Archaea

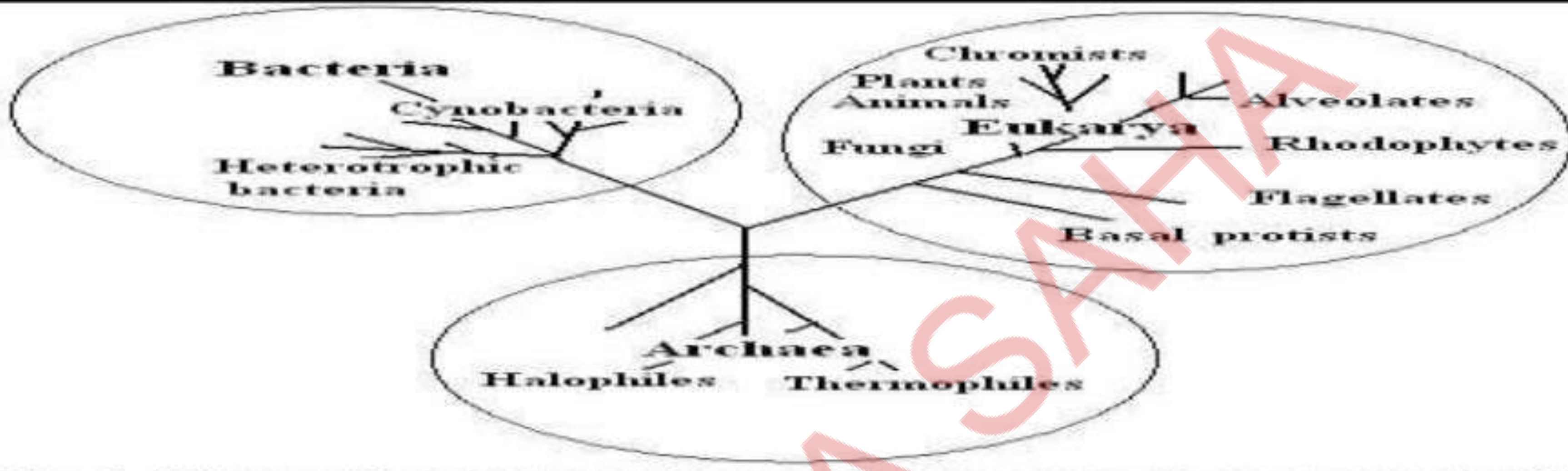
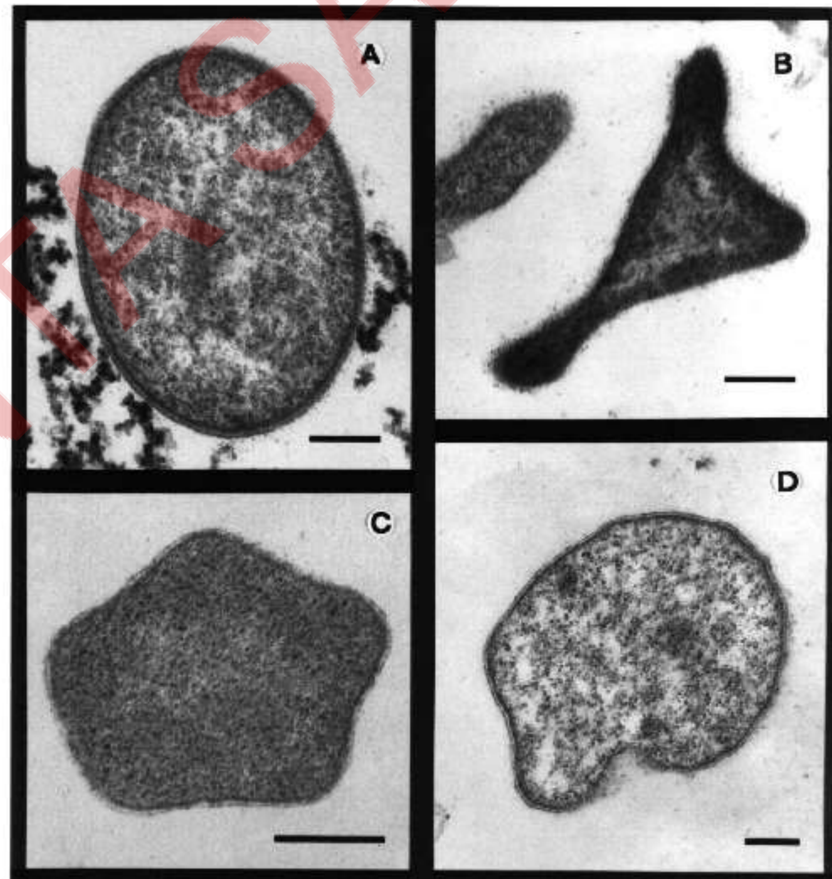


Fig 1. Three Domain system of living organism proposed by Carl Woese

Domain	Bacteria	Archaea	Eukarya			
Kingdom	Eubacteria	Archaebacteria	Protista	Fungi	Plantae	Animalia
Cell Type: Prokaryotic or Eukaryotic?	Prokaryotic	Prokaryotic	Eukaryotic	Eukaryotic	Eukaryotic	Eukaryotic
Cell Structures: Cell Wall or Chloroplast?	Cell Walls with peptidoglycan	Cell Walls without peptidoglycan	Cell walls of cellulose in some; some have chloroplasts	Cell Walls of chitin	Cell Walls of cellulose; chloroplasts	No cell walls or chloroplasts
Number of Cells: Unicellular or Multicellular?	Unicellular	Unicellular	Most Unicellular; some colonial; some multicellular	Most multicellular; some unicellular	Most multicellular; some green algae unicellular	Multicellular
Mode of Nutrition: Heterotroph or Autotroph?	Heterotroph or Autotroph	Heterotroph or Autotroph	Heterotroph or Autotroph	Heterotroph	Autotroph	Heterotroph
Examples: Type of organism?	*Streptococcus, Escherichia coli*	Methanogens, halophiles	*Amoeba, Paramecium,* Slime Molds, Giant Kelp	Mushrooms, Yeast	Mosses, Ferns, Flowering Plants	Sponges, Worms, Insects, Fishes, Mammals

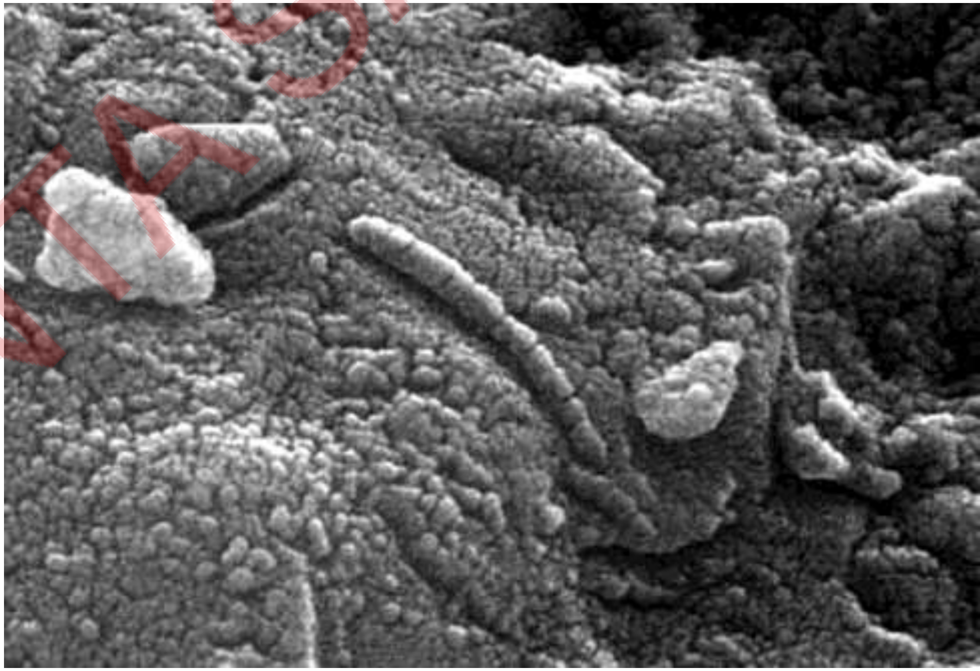
Introduction

- They were only thought to live in 'extreme' environments, but now have been found in more milder environments and may contribute up to 20% of the Earth's total biomass!



Evolution

- Archaea are thought to have been one of the earliest forms of life to evolve on our planet.
- Fossilized remains of Archaea have been dated to 3.5 billion years ago!



