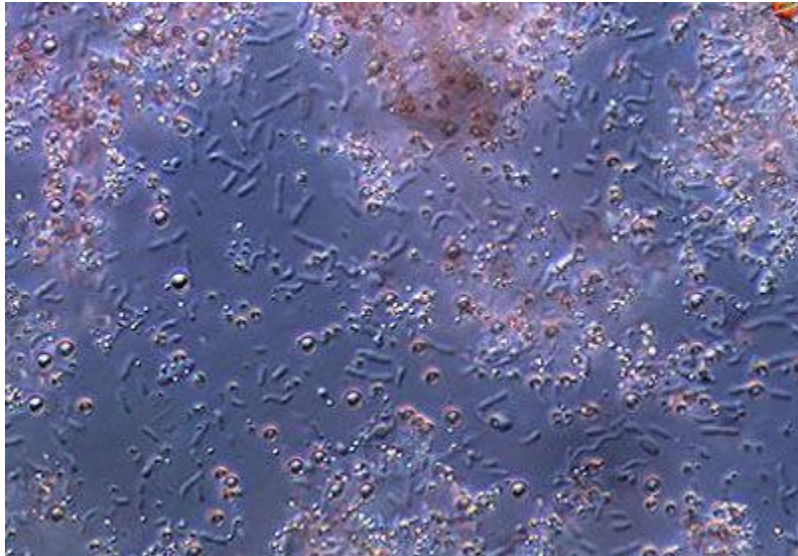


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## Archaea



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Archaea are a domain of single-celled microorganisms. They have no cell nucleus or any other organelles inside their cells. In the past Archaea were classified as an unusual group of bacteria and named archaeobacteria, but since the Archaea have an independent evolutionary history and manifest numerous differences in their biochemistry from other forms of life, they are now classified as a separate domain in the three-domain system. In this system the three primary branches of evolutionary descent are the Archaea, Eukarya and Bacteria. Archaea are further divided into four recognized phyla, although other phyla may exist. Of these groups the Crenarchaeota and the Euryarchaeota are most intensively studied. Classifying the archaea is somewhat challenging, since the vast majority have never been studied, and have chiefly been detected by analysis of their nucleic acids in samples from the environment.

Archaea replicate asexually in a process known as binary fission. Archaea achieve a swimming motility via one or more tail-like flagellae. Many archaeans are extremophiles, achieving wide environmental tolerance of temperature, salinity, and even radioactive environments. Archaea are thought to be significant in global geochemical cycling, since they comprise an estimated 20 percent of the world's biomass; however, very little is known about the domain, especially marine and deep-sea benthic varieties.

## **Evolution**

Very early probable prokaryotic cell fossils have been dated at approximately 3.5 billion years before present day, making them some of the most primitive and ancient life forms on Earth; however, prokaryotes generally lack distinctive morphologies, thus fossil shapes cannot be used to identify them as archaea. Instead, chemical fossils of unique lipids hold greater information, since such compounds do not occur in other organisms. Some research indicates archaean or eukaryotic lipid remains are present in shales as old as 2.7 billion years. Such lipids have been identified in Precambrian formations, the earliest of which are present in the Isua greenstone belt of western Greenland. This locale boasts the Earth's oldest sediments, circa 3.8 billion years of age.

Carl Woese was the first to posit that the bacteria, archaea, and eukaryotes represent separate evolutionary lines of descent that diverged at a very remote point in time on from an ancestral colony of organisms. Archaea and viruses likely had a relationship as early as 2 billion years before present day, some researchers positing that co-evolution may have been occurring between these groups at such an early time. It has been further suggested that the last common ancestor of the bacteria and archaea was a thermophile, raising the likelihood that low temperatures are really the extreme environments viewed from an ancestral archaea point of view, and organisms that can tolerate cold conditions appeared only later in evolutionary time.

## **Taxonomy**

It was not until 1977 that archaea were recognized as a separate domain of prokaryotes through the work of Woese and Fox. Until 1965 the chief techniques of distinguishing microorganisms were use of morphology and metabolic functions. Woese and Fox culminated a research direction begun by a number of researchers started in the early 1960s, in which gene coding of DNA material was viewed as a more fundamental technique for organism relatedness. By the close of the 20th century, an enhanced understanding of the significance and ubiquity of archaea arose by using the polymerase chain reaction to detect prokaryotes in samples of water or soil based solely upon their nucleic acid.

