Evolution

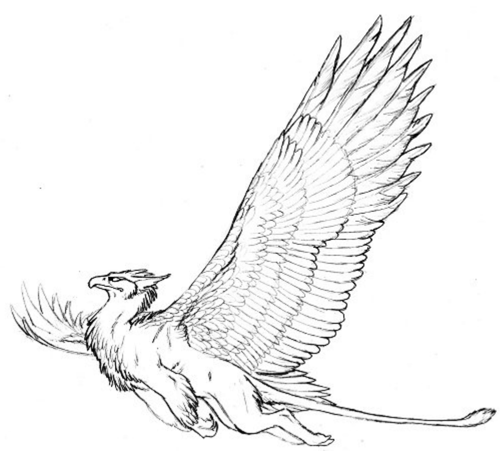
- Macroevolution: the history of origin and diversification of life over time
- Microevolution: change in the frequency of alleles in a population over generations
- The mechanisms by which these changes occur
- Study of evolution began with classification of biodiversity

Biological classification

- Carol Linnaeus (von Linne') 1707-1778
- Binomial nomenclature
- Linnaean hierarchy *species*-*genera*-families-*orders*-*classes*-phyla-*kingdoms*
- *Systema Naturae*

Linnaean Gardens at Uppsala Sweden

Classification showed that biological diversity was not chaotic



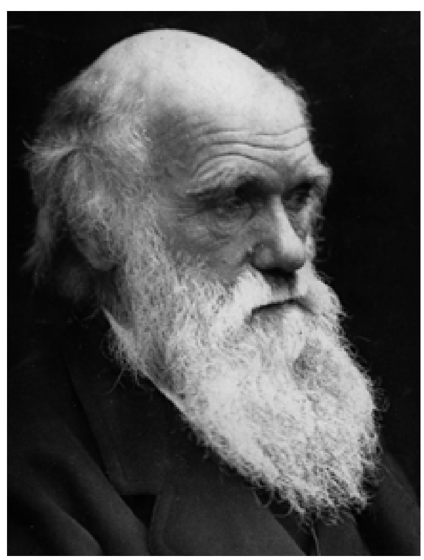
griffin *or* **griffon**
Date: 14th century

A mythical animal typically having the head, forepart, and wings of an eagle and the body, hind legs, and tail of a lion

The pattern in biodiversity can be explained by descent with modification

- Inherited similarities among descendants of an ancestor are homologies
- Homologies can therefore be used to infer relatedness
- What about analogies?

Darwin in 1836 and ~1880



Charles Darwin (1809-1882)

- Brought together the evidence that organisms gradually change and diversify
- Also proposed a workable theory of evolution by natural selection
- Darwin co-authored the first publication of the idea with Alfred Russel Wallace

Evolution by natural selection

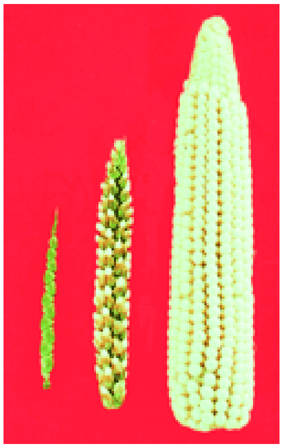
- Organisms possess heritable variations (different alleles).
- More individuals are born than will survive to reproduce.
- Some individuals are more likely to reproduce because of their heritable characteristics
- Those characteristics become more common in the next generation

- Differential reproductive success of certain individuals leads to change in allele frequency in the population
- Evolution happens to <u>populations</u>, not individuals
- Evolution can happen through artificial selection, natural selection, or by chance ("genetic drift").

Darwin's evidence

- Domesticated varieties and effects of artificial selection
- Fossil record of change over time
- Comparative anatomy and homology
- Biogeography- (including island faunas)

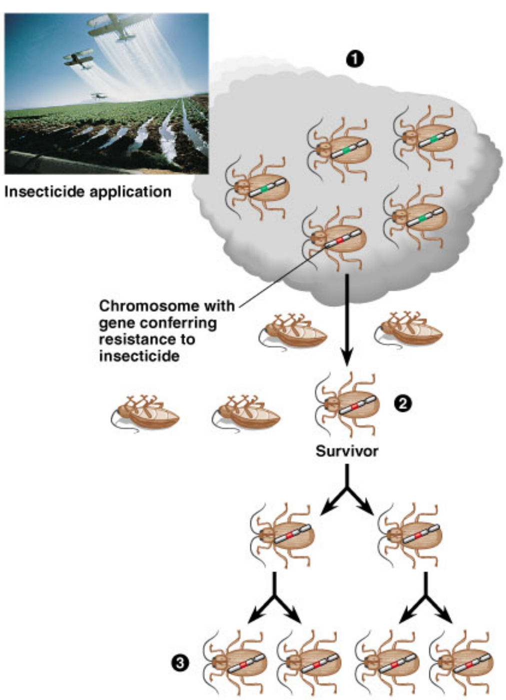
Artificial selection alters animals and plants through the same mechanism as natural selection - but is directed by man



