LECTURE PRESENTATIONS
For BROCK BIOLOGY OF MICROORGANISMS, THIRTEENTH EDITION
Michael T. Madigan, John M. Martinko, David A. Stahl, David P. Clark

Chapter 17-18

Bacteria

Lectures by
John Zamora
Middle Tennessee State University

17.1 Phylogenetic Overview of *Bacteria*

- *Proteobacteria*
  - A major lineage (phyla) of *Bacteria*
  - Includes many of the most commonly encountered bacteria
  - Most metabolically diverse of all *Bacteria*
    - Chemolithotrophy, chemoorganotrophy, phototrophy
  - Morphologically diverse
  - Divided into five classes
    - *Alpha*-, *Beta*-, *Delta*-, *Gamma*-, *Epsilon*-

II. Phototrophic, Chemolithotrophic, and Methanotrophic *Proteobacteria*

- 17.2 Purple Phototrophic Bacteria
- 17.3 The Nitrifying Bacteria
- 17.4 Sulfur- and Iron-Oxidizing Bacteria
- 17.5 Hydrogen-Oxidizing Bacteria
- 17.6 Methanotrophs and Methylotrophs

17.2 Purple Phototrophic Bacteria

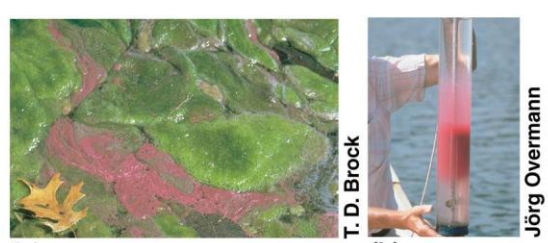
- *Purple phototrophic bacteria*
  - Carry out anoxygenic photosynthesis; no O_2 evolved
  - Morphologically diverse group
  - Genera fall within the *Alpha*-, *Beta*-, or *Gammaproteobacteria*
  - Contain bacteriochlorophylls and carotenoid pigments
  - Produce intracytoplasmic photosynthetic membranes with varying morphologies

17.2 Purple Phototrophic Bacteria

- *Purple sulfur bacteria*
  - Use hydrogen sulfide (H_2S) as an electron donor for CO_2 reduction in photosynthesis
  - Sulfide oxidized to elemental sulfur (S^0) that is stored as globules either inside or outside cells
    - Sulfur later disappears as it is oxidized to sulfate (SO_4^{2-})

17.2 Purple Phototrophic Bacteria

- *Purple sulfur bacteria* (cont'd)
  - Many can also use other reduced sulfur compounds, such as thiosulfate ($S_2O_3^{2-}$)
  - All are *Gammaproteobacteria*
  - Found in illuminated anoxic zones of lakes and other aquatic habitats where H_2S accumulates, as well as sulfur springs



(a) (b)

17.2 Purple Phototrophic Bacteria

- *Purple nonsulfur bacteria*
  - Organisms able to use sulfide as an electron donor for CO_2 reduction
  - Most can grow aerobically in the dark as chemoorganotrophs
  - Some can also grow anaerobically in the dark using fermentation or anaerobic respiration
  - Most can grow photoheterotrophically using light as an energy source and organic compounds as a carbon source
  - All in *Alpha*- and *Betaproteobacteria*

17.3 The Nitrifying Bacteria

- *Nitrifying bacteria*
  - Able to grow chemolithotrophically at the expense of reduced inorganic nitrogen compounds
  - Found in *Alpha*-, *Beta*-, *Gamma*-, and *Deltaproteobacteria*
  - *Nitrification* (oxidation of ammonia to nitrate) occurs as two separate reactions by different groups of bacteria
    - *Ammonia oxidizers* (e.g., *Nitrosococcus*)

      Reaction: $NH_3 + 1\frac{1}{2} O_2 \longrightarrow NO_2^- + H_2O$
    - *Nitrite oxidizer* (e.g., *Nitrobacter*)

      Reaction: $NO_2^- + \frac{1}{2} O_2 \longrightarrow NO_3^-$

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17.3 The Nitrifying Bacteria

- *Nitrifying bacteria* (cont'd)
  - Many species have internal membrane systems that house key enzymes in nitrification
    - Ammonia monooxygenase: oxidizes NH_3 to NH_2OH
    - Nitrite oxidase: oxidizes NO_2^- to NO_3^-
    - Widespread in soil and water