Characteristics of Archaebacteria

- Can only live in areas **without oxygen**
- **Extremophillic** (thrive under extreme conditions)
- Prokaryotic (very similar to **bacteria**)
  - Single-celled
  - No nucleus
  - No membrane bound organelles
  - Navigate using one or more flagella

Characteristic	Archaea	Bacteria	Eukarya
Membrane lipids with branched hydrocarbons	✔		
Chromosomes are circular	✔	✔	
Lacks nuclear envelopes	✔	✔	
Lacks membrane bound organelles	✔	✔	
Methionine is the initiator amino acid for protein synthesis	✔		✔
Lack peptidoglycan in the cell wall	✔		✔
Growth not inhibited by streptomycin and chloramphenicol	✔		✔
Histones are associated with DNA	✔		✔
Contains several types of RNA polymerase	✔		✔

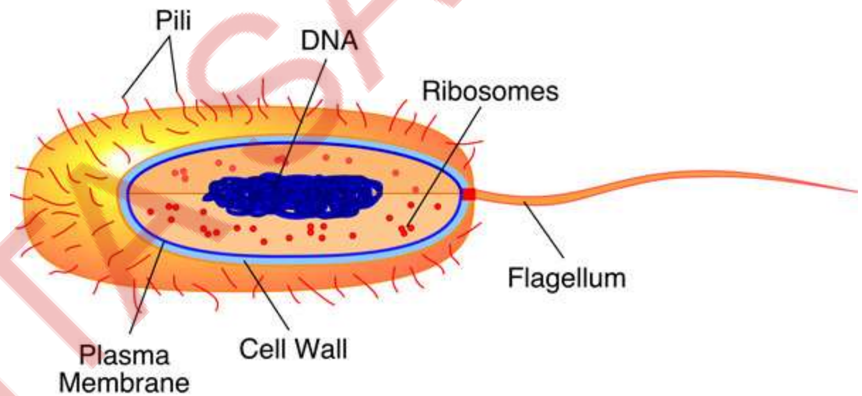
Typical for archaea and bacteria	Typical for archaea and eukaryotes	Typical only for archaea
The absence of the nucleus and membrane organelles	The absence of peptidoglycan (murein)	The structure of the cell wall (cell walls of some archaea contain psevdomurein)
Ring chromosome	DNA is associated with histone protein	The cell membrane lipids contain ether linkage bond
Genes are combined into operons	Translation of protein begins with the methionine residue	The structure of flagellin
No introns and RNA processing	Similar RNA polymerase and other components of the transcription	The structure of the ribosome (some signs closer to the bacteria, while some others - with eukaryotes)
Polycistronic mRNA	Similar mechanisms of replication and repair of DNA	The structure and metabolism of tRNA
Cell size (more than 100 times less than in eukaryotes)	A similar ATPase (type V)	No fatty acid synthase

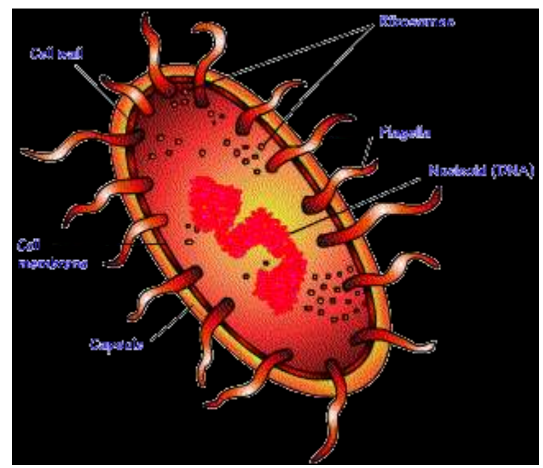
Table 4.1 Comparison of Bacterial and Archaeal Cells

Property	Bacteria	Archaea
Plasma membrane lipids	Ester-linked phospholipids and hopanoids form a lipid bilayer; some have sterols	Glycerol diethers form lipid bilayers; glycerol tetraethers form lipid monolayers
Cell wall constituents	Peptidoglycan is present in nearly all; some lack cell walls	Very diverse but peptidoglycan is always absent: some consist of S-layer only, others combine S-layer with polysaccharides or proteins or both; some lack cell walls
Inclusions present	Yes, including gas vacuoles	Yes, including gas vacuoles
Ribosome size	70S	70S
Chromosome structure	Most are circular, double-stranded (ds) DNA; usually a single chromosome	All known are circular, dsDNA
Plasmids present	Yes; circular and linear dsDNA	Yes; circular dsDNA
External structures	Flagella, fimbriae (pili) common	Flagella, pili, and piluslike structures common
Capsules or slime layers	Common	Rare

Morphology

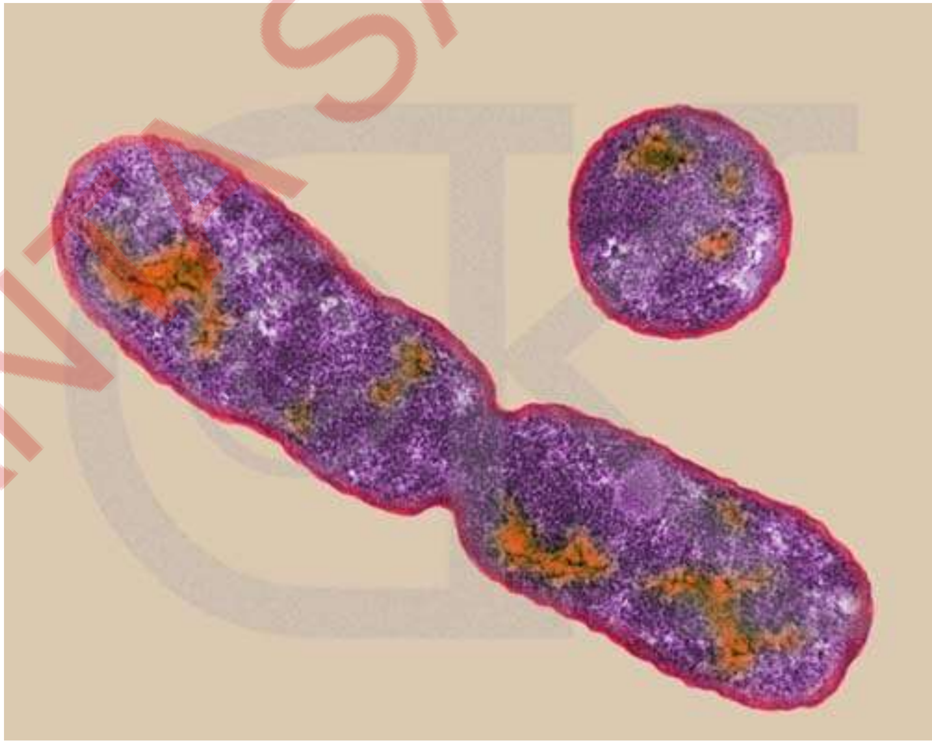
- microscopic, ranging in size from 0.1 to 15 μm.
- Come in many shapes such as spheres (cocci), rods (bacilli), spirals (spirilli) and plates.
- The majority have pili and flagella





Reproduction

- Asexual reproducers,
- They use binary fission, budding or fragmentation to propagate.



Archaeal cell walls

- lack peptidoglycan
- cell wall varies from species to species but usually consists of complex heteropolysaccharides
- Methanogens have walls containing pseudomurein

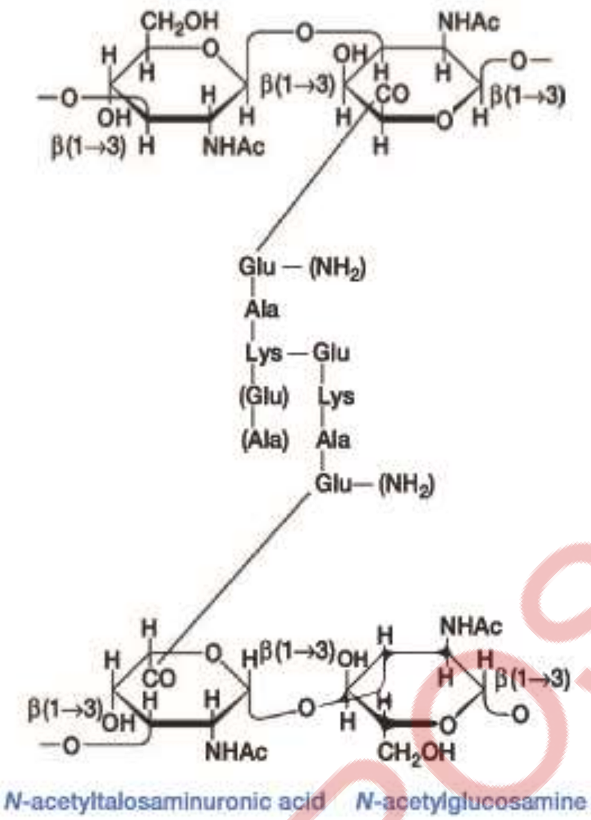


Figure 4.7 Pseudomurein. The amino acids and amino groups in parentheses are not always present. Ac represents the acetyl group.

