RNA World Hypthesis & origin of life

Unit II, Paper- Zoo-301

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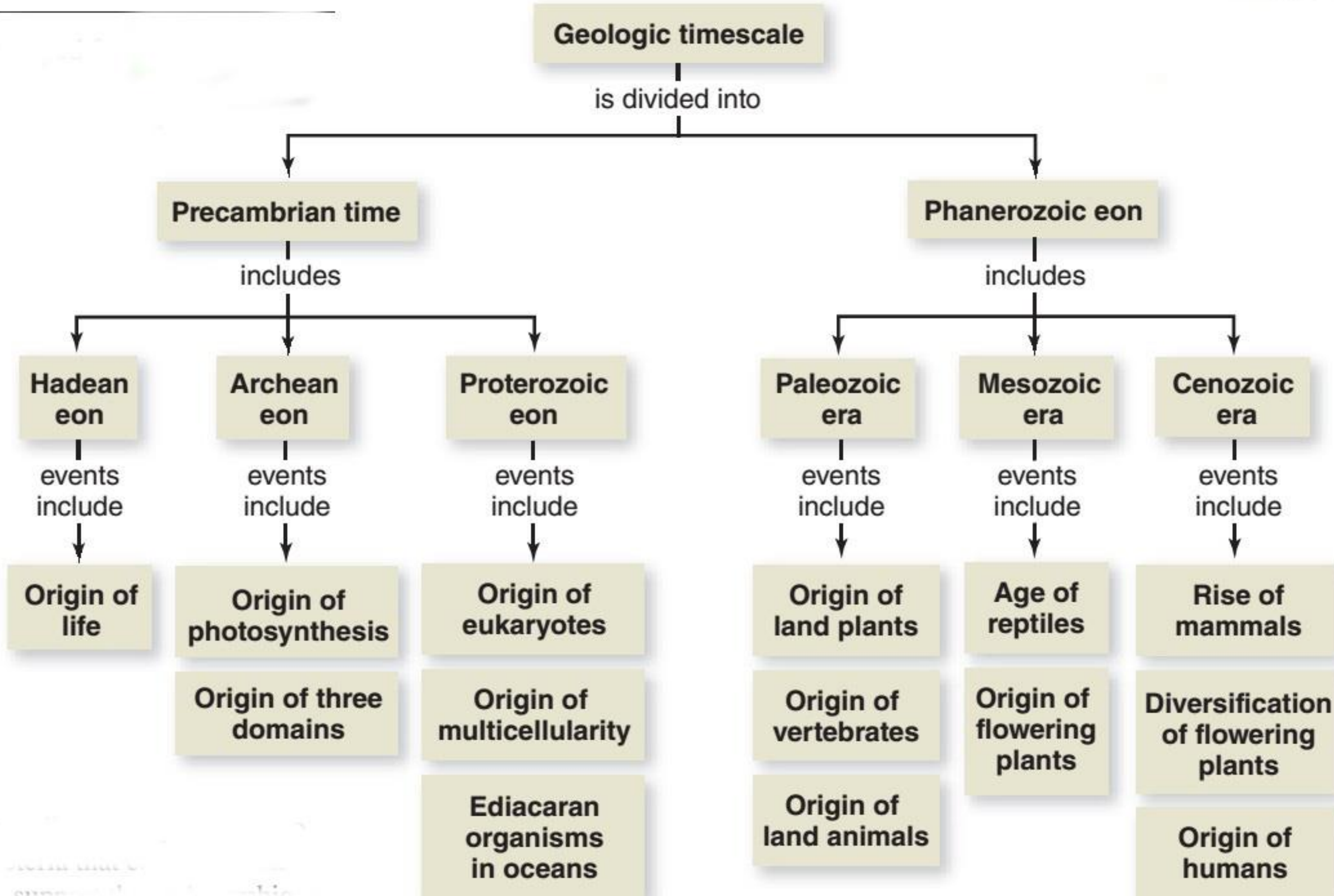
The Evolutionary History of Life

geologic time scale: a division of Earth's history into eons, eras, periods, and epochs defined by major geological or biological events



Geologic timescale
is divided into
Precambrian time
Phanerozoic eon
includes
includes
Hadean eon
Archean eon
Proterozoic eon
Paleozoic era
Mesozoic era
Cenozoic era
events include
events include
events include
events include
events include
events include
Origin of life
Origin of photosynthesis
Origin of three domains
Origin of eukaryotes
Origin of multicellularity
Ediacaran organisms in oceans
Origin of land plants
Origin of vertebrates
Origin of land animals
Age of reptiles
Origin of flowering plants
Rise of mammals
Diversification of flowering plants
Origin of humans

Defining Life

- In fact, when we consider what life really is, and how living systems can be distinguished from nonliving ones, the ability to store and transmit information (genotype) and the ability to express t4hat information (phenotype) are perhaps the most important criteria that set life apart from nonlife.
- Besides, the ability to evolve is a crucial component of any definition of life.

Origin of Life ????

- In 2004, a poliovirus was synthesized in lab using simple chemicals. This virus was capable of replicating its genome and could infect living cells.

- Although viruses are not cells, they show some similarities to living things and may be similar to some of the earliest forms of life.

Origin of Life ????

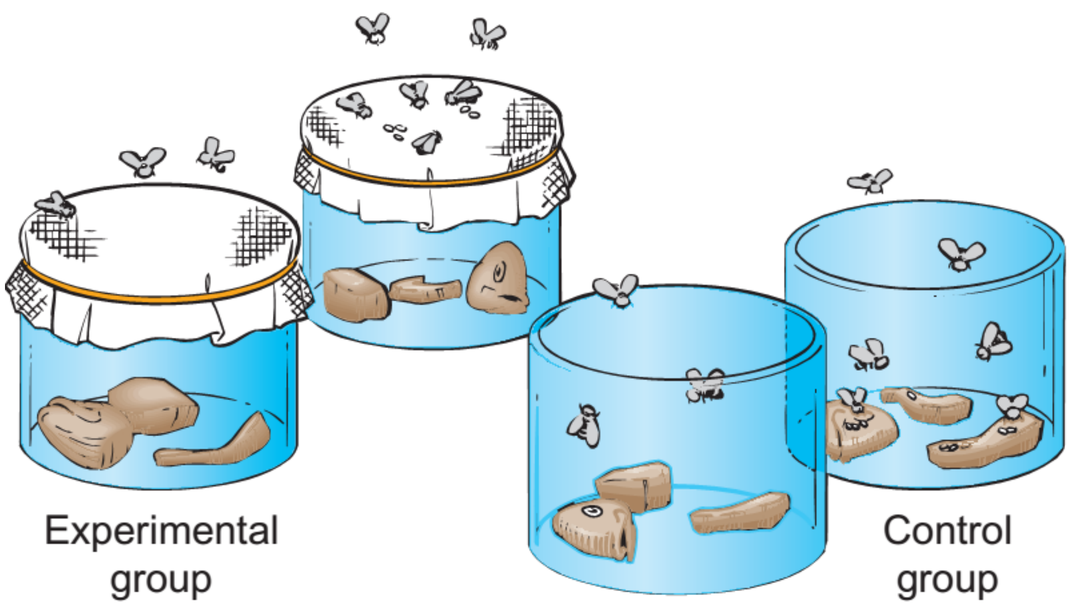
- What conditions on Earth billions of years ago could have allowed for the creation of the first living thing?
- What additional steps would be necessary to get cells from simple chemicals?

Early Thoughts About the Origin of Life

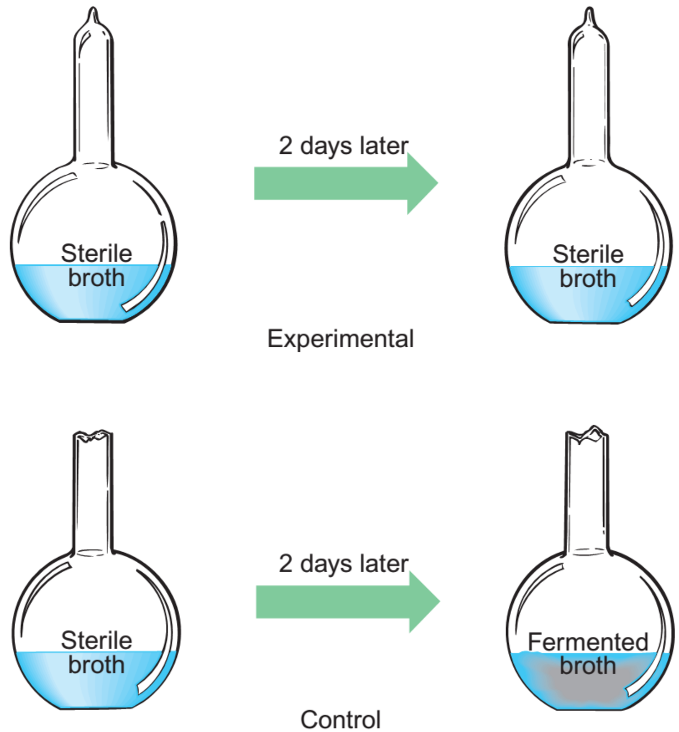
- Spontaneous generation is the concept that living things arise from nonliving material. Aristotle (384–322 b.c.) proposed this concept and it was widely accepted until the seventeenth century.
- People believed that maggots arose from decaying meat; mice developed from wheat stored in dark, damp places; lice formed from sweat; and frogs originated from damp mud.

Early Thoughts About the Origin of Life

- In 1668, Francesco Redi, an Italian physician, performed an experiment that challenged the concept of spontaneous generation.
- Redi concluded that the maggots arose from the eggs of the flies (biogenesis), not from spontaneous generation in the meat.



Early Thoughts About the Origin of Life

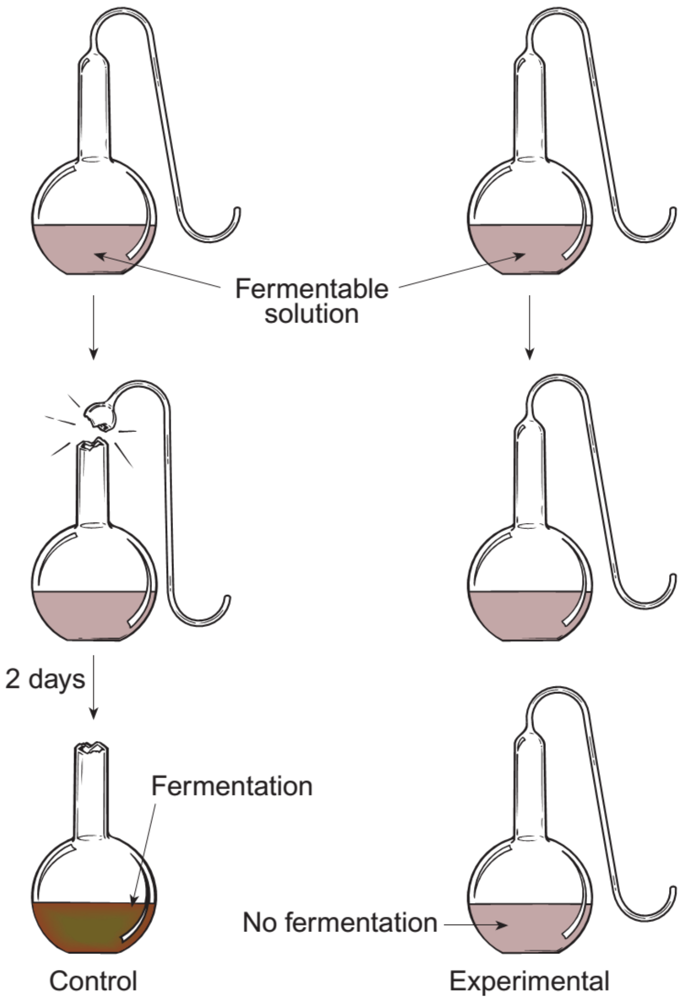


Spallanzani's Experiment

Spallanzani boiled a meat and vegetable broth and placed this mixture into clean flasks. He sealed one and put it in boiling water. As a control, he subjected another flask to the same conditions, except he left it open. Within 2 days, the open flask had a population of microorganisms. Spallanzani maintained that this demonstrated that spontaneous generation did not occur and that something from the air was responsible for the growth in the broth.

Early Thoughts About the Origin of Life

Pasteur's Experiment



Louis Pasteur conducted an experiment designed to test the idea that a "vital element" (oxygen) from the air was necessary to produce life. He boiled a mixture of sugar and yeast in swan-neck flasks that allowed oxygen, but not airborne organisms, to enter them. He left some flasks intact (the experimental group) and broke the neck off others (the control group). Within 2 days, there was growth in the flasks that had their swan necks removed but none in the intact flasks. Thus, Pasteur concluded that it was not oxygen in the air that caused growth in the flasks but that the growth resulted from living things, which entered the flask when the swan neck was broken off. This supported the concept of biogenesis and argued against the concept of spontaneous generation.

Current Thinking About the Origin of Life

- it is clear that current living things are the result of biogenesis.
- But that does not answer the question of how the first living thing developed.
- There are many different hypotheses that have some supporting evidence.
- **An Extraterrestrial Origin for Life on Earth** : Early in the 1900s, Swedish scientist Svante Arrhenius popularized the *idea of panspermia*. Panspermia is the concept that life arose outside Earth and that living things were transported to Earth to seed the planet with life.
- In 1996, a meteorite found in Antarctica generated excitement about the possibility of life on other planets. Its chemical makeup suggested it had been a portion of the planet Mars that had been ejected from that planet as a result of a collision with an asteroid.

Current Thinking About the Origin of Life

- **An Extraterrestrial Origin for Life on Earth** :
- Analysis of the meteorite showed the presence of complex organic molecules and tiny, microscopic objects that were thought to be ancient microorganisms. While scientists no longer think these objects are microorganisms or were formed by living things, many still think conditions on Mars may have been able to support life in the past.
- Evidence from Mars and Beyond: The robotic vehicle rovers on surface of mars in year 2003, by NASA revealed that that it is highly likely that in the past, liquid water existed in large enough quantities to form rivers, lakes, and perhaps salty oceans.
- Although none of these discoveries proves that life exists or existed elsewhere in the universe, they keep open the possibility that life may have originated elsewhere and arrived on Earth.

An Earth Origin for Life on Earth

- A popular alternative explanation for the origin of life on Earth focuses on chemical evolution. This hypothesis proposes that chemical reactions between simple, inorganic chemicals produced complex, carbon-containing organic molecules. These organic molecules, in turn, combined to form the first living cell.
- Several pieces of evidence support the idea that life could have arisen on Earth.

Origin for Life on Earth- Evidences

1. The temperature range on Earth allows for water to exist as a liquid on its surface. This is important, because water is the most common compound of living things.
2. Analysis of the atmospheres of the other planets in our solar system shows that they all lack oxygen. The oxygen in Earth's current atmosphere is the result of photosynthesis by living organisms. Therefore, before there was life on Earth, the atmosphere probably lacked oxygen.
3. Experiments demonstrate that organic molecules can be generated in an atmosphere that lacks oxygen.
4. Because it is assumed that all of the planets have been cooling off as they age, it is very likely that Earth was much hotter in the past. The large portions of Earth's surface that are of volcanic origin strongly suggest a hotter past.
5. The discovery of specialized Bacteria and Archaea that live in extreme environments of high temperature, high salinity, low pH, or the absence of oxygen suggests that they may have been adapted to life in a world that is very different from today's Earth. These kinds of organisms are found today in unusual locations, such as hot springs and around thermal vents in the ocean floor, and may retain characteristics that were essential to the first organisms formed on the primitive Earth.

Origin of life through the lens of The "Big Bang" and the Origin of the Earth

- *The "Big Bang"* :
- our universe began as a very dense mass of matter that had a great deal of energy. This dense mass of matter exploded in a "big bang" about 13 billion years ago, resulting in the formation of simple atoms, such as hydrogen and helium.
- When huge numbers of these atoms collected in one place, stars formed. Stars consist primarily of hydrogen and helium atoms. The light from stars is the result of nuclear fusion, in which these atoms combine to form larger atoms.
- According to this theory, all of the chemical elements were formed as a result of nuclear fusion.

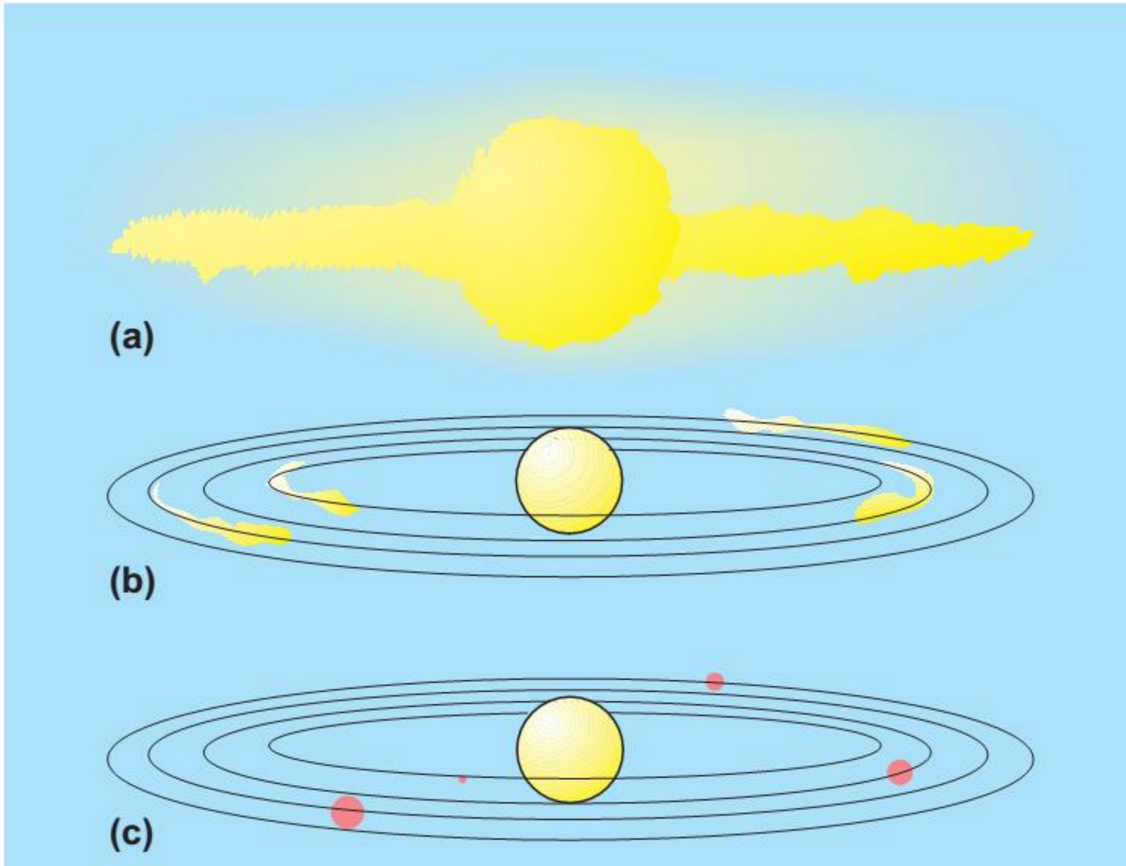
Origin of life through the lens of The "Big Bang" and the Origin of the Earth

- *The Formation of the Planet Earth* :
- Many scientists believe that Earth—along with other planets, meteors, asteroids, and comets—was formed at least 4.6 billion years ago.
- The *protoplanet nebular model* proposes that the solar system was formed from a large cloud of gases and elements produced by previously existing stars
- The simplest and most abundant gases were hydrogen and helium, but other, heavier elements had been formed by nuclear fusion and were present as well.
- A gravitational force was created by the collection of particles within this cloud, which caused other particles to be pulled from the outer edges to the center.

Origin of life through the lens of The "Big Bang" and the Origin of the Earth

- *The Formation of the Planet Earth* :
- As the particles collected into larger bodies, gravity increased and more particles were attracted to the bodies. Ultimately, a central body (the Sun) was formed, with several other bodies (planets) moving around it.
- Like other stars, the Sun consists primarily of hydrogen and helium atoms that are being fused together to form larger atoms, with the release of large amounts of thermonuclear energy.
- Thermonuclear reactions also occurred as the particles became concentrated to form Earth. Thus, the early Earth would have been a very hot place. Geologically, this period in the history of Earth is called the "Hadean Eon." The term Hadean means "hellish." Although not as hot as the Sun, the material of Earth formed a molten core, which became encased by a thin outer crust as it cooled.

The Formation of Our Solar System



(a) As gravity pulled gases and other elements toward the center, the accumulating matter resulted in the formation of the Sun. *(b)* In other regions, smaller gravitational forces caused the formation of the Sun's planets. *(c)* Finally, the solar system was formed.

The Chemical Evolution of Life on Earth

1. Simple organic molecules must first have been formed from inorganic molecules.
2. Simple organic molecules must have combined to form larger organic molecules, such as RNA, proteins, carbohydrates, and lipids.
3. A molecule must have served as genetic material.
4. Genetic material must have become self-replicating.
5. Some molecules must have functioned as enzymes.
6. The molecules serving as genetic material and other large organic molecules must have been collected and segregated from their surroundings by a membrane.
7. The first life-forms would have needed a way to obtain energy from their surroundings in order to maintain their complex structure.

How did life originate on earth?

Stage 1: Nucleotides and amino acids were produced prior to the existence of cells.

Stage 2: Nucleotides became polymerized to form RNA and/or DNA, and amino acids became polymerized to form proteins.

Stage 3: Polymers became enclosed in membranes.

Stage 4: Polymers enclosed in membranes acquired cellular properties.