17.3 The Nitrifying Bacteria

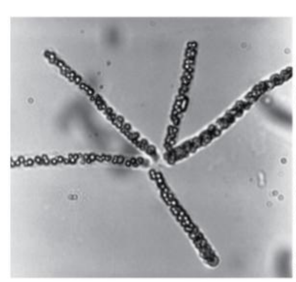
- *Nitrifying bacteria* (cont'd)
  - Highest numbers in habitats with large amounts of ammonia
    - Examples: sites with extensive protein decomposition and sewage treatment facilities
  - Most are obligate chemolithotrophs and aerobes
    - One exception is Anammox organisms, which oxidize ammonia anaerobically

17.4 Sulfur- and Iron-Oxidizing Bacteria

- *Sulfur-oxidizing bacteria*
  - Grow chemolithotrophically on reduced sulfur compounds
  - Two broad classes:
    - Neutrophiles
    - Acidophiles
  - Some acidophiles able to use ferrous iron (Fe^{2+})
  - *Thiobacillus* and close relatives are most studied
    - Sulfur compounds most commonly used as electron donors are H_2S, S^0, $S_2O_3^{2-}$; generates sulfuric acid

17.4 Sulfur- and Iron-Oxidizing Bacteria

- *Sulfur-oxidizing bacteria* (cont'd)
  - *Thiothrix*
    - Filamentous sulfur-oxidizing bacteria in which filaments group together at their ends by a holdfast to form cellular arrangements called rosettes
    - Obligate aerobic mixotrophs



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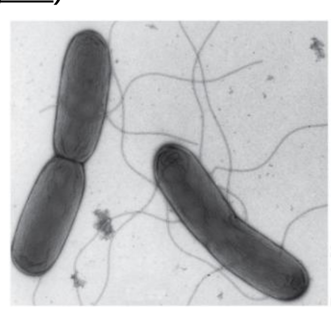
17.5 Hydrogen-Oxidizing Bacteria

- *Hydrogen-oxidizing bacteria*
  - Most can grow autotrophically with H_2 as sole electron donor and O_2 as electron acceptor ("knallgas" reaction)
  - Both gram-negative and gram-positive representatives
  - Contain one or more hydrogenase enzymes that use H_2 either to produce ATP or for reducing power for autotrophic growth

17.5 Hydrogen-Oxidizing Bacteria

- *Hydrogen-oxidizing bacteria* (cont'd)
  - Most are facultative chemolithotrophs and can grow chemoorganotrophically
  - Some can grow on carbon monoxide (CO) as electron donor (*carboxydotrophs*)



17.6 Methanotrophs and Methylotrophs

- *Methanotrophs*
  - Use CH_4 and a few other one-carbon (C_1) compounds as electron donors and source of carbon
  - Widespread in soil and water
  - Obligate aerobes
  - Morphologically diverse

17.6 Methanotrophs and Methylotrophs

- *Methylotrophs*
  - Organisms that can grow using carbon compounds that lack C-C bonds
  - Most are also methanotrophs

17.6 Methanotrophs and Methylotrophs

- *C_1 methanotrophs*
  - Methanotrophs contain *methane monooxygenase*
    - Incorporates an atom of oxygen from O_2 into methane to produce methanol
  - Methanotrophs contain large amounts of sterols

17.6 Methanotrophs and Methylotrophs

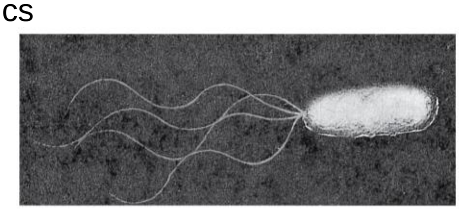
- Ecology and Isolation of Methanotrophs
  - Widespread in aquatic and terrestrial environments
  - Methane monooxygenase also oxidizes ammonia; competitive interaction between substrates
  - Certain marine mussels have symbiotic relationships with methanotrophs

