

BROAD PATTERNS OF EVOLUTION

Evolution occurs at the population level, evolutionary impact of natural selection is seen in how a population changes over time.

THE EVOLUTION OF POPULATIONS

evolution changes in allele frequency

allele (all add up to 1)

frequency

population group individuals of the same species that live in the same area & interbreed to produce fertile offspring

genetic variation differences in genen composition

sources of genetic variation *sexual reproduction*

mutation (change in nucleotide sequence)

point mutations (single nucleotide change) ex. sickle-cell

delete, disrupt, duplicate, rearrange loci

genetic variation is required for evolution, but does not guarantee a population will

CHANGE IN ALLELE FREQUENCY

	effect on allele frequency	causes
genetic drift	unpredictable fluctuation of alleles, reduces genetic variation, can limit natural selection	founder effect, pop. bottleneck
founder effect	few individuals isolated, diff. allele frequencies in small founder pop.	chance

CHANGE IN ALLELE FREQUENCY (cont)

bottleneck effect	reduced genetic variation and increased frequency of harmful alleles	sudden environmental change
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3 mechanisms change allele frequency = genetic drift, gene flow, natural selection (consistent adaptive evolution)

SEXUAL SELECTION

what is it? individuals w certain characteristics are more likely to find mates

sexual dimorphism marked differences between sexes (ex. pavo real)

intrasexual selection selection within same sex for mates

intersexual selection one sex is choosy with mates

sexual selection is natural selection for mating success

NATURAL SELECTION MODES

directional conditions favor individuals at one end of the phenotypic range

disruptive conditions favor individuals at both extremes of phenotypic range

stabilizing conditions favor intermediate variants

*natural selection **consistently** causes adaptive evolution by acting on phenotypes*

Hardy-Weinberg Principle: Equilibrium Population

condition	consequence if condition is not kept
1. no mutations	gene pool is modified
2. **random mating	inbreeding = no random mixing of gametes, genotype frequencies change

Hardy-Weinberg Principle: Equilibrium Population (cont)

- 3. **no natural selection** allele frequencies change
- 4. **very large pop. size** in small pop. allele frequencies change by chance (*genetic drift*)
- 5. **no gene flow** gene flow can alter allele frequencies

CAUSES OF EVOLUTION

Causes of Evolution	
Process	Consequence
Mutation	Creates new alleles; increases variability
Gene flow	Increases similarity of different populations
Genetic drift	Causes random change of allele frequencies; can eliminate alleles
Nonrandom mating	Changes genotype frequencies, but not allele frequencies
Natural and sexual selection	Increases frequency of favored alleles; produces adaptations

DEFINITION OF SPECIES

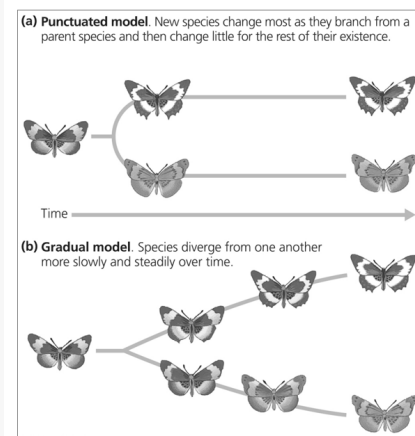
concept	defines species by
biological	reproductive compatability
reproductive isolation → new species	gene flow between populations holds gene pool together, species pop. resemble each other
<i>limitations</i>	<i>gene flow between morphologically & ecologically distinct species (ex. grolar bear)</i>
morphological	structural features
ecological	ecological niche, interactions w nonliving and living environment
<i>based on potential to interbreed, not physical similarity</i>	

