Human Life on Earth

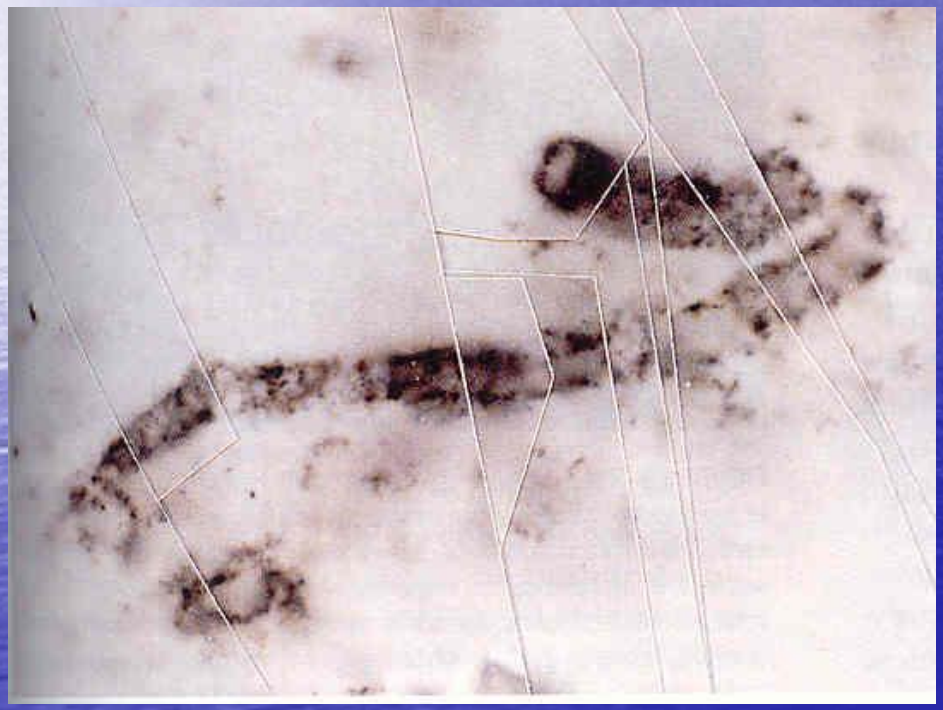
When did life begin?

- Quite early in Earth's history
- Cannot pinpoint time, but can narrow down a time period with 3 lines of evidence

When did life begin?

- Stromatolites (3.5 bill. Yr)
  - Rocks with distinctive layer structure
- Look identical to living mats of microbes
  - Layers of microbes and sediment
  - Top layer uses photosynthesis
  - Lower layers use top layer's byproducts

When did life begin?



- Microfossils dating to 3.5 billion years ago
- Difficult to distinguish from mineral structures
- Analysis shows that some structures contain organic carbon
  -found in at least 3 sites

When did life begin?

- Evidence in metamorphic rocks that life existed 3.85 billions years ago
- Low C^{12}/C^{13} fraction in rock layers suggests life
  - Biological processes prefer C^{12} to C^{13}
    - Find lower fraction of C^{13}
  - Non-biological processes have no preference, so find equal amounts

When did life begin?

