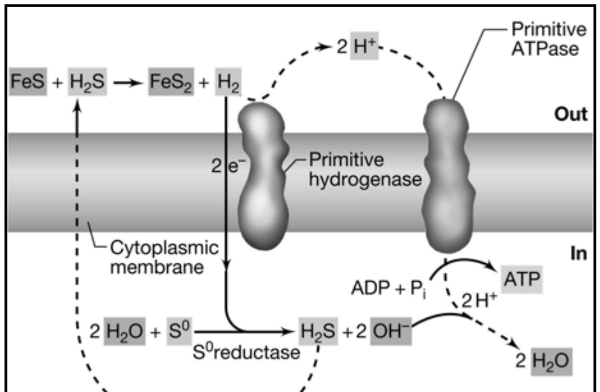
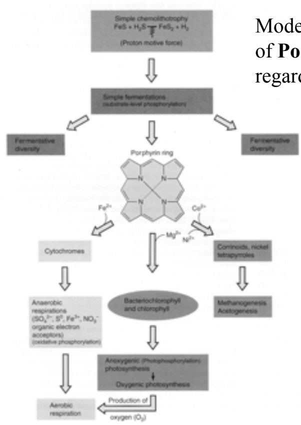
The Molecular Clues to the Origin of Life on Earth

- Molecules of living organisms are rich in **hydrogen-containing carbon** compounds that are highly reduced. This suggests that there were little or no free molecular oxygen on primitive Earth.
- All **amino acids** exist in both the right-handed and left-handed state. However, only 20 amino acids of the left-handed variety are used by living organisms in proteins. Therefore, suggesting there was a single origin of life.
- **DNA** & **RNA** are the universal informational basis of all life forms on Earth.
- **ATP** is the universal energy currency of all living organisms; suggesting a common origin of metabolism.
- In any cell, first steps of carbohydrate metabolism involve **fermentation**, with the last steps in aerobic organisms the usage of oxygen via **respiration** – suggesting that aerobic organisms evolved from anaerobic ones.



The formation of pyrite leads to H_2 production, which fuels ATPase



Model for the development of **Porphyrin Ring** diversity regarding metabolic pathways

To understand how the origin of life from abiotic material occurred, we have to consider two critical concepts:

1. The extension of the idea of natural selection to the chemical level.

2. The realization that the condition of the early Earth when life first arose must have been vastly different from present:

> (a) Non-oxidizing atmosphere: present level of oxygen, which began to accumulate around 2.1 billion years ago with the presence of cyanobacteria, would have been lethal to primitive organisms
>
> (b) Abundant resources produced non-biologically
>
> (c) Long time scale without competition

Origins of Life Models

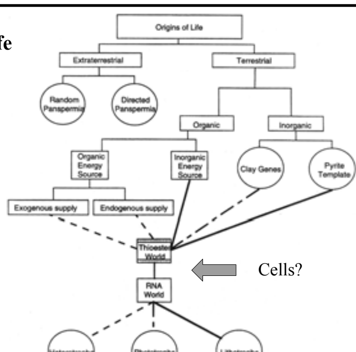


Figure 10.6 Relationships among various theoretical or conceptual models for the origins of life.[77] Dashed and solid lines at the bottom of the figure connect mechanisms with putative metabolic type of first organisms. The thioester world is proposed as an intermediate leading to an RNA world

Thioester World
Chemical Transformations

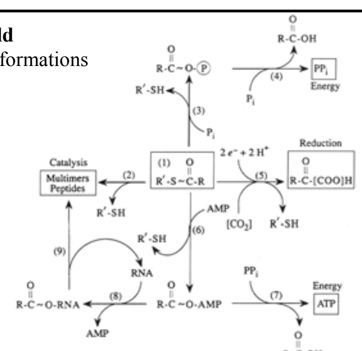


Figure 10.10 Synopsis of chemical transformations in the thioester world illustrating: (1) a pool of thioesters; (2) polymerisation of protoenzymes; (3) generation of high-energy phosphate esters; (4) generation of pyrophosphate, a primordial energy carrier; (5) thioester-based organic synthesis reactions; (6) formation of high-energy adenylate derivatives; (7) production of ATP; (8) generation of acyl-RNA complexes (e.g. amino-charged tRNA); (9) peptide formation[29]