THE ORIGIN OF SPECIES

speciation	one species splits into two or more species
speciation rates	range from 4,000 y to 40 million y (avg. 6.5 my)
<i>allopatric</i>	geographically isolated populations
	population -gene flow interrupted→ subpopulation
	mutation, genetic drift, natural selection, reproductive isolation
reproductive isolation	can't breed bc of differences
behavioral isolation	prezygotic barrier, specific mates
<i>sympatric</i>	population (no geographic barrier)→ new species
	reproductive barrier, reduced gene flow
	polyploidy, habitat differentiation, sexual selection
polyploidy	extra chromosomes
	<i>auto</i> : same species <i>allo</i> : diff species
habitat differentiation	new ecological niches
sexual selection	female selecting mates
microevolution (speciation)	many speciations, extinctions → macroevolution



SPECIATION MODELS



punctuated = rapid speciation gradual = slow speciation

REPRODUCTIVE ISOLATION

reproductive barriers depend on environmental & genetic factors

Prezygotic Barriers prevent mating between species

geographical physical barrier (rivers, mountains)

habitat/ecological same area, diff habitats

temporal diff breeding times

behavioral unique courtship rituals

mechanical morphological diff

gametic cannot fertilize

Postzygotic Barriers prevent a viable, fertile hybrid

REPRODUCTIVE ISOLATION (cont)

reduced hybrid viability poor development/survival

reduced hybrid fertility fertile hybrid

hybrid breakdown infertile 2nd gen

Hybrid Zones diff species mate, incomplete reproductive barriers

*novel genetic variation outcomes = **

reinforcement hybrids cease ← hybrids less fit

fusion two species fuse ← weakened rep. barriers

stability continued hybrids ← hybrids equally fit

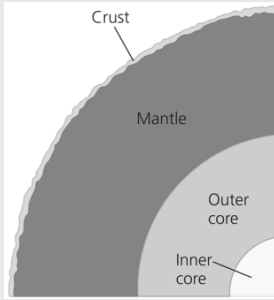
biological barriers that impede fertile offspring

THE GEOLOGIC RECORD

Table 23.1 The Geologic Record

Eon	Era	Period	Epoch	Age (Millions of Years Ago)
Phanerozoic	Cenozoic	Quaternary	Holocene	0.01
			Pleistocene	2.6
		Neogene	Pliocene	5.3
			Miocene	23
		Paleogene	Oligocene	33.9
			Eocene	56
	Mesozoic	Cretaceous	Paleocene	66
				145
			Jurassic	201
			Triassic	252
		Paleozoic	Permian	299
			Carboniferous	359
			Devonian	419
			Silurian	444
Proterozoic		Ordovician	485	
		Cambrian	541	
Archaean		Ediacaran	635	
			2,500	
Hadean			4,000	
			Approx. 4,600	

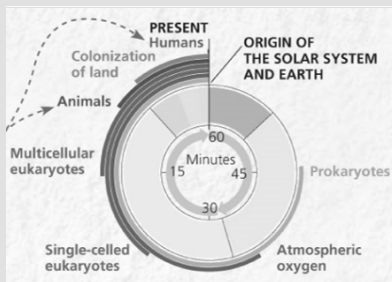
TECTONIC PLATES THEORY



continents are part of plates of Earth's crust, floating on hot mantle

3 occasions (1 billion, 600 million, and 250 million years ago) when most of the landmasses of earth came together to form a supercontinent

HISTORY OF EARTH



FOSSILS

fossils are the traces of ancient life, naturally preserved, but an incomplete chronicle of evolution

macroevolution evolution above the species level, *interspecific variation*

microevolution evolutionary change in allele frequencies in a population over generations, *intraspecific variation*

favor species that existed for a long time, were abundant/widespread, had hard shells, skeletons

FOSSIL FORMATION

Formation of stratum with Fossils

- Stratum (plural strata) is a rock layer which is formed when new layers of sediment cover older ones and compress them
- Many fossils are found in sedimentary rock layers (strata), because such rock forms in areas sediment moved by water can cause the burial of organisms

① Rivers carry sediment into aquatic habitats such as seas and swamps. Over time, sedimentary rock layers (strata) form under water. Some strata contain fossils.