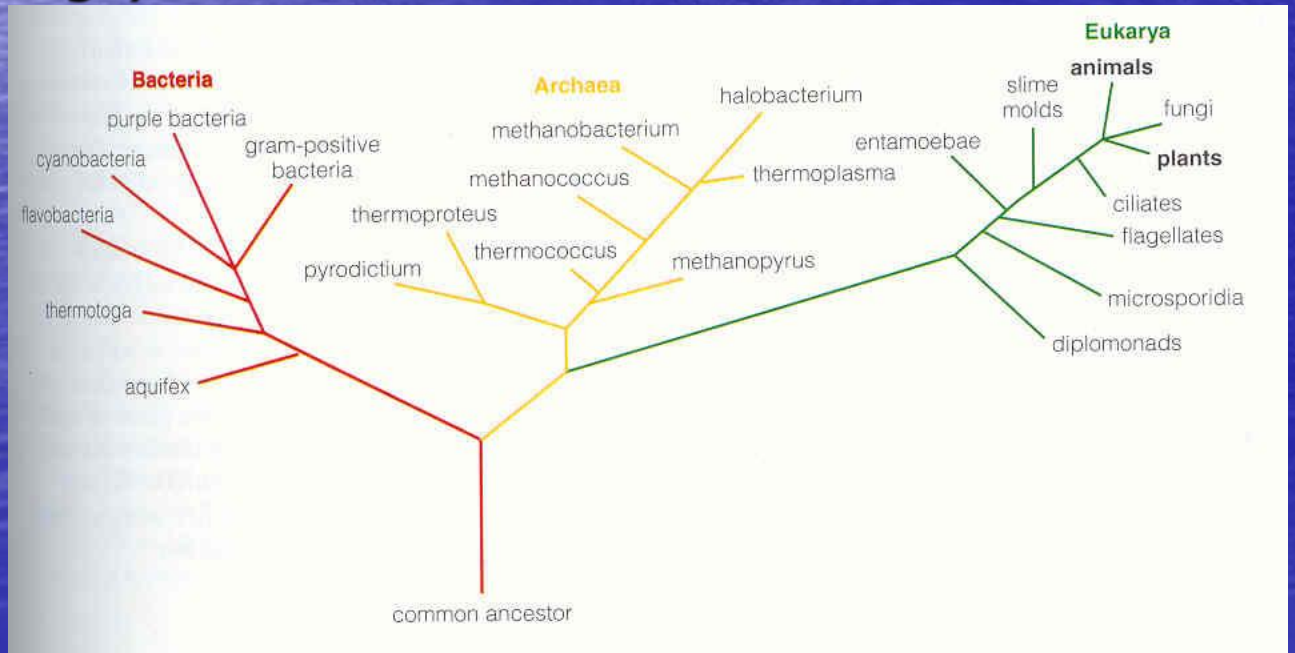
- Rocks before ~4 billion years old are rare and hard to find
- Time of heavy bombardment ended about 3.8-4.0 billion years ago
  - Last devastating impact between 4.2-3.9 bill. Yr ago
- Evidence suggests life as long as 3.85 billion years ago and definitely at 3.5 billion years ago
- Life rose and dominated the planet between 100-500 million years

Living Fossils

- DNA used as living fossil
- The more alike the DNA sequence between species, the more recent their divergence and extinction of their common ancestor

Living Fossils

- Bacteria and Archaea: genetic material NOT separated from rest of cell
- Eukarya: DNA separated from rest of cell by membrane
- Extremophiles (live near deep-sea vents or in hot springs) closest to root of tree of life



Where did life begin?

- Land is unlikely
  - No O_2, no ozone: UV destroys molecular bonds
- Shallow ponds
  - Once favored, full of organic material
  - When evaporated, organic chemical concentration increases making it easier to combine complex molecules leading to life
  - Current experiments indicate lack of chemical energy sufficient to support life
- Deep-sea vents/hot springs
  - DNA evidence suggests that early organisms survived in conditions similar to deep-sea vents
  - Plenty of chemical energy available

How did life begin?