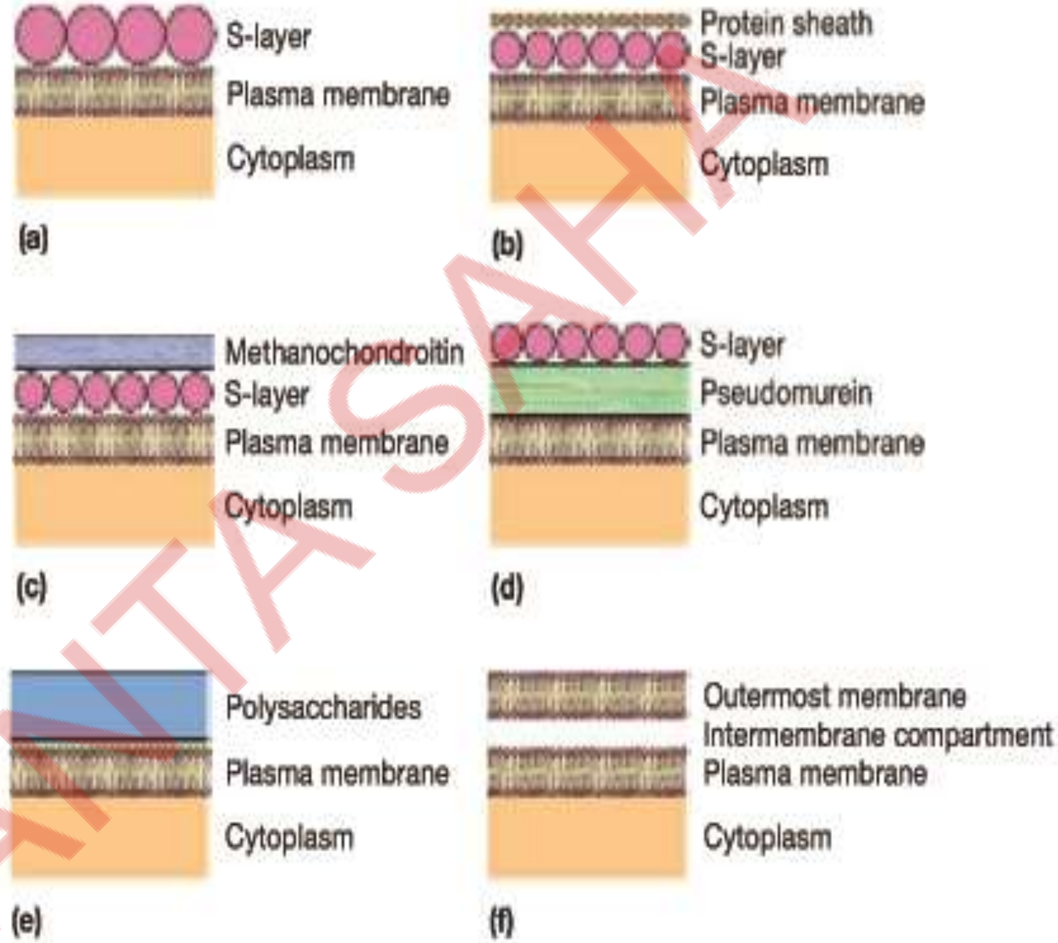
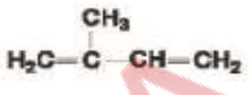


Figure 4.6 Archaeal Cell Envelopes. (a) *Methanococcus, Halobacterium, Pyrodictium, Sulfolobus*, and *Thermoproteus* cell envelopes. (b) *Methanospirillum* cell envelope. (c) *Methanosarcina* cell envelope. (d) *Methanothermus* and *Methanopyrus* cell envelopes. (e) *Methanobacterium, Methanosphaera, Methanobrevibacter, Halococcus*, and *Natronococcus* cell envelopes. For *Methanosphaera*, the polysaccharide layer is composed of pseudomurein. (f) *Ignicoccus* cell envelope. The outermost membrane contains protein complexes that form pores.

Cell wall less Archaea – *Ignicoccus hospitalis*

CELL MEMBRANE



Isoprene

Figure 4.3 Isoprene. This five-carbon, branched molecule is the building block of archaeal lipids.

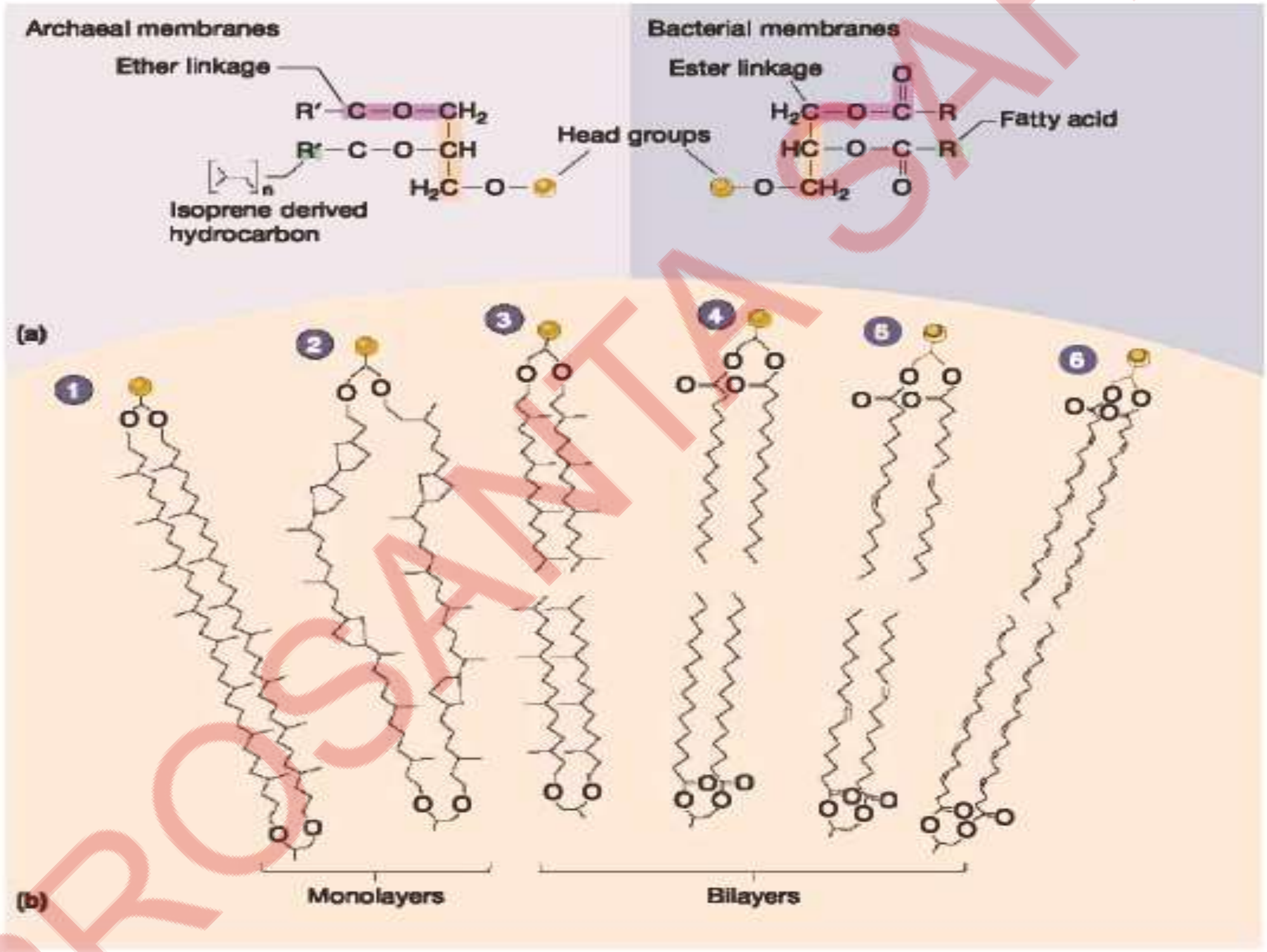
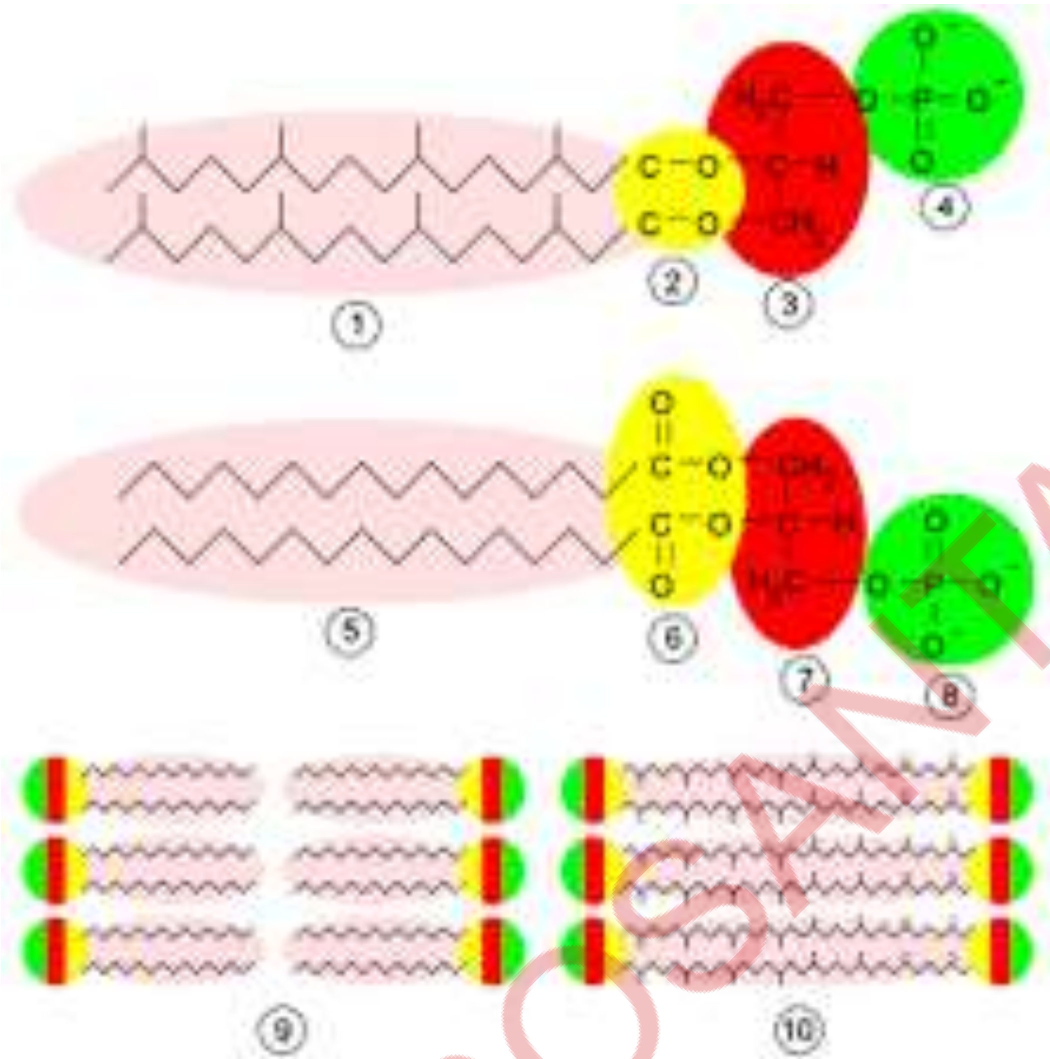
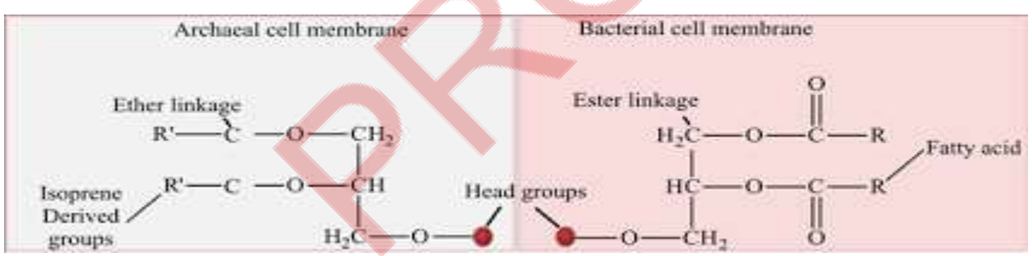
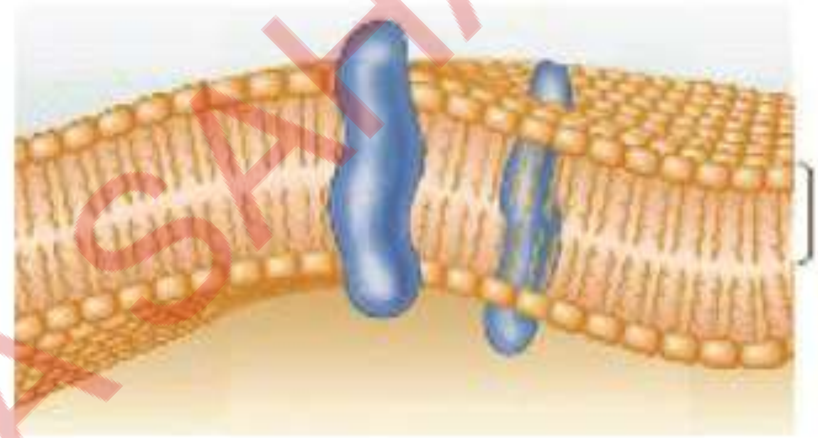