② As water levels change and geological activity pushes layers of rock upward, the strata and their fossils are exposed.

Younger stratum with more recent fossils
Older stratum with older fossils

FOSSIL DATING

relative age determined by rock strata sequence

younger stratum has more recent fossils older stratum has older fossils

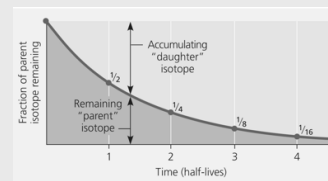
absolute age determine through radiometric dating

radioactive "parent" isotope decays to "daughter" isotope at a constant rate

half-life

known time required for half parent isotope to decay

RADIOMETRIC DATING



If the half-life of carbon-14 is about 5,730 years, then a fossil that has 1/8th the normal proportion of carbon-14 to carbon-12 should be about how many years old? $5730 \text{ Years} \times 3 = 17190 \text{ years}$

CREATIONS ACCORDING TO FOSSILS

earliest **prokaryote** fossils (ARCHAEAN EON) form *stromatolites* dating back 3.5 BYA, sole inhabitants for 1.5 BY

increase in **atmospheric oxygen** 2.7 BYA



CREATIONS ACCORDING TO FOSSILS (cont)

cyanobacteria, other photosynthesizers	led to extinction of many
earliest eukaryote fossils (PROTEROZOIC EON)	1.8 BYA, gave rise to multicellular organisms
jawed vertebrates (PHANEROZOIC EON)	440 MYA
Cambrain explosion (535-525 mya)	+diversity, unique mammalian features
tetrapods (PALOZOIC ERA)	375 MYA colonized land
mammals	120 MYA, from synapsids

MASS EXTINCTIONS

can be caused by:

Habitat destruction and/or unfavorable environmental change

Biological causes (factors)-Origin of one new species can spell doom for another

Permian Mass Extinction (252mya) 96% marine life when extinct due to intense volcanisms
Paleozoic to Mesozoic era

Cretaceous Mass Extinction (66mya) +50% of all marine animals, many terrestrial plants and animals, dinosaurs (except birds) due to meteorite
Mesozoic to Cenozoic era

5-10 million years for diversity to recover

mass extinctions alter ecological communities and remove lineages, forever change the course of evolution and can also pave the way for *adaptive radiations*

ADAPTIVE RADIATION

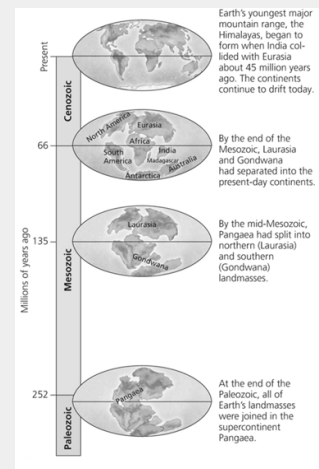
the evolution of many diversely adapted species from a common ancestor that allows new species to occupy different habitats

may follow: mass extinctions ex. mammals after extinction of dinosaurs

evolution of novel characteristics ex. rise of photosynthetic organisms

colonization of new regions organisms colonize new environments with little competition

CONTINENTAL DRIFT DURING PHANEROZOIC EON



Pangea (250 mya), organisms adapt (speciation) or go extinct

when continents drift can result in *allopatric speciation*

GENETIC MECHANISMS

developmental genes program development, influence rate, timing, spatial patterns

heterochrony evolutionary change in the rate or timing of developmental events ex. human vs chimpanzee jaw

GENETIC MECHANISMS (cont)

homeotic genes determine the organization of basic features

hox genes a class of homeotic genes, provide positional information during animal development

evolutionary novelties changes at the genetic level lead to developmental changes at the phenotypic level

exaptations structures that originally played one role but gradually acquired a different role ex. bird feathers

