What (if anything) are plants and where did they come from?

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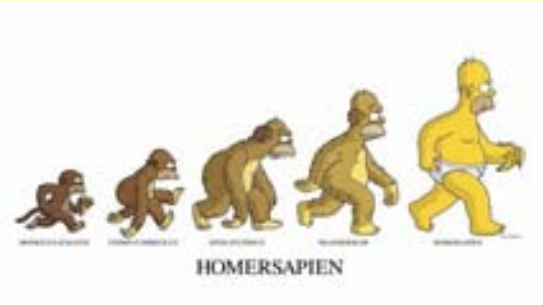
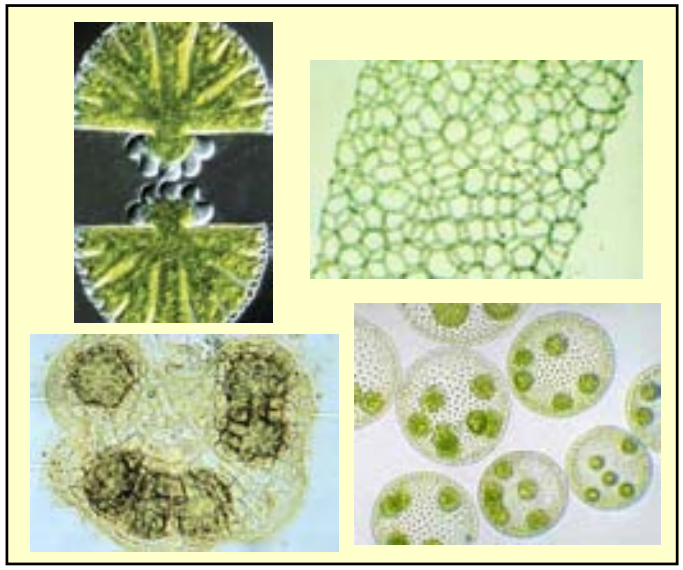
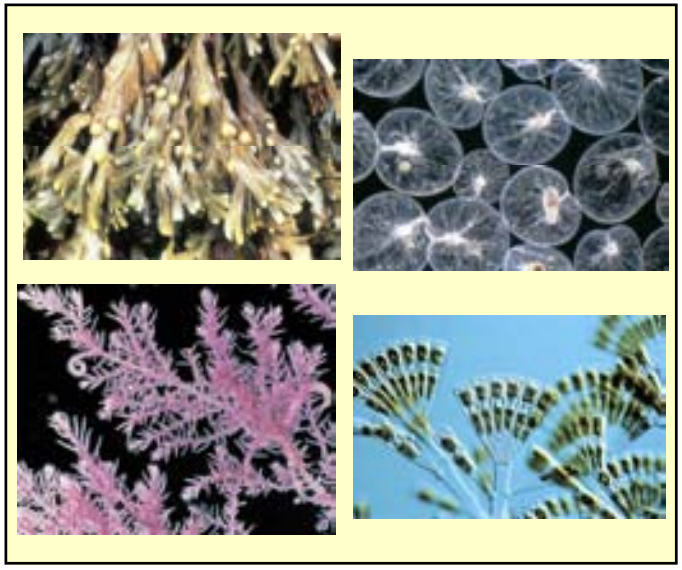
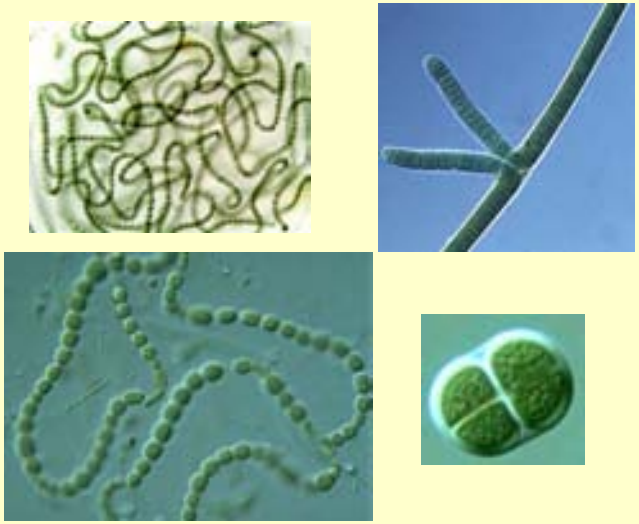
EVOLUTION