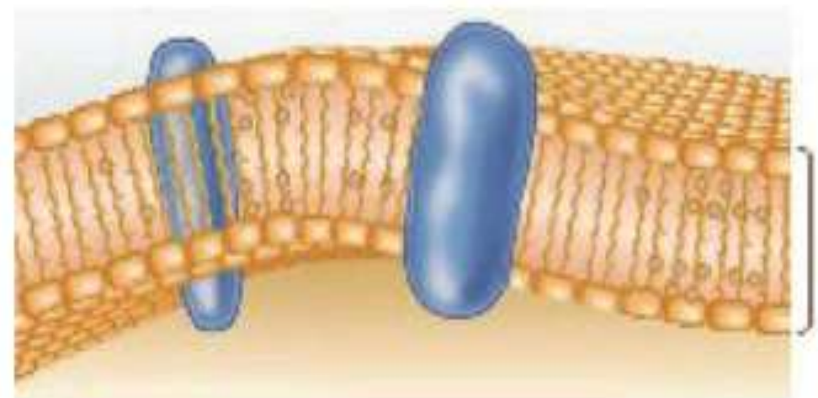
Figure 4.4 Comparison of Archaeal and Bacterial Membranes. (a) Archaeal membrane lipids are attached to glycerol by ether linkages instead of ester linkages, as found in bacteria and eukaryotes. The stereochemistry also differs. In archaeal lipids, the stereoisomer of glycerol is *sn*-glycerol-1-phosphate; in bacterial lipids, the stereoisomer is *sn*-glycerol-3-phosphate. Thus in archaeal lipids, the side chains are attached to carbons 2 and 3 of glycerol, and in bacterial lipids, the side chains are attached to carbons 1 and 2. (b) Examples of archaeal lipids are lipids 1, 2, and 3. Lipids 4, 5, and 6 are bacterial lipids. Note that some archaeal lipids can form monolayers (figure 4.5), whereas all bacterial lipids form bilayers.







(a) Bilayer of C_{20} diethers



(b) Monolayer of C_{40} tetraethers

igure 4.5 Examples of Archaeal Plasma Membranes.

Archaeal cytoplasm

- Similar to that of bacteria.
- Polyhydroxyalkonates, polyphosphate granules, glycogen granules, and gas vacuoles present; ribosomes; a nucleoid; and, in some cases, plasmids present.
- Cytoskeletal proteins – FtsZ (tubulin homologue), MreB (actin homologue), and crenactin.
- Ribosomes – like bacteria, composed of 50S and 30S subunits. Both have ribosomal RNA (rRNA) molecules of similar size: 16S in the small subunit, and 23S and 5S in the large subunit. Some archaeon has an additional rRNA, a 5.8S rRNA, in the large subunit. The large subunit of eukaryotic ribosomes contains both 5S and 5.8S rRNA molecules.
- Nucleoid - The chromosomes of all known archaea are circular, doublestranded deoxyribonucleic acid (DNA). Euryarchaeota are polyploid, but Crenarchaeota are monoploid. Supercoiling and the presence of nucleoid-associated proteins (NAPs) generally organize chromosomes. NAPs are positively charged. Many Euryarchaeota have histone proteins associated with their chromosomes, that form nucleosomes, similar to that of eukaryotes.

Archaella and Pili

- **Pili -** Archaeal pili are **composed of pilin proteins, homologues to bacterial type IV pili proteins. But the pili has central lumen.** Central lumens are not observed in bacterial type IV pili. They **perform several function like attachment and cell aggregation**.
- **Cannulae and Hami -** **Cannulae are hollow, tube like structures on the surface of thermophilic archaea like *Pyrodictium*. Hami are tiny hooks, which might function to attach cells to surfaces.** Archaeal cells that produce hami are members of biofilm communities.
- **Archaella** **are thinner than bacterial flagella. The filaments are not hollow. Archaellin proteins are arranged like the type IV pili**. Crenarcheal filaments composed of single type archaellin but Euryarcheal filaments many have many type archaellins, of which one type is abundant. **Rotation of archaella propels the cell, similar to bacteria**.

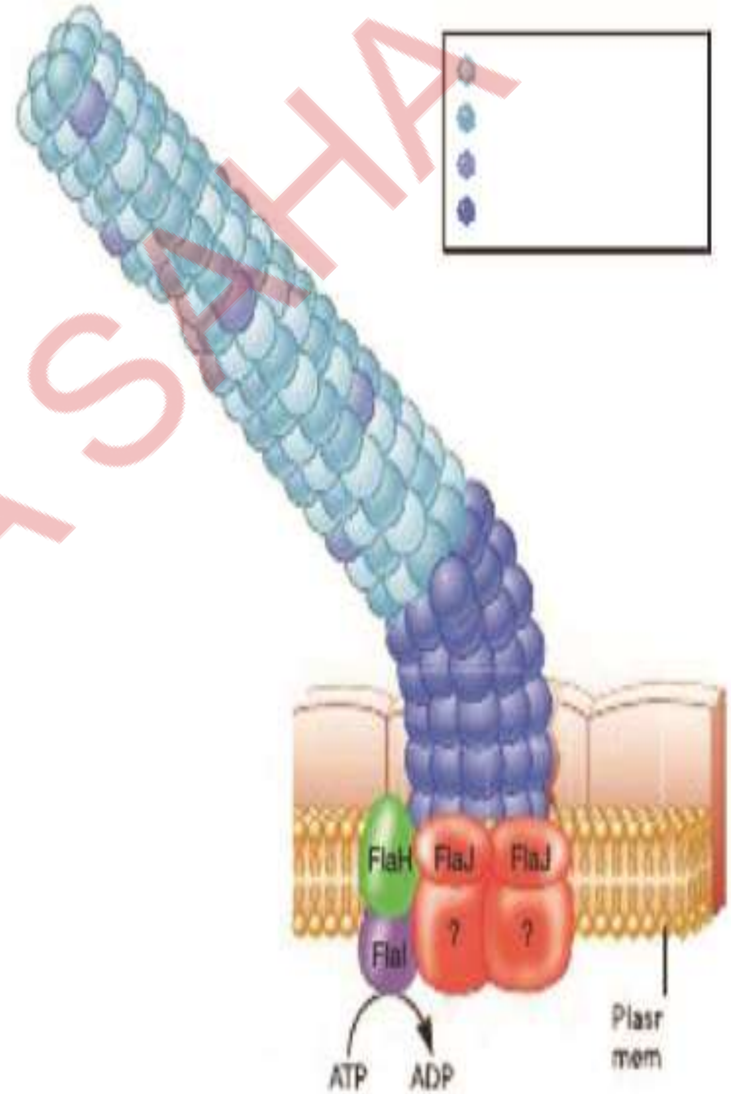


Figure 4.12 Archaeal Flagellum. The different shades of blue in the filament illustrate that the filament is composed of more than one type of flagellin. Clear images of the basal body have not been obtained, although some electron micrographs show a knob at the cell end of the flagellum, as illustrated here.