EUKARYOTES ARE "COMBINATION" ORGANISMS

Table 25.1 Inferred Origins of Key Eukaryotic Features

Feature	Original Source
DNA replication enzymes	Archaeal
Transcription enzymes	Archaeal
Translation enzymes	Mostly archaeal
Cell division apparatus	Mostly archaeal
Endoplasmic reticulum	Archaeal and bacterial
Mitochondrion	Bacterial
Metabolic genes	Mostly bacterial

consequence of endosymbiosis

PROTIST

is any eukaryotic organism that is not an animal, plant, or fungus

first eukaryote was a unicellular protist and most eukaryotes are protists

structural and functional diversity, most are aquatic, most are unicellular

complex at the cellular level, though simple when compared to eukaryotes

PROTIST (cont)

nutritional *photoautotroph* = producers (photosynthetic)

diversity: use energy from light (or inorganic chemicals) to convert CO₂ to organic compounds

heterotroph = consumers

parasites =

mixotroph =

photosynthetic protists *main producers in aquatic community*
biomass of photosynthetic protists is limited by the availability of nitrogen, phosphorus, or iron
diatoms, dinoflagellates, multicellular algae, others
blooms dramatic increase in abundance

symbiotic protists some are parasites that harm their hosts
ex. photosynthetic dinoflagellates provide food for coral reefs
ex. wood-digesting protists break down cellulose in the guts of termites

effect on human health

trypanosoma = excavate that causes sleeping sickness

apicomplexans = alveolate parasites
ex. plasmodium - causes malaria

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ORIGINS OF COMPLEX MULTICELLULARITY

multicellular colonies collections of connected cells, little to no differentiation, can be simple or complex

Multicellular organisms with differentiated cells likely originated from multiple different ancestors

1. origin of cyanobacteria
2. origin of mitochondria
3. origin of plastid (chloroplast)
4. origin of multicellular eukaryotes
5. origin of fungal-plant symbioses

EUKARYOTE SUPERGROUPS

Excavata (unicellular protists)

- **diplomonads; parabasalids** — lack plastids, cannot do photosynthesis, reduced mitochondria, mostly anaerobic
- **euglenozoans** — most have 2 flagella, diverse, include predatory heterotrophs, photoautotrophs, parasites
ex. trypanosoma - parasitic infection that causes sleeping sickness

SAR (Stramenopiles, Alveolates, Rhizarians)

includes most important photosynthetic organisms)





- **diatoms** — diverse photosynthetic unicellular algae can affect
- **brown algae (seaweed)** — largest & most complex, multicellular, mostly marine
brown due to carotenoids in plastid
anchored by *holdfast*, stem-like *stipe* supporting leaflike *blades*

EUKARYOTE SUPERGROUPS (cont)

Archaeplastids

- **red algae** — 2nd largest, mostly multicellular, can absorb green & blue light
red due to phycoerythrin pigment
- **green algae** — very similar to land plants, some are unicellular
 - ↳ **chlorophytes** — marine, terrestrial, mostly freshwater, multicellular, unicellular (free or symbiotic)
 - ↳ **charophytes** — most closely related to land plants
- **plants**
chloroplasts of land plants *cyanobacteria* → *green algae* → *land plants*

EUKARYOTE SUPERGROUPS

Supergroup	Major Clades	Specific Example
Excavata	Diplomonads, parabasalids, euglenozoans	<i>Euglena</i> 
SAR	Stramenopiles, alveolates, rhizarians	<i>Plasmodium</i> 
Archaeplastida	Red algae, green algae, plants	<i>Chlamydomonas</i> 
Unikonta	Amoebozoans, opisthokonts	<i>Amoeba</i> 

DIVERSIFICATION OF EUKARYOTES

eukaryotes

- a) plants
- b) animals
- c) fungi, molds, mushrooms, yeast
- d) protists

early eukaryotes date back *2.7 billion years ago*
unicellular, with nucleus, membrane, cytoskeleton, varied size & shape

diverse eukaryotes 1.8 billion years ago
novel biological features evolved: multicellularity, sexual life cycles, eukaryotic photosynthesis