Chemicals → Cells → Slimy lower forms of life → Plants and Animals → Humans









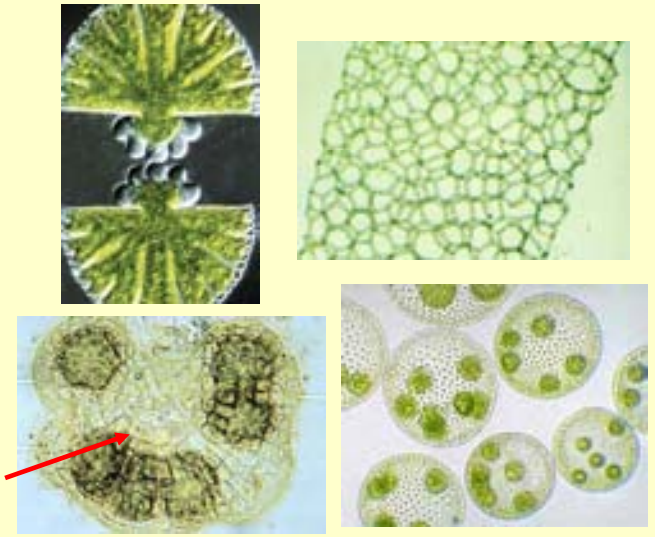
Kingdom Plantae
- Bryophytes
  - Phylum Hepatophyta (liverworts)
  - Phylum Anthocerophyta (hornworts)
  - Phylum Bryophyta (mosses)
- Vascular plants
  - Seedless vascular plants
    - Phylum Lycopodiophyta (lycophytes)
    - Phylum Pteridophyta (ferns and their allies, the whisk ferns and horsetails)
  - Seed plants
    - Phylum Cycadophyta (cycads)
    - Phylum Ginkgophyta (ginkgo)
    - Phylum Coniferophyta (conifers)
    - Phylum Gnetophyta (gnetophytes)
    - Phylum Anthophyta (angiosperms)

Kingdom Plantae

- chlorophylls a and b, carotenoids
- store starch inside chloroplast
- cellulose
- form phragmoplast during cell division

Characteristics suggest a common ancestor in the Chlorophyta, Class Charophyceae

- the most advanced charophytes (e.g. Chara, Coleochaete) are most similar to the higher plants



Key events:

- acquisition of chloroplasts
- colonization of land

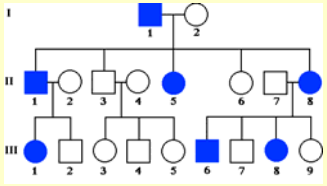
Reconstruction of these events:

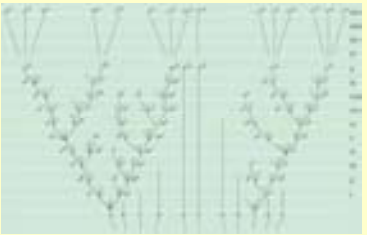
- fossils
- genes

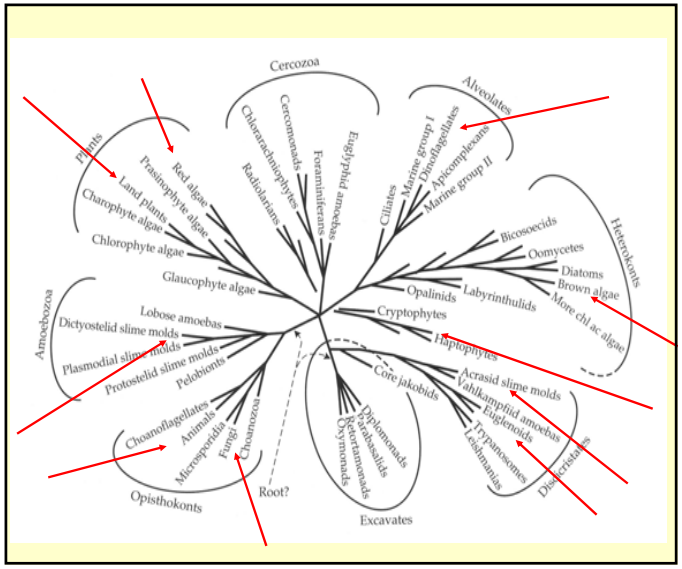
Phylogenetic thinking

What are phylogenies?