Artificial selection: diverse vegetables derived from wild mustard

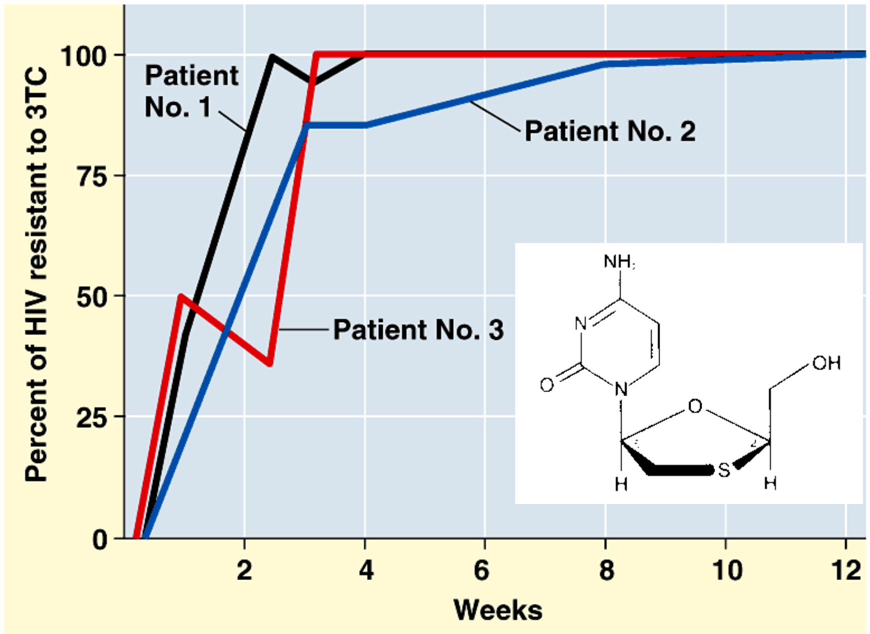
Natural selection and adaptation

- Adaptation = change to fit the environment.
- Characteristics that favor (survival and) reproduction become more common.
- Organisms can become more "perfected" but without intent, foresight, or planning.
- Compare with artificial selection.



"Natural" selection: Evolution of insecticide resistance in insect populations

Evolution of drug resistance in HIV



Population genetics & evolution

- Species
- Population
- Gene pool
- Genetic polymorphism
- Allele frequency
- Population genetics

The shallow end of the gene pool

Stability or change?

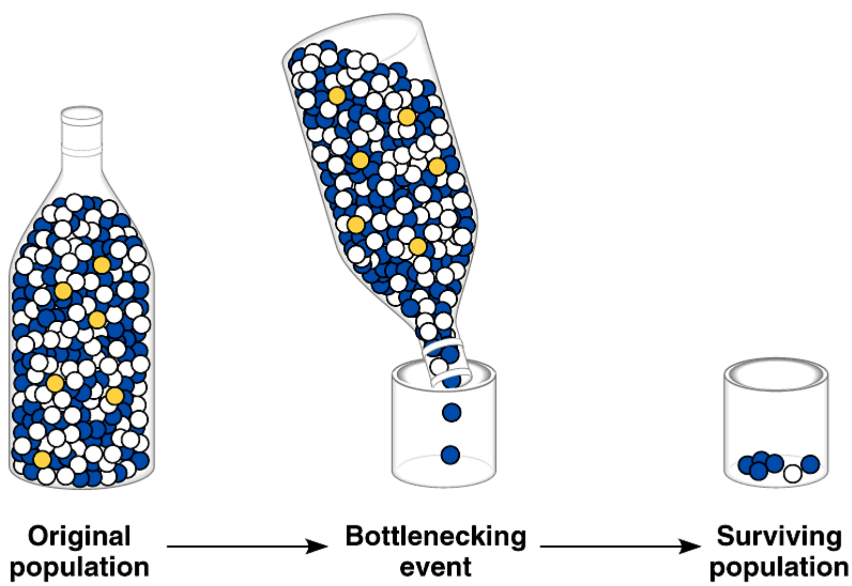
- Stability
  - If each individual has equal probability of reproducing, allele frequencies will tend to be stable.
- Evolution
  - If some genotypes reproduce more than others, allele frequencies and population characteristics will change.

Factors affecting microevolution

1. Genetic drift

- Change in the gene pool due chance (not selection)
- Bottleneck and founder effects
- Does not result in adaptation
- Effect depends on population size

Bottleneck analogy for genetic drift during near-extinction (or colonization)