DIVERSITIFICATION OF EUKARYOTES (cont)

large eukaryotes 635-541 million years ago (Ediacaran period) *soft-bodied* organisms
hard-bodied organisms 535-525 mya (Cambrian explosion)

ORIGIN OF MITOCHONDRIA & PLASTIDS

plastid membrane-bound organelle (plants, algae, others)
ex. chloroplast

endosymbiont theory mitochondria and plastids were formerly small bacteria that began living within larger cells

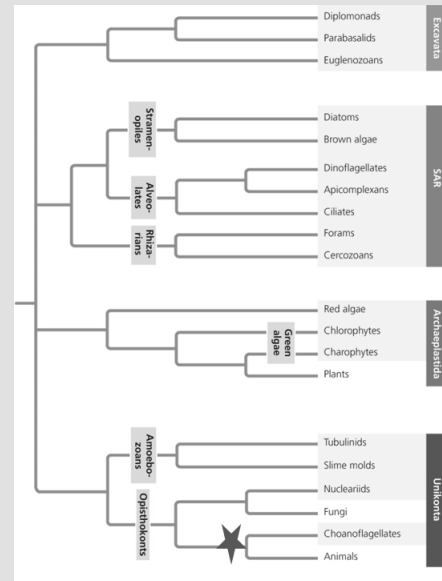
- key evidence**
- inner membranes are similar (transport proteins) to bacteria plasma membrane
 - replication is similar to bacteria cell division
 - have circular DNA like bacteria
 - transcribe/translate own DNA into proteins
 - ribosomes more similar to bacterial than eukaryotic

mitochondria come from a single *proteobacterium* ancestor which could do aerobic respiration using O₂ to make ATP

plastids come from a single *cyanobacterium* ancestor that could do photosynthesis

ALL eukaryotes have mitochondria, not many have plastids
anaerobic host cells may have benefited from aerobic endosymbionts as oxygen increased in the atmosphere

EUKARYOTIC DIVERSITY (PHYLOGENETIC TREE)



(protists are yellow) \

THE GREENING OF EARTH

- +4 billion years ago Earth was created, lifeless for the first 2 billion years
- 1.2 billion years ago cyanobacteria & protists
- +470 million years ago plants colonized land
- 500 million years ago plants, fungi, & animals moved to land
- 385 million years ago first forests



PLANTS

ancestors red, green, & brown algae
 multicellular
 eukaryotes
 photosynthetic autotrophs
 cellulose cell walls
 chloroplasts (chlorophyll a & b)
 modernly only **charophytes** share most traits w plants

chloroplasts of land plants cyanobacteria → green algae (charophytes) → land plants

moving to land... evolution of: **sporopollenin** — protective polymer surrounding charophyte zygotes → dry land
 BENEFITS: unfiltered sunlight, plenty CO₂, nutrient-rich soil
 CHALLENGES: scarcity of water, lack of support against gravity

key traits in plants not found in charophytes

- alternation of generations
- multicellular, dependent embryos
- walled spores produced in sporangia
- apical meristems

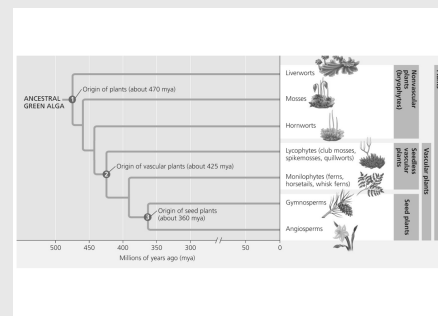
PLANTS (cont)

apical meristems — localized regions of cell division @ tips of roots & shoots, mitotic division = + mineral & nutrients

derived traits • cuticle — waxy coating, prevents water loss
 • stomata — specialized pores, CO₂-O₂ exchange

plants affect soil formation, roots stabilize soil and are nutrients when they decay, 50% atmospheric O₂