- genealogies extended over evolutionary time
- views evolution as descent from common ancestors
- phylogenetic reconstruction permits the assessment of relationships and the study of evolutionary events in the past



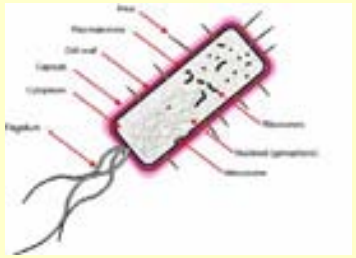




So plants form one of many eukaryotic groups of organisms

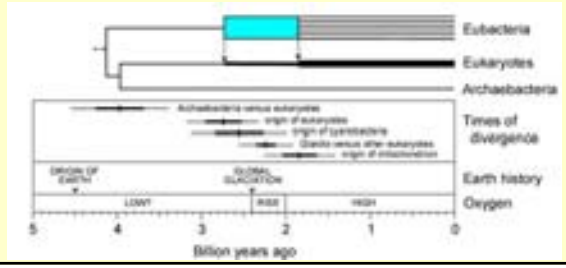
Where did eukaryotes come from?

(from prokaryotes)



Presumed Chronology:

- earth formed around 4.5 billion years ago
  - oldest rocks around 3.8 bya
  - oldest fossil cells 3.2 - 3.5 bya
- diverence of prokaryotes (eubacteria/archaea)
- divergence of archaea and ancestors of eukaryotes



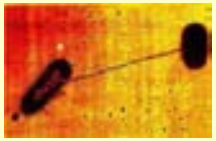
Archaea, bacteria and eukaryotes

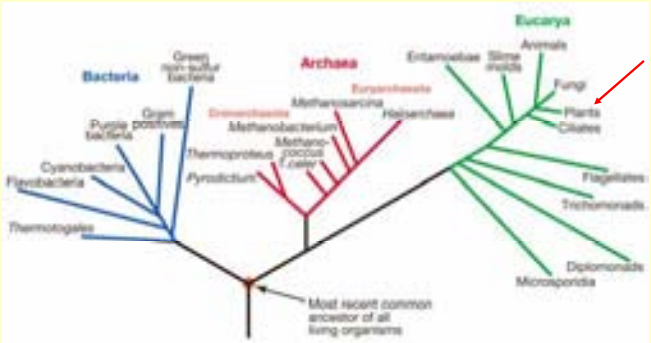
- In 1977 Carl Woese compared ribosomal RNA sequences of representatives of prokaryotic and eukaryotic groups
- found that the prokaryotic groups are enormously diverse and form two ancient lineages

  ARCHAEA

  BACTERIA

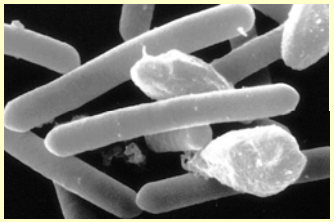
- also found that eukaryotes shared common ancestry with archaeans