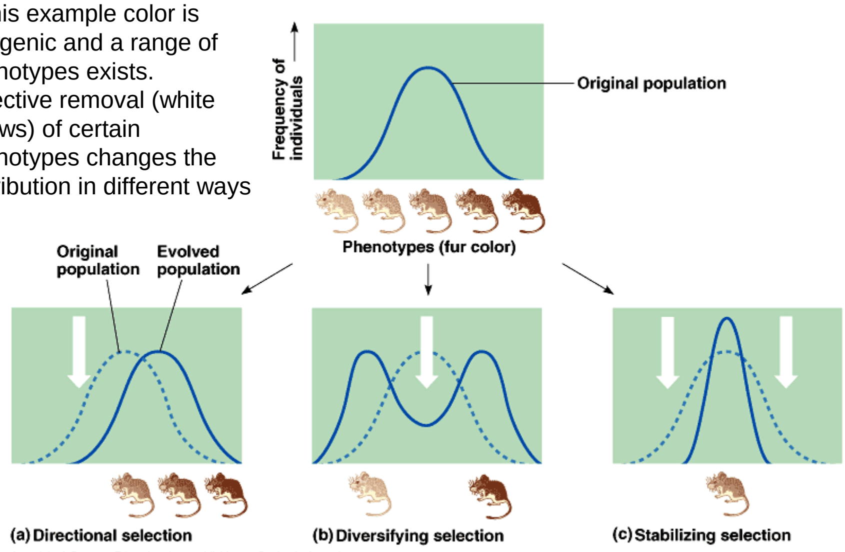
Factors affecting microevolution

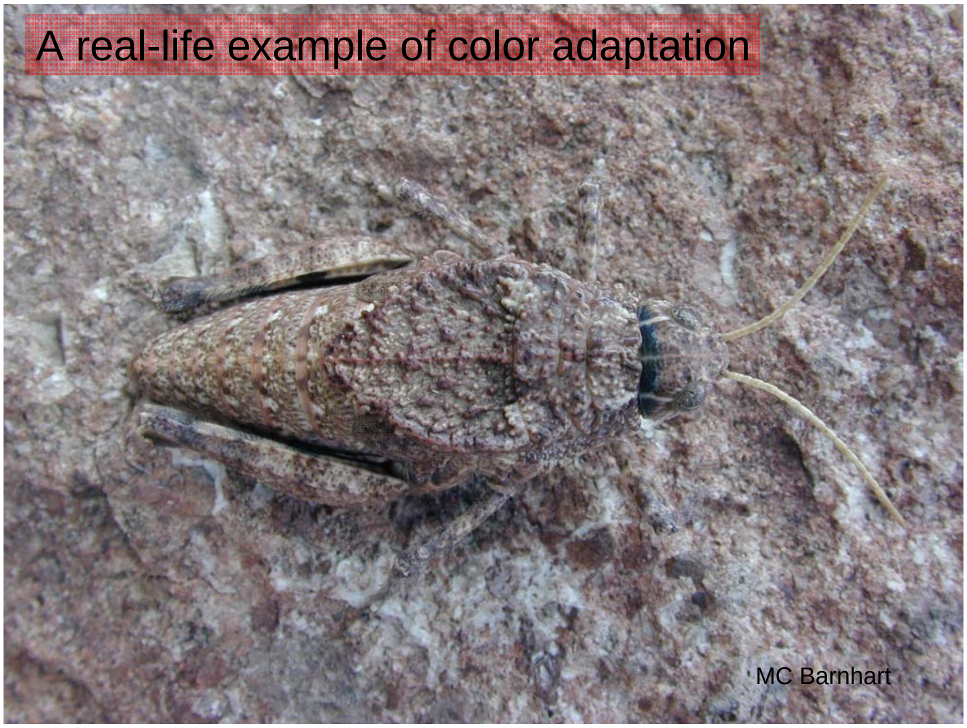
2. Selection

- Natural or artificial
- Directional
- Diversifying
- Stabilizing
- Frequency dependent
- Sexual

Possible effects of natural selection on a polygenic trait in a population

In this example color is polygenic and a range of phenotypes exists. Selective removal (white arrows) of certain phenotypes changes the distribution in different ways





Phrynotettix
(toad lubber grasshopper)

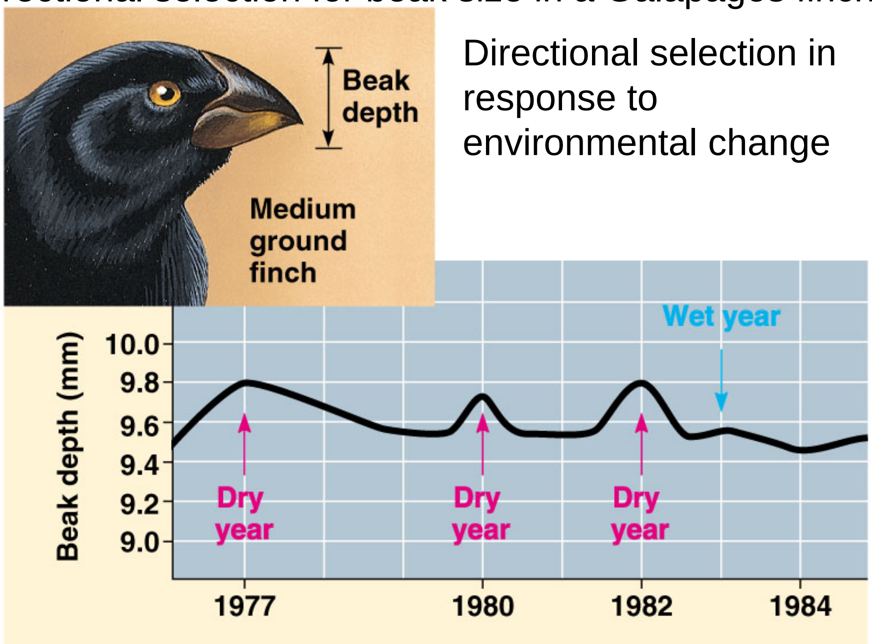
Populations in different places have different colors that match the prevailing backgrounds

Fort Huahaca

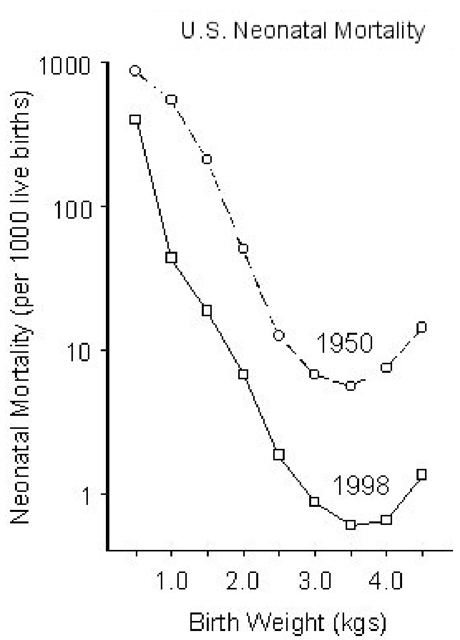
On rhyolite (at Pena Blanca)