III. Aerobic and Facultatively Aerobic Chemoorganotrophic *Proteobacteria*

- 17.7 *Pseudomonas* and the Pseudomonads
- 17.8 Acetic Acid Bacteria
- 17.9 Free-Living Aerobic Nitrogen-Fixing Bacteria
- 17.10 *Neisseria*, *Chromobacterium*, and Relatives
- 17.11 Enteric Bacteria
- 17.12 *Vibrio*, *Aliivibrio*, and *Photobacterium*
- 17.13 Rickettsias

17.7 *Pseudomonas* and the Pseudomonads

- All genera within the pseudomonad group are
  - Straight or curved rods with polar flagella
  - Chemoorganotrophs
  - Obligate aerobes
- Species of the genus *Pseudomonas* and related genera can be defined on the basis of phylogeny and physiological characteristics



Arthur Kelman

17.7 *Pseudomonas* and the Pseudomonads

- Pseudomonads
  - Nutritionally versatile
  - Ecologically important organisms in water and soil
  - Some species are pathogenic
    - Includes human opportunistic pathogens and plant pathogens

17.7 *Pseudomonas* and the Pseudomonads

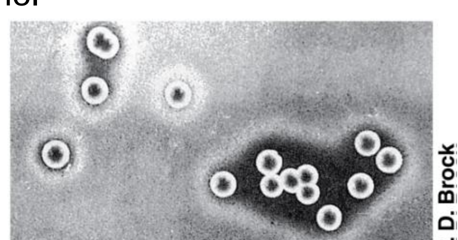
- *Zymomonas*
  - Genus of large, gram-negative rods that carry out vigorous fermentation of sugars to ethanol
  - Used in production of fermented beverages

17.8 Acetic Acid Bacteria

- *Acetic acid bacteria*
  - Organisms that carry out complete oxidation of alcohols and sugars
    - Leads to the accumulation of organic acids as end products
  - Motile rods
  - Aerobic
  - High tolerance to acidic conditions

17.8 Acetic Acid Bacteria

- *Acetic acid bacteria* (cont'd)
  - Commonly found in alcoholic juices
    - Used in production of vinegar
  - Some can synthesize cellulose
  - Colonies can be identified on $CaCO_3$ agar plates containing ethanol



17.9 Free-Living Aerobic Nitrogen-Fixing Bacteria

- Major genera capable of fixing N_2 nonsymbiotically are *Azotobacter*, *Azospirillum*, and *Beijerinckia*
  - *Azotobacter* are large, obligately aerobic rods
    - Can form resting structures (cysts)
  - All genera produce extensive capsules or slime layers
    - Believed to be important in protecting nitrogenase from O_2

17.10 *Neisseria, Chromobacterium*, and Relatives

- *Neisseria, Chromobacterium*, and their relatives can be isolated from animals, and some species of this group are pathogenic

17.11 Enteric Bacteria

- *Enteric bacteria*
  - Phylogenetic group within the *Gammaproteobacteria*
  - Facultative aerobes
  - Motile or nonmotile, nonsporulating rods
  - Possess relatively simple nutritional requirements
  - Ferment sugars to a variety of end products

17.11 Enteric Bacteria

- Enteric bacteria can be separated into two broad groups by the type and proportion of fermentation products generated by anaerobic fermentation of glucose
  - *Mixed-acid fermenters*
  - *2,3-butanediol fermenters*

17.11 Enteric Bacteria

- *Escherichia*
  - Universal inhabitants of intestinal tract of humans and warm-blooded animals
    - Synthesize vitamins for host
  - Some strains are pathogenic
- *Salmonella* and *Shigella*
  - Closely related to *Escherichia*
  - Usually pathogenic
  - *Salmonella* characterized immunologically by surface antigens

17.12 *Vibrio, Aliivibrio*, and *Photobacterium*

- *The Vibrio group*
  - Cells are motile, straight or curved rods
  - Facultative aerobes
  - Fermentative metabolism
  - Best-known genera are *Vibrio, Aliivibrio*, and *Photobacterium*
  - Most inhabit aquatic environments

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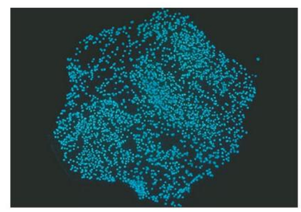
17.12 *Vibrio, Aliivibrio*, and *Photobacterium*