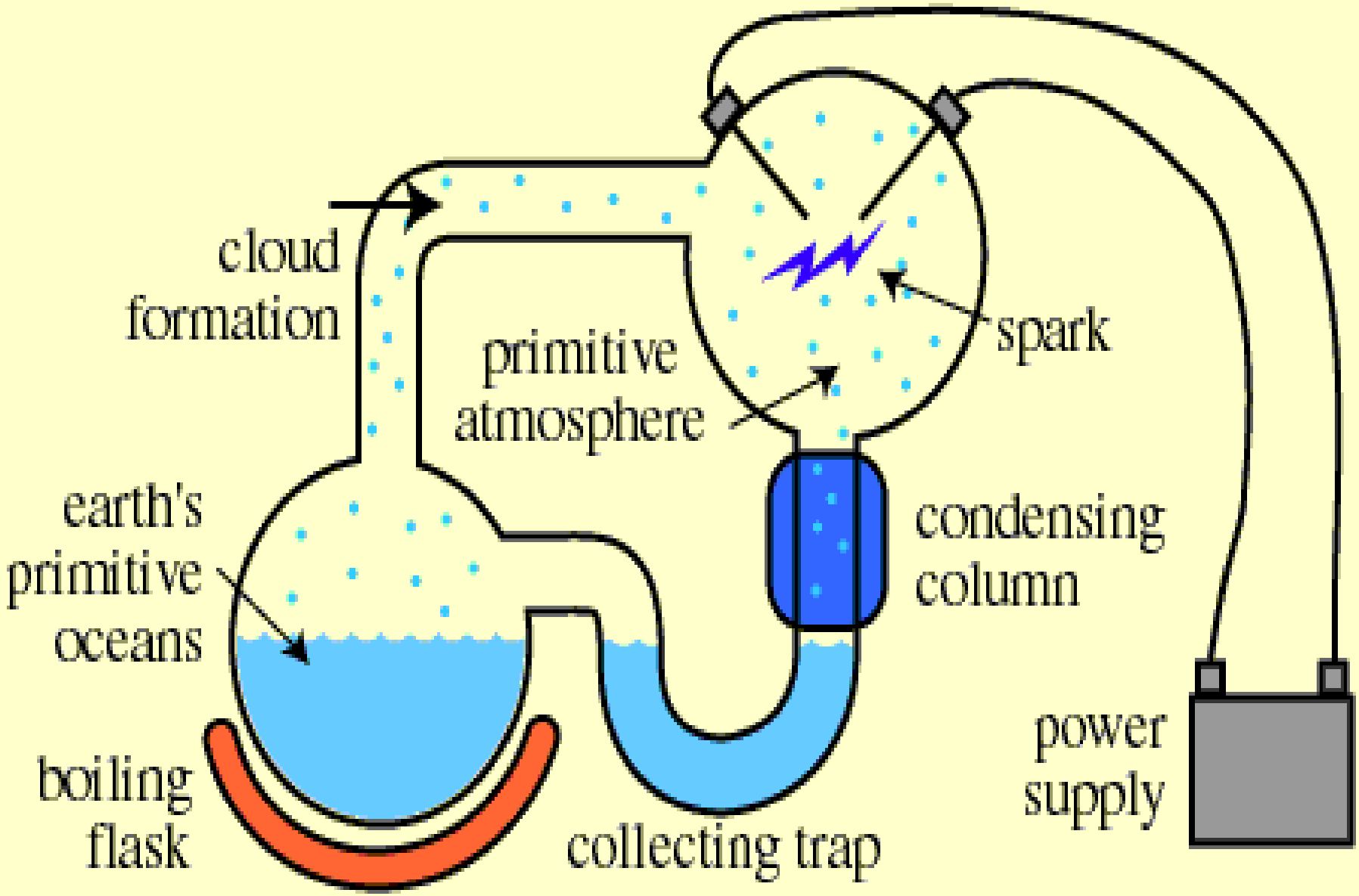
- Simplest organisms today and those dated 3.5 billion years ago are remarkable advanced
- What are the natural chemical processes that could have led to life?
- Assumptions
  - Life began under chemical conditions of early Earth
  - Life did not migrate to Earth

Organic Chemistry on Early Earth

- In 1920's, scientists hypothesized that the chemicals in the early atmosphere, fueled by sunlight, would spontaneously create organic molecules
- Tested by Miller-Urey experiment 1950's

Miller-Urey Experiment

- First flask partially filled with water and heated to produce water vapor (sea)
- Water vapor was moved to a second flask where methane and ammonia vapor was added (atmosphere)
- Electric sparks (lightening) in second flask was energy source for chemical reactions
- Below second flask, water vapor cooled (rain) and recycled to first flask (sea)
- Result: turned brown with amino acids and other complex organic molecules


cloud formation
primitive atmosphere
spark
earth's primitive oceans
condensing column
power supply
boiling flask
collecting trap

Time to think……

We have discussed the formation of the solar system and the formation of the terrestrial planets. Now, what is wrong with the Miller-Urey experiment?

Variations of Miller-Urey Experiment

- Different mixes of gases to represent atmosphere
- Different energy sources, like UV (sunlight)
- Results: ALL PRODUCE AMINO ACIDS AND COMPLEX ORGANIC MOLECULES
  - Not as much as original experiment
  - MUST be more sources of organic material

Sources of Organic Molecules

- Chemical reactions in atmosphere
  - Lab experiments show this is likely
- Organic material brought by impacts
  - Chemical analysis of comets and carbonaceous chondrites show that they have organic molecules
- Chemical reactions near deep-sea vents
  - Heat from undersea volcano can fuel chemical reactions between water and minerals

Transition from chemistry to biology

- Organic molecules are building blocks of life.
- Low probability of forming life even if repeated several times.
- Intermediate steps of high probability are necessary

Search for Self-Replicating Molecule

- Work backward from organisms that live today
- DNA is double-stranded = complicated
- RNA obvious candidate, more simple than DNA
  - Hereditary information
  - Can serve as template for replication
  - Fewer steps to produce backbone structure

Search for Self-Replicating Molecule

- Problem: RNA and DNA require enzymes to replicate
- In 1980's determined that RNA might catalyze their own replication instead of other enzymes
- Early Earth was an RNA-world