The Formation of the First Organic Molecules

CHEMICAL REACTIONS NEEDED TO START LIFE

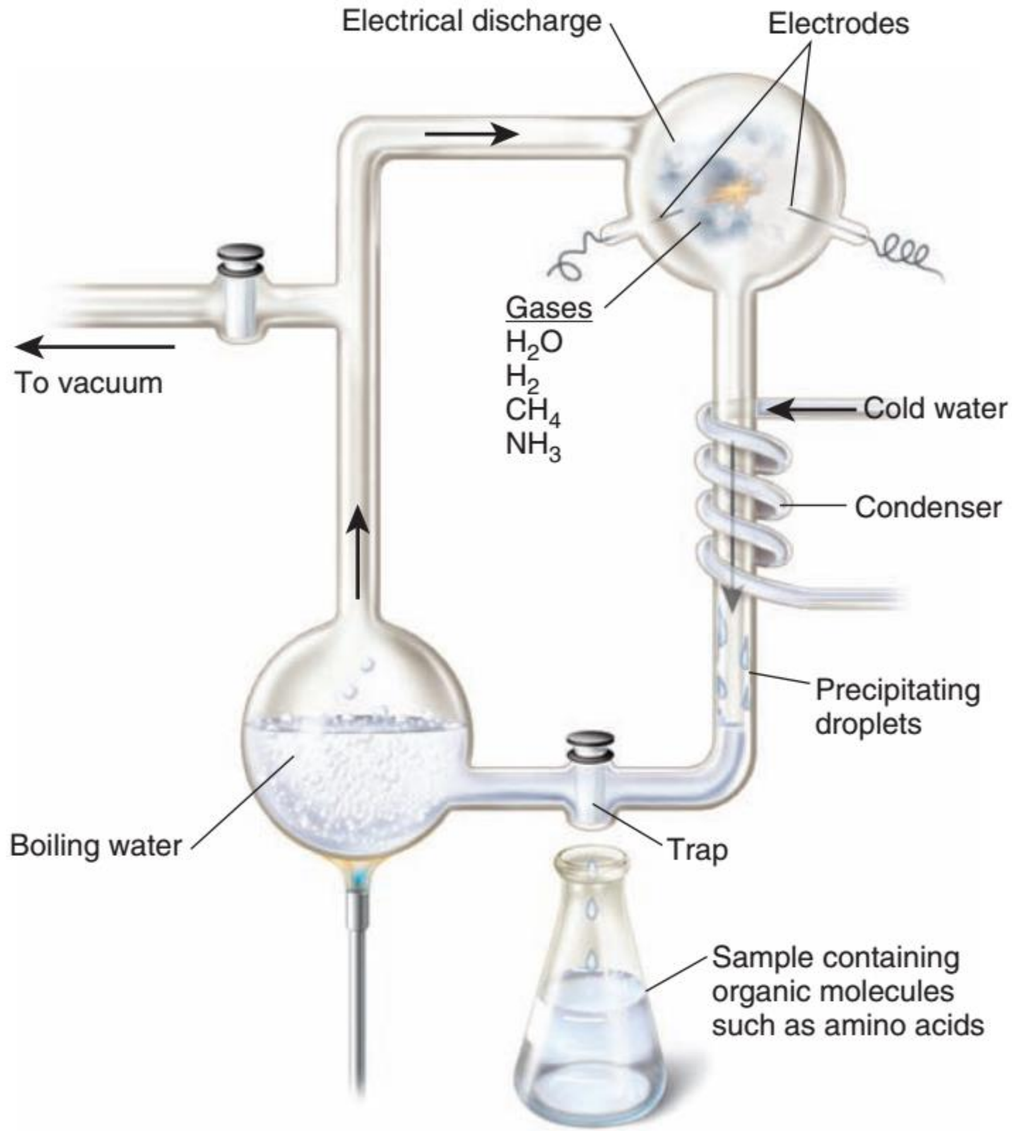
- The chemical reactions essential to start life on Earth are called **redox reactions**. These involve exchange of electric charge (resulting from movement of electrons) between the reacting atoms and molecules. For example, the process producing water is a redox reaction. First, a hydrogen molecule is converted to two hydrogen nuclei (positively charged protons) and two electrons (negatively charged): $H_2 \rightarrow 2\,H^+ + 2\,e^-$
- Second, the two protons and two electrons are combined with an oxygen atom to produce water $(\frac{1}{2}\,O_2 + 2\,H^+ + 2\,e^- \rightarrow H_2O)$.
- Here oxygen accepts an electron becoming more negatively charged—called reduced—with the charge of hydrogen increased or hydrogen becomes oxidized (because it combines with oxygen; the word redox comes from the combined first letters in reduced and oxidized).
- A redox reaction involves transfer of one or more electrons from an electron donor (oxidized) to an electron acceptor (reduced). This transfer produces energy that can then drive biochemical reactions responsible for life.

Stage 1: Organic Molecules Formed Prior to the Existence of Cells

- *Logic: Condition of early earth was more conductive to spontaneous formation of organic molecules.*
- 1938, Russian biochemist Alexander Oparin & Scottish biologist J.B.S. Haldane proposed spontaneous origin of organic molecules (known as ***primordial soup***) on early earth
- Prebiotic synthesis of organic molecules (or synthesis of molecules without living cell)
- Accumulation of organic molecules on ocean floor/earth surface formed ***prebiotic soup***
- **What is the mechanism?**

Hypothesis made to answer this Question

- 1. **Reducing atmosphere hypothesis :**
- Atmosphere on early earth enriched with water vapor, hydrogen gas (H_2), methane(CH_4), ammonia (NH_3) but lacked oxygen
- Methane & ammonia readily give up electrons to other molecules. Such redox reaction are required for formation of complex organic molecules from simple inorganic molecules
- In 1953, American chemist Stanley Miller & Harold Urey gave *evidence of abiotic origin of organic molecules* (see Figure)
- In 2011, scientist isolated 23 amino acids from Miller sample left in 1958.


Electrical discharge
Electrodes
Gases
H_2O
H_2
CH_4
NH_3
To vacuum
Cold water
Condenser
Precipitating droplets
Boiling water
Trap
Sample containing organic molecules such as amino acids

Hypothesis made to answer this Question

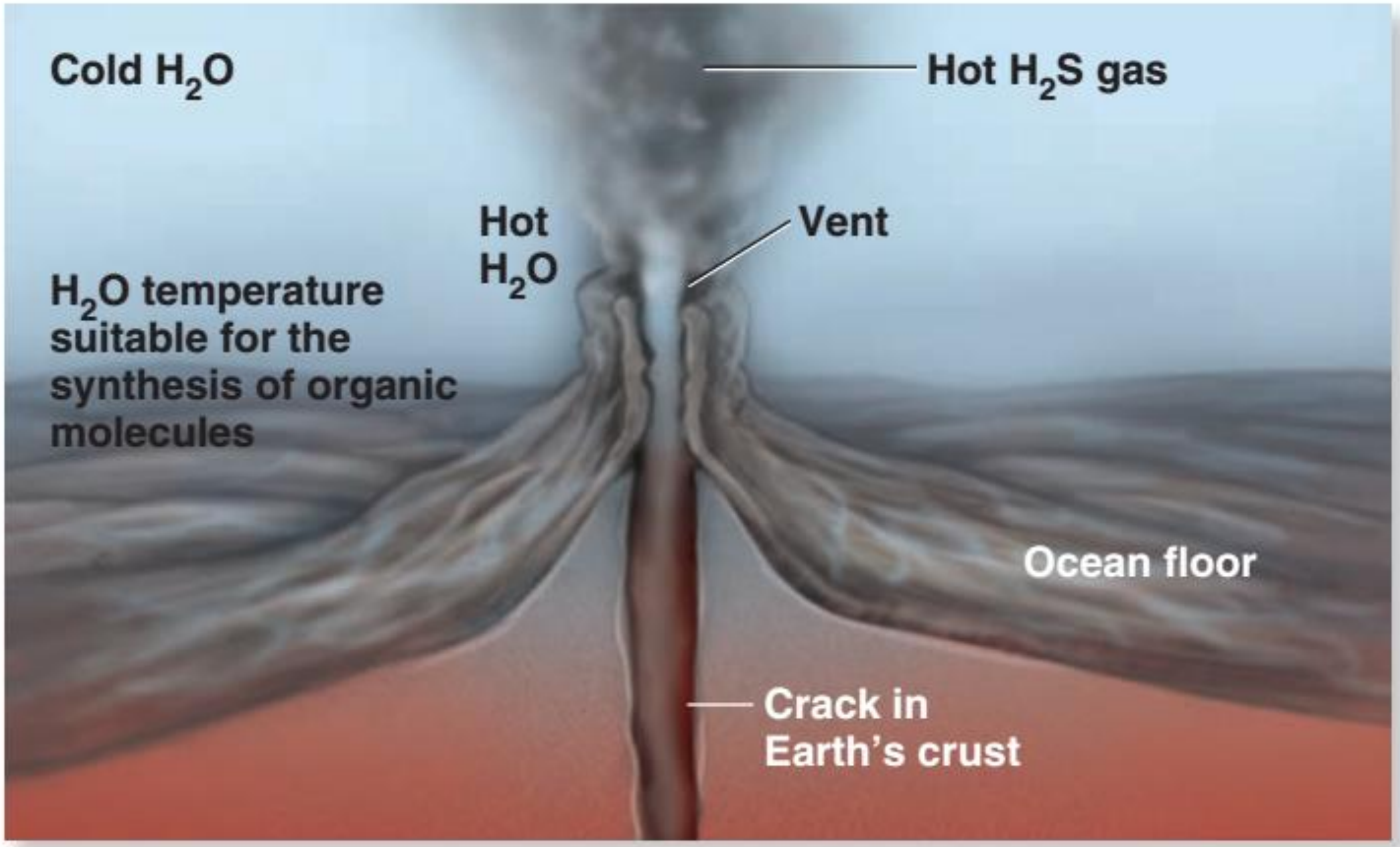
- 1. **Reducing atmosphere hypothesis :**
- However, this hypothesis was criticized because recent analysis of volcanic gas showed that early earth atmosphere had mixture of neutral gases: CO, CO_2, N_2, H_2O from which organic molecules can be made abiotically in different circumstances.
- High level of UV radiation destroys CH_4 & NH_3

2.Extraterrestrial hypothesis

- Organic molecules came from meteorites belonging to a class known as carbonaceous chondrites
- Criticized : these organic molecules destroyed by collision with earth

3. Deep-sea vent Hypothesis

- In 1988 by German physicist Gunter Wachtershauser
- Deep sea vents are cracks in the earth's surface where superheated water (300^0C) rich in metal ions & H_2S mixes abruptly with cold sea water.
- Reaction between iron & H_2S yields pyrites & H_2. This is found to provide energy for reduction of N_2 to NH_3.
- Conversion of at deep sea vents may have led to production of amino acids & nucleic acids
- In 2007, 1.43 billion year old fossils discovered near ancient deep sea vent by American scientist Timothy Kusky & colleagues indicating origin of life on ocean floor.
- Various types of fish, worms, clams, crabs, shrimp, bacteria are found in significant abundance till date



(a) Deep-sea vent hypothesis

(a) Deep-sea vents are cracks in the Earth's surface that release hot gases such as hydrogen sulfide (H2S). This heats the water near the vent and results in a gradient between the very hot water adjacent to the vent and the cold water farther from the vent. The synthesis of organic molecules can occur in this gradient.

(b) A deep-sea vent community

(b) Photograph of a biological community near a deep-sea vent, which includes giant tube worms and crab

The Formation of Macromolecules

LARGE ORGANIC MOLECULES AND THE ORIGIN OF FIRST LIVING ORGANISMS

the competing scenarios that attempt to explain the origin of first living organisms.

- *The metabolic-first hypothesis/ Iron-Sulfur World Hypothesis*
- The metabolism-first scenario argues that the presence of hydrogen and carbon dioxide in hydrothermal vents, combined with an iron-nickel-sulfur catalyst, yield a number of chemical substances that assemble and react to conduct the process of reverse Krebs cycle.
- The surface of iron sulfide support a complex, self-sustaining sequence of metabolic reactions, leading to the formation of new and more complex catalysts and metabolic pathways. Because of its dependence on iron sulfide, the metabolic-first scenario is also known as Iron-Sulfur World Hypothesis.

the competing scenarios that attempt to explain the origin of first living organisms.

- *The metabolic-first hypothesis/ Iron-Sulfur World Hypothesis.*
- first developed by German chemist Günter Wächtershäuser in the 1980s, which says, the first metabolic reactions began on the surface of minerals such as iron sulfide and nickel sulfide around hydrothermal vents deep in oceans. These minerals act as catalysts producing carbon from the existing inorganic material like carbon monoxide (CO) existing in the vents or carbon dioxide (CO2) generated by volcanic activities and finding their way to ocean floors through ridges at the floor of the oceans.
- The process of carbon release from these compounds requires hydrogen. The hydrogen will be supplied from hydrogen sulfide (H2S) in the vents or from ocean water.
- Using the reducing power of hydrogen sulfide (the ability to release electrons), iron sulfide and nickel sulfide catalyzed the reduction of carbon dioxide to small organic molecules, accelerating conversion of inorganic to organic molecules. The basic substrate material for this reaction is iron sulfide in the surface of the rocks.

the competing scenarios that attempt to explain the origin of first living organisms.

- The metabolic-first hypothesis/ Iron-Sulfur World Hypothesis.
- Furthermore, the iron sulfide donated electrons to carbon monoxides, converting them into acetic acid and starting reactions that led to the formation of large chains of amino acids that formed proteins (Plaxo and Gross, 2006). The energy needed for these reactions came from the redox process because of the chemical disequilibrium when the hot water from the hydrothermal vents merged into the colder ocean water.

HOW THE ENERGY NEEDED TO FORM THE FIRST ORGANIC COMPOUNDS WAS SUPPLIED?

The carbon dioxide in the atmosphere is dissolved in ocean water producing carbonic acid (H_2CO_3) (Figure 19.2). This gives up protons (in the form of hydrogen atom) to produce bicarbonate (HCO_3^-), which is then converted to carbonate ion (CO_3^{2-}) as well as hydrogen ion (H^+). This increases proton concentration in ocean waters, making this environment more acidic. On the other hand, the fluid coming out of the vents is alkaline (low in proton concentration). The difference in the proton concentrations between the ocean water and the fluid coming out of the vents produces the energy needed (in the absence of ATP molecules) to run the reverse citric acid (Krebs) cycle and to conduct the first chemical reactions leading to production of the first organic compounds.

Stage2: Organic Polymers May Have Formed on the Surface of Clay

- *clay world hypothesis or Gene first hypothesis:*
- A kind of mineral called clay is likely to have played that role in the assembly of the genes and the origin of life. The oldest known terrestrial material, zircon grains, indicates that clays existed in great abundance on Earth 4.4 billion years ago, implying that clays were common at the time we believe life started (Bennett and Shostak, 2004)
- Structurally, the clay minerals consist of layers of molecules to which other molecules can attach.
- As a result, **when organic molecules combine with clay, they are kept in close proximity to each other, allowing them to react with one another, creating a long chain of molecules.** Different layers of clay consist of different chemical elements and compounds. This *variability between different layers of clay could make them function like genes*.

Stage2: Organic Polymers May Have Formed on the Surface of Clay

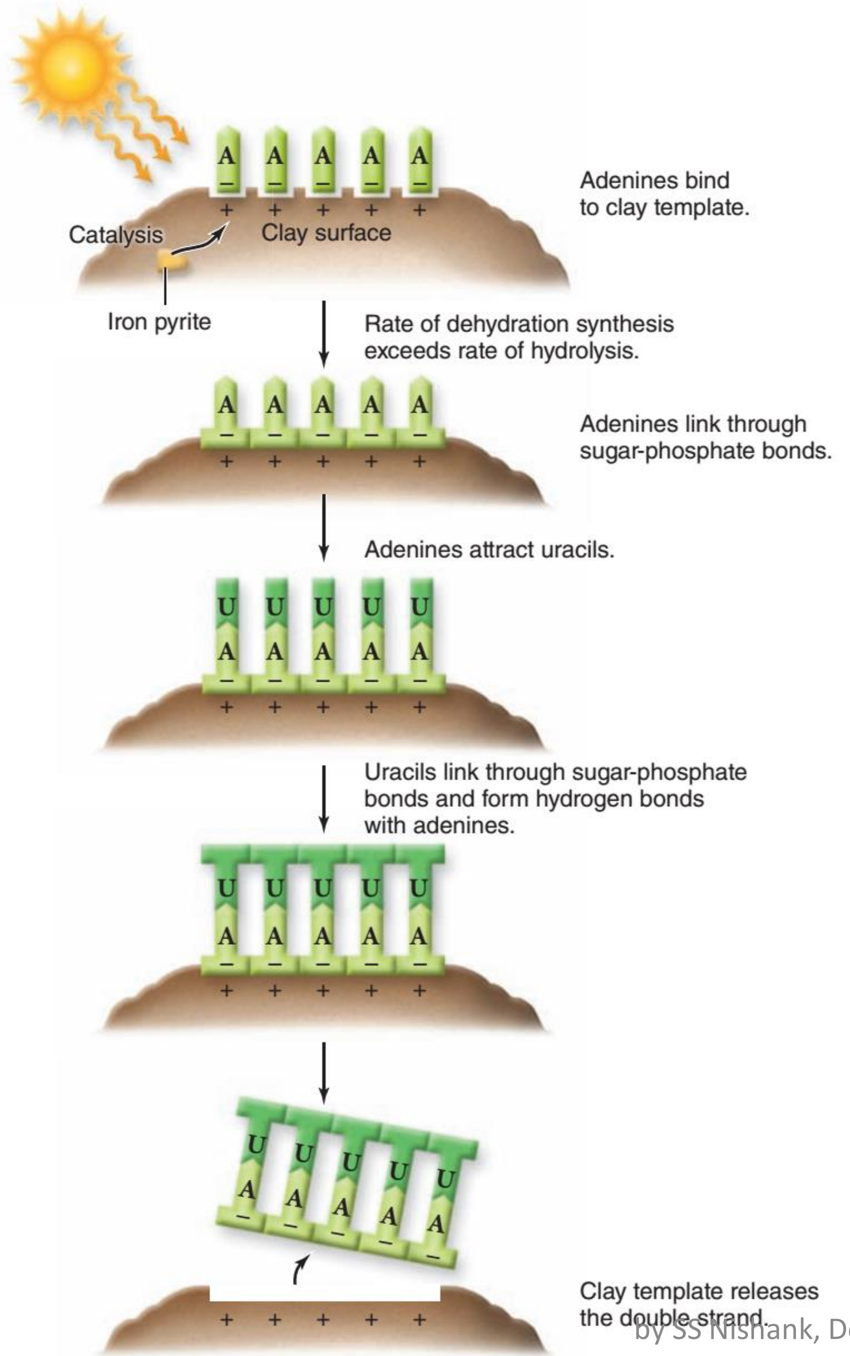
- *clay world hypothesis or Gene first hypothesis:*
- For example, the charged ions in one layer of clay could act as templates and catalyze the formation of the next layer of clay. Any errors in replication (mutation), which is the packing of alumina and silica that occur during the copying process, would be reflected in all of the next layers. If these mistakes increase the efficiency of the replicating process, they will generate a selective advantage by speeding up the replication and production of new chemical compounds that would satisfy our definition of life.
- Also, ions in clay layers could act as catalysts to speed up the organic reactions and polymerization of the RNA. Given this scenario, it is likely that clays in Earth's oceans may be responsible for generating the first organic molecules able to replicate themselves (hence fulfilling one of the definitions of a living system). **This is the so-called clay world hypothesis**.

Stage2: Organic Polymers May Have Formed on the Surface of Clay

- Logic: Polymers with at least 30-60 monomers needed to store enough information to make a viable genetic system. But since hydrolysis competes with polymerization, *synthesis of polymers did not occur in a watery prebiotic soup but instead took place on a solid surface or in evaporating tidal pools.*
- clay particles may have been a factor in concentrating simple organic molecules. Small particles of clay have electrical charges, which can attract and concentrate organic molecules, such as proteins, from a watery solution. Once the molecules became concentrated, it would have been easier for them to interact to form larger macromolecules.
- 1951, Irish X-ray crystallographer John Bernal claimed in his book *The physical basis of life* that clays, muds & inorganic crystals are powerful means to concentrate & polymerize organic molecules.

Stage2: Organic Polymers May Have Formed on the Surface of Clay……………………

- But in 2004, American chemist Luke Leman, English chemist *Leslie Orgel* & Iranian-American chemist *M.Reza Ghadiri* indicated that polymers can also form in aqueous solution. *Carbonyl sulfide*, a simple gas present in volcanic gases & deep sea vent emissions, can bring about the formation of peptides from amino acids under mild conditions in water.
- *These results indicate that synthesis of polymers could have taken place in the prebiotic soup*.



A Possible Role for Clay. Chains of nucleotides may have formed on clay templates. In this hypothesized scenario, iron pyrite ("fool's gold") was the catalyst for polymer formation, and sunlight provided the energy.

Stage3: Cell-Like Structures May Have Originated When Polymers Were Enclosed by a Boundary

- The term *protobiont* is used to describe an aggregate of prebiotically produced molecules & macromolecules that acquired a boundary such as lipid bilayer that allowed it to maintain an internal chemical environment distinct from that of its surroundings.

Stage3: Cell-Like Structures May Have Originated When Polymers Were Enclosed by a Boundary……

- *What characteristics make protobionts possible precursors of living cells*? Scientists envision the existence of four key features attributed to protobionts

1. A boundary, such as a membrane, separated the internal contents of the protobiont from the external environment.
2. Polymers inside the protobiont contained information.
3. Polymers inside the protobiont had catalytic functions.
4. The protobionts eventually developed the capability of self-replication.

Stage3: Cell-Like Structures May Have Originated When Polymers Were Enclosed by a Boundary……

- Protobiont may have existed as coacervates or liposomes.
- Coacervates (L. *coacervare* to assemble together) are droplets that form spontaneously from the association of charged polymers such as proteins, carbohydrates or nucleic acids surrounded by water.
- Measure 1-100 µm with osmotic properties
- Alexander I. Oparin, speculated that a structure could have formed consisting of a collection of organic macromolecules surrounded by a film of water molecules. *This arrangement of water molecules, although not a membrane, could have functioned as a physical barrier between the organic molecules and their surroundings.* He called these structures *coacervates*.

Stage3: Cell-Like Structures May Have Originated When Polymers Were Enclosed by a Boundary…..

- Evidence of coacervates that exhibit some lifelike traits:
- They can selectively absorb molecules from the surrounding water and incorporate them into their structure. Also, the chemicals within coacervates have a specific arrangement—they are not random collections of molecules.
- Some coacervates contain proteins (enzymes) that direct a specific type of chemical reaction. For instance, when glucose-1-phosphate was made available to coacervate containing enzyme, glycogen phosphorylase, it produced starch that merged with wall of coacervate & increased the size.
- When enzyme amylase was included, the starch broke down to maltose, which was released from coacervates.

Stage3: Cell-Like Structures May Have Originated When Polymers Were Enclosed by a Boundary…..

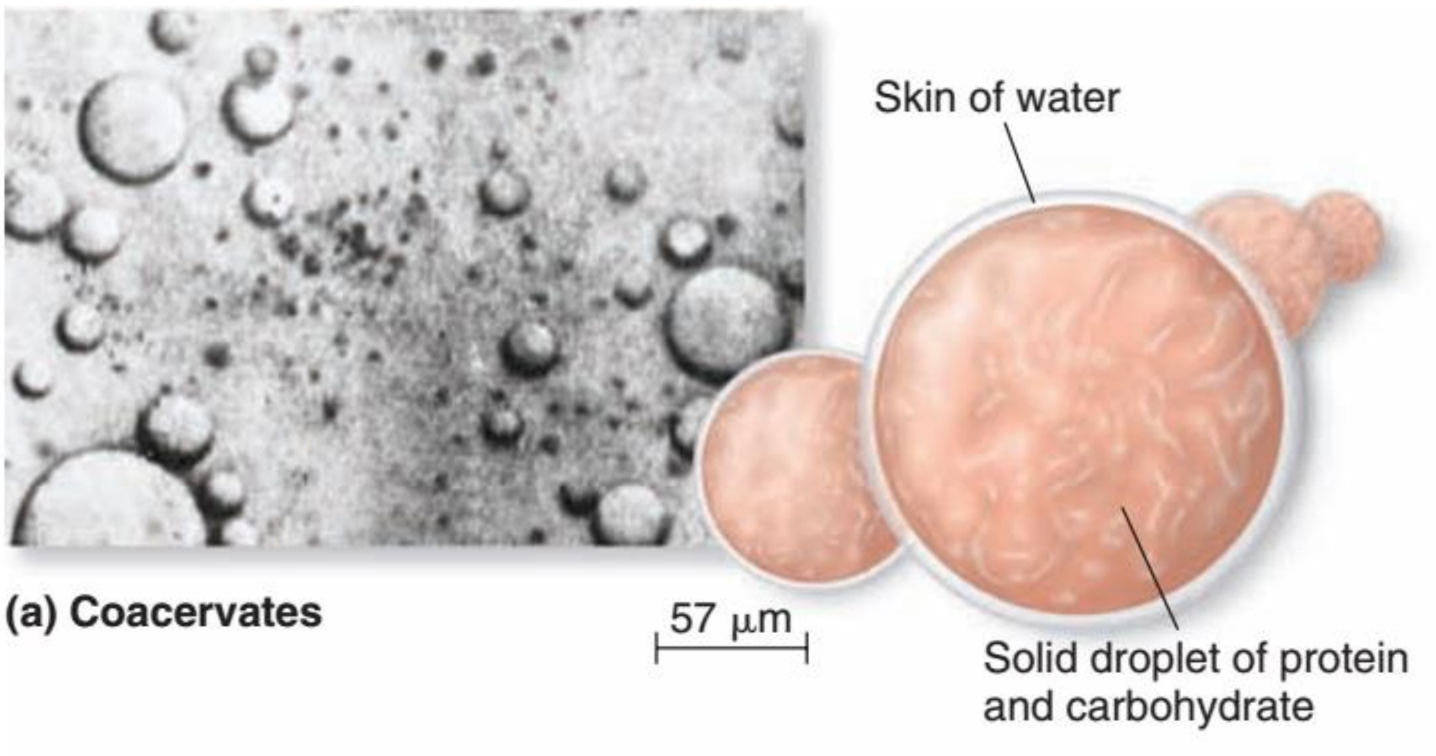
- Evidence of coacervates that exhibit some lifelike traits:
- Because they lack a definite membrane, no one claims that coacervates are alive, but these structures do exhibit some lifelike traits: They can increase in size and can split into smaller particles if the right conditions exist.

