Prokaryotic origin, classification and reproduction

From high school to college, biology students are required to understand the key components needed for “cell” organization. One crucial topic centers around how prokaryotic cells are different from eukaryotic cells, such as organelles, plasma membranes, metabolic processes, and reproduction strategies.

The key properties of life, particularly for early cell formation, required the ability to accurately replicate and perform metabolic functions. Early protobionts (a precursor cell model to prokaryotic cell structure) fit this set of requirements by maintaining a membrane-like structure composed of lipids. This lipid membrane maintains an internal chemical environment different from the outside environment in which it lives. In the laboratory, liposome protobionts show that they can both reproduce and have simple metabolic reactions. Current research suggests that RNA was most likely the first “genetic” material (predating DNA) and used for early protein synthesis. Presence of RNA improved a cell’s ability to survive, both metabolically (enzyme catabolic reactions) and with replications of strands in short series, which can be passed onto offspring.

Early earth history timelines suggest that early cell formation (the protobiont model) arose during Archean eon (which started about 4 Billion years ago). Considering the evidence of prokaryotic cell fossils which date back 3.5 billion years ago (ie: cyanobacteria) it is likely that the earliest protobiont cell structure formed before that time. Stromatolites are early prokaryotic biofilm structures that bound sediment together, in warm shallow waters Stromatolites are some of the earliest evidence in the rock strata found of microbial communities 3.5 Billion years ago. Early stromatolites were flagellated, single cells, which formed biofilms at the water, air, sediment interface. Many were photosynthetic, and inhabited a variety of temperature and saline conditions around the world.

Soon after prokaryotic cells organized (those that lack a membrane bound nucleus, mitochondria, or other membrane bound organelles), evolutionary biologists believe a divergence gave rise to the more complex archaebacteria lineage. Archaebacteria cell structure have more complex macromolecules (proteins, carbohydrates, tRNA, RNA polymerase) than do the prokaryotic cell type. As cell structure moved to more complexity diversity, other cell types arose in the fossil records (about 1.7 - 2.5 billion years ago), the eukaryotic cell types.