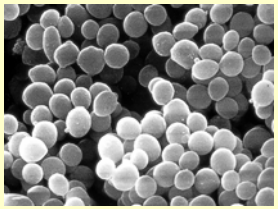


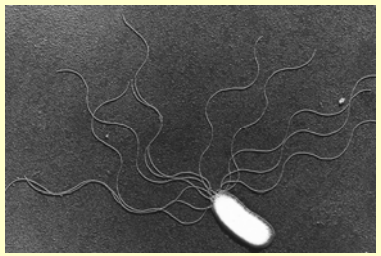


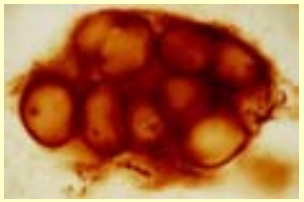
Prokaryotic modes of nutrition

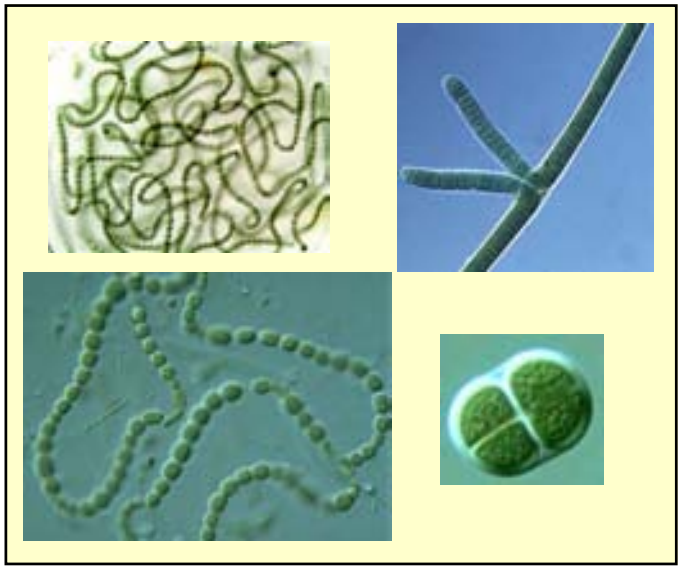
Nutritional Type	Energy Source	Carbon Source	Examples
Photoautotrophs	Light	CO_2	Cyanobacteria, some Purple and Green Bacteria
Photoheterotrophs	Light	Organic compounds	Some Purple and Green Bacteria
Chemoautotrophs or Lithotrophs	Inorganic compounds, e.g. H_2, NH_3, NO_2, H_2S	CO_2	A few Bacteria and many Archaea
Chemoheterotrophs or Heterotrophs	Organic compounds	Organic compounds	Most Bacteria, some Archaea