Stage3: Cell-Like Structures May Have Originated When Polymers Were Enclosed by a Boundary…..

Coacervates

One hypothesis proposes that a film of water, which acted as a primitive cell membrane, could have surrounded organic molecules, forming a structure that resembles a living cell. Such a structure can easily be produced in the lab. This view shows one large and several small spherical coacervates.

Stage3: Cell-Like Structures May Have Originated When Polymers Were Enclosed by a Boundary…..



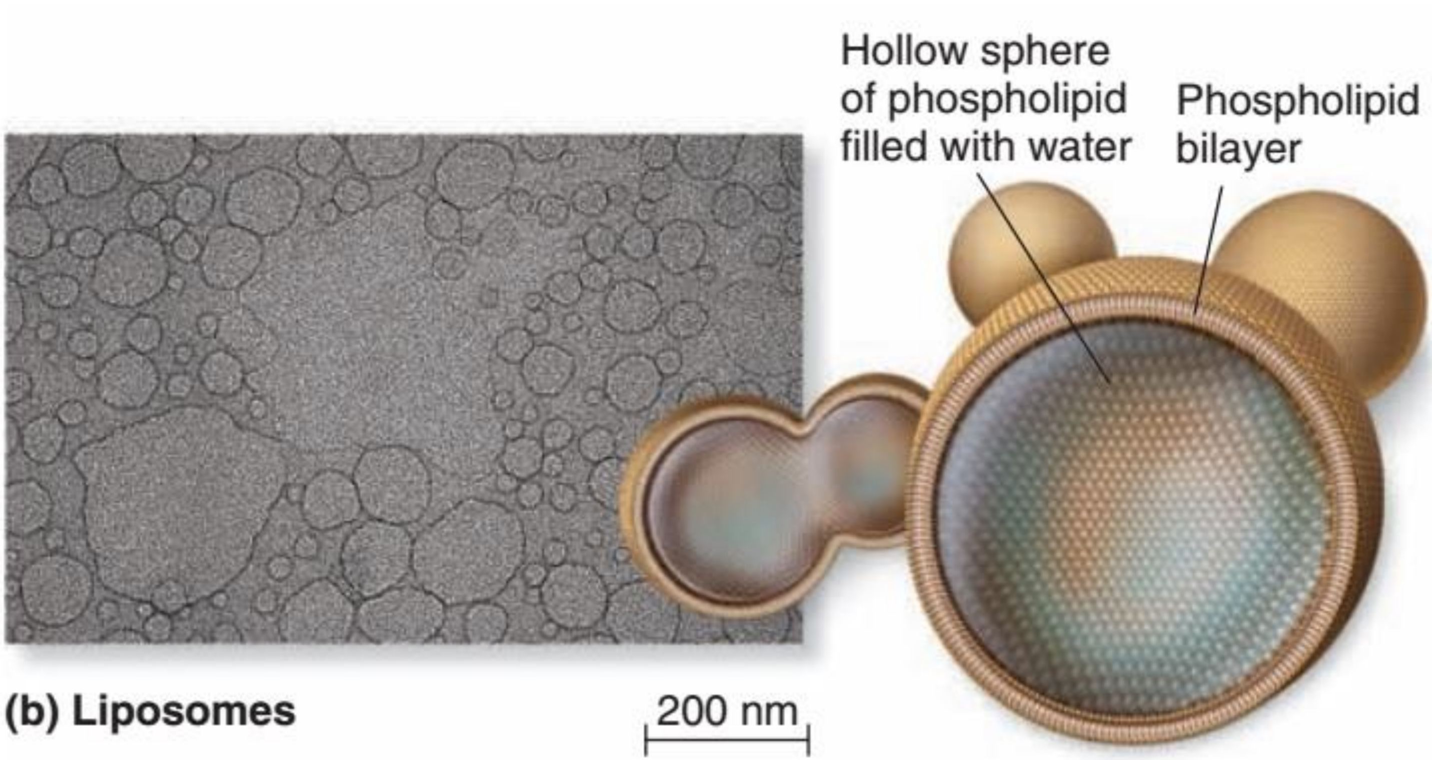
(a) Coacervates

Stage3: Cell-Like Structures May Have Originated When Polymers Were Enclosed by a Boundary……

- An alternative hypothesis is that the early, cell-like structure could have consisted of a collection of organic macromolecules with a double-layered outer boundary. These structures have been called microspheres.
- Some of the protein material produces a double-boundary structure enclosing the microsphere. Although these boundaries do not contain lipids, they exhibit some membrane like characteristics and suggest the structure of a cellular membrane.
- Microspheres swell or shrink, depending on the osmotic potential in the surrounding solution. They also display a type of internal movement (streaming) similar to that exhibited by living cells and contain some molecules that function as enzymes.
- Using ATP as a source of energy, microspheres can direct the formation of polypeptides and nucleic acids. They can absorb material from the surrounding medium and form buds, resulting in a second generation of microspheres.

Stage3: Cell-Like Structures May Have Originated When Polymers Were Enclosed by a Boundary……

- Liposome: vesicles surrounded by a phospholipid bilayer.
- Lipids when dissolved in water spontaneously form liposomes
- Some liposome store energy in form of an electrical gradient. Such liposomes can discharge this energy in a neuron like fashion.
- Liposomes can grow & divide, a primitive form of self replication shown by a expt. by Danish chemist Martin Hanczyc, American chemist Shelly Fujikawa, Canadian-American biologist Jack Szostak. If RNA is on clay liposome can uptake RNA.


Hollow sphere
of phospholipid
filled with water
Phospholipid
bilayer
200 nm

(b) Liposomes

Stage 4: Cellular Characteristics May Have Evolved via Chemical Selection, Beginning with an RNA World

- *RNA world Hypothesis*:
- The RNA World hypothesis proposes that catalytic RNA molecules were a transitional form between nonliving matter and the earliest cells.
- In 1989, Sidney Altman and Thomas Cech, shared the Nobel Prize for discovery of ribozyme.
- The RNA World hypothesis posits that the primordial form was an RNA-based living system that later evolved into life-forms like those we see today, in which DNA stores biological information and proteins manifest this information.
- RNA was living systems which can be distinguished from nonliving ones, by having the ability to store and transmit information (genotype) and the ability to express that information (phenotype).

Stage 4: Cellular Characteristics May Have Evolved via Chemical Selection, Beginning with an RNA World

- *RNA world Hypothesis*:
- Besides it had the ability to evolve.
- Evolution—descent with modification—requires both the ability to record and make alterations in heritable information and a sorting process that distinguishes valuable changes from detrimental ones. The former is a property of genotype, while the latter occurs as a result of variation among individuals in phenotype. These are the characteristics features of RNA.
- The phenotypes of most involve the formation and breaking of phosphoester bonds in RNA or DNA. The chemistry of these reactions is precisely what is needed to replicate nucleic acids.
- This observation gives support to the idea of a primordial RNA World, where RNA would be responsible for replicating itself.
- If an RNA molecule could make a copy of itself while accommodating the possibility of mistakes—mutations—then it would exhibit many of the characteristics of modern life and could therefore be considered alive.

Stage 4: Cellular Characteristics May Have Evolved via Chemical Selection, Beginning with an RNA World

- *RNA world Hypothesis*:
- It says the first living things on earth used RNA as both genetic material and for catalytic activity, which includes the replication of genetic material.
- In RNA World hypothesis, the first living things consisted of three parts: a ribozyme with RNA polymerize activity (the formation of a complex RNA molecule by combining smaller and simpler molecules), a template RNA to direct polymerization, and a physical container (membrane) (Plaxo and Gross, 2006).
- Two RNA molecules (not just one) are needed to start this process and for the ribozymes to catalyze reactions.
- In order for an RNA molecule to serve as a template to synthesize a new RNA molecule, a molecule must be unfolded and exposed to the monomer (simpler molecule) that would polymerize on it. In this scenario, the formation of two ribozymes is essential. A container is also needed to keep together the genetic material and the molecules it encodes. Without this, the material would diffuse away and not interact.

Stage 4: Cellular Characteristics May Have Evolved via Chemical Selection, Beginning with an RNA World

- *RNA world Hypothesis*:
- To summarize, in the RNA World hypothesis, our very first ancestors started life as two RNA molecules (a self-replicating ribozyme) within a lipid membrane. Nucleotide monomers then "leaked" into the membrane and polymerized into new copies of ribozymes. This process continued, generating more RNA molecules and leading to increased molecular weight within the lipid membrane.
- The RNA World hypothesis proposes that catalytic RNA molecules were a transitional form between nonliving matter and the earliest cells.
- The RNA World hypothesis is based on the realization, that RNA can possess both a genotype and a phenotype

Stage 4: Cellular Characteristics May Have Evolved via Chemical Selection, Beginning with an RNA World

- *RNA world Hypothesis*: says RNA is ancient. So what is the evidence?
- 1. RNA is involved in protein synthesis machinery e.g. ribosomal RNA carries out the catalytic steps in protein synthesis.
- 2. the basic currency for biological energy is ribonucleoside triphosphates, such as ATP and GTP. These molecules are involved in almost every energy-transfer operation of all cells and are even components of electrontransfer cofactors such as NAD (nicotinamide adenine dinucleotide), FAD (flavin adenine dinucleotide), and SAM (S-adenosyl methionine).

Stage 4: Cellular Characteristics May Have Evolved via Chemical Selection, Beginning with an RNA World

- *RNA world Hypothesis*:
- The genotype is the primary sequence of nucleotides along the RNA (Figure 17.2a), much like the genotype of a modern organism, is the sequence of nucleotides along the DNA in the chromosome.
- Catalytic RNA, for example, contains between 30 and 1,000 ribonucleotides that form its primary sequence, and hence its genotype.
- The *Tetrahymena* ribozyme was discovered by Cech and colleagues stretches some 400 nucleotides from head (the 5’ end) to tail (the 3’ end). This RNA is an intron (an intervening sequence between two genes) that separates two regions of the *Tetrahymena* genome that code for ribosomal RNA (rRNA) genes.
- In ribozymes, the folded state can have an active site that enables the RNA to catalyze a chemical reaction on a substrate, like a protein enzyme. This reactivity gives RNA its phenotype.

Stage 4: Cellular Characteristics May Have Evolved via Chemical Selection, Beginning with an RNA World

- *RNA world Hypothesis*:

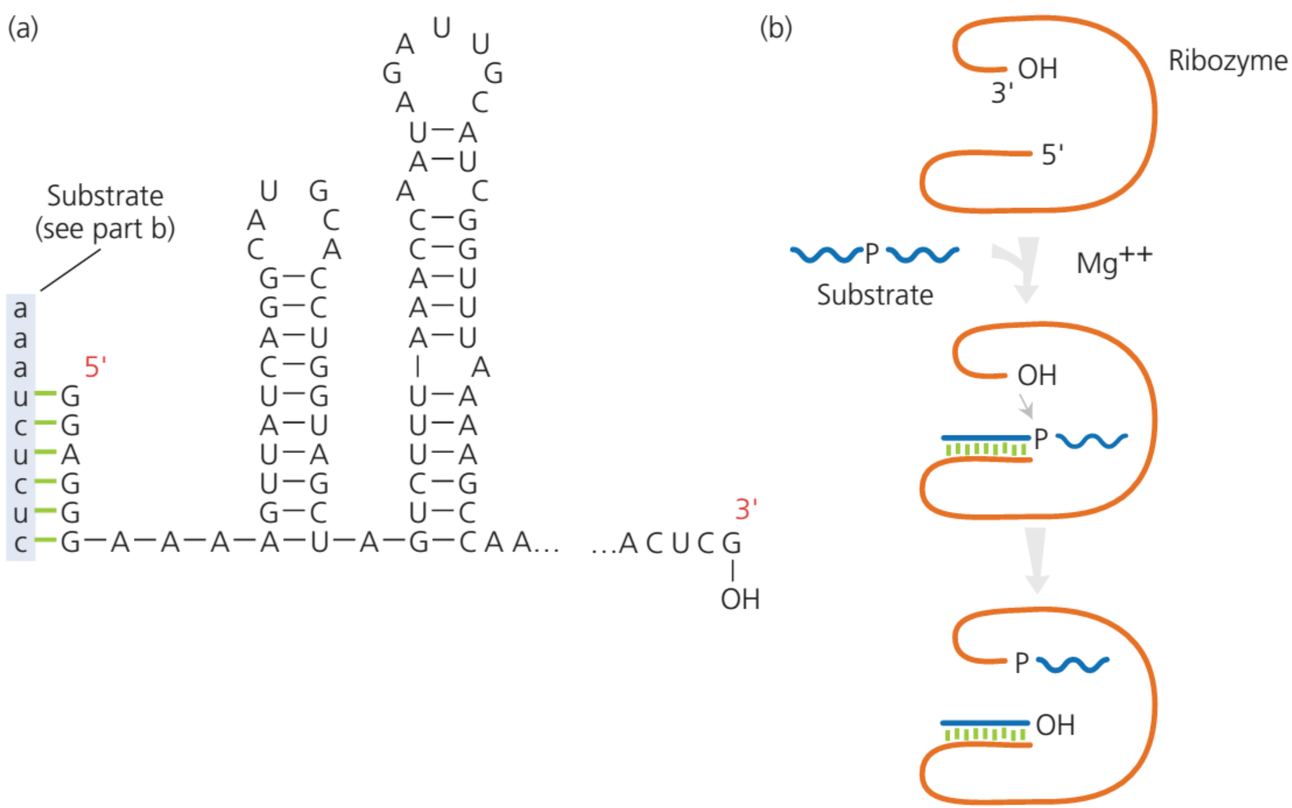


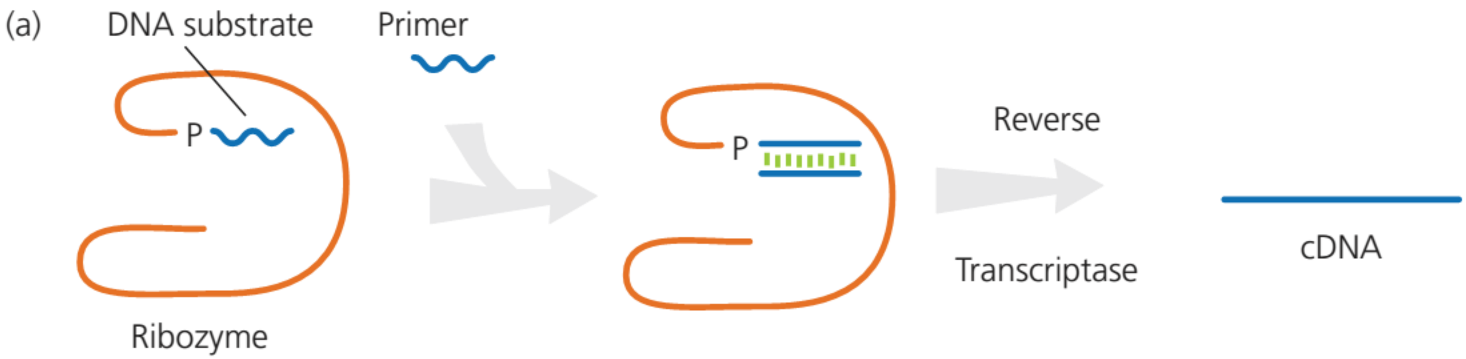
Figure 17.2 The ribozyme from *Tetrahymena thermophila* (a) The primary nucleotide sequence is the genotype. A secondary structure is formed when nucleotides pair as the molecule folds back on itself. (b) The catalysis performed by the ribozyme in vitro is the phenotype. A short oligonucleotide substrate (blue) binds to the 5′ end of the ribozyme (orange) through complementary base pairing (green ticks). The ribozyme catalyzes the breakage of a phosphoester bond in the substrate and the ligation of the 3′ fragment to its own 3′ end.

Stage 4: Cellular Characteristics May Have Evolved via Chemical Selection, Beginning with an RNA World

- *RNA world Hypothesis*:
- In test tubes, a shortened version of the ribozyme can catalyze a phosphoester transfer reaction on a short RNA substrate, called an oligonucleotide (a piece of single-stranded nucleic acid 5 to 30 nucleotides in length). In the reaction, the 3’ half of the substrate is broken off by the ribozyme and attached to the ribozyme’s own 3’ end (Figure 17.2b).

Stage 4: Cellular Characteristics May Have Evolved via Chemical Selection, Beginning with an RNA World

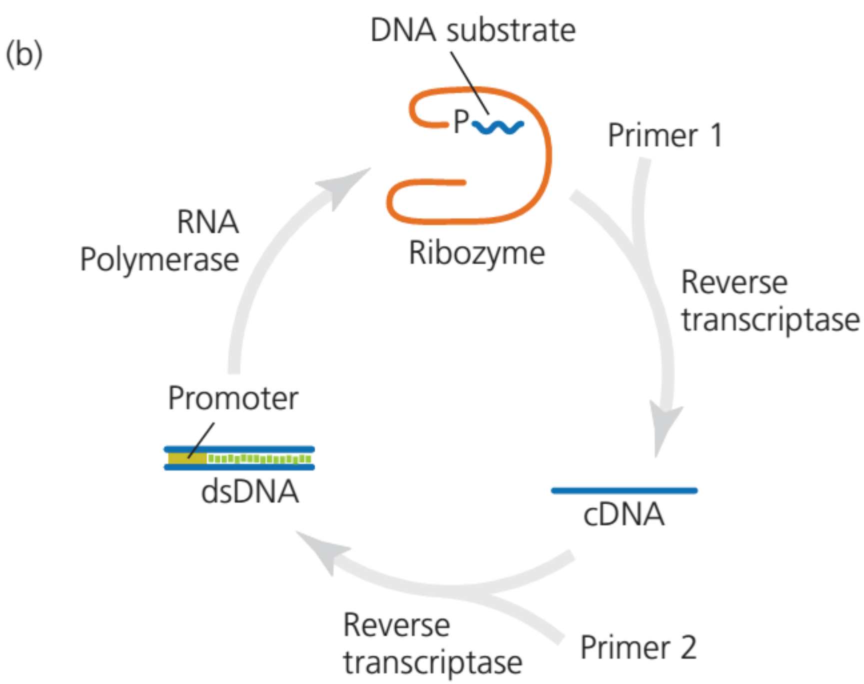
- *RNA world Hypothesis*:
- If RNA is ancient form of life next question is, **can RNA evolve????**
- A good example is the life cycle of the HIV virus. HIV uses the protein enzyme reverse transcriptase to copy its RNA strand into a DNA complement, which can then be converted into double-stranded DNA. Given that RNA can store genetic information, populations of RNA molecules should be able to evolve.
- If an RNA molecule has a phenotype that involves catalyzing a specific chemical reaction, can we apply selection to improve or modify this phenotype and observe a heritable change?
- **Amber Beaudry and Gerald Joyce** (1992) exploited the catalytic capacity of the *Tetrahymena* ribozyme to address this question. *They used the ribozyme's ability to pick up a new 3 tail,* as shown in Figure 17.2b, to distinguish ribozymes that perform this catalysis from those that do not. The acquisition of the ability to self-replicate by a collection of organic molecules, such as RNA, is arguably the point at which nonliving matter came to life.



Challenge ribozyme to catalyze reaction involving DNA substrate, as shown in Figure 17.2b.

Add primer that is complementary to the substrate tail picked up in (a)…

…and reverse transcriptase to make cDNA copy of ribozymes that succeeded in catalyzing reaction with DNA substrate.



Use additional primers, reverse transcriptase, and RNA polymerase to make copies of successful ribozymes. Some of these copies may carry mutations that improve the performance of the ribozyme on DNA substrates.

Test-tube selection and reproduction of RNA shown in previous slide

(a) Selection. A pool of RNAs (orange), made by random mutagenesis of a ribozyme, is challenged to perform a desired chemical reaction. Only those that perform the reaction acquire a short "tail" of DNA nucleotides attached to their 3' end (blue).

(b) Reproduction. RNA sequences that have acquired a 3' tail (top) bind primer 1 by complementary base pairing and are copied by reverse transcriptase into complementary DNA (cDNA). A second primer then binds to the cDNA so that the reverse transcriptase, which copies DNA in addition to RNA, can make the DNA double stranded. Primer 2 contains the promoter region for RNA polymerase, so that the doublestranded DNA can be copied back into RNA.

The task in this case was that the substrate oligonucleotide was provided in the form of DNA, not RNA. The naturally occurring sequence of the *Tetrahymena* ribozyme (the "wild type") used to start these experiments could cleave a DNA substrate only at a miserably slow rate. Beaudry and Joyce hoped that in the mutant pool there were variant sequences that, by chance, had an increased capacity for DNA cleavage.

Stage 4: Cellular Characteristics May Have Evolved via Chemical Selection, Beginning with an RNA World

- *RNA world Hypothesis*:
- After 10 such generations, the activity of the average RNA in the population in cleaving DNA substrates and attaching one of the resulting fragments to its own 3’ end had improved by a factor of 30.
- Individual ribozymes carrying mutations at positions 94, 215, 313, and 314 proved to have a catalytic efficiency (i.e. *Ability to pick up a new 3’ tail using DNA substrates*) over 100 times greater than that of earlier ancestral sequence.
- *This experiment demonstrated that* RNA molecules in solution can possess features of living organisms that allow them to evolve*. Each RNA has a function of both survival (substrate catalysis) and reproduction (ability to be reverse- and forward-transcribed).*

Stage 4: Cellular Characteristics May Have Evolved via Chemical Selection, Beginning with an RNA World

- *RNA world Hypothesis*:
- A main premise of the RNA World hypothesis is that RNA predates the use of proteins to do most biological work. The piece of evidence that we lack is thus the demonstration that RNA can copy itself.
- Whether the RNA World used only one type of self-replicating RNA or a suite of interacting RNAs, an RNA with a replicase phenotype would be necessary.
- David Bartel and coworkers, for example, ***have used test-tube evolution to search for ribozymes capable of synthesizing RNA*** (Bartel and Szostak 1993) by seeing at the ability of which RNA (from the pool of long RNA strands) bind the maximum nos. of same short RNA strand.