The greatest remaining puzzle is whether to acknowledge species within the domain of archaea. While morphological and DNA findings support the recognition of species, it is not clear that significant gene transfer is prohibited, thereby annihilating the validity of species. In any case, in the present treatment we shall allow the attribution of species, if for no other reason than to follow published research designations and for simplicity of naming.

## **General morphology**

Archaea and bacteria are superficially similar in size and shape, although some archaea species have remarkable geometric shapes, such as the flat and square-shaped cells of some genus *Haloquadra* members. Despite this visual similarity to bacteria, archaea possess genes and several metabolic pathways that are more closely related to those of eukaryotes: notably the enzymes involved in gene transcription and translation. Other aspects of archaean biochemistry are unique, such as the occurrence on ether lipids within their cell membranes.

As with bacteria, archaea have no interior membranes or organelles. Cell membranes are typically bounded by a cell wall and motility is achieved using one or more flagellar tail structures. Archaea most resemble gram-positive bacteria. Most archaea exhibit a single plasma membrane and cell wall, lacking a

periplasmic space; however, *Ignicoccus* manifests a notably large periplasm with membrane-bound vesicles, enclosed by an outer membrane.

Certain archaea aggregate to yield filaments of cells as long as 200 nanometers—such forms are prominent in biofilms. *Thermococcus coalescens*, on the other hand, have cells that can fuse in culturing to produce monster single cells.

Genus *Pyrodictium* archaea form an elaborate multicell colony manifesting arrays of slender elongated hollow tubes termed cannulae that protrude from the cellular surface and connect into a dense agglomeration; this protruding form appears to encourage connection or nutrient exchange with neighboring cells of the same genus.

Crenarchaeota exhibit a diverse set of geometries: irregularly shaped lobed cells, needle-like filaments that are less than 500 nanometers in cross-section and amazing rectangular rods. These odd morphologies are likely produced both by their cell walls as well as a prokaryotic cytoskeleton. Proteins associated with cytoskeleton elements of other organisms exist in archaea.

### **Flagella**

Archaeal flagella function like their bacterial counterparts, with elongated stalks driven by rotatory motors at the base. The motors themselves are powered by the electrochemical gradient across the membrane. However, archaeal and bacterial flagella came from different ancestors. The bacterial flagellum is hollow and is assembled by subunits moving up the central pore to the tip of the flagella, while archaeal flagella are constructed from addition of subunits at the base.

### **Membranes**

The membranes of Archaea are constructed from molecules unlike those in other life forms; this morphology demonstrates the ancestral distance from bacteria and eukaryotes. For every organism, cell membranes are made of phospholipid molecules. These phospholipids exhibit a polar part that dissolves in water (a phosphate head), and a hydrophobic non-polar part (a lipid tail) that is water insoluble. These dissimilar ends are connected by a glycerol group. In water, phospholipids aggregate, with heads facing the water and tails facing the opposite direction. The principal structure in cell membranes is a dual layer of phospholipids, often termed a lipid bilayer.

These phospholipids are distinct for a number of reasons:

In the case of bacteria and eukaryotes, membranes consist chiefly of glycol-ester lipids, but archaea have membranes made of glycerol-ether lipids. Ether bonds are chemically more stable than ester bonds, assisting archaea in survival at extreme temperatures and extreme pH environments.

Stereochemistry of the glycerol group is the reverse of that found in other organisms. This implies that archaea use wholly different enzymes for synthesizing phospholipids than bacteria and eukaryotes. Such enzymes developed in very ancient geological times, suggesting an early split from the other two domains.

In some archaea the lipid bilayer is replaced by a monolayer, in which tails of two independent phospholipid molecules are fused into a single molecule with two polar heads. This fusion may make their membranes more rigid and better able to resist harsh environments. *Ferroplasma* is an example—this organism's survival in its highly acidic habitat is abetted by such tail fusion. Archea lipid tails are chemically distinct from other organisms.

Archaea lipids are based upon the isoprene sidechain: they are long chains with complex side-chains and often cyclopropane or cyclohexane rings. Although isoprenoids play an important role in the biochemistry of many organisms, only the archaea use them to make phospholipids. These branched chains may aid archaean membranes from leaking at high temperatures.