On limestone (near Tucson)

Directional selection for beak size in a Galápagos finch

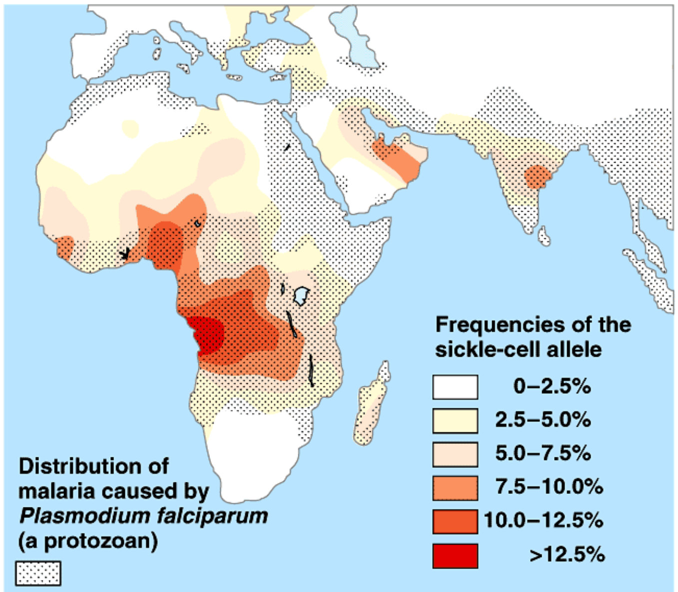


Directional selection in response to environmental change



Stabilizing selection on birth weight

Mapping malaria and the sickle-cell allele



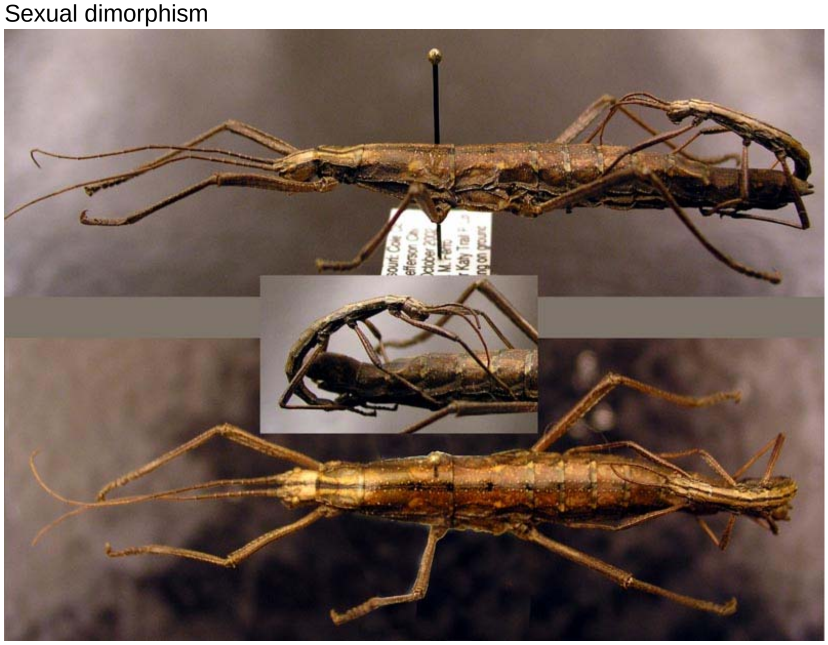
- Frequency-dependent selection
- Balanced polymorphism

Factors affecting microevolution
continued

- Sexual selection
  - Competition for mates and reproductive success within a species
  - Intrasexual competition
  - Intersexual choice
  - Leads to sexual dimorphism

Male peacock, hoping to be selected…

Sexual dimorphism



Anisomorpha ferruginea

Factors affecting microevolution
continued

3. Gene flow

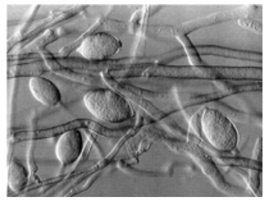
- Immigration or emigration of individuals to and from a population can alter allele frequencies and bring in new alleles

4. Mutation

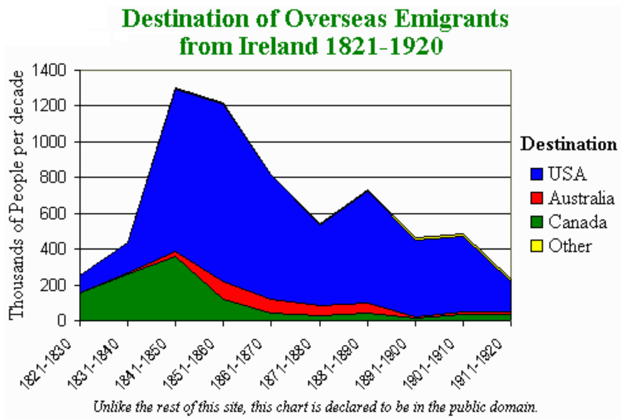
- Mutation is a source of new alleles but is unlikely to change allele frequencies because it is a rare event

