What are the characteristics of archaea bacteria

Describe the unique features of each category of Archaea Explain why archaea might not be associated with human microbiomes or pathology Give common examples of archaea commonly associated with unique environmental habitats Like organisms in the domain Bacteria, organisms of the domain Archaea are all unicellular organisms. However, archaea differ structurally from bacteria in several significant ways, as discussed in Unique Characteristics of Prokaryotic Cells. To summarize: The archaeal cell membrane is composed of ether linkages with branched isoprene chains (as opposed to the bacterial cell membrane, which has ester linkages with unbranched fatty acids). Archaeal cell walls lack peptidoglycan, but some contain a structurally similar substance called pseudopeptidoglycan or pseudomurein. The genomes of Archaea are larger and more complex than those of bacteria. Domain Archaea is as diverse as domain Bacteria, and its representatives can be found in any habitat. Some archaea are mesophiles, and many are extremophiles, preferring extreme hot or cold, extreme salinity, or other conditions that are hostile to most other forms of life on earth. Their metabolism is adapted to the harsh environments, and they can perform methanogenesis, for example, which bacteria and eukaryotes cannot. Between 1990 and 2002, archaea were classified into one of two phyla: Euryarchaeota and Crenarchaeota. Today, with advances in technology and analytics, the domain includes at least 4 major supergroups: Euryarchaeota, TACK, Asgard and DPANN (Figure 4.47). Figure 4.47. An updated tree of life. This tree is based on ribosomal protein sequences from sequenced genomes. The Archaea are located at the bottom, along with the Eukaryotes, which emerge from within the archaea. [Credit: Hug et al., 2016] As far as we know, archaea are not associated with infectious diseases in humans, animals, plants, or microorganisms. However, many play important roles in the environment and may thus have an indirect impact on human health. Archaea exhibit a variety of chemical reactions in their metabolism and use many sources of energy. As a result of this and their widespread distribution, archaea play critical roles in cycling of elements in the biosphere. Some archaea are lithotrophs, obtaining energy from inorganic compounds such as elemental sulphur, H_2S or ammonia. Lithotrophs are also autotrophic, using CO_2 in the atmosphere as a source of carbon, “fixing” the carbon into biomass. Metabolism Some archaea are methanogens. These organisms are unique in that they can reduce carbon dioxide in the presence of hydrogen, producing methane. They can live in the most extreme environments and can reproduce at temperatures varying from below freezing to boiling. Methanogens have been found in hot springs as well as deep under ice in Greenland. Some scientists have even hypothesized that methanogens may inhabit the planet Mars because the mixture of gases produced by methanogens resembles the makeup of the Martian atmosphere. Methanogens are thought to contribute to the formation of anoxic sediments by producing hydrogen sulphide, making “marsh gas.” They also produce gases in ruminants and humans. Some genera of methanogens, notably Methanosarcina, can grow and produce methane in the presence of oxygen, although the vast majority are strict anaerobes. The class Halobacteria (which was named before scientists recognized the distinction between Archaea and Bacteria) includes halophilic (“salt-loving”) archaea. Halobacteria require a very high concentrations of sodium chloride in their aquatic environment. The required concentration is close to saturation, at 36%; such environments include the Dead Sea as well as some salty lakes in Antarctica and south-central Asia. One remarkable feature of these organisms is that they are phototrophic, using sunlight as a source of energy. They are, however, not photosynthetic. These organisms obtain their carbon and the majority of their energy from organic molecules. However, they possess a light-activated proton pump, bacteriorhodopsin, that generates a proton gradient across the plasma membrane. This gradient is a form of potential energy, the proton motive force. The light-absorbing pigment associated with bacteriorhodopsin gives these archaea, and the bodies of water they inhabit, a beautiful red-purple colour (Figure 4.48). Figure 4.48. Halobacteria growing in these salt ponds gives them a distinct purple colour. [credit: modification of work by Tony Hisgett] Notable species of Halobacteria include Halobacterium salinarum, which may be the oldest living organism on earth; scientists have isolated its DNA from fossils that are 250 million years old. This species produces proteinaceous gas vesicles to give it the appropriate buoyancy to float to the region in the water column with the optimal wavelength of light. On solid media, H. salinarum colonies producing these vesicles appear pink instead of red (Figure 4.49). Figure 4.49. Colonies (a) and cells of Halobacterium salinarum producing gas vesicles (b,c). (a) Colonies on solid media grown for one week at 40 °C and three weeks at room temperature. Vesicle (Vac+) cells form pink white colonies, whereas colonies of Vac− mutants are red and transparent. (b) Cells grown in liquid media observed by phase-contrast light microscopy. (c) Cells of a Vac+ colony investigated by transmission electron microscopy. The pleomorphic shape of the cells grown for three months on solid media