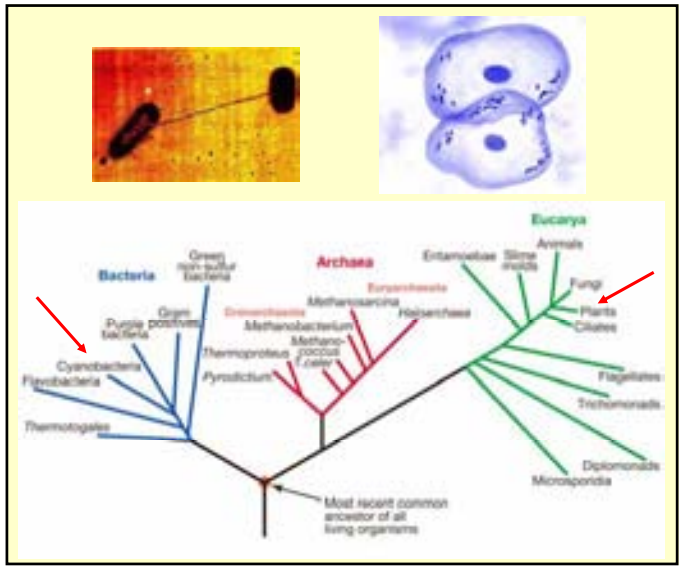


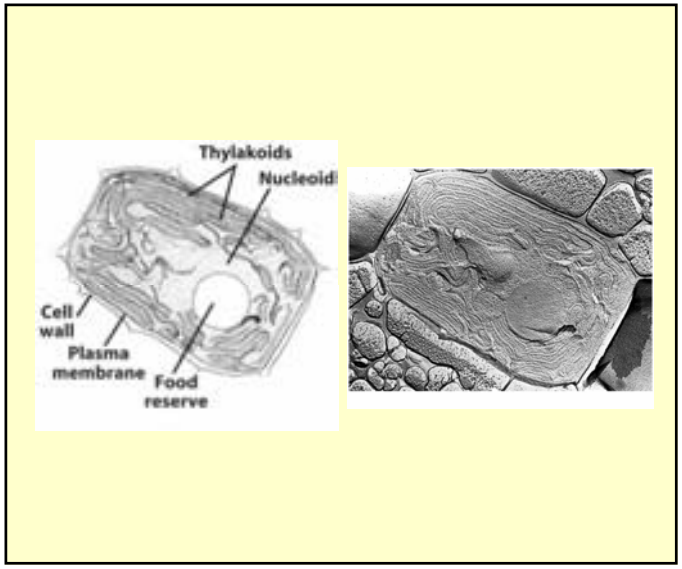


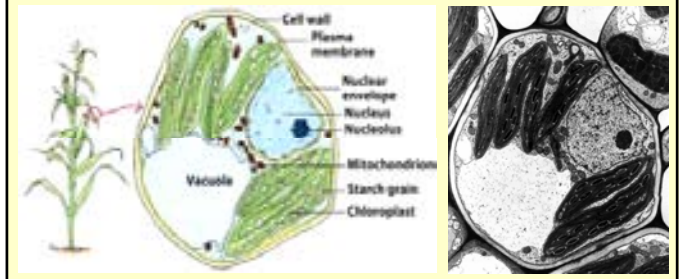







Eucarya
Animals
Entamoebae
Slime molds
Fungi
Plants
Ciliates
Archaea
Bacteria
Green non-sulfur bacteria
Euryarchaeota
Methanosarcina
Crenarchaeota
Halobacterium
Gram positives
Purple bacteria
Methanobacterium
Methano-coccus
Thermoproteus
Pyrodictium
Cyanobacteria
Flavobacteria
Thermotogales
Flagellates
Trichomonads
Diplomonads
Microsporidia
Most recent common ancestor of all living organisms

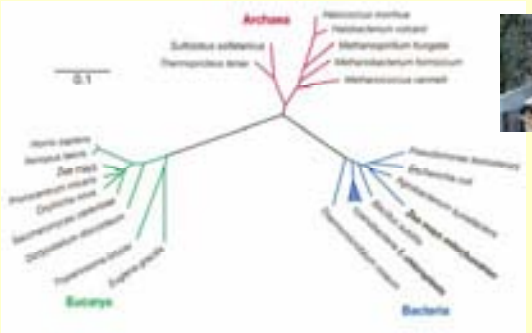

Thylakoids
Nucleoid
Cell wall
Plasma membrane
Food reserve

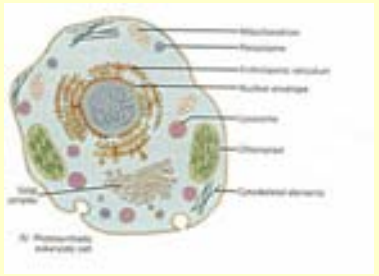

Cell wall
Plasma membrane
Nuclear envelope
Nucleus
Nucleolus
Vacuole
Mitochondrion
Starch grain
Chloroplast

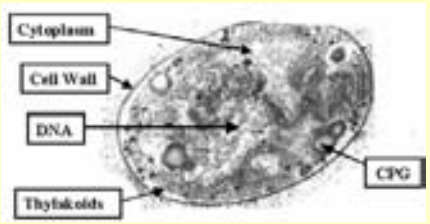
Complex eukaryotic cells are symbiotic associations

• earliest cells were mergers of archaean and bacterial genomes (discovered very recently)

• mitochondria and plastids arose by endosymbiosis (an old idea confirmed by studies done by Lynn Margulis)





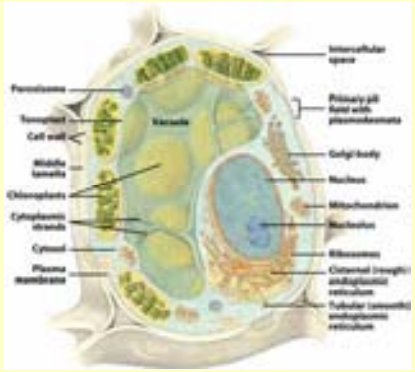


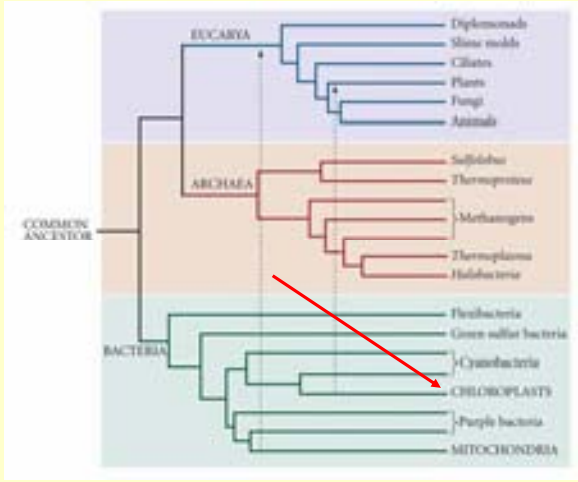
Bacterium

Mitochondrion

Ancestors of green plants (green algae) and other photosynthetic eukaryotes (brown algae, red algae, etc.) diverged from common ancestors very early (over 1 billion years ago)

