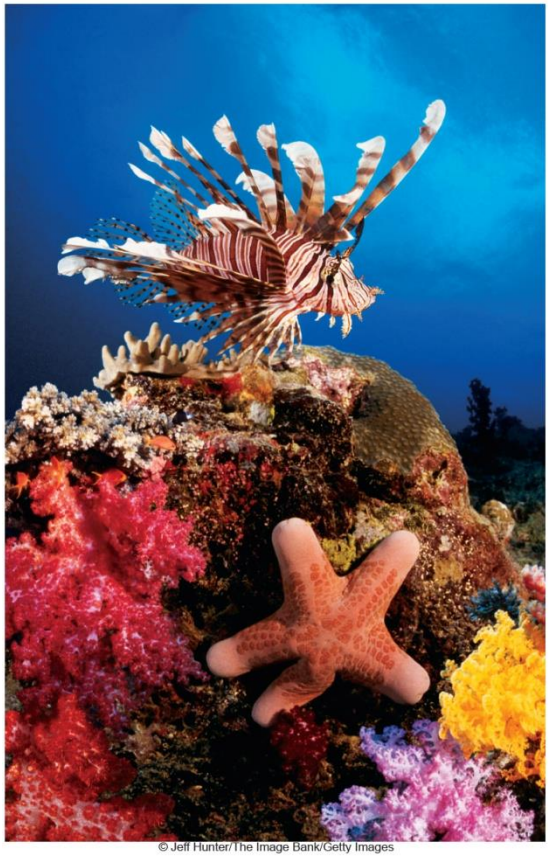
The Origin and Diversity of Life

Chapter 26



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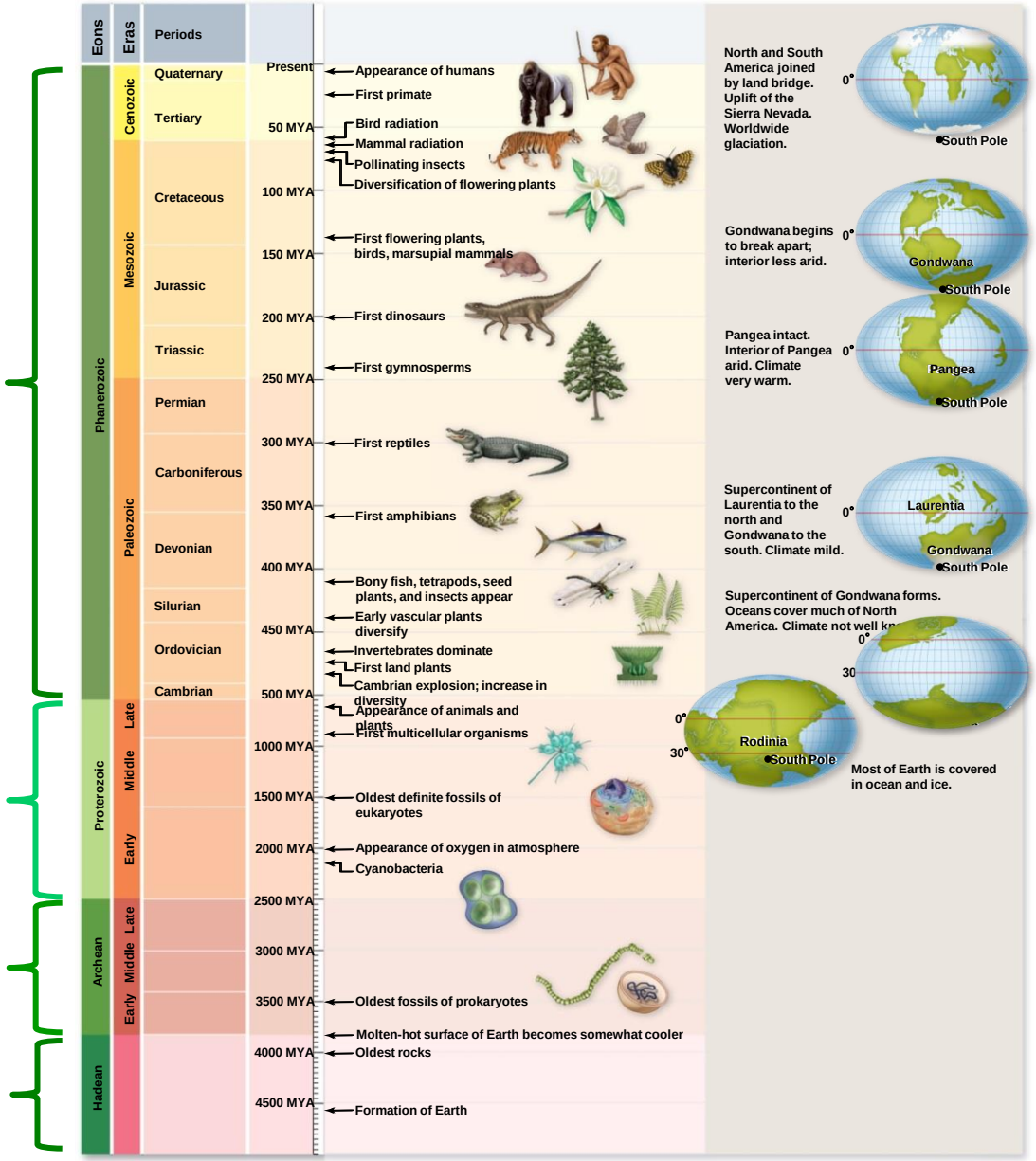
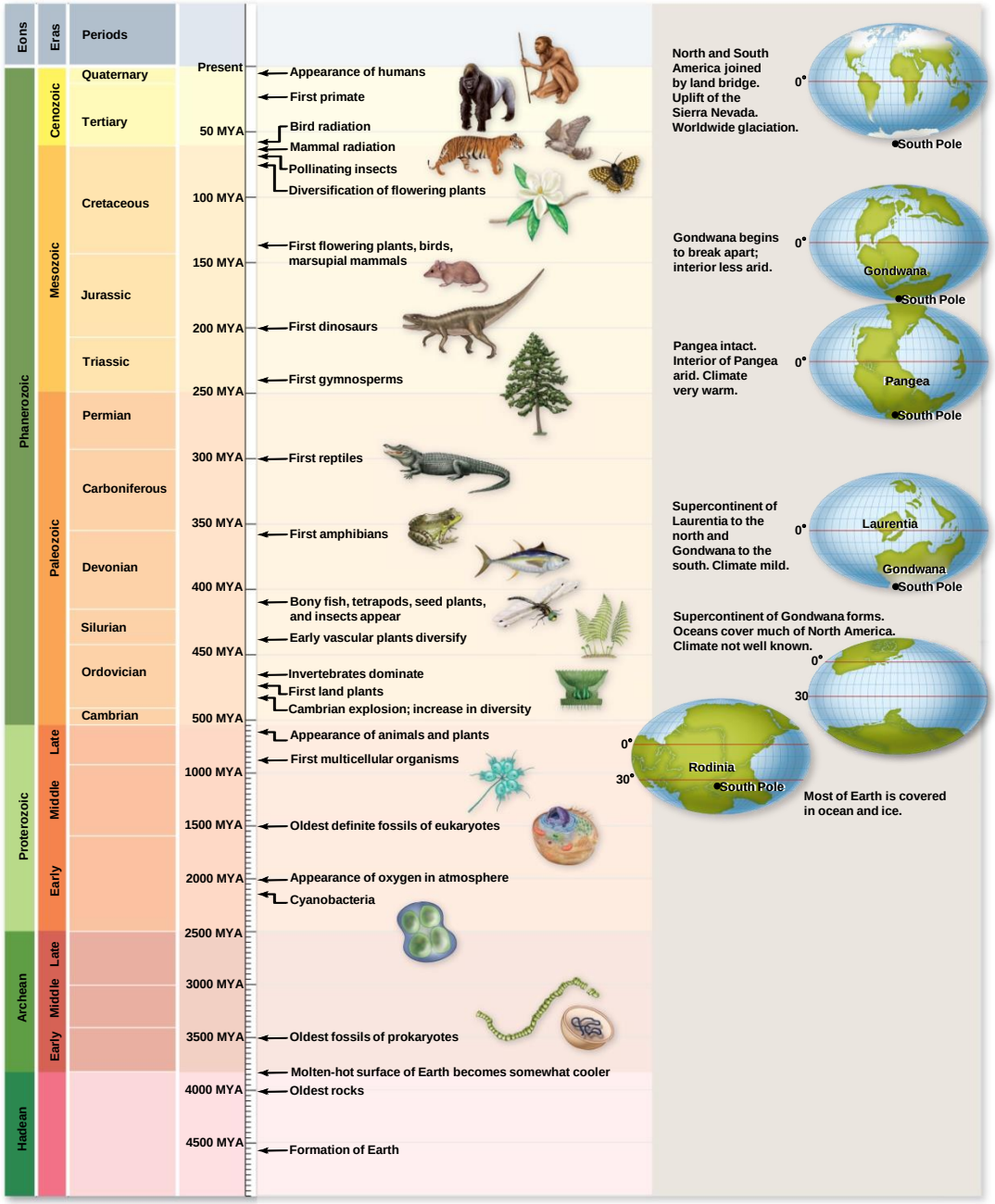
Deep Time

Geologic time is divided into four eons

- Eons are subdivided into eras, which are further subdivided into periods





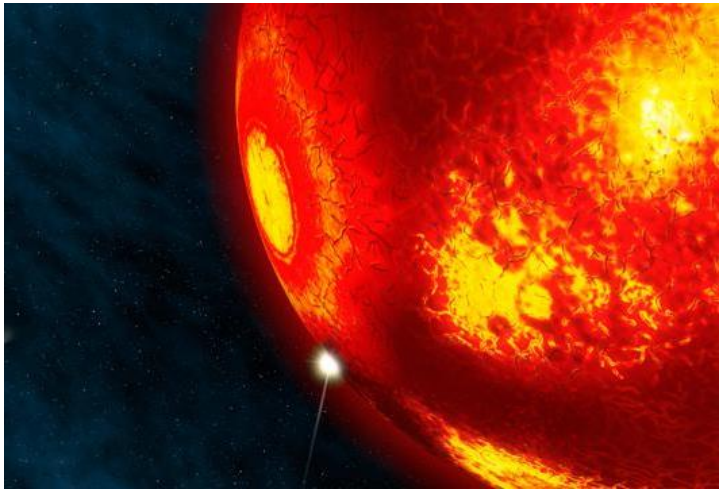
Hadean

http://www.bbc.co.uk/science/earth/earth_timeline/earth_formed

Deep Time

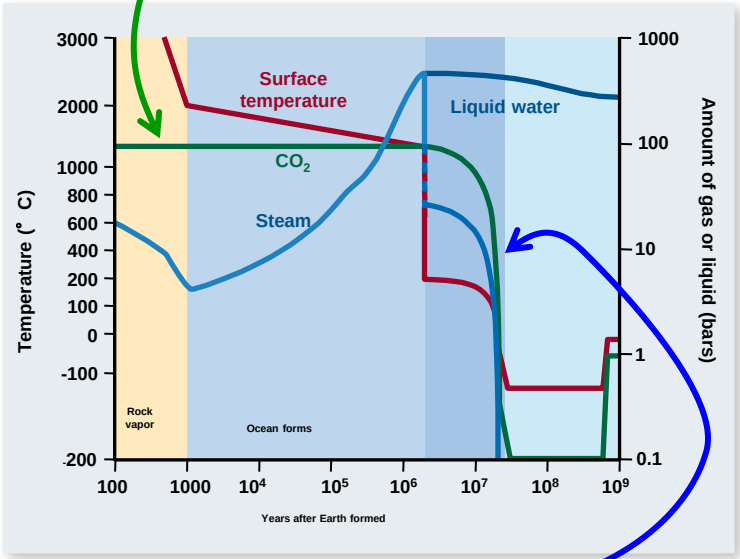
The Earth formed as a hot mass of molten rock about 4.6 billion years ago (BYA)

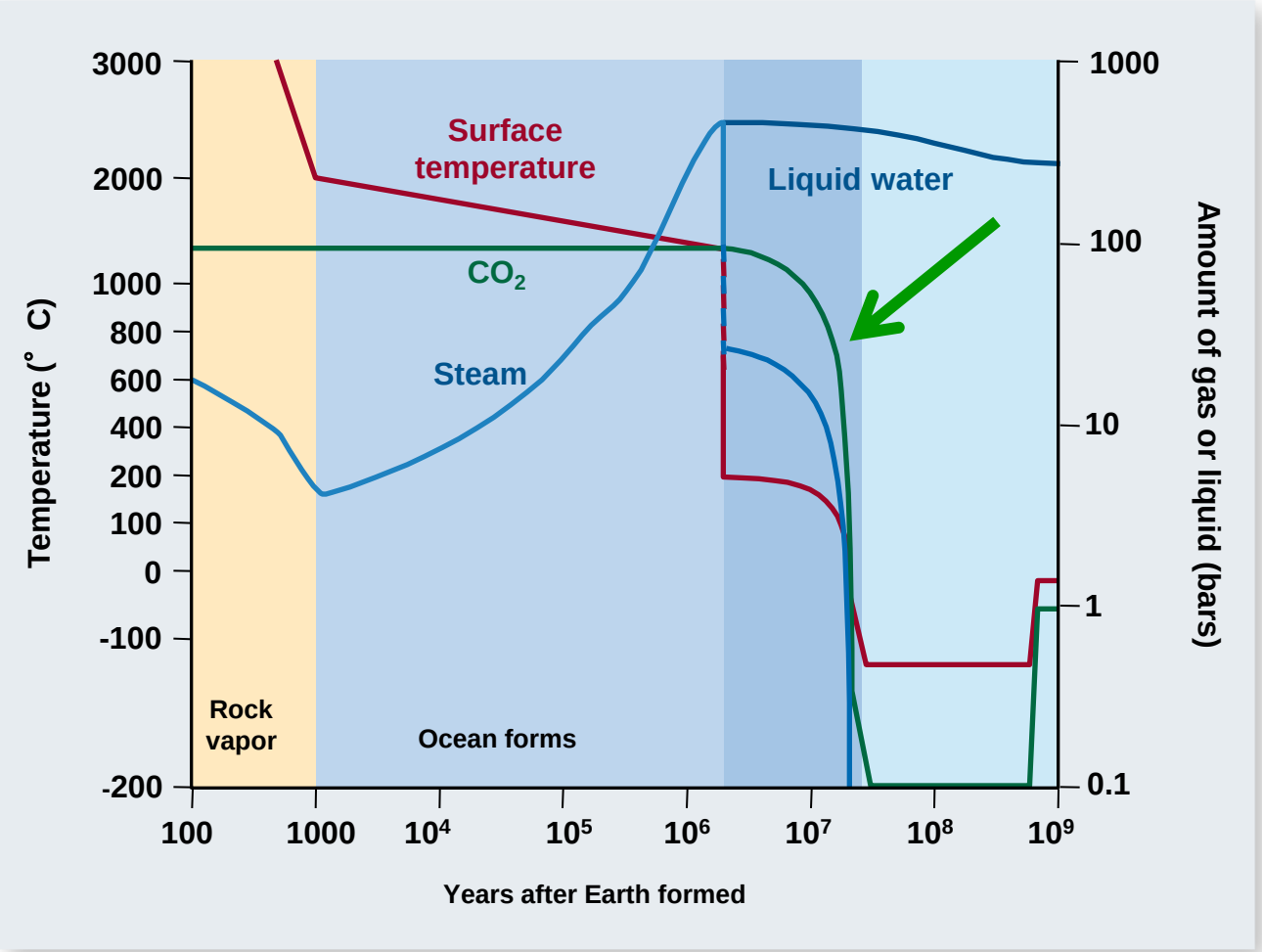
- The rocky mantle melted as atmospheric temperatures exceeded 2000^{o} C
- Hadean Earth was pummeled by asteroids, which could potentially vaporize entire oceans
- As it cooled, chemically-rich oceans were formed from water condensation



http://journalofcosmology.com/ClimateChange116.html

- CO_2 levels shifted and affected temperature
  - Early atmosphere high CO_2 levels
  - Water slowly vaporized from the molten rock
- Increased weathering converted silicate rock to soil
  - CO_2 formed carbonic acid
  - Carbonic acid released bicarbonate ions (HCO_3^-) and Ca_2^+ from rock
- Decreases in CO_2 lowered Earth's temperature