HIGHLIGHTS OF PLANT EVOLUTION



PLANT CLASSIFICATION

vascular plants vascular tissue for H₂O/nutrient transport

- **xylem** - conducts most H₂O/minerals (*tracheids* have lignin = water-conducting cells, provide structural support)
- **phloem** - tubes of cells, distribute sugars, amino acids, other org. prod
- **lignin** = polymer that makes plants rigid, allowing them to grow tall



PLANT CLASSIFICATION (cont)

nonvascular plants

- bryophytes lack vascular tissue
- **rhizoids** - root-like anchor
- **gametophytes** = larger, live longer than sporophytes
- mature **sporophyte** fully depends on gametophyte for nutrition
- limited to moist habitats
- *liverworts*
- *mosses*
- *hornworts*

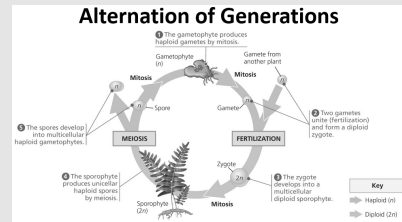
seedless vascular

- *early vascular plants
- **sporophytes** = large/more complex gen.
- *gametophyte* & *sporophyte* are independent
- sperm swims through water to egg (like bryophytes)
- *lycophytes (club mosses)*
- *monilophytes (ferns)*

seed plants

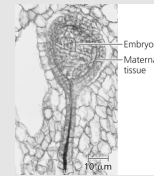
- *reduced gametophytes, ovules, pollen
- **seed** = embryo + food supply + protective coat
- *gymnosperms* = *naked seeds*
- *angiosperms* = *enclosed seeds in ovaries* (flowers & fruits)

ALTERNATIONS OF GENERATIONS



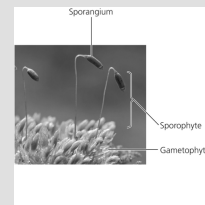
gametophyte generation is *haploid* and produces *haploid* gametes by mitosis
fusion of sperm+egg creates **diploid sporophyte** and produces *haploid* spores by meiosis

MULTICELLULAR, DEPENDENT EMBRYOS



embryo within female gametophyte tissue, placental transfer cells → nutrients
embryophytes —embryo dependent on parent plant

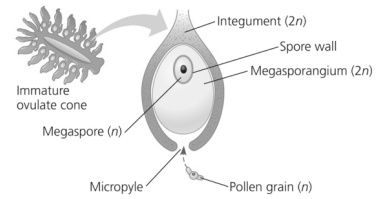
WALLED SPORES PRODUCED IN SPORANGIA



sporangia— multicellular organs that produce spores
sporopollenin (strong polymer) —in walls, resistant to harsh environments

OVULATE CONE

In seeded plants, gametophytes develop from spores that are retained within tissues of the parent sporophyte



(a) Unfertilized ovule. In this longitudinal section through the ovule of a pine (a gymnosperm), a fleshy megasporangium is surrounded by a protective layer of tissue called an integument. The micropyle, the only opening through the integument, allows entry of a pollen grain.

ovule= *megaspore* (haploid spore → female gametophyte) +
protective layer(integument)

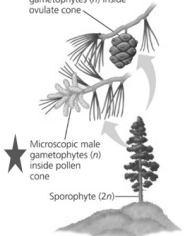
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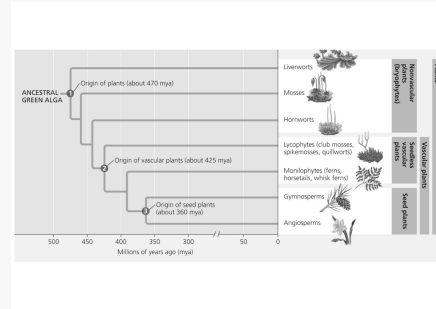
POLLEN CONE