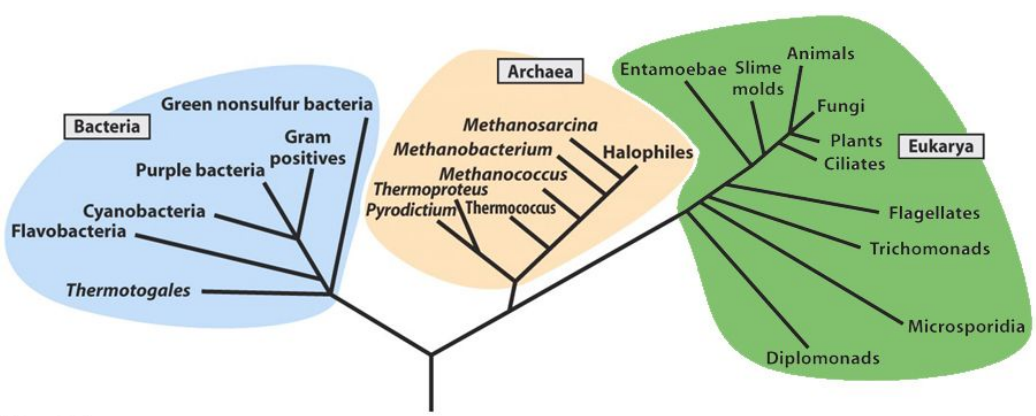

Figure 12-7
Biology of Plants, Seventh Edition
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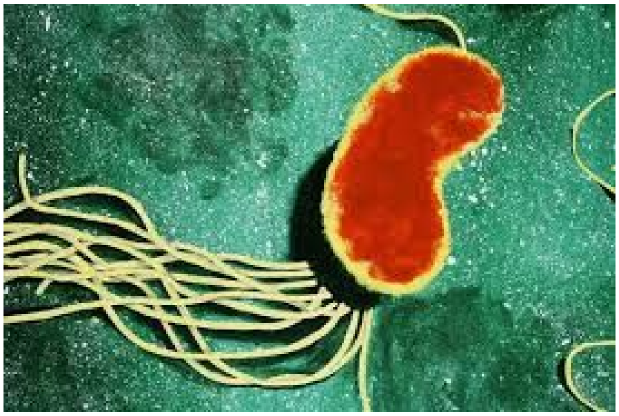
The origin of multicellularity follows the split from eukaryotic bacteria domain (prokaryotic cell structures) followed later by the divergence of eukaryotic cell types and archaebacteria. Due to changes in the earth’s surface, a number of fossil record gaps occur between 1.7 billion years ago and 565 million years ago (MYA), limiting our ability to connect fossil evidence fluidly.

Classification of prokaryotes:



As some of the oldest organisms on the planet, Prokaryotic cells have had a long time to diversify. Changes in environmental conditions paired with natural selection pressures have aided this diversification. Identification and classification of these cells is based on their metabolic processes and morphological traits. The most common prokaryotic bacteria shapes are spherical, rod shaped, and spiral. Beyond these simple shape classifications, prokaryotic bacteria are named according to formation of how or if they aggregate (ie strepto-, staphlo -) and their cell wall composition. Gram negative bacteria are structurally more complex in cell wall structure and membrane layers than the more simpler composition of Gram positive bacteria.

Pseudomonas fluorescens (P.flu) is a gram negative, rod shaped bacteria with flagella, that has commensalistic relationships with plants. *Pseudomonas* literally means "false unit." *Fluorescence* is used because the bacteria has greenish fluorescent soluble pigment which increases its presence in low iron conditions. Under high iron conditions they fluoresce less. As an obligate aerobe, some strains of *P.flu* can use NO_3 as an electron acceptor, in low O_2 conditions. *P.flu* grows well in many conditions, and particularly well in mineral salt media, with a variety of carbon sources (glucose, fructose, glycerol, etc). Temperature range ideals are 25-30C, however some have been found to still proliferate at lower temperatures.

Metabolically, prokaryotes are classified initially as autotrophic or heterotrophic, and secondarily based on what energy source (the sun or organic chemicals) and what carbon source (CO2 or organic compounds) are used for growth and metabolism. Obligate aerobes require oxygen for cellular respiration, whereas obligate anaerobes would be poisoned by oxygen. Nitrogen is essential for the production of amino acids (protein building) and nucleic acids (RNA and DNA). Prokaryotes that have the ability to process nitrogen better would both benefit its own lifecycle, as well as other organisms it may associate with, ie: *P.flu* commensalism w/ sugar beets.

Pseudomonas fluorescens SBW25 has been isolated from the leaves of sugar beets. *P.flu* is a diverse species which inhabits soil, water, and plant surfaces. It has been found to provide plants with antimicrobial resistance, possibly by way of outcompeting for iron resources with other pathogens to the plant. A number of other research studies are looking at the antimicrobial abilities of *P.flu*. Many *P.flu* strains contain lipases and proteases which make milk spoil by breaking casein down, and coagulating proteins (biofilms). Along with the main yogurt bacterias (Lactobacillus, bifidobacteria, etc) it is what sours the milk and creates the unique yogurt flavor and texture.

Other research involving different *P.flu* strains, include its use to remove invasive species of zebra mussels, which seems to be 90% effective at "intoxicating" the zebra mussels due to their interaction with the mussels digestive gland and lysis of those cells. *P.flu* has been found to produce the antibiotic Mupirocin, which has been found to be effective against MRSA (antibiotic resistant bacteria) in burn patients.