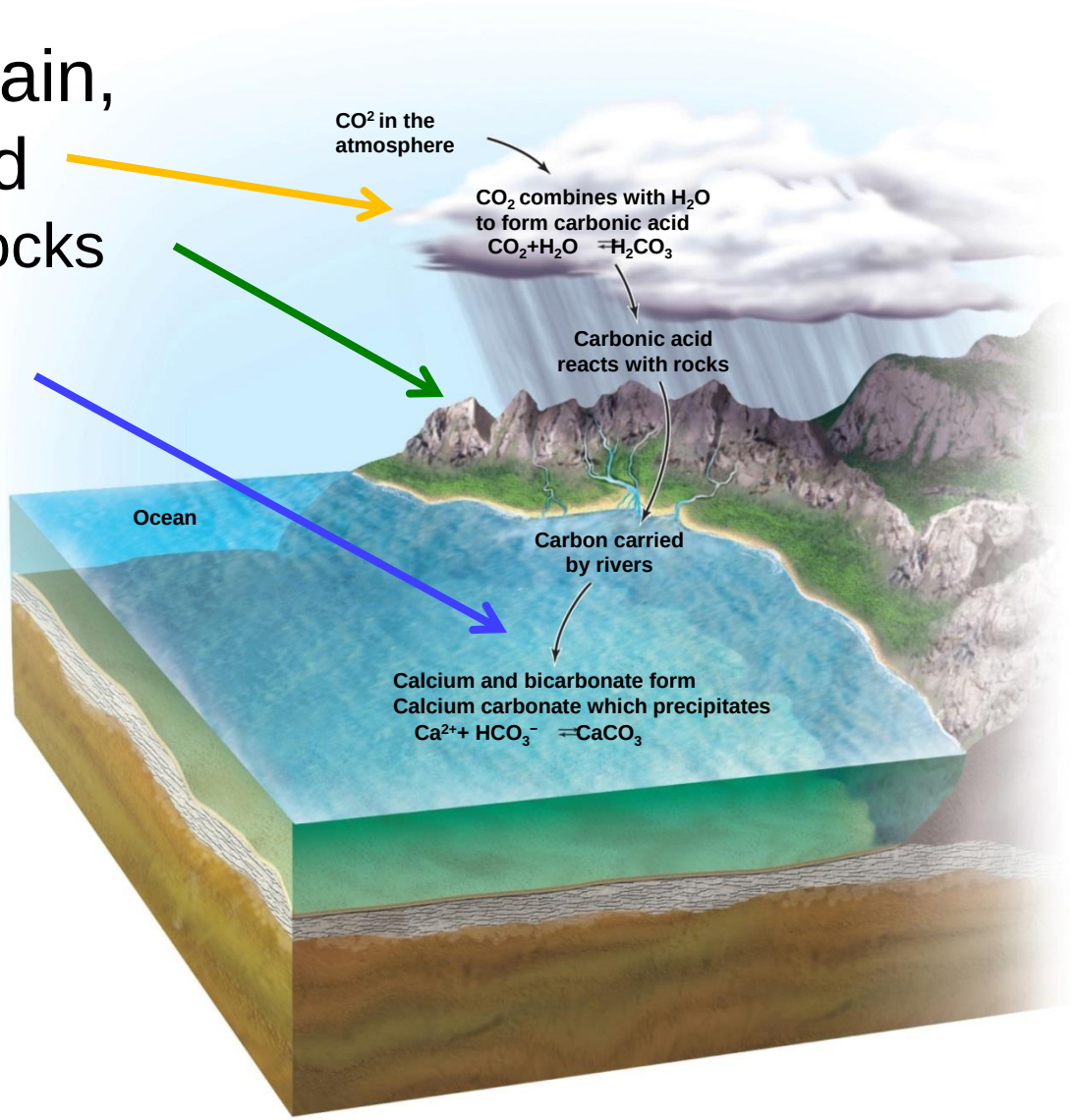




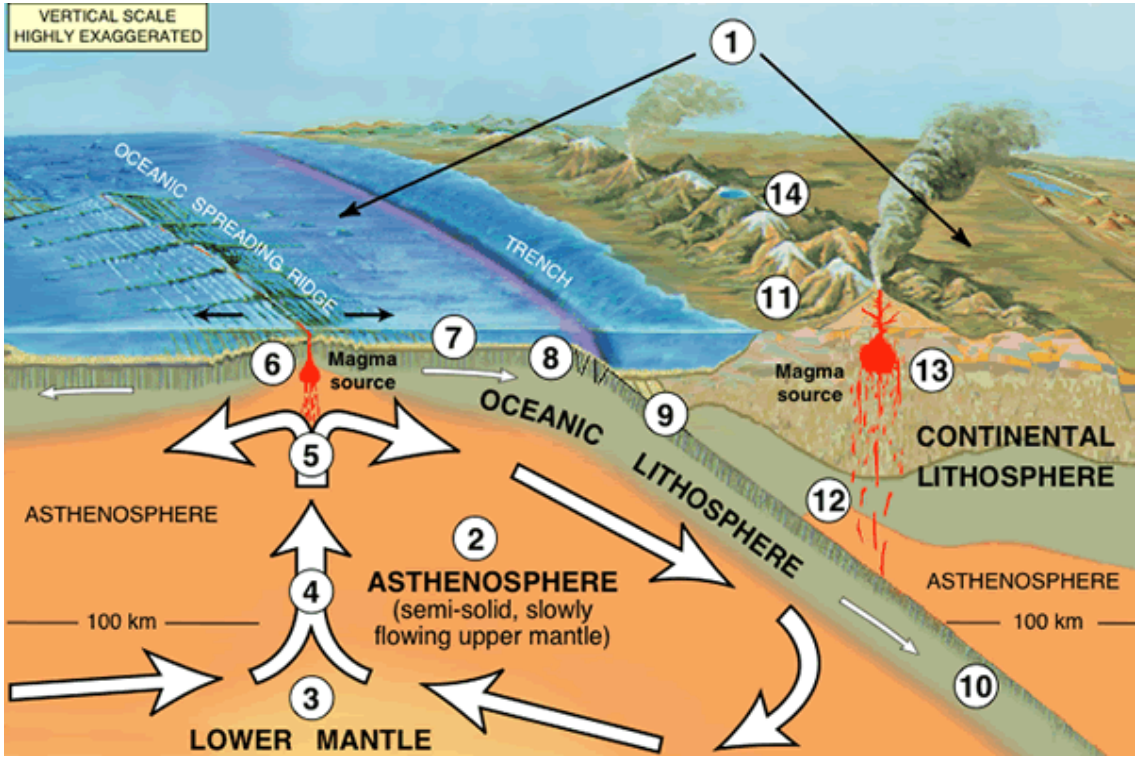
A rapid decrease in atmospheric CO_2 during the Hadean led to a corresponding decrease in temperature and a frozen ocean.

CO_2 combines with rain, forming carbonic acid

- Dissolves (weathers) rocks
- Transfers carbon and minerals to the oceans

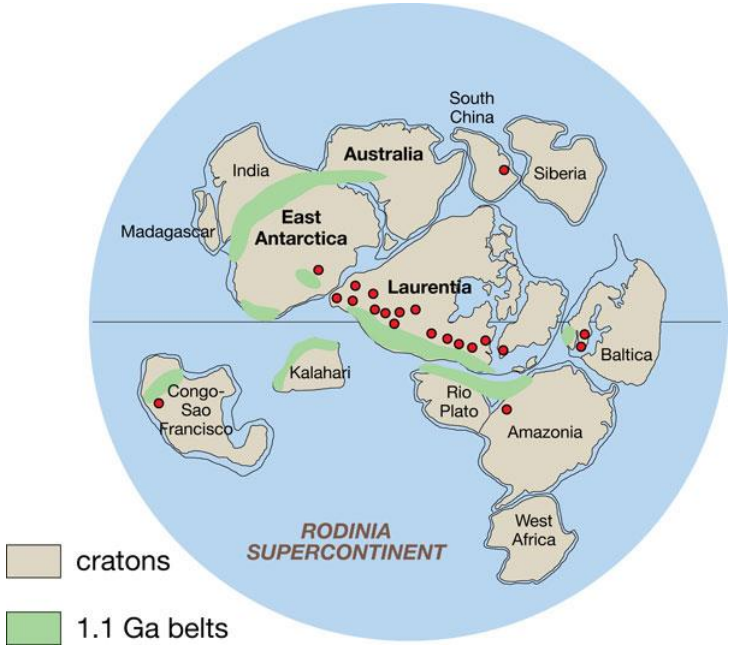


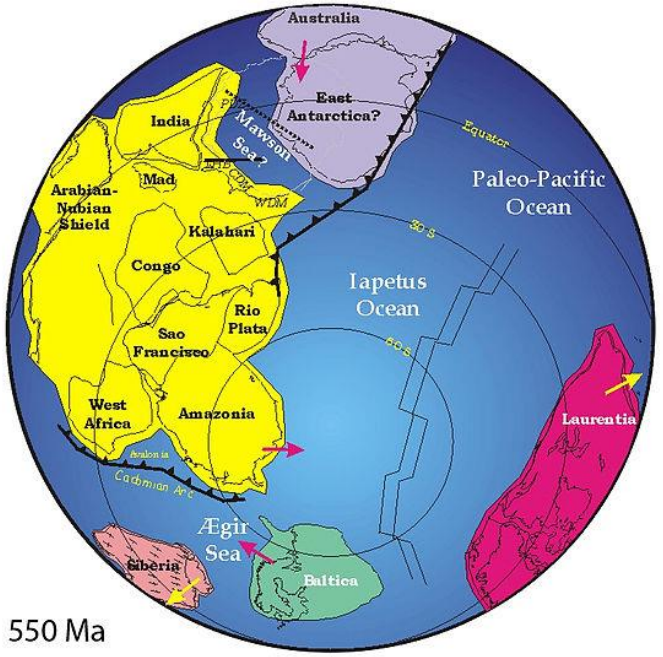
- Continents moved over geological time (**plate tectonics**)
  - Earth's crust formed rigid slabs of rock called plates
    - Under continents and oceans



http://volcanoes.usgs.gov/about/edu/dynamicplanet/nutshell.php

- Two supercontinents formed
  - **Rodinia** (all continents) - ~1100 to 650 mya
  - **Gondwana** (all current Southern Hemisphere continents) – ~500 mya
  - **Pangea** (from **Gondwana** and **Laurentia**) – ~225 mya





http://en.wikipedia.org/wiki/Rodinia

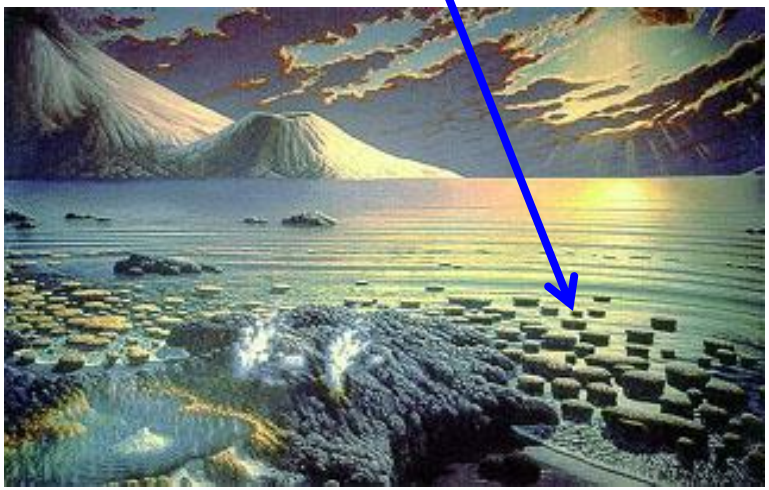
http://en.wikipedia.org/wiki/Gondwana

http://www.corzakinteractive.com/earth-life-history/31_proterozoic.htm

Life emerged in the **Archean**

- Proterozoic (early life) eon occurred
  - Two billion years into Earth's history (2500 – 500 mya)
  - Characterized by formation of Rodinia
- Rodinia broke up during Proterozoic eon
  - **Cambrian** period (~500 mya) showed diversification of multicellular organisms

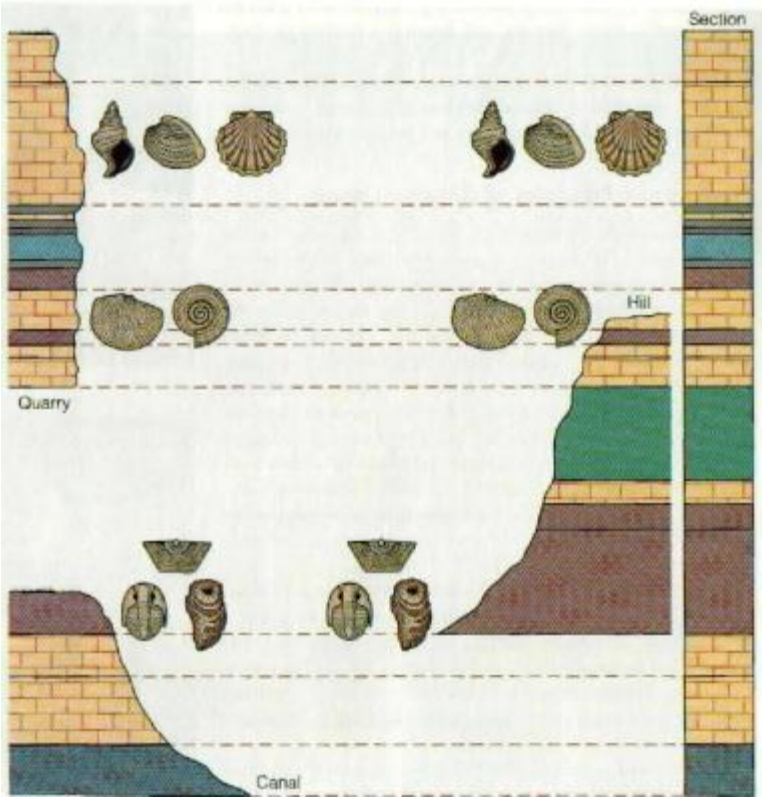
Cyanobacterial stromatolites

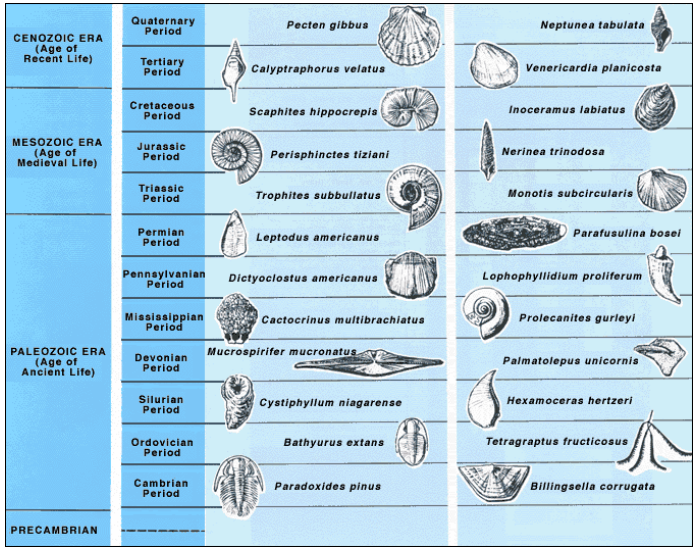


http://www2.estrellamountain.edu/faculty/farabee/BIOBK/biobookpaleo2.html

The past can be reconstructed from the fossil record

- Fossils are the preserved remains of once-living organisms
- Process of fossilization is a rare event





