Archaea

By-

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Archaea

- Comparison of the sequences of rRNA from a great variety of organisms shows that organisms may be divided into three major groups:
- bacteria
- archaea
- eucaryotes

Characteristics

- As a group the ***Archaea [Greek archaios, ancient] are quite diverse,*** both in morphology and physiology.
- They can stain either gram positive or gram negative and may be spherical, rod-shaped, spiral, lobed, plate-shaped, irregularly shaped, or pleomorphic.
- Some are single cells, whereas others form filaments or aggregates.
- They range in diameter from 0.1 to over 15 μm, and some filaments can grow up to 200 μm in length.
- Multiplication may be by binary fission, budding, fragmentation, or other mechanisms.
- Archaea are just as diverse physiologically.
- They can be aerobic, facultatively anaerobic, or strictly anaerobic.
- Nutritionally they range from chemolithoautotrophs to organotrophs.
- Some are mesophiles; others are hyperthermophiles that can grow above 100°C.

… **Characteristics**

- Archaea often are found in extreme aquatic and terrestrial habitats.
- They are often present in anaerobic, hypersaline, or hightemperature environments.
- Recently archaea have been discovered in cold environments.
- It appears that they constitute up to 34% of the procaryotic biomass in coastal Antarctic surface waters .
- Few are symbionts in animal digestive systems.

...Characteristics

- The archaeal chromosomes that have been studied are single closed DNA circles.
- However, the genomes of some archaeons are significantly smaller than the normal bacterium.
- *E. coli DNA has a size of* about 2.5×10^9 daltons, whereas *Thermoplasma acidophilum DNA* is about 0.8×10^9 daltons.
- The variation in G+C content is great, from about 21 to 68 mol%, and is another sign of archaeal diversity.
- Archaea have few plasmids.
- Recently the genome of the archaeon *Methanococcus jannaschii* was completely sequenced and compared with the genomes of other organisms.
- About 56% of its 1,738 genes are unlike those in bacteria and eucaryotes.
- If this degree of difference is characteristic of the domain Archaea, these organisms are as distinctive genotypically as they are in other respects.

- Archaeal mRNA appears similar to that of bacteria rather than to eucaryotic mRNA.
- Polygenic mRNA has been discovered, and there is no evidence for mRNA splicing.
- Archaeal promoters are similar to those in bacteria.
- Although archaeal ribosomes are 70S, similar to bacterial ribosomes, electron microscopic studies show that their shape is quite variable and sometimes differs from that of both bacterial and eucaryotic ribosomes.
- Some archaea, such as many methanogens in the phylum Euryarchaeota, differ from other procaryotes in having histone proteins that bind with DNA to form nucleosome-like structures.
- Finally, archaeal DNA-dependent RNA polymerases resemble the eucaryotic enzymes, not the bacterial RNA polymerase.
- They are large, complex enzymes and are insensitive to the drugs rifampin and streptolydigin.
- These and other differences distinguish the archaea from both bacteria and eucaryotes.

Phylogeny

- The phylogeny of Archaea currently used is based on 16S rRNA sequence comparison.
- From this rRNA-based phylogeny, the archaeal domain has been divided into two phyla, the Euryarchaeota and the Crenarchaeota.
- The euryarchaeotes are given this name because they occupy many different ecological niches and have a variety of metabolic patterns.
- The phylum *Euryarchaeota is very diverse with seven classes :*
  - *Methanobacteria,*
  - *Methanococci,*
  - *Halobacteria,*
  - *Thermoplasmata,*
  - *Thermococci,*
  - *Archaeglobi*
  - *Methanopyri)*
- Nine orders, and 15 families.
- The methanogens, extreme halophiles, sulfate reducers, and many extreme thermophiles with sulfur-dependent metabolism are located in the *Euryarchaeota. Methanogens are the* dominant physiological group.