Stage 4: Cellular Characteristics May Have Evolved via Chemical Selection, Beginning with an RNA World

- Unlike other polymers, RNA exhibits three key functions:

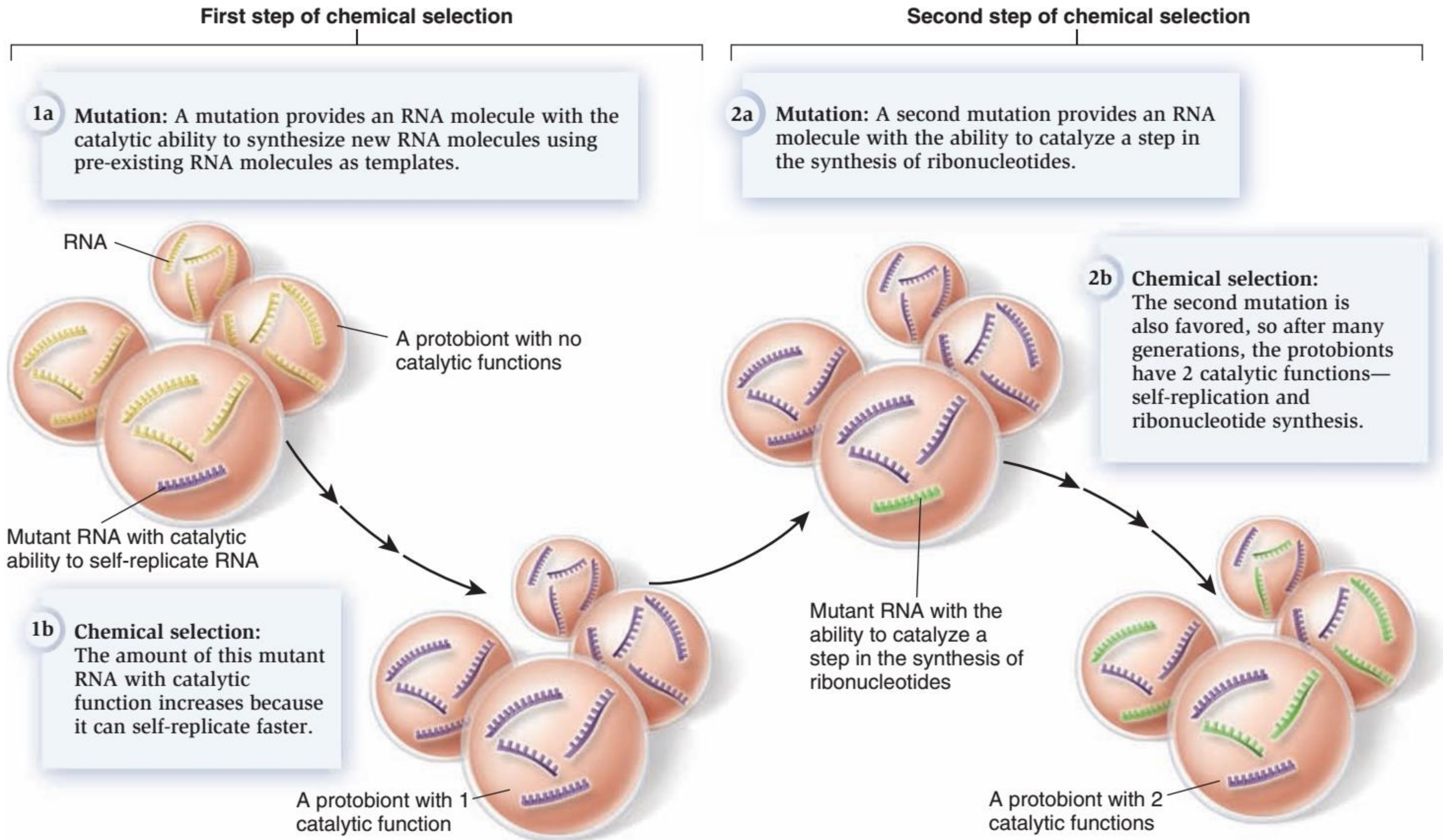
1. RNA has the ability to store information in its nucleotide base sequence.
2. Due to base pairing, its nucleotide sequence has the capacity for self-replication.
3. RNA can perform a variety of catalytic functions. The results of many experiments have shown that some RNA molecules can function as **ribozymes**—RNA molecules that catalyze chemical reactions.

How did the RNA molecules that were first made prebiotically evolve into more complex molecules that produced cell-like characteristics?

Stage 4: Cellular Characteristics May Have Evolved via Chemical Selection, Beginning with an RNA World

- Ans. Chemical selection followed by chemical evolution.
- *Chemical selection occurs when* a chemical within a mixture has a special properties or advantages that cause it to increase in number relative to other chemicals in the mixture.
- Chemical selection results in chemical evolution—a population of molecules changes over time to become a new population with a different chemical composition

A hypothetical scenario illustrating the process of chemical selection.



- In this scenario, protobionts containing RNA exhibited the properties of life due to RNA genomes that were copied and maintained through the catalytic function of RNA molecules.

- Further mutation in these RNA molecules could have added more new functions that is selected by nature- a process called chemical selection.

- Chemical selection would have eventually produced an increase in complexity in these protobionts, with *RNA molecules accruing activities such as the ability to link amino acids together into proteins and other catalytic functions.*

Lab investigation:
Chemical selection of RNA molecules in the laboratory can result in chemical evolution

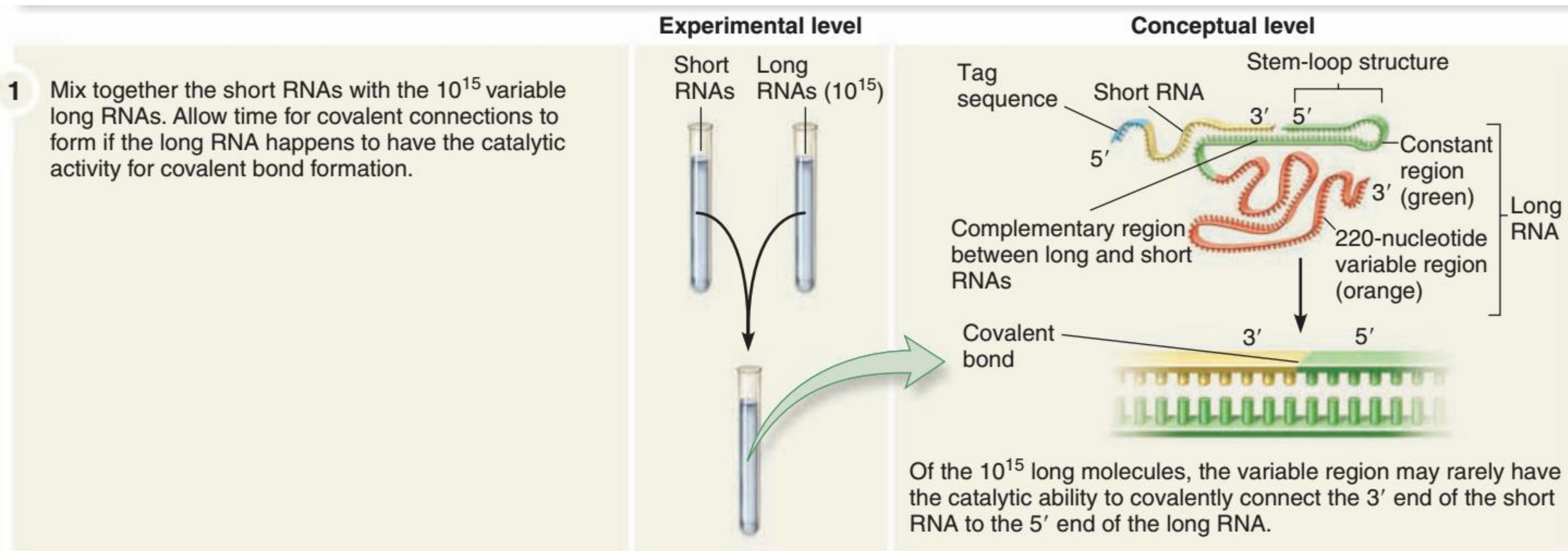
Bartel and Szostak Demonstrated Chemical Evolution in the Laboratory

HYPOTHESIS Among a large pool of RNA molecules, some of them may contain the catalytic ability to make a covalent bond between nucleotides; these can be selected for in the laboratory.

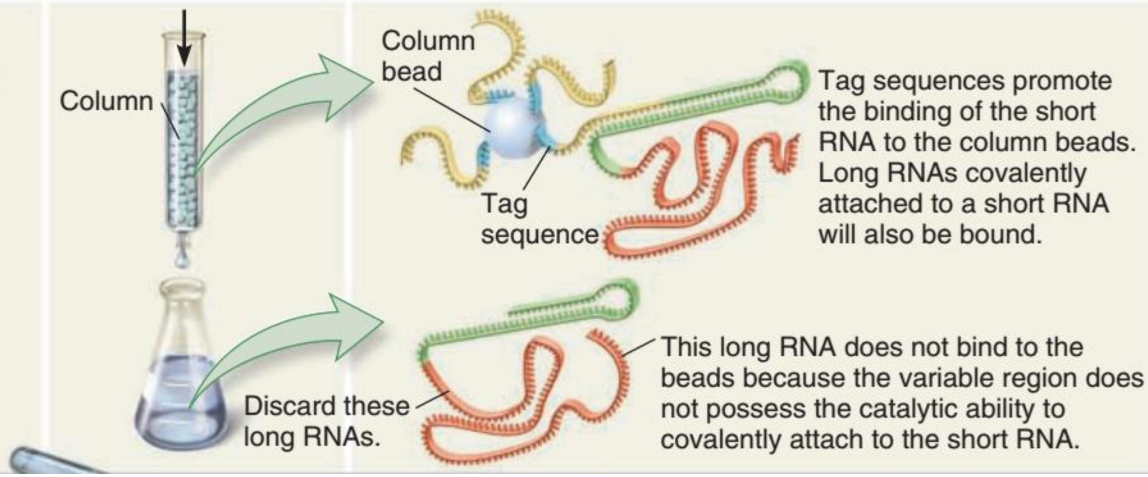
KEY MATERIALS Many copies of short RNA were synthesized that had a tag sequence that binds tightly to column packing material called beads. Also, a population of 10^{15} long RNA molecules was made that contained a constant region with a stem-loop structure and a 220-nucleotide variable region. Note: The variable regions of the long RNAs were made using a PCR step that caused mutations in this region.

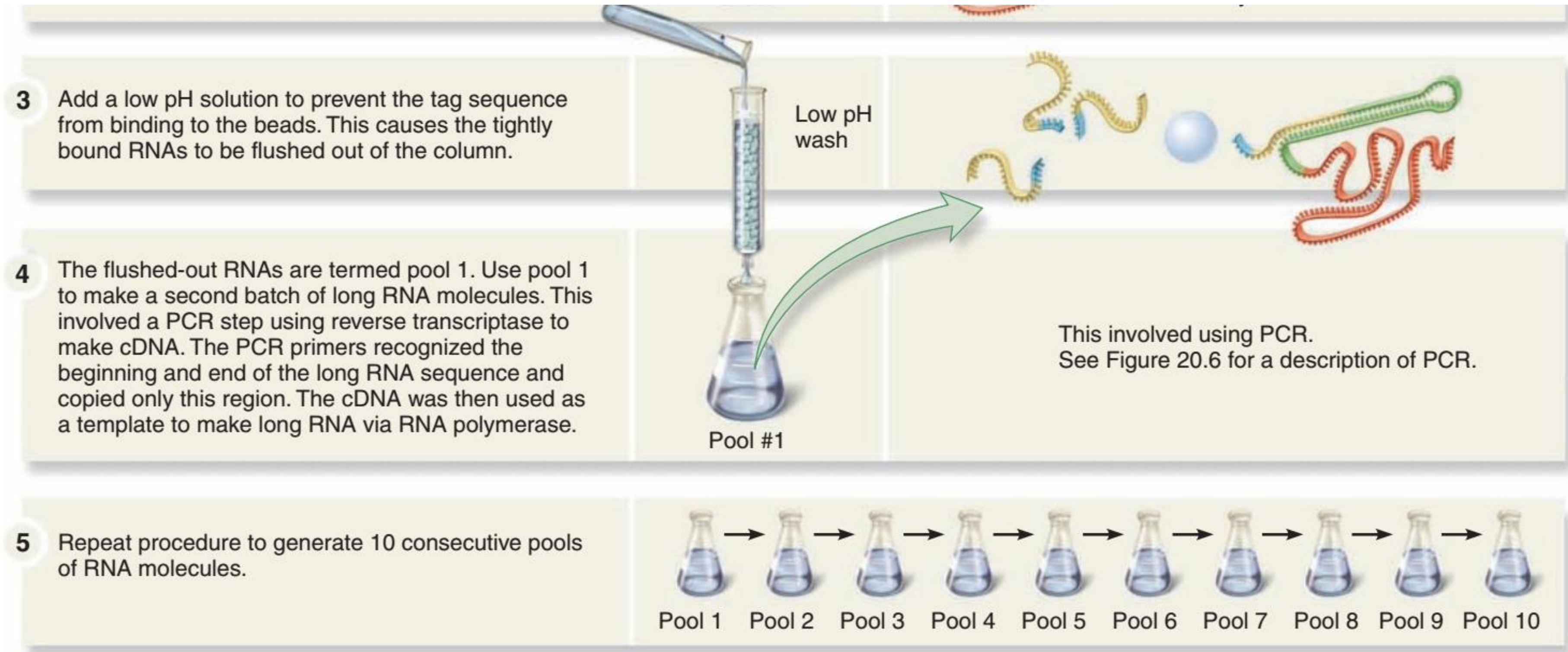
Research question was: can we find a RNA which can act as ribozyme i.e. having ability to make phosphoester bond with a single stranded oligonucleotide??

Conducted by American biologist David Bartel & Jack Szostak in 1993


Experimental level
Conceptual level
1
Mix together the short RNAs with the 10^15 variable long RNAs. Allow time for covalent connections to form if the long RNA happens to have the catalytic activity for covalent bond formation.
Short RNAs
Long RNAs (10^15)
Tag sequence
Short RNA
Stem-loop structure
3′ 5′
5′
Constant region (green)
3′
Long RNA
Complementary region between long and short RNAs
220-nucleotide variable region (orange)
Covalent bond
3′ 5′
Of the 10^15 long molecules, the variable region may rarely have the catalytic ability to covalently connect the 3′ end of the short RNA to the 5′ end of the long RNA.

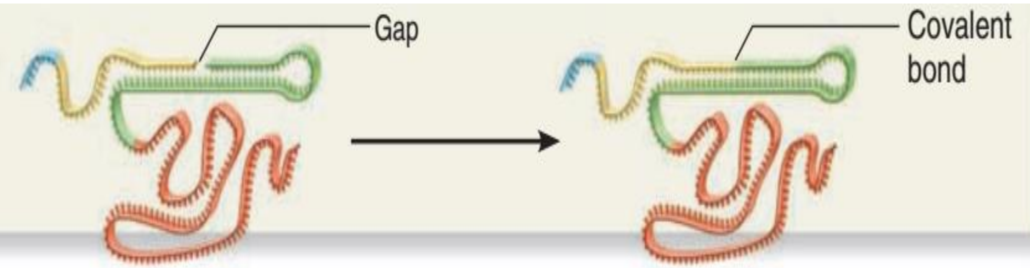
2 Pass the mixture through a column of beads that binds the tag sequence found on the short RNA. Add additional liquid to flush out long RNAs that are not covalently attached to short RNAs.

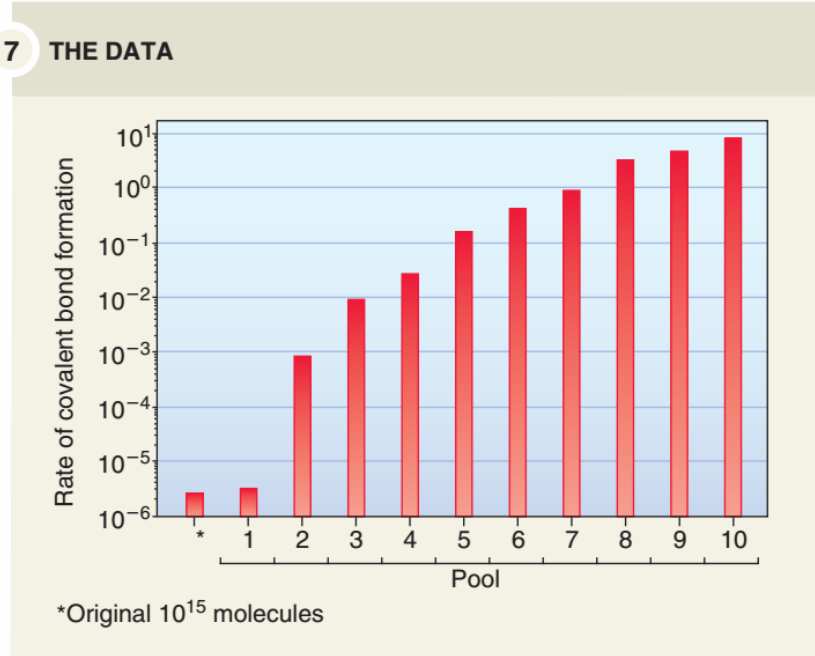




3 Add a low pH solution to prevent the tag sequence from binding to the beads. This causes the tightly bound RNAs to be flushed out of the column.
Low pH wash
4 The flushed-out RNAs are termed pool 1. Use pool 1 to make a second batch of long RNA molecules. This involved a PCR step using reverse transcriptase to make cDNA. The PCR primers recognized the beginning and end of the long RNA sequence and copied only this region. The cDNA was then used as a template to make long RNA via RNA polymerase.
Pool #1
This involved using PCR.
See Figure 20.6 for a description of PCR.
5 Repeat procedure to generate 10 consecutive pools of RNA molecules.
Pool 1
Pool 2
Pool 3
Pool 4
Pool 5
Pool 6
Pool 7
Pool 8
Pool 9
Pool 10

6 Test a sample of the original population and each of the 10 pools for the catalytic ability to make a covalent bond between adjacent nucleotides.



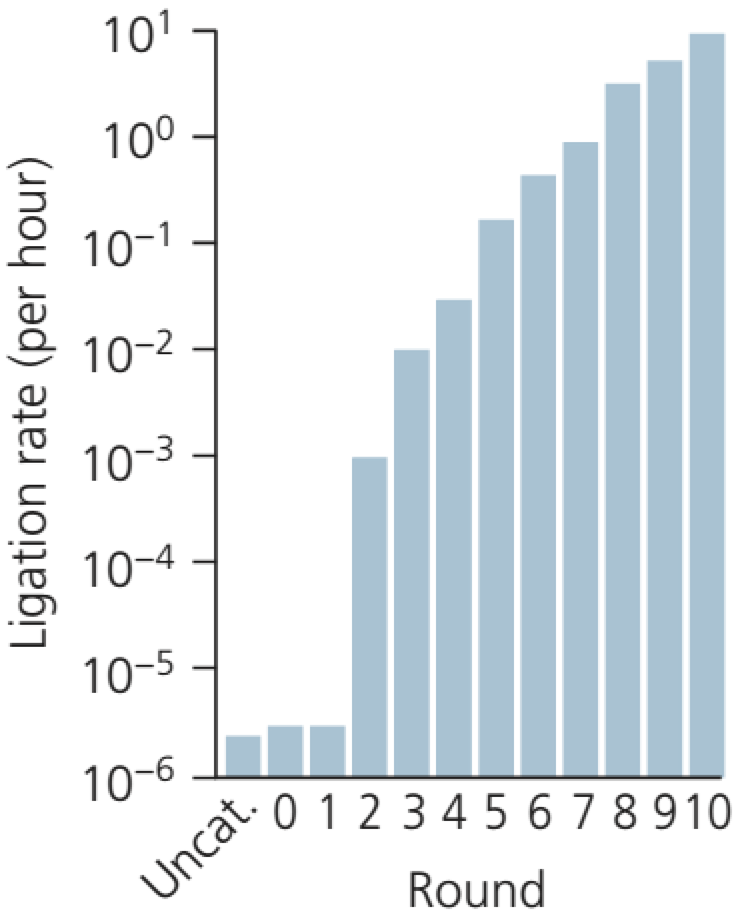


8 CONCLUSION The increase in covalent bond formation from pool 1 to pool 10 indicates that chemical selection can occur.

9 SOURCE Bartel, D. P., and Szostak, J. W. 1993. Isolation of new ribozymes from a large pool of random sequences. *Science* 261:1411–1418.

This result shows that chemical selection can change the functional characteristics of a group of RNA molecules over time by increasing the proportion of those molecules with enhanced function

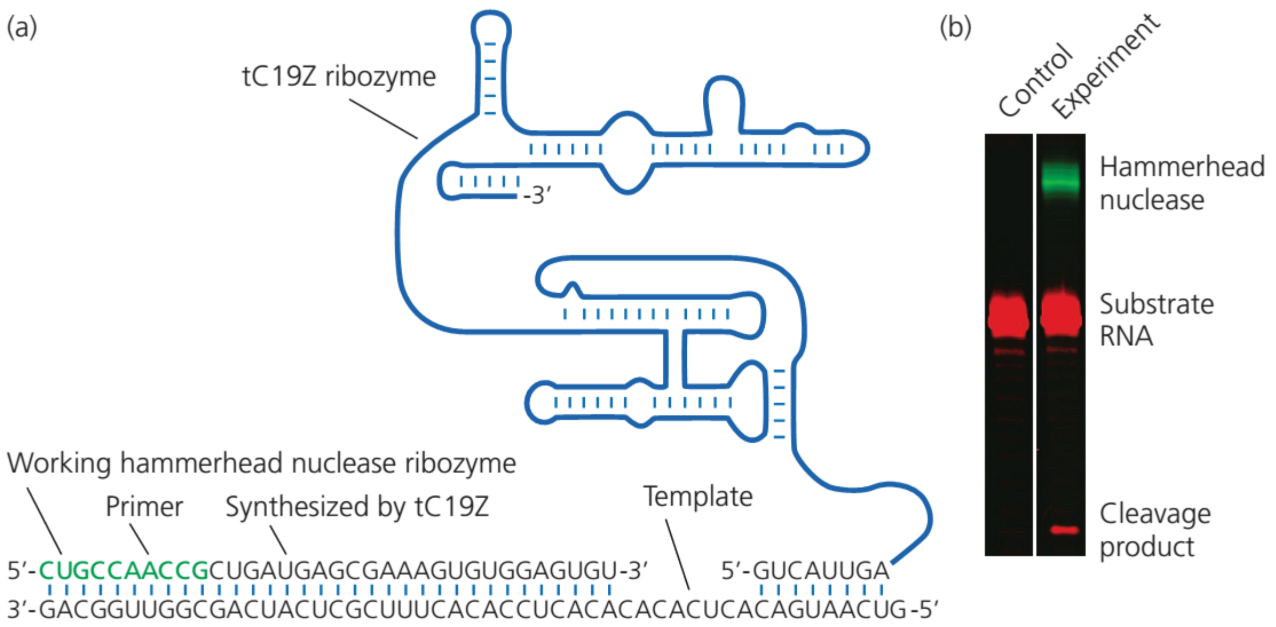
- *Bartel and Szostak's expt. Shows that ribozymes evolve to synthesize RNA*
- In this expt. the RNAs most likely to survive from one generation to the next are the ones that are most efficient at catalyzing phosphoester bonds. After 10 rounds of selection, the RNA pool had evolved ribozymes that could catalyze the formation of phosphoester bonds at a rate 7 million times faster than such bonds form without a catalyst.