Seed plants (gymnosperms and angiosperms)	
Gametophyte	Reduced (usually microscopic), dependent on surrounding sporophyte tissue for nutrition
Sporophyte	Dominant
Example	<p>Gymnosperm</p> <p>Microscopic female gametophytes (n) inside ovulate cone</p>  <p>Microscopic male gametophytes (n) inside pollen cone</p> <p>Sporophyte (2n)</p>

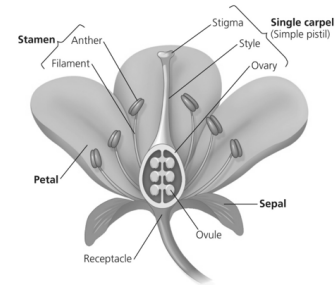
pollen grain = *microspores* (haploid spores → male gametophyte) + *protective wall* (w/ sporopollenin)

**pollination - transfer of pollen to seed plant's ovules

EVOLUTION OF ROOTS & LEAVES



FLOWERS & FRUITS



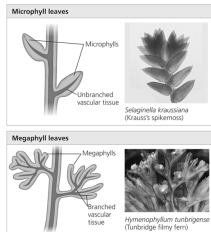
stamen = *filament* (stalk) + *anther* (sac produces pollen)

carpel = ovary (@ base) + style + stigma (where pollen is received)

ovary - 1/+ ovules

EVOLUTION OF ROOTS & LEAVES

- Roots anchor vascular plants and enable them to absorb water and nutrients from the soil
- Leaves are the primary photosynthetic organ of vascular plants
 - Microphylls, small leaves with a single vein
 - Megaphylls, larger, more productive leaves with a highly branched vascular system



FUNGI

oldest fossils 460 million years ago, terrestrial

heterotrophs that feed by absorption

FEED BY ABSORPTION secrete hydrolytic enzymes to break down complex molecules → small org. comp

chitin cell walls

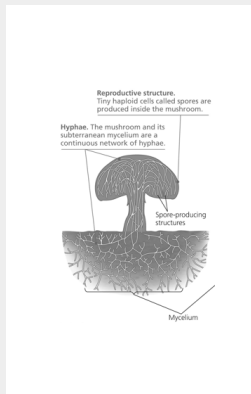
diversification •mold (multicellular)
•yeast (unicellular)

life cycles & reproduction •most propagate by producing many spores, sexually or asexually

key role in land plant colonization symbiotic interactions...

fungi/other decomposers (fungi/bacteria) break down dead organisms and return nutrients to physical environment

FUNGAL ADAPTATIONS TO LAND



SYMBIOTIC INTERACTIONS

mutualism benefits BOTH

plant + fungi (*endophytes*) inside leaves/other
•plant provide nutrition, some endophytes make toxins that deter herbivores/pathogens

parasitism benefits one, harms other

fungi absorb nutrients from host cells

lichen *photosynthetic microorganism*(algae/cyanobacteria)-*fungus*

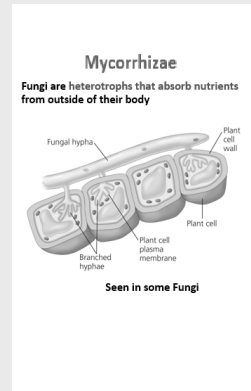
•fungi benefit from carbs produced by algae/cyanobacteria
•microorganism is protected by fungal filaments, gather moisture/nutrients

lichens break down surface & promote soil formation so plants can grow, on land 420 mya

