofollis

Methanosarcinales: one lineage of methanogenic Archaea (among several). Methanogens produce methane (CH4) through the process of methanogenesis and can use diverse substrates such as acetate, CO, and CO2. Interestingly, they do not use such 'normal' compounds as glucose unless paired with a bacterium. *The methanogens are morphologically diverse, including rods, cocci, spirilla, and plate-like forms. They are strictly anaerobic, chemoorganotrophic, and often (but not always) have low GC content in their genomes (usually on the order of 30-40%).*

Methanosarcina

Methanopyrales (methanogens; see Methanosarcinales, above. Note that *Methanopyrus* is distinct because it's *the only methanogen that is also a hyperthermophile* (optimum = 100°C). Because of that trait, and because it's an *early-diverging lineage* the book discusses it with the Thermococcales, even though it's phylogenetically distinct. It apparently uses a cytoplasmic component to thermostabilize its enzymes and DNA. It also has a very distinctive cell wall lipid.)

Methanopyrus

Thermococcales: the *most famous hyperthermophiles* among the Archaea. These are *early-diverging lineages of Archaea and are thought to reflect the ancient earth's extreme conditions*. *Thermococcus* is spherical, with a tuft of polar flagella; it's an obligate anaerobe, a chemoorganotroph, is found in anoxic waters, and flourishes above 70°C. *Pyrococcus* is similar but flourishes at 70-106°C (optimum = 100°C).

Pyrococcus
Thermococcus

Thermoplasmatales: the *extreme acidophiles*, characterized by *small genomes, chemoorganotrophic or chemolithotrophic lifestyles, and really variable cell sizes* (ranging from 0.2-5um in diameter). Members of the group are found in solfataras and coal piles (hot, acidic: *Thermoplasma* and *Picrophilus*) and in mine tailings (not hot, but acidic; *Ferroplasma*). *Picrophilus* can live at a pH at or even below 0. The other two genera, *Ferroplasma* and *Thermoplasma*, are remarkable in that they *lack cell walls* (they have a plasmoid growth form) - which is wild given their habitats. *Thermoplasma* has a distinctive cell membrane made up of a lipopolysaccharide-like material with a tetra-ether lipid and both mannose and glucose units. This is very stable under very hot, acidic conditions.

Ferroplasma
Picrophilus
Thermoplasma

2. Phylum Crenarchaeota: several of these are hyp**o**thermophiles (psychrophiles), but not much is known about their taxonomy. Most of those are found in the 'Marine ENV' branch on the Archaea tree. The hyp**er**thermophiles have been studied more thoroughly, so they are the focus of our discussion. Among cultured Archaea, the *Crenarchaeota include the most hyperthermophilic species*. Most are chemolithotrophs, and in many extremely hot environments, they are the most *important primary producers*. The hyperthermophilic Crenarchaeota cluster together on short branches on the tree, suggesting slow evolution (see discussion of Korarchaeota below for more thoughts on that).

Desulfurococcales: Unlike the other hyperthermophilic Crenarchaeota, the Desulfurococcales are known from *submarine volcanic habitats*, including both shallow-water and deep-sea thermal vents. *Pyrolobus* is the *most hyperthermophilic* of all known organisms; its optimum temperature is 113°C. This is a highly diverse order with a variety of different ecological roles.

Desulfurococcus
Hyperthermus
Pyrodictium
Pyrolobus
Ignicoccus

Sulfolobales: These *hyperthermophiles are found in terrestrial volcanic habitats*, including hot springs. *Sulfolobus* is an *aerobic chemolithotroph that can grow chemoorganotrophically, has a coccus form, occurs at temperatures >90°C, and flourishes at pH values of 1-5.* Their cells adhere to sulfur crystals in nature. The genus was discovered in 1970 by the author of your textbook.

Sulfolobus

Thermoproteales: These *hyperthermophiles* are grouped by the book with Sulfolobales, *but they differ phylogenetically (different order), because they do not flourish under severely acidic conditions, because they are rod-shaped to filamentous, and because they are strict anaerobes. Like the Sulfolobales, the Thermoproteales are found in terrestrial volcanic habitats and hot springs.*

Thermoproteus

3. Phylum "Korarchaeota"

These hyperthermophiles are known only from a single hot spring in Yellowstone, and little is known about their ecology. They are often discussed in the context of the 'slow evolutionary clock' idea. Briefly, the idea (as discussed in the book and in class) is that hyperthermophilic Archaea appear to evolve more slowly than other lineages of life. This could be depicted on a phylogenetic tree with (1) branches of the same length as the other lineages of life, but fewer changes (hatch marks on the branches for the hyperthermophilic Archaea); or (2) shorter branches for the hyperthermophilic Archaea relative to the other lineages of life. Interestingly, hyperthermophilic Bacteria seem to show the same slow rate of evolution. One hypothesis is that this reflects the extreme environment in which these organisms live: organisms at very high temperatures must be under very strong selective pressure to maintain those genes that permit life there.

4. Phylum "Nanoarchaeota"

These hyperthermophiles are one of the few examples known of Archaea that are symbiotic with other Archaea (they associate with *Ignicoccus*). They were discovered by Karl Stetter in 2002, their genome is known (and is small), they are obligate symbionts, and they have the smallest cell-size known (diameter = 400 nm).

Nanoarchaeum