## **Metabolism**

Many fundamental metabolic pathways are shared between all forms of life. As a case in point, archaea invoke a modified form of glycolysis and either a complete or partial citric acid cycle. These likenesses to other organisms reflect archaean early origins as well as archaean high metabolic efficiency.

A vast variety of chemical reactions are applied by archaea in supporting their metabolic behavior. Employing a host of energy sources, these reactions can be grouped into nutritional groups. In some cases inorganic compounds (e.g., ammonia and sulphur) supply the energy to archaeans known as lithotrophs. The other set of archaea employ the sun's energy; while not engaging in actual oxygen-producing photosynthesis, this archaean group is known as the phototrophs. (No archaea are known to use photosynthesis.) Phototrophic archaea use the sun's energy to produce chemical energy in the form of ATP. In the Halobacteria, light-activated ion pumps like bacteriorhodopsin produce ion gradients by pumping ions out of the cell through the plasma membrane. The energy stored in such electrochemical gradients is subsequently converted into ATP by ATP synthase in a process that is a form of photophosphorylation. The ability of these light-driven pumps to transport ions across membranes depends on sunlight-driven alterations in the structure of a retinol cofactor embedded in the protein center.

Some swamp-dwelling archaea thrive in anaerobic settings; in fact, this primitive form of metabolism may have powered the first free-living organism. Such methanogenic metabolism relies upon carbon dioxide as an electron acceptor to oxidize hydrogen. Methanogenesis invokes a gamut of coenzymes unique to these archaea, including coenzyme M and methanofuran. Sometimes various alcohols, and acetic or formic acid, are employed as methanogenic electron acceptors. These reactions are common in intestine-dwelling archaea. Acetic acid is also decomposed into methane and carbon dioxide by acetotrophic archaea. These acetotrophs are archaea in the order Methanosarcinales, and are a major part of the ecological micro-organism communities that produce biogas.

Atmospheric carbon is another source of energy input for autotrophic archaea who employ carbon fixation. This process involves either: (i) a highly modified form of the Calvin cycle or (ii) a metabolic pathway termed the 3-hydroxypropionate/4-hydroxybutyrate cycle.

## **Reproduction**

Having no cell nucleus, archaea do not reproduce via mitosis; rather, they procreate using a process called binary fission. In this binary fission process, archaeal DNA replicates, and the two strands are pulled apart as the cell grows. In some cases more than two daughter chromosomes can be created and subsequently pull apart, in a process called multiple fission.

Archaeal chromosomes replicate from multiple origins of replication, using DNA polymerases that resemble counterpart eukaryotic enzymes. However, the proteins that direct cell division, such as the protein FtsZ, that forms a contracting ring around the cell, and the components of the septum constructed across the center of the cell, resemble their bacterial likenesses.

Onyenwoke et al. demonstrated that archaea, unlike many bacteria and eukaryotes, produce no spores.

It was first thought that most archaea were extremophiles, existing at the environmental limits of abiotic factor ranges. Recently, it has been found that there are numerous archaea living in a broad range of habitats and environmental conditions.

Some Haloarchaea undergo phenotypic switching and grow as several different cell types, including thick-walled structures that are highly resistant to osmotic shock. These thickened walls permit survival under hyposaline (low salt) circumstances, but these alternative phenotypes are not actual reproductive structures—rather, they may assist the archaea in reaching new habitats.

Indeed, some archaea thrive in extreme temperatures, often above 100 degrees C; for example, they occur in geysers, black smokers, and oil wells. Other viable environments include very cold environments and highly saline, acidic, or alkaline media. For example, *Picrophilus torridus*, an extreme archaean acidophile, thrives at pH of essentially zero, equivalent to a 1.2-molar concentration of sulfuric acid. Archaea are also found in very cold ocean environments, including polar seas. Many archaea also occur throughout the world's oceans among plankton communities as part of the picoplankton. Moreover, archaea include mesophiles that grow in mild conditions, in marshes, sewage, the oceans, and soils.

Halophiles, including the genus *Halobacterium*, survive in hypersaline environments such as salt lakes, and can outcompete bacterial counterparts at salinities greater than 20 percent. Thermophiles grow best at temperatures above 45°C, in locales such as hot springs; hyperthermophilic archaea grow optimally at temperatures greater than 80°C. Strain 166 of the archaean *Methanopyrus kandleri* survives at 122°C, the highest recorded temperature for any organism.

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