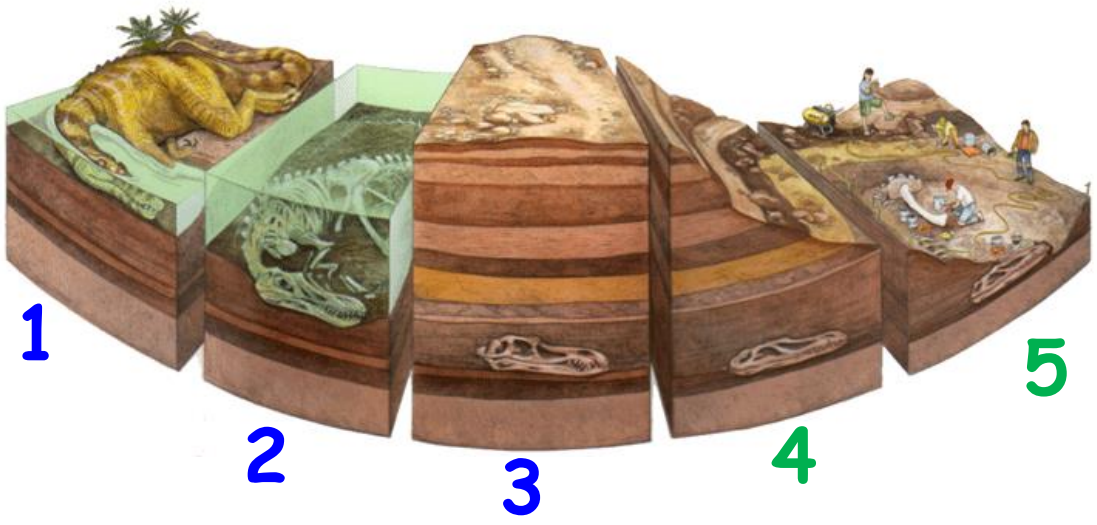
Common, well-known “index fossils” used to date strata, even though it may not be contiguous

http://en.wikipedia.org/wiki/Index_fossil

http://www.bio.miami.edu/dana/160/160S13_4.html

The past can be reconstructed from the fossil record

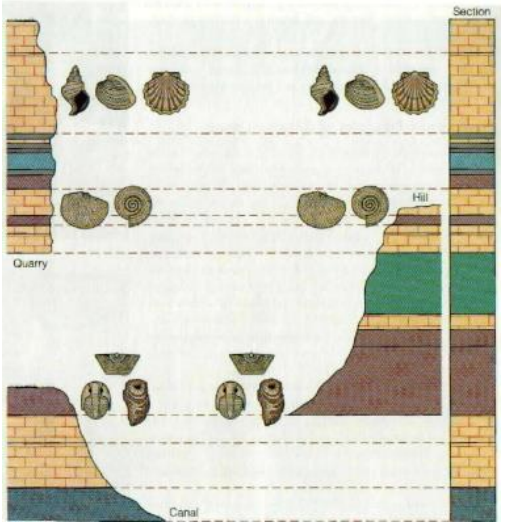
- Rock fossils are created when three events occur
  - Organism *buried* in sediment
  - Calcium in bone, shell or other hard tissue *mineralizes*
  - Surrounding sediment hardens to *form rock*
    - Then *erosion* must expose fossils…
    - and someone must *find them*



http://www.bio.miami.edu/dana/160/160S13_4.html

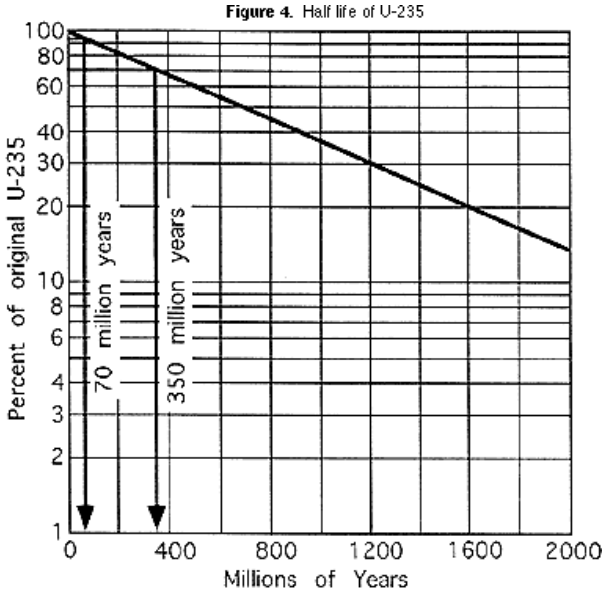
Aging fossils

- **Relative age**: position of the fossil in the sediment



- **Absolute age**: age of fossils is estimated by rates of radioactive decay

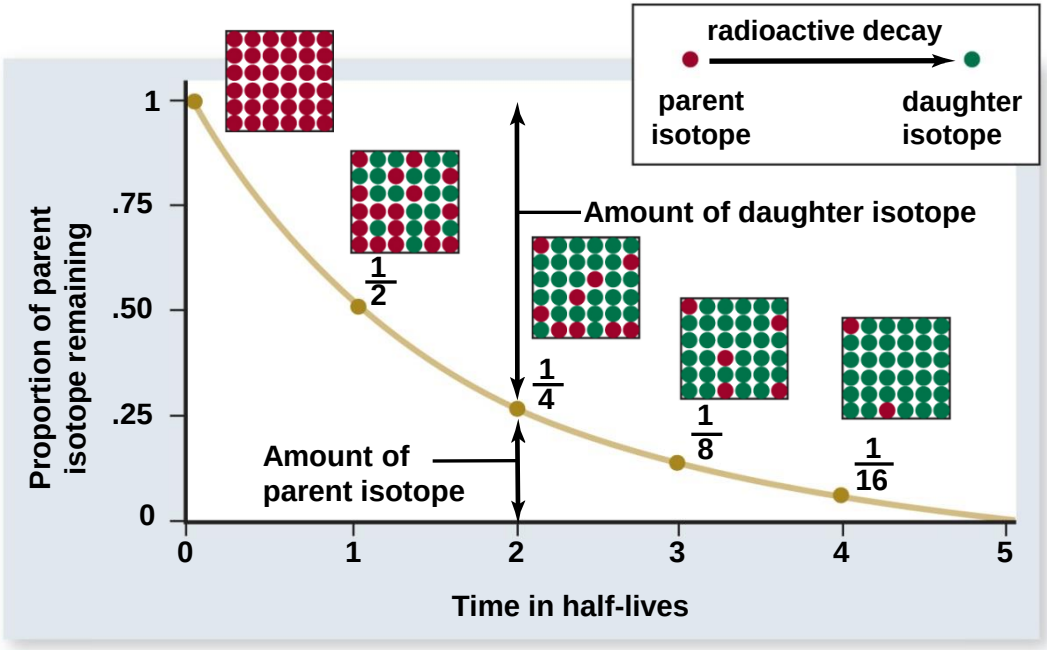
% of original isotope (U-235) decreases with age

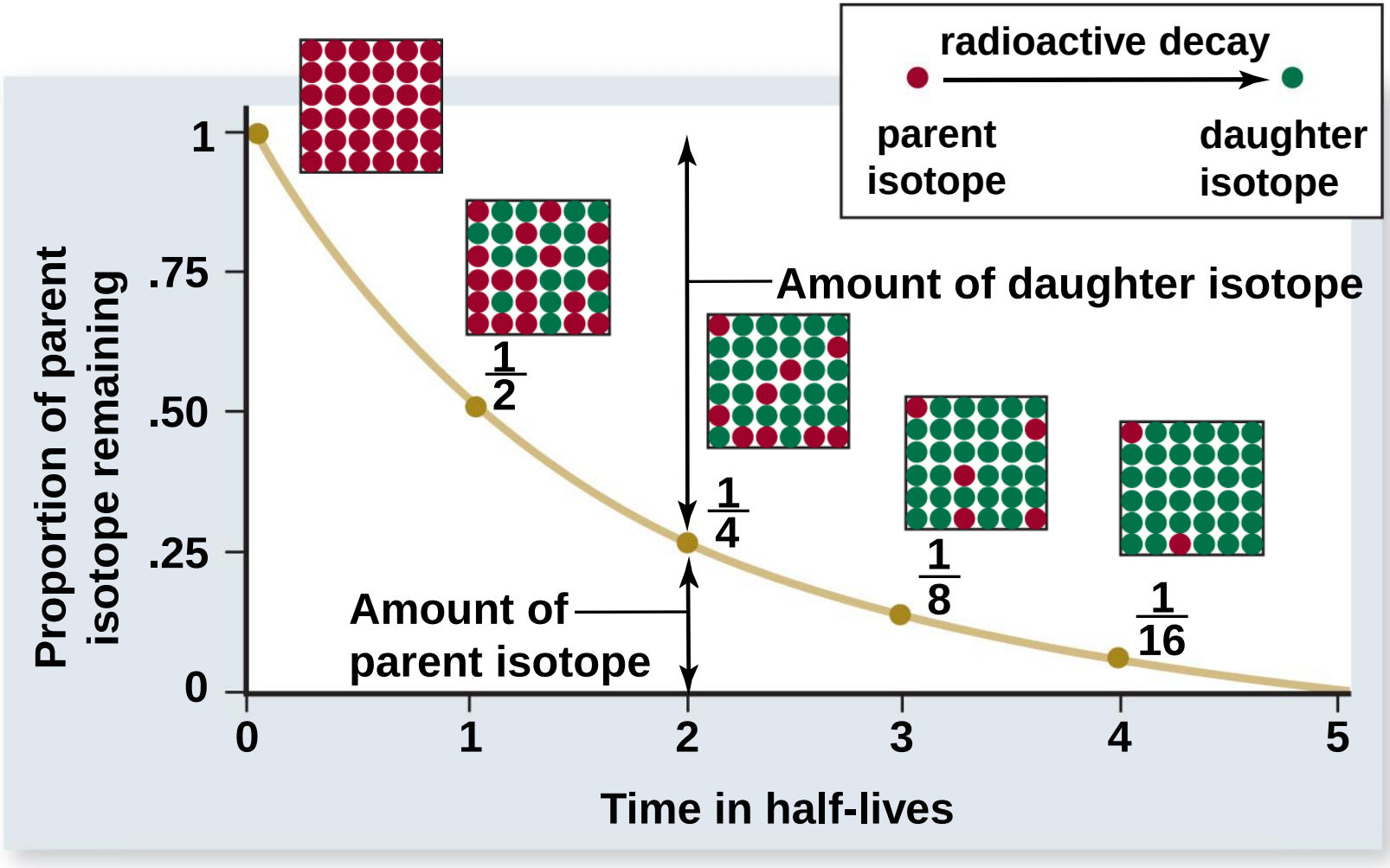


http://www.ucmp.berkeley.edu/fosrec/McKinney.html

Absolute Age

- **Isotopes** transform at precisely known rates into nonradioactive forms
  - The rate of decay is known as an isotope's **half-life**
    - Amount of time needed for one-half of the original amount to be transformed





Absolute Age

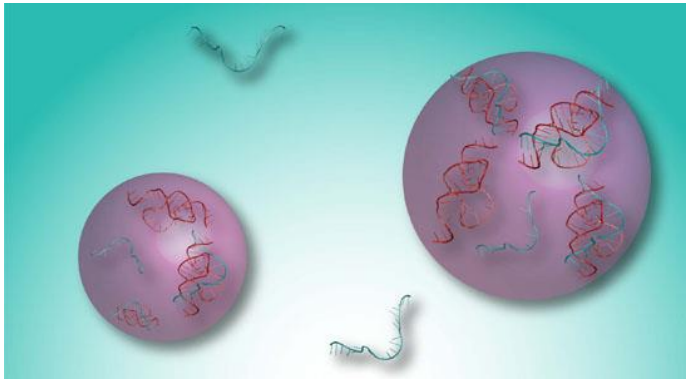
- Types of isotopes used in aging fossils
  - Potassium isotopes: 1.25 billion year half-life
  - Carbon isotopes: 5700 year half-life

Isotope		Half-life of parent (years)	Useful range (years)
Parent	Daughter		
Carbon 14	Nitrogen 14	5,730	100 - 30,000
Potassium 40	Argon 40	1.3 billion	100,000 - 4.5 billion
Rubidium 87	Strontium 87	47 billion	10 million - 4.5 billion
Uranium 238 Uranium 235	Lead 206 Lead 207	4.5 billion 710 million	10 million - 4.6 billion

http://www2.estrellamountain.edu/faculty/farabee/BIOBK/biobookpaleo1.html

Conditions on Early Earth

- Seems likely that Earth's first organisms emerged and lived at very high temperatures
- First organisms emerged between 3.8 and 2.5 BYA
- Early atmosphere composition not agreed on
  - May have been a reducing atmosphere
  - Would have made it easier to form carbon-rich molecules

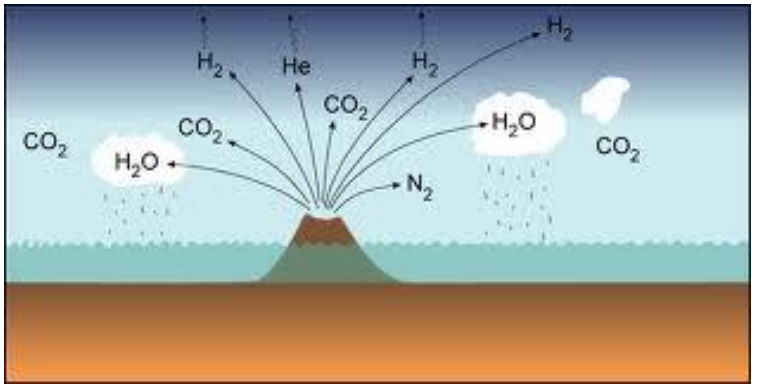


See article: *Chemical Model Shows How First Life Forms Might Have Packaged RNA*, 15-Oct-2012, SciTechDaily.com

http://scitechdaily.com/chemical-model-shows-how-first-life-forms-might-have-packaged-rna/

Organic molecules may have originated on early Earth

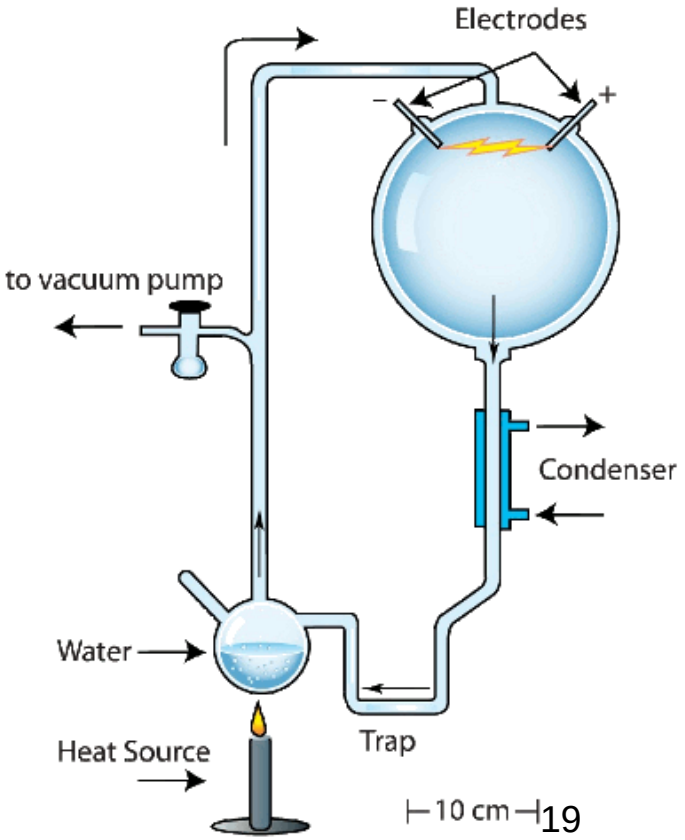
- Few geochemists agree on exact composition of early atmosphere
  - Popular view of early atmosphere
    - Carbon dioxide (CO_2)
    - Nitrogen gas (N_2)
    - Water vapor (H_2O)
    - Hydrogen gas (H_2)
    - Other sulfur, nitrogen, and carbon compounds