Search for Replicating Molecule

- On Early Earth, short strands of RNA-like molecules were produced spontaneously partially or completely
- RNA-like molecules that could replicate faster with less errors soon dominated population
- Copying errors introduced mutations, ensuring the production of many variations of successful molecules
- Allowed molecular evolution to continue
- RNA-world gave way to DNA-world
  - DNA less prone to copying errors
  - DNA more flexible hereditary material
  - RNA kept some of its original functions

Assembling Complex Organic Molecules

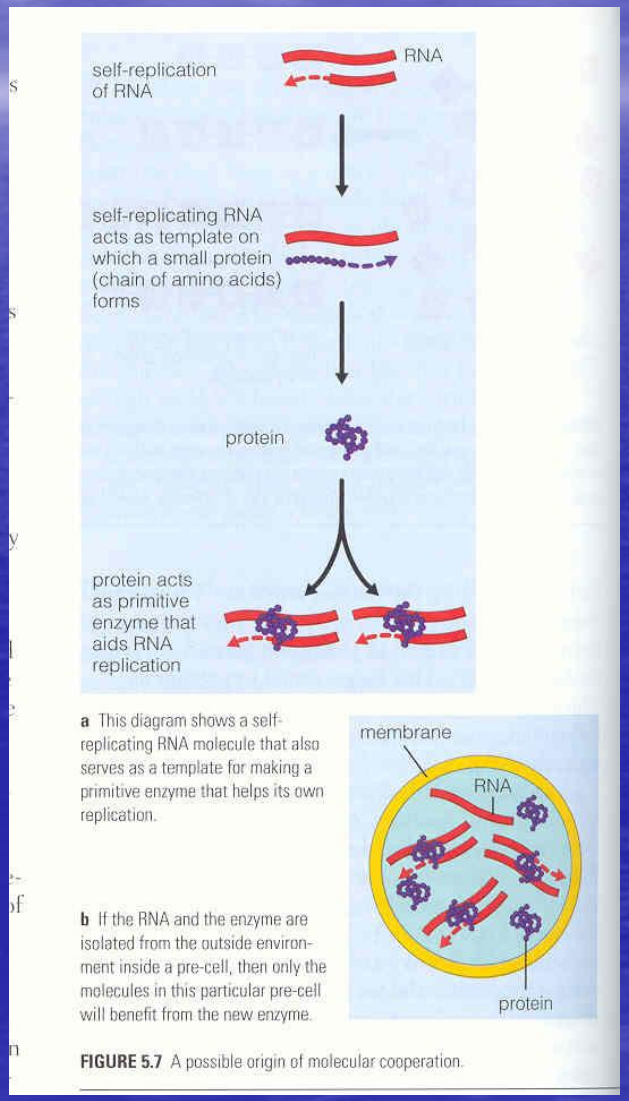
- Organic soup was too dilute to favor the creation of complex organic molecules
- Lab experiment with possible solution: When hot sand, clay or rock is placed in dilute organic solution, complex molecules self-assemble
  - Organic molecules stick to surface of clay
  - Increases density and likelihood of reactions
  - Strands of RNA up to 100 bases have been produced this way

Assembling Complex Organic Molecules

- Other inorganic minerals may have also had a similar role
- Iron pyrite (fool's gold)
  - Positive charges on surface which allows organic molecules to adhere
  - Formation of pyrite releases energy which could be used as fuel for chemical reactions

Early Cell-like Structures

- Advantages to enclosing enzymes with RNA molecules
- Close proximity increases rate of reactions between them
- Isolate contents from outside world



Early Cell-like Structures

- Lab experiments suggest that membrane structures existed on early Earth
- Form spontaneously
  - Cool down warm-water solution of amino acids
  - Mix lipids (fats) with water

Early Evolution and Rise of O_2

- First organisms had simple metabolism
- Atmosphere was O_2 free, must have been anaerobic
- Probably chemoheterotrophs
  - Obtained nutrients from organic material
  - Obtained nutrients from inorganic material
    - Modern archaea appear to be close to the root of the tree of life
    - Obtaining energy from chemical reactions involving hydrogen, sulfur and iron compounds (all abundant on early Earth)