...Phylogeny

- The crenarchaeotes **are thought to resemble** the ancestor of the archaea, and almost all the well-characterized species are thermophiles or hyperthermophiles.
- The phylum Crenarchaeota is divided into one class, Thermoprotei, and three orders.
- However, a number of discoveries have challenged this simple bipartite view in recent years.
- Over the past 15 years, a few new archaeal phyla have been proposed:
  - *Korarchaeota* ,
  - *Thaumarchaeota*,
  - *Nanoarchaeota,*
  - *Aigarchaeota*,
  - *Parvarchaeota* and
  - *Bathyarchaeota*
- All but the last three phyla have been listed in LPSN (*List of Prokaryotic Names with Standing in Nomenclature*).

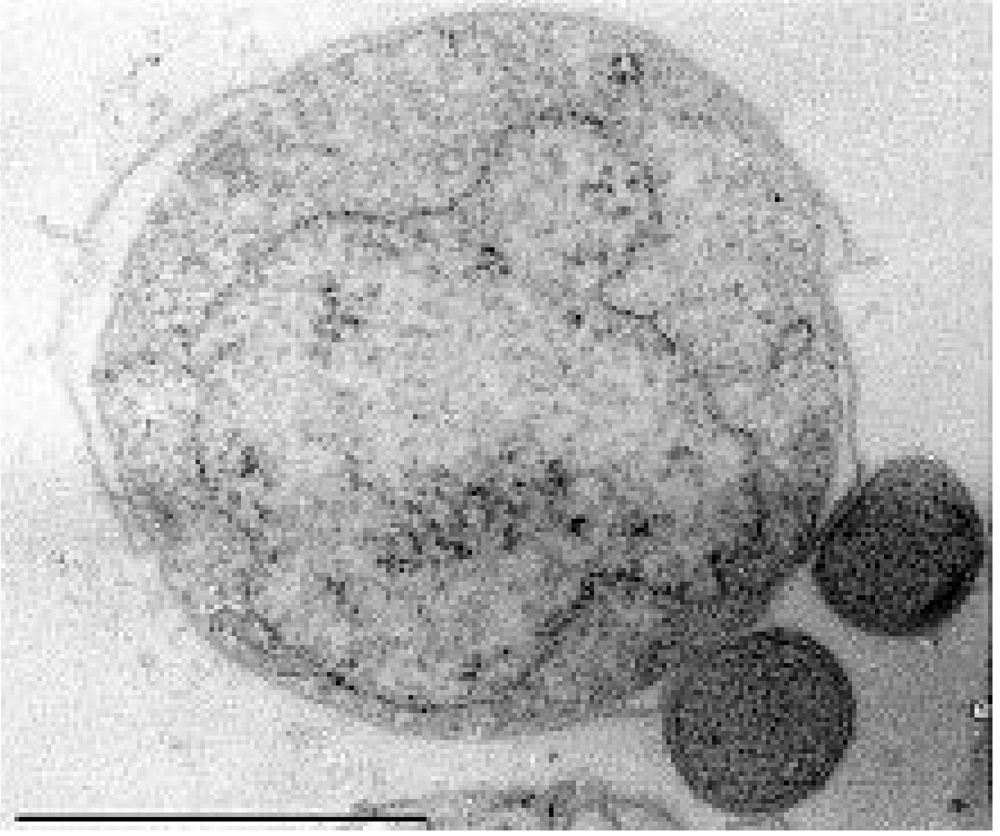
Nanoarchaeota

- The Nanoarchaeota are a group of symbiotic Archaea that engage in close interspecies associations with diverse archaeal hosts.
- Nanoarchaeote sequences have been recovered from high-temperature geothermal springs and marine hydrothermal vents around the world.
- However, few Nanoarchaeota have been successfully isolated with their hosts in the laboratory.
- Cultivated nanoarchaeotes are ectosymbionts with small cell diameters (~100–400 nm) and reduced genomes (0.491–0.606 Mbp).
- Described Nanoarchaeota lack most genes involved in major biosynthetic pathways and likely obtain many cellular products directly from their hosts.
- Without a complete ATP synthase complex, nanoarchaeotes may also rely on their hosts to provide ATP.
- Described nanoarchaeote genomes show varying levels of reduction, consistent with a host-reliant lifestyle.
- However, some nanoarchaeotes retain genes involved in the gluconeogenesis pathway, archaeal flagella and CRISPR-Cas systems.