Evolution of catalytic ability in a laboratory population of ribozymes The graph shows the average rate at which the members of Bartel and Szostak's (1993) RNA pool catalyzed the formation of phosphoester bonds (ligation rate) as a function of round of selection. Note the logarithmic scale on the vertical axis. From Bartel and Szostak (1993).

- *Aniela Wochner and colleagues (2011), using a strategy similar in spirit to that of Bartel and Szostak, produced a ribozyme that can synthesize another ribozyme.*
- In this expt. researchers started with R18, a ribozyme generated by Wendy Johnston and colleagues (2001) that can use an RNA template to add 14 RNA nucleotides to an RNA primer.
- Wochner and colleagues subjected a population of R18 copies to selection for the ability to synthesize longer RNAs. They identified particular sequence changes responsible for improved performance, then used genetic engineering to incorporate these beneficial mutations into R18.
- The result was a new ribozyme, tC19, that can synthesize RNA molecules 95 nucleotides long—nearly half tC19's own size.
- The scientists subjected a second population of R18 copies to selection for the ability to copy a greater variety of template sequences, identified mutations conferring improved performance, and engineered them into tC19.

- The final result, tC19Z, proved ability to synthesize, with 99.8% accuracy, functional copies of a different ribozyme a hammerhead nuclease (Figure 17.7). Ribozyme tC19Z is not capable of self-replication.



An RNA polymerase ribozyme that can synthesize another ribozyme (a) The secondary structure of tC19Z plus the template for another ribozyme—called a hammerhead nuclease—that, given a primer, tC19Z can copy. After Bentin (2011) and Wochner et al. (2011). (b) Electrophoresis gels demonstrating that the hammerhead nuclease synthesized by tC19Z can cleave an RNA substrate. From Wochner et al. (2011).

The Development of Metabolic Pathways

- Fossil evidence indicates that there were primitive forms of life on Earth about 3.5 billion years ago.
- Regardless of how they developed, these first primitive cells would have needed a way to add new organic molecules to their structures as previously existing molecules were lost or destroyed.
- There are two ways to accomplish this.
- Heterotrophs capture organic molecules, such as sugars, amino acids, or organic acids, from their surroundings, which they use to make new molecules and provide themselves with energy.
- Autotrophs use an external energy source, such as sunlight or the energy from inorganic chemical reactions, to combine simple inorganic molecules, such as water and carbon dioxide, to make new organic molecules.
- These new organic molecules can then be used as building materials for new cells or can be broken down at a later date to provide energy.

The Development of Metabolic Pathways-The Heterotroph Hypothesis

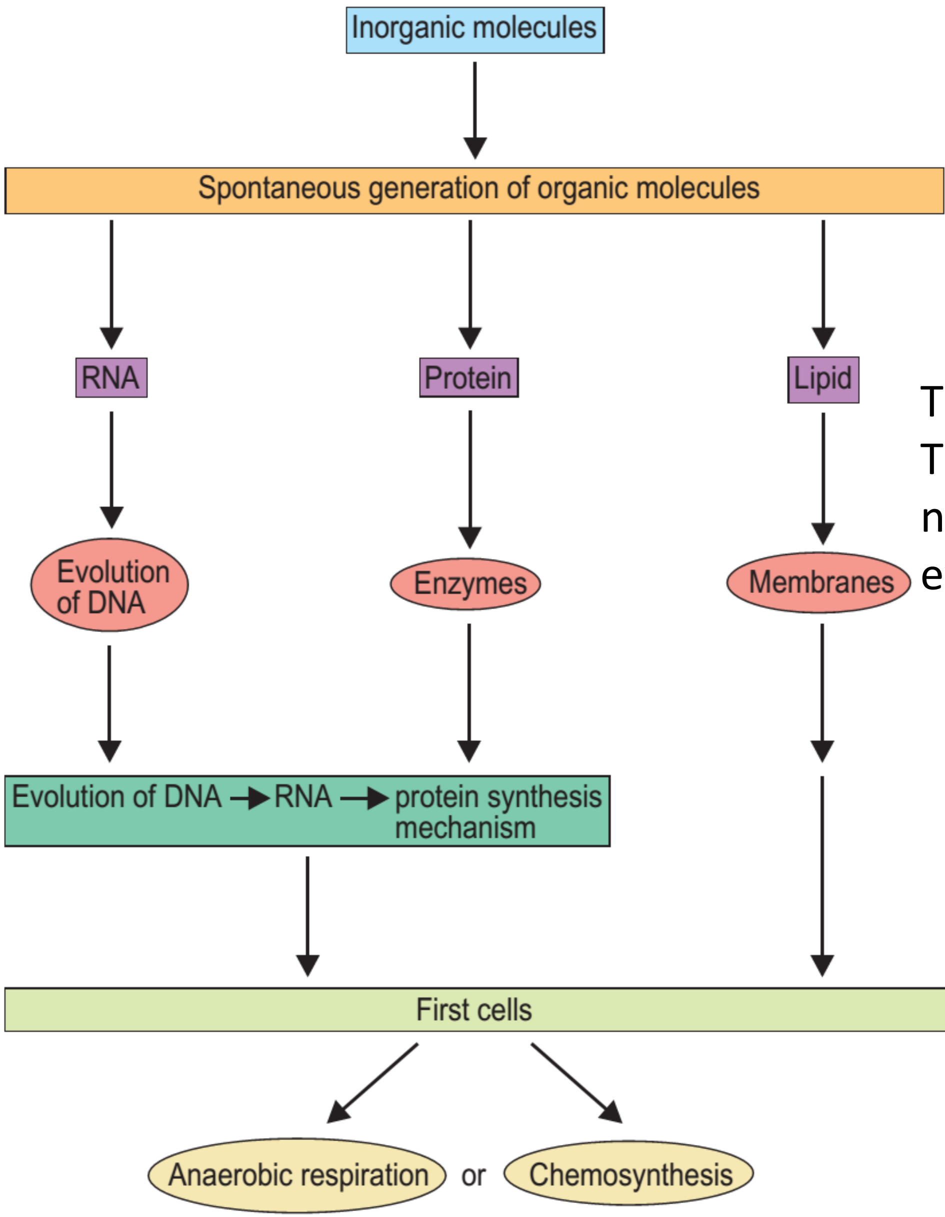
- Early heterotrophs would have been anaerobic organisms. The compounds that could be used easily by these cells would have been the first to become depleted. However, some of the heterotrophs may have contained a mutated form of nucleic acid, which allowed them to convert previously unusable material into something they could use.
- Heterotrophic cells with such mutations could have survived, whereas those without such mutations would have become extinct as the compounds they used for food became scarce.
- Such cells could use chemical reactions to convert unusable chemicals into usable organic compounds. Thus, additional steps would have been added to their metabolic processes, and new metabolic pathways would have evolved.

The Development of Metabolic Pathways - The Autotroph Hypothesis

- the first organisms were autotrophs.
- Evidences for it: many different kinds of prokaryotic organisms are autotrophic and live in extremely hostile environments resembling the conditions that may have existed on the early Earth. These organisms are found in hot springs—such as those found in Yellowstone National Park; in Kamchatka, Russia (Siberia); and near thermal vents—areas where hot, mineralrich water enters seawater from the deep ocean floor.
- They use energy released from inorganic chemical reactions to synthesize organic molecules from inorganic components. Because of this, they are called chemoautotrophs.
- If the first organisms were autotrophs, there would have been competition among different cells for the inorganic raw materials they needed for their metabolism, and there would have been changes in the metabolic processes as mutations occurred.
- There could have been subsequent evolution of a variety of cells, both autotrophic and heterotrophic, which could have led to the diversity of prokaryotic organisms seen today.

The Development of Metabolic Pathways -

- currently there are three competing theories of the origin of life on Earth as shown in figure:
  1. Life arrived here from an extraterrestrial source.
  2. Life originated on Earth as a heterotroph.
  3. Life originated on Earth as an autotroph.



The Chemical Evolution of Life: This diagram summarizes the steps necessary for primitive cells to evolve from inorganic molecules.

How Organisms Obtain Their Energy and Carbon

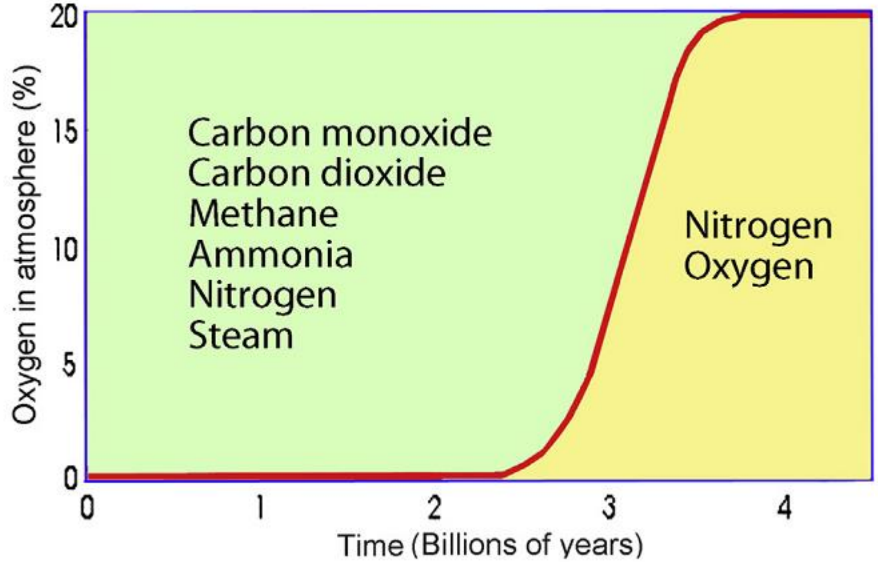
Nutritional Category	Energy Source	Carbon Source
Photoautotrophs (some bacteria, some eukaryotes)	Light	Carbon dioxide
Photoheterotrophs (some bacteria)	Light	Organic compounds
Chemoautotrophs (some bacteria, many archaea)	Inorganic substances	Carbon dioxide
Chemoheterotrophs (found in all three domains)	Usually organic compounds; sometimes inorganic substances	Organic compounds

The Development of Metabolic Pathways -

- Photoautotrophs perform photosynthesis. They use light as their energy source and carbon dioxide (CO2) as their carbon source. E.g. cyanobacteria using chlorophyll a & produce oxygen. However phototrophic bacteria use bacteriochlorophyll rather than chlorophyll a as their key photosynthetic pigment, and they do not produce O2. Instead, some of these photosynthesizers produce particles of pure sulfur because hydrogen sulfide (H_2S), rather than H_2O, is their electron donor for photophosphorylation.
- Photoheterotrophs use light as their energy source but must obtain their carbon atoms from organic compounds made by other organisms. Their “food” consists of organic compounds such as carbohydrates, fatty acids, and alcohols.

The Development of Metabolic Pathways -

- Chemoautotrophs obtain their energy by oxidizing inorganic substances, and they use some of that energy to fix carbon. Some chemoautotrophs use reactions identical to those of the typical photosynthetic cycle, but others use alternative pathways for carbon fixation. Some bacteria oxidize ammonia or nitrite ions to form nitrate ions. Others oxidize hydrogen gas, hydrogen sulfide, sulfur, and other materials. Many archaea are chemoautotrophs.
- Chemoheterotrophs obtain carbon atoms from one or more complex organic compounds that have been synthesized by other organisms, and usually obtain energy from breaking down these organic compounds as well. Most known bacteria and archaea are chemoheterotrophs—as are all animals and fungi and many protists.



Carbon monoxide-acetate pathway

$3CO + 10H^{+} + 2ADP + 2Pi \rightarrow$
$CH_3COOH + H_2O + CH_4 + 2ATP$

Photosynthesis pathway

$12CO_2 + 12H_20 + 12ADP + 12\ Pi + 12\ NADPH \rightarrow$
$C_{12}H_{24}O_{12} + 12O_2 + 12NADP+ + 12ATP$

Oxidative phosphorylation pathway

$NADH + H^{+} + 3ADP + 3Pi + \frac{1}{2}O_2 \rightarrow$
$NAD^{+} + H_2O + 3ATP$

THE ORIGIN OF DNA

- It is believed that DNA predates the earliest life on the planet. It is likely that DNA originated from RNA in an RNA/protein world.
- This hypothesis is supported by the evidence showing that DNA is a modified form of RNA, with the ribose sugar in RNA (OH) reducing to deoxyribose in DNA, and the base uracil (U) into thymidine (T) through the methylation process [addition of a methyl R-CH3 group].
- A complication here is that DNA synthesis requires protein as a catalyst and proteins cannot be synthesized without DNA to fix the order and sequence of the nucleotides.
- The first step in the synthesis of DNA was the formation of U-DNA (DNA containing uracil). This took place through a chemical reaction converting deoxyuridine Triphosphate (dUTP) to *deoxyuridine Monophosphate* (dUMP):

$$dUTP + H_2O \rightarrow dUMP + diphosphate$$

- catalyzed by the enzyme dUTP *diphosphatase*.

THE ORIGIN OF DNA

- This enzyme has two functions: first it removes dUTP from the deoxynucleotides, reducing the likelihood of this base being incorporated into DNA and hence DNA containing uracil, and
- in a second step, dTTP being produced in modern cells by the modification of deoxyuridine monophosphate (dUMP) into deoxythymidine triphosphate (dTMP) by thymidylate synthases, followed by phosphorylation

- This is how uracil in RNA is replaced by thymine in DNA. The molecule dTTP is produced in the cells by the modification of dUMP into dTMP (and dTTP) by the enzyme *thymidylate synthases* (followed by phosphorylation). The above explains formation of DNA from RNA.
- In today's cells, dUMP is produced from dUTP by deoxyuridine triphosphatases, or from deoxycytidine monophosphate (dCMP) by dCMP deaminases. This is another sign that thymidine (T)-DNA originated after U-DNA.

THE ORIGIN OF DNA

- The evolution of DNA also required the appearance of enzymes able to incorporate dNTPs, firstly using RNA templates (reverse transcriptases) and later on using DNA templates (DNA polymerases).

how did amino acids polymerize and form proteins and peptides on primitive Earth?

- Investigators have proposed several ways in which proteins and peptides may have been formed, these include:
- High energy radiation and ion polycondensation which polymerized amino acids
- Controlled exposure to heat at 175°C causing amino acids to polymerize into proteins
- Salt induced peptide polymerization with the assistance of clay materials
- Condensation of amino acids in ammonia at 160°C, which generated polymers
- Creation of volcanic settings in which amino acids were converted into peptides by the use of coprecipitated (Ni, Fe)S and CO in conjunction with H2S
- Carbon disulfide, a gas discharged from volcanoes, which causes homo- and hetero-peptides to be produced
- HCN and other ingredients of primitive atmospheres can polymerize amino acids

how did amino acids polymerize and form proteins and peptides on primitive Earth?

- Heated ammonium cyanide which causes amino acids to polymerize .
- Clay and water subjected to cyclic variations in temperature formed oligopeptides

Biochemistry of Early Life

The Earliest Life Form

A drop of fatty acid formed a micelle which led to a bilayer vesicle. Protocells were made in a fatty acid vesicles containing nucleotides, amino acids, oligoribonucleotides (random RNA sequences) and a saline solution. This was the like the first life form. The protocell had to contain some RNA ribozyme random sequences to aid in early enzyme-like reactions and transport of amino acids and nucleotides into the protocell. The protocells must have used a ribozyme RNA polymerase activity to make RNA from nucleotides which the cell absorbed.

↓

Simplitic Life 1

The simple life develops the carbon monoxide - ATP energy system

↓

Simplitic Life 2

Amino acids form oligopeptides and proteins using 10 possible pathways

↓

Simplitic Life 3

Establishment of the RNA genetic codes.

↓

Simplistic Life 4

Establishment of tRNAs and aminoacyl tRNA synthetases

↓

Simplitic Life 5

Activation of translation using ribozymes to substitute RNA-dependent RNA polymerase and aminoacyl tRNA synthetases

A postulate linking the earliest life-form with cyanobacteria.

Simple Life 6

Synthesis of RNA-dependent RNA polymerase

↓

Simple Life 7

RNA is coded for translation enzymes using genetic code

↓

Simple Life 8

Active synthesis of proteins and enzymes

↓

Simple Life 9

RNA is placed in chromosomes inside the cellular nucleoid, an organelle

↓

Simple Life 10

Using $C0_2$ and ATP from the carbon monoxide energy cycle to make glucose by Calvin cycle.

↓

Cyanobacteria

Initial stages of Cyanobacteria start photosynthesis and replace RNA storage with DNA storage

A postulate linking the earliest life-form with cyanobacteria.

Biochemistry of Early Life

- The starting original life-form develops or evolves with time forming Simple Life-1
- Simple Life-1 gains the simplest energy system, the carbon monoxide–Methane/adenosine triphosphate (ATP) energy system. This uses carbon monoxide, expels methane and generates ATP. This pathway requires two enzymes, which can be provided by random ribozymes.
- The carbon monoxide–Methane/ATP energy system generated ATP. This permitted high energy ATP, cytidine triphosphate (CTP), uridine triphosphate (UTP), and guanosine triphosphate (GTP) generation, and allowed ATP to power future enzymatic and present ribozyme reactions.

Biochemistry of Early Life

- The second evolutionary step (Simple Life-2, Fig. 2.1) involved polymerization of amino acids to make oligopeptides and proteins. Ten independent approaches have been proposed
- High energy radiation and ion polycondensation may have polymerized amino acids
- Controlled exposure to heat at 175°C caused amino acids to polymerize to proteins
- Salt induced peptide polymerization with the assistance of clay materials
- Condensation of amino acids in ammonia at 160°C generated polymers
- In volcanic settings, amino acids were converted into their peptides by the use of coprecipitated (Ni, Fe)S and CO in conjunction with H2S
- In the presence of carbon disulfide, a gas discharged from volcanoes, homo- and hetero-peptides were produced
- Polymerization of amino acids was possible using HCN and ingredients of primitive atmospheres

Biochemistry of Early Life

- Amino acids from a primitive environment polymerized using heated ammonium cyanide
- In clay and water subjected to cyclic variations in temperature, longer oligopeptides were formed
- Peptide formation in the prebiotic era by thermal condensation of glycine in fluctuating clay environments

Biochemistry of Early Life

- The third evolutionary step (Simple Life-3→Simple Life-7, see Figure) is a multistep evolutionary event involving the activation of RNA-dependent RNA translation in the simple life-form.
- Firstly, Simple Life-3, is the determination of the genetic code; secondly, Simple Life-4, is the synthesis of amino acids tRNAs; thirdly, Simple Life-5, is the activation of translation using ribozymes to substitute for the specific aminoacyl tRNA synthetases; fourthly, Simple Life-6, is the synthesis of aminoacyl tRNA synthetases; and finally, Simple Life-7, RNA is coded for the synthesized proteins.
- In Simple Life-8 (see Fig.) , active synthesis of amino acids and proteins occurs. In Simple Life-9, RNA is placed in chromosomes inside the cellular nucleoid (an organelle). In Simple Life-10, cells make enzymes and use them and ribozymes for the Calvin cycle, using CO2 and ATP from the carbon monoxide energy cycle to make glucose.
- Cells then become cyanobacteria, adopting photosynthesis and replacing RNA coding with DNA. Additional references describe sugar synthesis, energy pathways, amino acid synthesis and RNA synthesis

BOX 20.3: DIFFERENCES BETWEEN DNA AND RNA MOLECULES

There are three marked differences between DNA and RNA:

1. They differ in their sugar groups (which, along with a phosphate group, construct the backbone). In DNA the pentose sugar is deoxyribose, which differs from the one found in RNA by the absence of an oxygen atom (Figure B20.3).
2. Deoxyribose provides the sugar base of DNA and comes in four forms: adenine (*A*), cytosine (*C*), guanine (*G*), and thymine (*T*). RNA is also made of four bases, with the difference being that its nucleotide includes uracil (*U*) rather than thymine. The thymine has a methyl (CH_3) attached to its central carbon while uracil does not have the methyl group. Apart from these, the two compounds have the same chemical composition and structure (Figure B20.3).
3. DNA molecules have a double stranded structure whereas RNA consists of a single strand (Figure B20.3).