  - Atmosphere lacked oxygen gas (O_2)

http://myweb.cwpost.liu.edu/vdivener/notes/atmos_evoln.htm

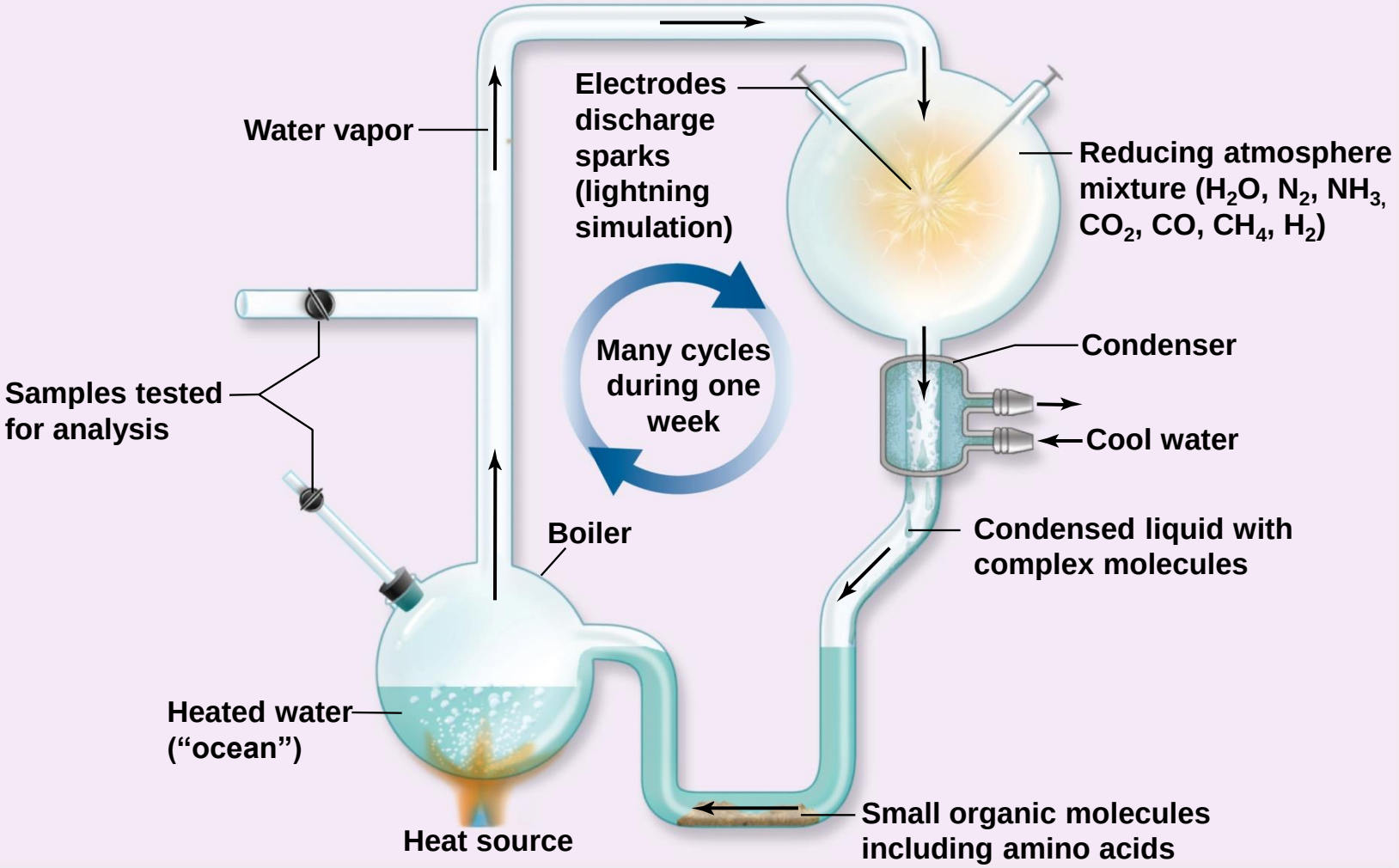
- In 1953, Miller and Urey did an experiment that reproduced early atmosphere
  - Assembled reducing atmosphere rich in hydrogen with no oxygen gas
  - Atmosphere placed over liquid water
  - Temperature below 100ºC
  - Simulated lightning with sparks



http://www.amnh.org/education/resources/rfl/web/essaybooks/earth/p_urey.html

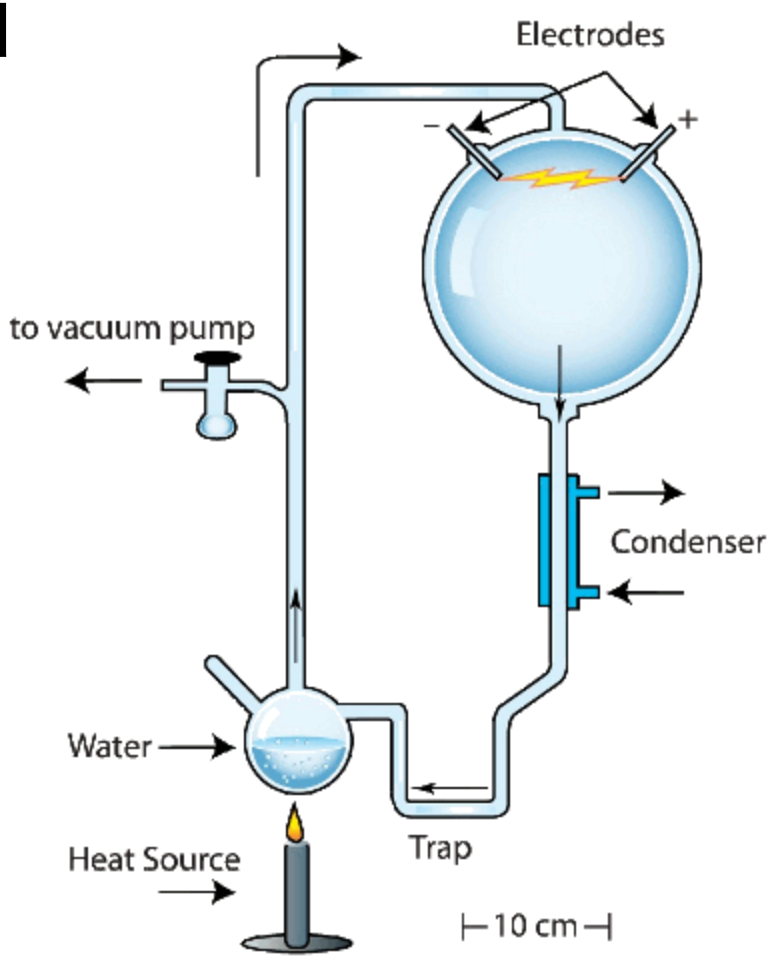
http://tikalon.com/blog/blog.php?article=2011/catalytic_life

The Miller–Urey Experiment



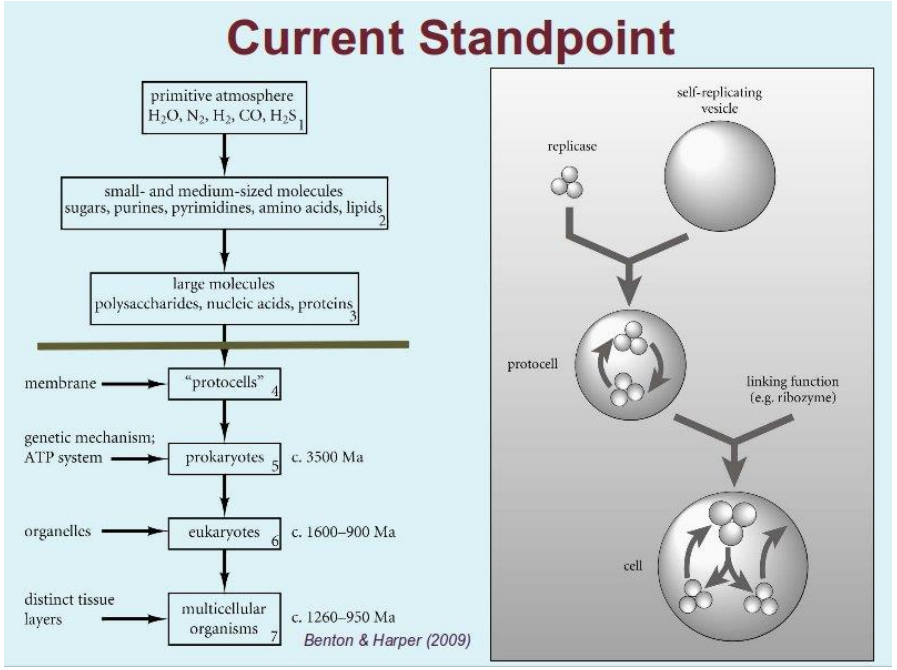
- Within a week they found that methane gas (CH_4) converted into other simple carbon compounds
  - Compounds combined to form simple molecules and then more complex molecules

- Later experiments produced more than 30 carbon compounds including amino acids
  - Adenine also produced



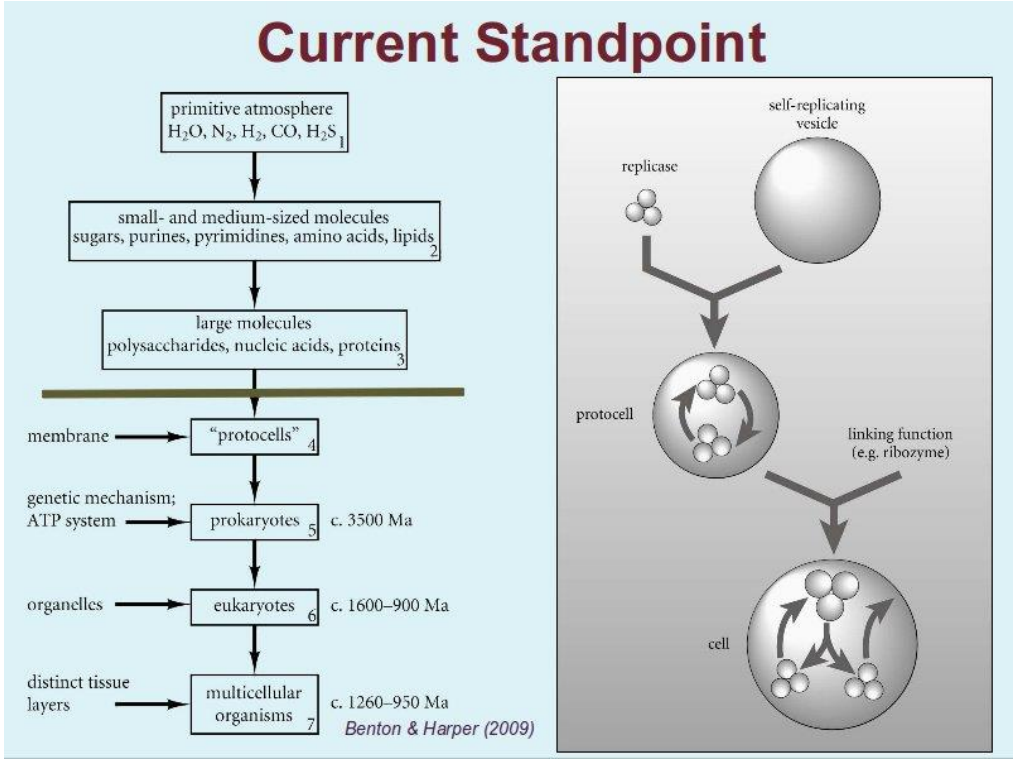
http://tikalon.com/blog/blog.php?article=2011/catalytic_life

- RNA may have been first genetic material
  - **Ribozyme** activity
- Amino acids polymerized into proteins
- Metabolic pathways emerged
  - Primitive organisms may have been autotrophic – built what they needed



http://bioteaching.wordpress.com/2011/05/27/the-origin-of-life-and-of-the-atmosphere/

- Lipid bubbles could increase the probability of metabolic reactions
  - Leads to cell membranes
- Other innovations contributed to diversity of life



http://bioteaching.wordpress.com/2011/05/27/the-origin-of-life-and-of-the-atmosphere/

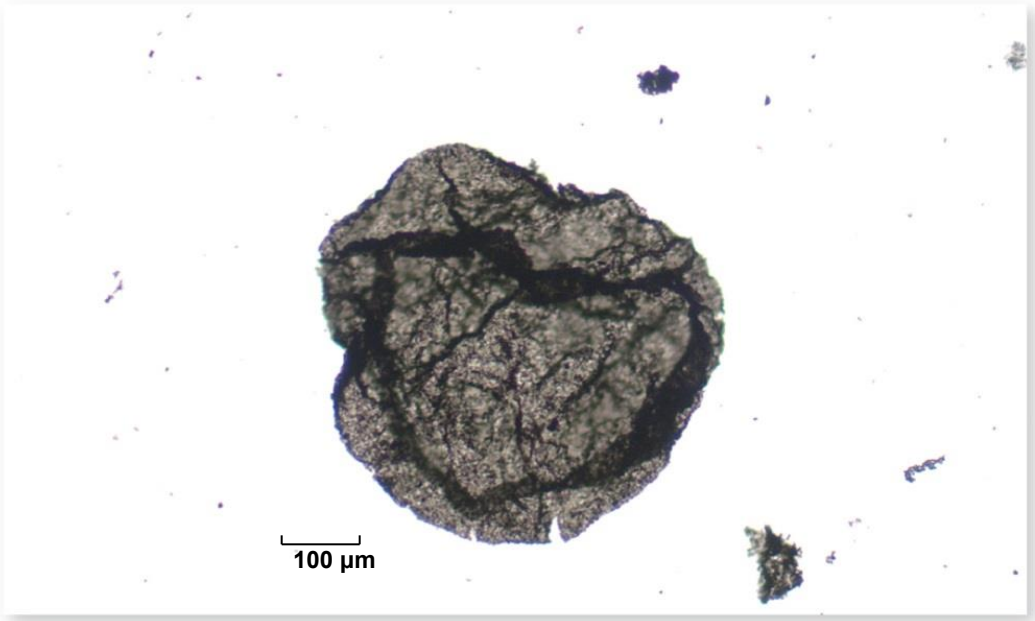
Organic molecues may have been introduced from extraterrestrial source

- Mars meteorite found with minerals that could have catalyzed complex organic molecules (RNA, carbohydrate rings)
- Conditions on Mars may have been more conducive to formation of organics than Earth ~3 bya
  - Molybdenum, boron & oxygen more prevalent on Mars (and less water) at that time

Life on earth 'began on Mars' – (article 28-Aug-2013) Geochemist argues that seeds of life originated on Mars and were blasted to Earth by meteorites or volcanoes… theguardian.com

The First Cells

- Microfossils are fossilized forms of microscopic life
  - Oldest are 3.5 billion years old
  - Seem to resemble present-day prokaryotes

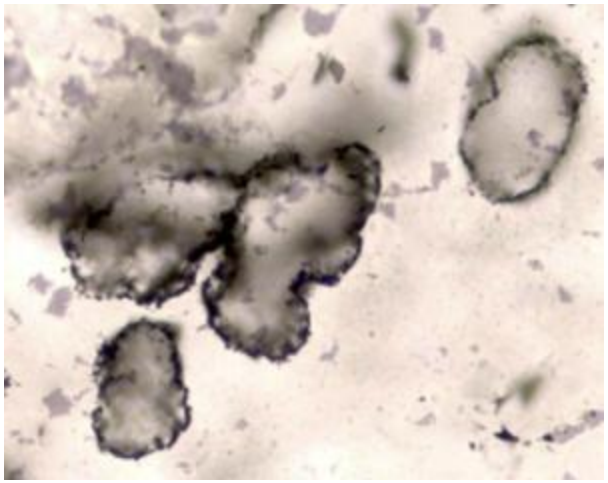


Picture courtesy of E. Javaux

- **Stromatolites** are mats of cyanobacterial cells that trap mineral deposits
  - Oldest are 2.7 billion years old
  - Modern forms are also known

http://www.sciencedaily.com/releases/2011/08/110821205241.htm

- Living things are selective in the carbon isotopes used
  - Rubisco preferentially incorporates carbon-12 over carbon-13
  - → lower $^{12}C/^{13}C$ ratios compared to nonliving rocks
- Isotopic analysis of ^{12}C in fossils suggests that carbon fixation was active as much as 3.8 BYA



Oldest fossilized cells from Western Australia, 3.4 to 3.49 billion years old

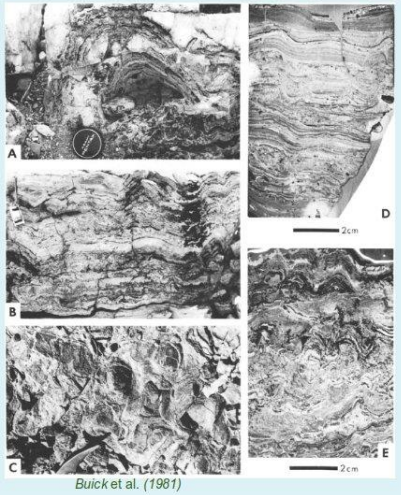
- Biomarkers
  - Organic molecules of biological origin
  - Proven difficult to find
  - Hydrocarbons derived from fatty acid tails of lipids were found in ancient rocks
    - Indicates that cyanobacteria are at least 2.7 billion years old
  - Fossil stromatolites (not from cyanobacteria, possibly extinct Archaeans) push possible origin of life back beyond 3.5 BYA

Cyanobacteria

Oldest: 2.72 Ga (Tumbiana Formation, Australia)

Biomarkers

Stromatolites



Buick et al. *(1981)*

Oldest: 3.49 Ga (Dresser Fm.)