Nanoarchaeum equitans

- ***Nanoarchaeum equitans*** is a species of marine archaea that was discovered in 2002 in a hydrothermal vent off the coast of Iceland by Karl Stetter.
- It has been proposed as the first species in a new phylum Nanoarcheota.
- Strains of this microbe were also found on the Sub-polar Mid Oceanic Ridge, and in the Yellowstone National Park.
- Since it grows in temperatures approaching boiling, at about 80 degrees Celsius, it is considered to be a thermophile.
- It grows best in environments with a pH of 6, and a salinity concentration of 2%. *Nanoarchaeum* appears to be an obligate symbiont on the archaeon *Ignicoccus.*
- It must be in contact with the host organism to survive.
- *Nanoarchaeum equitans* cannot synthesize lipids but obtains them from its host.
- Its cells are only 400 nm in diameter, making it the smallest known living organism, and the smallest known archaeon.

Nanoarchaeum equitans



Nanoarchaeum equitans

- *N. equitans*' genome consists of a single circular chromosome, and has an average GC-content of 31.6%.
- It lacks almost all of the genes required for the synthesis of amino acids, nucleotides, cofactors, and lipids, but encodes everything needed for repair and replication.
- *N. equitans* contains several genes that encode proteins employed in recombination, suggesting that *N. equitans* can undergo homologous recombination.
- *N. equitans* has small appendages that come out of its circular structure.
- The cell surface is covered by a thin, lattice-shaped S-layer, which provides structure and protection for the entire cell.
- *Mycoplasma genitalium* (580 Kbp in size, with 515 protein-coding genes) was regarded as a cellular unit with the smallest genome size until 2003 when *Nanoarchaeum* was sequenced (491 Kbp, with 536 protein-coding genes).

Phylum Crenarchaeota

- Most of the crenarchaeotes that have been isolated are extremely thermophilic, and many are acidophiles and sulfur dependent.
- The sulfur may be used either as an electron acceptor in anaerobic respiration or as an electron source by lithotrophs.
- Almost all are strict anaerobes.
- They grow in geothermally heated water or soils that contain elemental sulfur.
- These environments are scattered all over the world.
- Examples are the sulfur-rich hot springs in Yellowstone National Park, Wyoming, and the waters surrounding areas of submarine volcanic activity (**figure 20.8).**
- Such habitats are sometimes called solfatara.

(a)

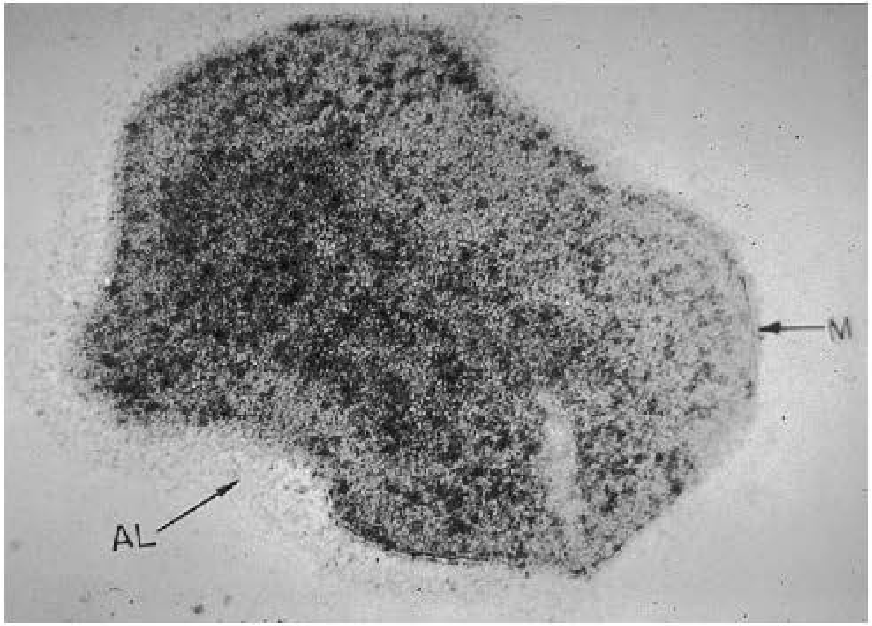
Figure 20.8 Habitats for Thermophilic Bacteria. (**a**) The pump geyser in Yellowstone National Park. The orange color is due to the carotenoid pigments of thermophilic bacteria. (**b**) The sulfur cauldron in Yellowstone National Park. The water is at its boiling point and very rich in sulfur. *Sulfolobus* grows well in such habitats.