Early Evolution

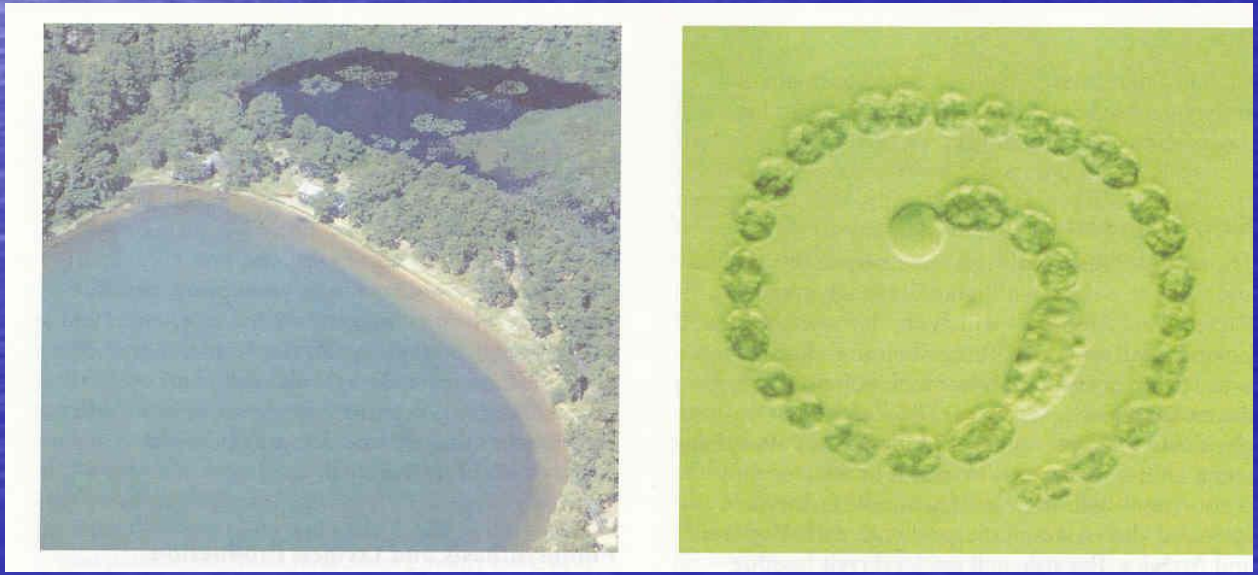
- Natural selection probably resulted in rapid diversification
- Modern DNA has enzymes that reduce the rate of mutations
- RNA is not so lucky, more likely to have copying errors
- Higher mutation rate in early evolution than now

Photosynthesis

- Most important new metabolic process evolved gradually
- Organisms that lived close to ocean surface probably developed means of absorbing sunlight (UV in particular)
- Once absorbed, developed method of turning it into energy
  - Modern organisms of purple sulfur bacteria and green sulfur bacteria much like early photosynthetic microbes, use H_2S instead of H_2O for photosynthesis

Photosynthesis

- Using water for photosynthesis developed later, perhaps 3.5 billion years ago
- First appearing in cyanobacteria (blue-green algae)
- By product of O_2, released into atmosphere
- Changed the world!



Rise of O_2

- O_2 is highly reactive
- All initial O_2 would react with rock and minerals in water
- O_2 could not accumulate in atmosphere until surface rock was saturated
- Rocks 2-3 bill. Yr old called banded iron formations, show atmosphere had <1% of current amount of O_2
- Rock evidence suggests that O_2 amounts in atmosphere began to rise about 2.0 bill. Yr ago
- Clear evidence of O_2 near current levels appears only 200 million yr ago
  - Find charcoal (fossil fuel)
  - Indicates enough O_2 in atmosphere for fires to burn

Rise of O_2

- Rise of O_2 would have created a crisis for life
- O_2 reacts with bonds of organic materials
- Surviving species avoided effects of O_2 because they lived or migrated to underground locations
  - Many anaerobic microbes found in such locales today

Early Eukaryotes

- Fossil evidence dates to 2.1 bill. Yr ago
- Dates to when O_2 rising in atmosphere
- DNA evidence suggests that prokaryotes and eukaryotes separated from common ancestor much earlier
- O_2 played a key role in eukaryote evolution
  - Cells can produce energy more efficiently using aerobic metabolism than anaerobic metabolism
  - Adaptations of aerobic organisms could develop adaptations that required more energy that would be available for anaerobic organisms