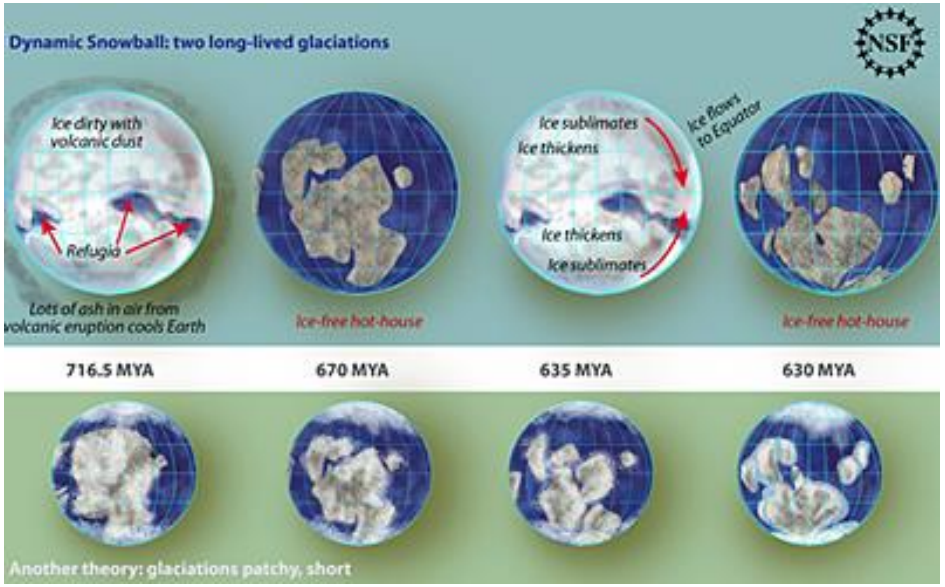
Not cyanobacteria!

http://bioteaching.wordpress.com/2011/05/27/the-origin-of-life-and-of-the-atmosphere/

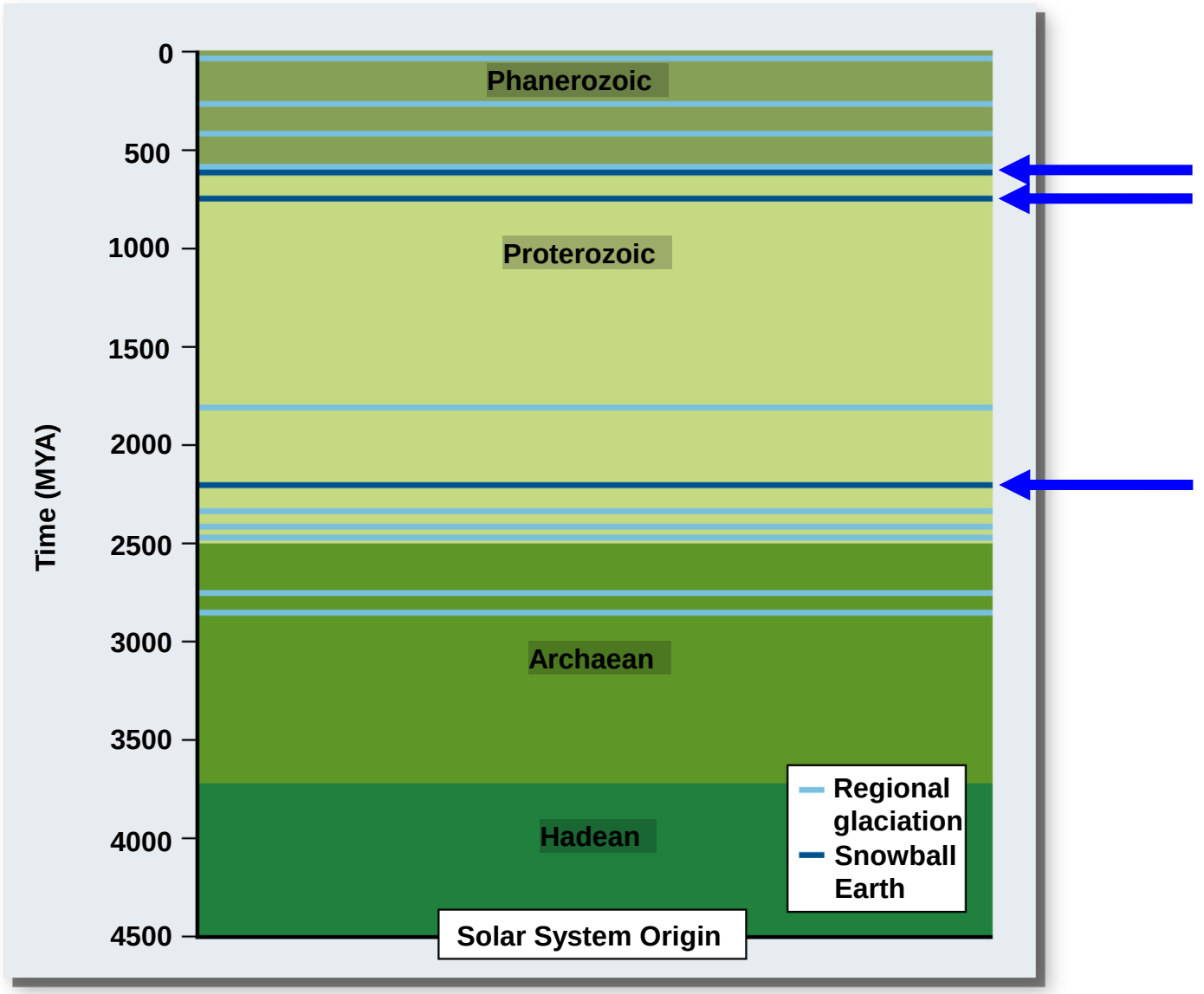
Earth's Changing System

- Climate (temperature and water availability) and atmosphere are among many factors that affect survival
  - Earth has been cooling since its formation
  - Extreme temperature drops resulted in glacial ice covering Earth pole-to-pole ("snowball Earth")

- Dramatic shifts in all these factors led to **mass extinctions** influencing the course of evolution



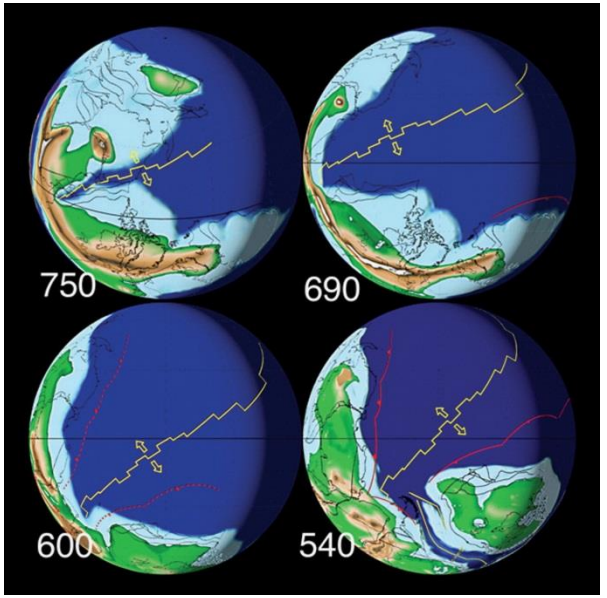
http://www.scientificcomputing.com/news/2010/03/scientists-find-signs-snowball-earth-amidst-early-animal-evolution#.UjzEFT-Gc_g

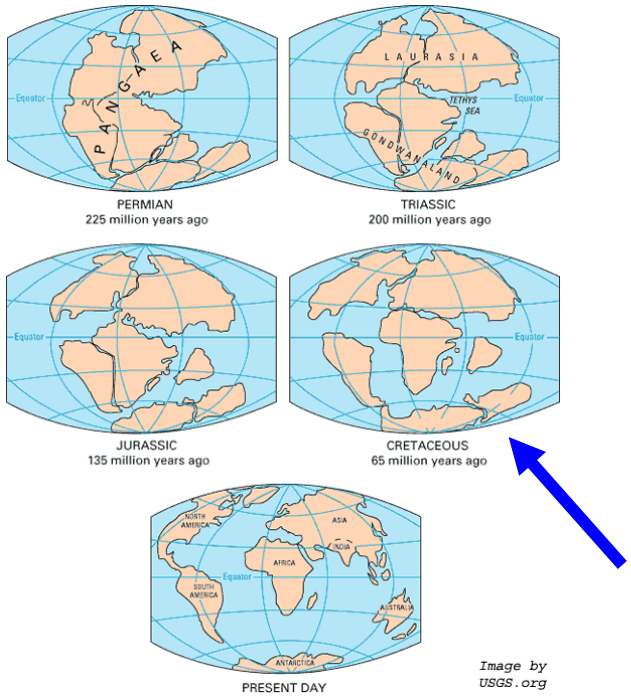


Three global glaciation events occurred during the Proterozoic

http://sp.lyellcollection.org/content/326/1/67/F8.expansion

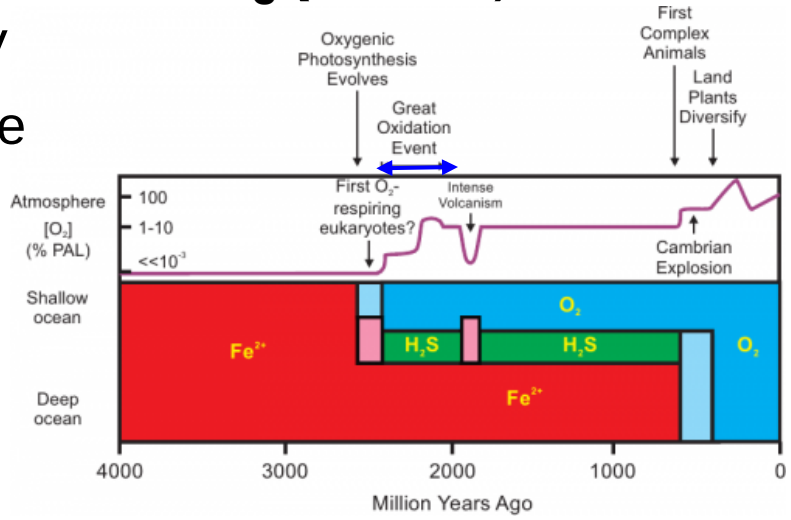
- Continental motion affected evolution
  - Continents sit on submerged tectonic plates that are in motion
  - Cenozoic era began 65 mya
    - Australia and Antarctica separated, as did Greenland and North America
    - The Atlantic Ocean continued to grow as plates in the mid-Atlantic spread
    - Greenhouse conditions during Cretaceous period led to a rise in sea level and continental areas were submerged.





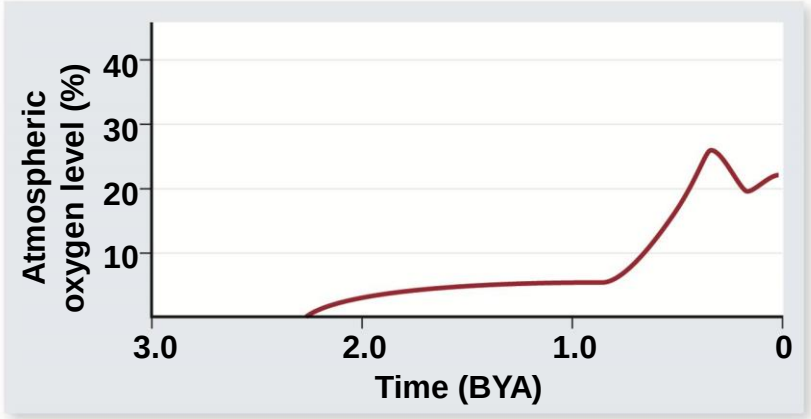
http://www.platetectonics.com/book/page_7.asp