- *The Vibrio group* (cont'd)
  - Some are pathogenic
  - Some are capable of light production (bioluminescence)
    - Catalyzed by luciferase, an O_2-dependent enzyme
    - Regulation is mediated by population density (quorum sensing)


Kenneth H. Nealson

17.13 Rickettsias

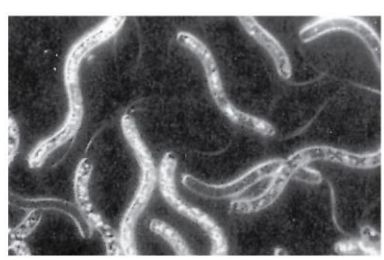
- Rickettsias
  - Small, coccoid or rod-shaped cells
  - Most are obligate intracellular parasites
  - Causative agent of several human diseases

IV. Morphologically Unusual *Proteobacteria*

- 17.14 Spirilla
- 17.15 Sheathed *Proteobacteria*: *Sphaerotilus* and *Leptothrix*
- 17.16 Budding and Prosthecate/Stalked Bacteria

17.14 Spirilla

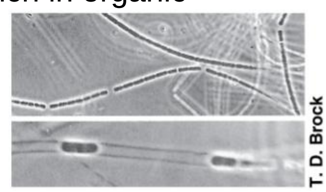
- Spirilla
  - Group of motile, spiral-shaped *Proteobacteria*
  - Key taxonomic features include
    - Cell shape and size
    - Number of polar flagella
    - Metabolism
    - Physiology
    - Ecology



Noel Krieg

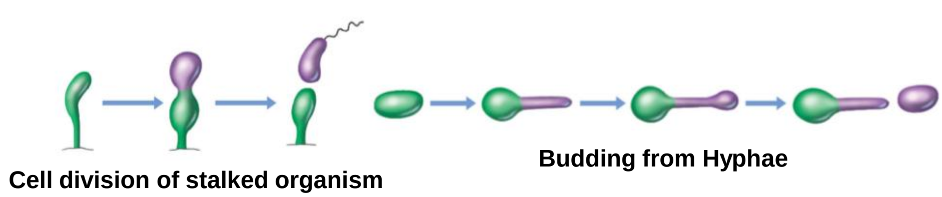
17.15 Sheathed *Proteobacteria*: *Sphaerotilus & Leptothrix*

- Sheathed Bacteria
  - Filamentous *Betaproteobacteria*
  - Unique life cycle in which flagellated swarmer cells form within a long tube or sheath
    - Under unfavorable conditions, swarmer cells move out to explore new environments
  - Common in freshwater habitats rich in organic matter



17.16 Budding and Prosthecate/Stalked Bacteria

- Budding and Prosthecate/Stalked Bacteria
  - Large and heterogeneous group
  - Primarily *Alphaproteobacteria*
  - Form various kinds of cytoplasmic extrusions bounded by a cell wall
  - Cell division different from other bacteria



17.16 Budding and Prosthecate/Stalked Bacteria

- Prosthecate and Stalked Bacteria
  – Appendaged bacteria that attach to particulate matter, plant material, and other microbes in aquatic environments
  – Appendages increase surface-to-volume ratio of the cells

V. *Delta-* and *Epsilonproteobacteria*

- 17.17 Myxobacteria
- 17.18 Sulfate- and Sulfur-Reducing *Proteobacteria*
- 17.19 The *Epsilonproteobacteria*

17.17 Myxobacteria

- Myxobacteria
  - Group of gliding (a form of motility) bacteria that form multicellular structures (*fruiting bodies*) and show complex developmental life cycles
  - *Deltaproteobacteria*
  - Chemoorganotrophic soil bacteria
  - Lifestyle includes consumption of dead organic matter or other bacterial cells

17.18 Sulfate- and Sulfur-Reducing *Proteobacteria*

- Dissimilative sulfate- and sulfur-reducing bacteria
  - Over 40 genera of *Deltaproteobacteria*
  - Use SO_4^{2-} and S^0 as electron acceptors, and organic compounds or H_2 as electron donors
    - H_2S is an end product
- Most obligate anaerobes
- Widespread in aquatic and terrestrial environments