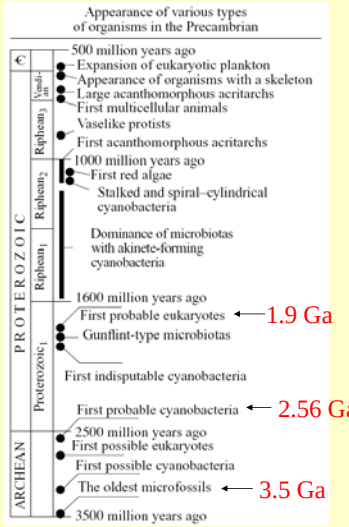
• each acquired plastids independently





Based on molecular data (and some fossil evidence):

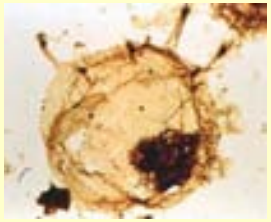
- cyanobacteria origin at 2.56 billion years ago (Ga)
- eukaryotes originate at around the same time (fossils at 1.9 Ga)
- "Great Oxidation Event" (mass extinction) 2.3 Ga
- mitochondrial symbiosis at 1.85 Ga
- plastid endosymbiosis at 1.5 Ga



- Oxygen produced by photosynthetic cyanobacteria changed the atmosphere from reducing to oxidizing
  - rocks older than about 2.3 bya have reduced forms of iron, sulfur, etc.
  - younger have oxidized forms
  - would have led to an enormous mass extinction

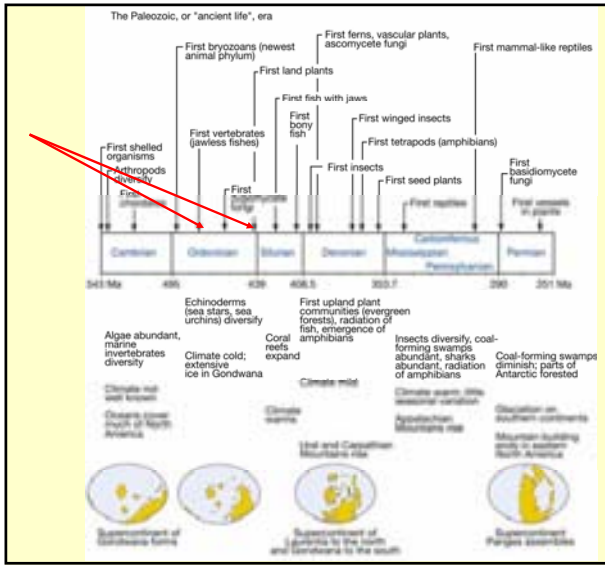
Fossil microorganisms both prokaryotic and eukaryotic

- bacterial fossils similar in appearance to present-day bacteria (fig of cyanobacteria)
- eukaryotes found in 1.5 by fossils (red algae at 1.2 by)
- molecular data suggest a much earlier origin
- both prokaryotes and eukaryotes remain unicellular for a billion years (so multicellularity is hardly an inevitability)



Multicellular life forms in fossils date from the Precambrian

- ~ 630 mya
- soft-bodied animals
- Cambrian animals a little later (550 mya)



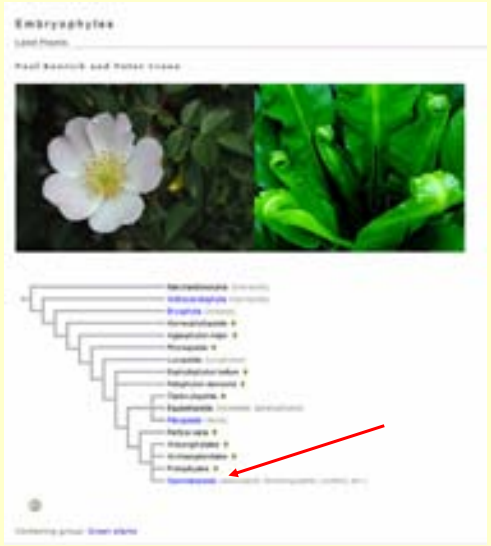
First land plants

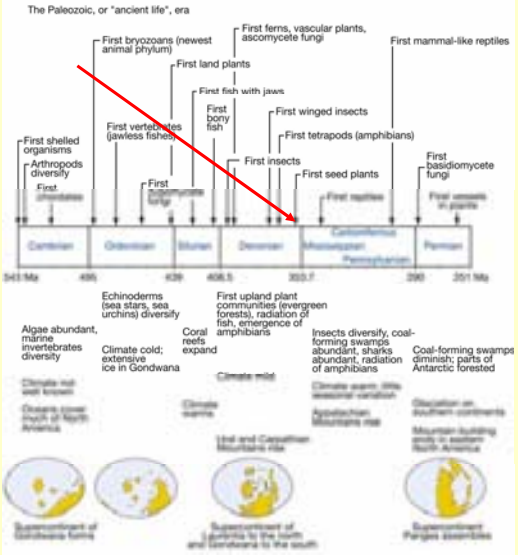
- earliest land plants represented by spores and sporangium fragments date from 470 mya
- macrofossil plants in fossil record (*Cooksonia*) date from 430 mya)