Archaeal Metabolism

- **Reductive acetyl CoA pathway - all**
- **HP/HB - Few Crenarcheota and Thaumarcheota**
- **DC/HB - Anaerobic Crenarcheota**

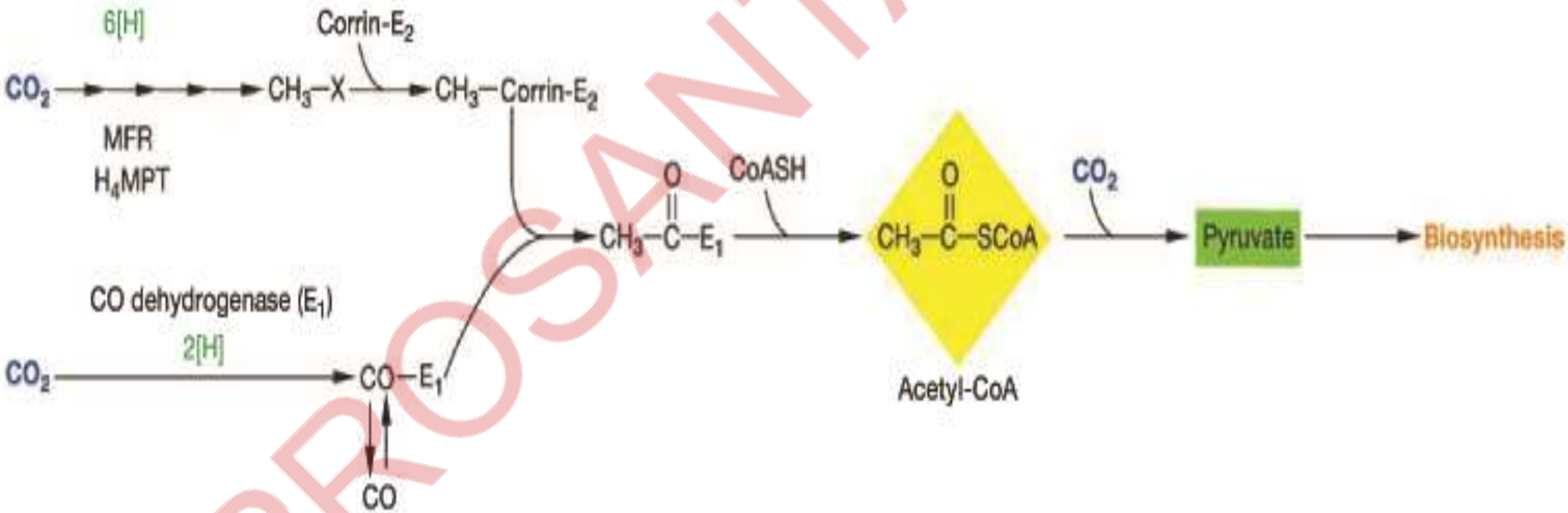


Figure 20.3 The Reductive Acetyl-CoA Pathway. Methanogens reduce two molecules of CO_2, each by a different mechanism, and combine them to form acetyl and then acetyl-CoA.

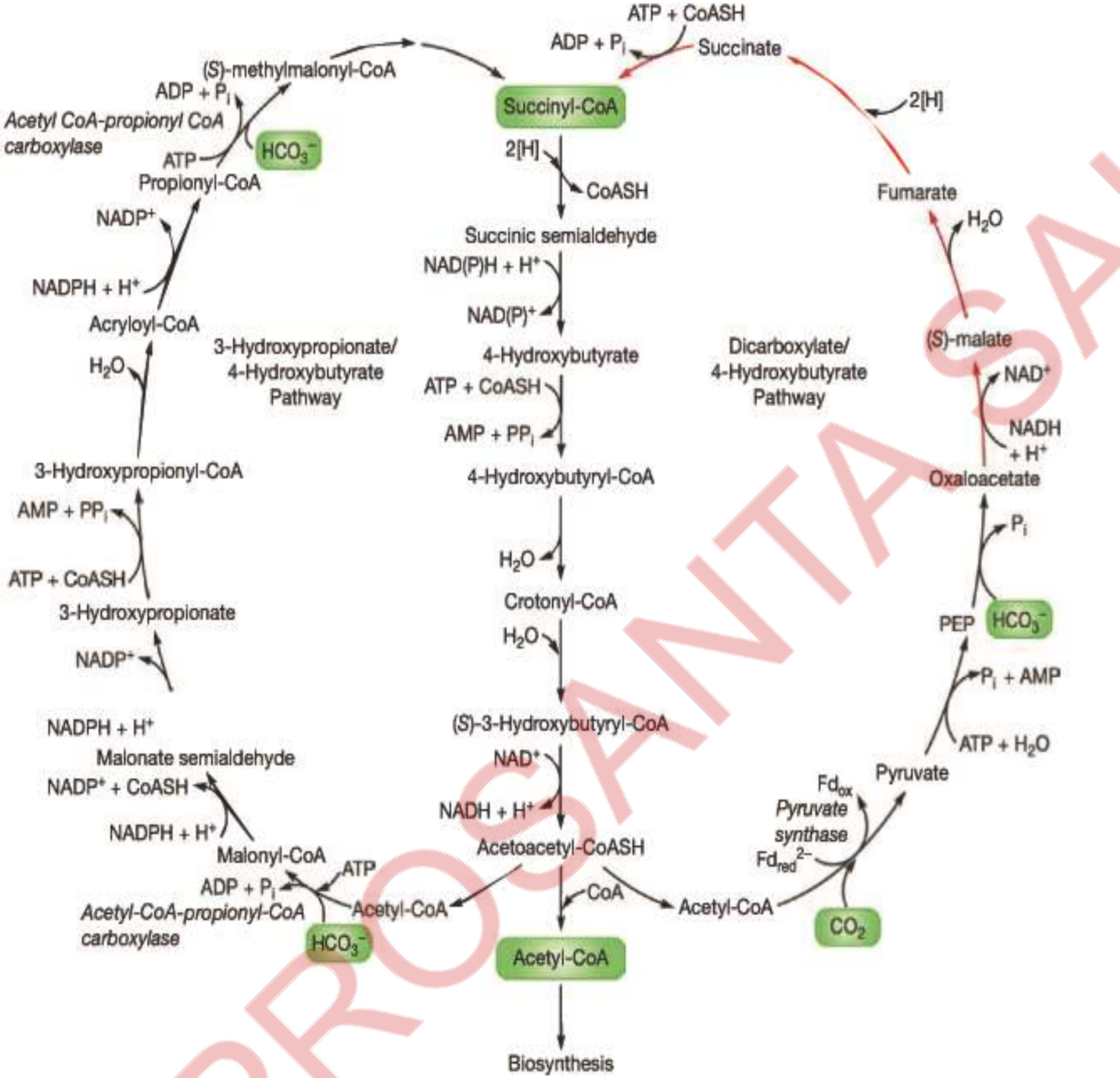


Figure 20.4 The 3-Hydroxypropionate/4-Hydroxybutyrate (HP/HB) and Dicarboxylate/4-Hydroxybutyrate (DC/HB) Cycles. Aerobic crenarchaea such as *Sulfolobus* and some thaumarchaea use the HP/HB pathway (left) to convert two bicarbonate ions into acetyl-CoA. Some crenarchaea fix one molecule of CO_2 and one HCO_3^- using the anaerobic DC/HB pathway (right). The reactions shown with red arrows are also used in the reductive tricarboxylic acid cycle.

3-hydroxypropionate/ 4-hydroxybutyrate (HP/HB) cycle

- Requires more energy input (9 ATP/ pyruvate synthesized)
- Can be operated under aerobic conditions
- Has less of a demand for metal cofactors

