Endosymbiotic Hypothesis: Origins of Mitochondria and Chloroplasts

There are great many differences between Eukaryotic and Prokaryotic cells in size, complexity, internal compartments. However, there is a curious similarity between prokaryotic cells and the organelles of eukaryotic cells in terms of DNA, binary fission, ribosomes, electron transport chain etc. These were first noted in the 1880s, but were largely ignored for almost a century. Based on these similarities, a hypothesis about the possible ancestors of mitochondria and chloroplasts came up.

Endosymbiotic Theory was first proposed by former Boston University Biologist Lynn Margulis in the 1960's and officially in her 1981 book "Symbiosis in Cell Evolution". Although now well accepted, she was ridiculed by mainstream biologists for a number of years.

Dr. Margulis was doing research on the origin of eukaryotic cells. She proposed that similarities between prokaryotes and organelles could best be explained by "endo-symbiosis".

[Endo = "within"]

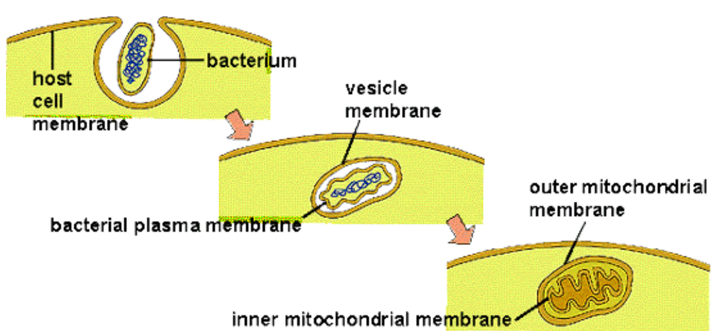
[Endocytosis = (cyto = cell) a process of 'cell eating' - cells are engulfed, but then usually digested as food]

[Endosymbiosis = cells are engulfed, but not digested...cells live together is a mutually benefitting relationship, or symbiosis]

Her hypothesis originally proposed that:

- Mimitochondria are the result of endocytosis of aerobic bacteria
- Chloroplasts are the result of endocytosis of photosynthetic bacteria
- In both cases by large anaerobic bacteria who would not otherwise be able to exist in an aerobic environment.
- This arrangement became a mutually beneficial relationship for both cells (symbiotic).

Margulis' original hypothesis proposed that aerobic bacteria (that require oxygen) were ingested by anaerobic bacteria (poisoned by oxygen), and may each have had a survival advantage as long as they continued their partnership. Aerobic bacteria would have handled the toxic oxygen for anaerobic bacteria, and anaerobic bacteria would ingest food and protected aerobic "symbiote". The result is that cell came up with double-membrane bound organelle. Inner lipid bilayer would have been bacterial plasma membrane, and outer lipid bilayer came from the cell that engulfed it.



Other evidence that supports this hypothesis:

1. The timeline of life on Earth:

a. Scientists have fossil evidence of bacterial life on Earth ~3.8 billion years ago. At this time, the atmosphere did not contain oxygen, and all life was anaerobic.

b. About ~3.2 billion years ago, fossil evidence of photosynthetic bacteria, or cyanobacteria, appears. These bacteria use the sun's energy to make sugar. Oxygen, released as a byproduct, began to accumulate in the atmosphere. However, oxygen is actually pretty toxic to cells, even our cells. As a result, anaerobic cells were now a disadvantage in an oxygen-containing atmosphere, and started to die out as oxygen levels increased.

c. Aerobic cells appear in the fossil record shortly after that (~2.5 Billion years ago). There cells were able to use that 'toxic' oxygen and convert it into energy (ATP) and water. Organisms that could thrive in an oxygen-containing atmosphere were now 'best suited to the environment'.

2. Organelles have their own DNA, and divide independently of the cell they live in: When Margulis initially proposed the Symbiotic Theory, she predicted that, if the organelles were really bacterial (prokaryotic) symbionts, they would have their own DNA. If her theory DID best explain the origin of eukaryotic cells, she reasoned, organelles would have DNA that resembled bacterial DNA and be different from cell's DNA. Amazingly, in the 1980's this was proven to be the case for two classes of organelles, the mitochondria and chloroplasts. Further, in late 1980's a team of Rockefeller University investigators announced their similar discovery regarding centrioles, structures that help eukaryotic cell in locomotion and cell division.

Source: https://www.biology.iupui.edu/biocourses/N100/2k2endosymb.html

Further reading: https://www.ruf.rice.edu/~bioslabs/studies/mitochondria/mitorigin.html