Thioester World
Mechanisms of synthesis

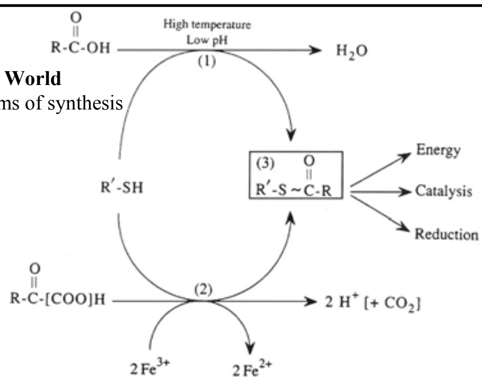


Figure 10.12 Mechanisms for synthesis of thioesters. (1) High temperature, low pH spontaneous synthesis from thiols and organic acids; (2) oxidative synthesis from thiols and α-keto organic acids based on ferric iron reduction[29]

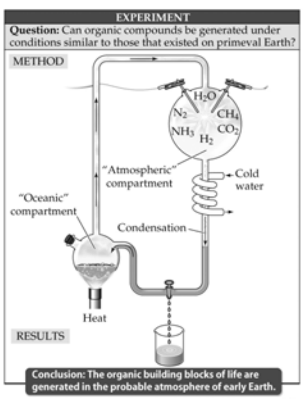
The Chemical Aspects of The Origin of Life

Life is the cumulative product of interactions among the many kinds of chemical substances that make up the cells of an organism.

The abiotic chemical evolution of life follows four major hurdles:

1. The abiotic synthesis and accumulation of small organic molecules, or monomers, such as amino acids and nucleotides.
2. The joining of these monomers into polymers, including proteins and nucleic acids.
3. The aggregation of abiotically produced molecules into droplets, e.g., protobionts, that had chemical characteristics different from their surroundings.
4. The origin of heredity or information transference.

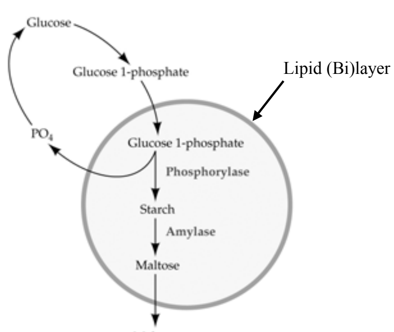
Diagram of Stanley Miller's apparatus



Necessary Conditions for the Origin of Life

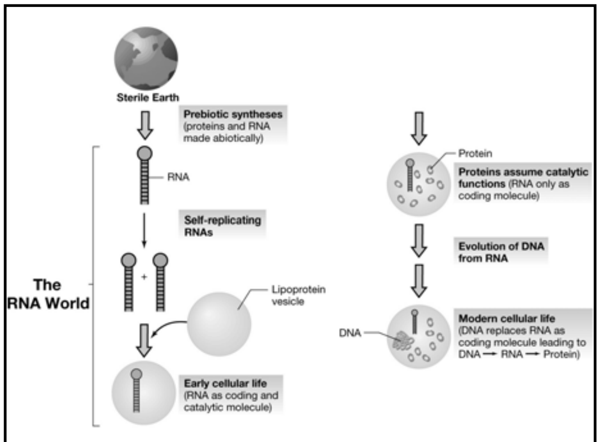
- Before life appeared, polymerization reactions generated the carbohydrates, lipids, amino acids, and nucleic acids of which organisms are composed. These molecules accumulated in the oceans.
- Originally "Darwin's Warm Pond" Hypothesis

Putative "Metabolism" of a Coacervate Drop

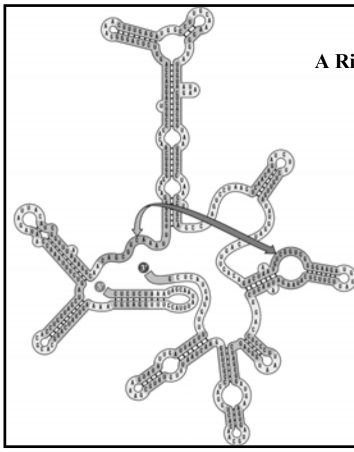


Protobionts: Enclosing Prebiotic Systems

- DNA probably evolved after RNA-based life became surrounded by membranes that provided an environment in which DNA was stable.