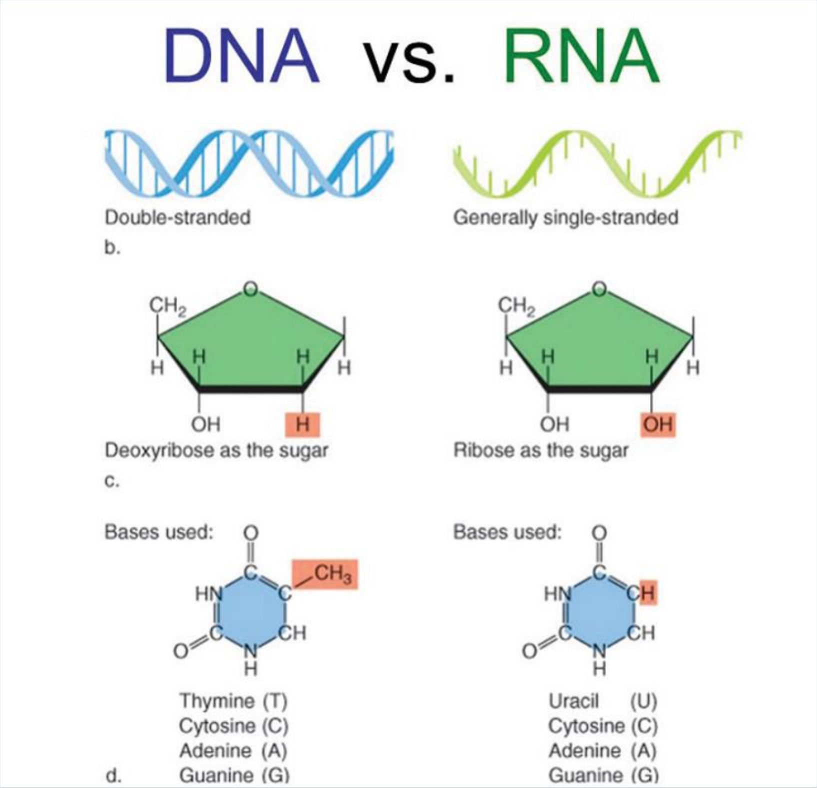
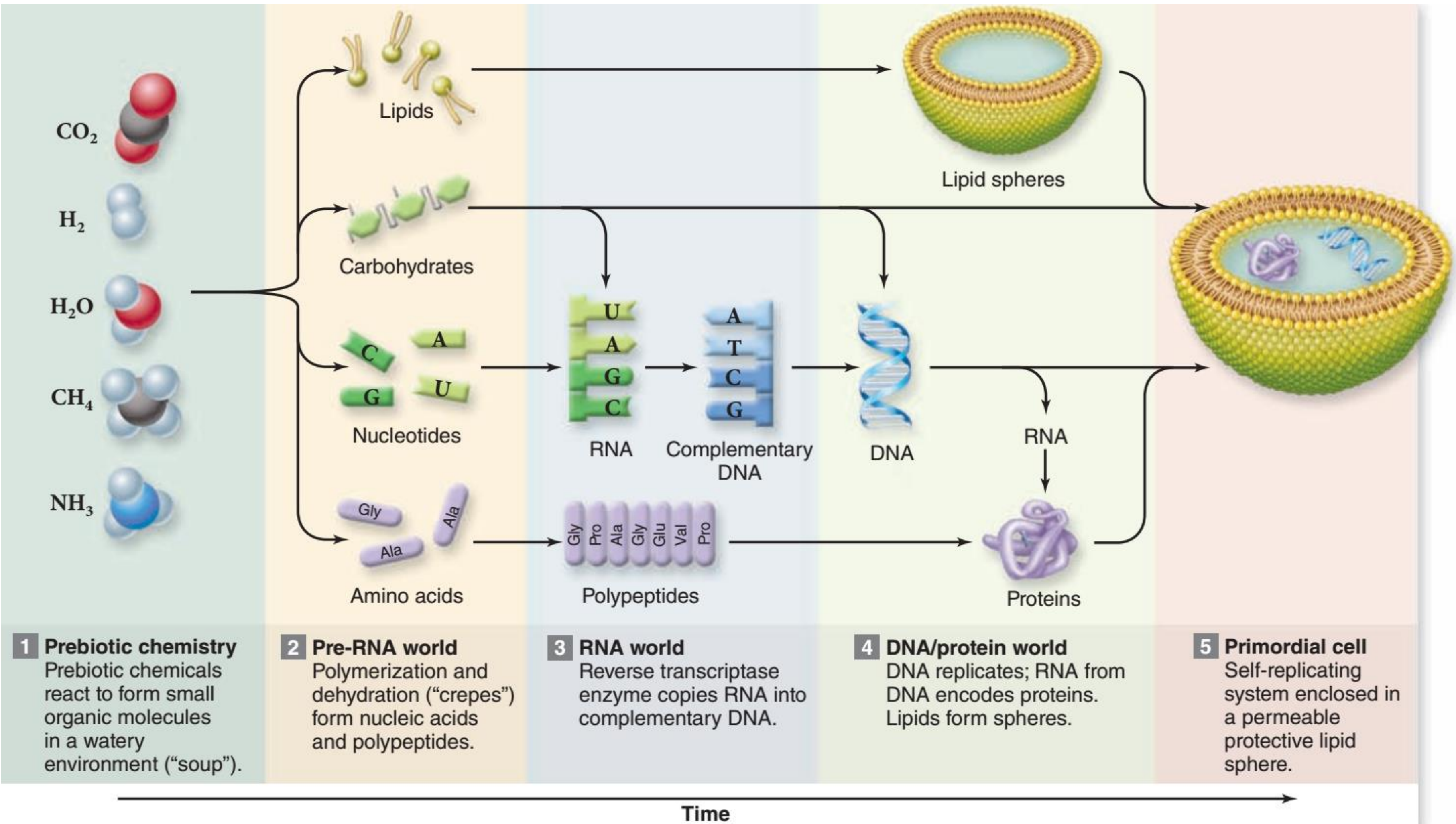
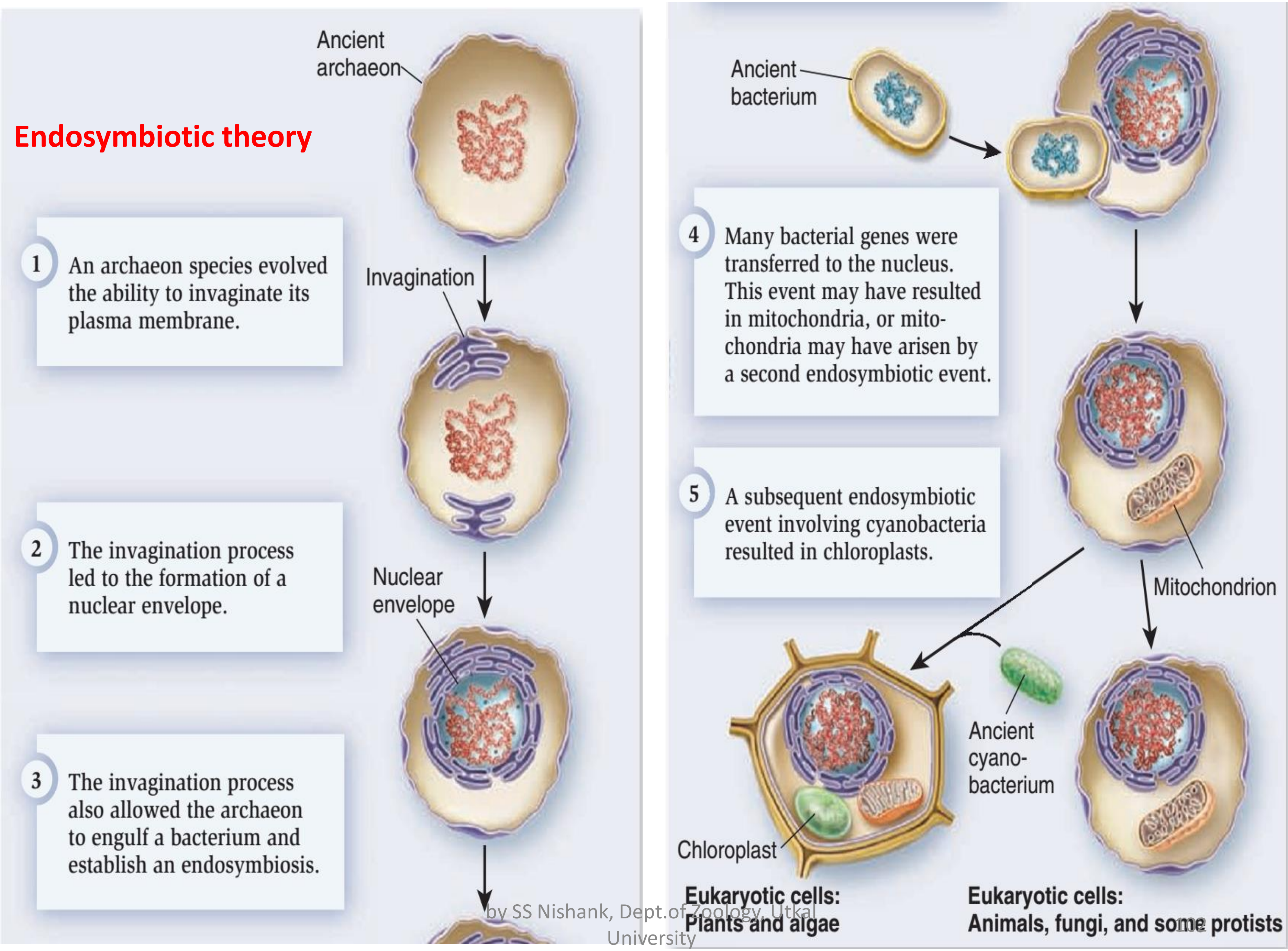


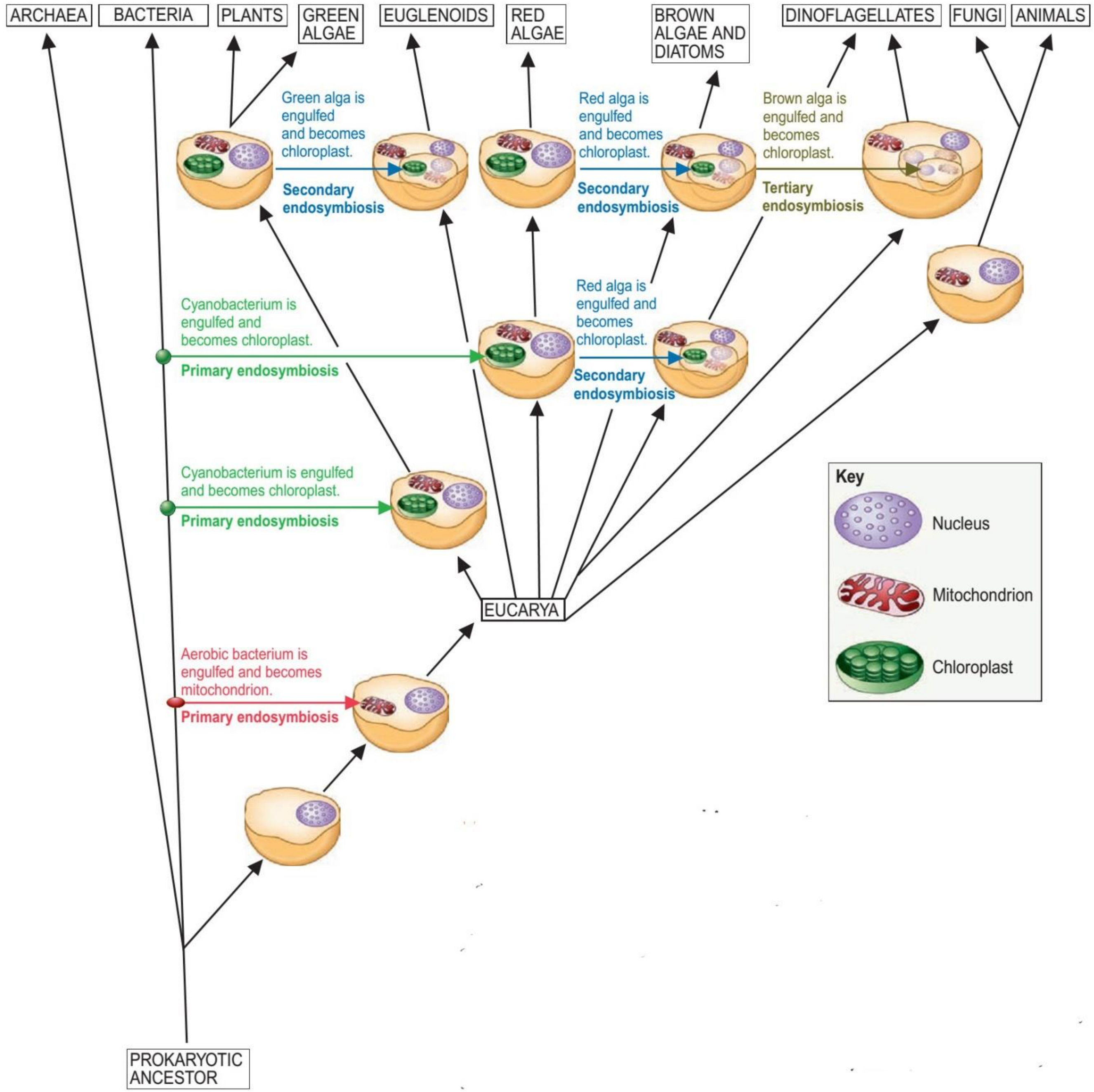
Figure B20.3. The comparison between DNA and RNA molecules. RNA has a hydroxyl group (OH) attached to its central carbon. This is replaced in DNA by only a hydrogen atom (H). The missing oxygen results in a deoxyribose molecule. Also, the nucleotide thymine in DNA is replaced by uracil in RNA. The difference between the two nucleotides is the addition of a methyl group CH_3 to thymine and hydrogen (H) to uracil.

Pathway to a Cell



Endosymbiotic theory

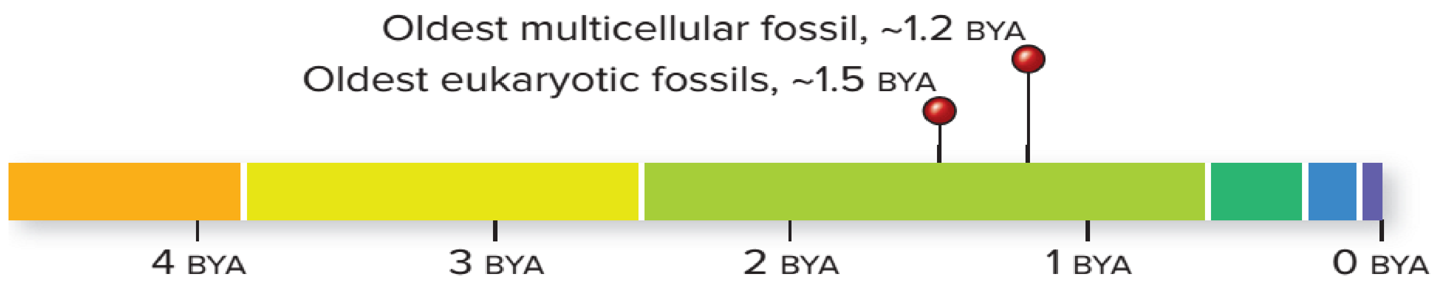


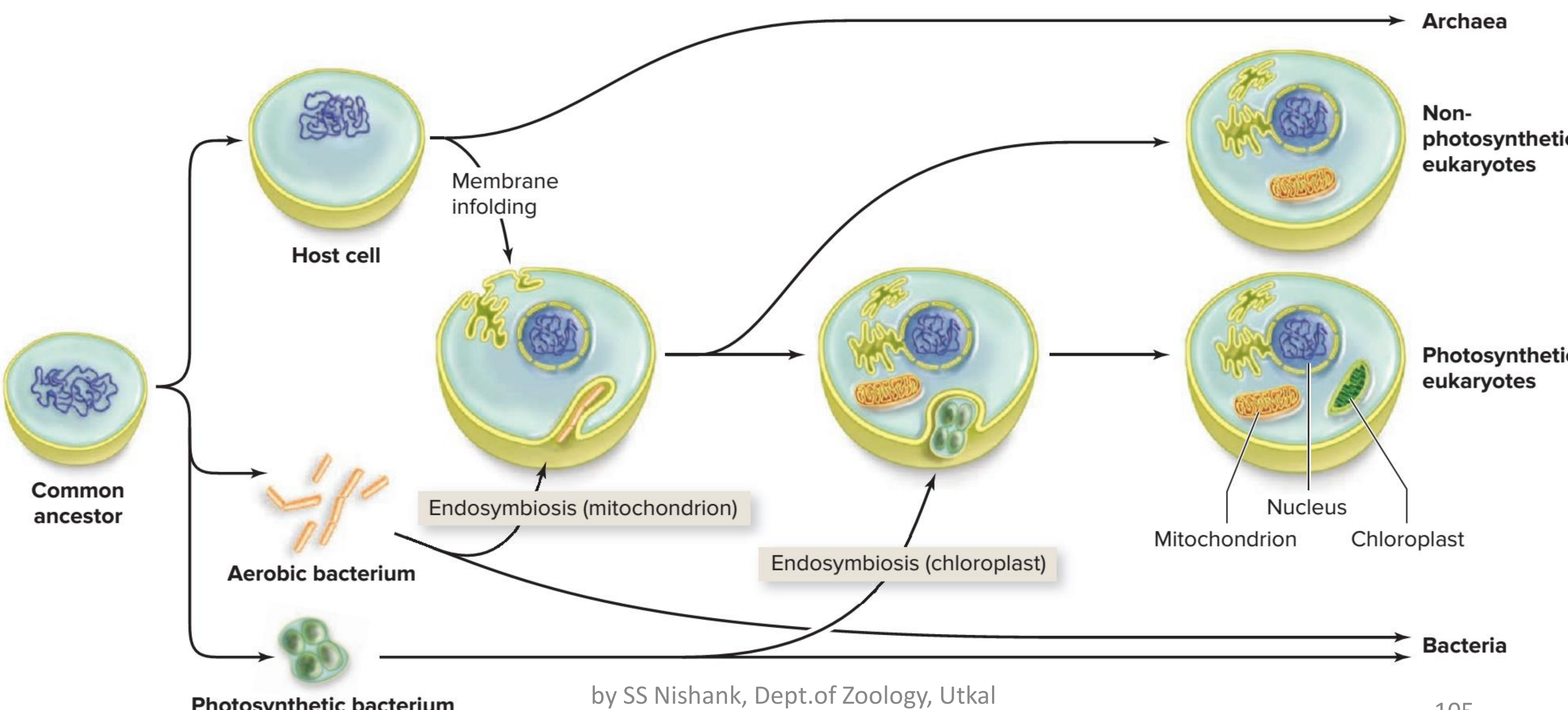

ARCHAEA
BACTERIA
PLANTS
GREEN ALGAE
EUGLENOIDS
RED ALGAE
BROWN ALGAE AND DIATOMS
DINOFLAGELLATES
FUNGI
ANIMALS
Green alga is engulfed and becomes chloroplast.
Secondary endosymbiosis
Red alga is engulfed and becomes chloroplast.
Secondary endosymbiosis
Brown alga is engulfed and becomes chloroplast.
Tertiary endosymbiosis
Cyanobacterium is engulfed and becomes chloroplast.
Primary endosymbiosis
Red alga is engulfed and becomes chloroplast.
Secondary endosymbiosis
Cyanobacterium is engulfed and becomes chloroplast.
Primary endosymbiosis
EUCARYA
Aerobic bacterium is engulfed and becomes mitochondrion.
Primary endosymbiosis
PROKARYOTIC ANCESTOR
Key
Nucleus
Mitochondrion
Chloroplast

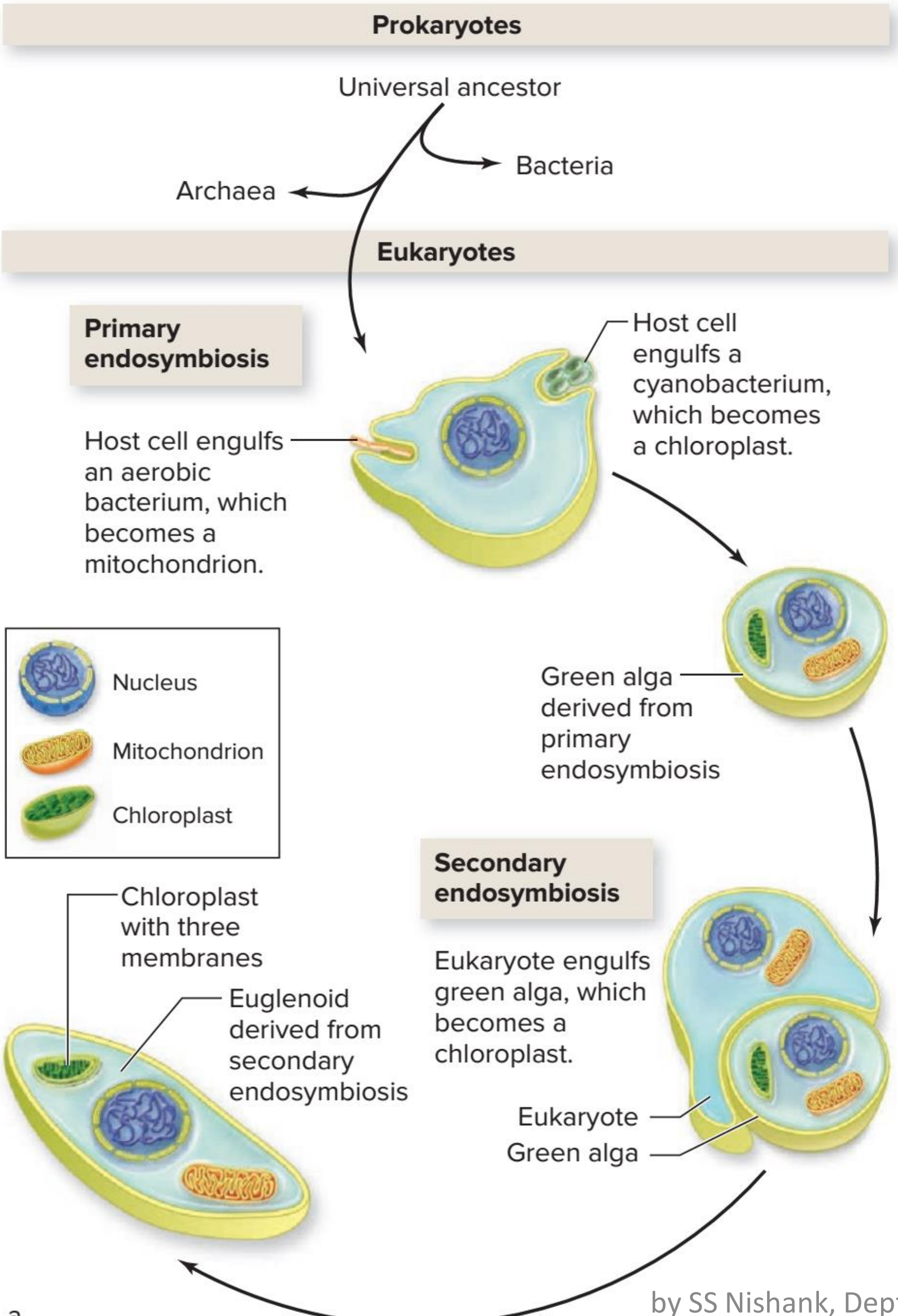
Evidences in favour of Endosymbiotic theory

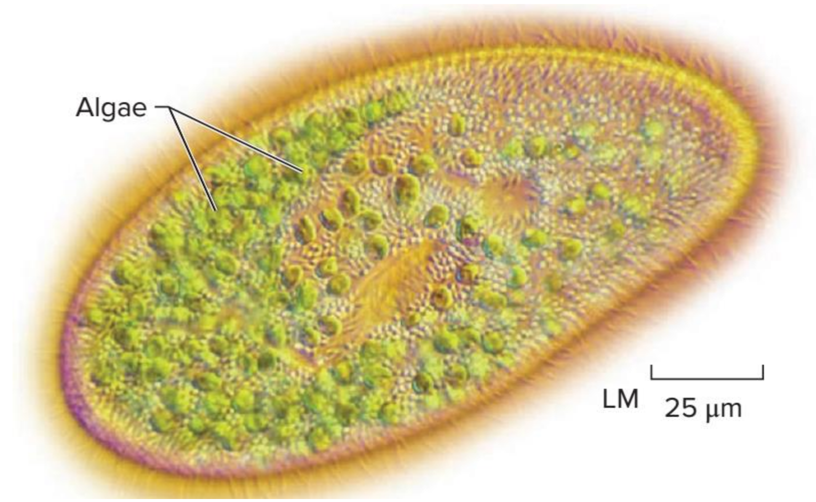
- similarities in size, shape, and membrane structure between the organelles and some types of bacteria;
- the double membrane surrounding mitochondria and chloroplasts, a presumed relic of the original engulfing event;
- the observation that mitochondria and chloroplasts are not assembled in cells but instead divide, as do bacterial cells;
- the similarity between the photosynthetic pigments in chloroplasts and those in cyanobacteria;
- the observation that mitochondria and chloroplasts contain DNA, RNA, and ribosomes (and the ribosomes are structurally similar to those in bacterial cells); and
- DNA sequence analysis, which shows a close relationship between mitochondria and aerobic bacteria (proteobacteria), as well as between chloroplasts and cyanobacteria.