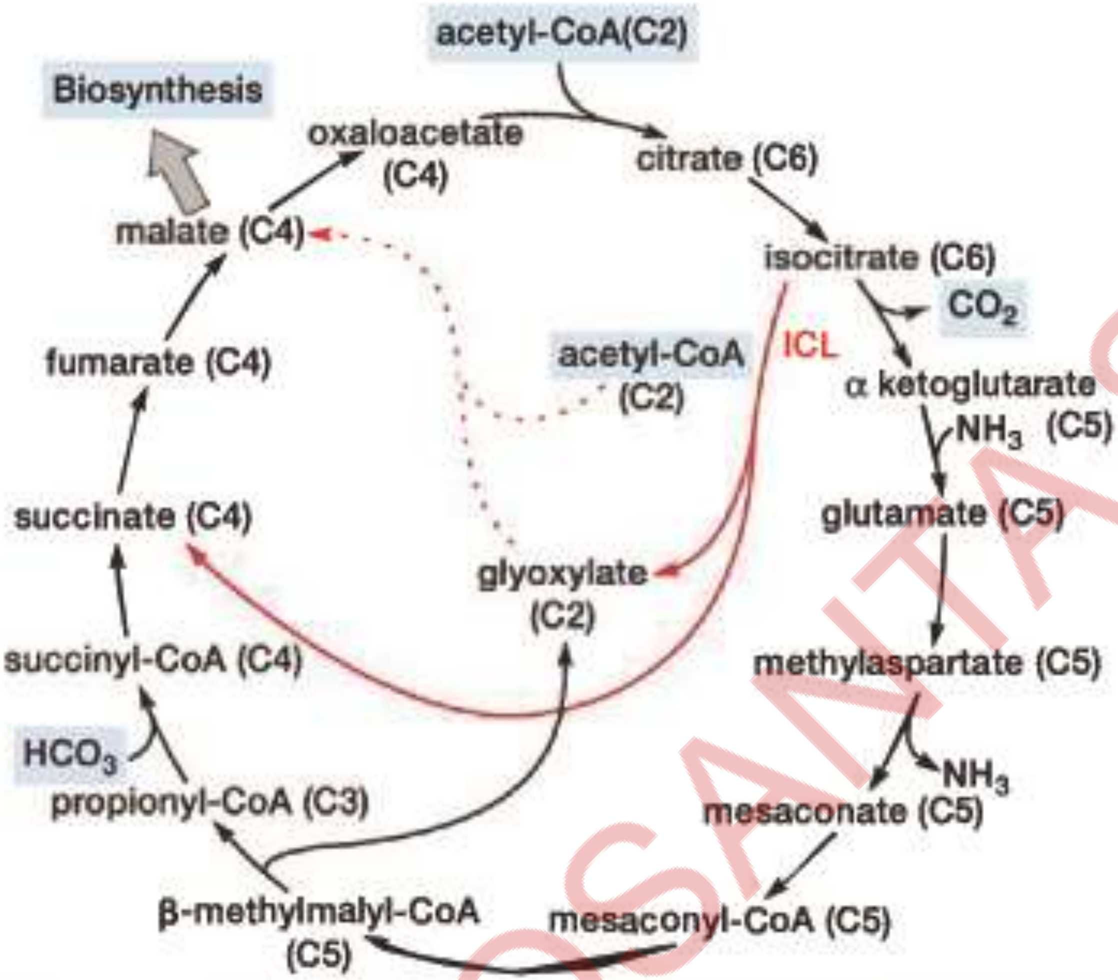


Figure 20.5 Glyoxylate and Methylaspartate Pathways Are Used for Acetyl-CoA Assimilation. Autotrophic archaea and some haloarchaea use the glyoxylate pathway (red and dashed arrows) to incorporate acetyl-CoA. Other haloarchaea lack the key enzyme isocitrate lyase (ICL) and assimilate acetyl-CoA via the longer methylaspartate pathway instead (black and dashed arrows).

- **Glyoxalate and Me-Asp pathays**
- **Isocitrate lyase required for glyoxalate pathway**
- **Me-Asp pathay more complicated but Halobacteria undertake it**
- **Glutamate is osmoprotectant.**

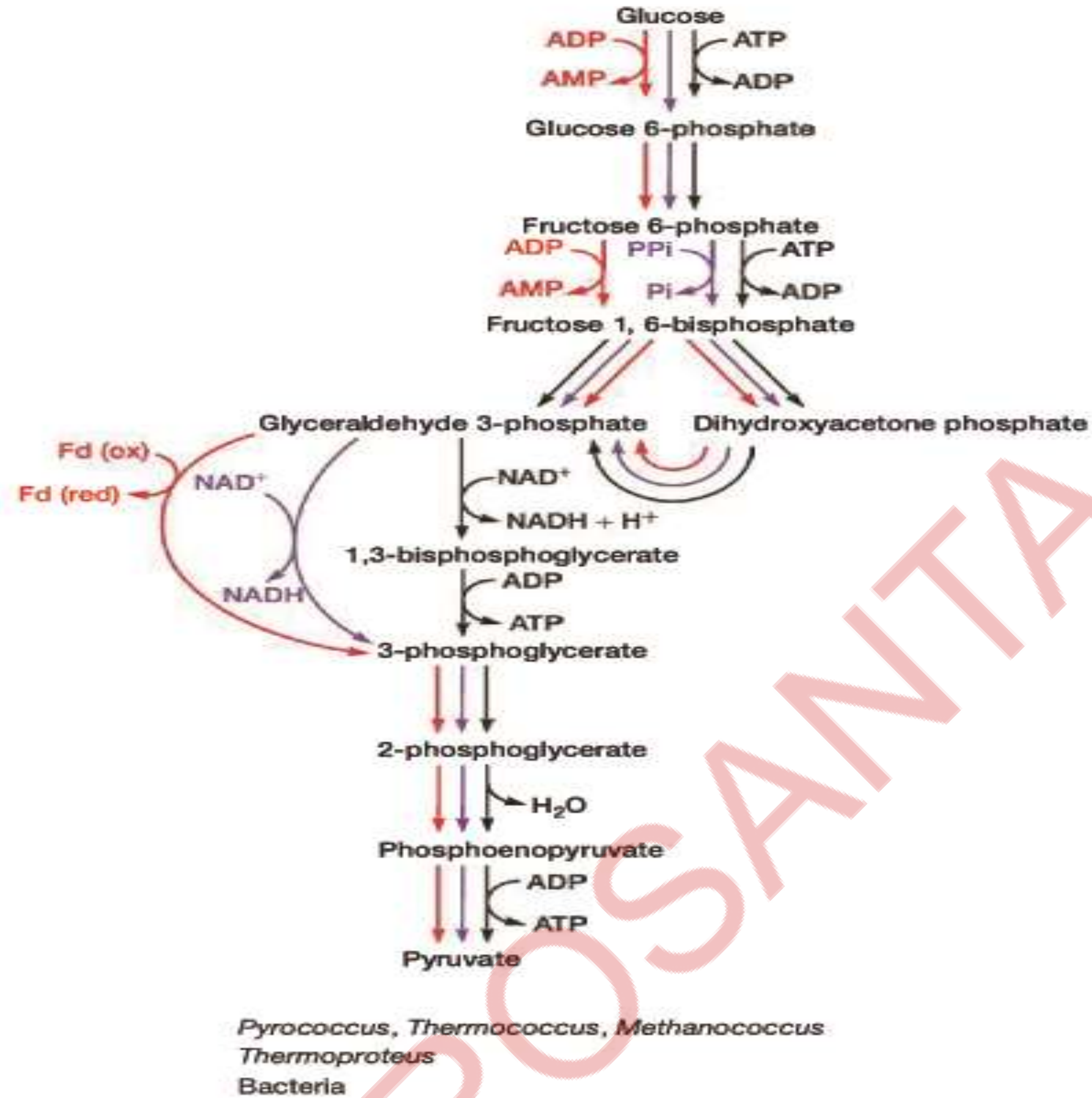
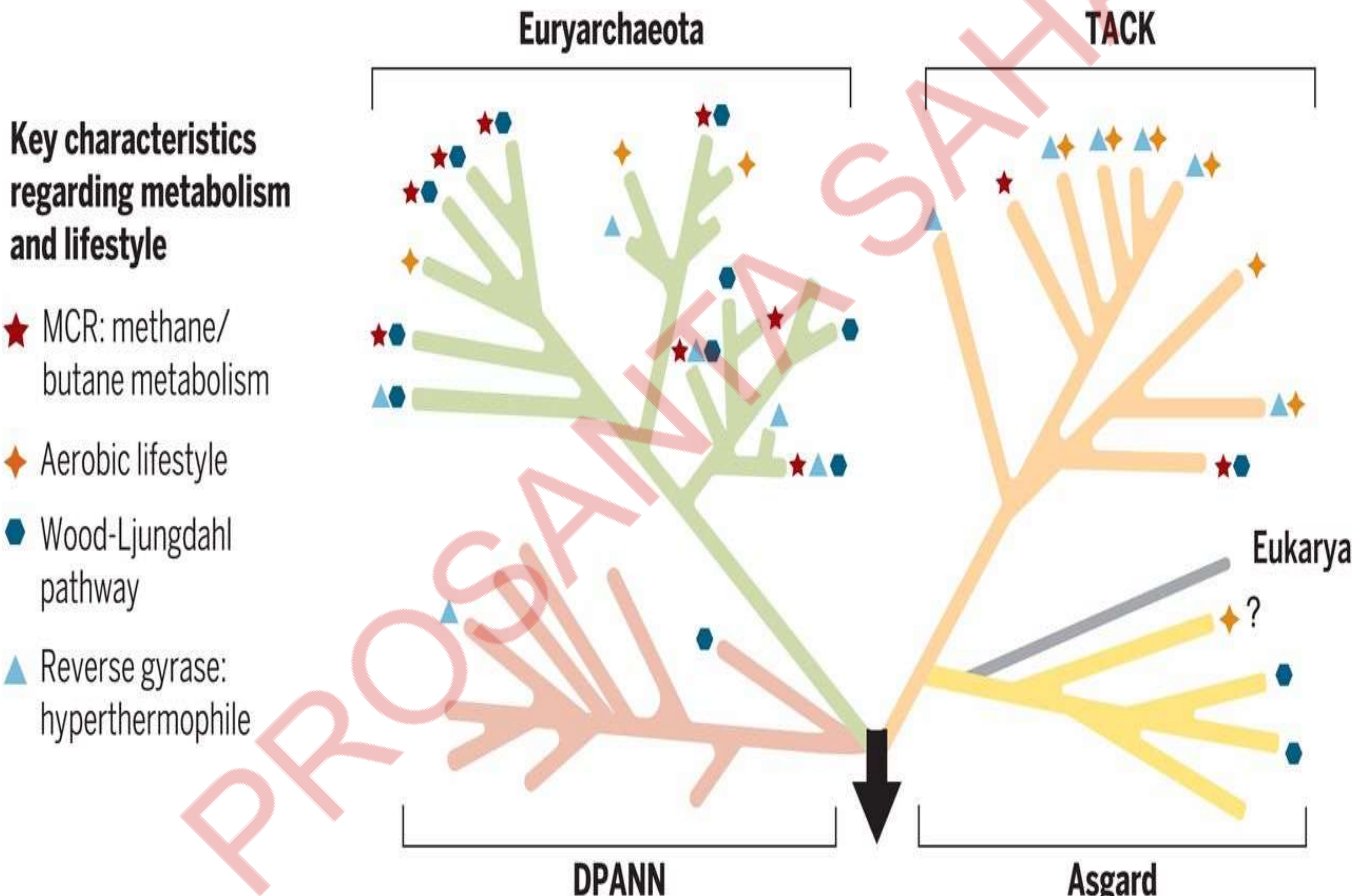