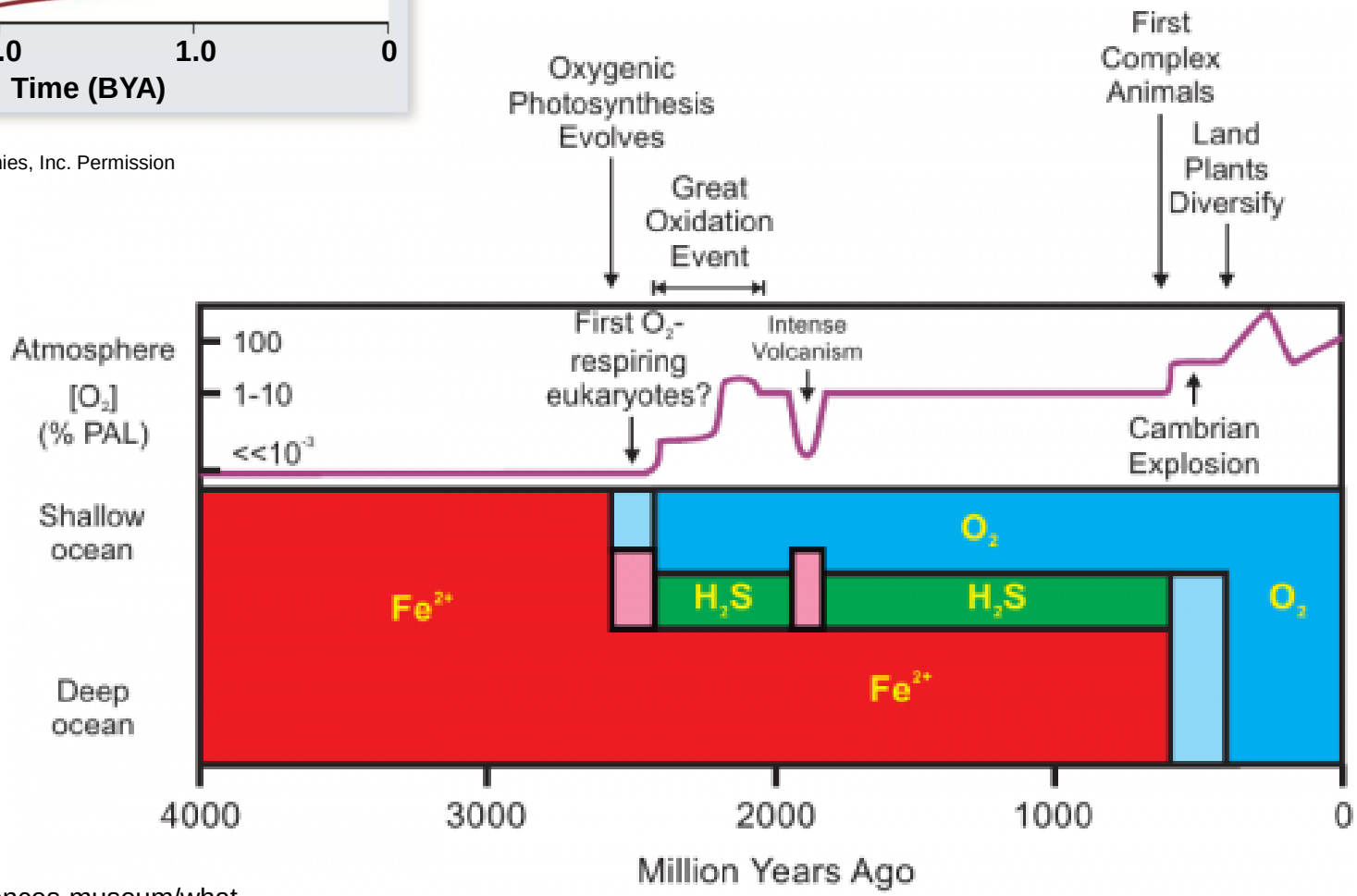
- Oxygenic photosynthesis produced atmospheric O_2 → "Great Oxygen Event"
  - From cyanobacteria (?) ~ 2.7 bya
  - O_2 is toxic to obligate anaerobes → extinction
  - 200-million-year lag between the origins of photosynthesis and substantial levels of O_2
    - Iron oxide in the oceans
    - O_2 in the atmosphere interacted with ultraviolet (UV) radiation from the Sun and formed **O_3 (ozone)**
      - Protected organisms from UV
      - Made surface more hospitable



https://uwaterloo.ca/earth-sciences-museum/what-earth/earths-oxygen-revolution

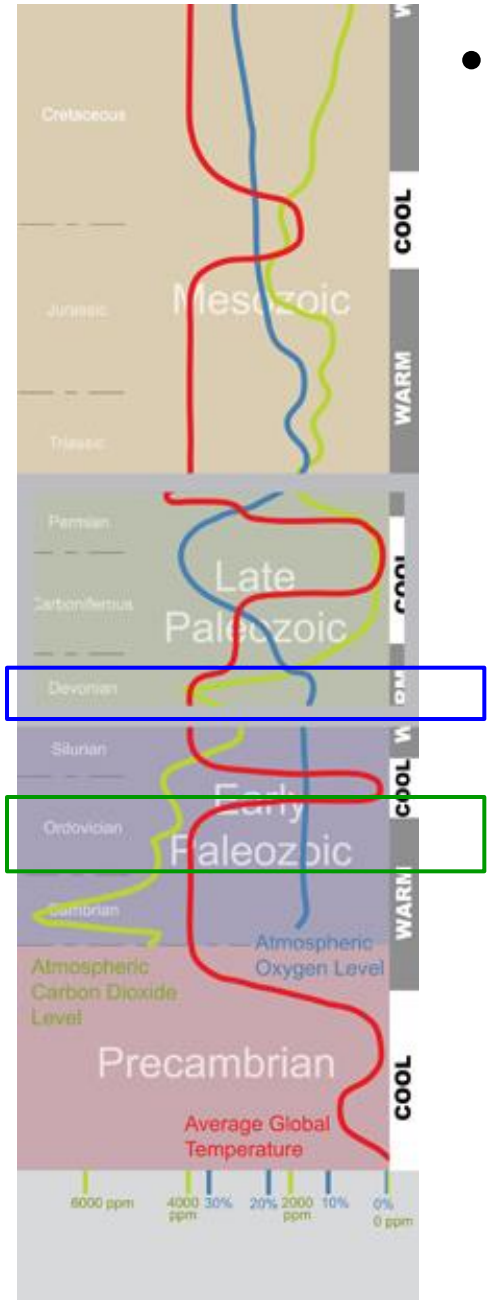
Atmospheric O_2 levels over time



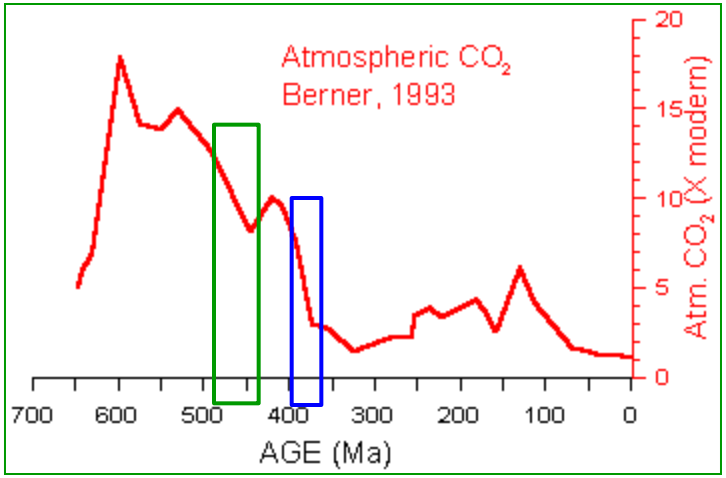


https://uwaterloo.ca/earth-sciences-museum/what-earth/earths-oxygen-revolution

http://www.earthsciences.hku.hk/shmuseum/earth_evo_06_02.php



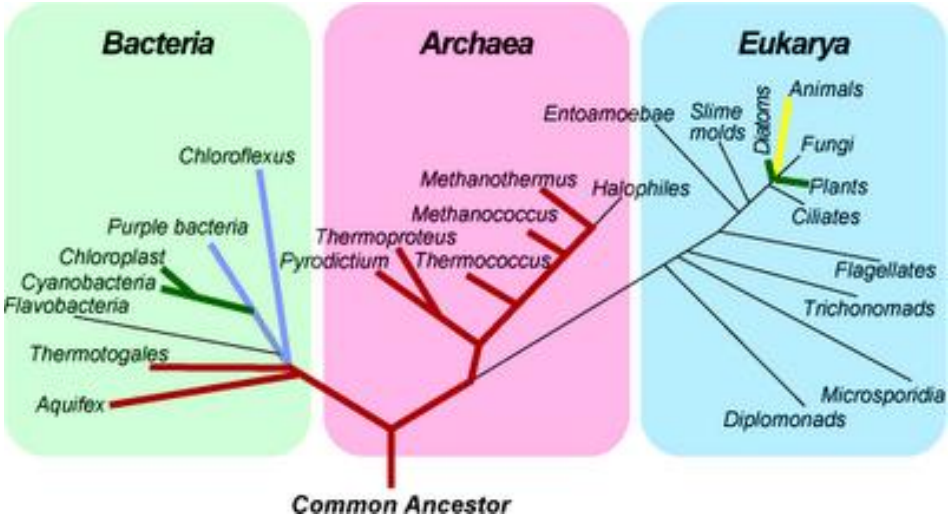
- Did plants contribute to glaciations?
  - Growing evidence that plants contributed to two glaciations
    - Colonization of land by plants followed by gradual cooling and abrupt glaciation 488 to 444 mya, coincident with Gondwana over South Pole
    - Diversification of vascular plants concurrent with second glaciation 400 to 360 mya, Gondwana also over South Pole



http://www.geo.arizona.edu/Antevs/nats104/00lect18.html

Ever-Changing Life on Earth

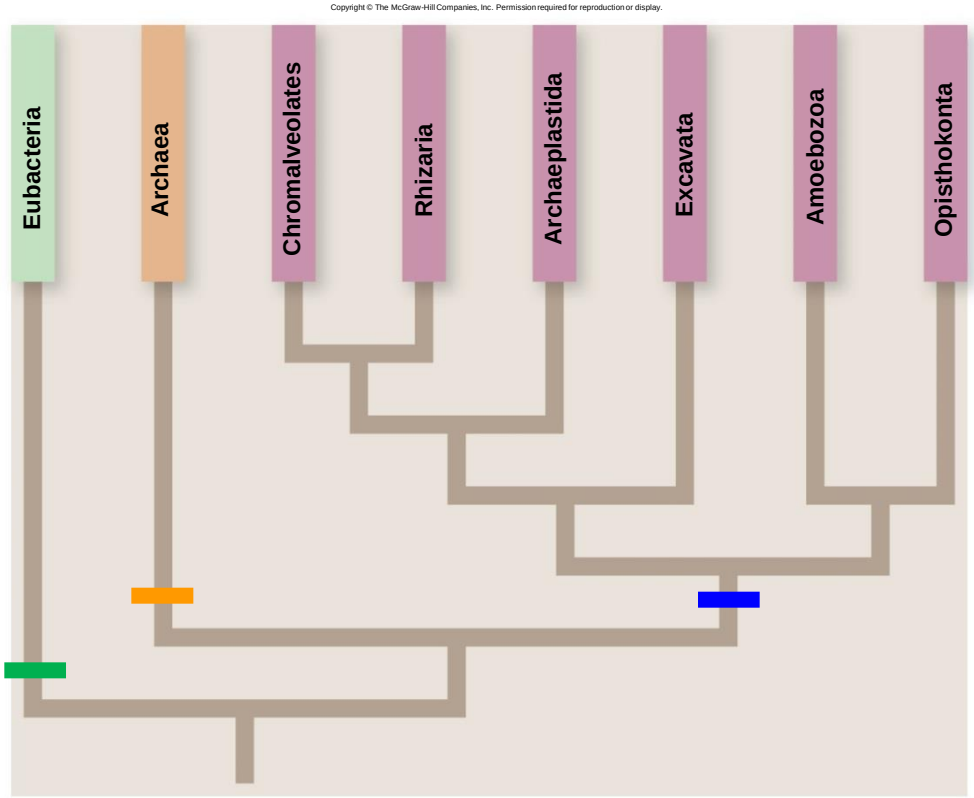
- Life evolved into three monophyletic domains
  - **Eubacteria**
  - **Archaea**
  - **Eukaryotes**
    - Six supergroups identified within the eukaryotes

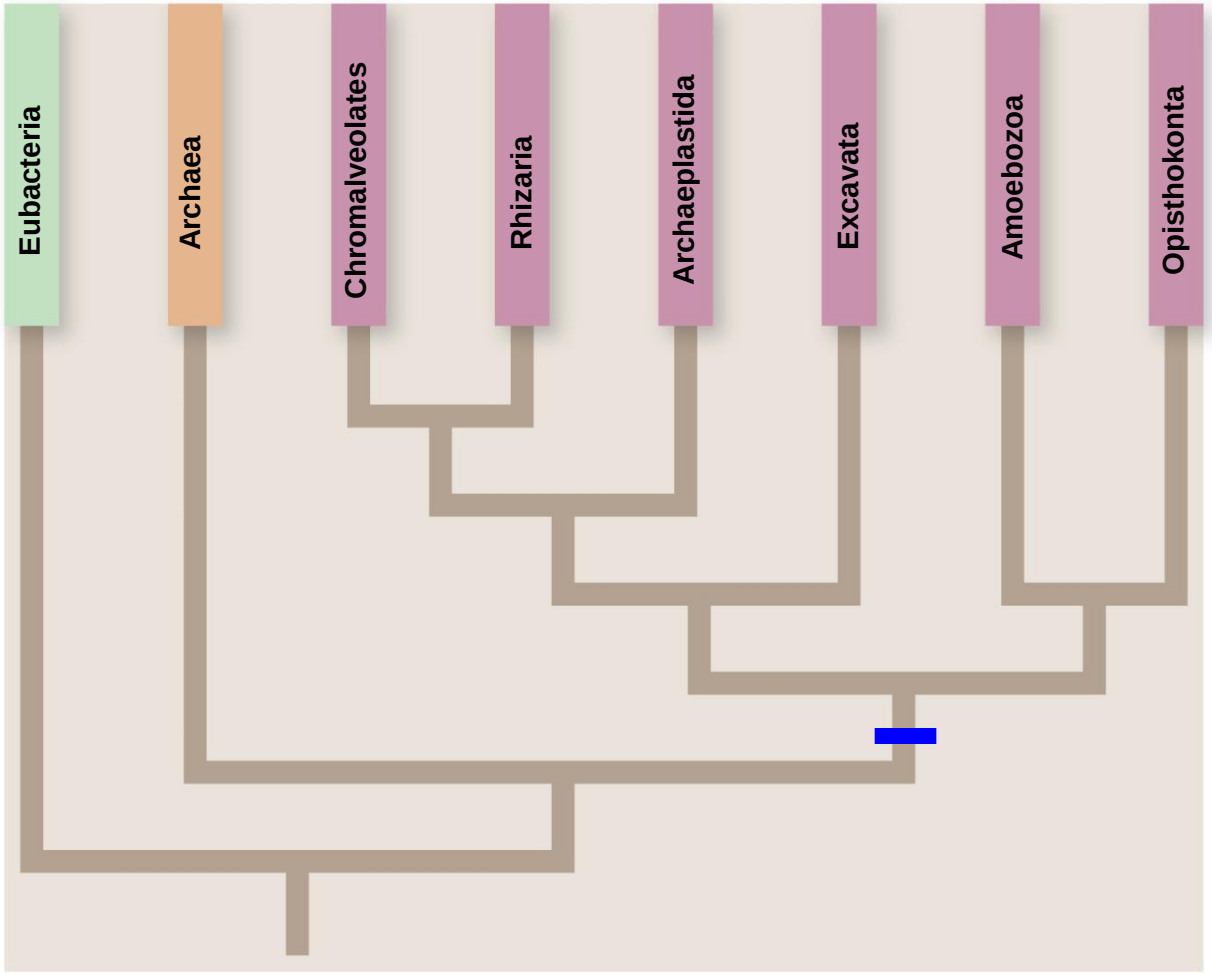


http://lady-rosales.blogspot.com/2010/08/three-domains-system-three-domain.html

- 3 domain system
  - Domain **Eubacteria**
  - Domain **Archaea**
  - Domain **Eukarya**

- Each of these domains forms a clade

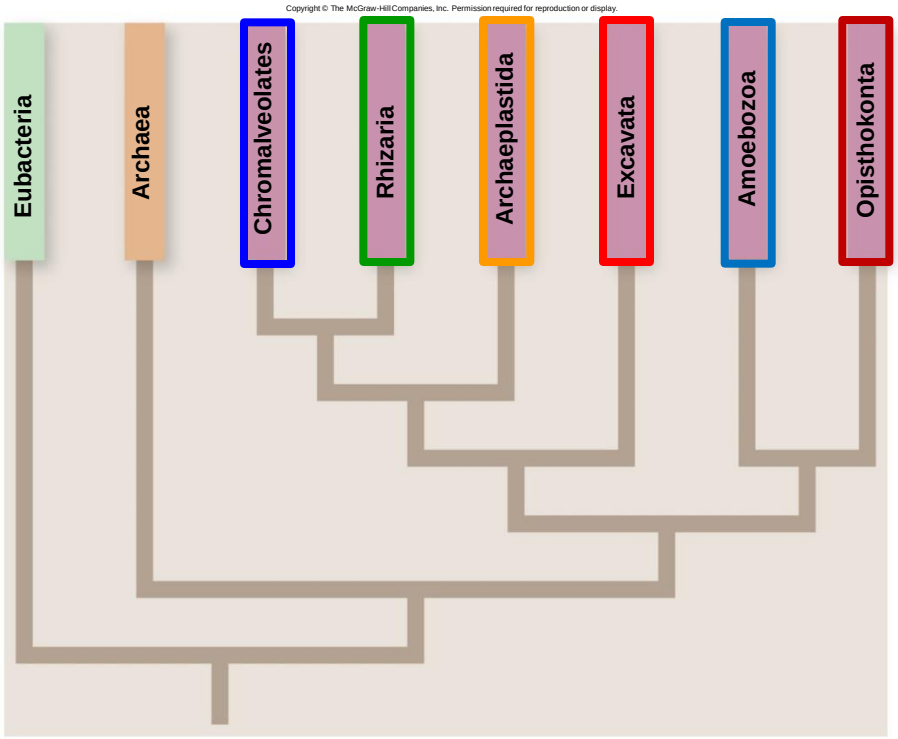




Six supergroups have been identified within the Eukaryote domain, one of three domains of life on Earth