17.18 Sulfate- and Sulfur-Reducing *Proteobacteria*

- Physiology of sulfate-reducing bacteria
  - *Group I*
    - Include *Desulfovibrio*, *Desulfomonas*, *Desulfotomaculum*, and *Desulfobulbus*
    - Oxidize lactate, pyruvate, or ethanol to acetate
  - *Group II*
    - Include *Desulfobacter*, *Desulfococcus*, *Desulfosarcina*, and *Desulfonema*
    - Oxidize fatty acids, lactate, succinate, and benzoate to CO_2

17.19 The *Epsilonproteobacteria*

- *Epsilonproteobacteria*
  - Abundant in oxic–anoxic interfaces in sulfur-rich environments
    - Example: hydrothermal vents
  - Many are autotrophs
    - Use H_2, formate, sulfide, or thiosulfate as electron donor

Overview of Other Bacteria

- *Bacteria* has many phyla other than *Proteobacteria*, including
  - Gram-positive bacteria
    - Large group of mostly chemoorganotrophs
  - Cyanobacteria
    - Oxygenic phototrophs that have evolutionary roots near those of gram-positive bacteria
  - Phylogenetically early-branching phyla
    - Such as *Aquifex* (grow at 95°C)
  - Other morphologically distinct groups

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Chapter 19

Archaea

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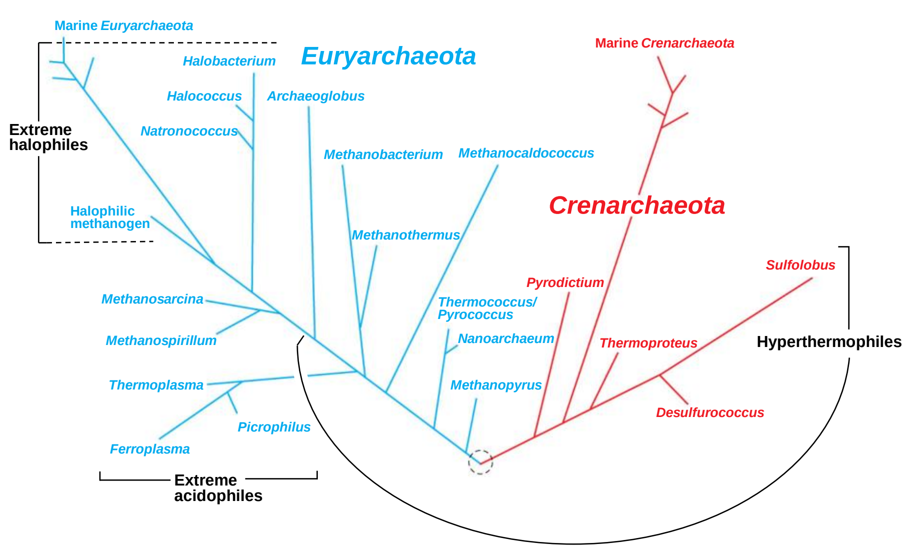
John Zamora
Middle Tennessee State University

19.1 Phylogenetic and Metabolic Diversity of *Archaea*

- *Archaea* share many characteristics with both *Bacteria* and *Eukarya*
- *Archaea* are split into two major groups (Figure 19.1)
  - *Crenarchaeota*
  - *Euryarchaeota*

Figure 19.1 Detailed phylogenetic tree of the Archaea based on 16S rRNA gene sequence comparisons



19.1 Phylogenetic and Metabolic Diversity of *Archaea*

- Bioenergetics and intermediary metabolism of *Archaea* are similar to those found in *Bacteria*
  - Except some *Archaea* use methanogenesis
  - Autotrophy via several different pathways is widespread in *Archaea*