...Phylum Crenarchaeota

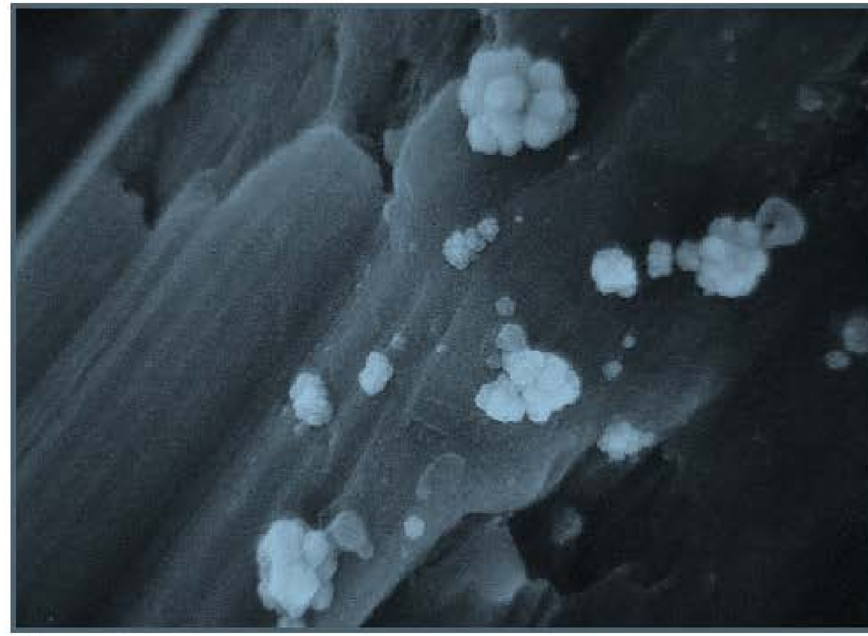
- These archaea can be very thermophilic and often are classified as hyperthermophiles.
- The most extreme example is *Pyrodictium,* an archaeon isolated from geothermally heated sea floors.
- *Pyrodictium* has a temperature minimum of 82°C, a growth optimum at 105°C, and a maximum at 110°C.
- Both organotrophic and lithotrophic growth occur in this group.
- Sulfur and H_2 are the most common electron sources for lithotrophs.
- At present, the phylum contains 69 genera; two of the better-studied genera are *Thermoproteus and Sulfolobus.*

Sulfolobus

- Members of the genus *Sulfolobus* are gram-negative, aerobic, irregularly lobed spherical archaeons with a temperature optimum around 70 to 80°C and a pH optimum of 2 to 3 (**figure 20.9*a,b*).**
- **For this reason, they are classed as thermoacidophiles,** so called because they grow best at acid pH values and high temperatures.
- Their cell wall contains lipoprotein and carbohydrate but lacks peptidoglycan.
- They grow lithotrophically on sulfur granules in hot acid springs and soils while oxidizing the sulfur to sulfuric acid.
- Oxygen is the normal electron acceptor, but ferric iron may be used.
- Sugars and amino acids such as glutamate also serve as carbon and energy sources.