Six supergroups of Eukarya

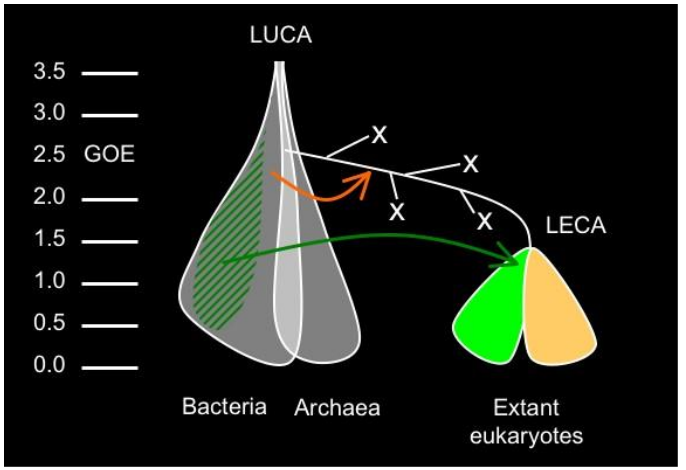
- **Chromalveolata**
  - brown algae, dinoflagellates, diatoms, ciliates, apicomplexans
- **Rhizaria**
  - forams, radiolarians
- **Archaeplastida**
  - red & green algae, land plants
- **Excavata**
  - *Euglena*, *Giardia*, *Trichomonas*
- **Amoebazoa**
  - *Amoeba*
- **Opisthokonts**
  - fungi, animals



No need to memorize

Compartmentalization of cells

- Compartmentalization of cells enabled the advent of eukaryotes
  - Bacteria and Archae ruled the Earth for 1 billion years
  - Bacteria and Archae are distinct from eukaryotes in that they lack compartmentalization



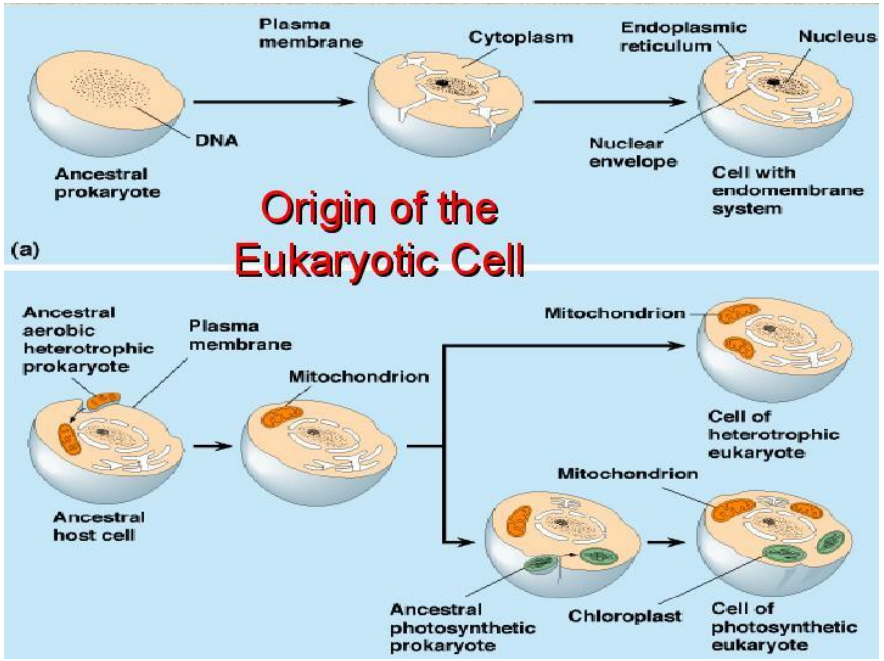
Last Universal Cellular Ancestor (LUCA)

Last eukaryote common ancestor (LECA)

- Eukaryotes developed extensive endomembrane system

https://www.icts.res.in/archive/program/details/288/

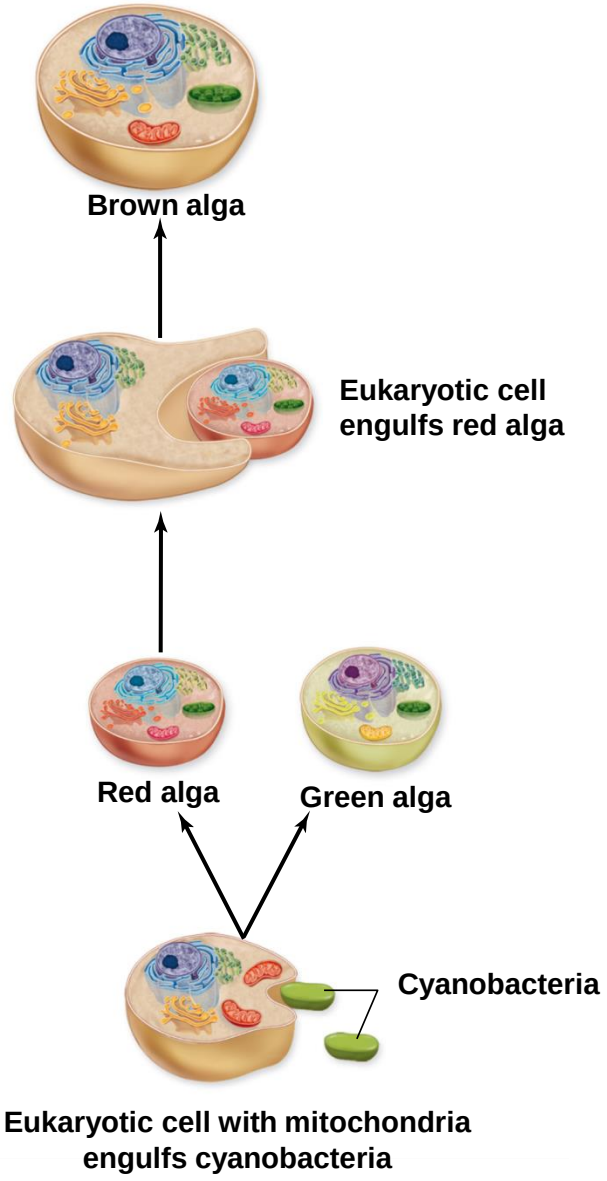
- Evolution of the endomembrane system
  - Nuclear membrane, not found in bacteria and archae, accounts for increased complexity in eukaryotes
    - Physical separation of transcription and translation adds additional levels of gene expression
  - Golgi apparatus and endoplasmic reticulum facilitate intracellular transport



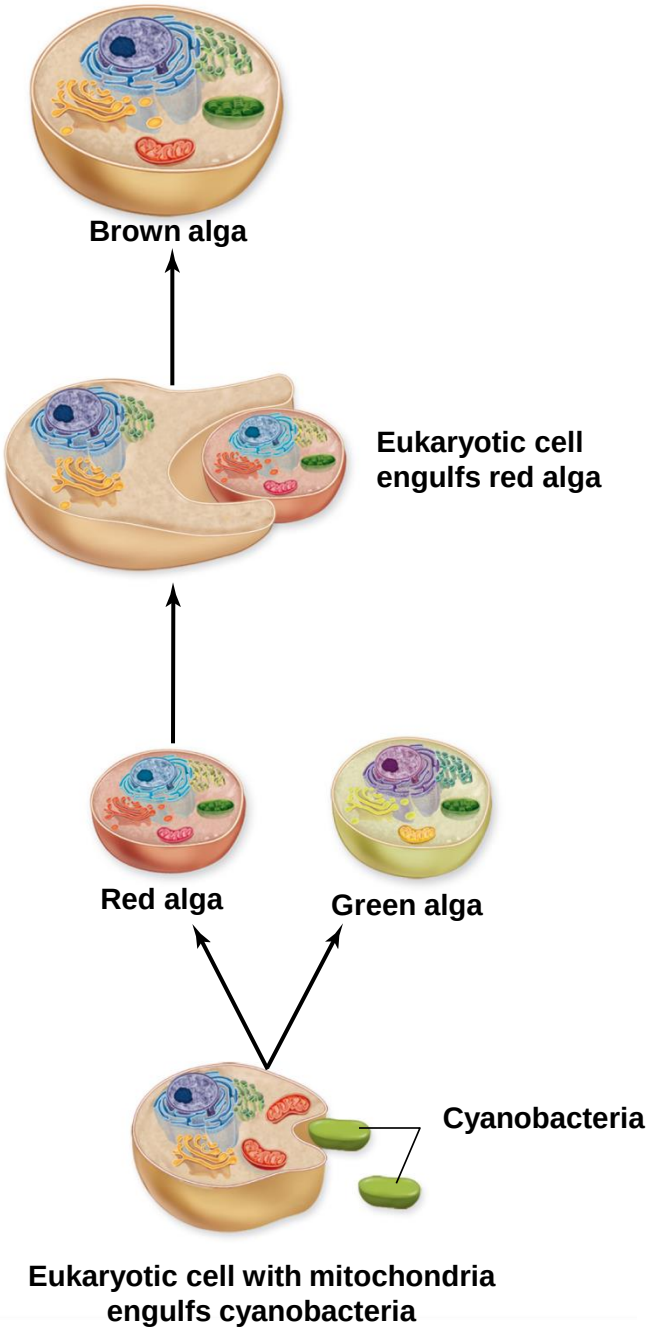
The nuclear membrane, ER and Golgi are thought to have arose from infolding of the plasma membrane, though alternative hypotheses have been proposed

http://krupp.wcc.hawaii.edu/BIOL101/present/lcture16/sld025.htm

- **Endosymbiosis** and the origin of eukaryotes
  - Mitochondria and chloroplasts entered early eukaryotic cells by endosymbiosis
  - *Mitochondria* are the descendants of relatives of purple sulfur bacteria and the parasite Rickettsia
  - *Chloroplasts* are derived from cyanobacteria

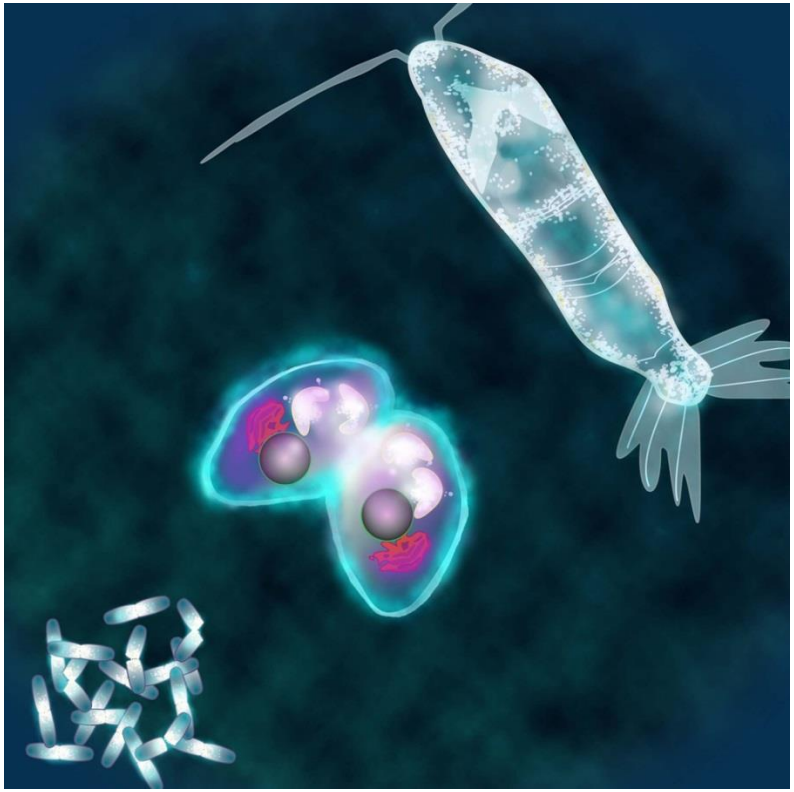


Endosymbiosis



Multicellularity leads to cell specialization

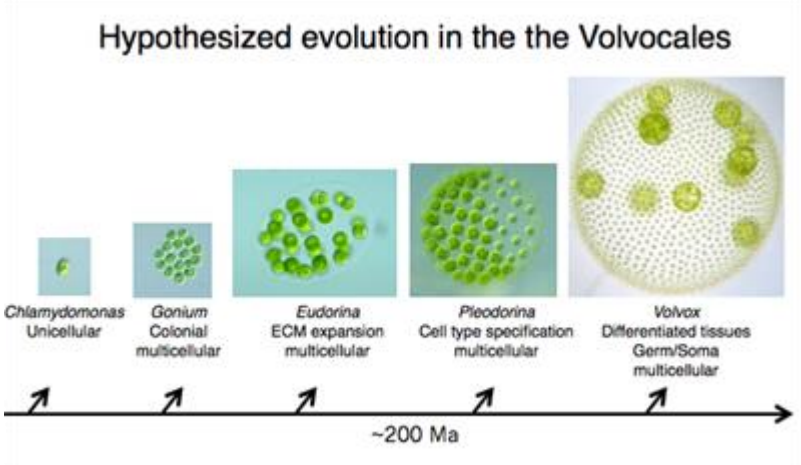
- Unicellular body plan tremendously successful
  - Unicellular prokaryotes and eukaryotes constituting about half of the biomass on Earth
  - Single cell has limits with cell specialization