differs from the rod-shaped cells seen in liquid culture. [Credit: F. Pfeifer] Archaea may be the most abundant organisms in the oceans where they play dominant roles in carbon fixation and ammonia oxidation. Some are hyperthermophiles, with some (notably, the genus Pyrolobus) capable of growth at temperatures up to 113 °C. Hyperthermophilic archaea are essential to deep sea vent ecosystems (Figure 4.50). They form the base of the unique deep sea vent food chain, using the H_2S from the vents as their energy source and fixing CO_2 . Figure 4.50. Hydrothermal vents and vent tube worms. (a) Hydrothermal vents (deep sea vents) are cracks in the earth’s crust where geothermally heated water leaks out. (b) Tubeworms are eukaryotic organisms that are specifically adapted to the high temperatures of hydrothermal vents. Species in the genus Thermoproteus are strict anaerobes, using sulphur or sulphate as terminal electron acceptors. They are flagellated and with a monolayer plasma membrane and are hyperthermophiles, with an optimal growth temperature of ~85 °C. Thermoproteus species may grow lithotrophically, using hydrogen as an energy source, or they may grow as heterotrophs. Archaea in the genus Sulfolobus (Figure 4.51) are thermophilic, preferring temperatures around 70–80°C and acidophilic, prefer a pH of 2–3. Sulfolobus can live in aerobic or anaerobic environments. In the presence of oxygen, Sulfolobus spp. use metabolic processes similar to those of heterotrophs. In anaerobic environments, they oxidize sulphur to produce sulphuric acid, which is stored in granules. Sulfolobus spp. are used in biotechnology for the production of thermostable and acid-resistant proteins called affitins. Affitins can bind and neutralize various antigens (molecules found in toxins or infectious agents that provoke an immune response from the body). Figure 4.51. Sulfolobus oxidizes sulphur and stores sulphuric acid in its granules. Two spindle-shaped viruses are seen being released from the host cell. Some other acidophilic archaea obtain their energy from reduced iron. In abandoned mines coal mines, the combination of the metabolic reactions of these and sulphur-oxidizing microbes, plus oxidation from exposure to air, leads to extreme acidification of the water in these mines. The result, acid mine drainage, causes severe ecological damage when gets into the surrounding environment: streams become highly acidic and the low pH causes dissolved minerals to precipitate, thus killing the life forms in those waters (Figure 4.52). Figure 4.52. Oxidation of sulphur to sulphuric acid, and iron, gives rise to acidic mine tailings. The low pH causes the iron and other minerals to precipitate, making these waters highly toxic to other life forms. Describe where Halobacteria live and their metabolism Describe the role of hyperthermophilic archaea in deep sea vent food chains How do Sulfolobus and other acidophilic archaea give rise to acid mine tailings? Until the phylogenetic work of Carl Woese led to the identification of this third domain, archaea were thought to be bacteria. The share many similarities with bacteria: they lack a nucleus or other membrane-bound organelles, putting them into the category of “prokaryote”, most are unicellular, they have 70S sized ribosomes, are typically a few micrometers in size, and reproduce asexually only. They are known to have many of the same structures that bacteria can have, such as plasmids, inclusions, flagella, and pili. Capsules and slime layers have been found but appear to be rare in archaea. There are, however, many unique features, and many other features that are shared between archaea and eukaryotes. This latter observation, which is reflected in the 2016 tree of life by Hug et al, and more recent ones, supports the proposal that the host for the first endosymbiotic event during eukaryogenesis, was an archaeaon. Plasma membrane As described previously, archaeal membrane lipids are ether-linked, as opposed to the ester-linked lipids found in bacteria and eukaryotes. The ether-linkage provides more chemical stability to the membrane. In addition, instead of the unbranched fatty acids characteristics of bacterial and eukaryotic membrane lipids, isoprenoid chains are found in archaea. These isoprenoid chains can have branching side chains and the lipids can exist as monolayers, where the isoprene chains of one phospholipid connect with the isoprene chains of a phospholipid on the opposite side of the membrane. Bacteria and eukaryotes only have lipid bilayers, where the two sides of the membrane remain separated (Figure 4.53). Figure 4.53. Comparison of Plasma Membrane Lipid Between Bacteria and Archaea. Cell Wall Like bacteria, the archaeal cell wall is a semi-rigid structure designed to provide protection to the cell from the environment and from the internal cellular pressure. While the cell walls of bacteria typically contain peptidoglycan, that particular chemical is lacking in archaea. Instead, archaea display a wide variety of cell wall types, adapted for the environment of the organism. Some archaea lack a cell wall altogether. While it is not universal, a large number of Archaea have a proteinaceous S-layer that is considered to be part of the cell wall itself (unlike in bacteria, where an S-layer is a structure in addition to the cell wall). For some archaea the S-layer is the only cell wall component, while in others it is joined by additional ingredients (Figure 4.54). The archaeal S-layer can be made of either protein or glycoprotein, often