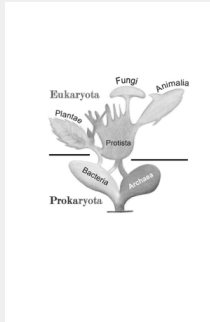
mycorrhizae *plant-fungal*— fungal hyphae transfer nutrients (phosphate/others) to plant

earliest land plants *lacked true roots/leaves*

MYCORRHIZAE

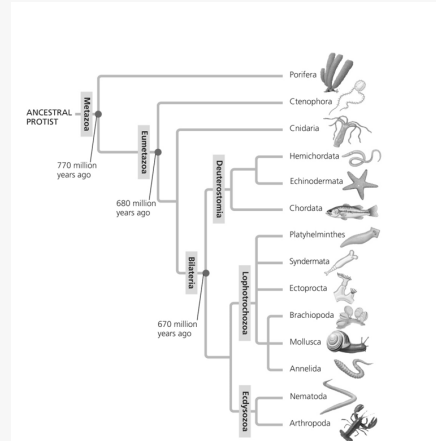


THE RISE OF ANIMAL DIVERSITY



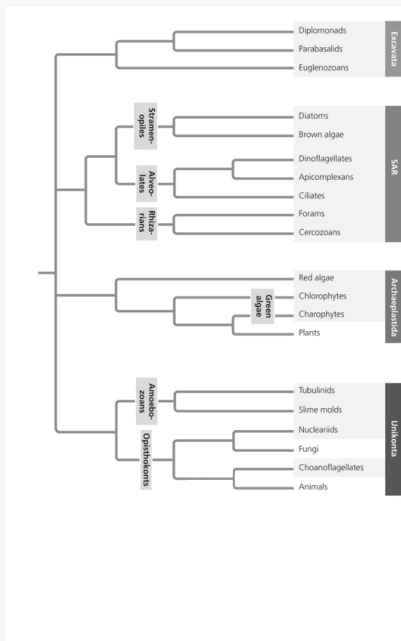
all animals (*metazoa*) share a common ancestor and likely evolve from multiple single-celled eukaryotes (*protist*)

DIVERSIFICATION OF ANIMALS



- ① all animals share a common ancestor
- ② sponges are sister group to ALL other animals
- ③ eumetazoa = animals with tissues
- ④ most animal phyla belong to Bilaterian clade
- ⑤ most animals are invertebrates

EUKARYOTIC SUPERGROUPS



sponges and choanoflagellates' (protists) similarities = animals evolved from choanoflagellate-like ancestor over 700 millions years ago

EARLY-DIVERGING ANIMAL GROUPS

sponges & cnidarians diverged from all other animals early on

- sponges (PORIFERA)**
- *basal animals*
 - lack true tissues
 - filter feeders: capture small particles in water water is drawn through pores into central cavity and flows out through an opening at the top

ANIMALS WITH TISSUES

eumetazoans "true animals" = tissues
include have symmetrical bodies
cnidarians and (radial or bilateral)
all others

- radial symmetry - single, central axis
most animals are sessile{nl}>>2 embryonic tissue layers
cnidarians (jellyfish, anemones) →endoderm
→ectoderm

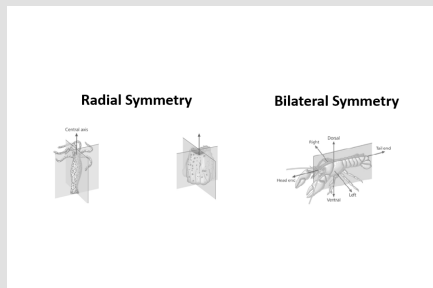
- bilateral symmetry - 2 axes
animals that move actively
>3 germ layers
→endoderm
→ectoderm
→mesoderm

cnidarians tissues + radial symmetry, blind digestive system, carnivores, lack brain/muscles, nerve net (simplest)

chordata bilaterians, vertebrates, complete digestive tract

bilateral invertebrates 95% animals

EUMATOZOAN SYMMETRY



BODY CAVITIES

most bilaterians possess a **body cavity** (*coelom*) - fluid/air filled space between digestive tract & outer body wall

cushions organs, acts as hydrostatic skeleton, organs move independently of body wall