(a)



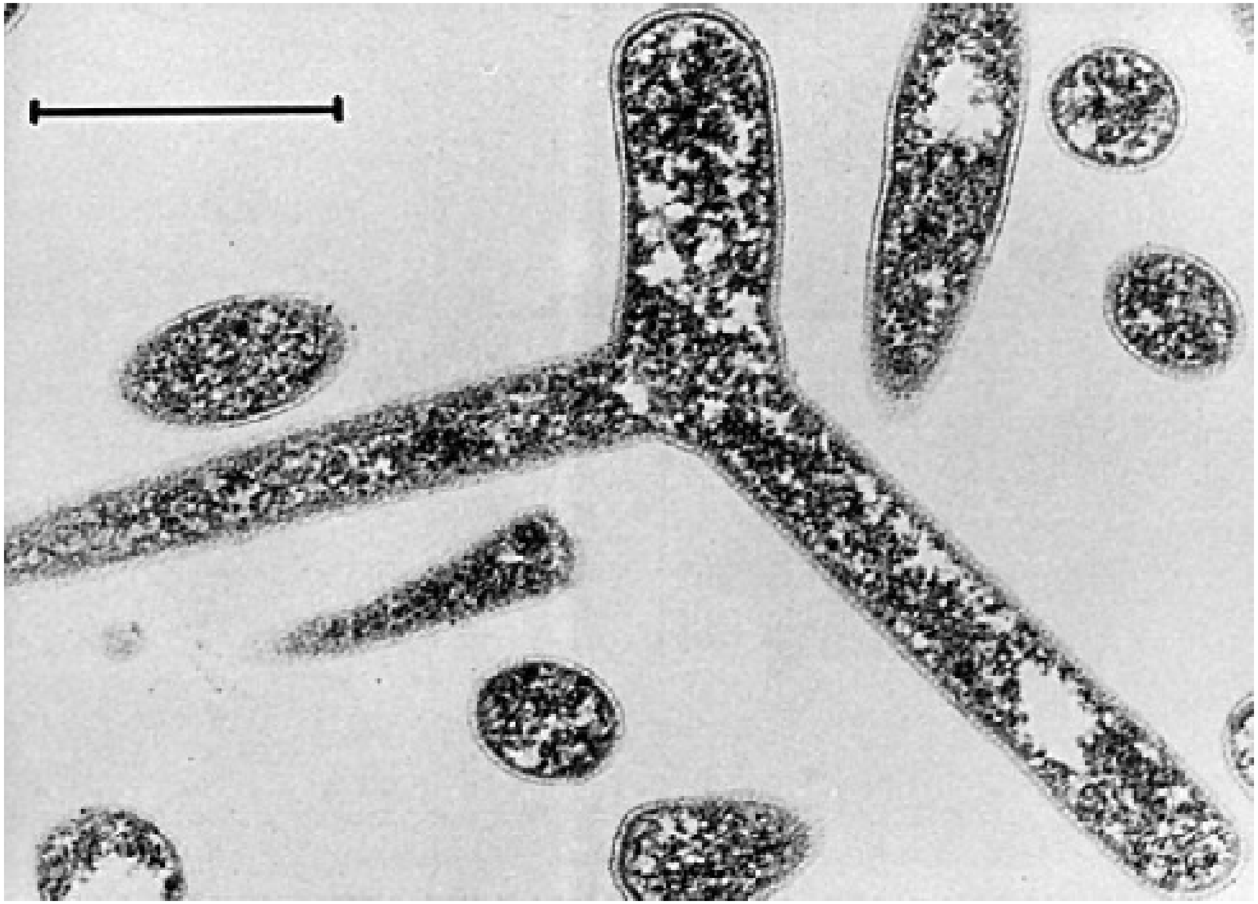
(b)

(a) A thin section of *Sulfolobus brierleyi.* The bacterium, about 1 m in diameter, is surrounded by an amorphous layer (AL) instead of a well-defined cell wall; the plasma membrane (M) is clearly visible.