Endosymbiotic theory

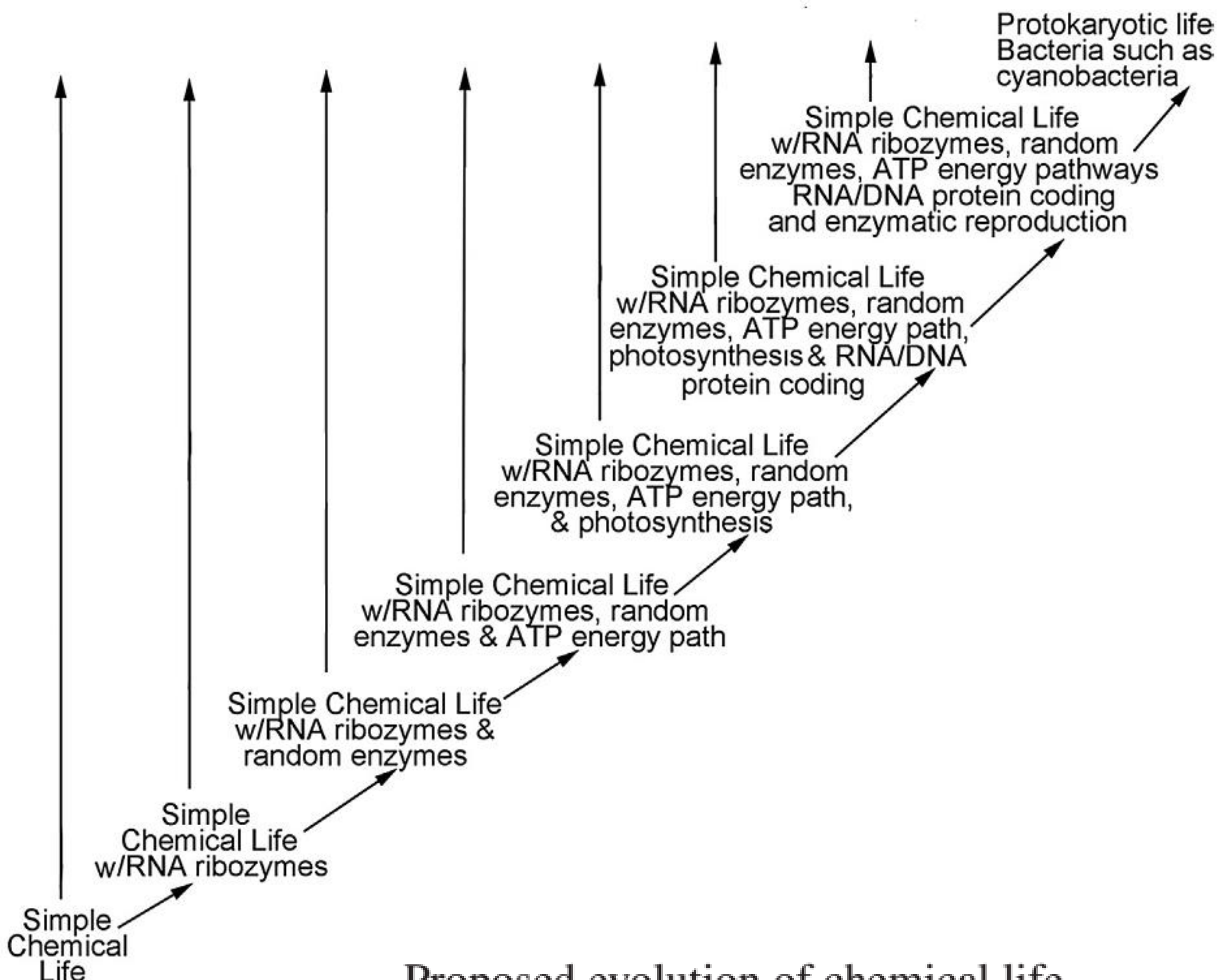








Eukaryotic algae
live inside this protist, *Paramecium bursaria.* This partnership and others like it provide evidence for the endosymbiosis theory.

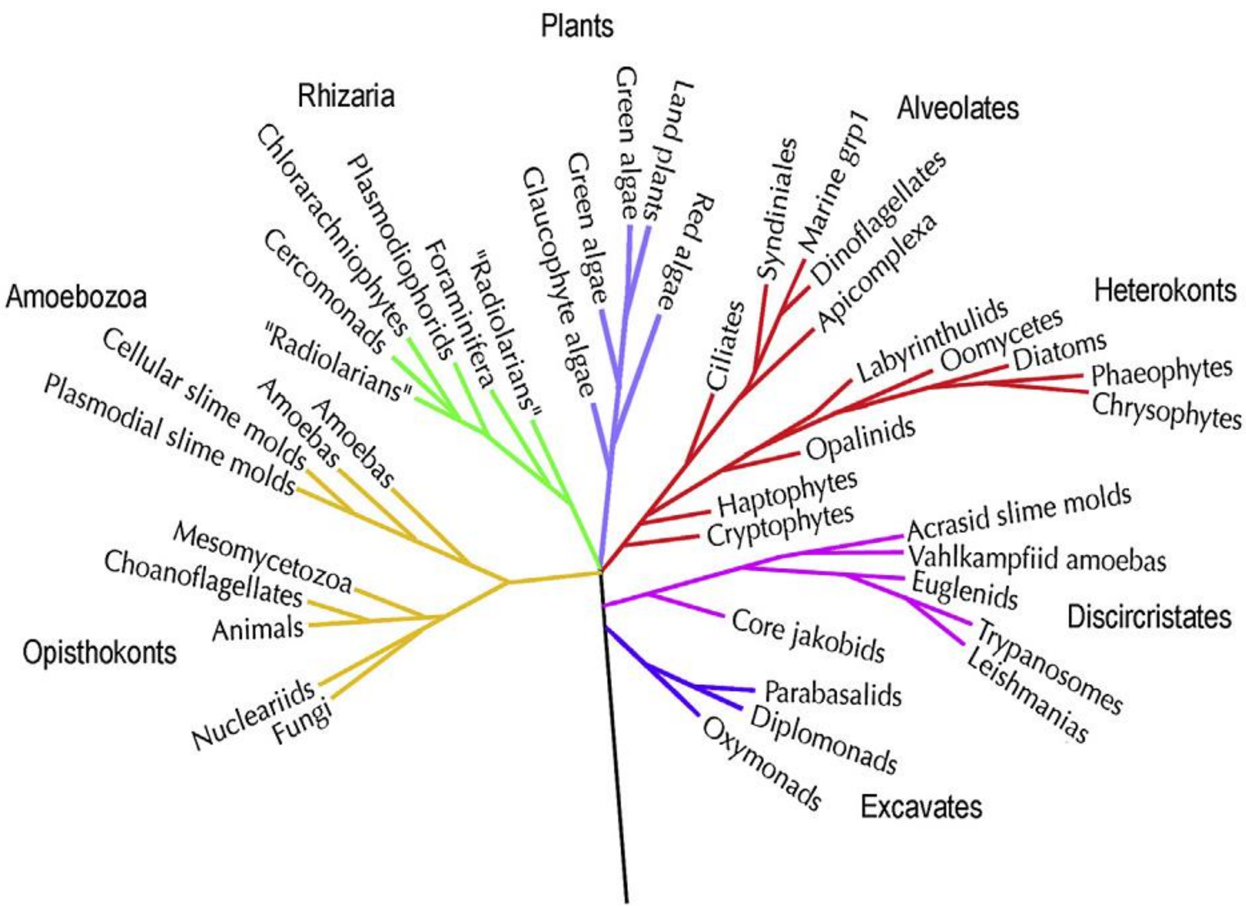


Proposed evolution of chemical life.

Evolution of Early Life

- A proposition of possible advancement steps needed to advance to prokaryotic life is presented in Figure. This is simply chemical life advancing to simple chemical life with RNA and RNA enzyme or ribozymes, advancing to a simple chemical life with random proteins or enzyme activities, advancing to a simple chemical life with an adenosine triphosphate energy pathway, advancing to a simple chemical life with photosynthesis, advancing to a simple chemical life with RNA/DNA protein coding, advancing to a simple chemical life with enzymatic reproduction, advancing to a prokaryotic life.
- The evolution of eukaryotes probably took place after the development of the oxygen-nitrogen rich atmosphere, 2.8billion years ago.
- How did the eukaryotic cell evolve? How did prokaryotic bacterium make this evolutionary leap to the more complex eukaryotic cell? The answer seems to be symbiosis or teamwork.

Eukaryote evolution.

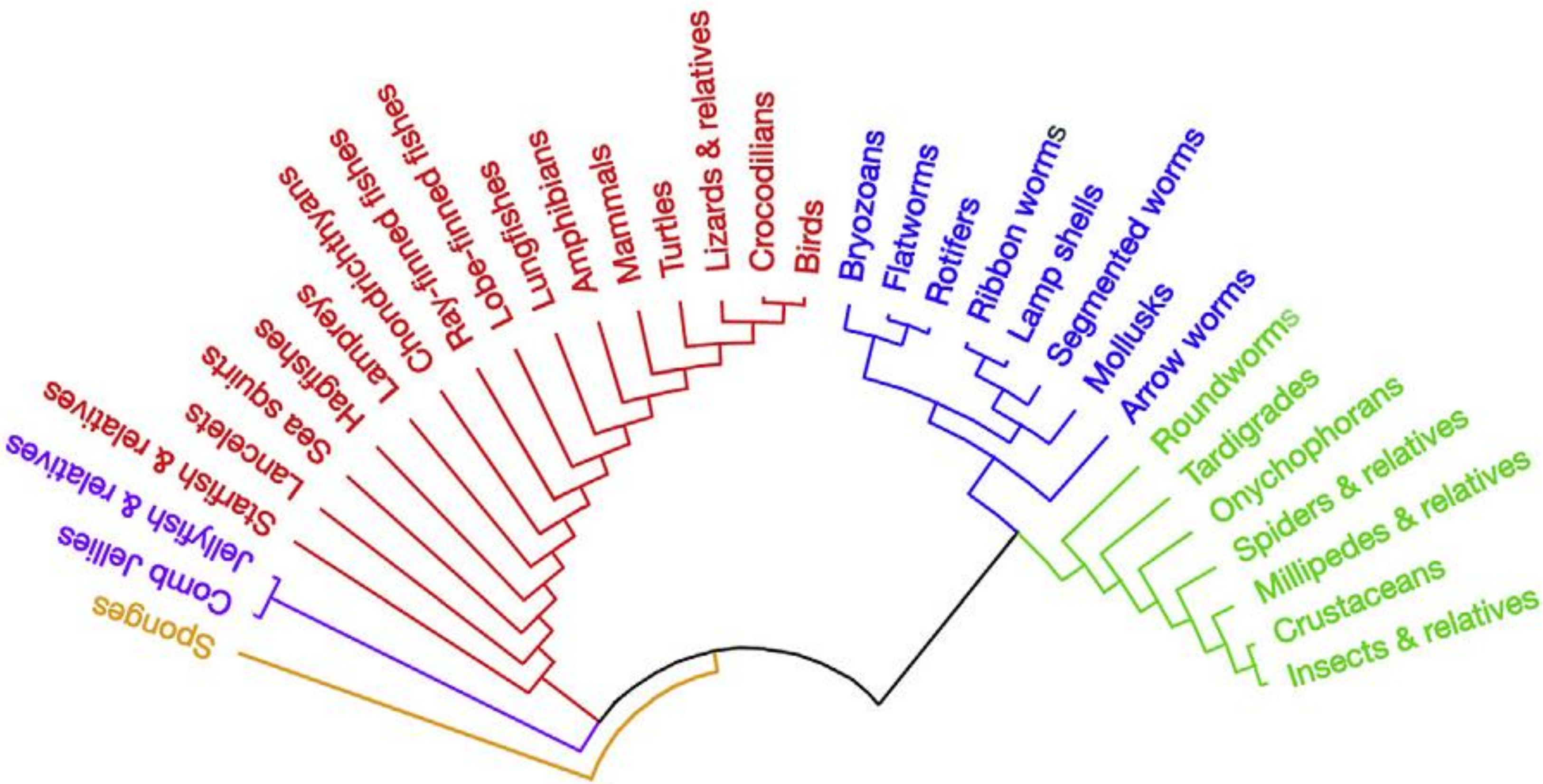


Evolution of Early Life

- Previous Figure shows the wide evolution of eukaryotes, and how animal are just a tiny part of the eukaryotic sphere or organisms.
- Eukaryotes can be classed as opisthokonts, the animal and fungus kingdoms together with the microorganisms that are conventionally assigned to the protist kingdom.
- Amoebozoa, a major taxonomic group containing about 2400 species of amoeboid protists, or amoeba and protozoa.
- Rhizaria, a species-rich supergroup of mostly unicellular eukaryotes. Plants, a group including all the flowers and plants found on Earth.
- Alveolates is a major groups of protists or single celled organisms. Heterokonts or stramenopiles are a major line of eukaryotes currently containing more than 25,000 known species. Most are algae, ranging from the giant multicellular kelp to the unicellular diatoms, which are a primary component of plankton.
- Discircristates clade consists of euglenozoa plus percolozoa. Excavates clade are a major subgroup of unicellular eukaryotes, containing a variety of free-living and symbiotic forms, and also includes some important parasites of humans.

Evolution of Early Life

- Through opisthokonts, and just one avenue of eukaryotic evolution channel of eukaryotes animals evolved with multiple organs.



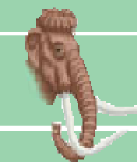
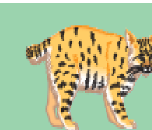
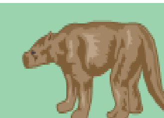
Animal evolution.

The key events are:

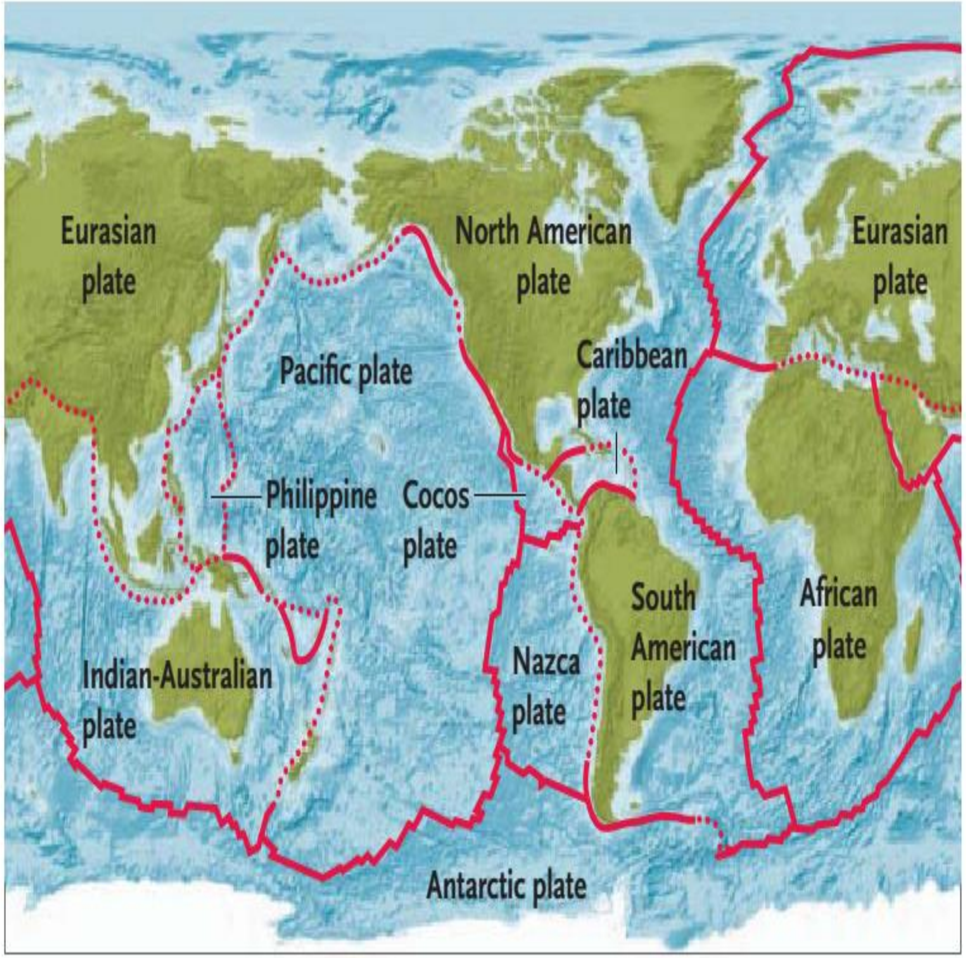
Formation of planet Earth 4.54 billion years ago
for the last 3.6 billion years, simple cells (prokaryotes);
for the last 3.4 billion years, cyanobacteria performing photosynthesis;
for the last 2 billion years, complex cells (eukaryotes);
for the last 1.2 billion years, eukaryotes which sexually reproduce
for the last 1 billion years, multicellular life;
for the last 600 million years, simple animals;
for the last 550 million years, bilaterians, water life forms with a front and a back;
for the last 500 million years, fish and proto-amphibians;
for the last 475 million years, land plants;
for the last 400 million years, insects and seeds;
for the last 360 million years, amphibians;
for the last 300 million years, reptiles;
for the last 200 million years, mammals;
for the last 150 million years, birds;
for the last 130 million years, flowers;
for the last 60 million years, the primates,
for the last 20 million years, the family Hominidae (great apes);
for the last 2.5 million years, the genus *Homo* (including humans and their predecessors);
for the last 200,000 years, anatomically modern humans.

Eon	Era	Period	Epoch	mya	Major Geologic and Biological Events
Phanerozoic	Cenozoic	Quaternary	Holocene	0.01	Modern humans evolve. Major extinction event is now under way.
			Pleistocene	2.6	
		Neogene	Pliocene	5.3	Tropics, subtropics extend poleward. Climate cools; dry woodlands and grasslands emerge. Adaptive radiations of mammals, insects, birds.
			Miocene	23.0	
		Paleogene	Oligocene	33.9	
			Eocene	56.0	
			Paleocene	66.0	Major extinction event
	Mesozoic	Cretaceous	Upper		Flowering plants diversify; sharks evolve. All dinosaurs and many marine organisms disappear at the end of this epoch.
				100.5	
			Lower		Climate very warm. Dinosaurs continue to dominate. Important modern insect groups appear (bees, butterflies, termites, ants, and herbivorous insects including aphids and grasshoppers). Flowering plants originate and become dominant land plants.
				145.0	
		Jurassic			Age of dinosaurs. Lush vegetation; abundant gymnosperms and ferns. Birds appear. Pangea breaks up.
				201.3	Major extinction event
		Triassic			Recovery from the major extinction at end of Permian. Many new groups appear, including turtles, dinosaurs, pterosaurs, and mammals.
				252	Major extinction event
	Paleozoic	Permian			Supercontinent Pangea and world ocean form. Adaptive radiation of conifers. Cycads and ginkgos appear. Relatively dry climate leads to drought-adapted gymnosperms and insects such as beetles and flies.
				299	
		Carboniferous			High atmospheric oxygen level fosters giant arthropods. Spore-releasing plants dominate. Age of great lycophyte trees; vast coal forests form. Ears evolve in amphibians; penises evolve in early reptiles (vaginas evolve later, in mammals only).
				359	Major extinction event
		Devonian			Land tetrapods appear. Explosion of plant diversity leads to tree forms, forests, and many new plant groups including lycophytes, ferns with complex leaves, seed plants.
				419	
		Silurian			Radiations of marine invertebrates. First appearances of land fungi, vascular plants, bony fishes, and perhaps terrestrial animals (millipedes, spiders).
				443	Major extinction event
		Ordovician			Major period for first appearances. The first land plants, fishes, and reef-forming corals appear. Gondwana moves toward the South Pole and becomes frigid.
				485	
		Cambrian			Earth thaws. Explosion of animal diversity. Most major groups of animals appear (in the oceans). Trilobites and shelled organisms evolve.
				541	
Precambrian	Proterozoic				Oxygen accumulates in atmosphere. Origin of aerobic metabolism. Origin of eukaryotic cells, then protists, fungi, plants, animals. Evidence that Earth mostly freezes over in a series of global ice ages between 750 and 600 mya.
				2,500	
	Archean and earlier				3,800–2,500 mya. Origin of bacteria and archaea. 4,600–3,800 mya. Origin of Earth's crust, first atmosphere, first seas. Chemical, molecular evolution leads to origin of life (from protocells to anaerobic single cells).