A Ribozyme from a Protist



Folding brings together complementary but distant base sequences allowing catalytic activity to occur

RNA World: Peptide Bond Formation

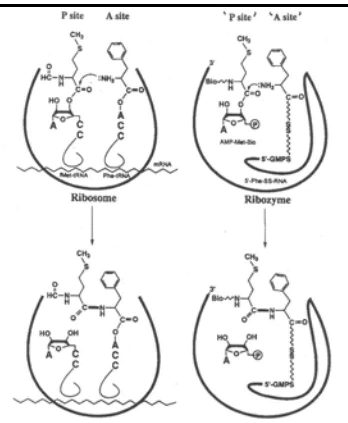
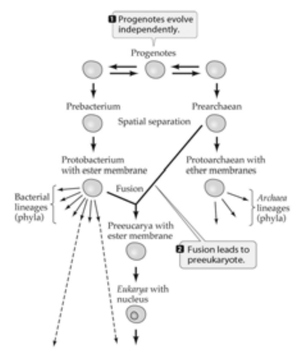
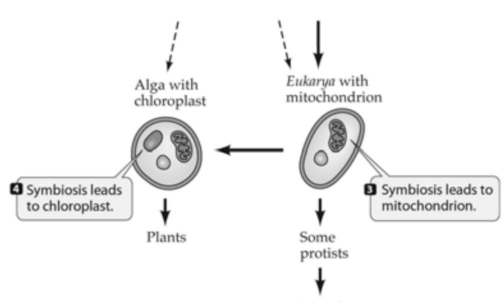


Figure 1 Peptide bond formation by a ribosome (left) and by a ribozyme (right).

Evolution of the main lines of descent



Evolution of the main lines of descent (cont.)



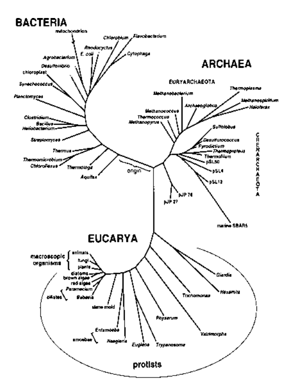


Figure 1. Diagrammatic "Universal" phylogenetic tree of life, based on small-subunit ribosomal RNA sequences. Based on analyses of Barns et al. (1996b), Olsen et al. (1994), and Sogin (1994).

Some Lessons from the BIG TREE:
Map of the Biological Record

Single origin for all life on Earth...

- Central Dogma intact
- ATP and PMF are universal themes
- Uniformity among chiral carbon compds (sugars & AAs)
- Hot start origin…

- Also Cyanobacteria did not arrive first on the scene!
- Now estimated at 2.5 –2.1 bya.

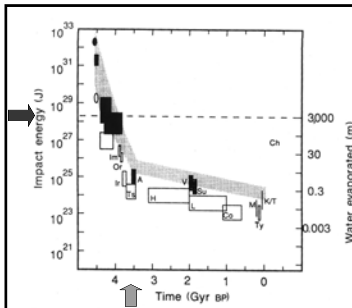
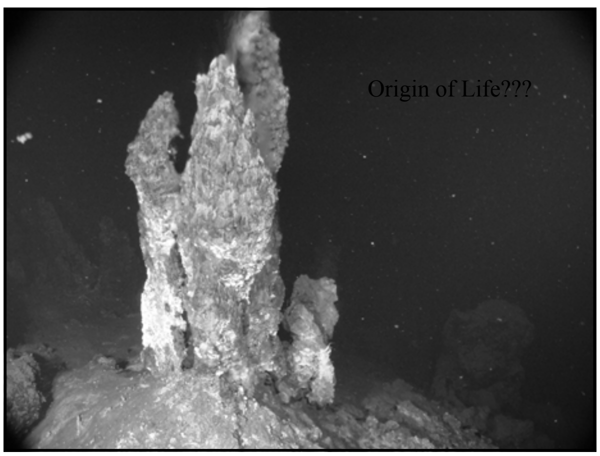