Genetic polymorphism is the raw material for evolution

- Evolution requires genetic diversity
- Significance for agriculture
  - Irish potato famines
  - National Genetics Resources Program
  - Genetic prospecting of wild relatives of crops
- Management of endangered species



[Great Irish Potato famine 1845-1851]



Two kinds of evolution

Microevolution

– change of allele frequency in a population over generations

Macroevolution

– origin of species and higher taxa through microevolutionary processes and other factors

Origin of species

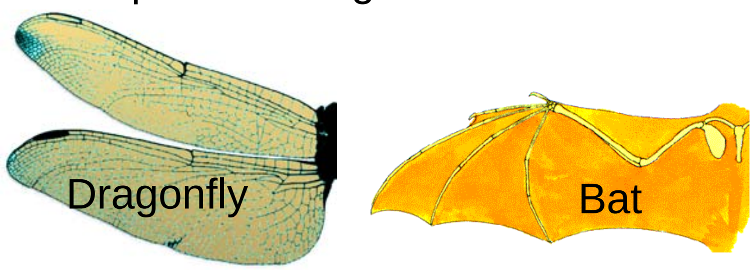
- Natural selection explains adaptation but does not necessarily explain the origin of species and higher taxa.
- Species generally do not interbreed or share alleles with one another, so each is an independent entity
- Darwin also summarized evidence that organisms had diversified and changed over time.

Homology and Analogy

- Homology:
  - two things are similar because of common origin and retention of similarity
  - they are both copies of an original (or copies of copies)
- Analogy
  - two things have different origin but have become similar.
  - They have converged

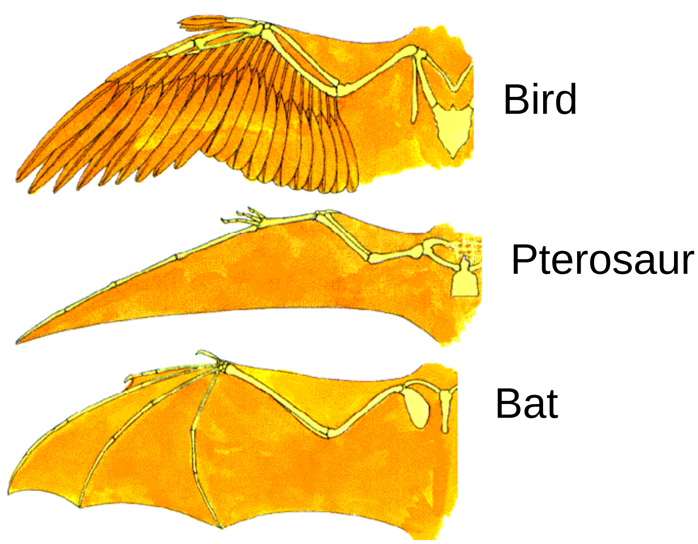
Distinguishing homology from analogy

- Homologies show similarity in details- from "the ground up", while analogies are more superficial similarities
- Example of analogous structures:



Vertebrate wings

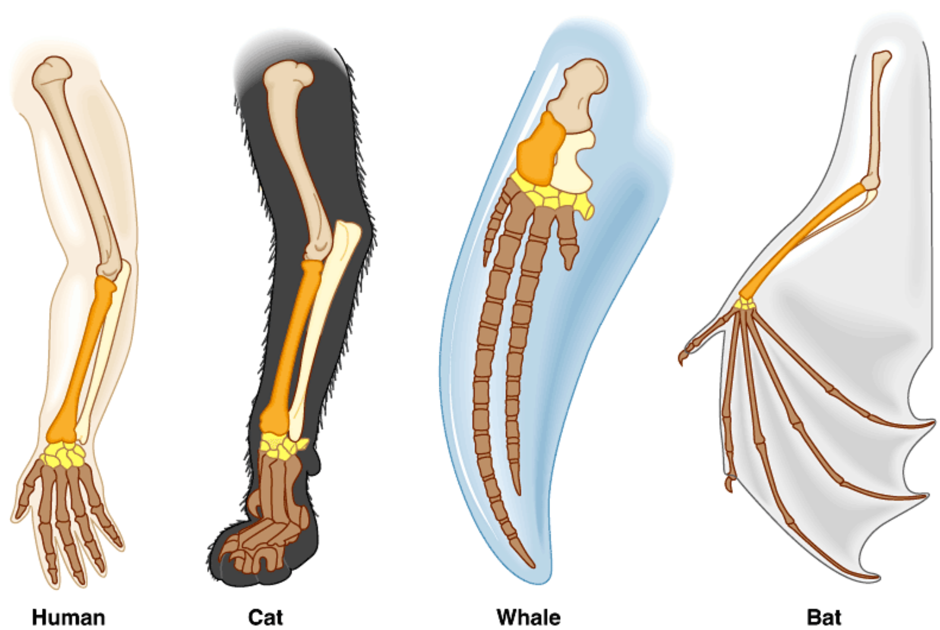
homologous limbs analogously adapted to flight



Evidence of evolution from comparative anatomy:

- Hypothesis: all vertebrates share a common ancestor.
- Prediction: all vertebrates should share certain homologies that they inherited from their shared ancestor.