(**b) A** scanning electron micrograph of a colony of *Sulfolobus* growing on the mineral molybdenite (MoS2) at 60°C. At pH 1.5–3, the bacterium oxidizes the sulfide component of the mineral to sulfate and solubilizes molybdenum.

Thermoproteus

- *Thermoproteus* is a long thin rod that can be bent or branched.
- Its cell wall is composed of glycoprotein.
- *Thermoproteus* is a strict anaerobe and grows at temperatures from 70 to 97°C and pH values between 2.5 and 6.5.
- It is found in hot springs and other hot aquatic habitats rich in sulfur.
- It can grow organotrophically and oxidize glucose, amino acids, alcohols, and organic acids with elemental sulfur as the electron acceptor.
- That is, *Thermoproteus* can carry out anaerobic respiration. *It will* also grow chemolithotrophically using H_2 and S_0.
- Carbon monoxide or CO_2 can serve as the sole carbon source.



Electron micrograph of *Thermoproteus tenax*.

Phylum Euryarchaeota: Methanogens

- Methanogens are strict anaerobes that obtain energy by converting CO_2, H_2, formate, methanol, acetate, and other compounds to either methane or methane and CO_2.
- They are autotrophic when growing on H_2 and CO_2.
- This is the largest group of archaea.
- There are five orders:
  - *Methanobacteriales,*
  - *Methanococcales,*
  - *Methanomicrobiales,*
  - *Methanosarcinales, and*
  - *Methanopyrales)*
- And 26 genera, which differ greatly in overall shape, 16S rRNA sequence, cell wall chemistry and structure, membrane lipids, and other features.

Methangens

- For example, methanogens construct three different types of cell walls.
  - Pseudomurein,
  - Proteins or
  - heteropolysaccharides
- Methanogens thrive in anaerobic environments rich in organic matter: the rumen and intestinal system of animals, freshwater and marine sediments, swamps and marshes, hot springs, anaerobic sludge digesters, and even within anaerobic protozoa.
- Methanogens often are of ecological significance.
- The rate of methane production can be so great that bubbles of methane will sometimes rise to the surface of a lake or pond.
- Rumen methanogens are so active that a cow can belch 200 to 400 liters of methane a day.
- Methanogenic archaea are potentially of great practical importance since methane is a clean-burning fuel and an excellent energy source.

Methangens

- Methanogenesis also can be an ecological problem.
- Methane absorbs infrared radiation and thus is a greenhouse gas.
- There is evidence that atmospheric methane concentrations have been rising over the last 200 years.
- Methane production may significantly promote future global warming.
- Recently it has been discovered that methanogens can oxidize iron and use it to produce methane and energy.
- This means that methanogens growing around buried or submerged iron pipes and other objects may contribute significantly to iron corrosion.

Methanobacterium

- In taxonomy, ***Methanobacterium*** is a genus of the Methanobacteriaceae family of Archaea.
- Methanobacterium are nonmotile and live without oxygen.
- Some members of this genus can use formate to reduce methane;
- others live exclusively through the reduction of carbon dioxide with hydrogen.
- They are ubiquitous in some hot, low-oxygen environments, such as anaerobic digestors, their wastewater, and hot springs.

Methanocaldococcus

- ***Methanocaldococcus*** formerly known as ***Methanococcus*** is genus of coccoid methanogen archaea.
- They are all mesophiles, except the thermophilic *M. thermolithotrophicus* and the hyperthermophilic *M. jannaschii*.
- The latter was discovered at the base of a "white smoker" chimney at 21°N on the East Pacific Rise and it was the first archaean genome to be completely sequenced, revealing many novel and eukaryote-like elements.
- The name *Methanocaldococcus* has Latin and Greek roots, *methano* for methane, *caldo* for hot, and the Greek *kokkos* for the spherical shape of the cells. Overall, the name means *spherical cell that produces methane at hot temperatures*.
- All species in *Methanocaldococcus* are obligate methanogens. They use hydrogen to reduce carbon dioxide.
- Unlike many other species within Euryarchaeota, they cannot use formate, acetate, methanol or methylamines as substrates.