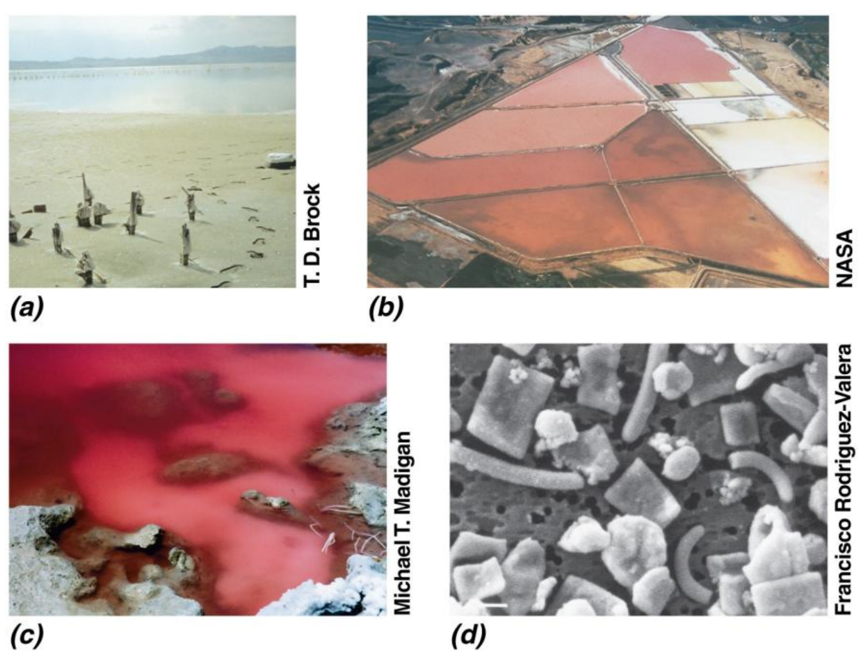
II. *Euryarchaeota*

- <u>*Euryarchaeota*</u>
  - Physiologically diverse group of *Archaea*
  - Many inhabit extreme environments
    - Examples: high temperature, high salt, high acid

19.2 Extremely Halophilic *Archaea*

- <u>*Haloarchaea*</u>
- Key genera: *Halobacterium*, *Haloferax*, *Natronobacterium*
  - – Extremely halophilic *Archaea*
  - – Have a requirement for high salt concentrations
    - Typically require at least 1.5 M (~9%) NaCl for growth
  - – Found in artificial saline habitats (e.g., salted foods), solar salt evaporation ponds, and salt lakes (Figure 19.2)

Figure 19.2 Hypersaline habitats for halophilic Archaea



19.2 Extremely Halophilic *Archaea*

- Extremely hypersaline environments are rare
  - Most found in hot, dry areas of world
- Salt lakes can vary in ionic composition, selecting for different microbes
  - Great Salt Lake similar to concentrated seawater
  - Soda lakes are highly alkaline hypersaline environments

19.2 Extremely Halophilic *Archaea*

- Water Balance in Extreme Halophiles
  - Halophiles need to maintain osmotic balance
    - This is usually achieved by accumulation or synthesis of compatible solutes
  - *Halobacterium* species instead pump large amounts of K^+ into the cell from the environment
    - Intracellular K^+ concentration exceeds extracellular Na^+ concentration and positive water balance is maintained

19.3 Methanogenic *Archaea*

- *Methanogens*
  - Key genera: *Methanobacterium, Methanocaldococcus, Methanosarcina*
    - Microbes that produce CH_4
    - Found in many diverse environments
    - Taxonomy based on phenotypic and phylogenetic features
- Process of methanogenesis first demonstrated over 200 years ago by Alessandro Volta

19.3 Methanogenic *Archaea*

- Substrates for Methanogens
  - Obligate anaerobes
  - 11 substrates, divided into 3 classes, can be converted to CH_4 by pure cultures of methanogens
    - Other compounds (e.g., glucose) can be converted to methane, but only in cooperative reactions between methanogens and other anaerobic bacteria

19.4 *Thermoplasmatales*

- *Thermoplasmatales*
- Key genera: *Thermoplasma, Ferroplasma, Picrophilus*
  - Taxonomic order within the *Euryarchaeota*
  - Thermophilic and/or extremely acidophilic
  - *Thermoplasma* and *Ferroplasma* lack cell walls

19.5 *Thermococcales* and *Methanopyrus*

- Three phylogenetically related genera of hyperthermophilic *Euryarchaeota*:
  - *Thermococcus*
  - *Pyrococcus*
  - *Methanopyrus*
- Comprise a branch near root of archaeal tree

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19.6 *Archaeoglobales*

- *Archaeoglobales*
  - Key genera: *Archaeoglobus, Ferroglobus*
    - Hyperthermophilic
    - Couple oxidation of H_2, lactate, pyruvate, glucose, or complex organic compounds to the reduction of SO_4^{2-} to H_2S