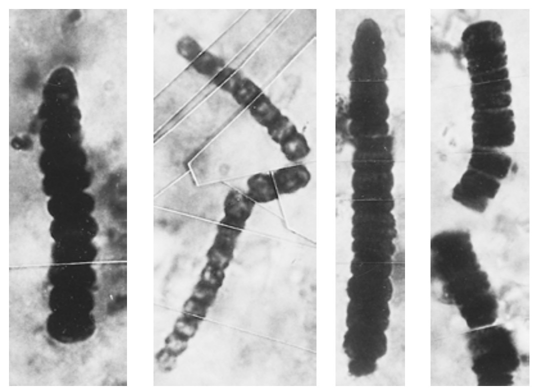
FIG. 1 The largest impacts on Earth and Moon. Open boxes are lunar, filled boxes terrestrial. Lunar craters are Tycho, Copernicus, Langrenus, Hausen, Tsiolkovski, Iridum, Orientale and Imbrium. Terrestrial events are the K/T impact, Manicougan, Sudbury, Vredevort and an impact energy corresponding to the thickness of Archaean spherule beds. Ovals are self energies of formation; the early box refers to a possible Moon-forming impact. Impact estimates between 3.8 and 4.4 Gyr are discussed in the text. The stippled region for Earth is inferred from these data. The depth of ocean vaporized by the impact is also given; the dashed line corresponds to an ocean-vaporizing impact. A possible but extremely unlikely collision with Chiron is placed safely in the future.

Impact Frustration period forces origins of life into a narrow time period to have gotten started!

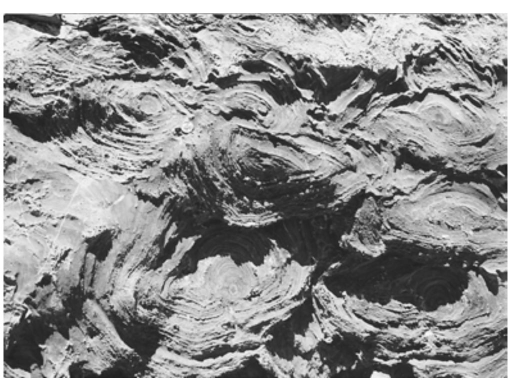
Hydrothermal vents may have served as zones of refuge.



Fossil Stromatolites and mat communities

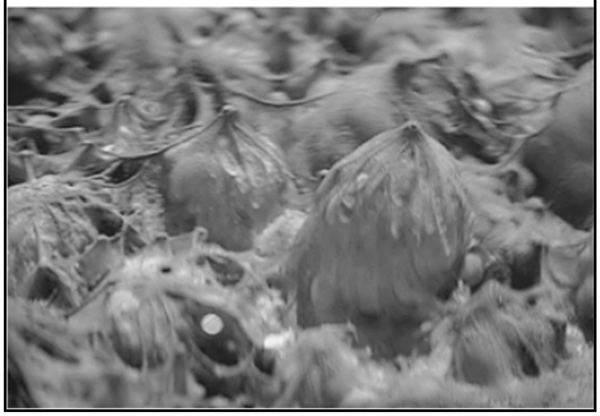


Fossil Stromatolites from Glacier Natl. Park

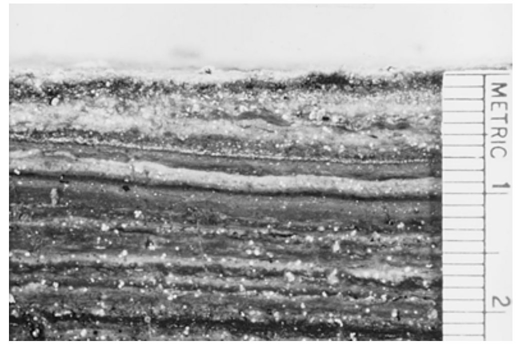


Living columnar stromatolites, Shark Bay, Western Australia

Modern Stromatolites from Yellowstone Natl. Park



Microbial mat communities



Photosynthesis Is the Source of Atmospheric O_2

- Cyanobacteria, which evolved the ability to split water into hydrogen ions and O_2, created atmospheric O_2. Accumulation of free O_2 in the atmosphere made possible the evolution of aerobic metabolism.

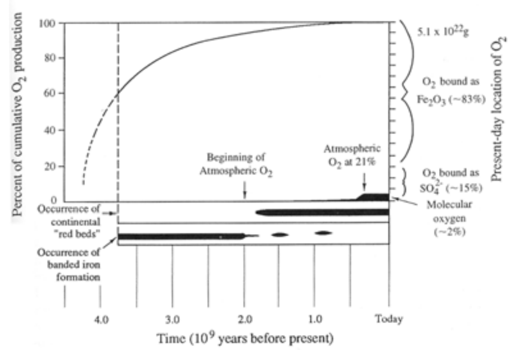


Figure 2.7 Cumulative history of O_2 released by photosynthesis through geologic time. Of more than 5.1×10^{22} g of O_2 released, about 98% is contained in seawater and sedimentary rocks, beginning with the occurrence of Banded Iron Formations at least 3.5 billion years ago (bya). Although O_2 was released to the atmosphere beginning about 2.0 bya, it was consumed in terrestrial weathering processes to form Red Beds, so that the accumulation of O_2 to present levels in the atmosphere was delayed to 400 mya. Modified from Schidlowski (1980).