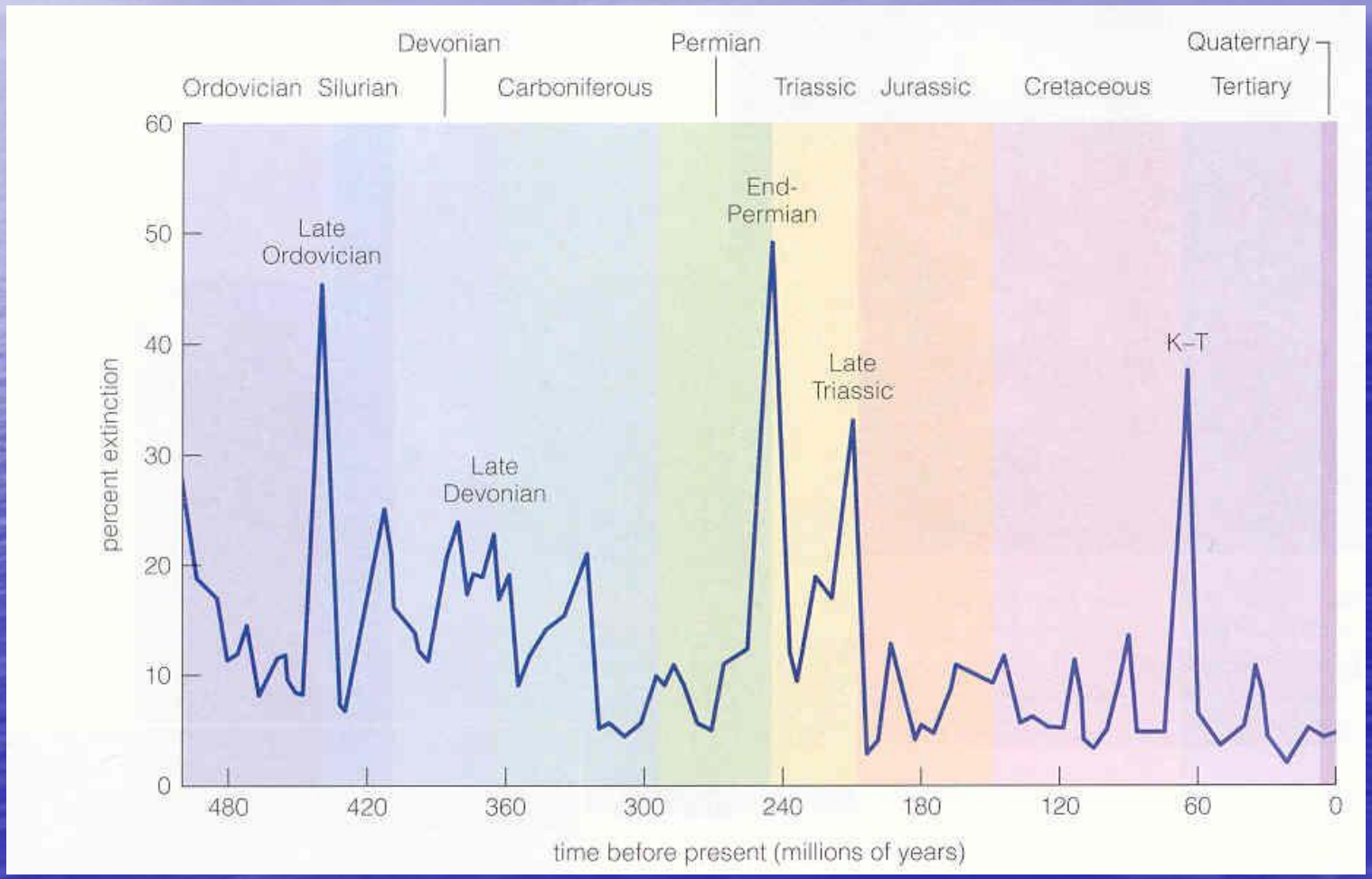
Colonization of Land

- Life flourished where liquid water exist
- Life on land was more complicated
  - Had to develop means of collecting solar energy above ground and nutrients below
- Life in shallow ponds or edges of lakes
  - Water evaporates
  - Natural selection favored that which could withstand periods of drought

Colonization of Land

- DNA evidence suggests that plants evolved from an algae
- It took only 75 mill. Yrs for animals to follow plants out of water

Mass Extinctions



Mass Extinctions

- Possible Causes
  - Impacts
    - Impact sites found for K-T boundary
    - Suspected for Permian extinction 245 mill yr ago
  - Active volcanism
    - Climate change
  - External influence for copying errors
    - Increase in solar particles or radiation hitting surface
    - Local supernova