Homologous structures: anatomical signs of descent



Molecular homologies

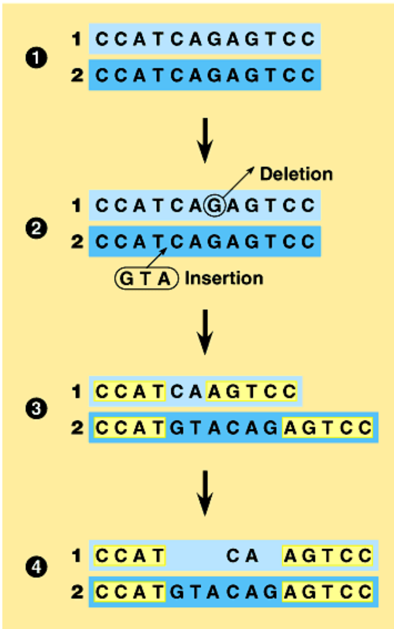
- If two genes are related by descent they should share sequence homologies
- Sequence similarity can be quantified (percent identity)
- Statistical analysis can be used to reconstruct relationships (molecular phylogeny)

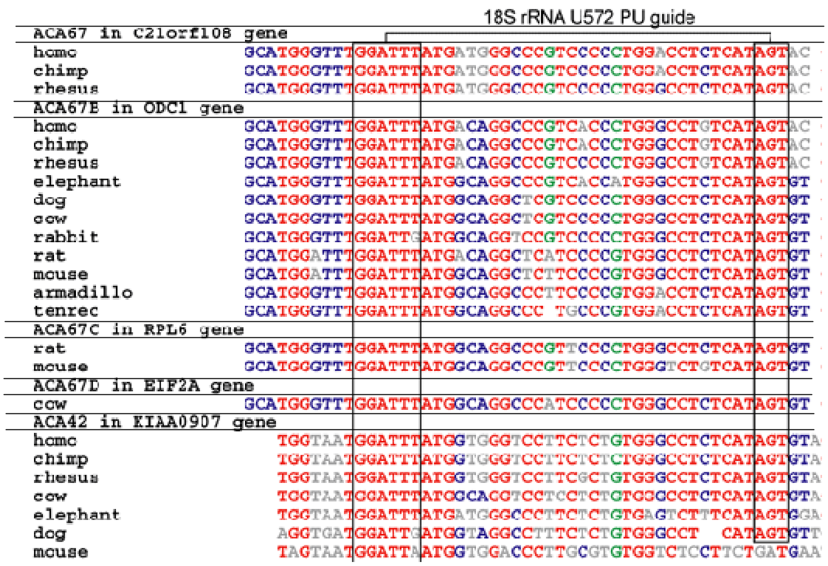
Aligning segments of DNA

Molecular characters are now used for cladistic analysis,

Figure at right shows two genetic elements that were initially identical (#1). Both were changed by mutation (#2-3).

Realignment and comparison (#4) reveals the remaining homologous regions





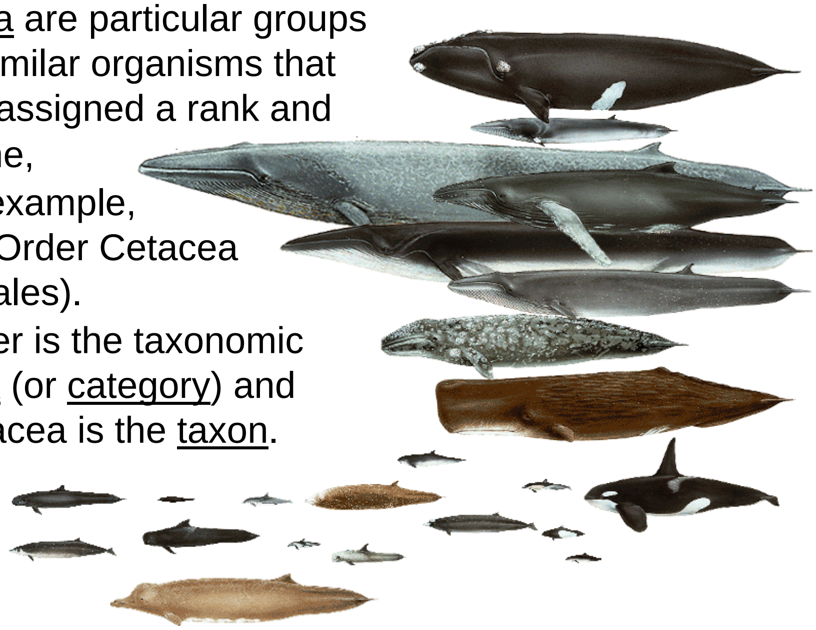
Biogeography

- Hypothesis: organisms in different places evolved there over time.
- Predictions- different species will occur in different places, and groups of related organisms found together geographically
- Evidence: endemic species and species groups, e.g. Australian marsupials, Galapagos birds, etc.

Biological classification

- Taxonomy = description, naming, and classification of species and higher taxa.
- Systematics = classification of taxa according to genealogical relationships.
- Phylogeny = the genealogical relationships of organisms.
- Modern biological classifications are hypotheses about phylogeny.

Taxa are particular groups of similar organisms that are assigned a rank and name,
for example,
the Order Cetacea (whales).
Order is the taxonomic rank (or category) and Cetacea is the taxon.