- conductive tissues of some sort (earliest ones were similar to mosses, with hydroids and leptoids)
- required water for fertilization (plant 'amphibians')
- most similar to present-day mosses, liverworts and ferns

Carboniferous landscapes dominated by seedless vascular plants (ferns and lycophytes)

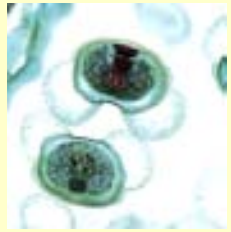
- remains mined today as coal
- present-day diversity is low, except for the ferns

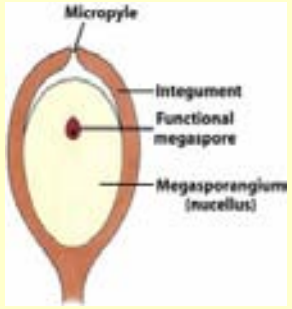


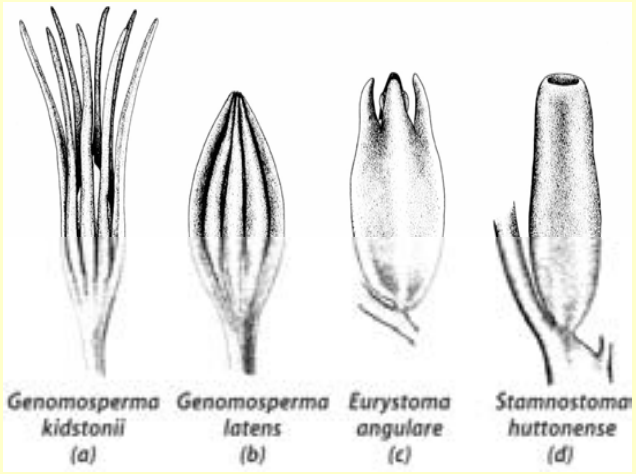


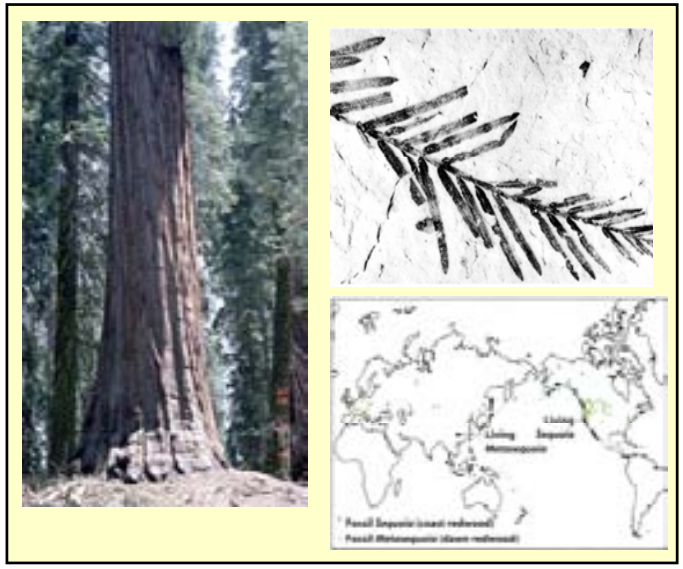
Seed plants first seen in the late Devonian