anchored into the plasma membrane of the cell. The proteins form a two-dimensional crystalline array with a smooth outer surface. A few S-layers are composed of two different S-layer proteins. While archaea lack peptidoglycan, a few contain a substance with a similar chemical structure, known as pseudomurein. Instead of NAM, it contains N-acetylalosaminuronic acid (NAT) linked to NAG, with peptide interbridges to increase strength. Methanochondroitin is a cell wall polymer found in some archaeal cells, similar in composition to the connective tissue component chondroitin, found in vertebrates. Some archaea have a protein sheath composed of a lattice structure similar to an S-layer. These cells are often found in filamentous chains, however, and the protein sheath encloses the entire chain, as opposed to individual cells. Figure 4.54. Archaeal cell wall structural diversity. Structures include pseudomurein, methanochondroitin, S-layers and a proteinaceous sheath. [Credit: Linda Bruslind] Archaea usually have a single circular chromosome, the size of which may be as great as 5,751,492 base pairs in Methanosarcina acetivorans, the largest known archaean genome. One-tenth of this size is the tiny 490,885 base-pair genome of Nanoarchaeum equitans, the smallest archaean genome known. It is estimated to contain only 537 protein-encoding genes. Smaller independent pieces of DNA, called plasmids, are also found in archaea. Plasmids may be transferred between cells by physical contact, in a process that may be similar to bacterial conjugation. Archaea can be infected by double-stranded DNA viruses that are unrelated to any other form of virus and have a variety of unusual shapes, including bottles, hooked rods, or teardrops. These viruses have been studied in most detail in thermophilics, particularly the orders Sulfolobales (see Figure 4.51) and Thermoproteales. Two groups of single-stranded DNA viruses that infect archaea have been recently isolated. One group is exemplified by the Halorubrum pleomorphic virus 1 (“Pleolipoviridae”) infecting halophilic archaea and the other one by the Aeropyrum coil-shaped virus (“Spiraviridae”) infecting a hyperthermophilic (optimal growth at 90-95°C) host. Notably, the latter virus has the largest currently reported ssDNA genome. Defences against these viruses may involve RNA interference from repetitive DNA sequences that are related to the genes of the viruses. Archaea are genetically distinct from bacteria and eukaryotes, with up to 15% of the proteins encoded by any one archaeal genome being unique to the domain, although most of these unique genes have no known function. Of the remainder of the unique proteins that have an identified function, most are involved in methanogenesis. The proteins that archaea, bacteria, and eukaryotes share form a common core of cell function, relating mostly to transcription, translation, and nucleotide metabolism. Other characteristic archaean features are the organization of genes of related function—such as enzymes that catalyze steps in the same metabolic pathway into novel operons, and large differences in tRNA genes and their aminoacyl tRNA synthetases. Transcription and translation in archaea resemble these processes in eukaryotes more than in bacteria, with the archaeal RNA polymerase and ribosomes being very close to their equivalents in eukaryotes. Although archaea only have one type of RNA polymerase, its structure and function in transcription seems to be close to that of the eukaryotic RNA polymerase II, with similar protein assemblies (the general transcription factors) directing the binding of the RNA polymerase to a gene’s promoter. However, other archaean transcription factors are closer to those found in bacteria. Post-transcriptional modification is simpler than in eukaryotes, since most archaean genes lack introns, although there are many introns in their transfer RNA and ribosomal RNA genes, and introns may occur in a few protein-encoding genes. Archaea are unicellular, prokaryotic microorganisms that differ from bacteria in their genetics, biochemistry, and ecology. Some archaea are extremophiles, living in environments with extremely high or low temperatures, or extreme salinity. Only archaea are known to produce methane. Methane-producing archaea are called methanogens. Halophilic archaea prefer a concentration of salt close to saturation and perform photosynthesis using bacteriorhodopsin. Archaeal membrane lipids are ether-linked and may form bilayers or monolayers Archaeal cell walls may consist of pseudomurein or proteinaceous S-layers Archaea may be infected by viruses. Many unique proteins are encoded by archaea, many of these proteins have unknown functions. Introns are more rare than eukaryotic species, and additionally unlike eukaryotes the introns usually do not reside in protein coding genes but rather rRNA and tRNA. Some archaea, based on fossil evidence, are among the oldest organisms on earth. Archaea do not live in great numbers in human microbiomes and are not known to cause disease. What accounts for the purple colour in salt ponds inhabited by halophilic archaea? What evidence supports the hypothesis that some archaea live on Mars? What is the connection between this methane bog and archaea (credit: Chad Skeers) Media AttributionsHug et al figure 1 proofs OSC_Microbio_04_06_Halobact Halobacterium salinarum colonies Deep sea vents OSC_Microbio_04_06_Sulfolobus Acidophilic archaea archaeal vs bacterial membrane lipids – corrected Archaeal cell wall structures