Taxonomic categories (ranks)

Domain
Kingdom
Phylum
Class
Order
Family
Genus
Species

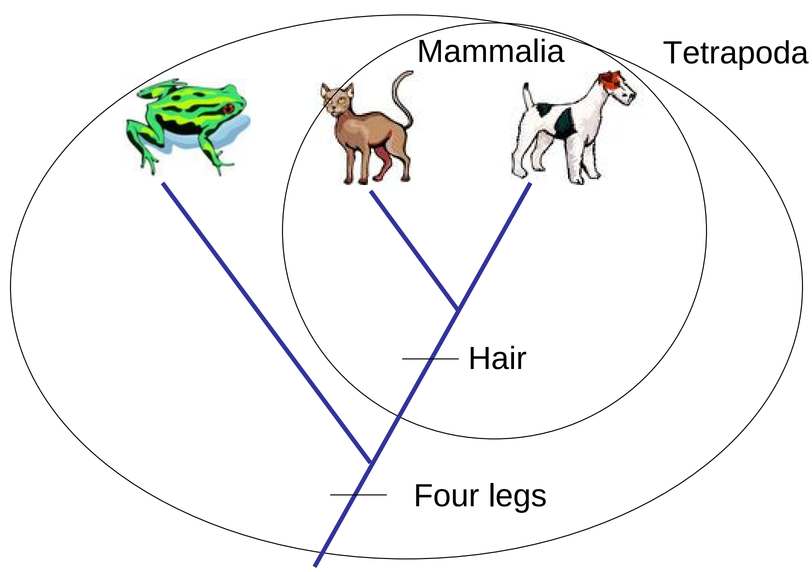
Higher taxonomic categories are more inclusive

- Genus contains 1 or more species
- Family contains 1 or more genera
- Order contains 1 or more families, etc.
- You should know the categories and the taxa in the first two (domains and kingdoms)

Biological Classification is a hypothesis about phylogeny

- Groups of species inherit homologous similarities from a shared ancestor.
- Therefore, classification based on homologies should reflect phylogeny.
- Taxa can be defined as branches of the family tree of species

A phylogenetic interpretation of taxa

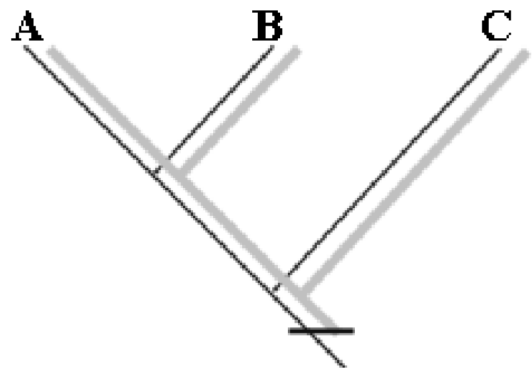


Phylogenetic systematics

- Most biologists agree that classification should reflect phylogeny.
- Each taxon is a branch of the phylogenetic tree.
- Each taxon should be monophyletic, including all the descendants of an ancestral species

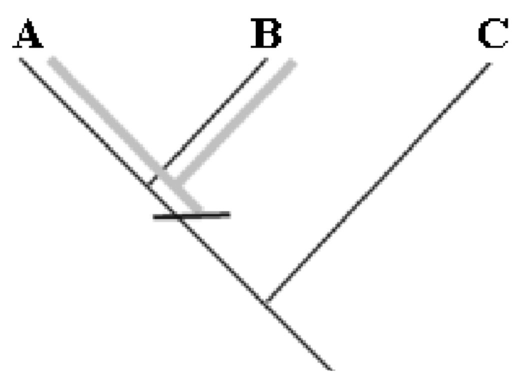
Cladistics

- A method by which phylogeny is deduced
- Refer to text and your lab manual for explanations
- Cladistics is based on homologies, but not all homologies are useful in deducing relationships
- Two kinds of homology: primitive (plesiomorphies) and derived (apomorphies)



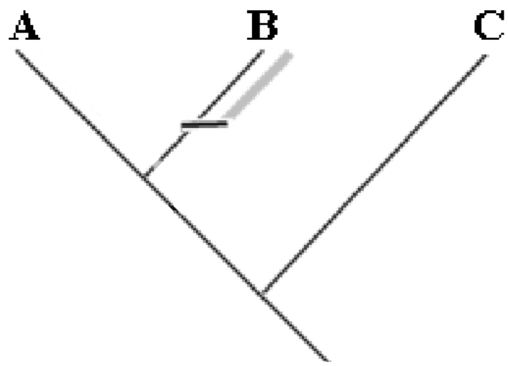
A primitive homology (plesiomorphy) shared by all 3 taxa.

Not phylogenetically informative (does not show who is more related).



Shared, derived homology (synapomorphy) of taxa A and B.

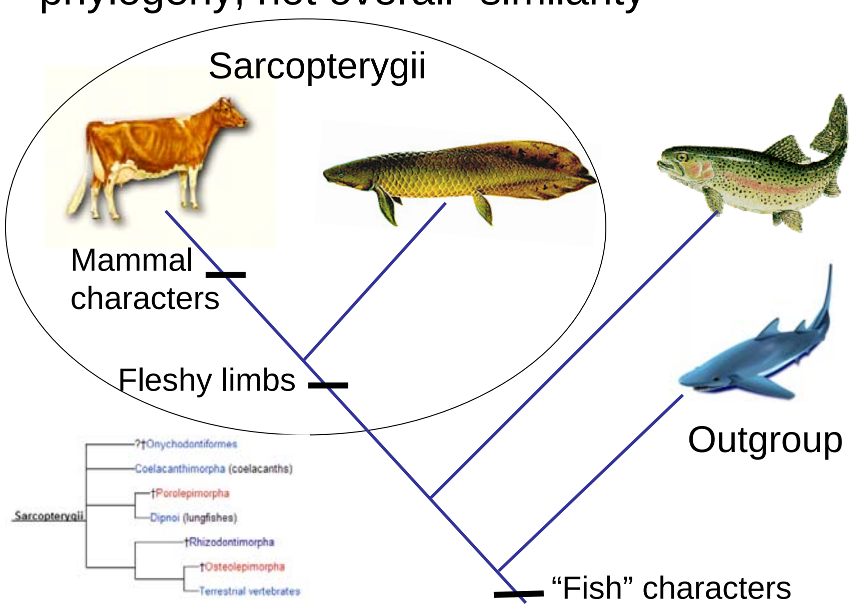
Provides evidence for closer relatedness of A and B.