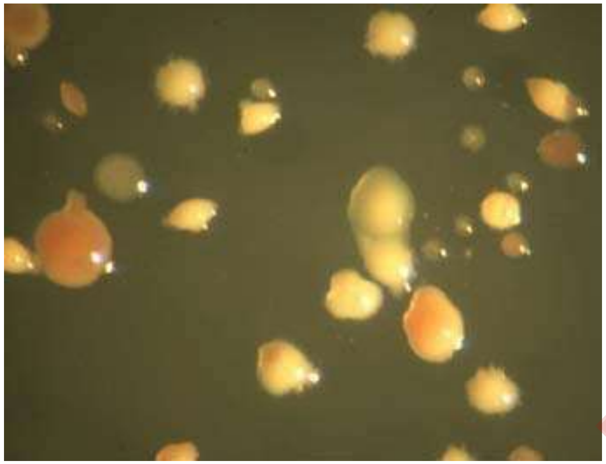
Figure 20.6 Modified Embden-Meyerhof Pathway. The pathway used by some archaea compared to that of bacteria. The only difference between the pathway used by *Thermoproteus* spp. and the other archaea shown is the use of NAD^+ as the electron acceptor rather than ferredoxin when glyceraldehyde 3-phosphate is oxidized to 3-phosphoglycerate. There is no net ATP produced in the archaeal pathway.

- **Catabolism by modified Embden - Mayerhof Pathway or Enter Duodoroff Pathway**

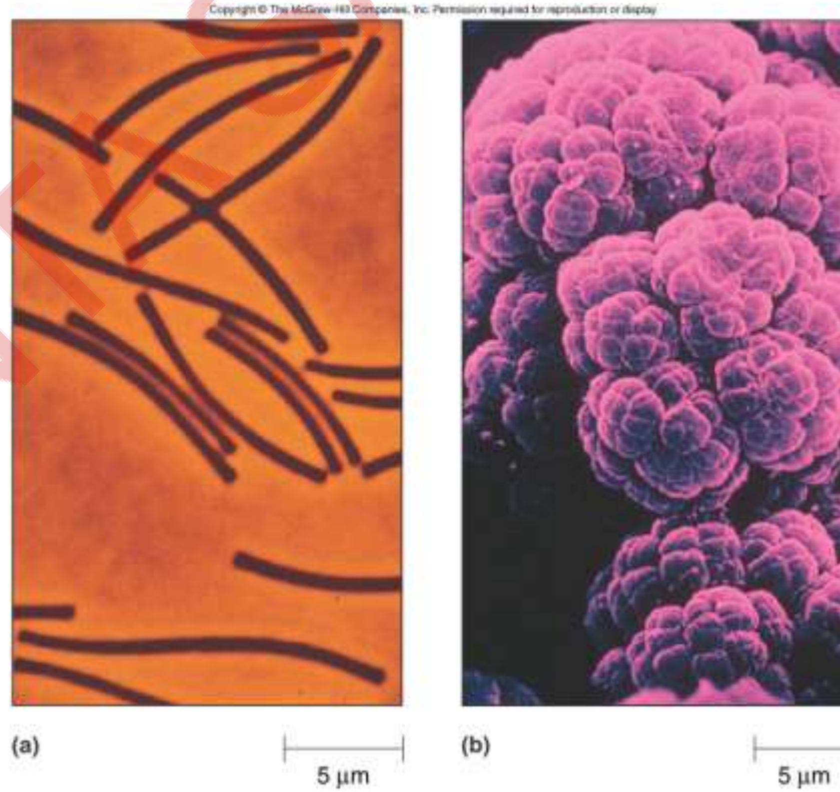
ARCHAEAL TAXONOMY



3 main types of Archaea

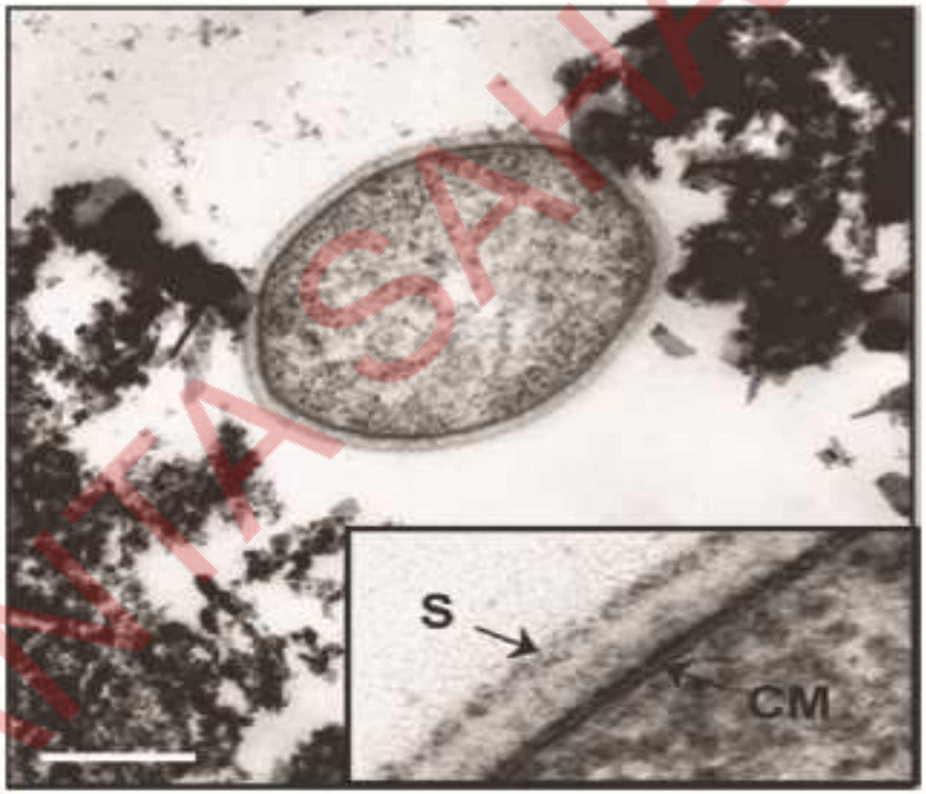


Colorful "salt-loving" archaea thrive in these ponds near San Francisco. Used for commercial salt production, the ponds contain water that is five to six times as salty as seawater.



SUPERPHYLUM TACK
Phylum Crenarcheota

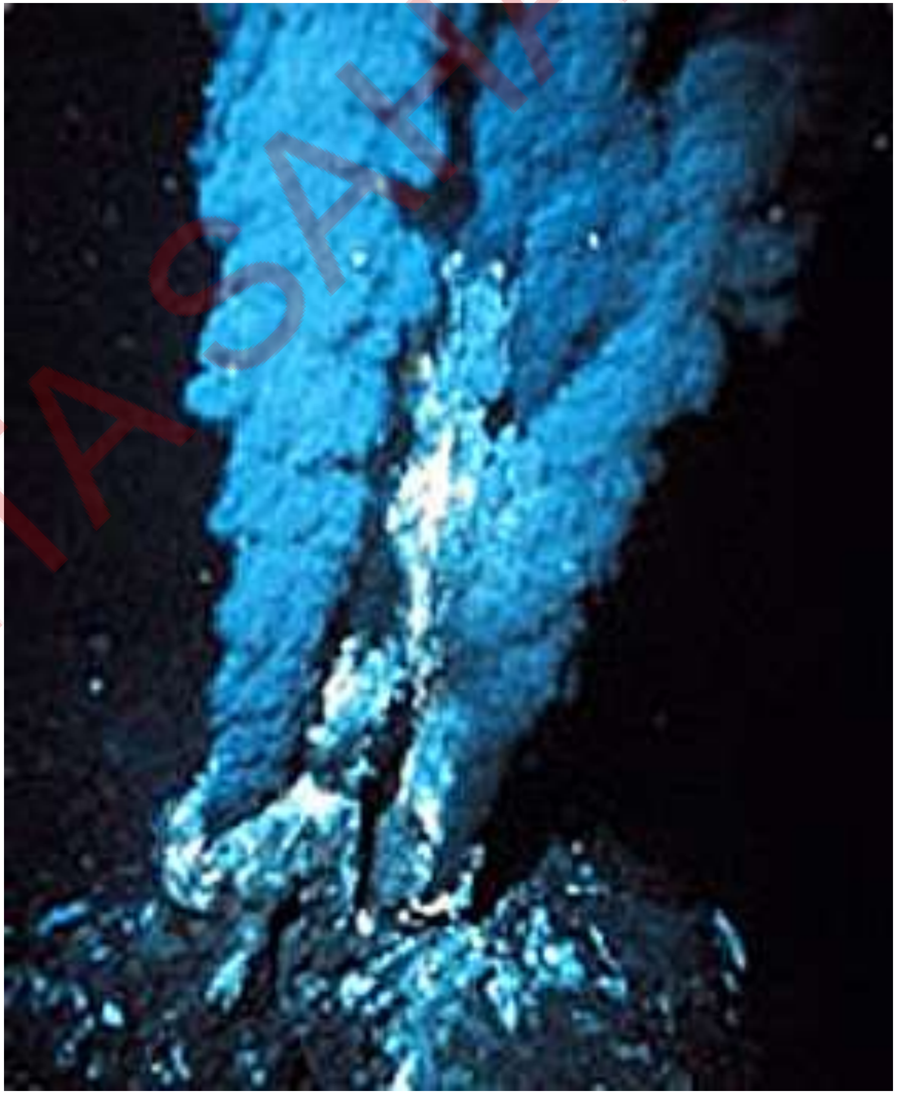
The crenarchaeotes are thought to resemble the ancestral archaea, and almost all the well-characterized species are thermophiles or hyperthermophiles.