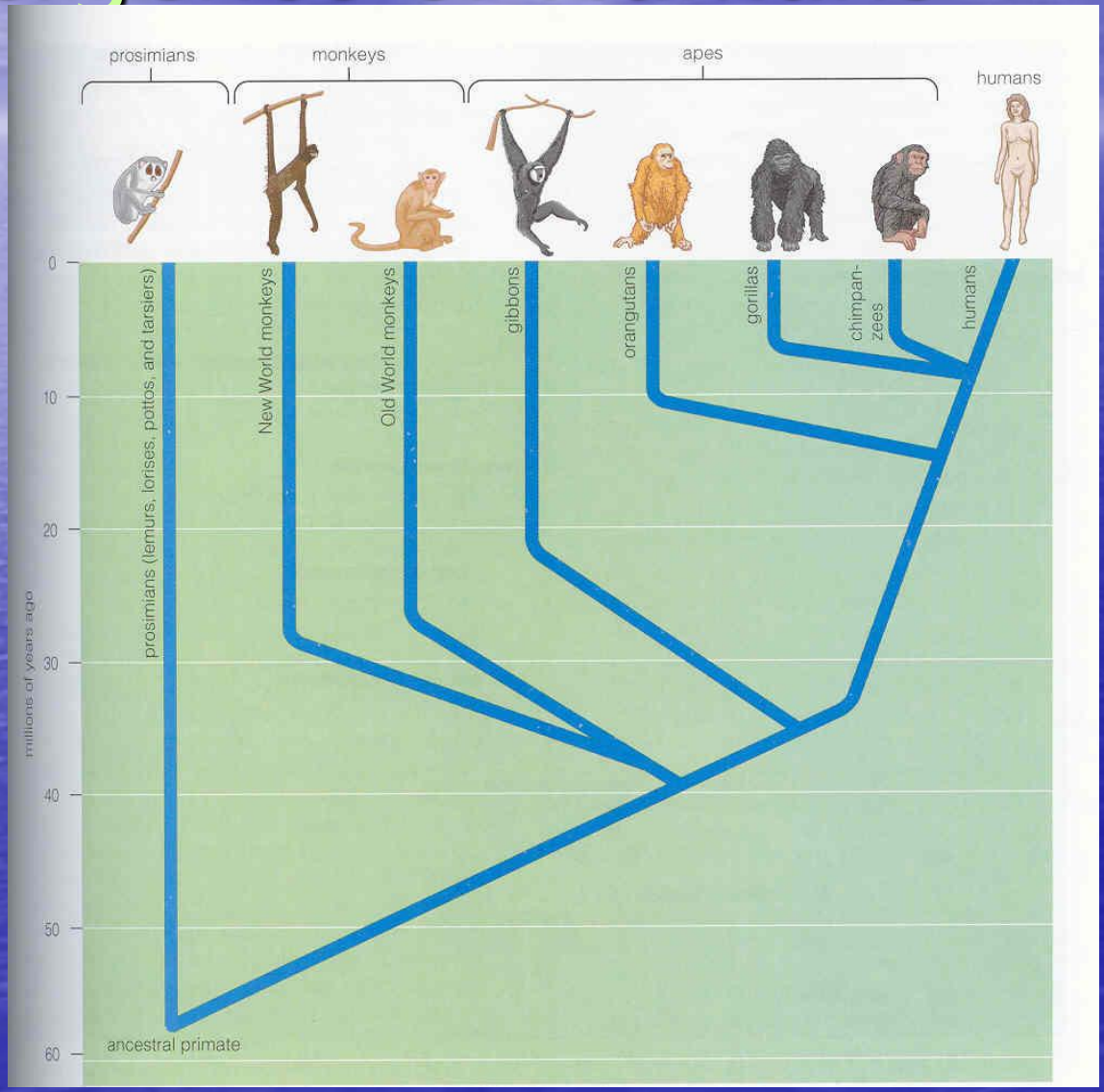
Primate Evolution

- Monkeys, apes, lemurs and humans have common ancestor that lived in trees
- Tree life
  - Limber arms for swinging between branches
  - Eyes in front of head for depth perception
  - Offspring would be born more helpless than other animals

Emergence of Humans

- Did NOT evolve from gorillas or monkeys
- Share a common ancestor that lived just a few million years ago
- 98% of human genome is identical to genome of the chimpanzee
- 2% difference in genome separates the success of humans verses chimps
  - Also indicates evolution of intelligence is complex