19.7 *Nanoarchaeum* and *Aciduliprofundum*

- *Nanoarchaeum equitans*
  - One of the smallest cellular organisms (~0.4 μm)
  - Contains one of the smallest genomes known
  - Lacks genes for all but core molecular processes
  - Depends upon host for most of its cellular needs

III. *Crenarchaeota*

19.8 Habitats and Energy Metabolism

- *Crenarchaeota*
  - Inhabit temperature extremes
  - Most cultured representatives are hyperthermophiles
    - Found in extreme heat environments
  - Other representatives found in extreme cold environments

19.8 Habitats and Energy Metabolism

- *Hyperthermophilic Crenarchaeota*
  - Most are obligate anaerobes
  - Chemoorganotrophs or chemolithotrophs with diverse electron donors and acceptors

19.9 *Crenarchaeota* from Terrestrial Volcanic Habitats

- *Thermoproteales*
  - Key genera: *Thermoproteus, Thermofilum*, and *Pyrobaculum*
  - Inhabit neutral or slightly acidic hot springs or hydrothermal vents

19.10 *Crenarchaeota* from Submarine Volcanic Habitats

- Shallow-water thermal springs and deep-sea hydrothermal vents harbor the most thermophilic of all known *Archaea*
  - *Pyrodictium* and *Pyrolobus*
    - Optimum growth temperature above 100°C
    - *Pyrolobus fumarii* Strain 121 grow up to 121°C
  - *Desulfurococcus* and *Ignicoccus*
  - *Staphylothermus*

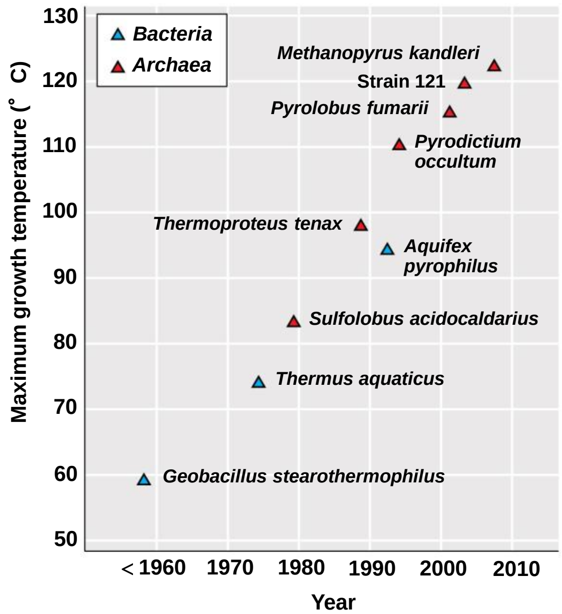
19.11 *Crenarchaeota* from Nonthermal Habitats

- Nonthermophilic *Crenarchaeota* have been identified in cool or cold marine waters and terrestrial environments by culture-independent studies
  - Abundant in deep ocean waters
  - Appear to be capable of nitrification

19.12 An Upper Temperature Limit for Microbial Life

- What are the upper temperature limits for life?
  - New species of thermophiles and hyperthermophiles being discovered (Figure 19.25)
  - Laboratory experiments with biomolecules suggest 140–150°C

Figure 19.25 Thermophilic and hyperthermophilic prokaryotes



19.13 Molecular Adaptations to Life at High Temperature

- Stability of Monomers
  - Protective effect of high concentration of cytoplasmic solutes
  - Use of more heat-stable molecules
    - For example, use of nonheme iron proteins instead of proteins that use NAD and NADH

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19.13 Molecular Adaptations to Life at High Temperature

- Protein Folding and Thermostability
  - Amino acid composition similar to that of nonthermostable proteins
  - Structural features improve thermostability
    - Highly hydrophobic cores
    - Increased ionic interactions on protein surfaces

19.14 Hyperthermophilic *Archaea*, H_2, and Microbial Evolution

- Hyperthermophiles may be the closest descendants of ancient microbes
  - Hyperthermophilic *Archaea* and *Bacteria* are found on the deepest, shortest branches of the phylogenetic tree
  - The oxidation of H_2 is common to many hyperthermophiles and may have been the first energy-yielding metabolism (Figure 19.28)

Figure 19.28 Upper temperature limits for energy metabolism