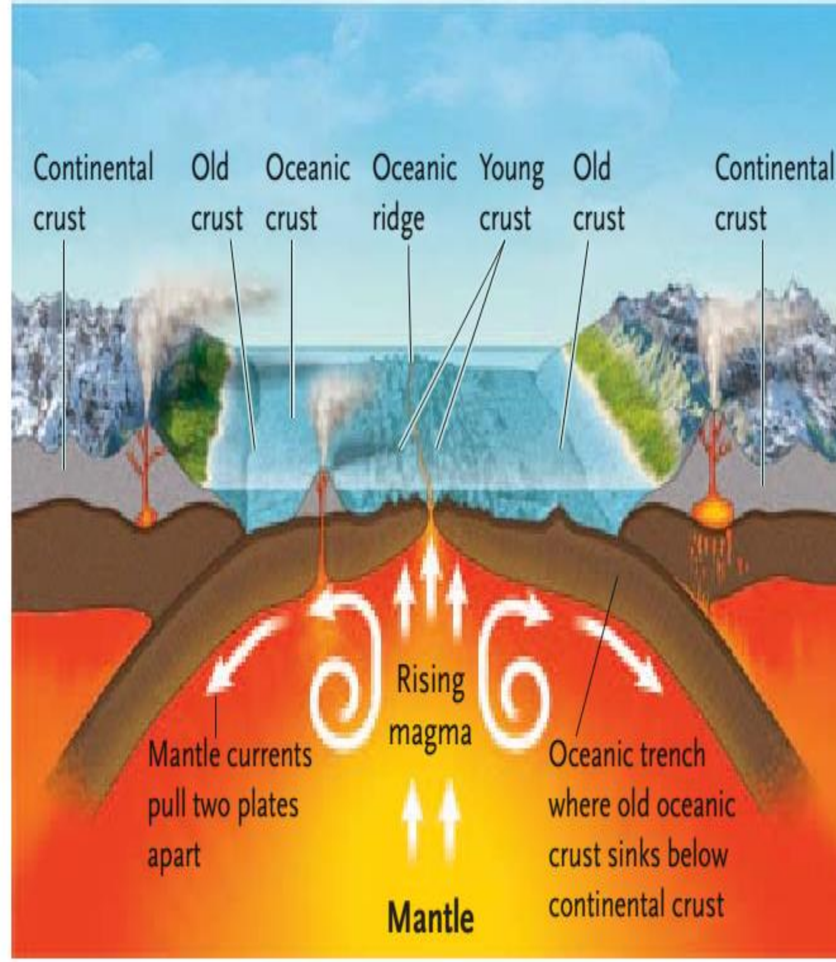
Cenozoic era

Geologic Time	Period	Epoch	Age (millions of years ago)	Some Important Events in the History of Life
Cenozoic era	Quaternary	Recent	0.01	Historical time 
		Pleistocene	1.8	Ice ages; humans appear 
	Tertiary	Pliocene	5	Origin of genus *Homo* 
		Miocene	23	Continued speciation of mammals and angiosperms 
		Oligocene	34	Origins of many primate groups, including apes 
		Eocene	56	Angiosperm dominance increases; origins of most living mammalian orders 
		Paleocene	65	Major speciation of mammals, birds, and pollinating insects 

A. Earth's crustal plates

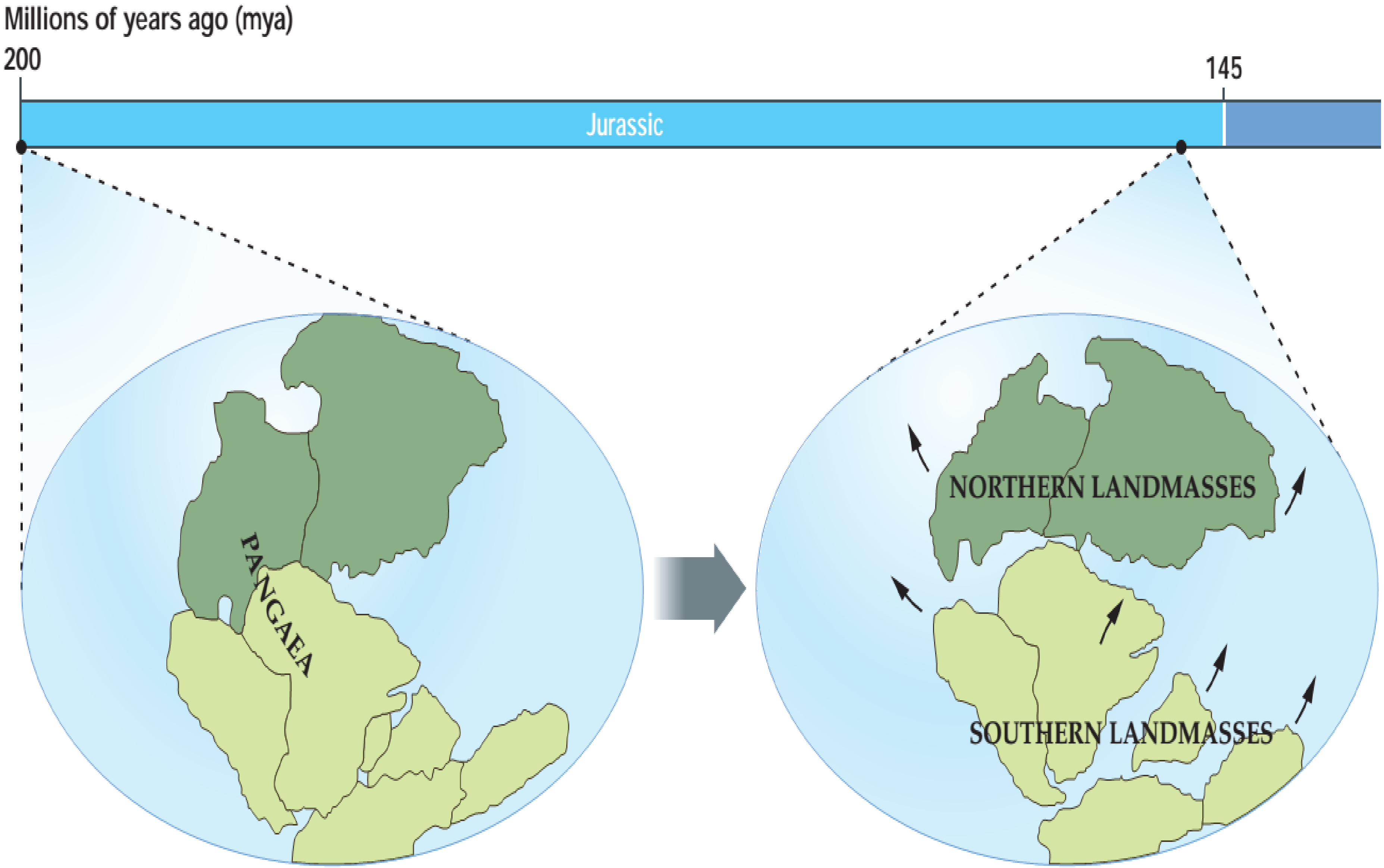


B. Model of plate tectonics



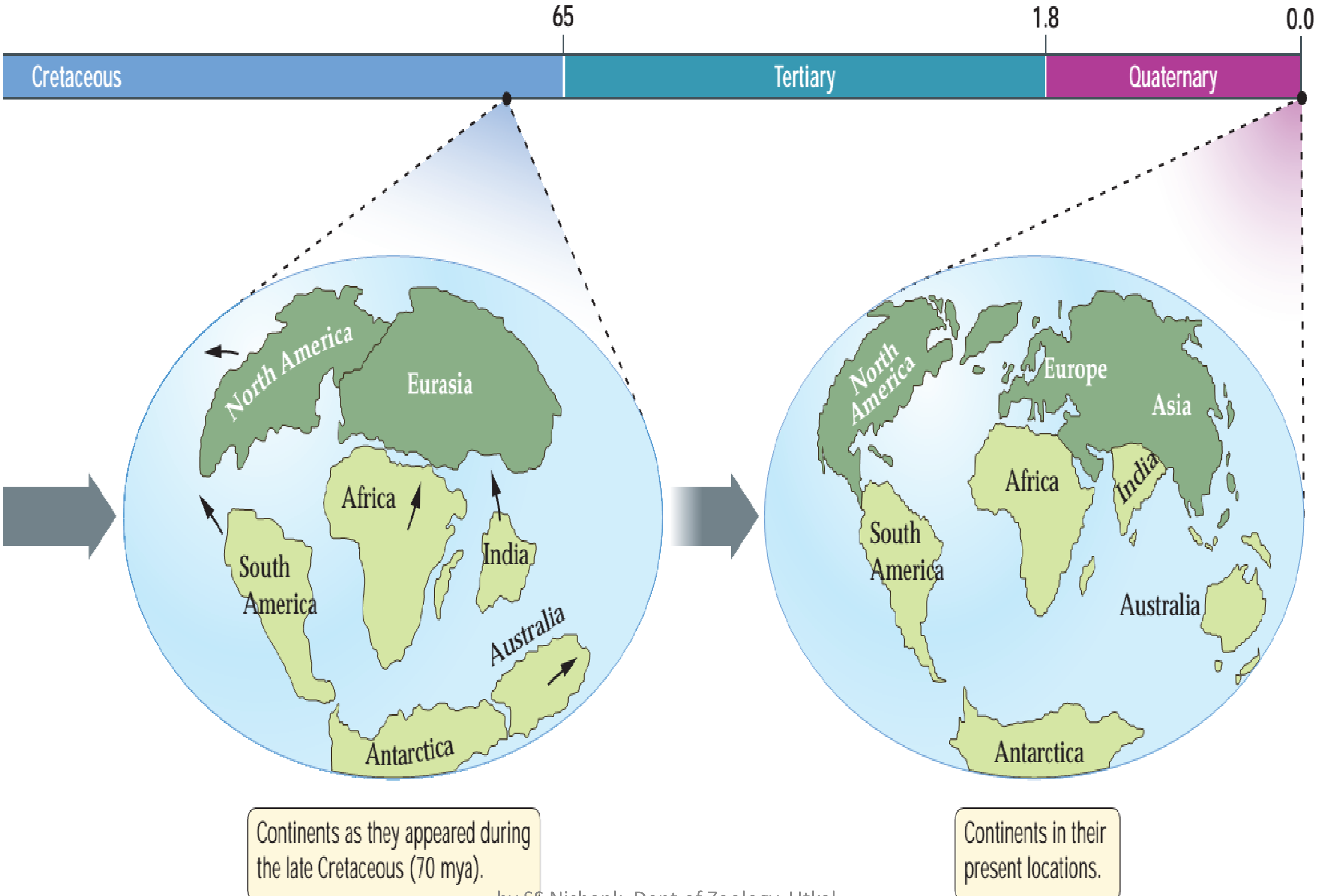
KEY

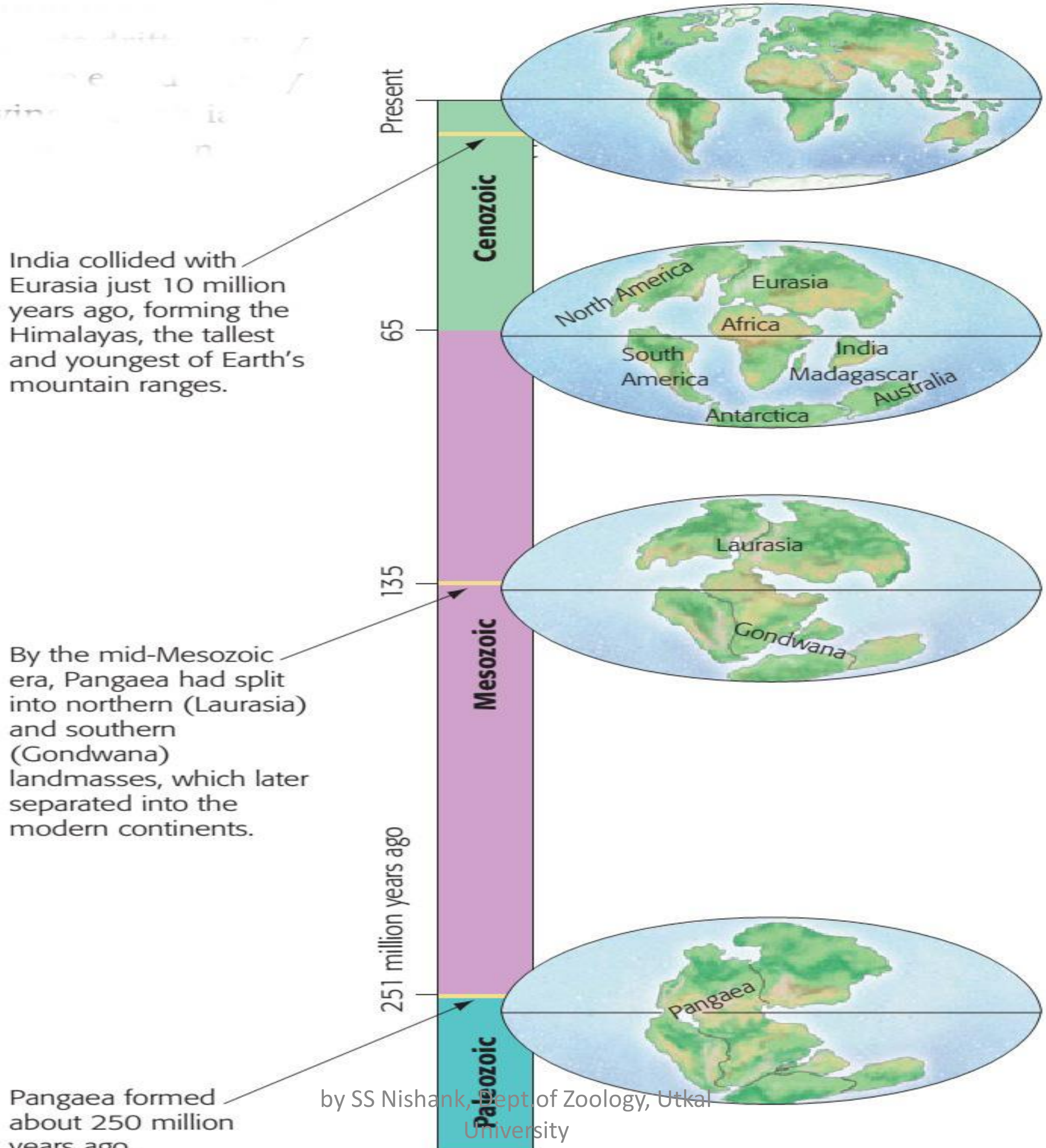
Oceanic ridge ······· Oceanic trench



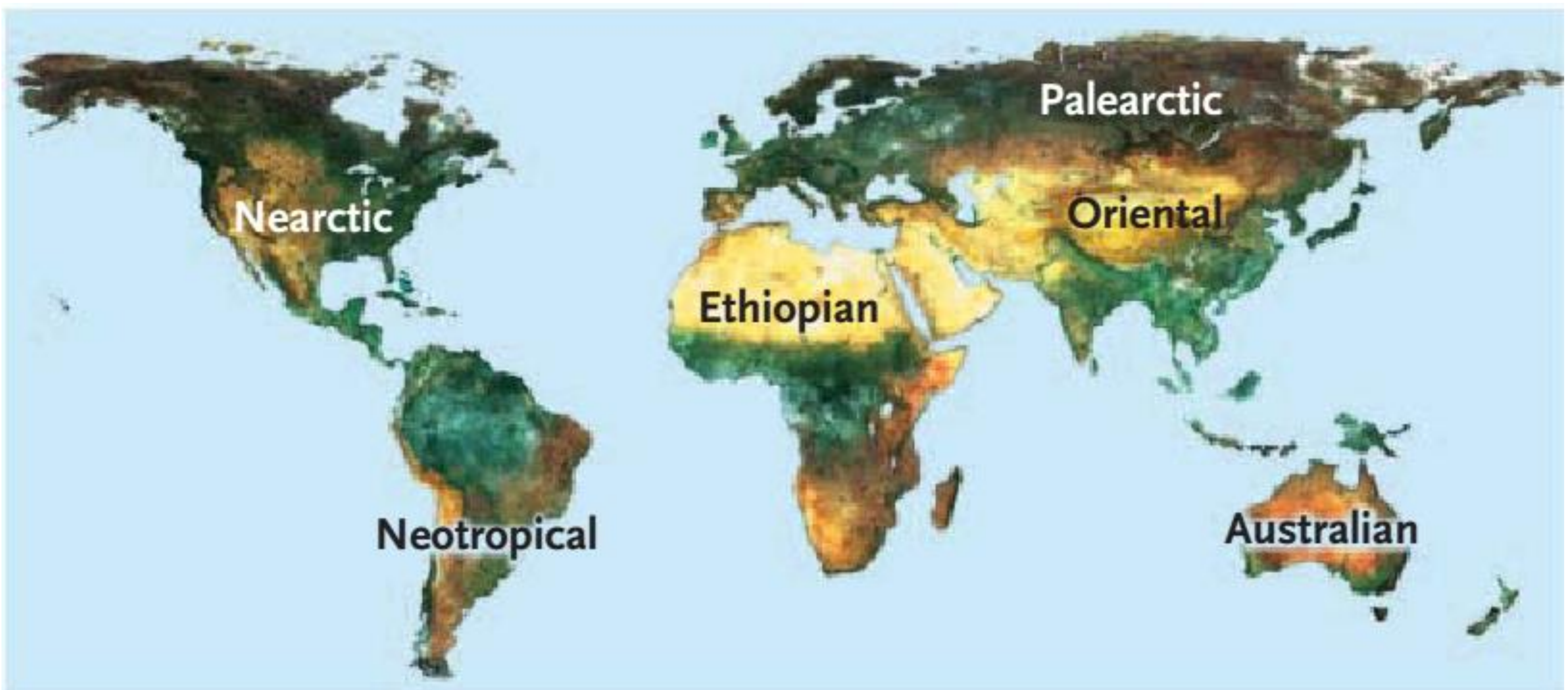
Early Jurassic (200 mya), shortly after supercontinent Pangaea began to drift apart.

Positions and movement of continents during late Jurassic (150 mya).

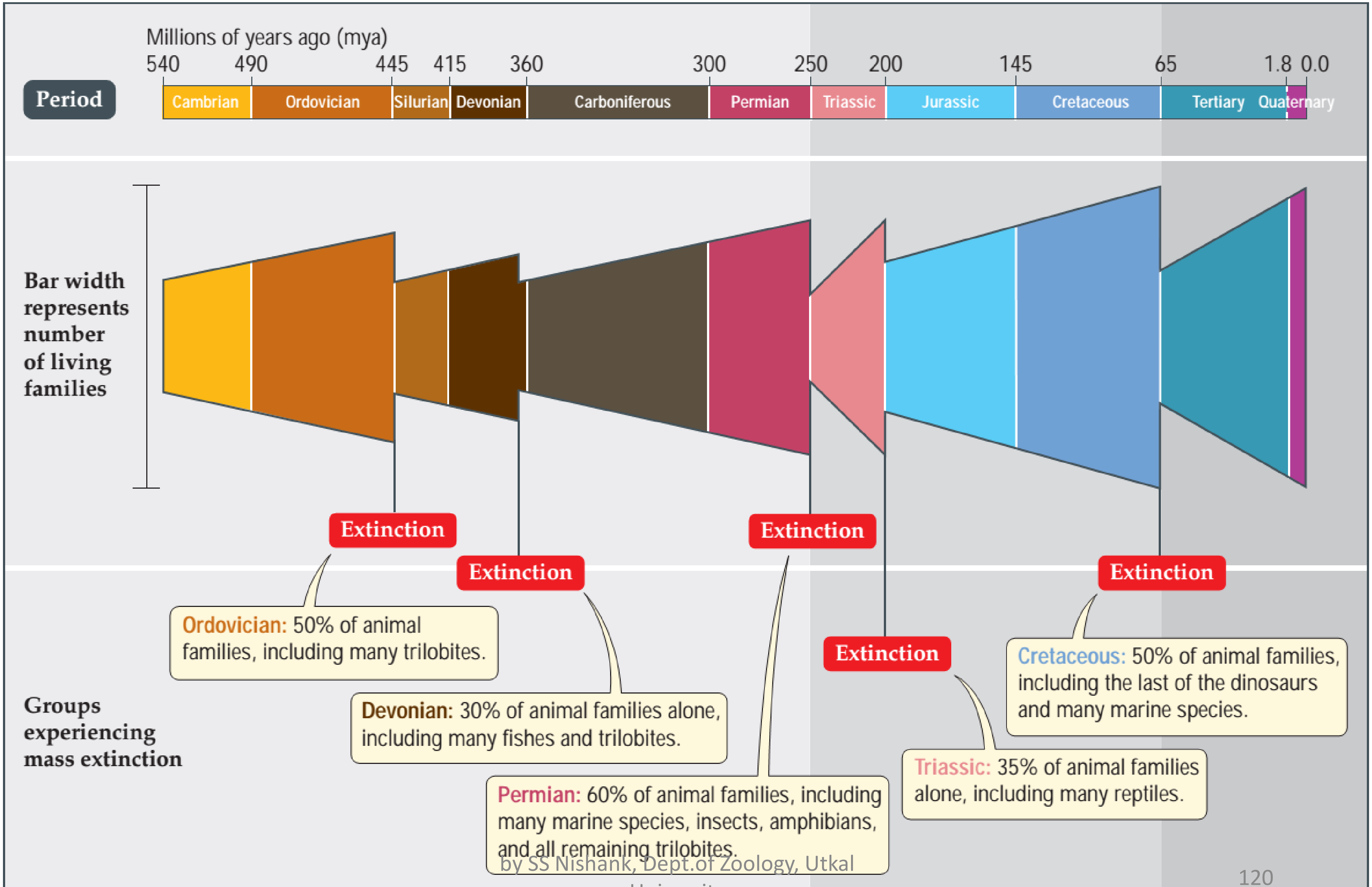

65
1.8
0.0
Cretaceous
Tertiary
Quaternary
North America
Eurasia
Africa
India
South America
Australia
Antarctica
North America
Europe
Asia
Africa
India
South America
Australia
Antarctica
Continents as they appeared during the late Cretaceous (70 mya).
Continents in their present locations.


India collided with Eurasia just 10 million years ago, forming the Himalayas, the tallest and youngest of Earth's mountain ranges.
By the mid-Mesozoic era, Pangaea had split into northern (Laurasia) and southern (Gondwana) landmasses, which later separated into the modern continents.
Pangaea formed about 250 million years ago.
Present
65
135
251 million years ago
Cenozoic
Mesozoic
Paleozoic
North America
Eurasia
Africa
South America
India
Madagascar
Australia
Antarctica
Laurasia
Gondwana
Pangaea

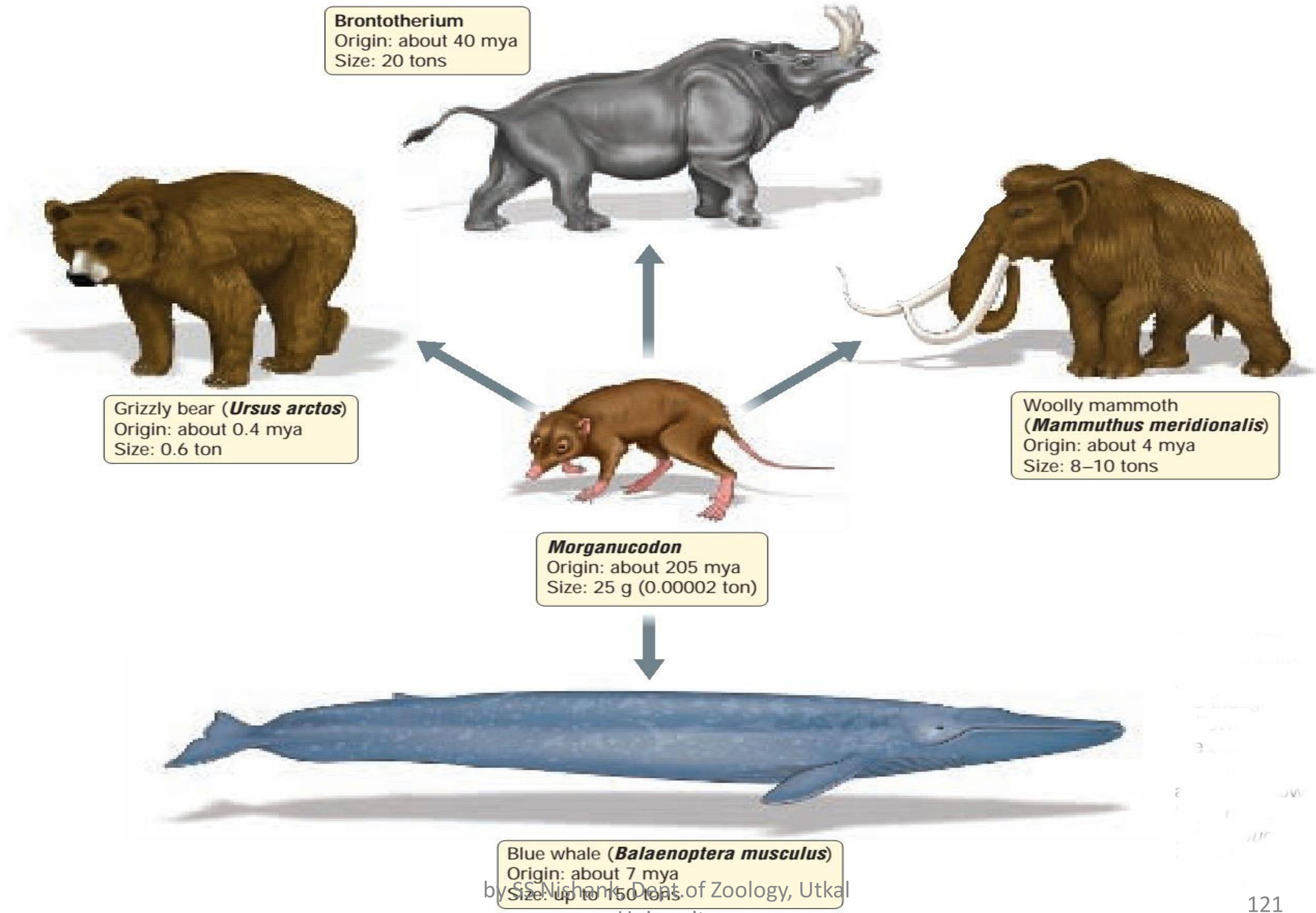
Wallace's biogeographical realms. Each realm contains a distinctive biota.



Five Mass Extinction



Effect of Mass Extinction



Convergent evolution in mammalian faunas.