P.flu is being studied as an organism to help in bioremediation projects to protect seeds and roots from fungal infections due to its production of antibiotic products and hydrogen cyanide. There is consideration of using it for a pesticide for agricultural uses. They are able to destroy soil pollutants and toxins such as: styrene, polycyclic aromatic hydrocarbons, and TNT.(web.mst.edu)

Reproduction:
Success of prokaryotes is due in part to their ability to reproduce quickly in favorable conditions. (*P.flu* approximately 8 generations in 24 hours). However, this rapid reproduction process of prokaryotic organisms will be limited by: nutrient supply for the new organisms; metabolic waste produced by the growing colony numbers which can poison their environ; competitions from other microorganisms, and possible predation. Most prokaryotic reproduction is facilitated by binary fission, in which daughter cells have the equivalent genetic information as their "parent". As prokaryotic genomic DNA is circular and typically smaller in size than most eukaryotes, replication, transcription and translation are easily processed in a short turn around time. Mitosis and protein synthesis are incredibly similar to the eukaryotic process.

Because prokaryotes reproduce rapidly w/ fission, DNA, and RNA mutations (deletions, insertions, base pair substitutions, etc) can also rise rapidly in the new generations. In sexually reproducing organisms, genetic variation typically happens with changes to allelic arrangements or new combinations due to reorganization during meiosis and fertilization. Though some prokaryotes do occasionally reproduce sexually (conjugation), diversification commonly results from mutations in the binary fission process. Short generation times, compounded with large populations with the added factor of mutations,lead to rapid evolution trends in a bacteria population. These factors make prokaryotic organisms so interesting to study in a longitudinal sequence. (see lenski film)

Genetic recombination in Prokaryotes could result from three processes:

1) **Horizontal gene transfe**r can be facilitated by transformation, a process in which harmless strains of a bacteria may be growing in media that contains pathogenic DNA, and plasmids are exchanged between individuals. This plasmid exchange could potentially contain a few genes or large groups of genetic material, which is then incorporated into the new cells DNA. Griffith's experiments in 1928 with mice, and two strains of Streptococcus pneumoniae, or more current research on antibiotic resistant strains of bacteria.
2) **Transductions** also a horizontal gene transfer, is accomplished when virus' (bacteriophage) carry bacterial genes from one host to another. This typically is by accident while the phage is using the host to replicate itself and its DNA. Sections of recombinant DNA may occur which have spliced the viral DNA into the host's.
3) **Conjugation** (sexual reproduction) occurs typically between similar species of bacteria. During conjugation, the transfer of DNA is donated by one cell, and taken up by the other across a mating bridge. The shared DNA may be a full plasmid or simply a segment of DNA. It is now known that bacteria have surface proteins which identify DNA from close relatives and will uptake and incorporate those strands into their own.

Current trends in research allow for the ability to cryopreserve store samples from each generation, which then makes it easy to either compare both phenotypic and genotypic specimens from the same lineage, as well as perform DNA analysis on each type of specimen.

- Lenski (Michigan state) shows evidence of parallel changes in the same genotypic locations from two different colonies with the same ancestors. a good example of adaptive evolution)
- longitudinal studies documenting adaptive evolutions - ie: connections to research papers

- pg 560 8th ed for Cooper Lenski protocol example and graph.

Resources:

Campbell, Biology text, 8th ed

European Bioinformatics InstituteProtein Information ResourceSIB Swiss Institute of Bioinformatics. ""Sequence-based Analysis of PQBR103; a Representative of a Unique, Transfer-proficient Mega Plasmid Resident in the Microbial Community of Sugar Beet."" *UniProt*. N.p., n.d. Web. 28 Mar. 2017. http://www.uniprot.org/proteomes/UP000002332

Infoplease. Infoplease, n.d. Web. 28 Mar. 2017. http://www.infoplease.com/cig/biology/origin-prokaryotes.html

Protobiont video link: https://www.youtube.com/watch?v=Z0zdEJXhgG0

"Pseudomonas Fluorescens." *Pseudomonas Fluorescens*. N.p., n.d. Web. 28 Mar. 2017 http://web.mst.edu/~microbio/BIO221_2009/P_fluorescens.html

https://microbewiki.kenyon.edu/index.php/Pseudomonas_fluorescens