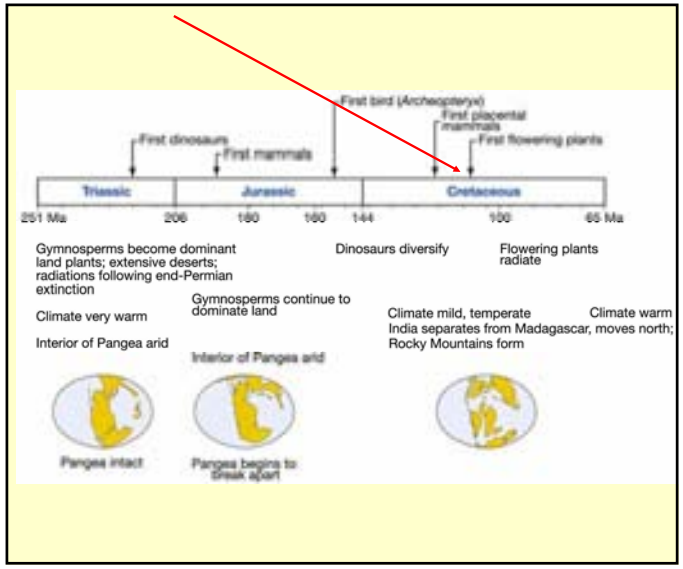
- air-transported pollen grains
- internal fertilization
- covered ovule, which develops into a seed
- no need for liquid water for fertilization
- biologically equivalent to 'reptiles' (amniotes)

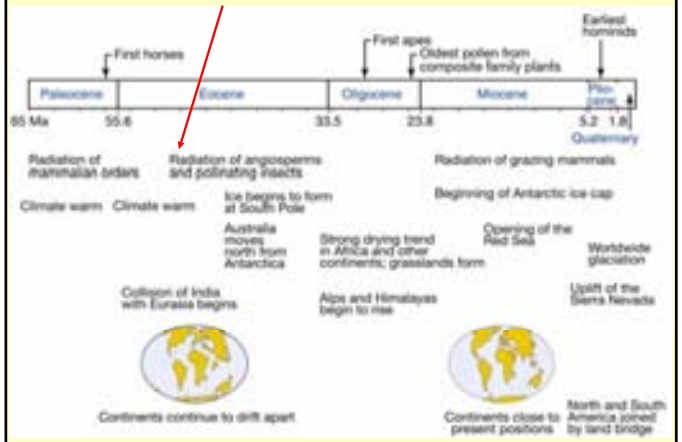






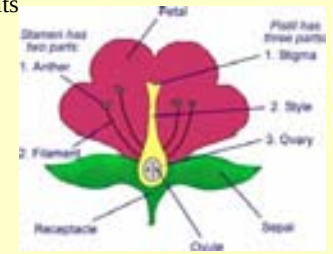


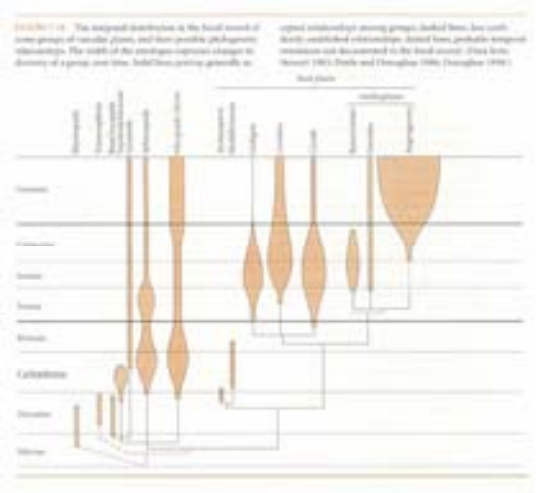

First bird (Archaeopteryx)
First placental mammals
First dinosaurs
First mammals
First flowering plants
Triassic
Jurassic
Cretaceous
251 Ma
206
180
160
144
100
65 Ma
Gymnosperms become dominant land plants; extensive deserts; radiations following end-Permian extinction
Dinosaurs diversify
Flowering plants radiate
Gymnosperms continue to dominate land
Climate very warm
Interior of Pangea arid
Climate mild, temperate
India separates from Madagascar, moves north; Rocky Mountains form
Climate warm
Interior of Pangea arid
Pangea intact
Pangea begins to break apart



First flowering plants seen in the Cretaceous (125 mya)

- flowers modified from shoot apices produce fused microsporangia (stamens) and ovules inside an ovary
- double fertilization (also seen in some gymnosperms)
- seeds develop inside fruits





1. What are plants?
2. When do the first ‘plants’ appear on the planet?
3. What is the significance of plants to the history of life on the planet?
4. When do these grade-level groups of ‘plants’ appear?
   - Cyanobacteria
   - Green algae
   - Vascular land plants
   - Seed plants
   - Flowering plants