(b)

Figure 20.9 An Extremely Hyperthermophilic Crenarchaeote. (a) A member of the family *Pyrodictiaceae* (tube on left) grows following autoclaving at 121°C, as shown by its ability to reduce Fe(III) to magnetite when incubated anaerobically (tube on right is sterile control). (b) A transmission electron micrograph shows the S-layer cell envelope (S) and plasma membrane (CM). Scale bar = 1 μm.

- Hyperthermophiles - All grow best above 80°C and most grow well above the boiling point of water!
- Most have been discovered in geothermically heated waters, such as hot springs. eg. Pyrobolus fumarii
- Thermoacidophilic - Sulfobolus, 80deg, pH 2-3
- Also called hyperacidophiles because they live in waters with a low (acidic) pH, usually containing strong sulfuric acid.
- Glycoprotein cell wall - Thermoproteus, 75-100deg, pH 3-4



SUPERPHYLUM TACK
Phylum Thaumarcheota

- Mesophilic Crenarcheota
- Cell membrane contains Thaumarcheol
- Cyclohexane rings in diglyceroltetraether cell membranes.
- Stability at high temp and fluidity at lower temp.

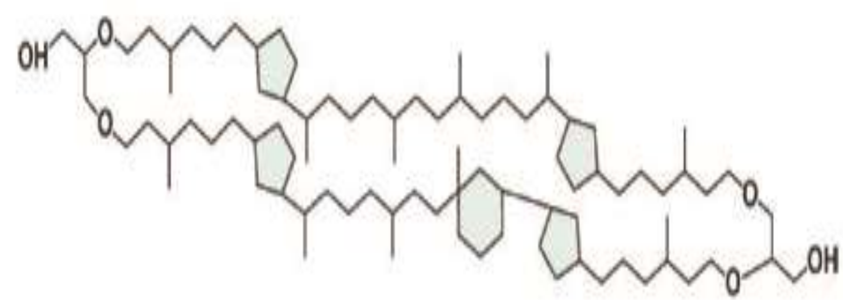


Figure 20.12 Crenarchaeol. This membrane lipid is composed of dicyclic biphytane and a tricyclic biphytane.

Super Phylum DPANN

- They include small symbionts of other archaeal cells. Like Parasitic archaeon *Nonarchaeum equisitans* is parasitic on Crenarcheic host *Ignicoccus hospitalis*

Proposed Phylum Asgard

- Close relative of eukaryotes..
- Represented by metagenomic data only... not obtained in culture.
- Eukaryote like proteins like actin, tubulin, DNA polymerase, Ribosome components.

Phylum Euryarcheota

The euryarchaeotes are given this name because they occupy many different ecological niches and have a variety of metabolic patterns. The methanogens, extreme halophiles, sulfate reducers, and many extreme thermophiles with sulfur-dependent metabolism are placed in the Euryarchaeota.

Methanogens and Methanotrophs

- Methanogens - Methane producing archaea that live in oxygen free environments.
- They use nitrogen, carbon dioxide or hydrogen sulfide to get energy and produce methane as a waste product.
- Methanotrophs oxidise methane.

Extreme Halophiles

- They were the first archaea to be studied, 110 years ago when salt was the primary preservation agent.
- Virtually all halophiles can live at the saturation point of salt, 32% or 5.5 M NaCl. The oceans are not salty enough for these guys.
- Kingdom Protista (*Dunaliella*) and Kingdom Bacteria (purple sulfur bacteria) also have halophilic species.

Extreme Halophiles

- Live in places with a high salt concentration, like the Dead Sea or Great Salt Lake.
- They can also live on super-salted foods and in solar salt evaporation ponds (right).
- **ARCHAEORHODOPSIN –** A protein found in ***Halobacterium salinarum*** that functions as a light-driven proton pump to harvest light energy in absence of chlorophyll. **Functions** - Light-driven influx of KCl into cell upto 4-5M conc. And position archaea optimally in water column.

Thermoplasms

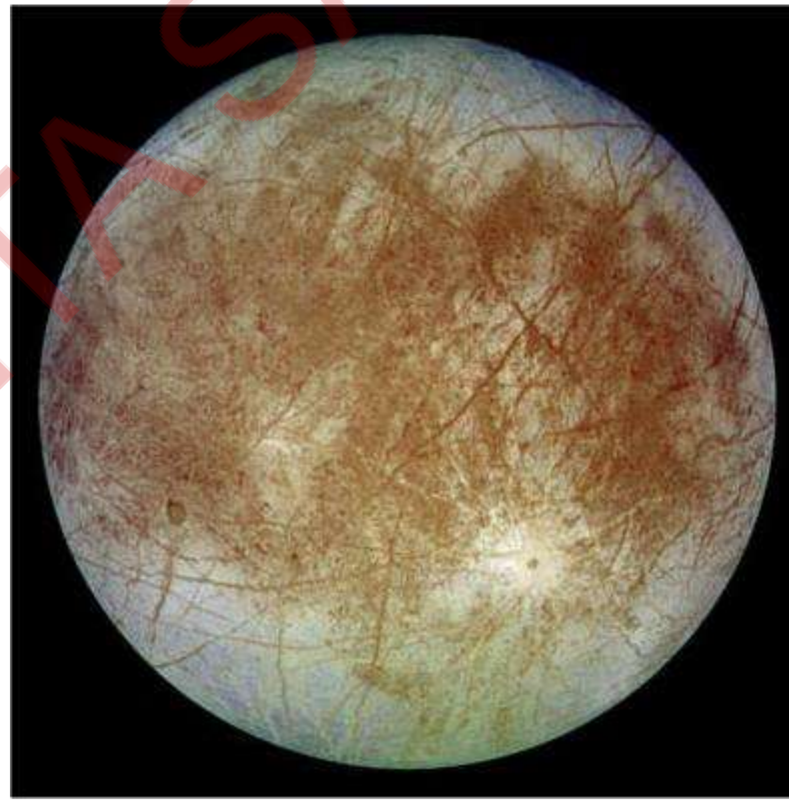
- Lack cell wall
- 55-59deg C , pH 1-2
- found in coal mines where large amount of FeS is oxidized to H_2SO_4 by chemolithotrophic bacteria resulting in hot acidic condition.
- Plasma membrane contains CALDARCHAEOL
- eg *Thermoplasma, Picrophilus, Ferroplasma*

Sulfur reductants

- **Extremely thermophilic S0 reducer - reduce Sulphur to Sulfides. These archaea are strictly anaerobic chemoorganoheterotrophs. They have archaella and are motile. Optimum growth is at 88-100degC. Eg. *Thermococcus, Paleococcus, Pyrococcus.***
- **Sulfate reducing Euryarchaeota - Reduce Sulfate, Sulphite or thiosulphate, but never Sulfur. They are thermophilic with growth optimum at 83degC. Eg. *Archaeoglobus* sp.**

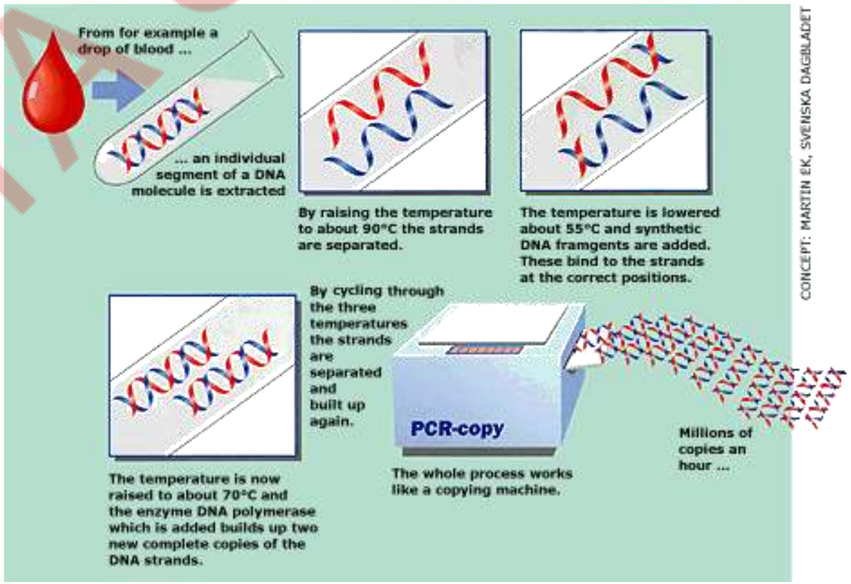
Archaea and Space???

- NASA is interested in salt deposits on Mars and one of Jupiter's moons, Europa, because they have huge salt formations that some scientists believe could hold archaea.
- May suggest life started elsewhere…



Archaea and Biotechnology

- Archaea were deemed very useful for scientists because they contain enzymes that work under harsh conditions.
- Scientists isolated and purified these enzymes and now use them in a variety of processes.
- Archaean enzymes are used in DNA analysis, disease analysis, toxic waste removal and PCR, which is a technique used to make DNA fingerprints.



THANK YOU