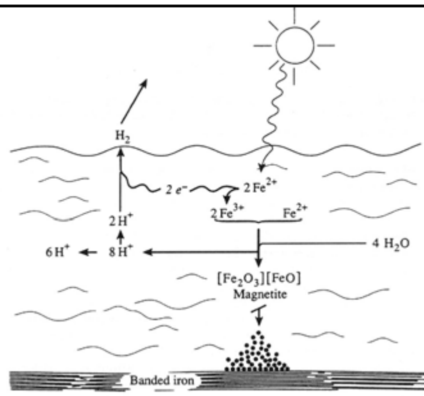
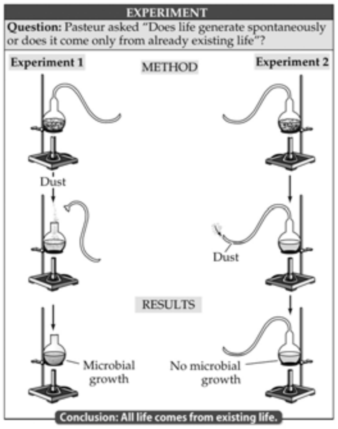


Figure 10.11 Light-driven hydrogen production and iron oxidation resulting in early banded iron formations[29]

Is Life Evolving from Nonlife Today?

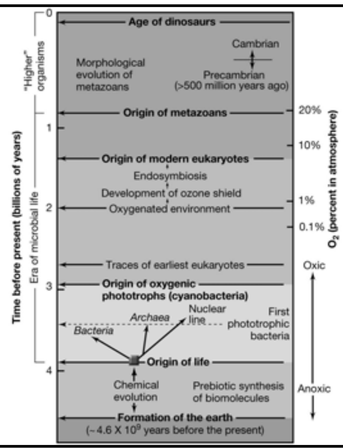
- Because most of the chemical reactions that gave rise to life occur readily under the conditions that prevailed on early Earth, life's evolution was "probably" inevitable.
- Experiments by Louis Pasteur and others convinced scientists that life does not come from nonlife on Earth today.



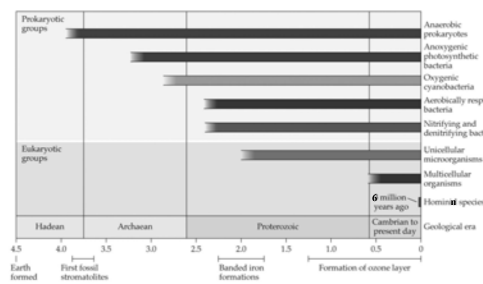
Pasteur was also the father of "origins of life" research

Is Life Evolving from Nonlife Today?

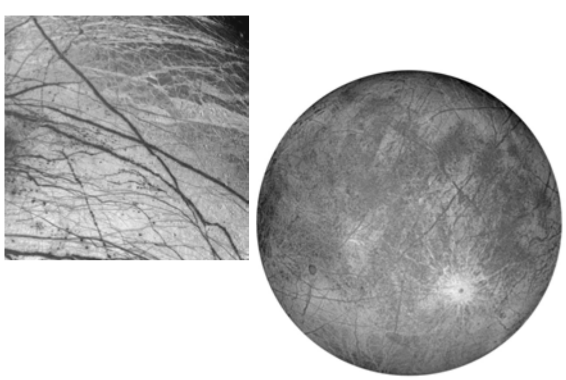
- New life is no longer being assembled from nonliving matter because simple biological molecules that form in today's environment are oxidized or consumed by existing life.
- Now we have competition & oxygen!



Geological and evolutionary timetable



Europa, Jupiter's moon: Astrobiology???



Does Life Exist Elsewhere in the Universe?

- Conditions that permit the evolution and maintenance of simple prokaryotic life may be widespread in the universe, but multicellular life has more stringent requirements, including a planet with a relatively circular orbit, a rapid rate of spin, nearby planets that intercept impacts, and a large moon that stabilizes the planet's orbit. Such conditions may be very rare.