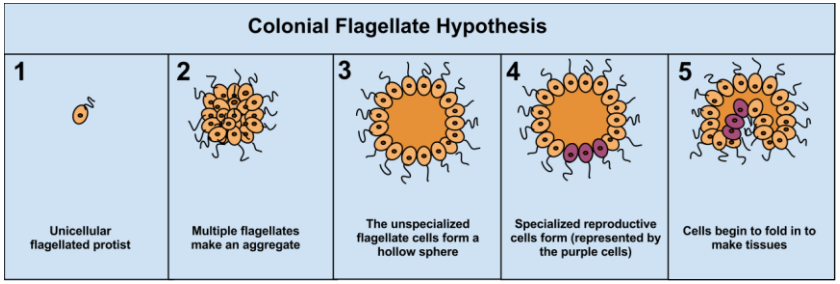


http://web.mit.edu/newsoffice/2012/microbe-metabolism-0104.html

Multicellularity leads to cell specialization

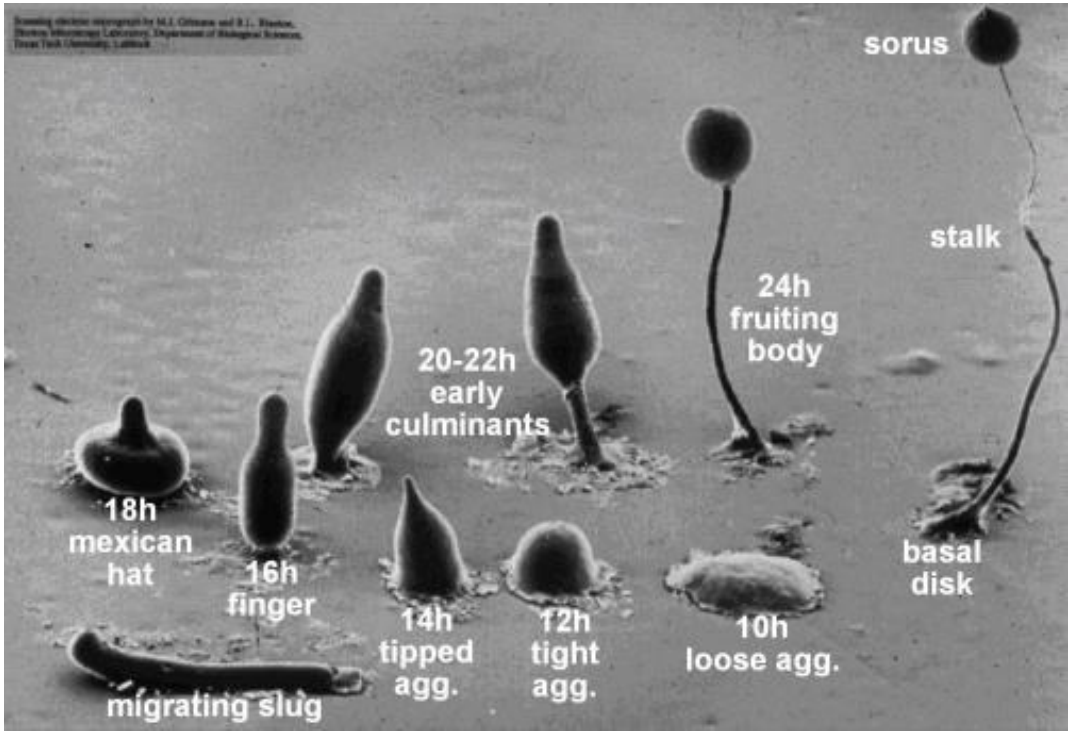
- **Multicellularity**
  - Allowed organisms to deal with environment in novel ways through differentiation
  - Evolved independently in eukaryote supergroups

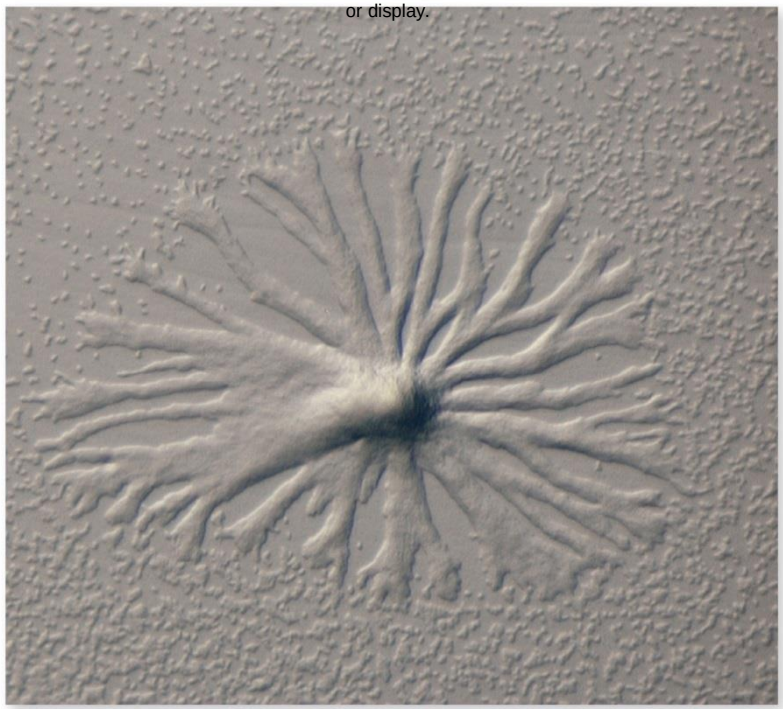




Eukaryotes form colonial aggregates of many cells.

Aggregation of *Dictyostelium discoideum* forms a colonial organism

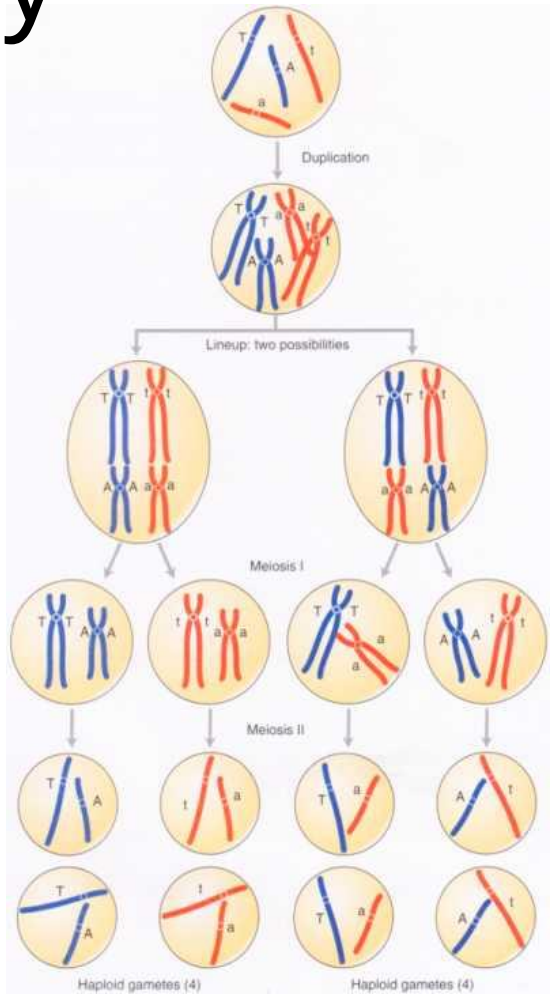




http://www.devbio.biology.gatech.edu/?page_id=34

Sexual reproduction increases genetic diversity

- Sexual reproduction allows greater genetic diversity
  - Meiosis
  - Crossing over
- First eukaryotes were probably haploid
  - Diploids arose independently on separate occasions
    - Fusion of haploid cells



http://campus.murraystate.edu/academic/faculty/eweber/bio101/notes/snotes/10_29_12_bio101.html

Rapid diversification occurred during the Cambrian “Explosion”

- Evolutionary innovations occurred while life was primarily aquatic
  - Established the foundations for tremendous diversity
  - Cambrian radiation was confined to ocean
  - First multicellular animals appeared 50 million years following Cambrian radiation

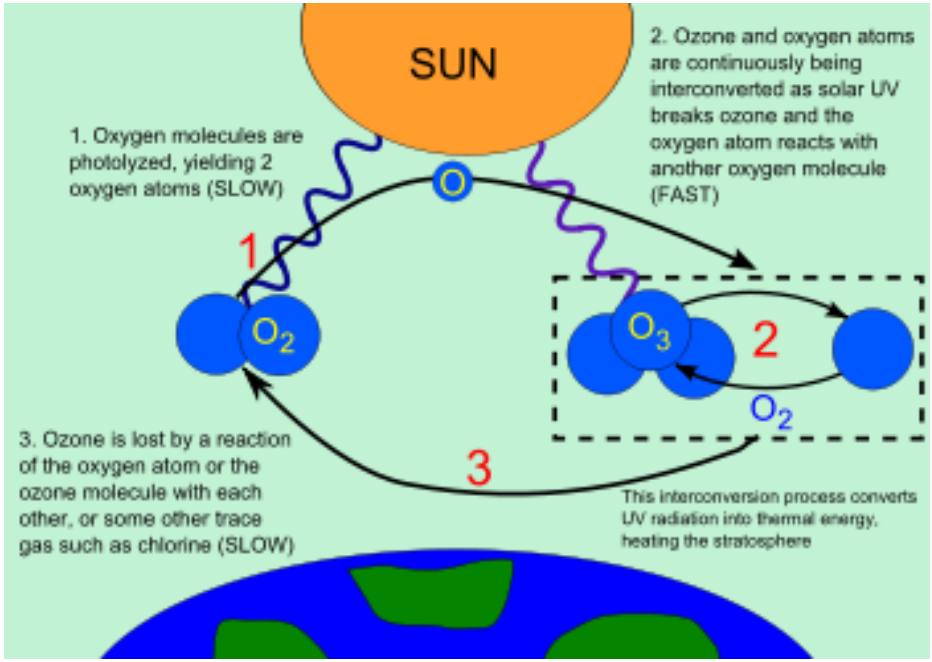
http://www.astrobio.net/exclusive/3733/skeletons-in-the-pre-cambrian-closet

With permission of the Royal Ontario Museum and Parks Canada © ROM. Photo Credit: J.B. Caron

Fossil from the Cambrian explosion, found in the Burgess Shale deposits of western Canada

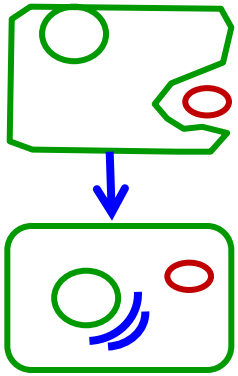
Major innovations allowed for the move onto land

- Plants and then animals colonized terrestrial environments after Cambrian radiation
  - Evolution of photosynthesis protected organisms on land by the production of O_2
    - Ozone layer protected from UV light

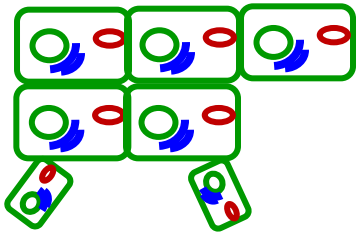


Key Eukaryotic Characteristics

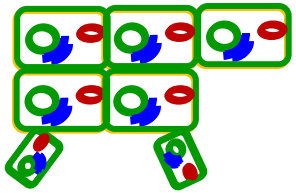
- **Compartmentalization**
  - Allows for *increased subcellular specialization*
  - Nuclear membrane allows for additional levels of control of transcription and translation



- **Multicellularity**
  - Allows for *differentiation of cells* into tissues

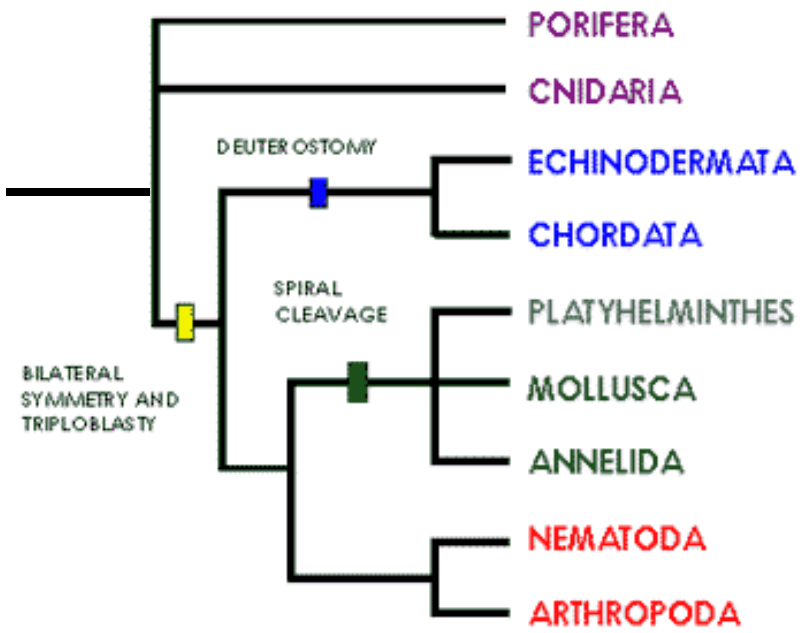


- **Sexual reproduction**
  - Allows for *greater genetic diversity*



Naming diverse organisms is essential in biology

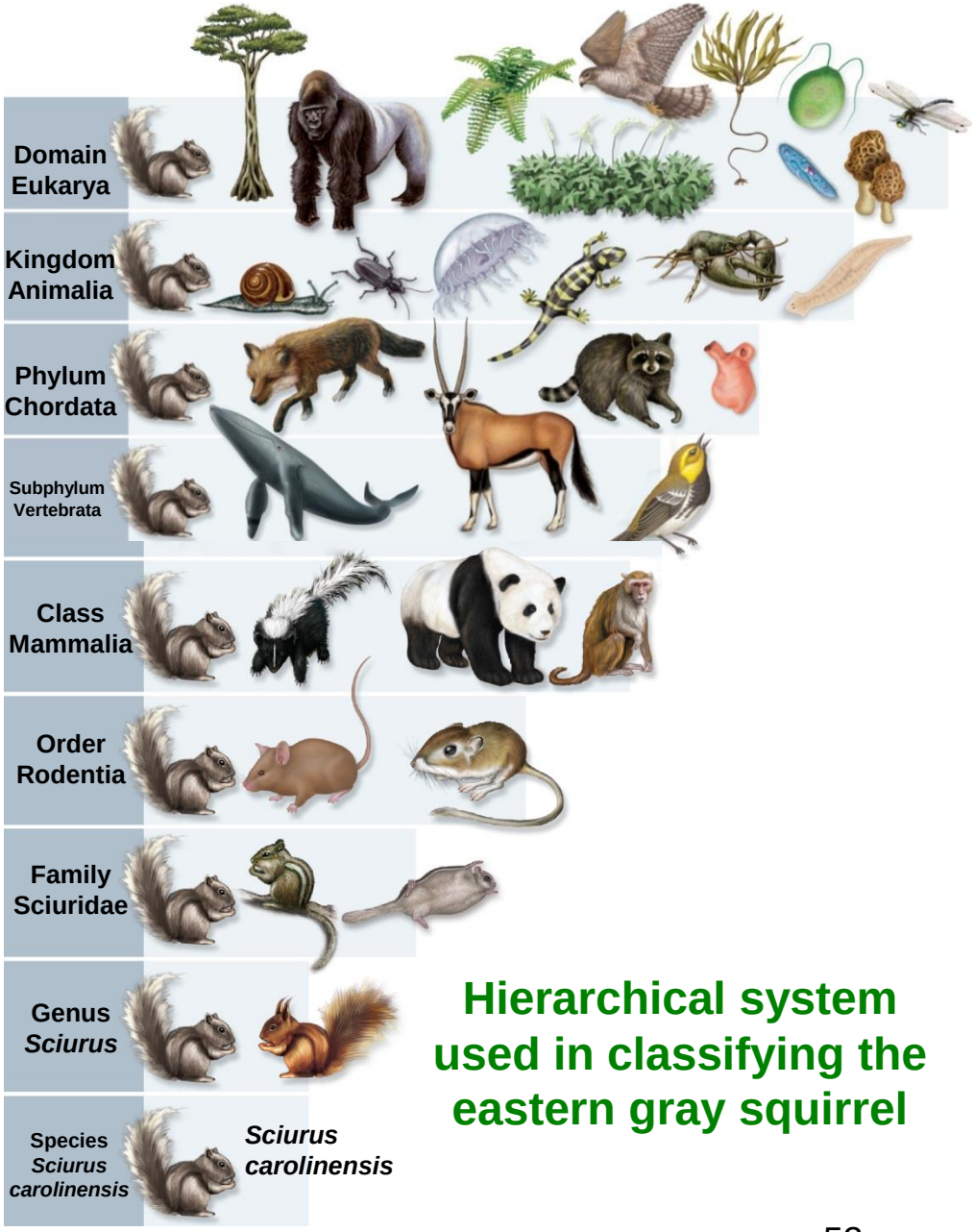
- Shifted from emphasis on identifying and naming organisms to constructing evolutionary hypotheses (phylogenies) to explain the relatedness of species
  - Don’t always match well with traditional taxonomy



- Organisms grouped into clusters
  - Domain
  - Kingdom
  - Phylum
  - Class
  - Order
  - Family
  - Genus
  - Species

  - Other categories assist with classification

Know these taxa, and the hierarchy



Hierarchical system used in classifying the eastern gray squirrel

Hierarchical system used in classifying the eastern gray squirrel