Halobacteria

- The **extreme halophiles or halobacteria, class *Halobacteria, are*** another major group of archaea, currently with 15 genera in one family, the *Halobacteriaceae.*
- ***They are aerobic*** chemoheterotrophs with respiratory metabolism and require complex nutrients, usually proteins and amino acids, for growth.
- Species are either nonmotile or motile by lophotrichous flagella.
- These procaryotes require at least 1.5 M NaCl (about 8%, wt/vol), and usually have a growth optimum at about 3 to 4 M NaCl (17 to 23%).
- They will grow at salt concentrations approaching saturation (about 36%).
- *Halobacterium's cell wall is so dependent on the* presence of NaCl that it disintegrates when the NaCl concentration drops to about 1.5 M.
- Thus halobacteria only grow in high-salinity habitats such as marine salterns *and salt lakes* such as the Dead Sea between Israel and Jordan, and the Great Salt Lake in Utah.
- They also can grow in food products such as salted fish and cause spoilage.
- Halobacteria often have red-to-yellow pigmentation from carotenoids that are probably used as protection against strong sunlight.
- *They can reach such* high population levels that salt lakes, salterns, and salted fish actually turn red.

Halobacterium

- Probably the best-studied member of the family is *Halobacterium salinarium (H. halobium).*
- *This procaryote is unusual because it can* trap light energy photosynthetically without the presence of chlorophyll.
- When exposed to low oxygen concentrations, some strains of *Halobacterium synthesize a modified cell membrane called the* **purple membrane, which contains the protein bacteriorhodopsin.**
- ATP is produced by a unique type of photosynthesis without the participation of bacteriochlorophyll or chlorophyll.

Halococcus

- *Halococcus* is a genus of extreme halophilic archaea, meaning that they require high salt levels, sometimes as high as 32% NaCl, for optimal growth.
- Rhodopsinprotein and other proteins serve to protect *Halococcus* from the extreme salinities of their environments.
- Because they can function under such high-salt conditions, *Halococcus* and similar halophilic organisms have been used in the food industry and even in skin-care products.
- *Halococcus* is found in environments with high salt levels, mainly inland bodies of salt water, but some may be located in highly salted soil or foods.
- The pigmented proteins in some species cause the reddish tint found in some areas of the Dead Sea and the Great Salt Lake, especially at the end of the growing season.
- When under cultivation, the organisms grew best under high salinity conditions.
- *Halococcus* species are able to survive in high-saline habitats because of chlorine pumps that maintain osmotic balance with the salinity of their habitat, and thus prevent dehydration of the cytoplasm.

Thermoplasms

- Procaryotes in the class Thermoplasmata are thermoacidophiles that lack cell walls.
- At present, only two genera, *Thermoplasma* and *Picrophilus,* are known.
- They are sufficiently different from one another to be placed in separate families, Thermoplasmataceae and Picrophilaceae.
- Thermoplasma grows in refuse piles of coal mines.
- These piles contain large amounts of iron pyrite (FeS), which is oxidized to sulfuric acid by chemolithotrophic bacteria.
- As a result the piles become very hot and acidic.
- This is an ideal habitat for *Thermoplasma* since it grows best at 55 to 59°C and pH 1 to 2.
- Although it lacks a cell wall, its plasma membrane is strengthened by large quantities of diglycerol tetraethers, lipopolysaccharides, and glycoproteins.

Thermoplasma

- The organism's DNA is stabilized by association with a special histone like protein that condenses the DNA into particles resembling eucaryotic nucleosomes.
- At 59°C, Thermoplasma takes the form of an irregular filament, whereas at lower temperatures it is spherical.
- **The cells may be flagellated and motile.**

Thermococcus

- **Extremely Thermophilic S0-Metabolizers**
- Belongs to order, *Thermococcales.*
- *The Thermococcales are strictly anaerobic* and can reduce sulfur to sulfide.
- They are motile by flagella and have optimum growth temperatures around 88 to 100°C.
- The order contains one family and two genera, *Thermococcus and Pyrococcus.*