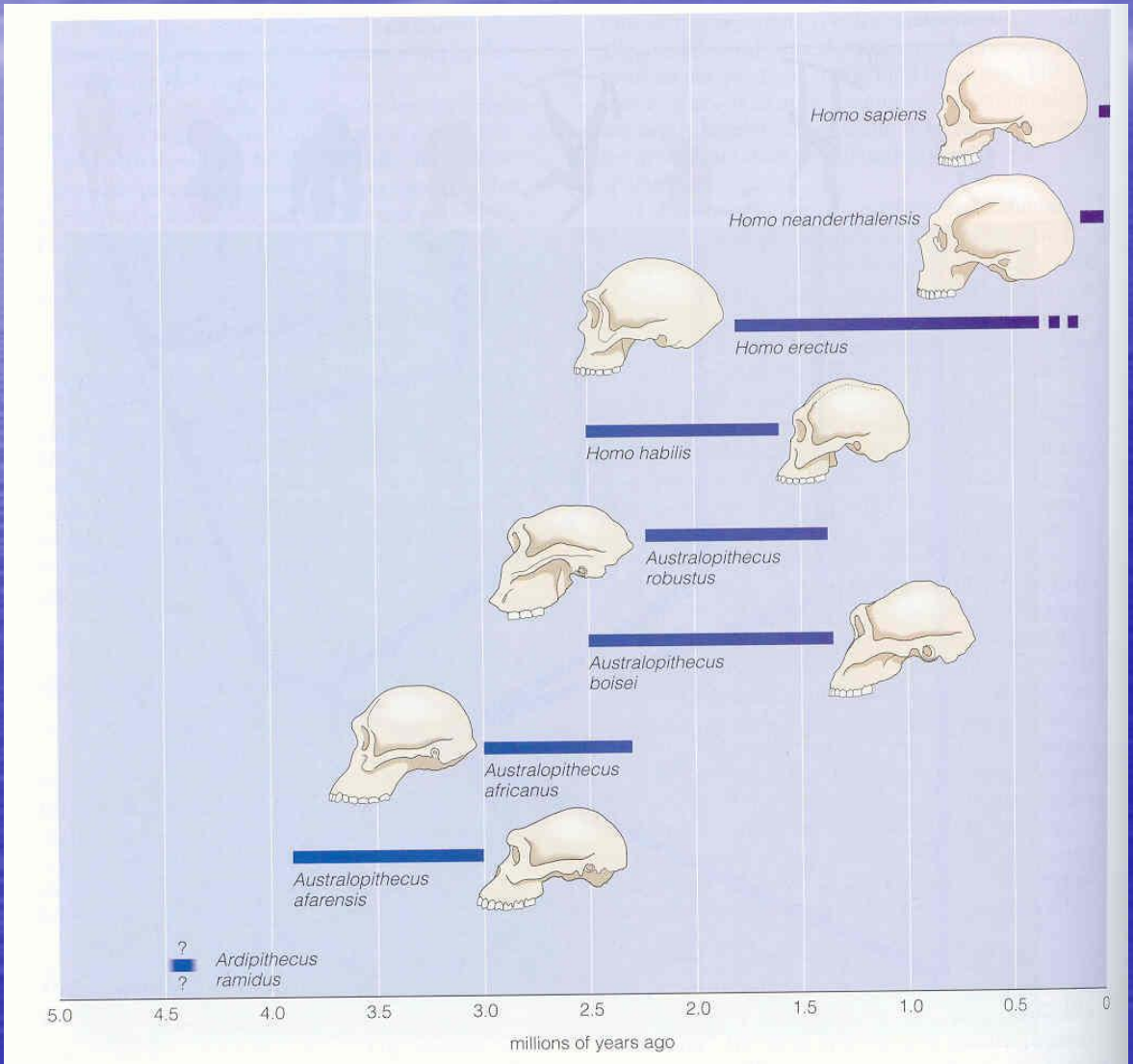
Emergence of Humans



Emergence of Humans

- After hominids diverged from chimps and gorillas, evolution has followed a complex path
- Numerous hominids species existed, some during the same time period
  - All humans are the same species
- First skull fossils that are identical to modern human skulls dates to 100,000 yr old
- Our ancestors shared the Earth with Neanderthals
  - Went extinct 35,000 years ago

Emergence of Humans



Cultural and Technological Evolution

- Have not undergone biological evolution in 40,000 years
  - Mutation rates are slow
- Dramatic cultural changes
  - Transmission of knowledge between generations
    - Spoken to written word, thousands of years
    - agriculture
- Technological evolution
  - Result of coupling between science and technology
  - About 100 years between industrial revolution to landing on the Moon and generating weapons of mass destruction