Derived characteristic of B (autapomorphy).

Does not indicate the closer relationship of A and B, and could make A & C appear closer

Phylogenetic systematics is based on phylogeny, not overall "similarity"



Outgroup comparison

- Whether a character is primitive or derived is determined by examining an outgroup.
- Outgroup is less closely related to the taxa in question than they are to each other.
- Especially useful if a primitive feature has been lost.

Cladistic analysis

- Identify derived homologies of the in-group (by comparison with out-group)
- Group the taxa so as to achieve maximum <u>parsimony</u>.
- The arrangement that corresponds with the smallest number of character origins and losses is the most likely to be correct.

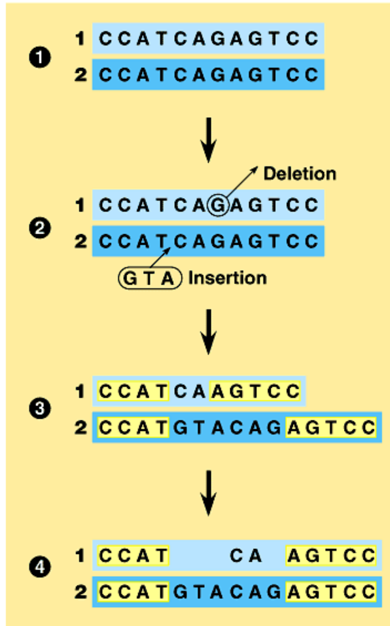
Aligning segments of DNA

<u>Molecular characters</u> are now used for cladistic analysis

nucleotides in DNA or RNA

Amino acid sequences in proteins

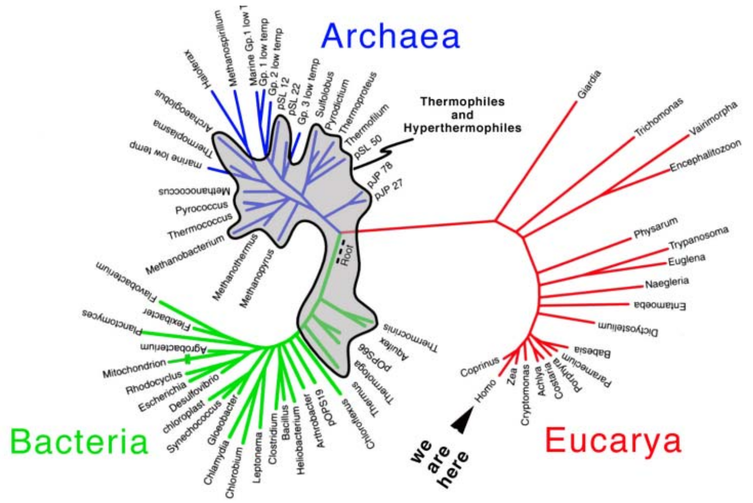
A very large number of characters to compare!



Molecular phylogeny

- Comparison of genetic sequences used to deduce relationships
- Some regions of the DNA evolve fast- used to compare close relatives (e.g. microsatellites)
- Some regions evolve slowly- used to compare distant relatives (e.g. ribosomal RNA genes)

A cladogram of the 3 domains of life, based on cladistic comparisons of ribosomal RNA sequences



Species concepts

- Biologists argue about the definition of a “species”.
- One useful definition is the Biological Species Concept,
- Another is the Phylogenetic Species Concept, which defines species as <u>genetically distinct lineages</u> (descendants of a shared ancestor)

Biological Species Concept (BSC)

- A species is a reproductive community- a group of organisms that can interbreed and produce viable, fertile offspring.
- Species are <u>reproductively isolated</u> from each other (don't interbreed with other species) because of genetically determined characteristics.
- What kind of characteristics cause this?

Prezygotic reproductive barriers

- Characteristics that prevent individuals of two species from mating with one another or prevent fertilization.
- Examples include different mate-attracting behaviors, breeding times, habitat preferences, sperm-recognition proteins, mechanical barriers to mating, etc.

Example of a prezygotic barrier to hybridization: Eastern and Western meadowlarks don't hybridize because females prefer the song of their own species.

(The links are to sound files)

Eastern – *Sturnella magna*

Western- *Sturnella neglecta*

Postzygotic barriers

- Characteristics that prevent hybrid zygotes from developing or reproducing or lead to lower survival of hybrids
- Characters that cause hybrids to be sterile or less fertile, e.g. mules are sterile (hybrids of donkey *Equus asinus* and horse *Equus caballus*)



BSC defines species by reproductive isolation, not by degree of similarity

Different species can be very similar, and…

Populations of the same species can be rather different

Problems with BSC (Biological species concept)

- Reproductive isolation is often difficult to test directly (whether two populations are capable of interbreeding).
- BSC only applies to organisms that reproduce sexually. Many organisms don't, including all prokaryotes & many animals and plants.
- There are other ways to define species

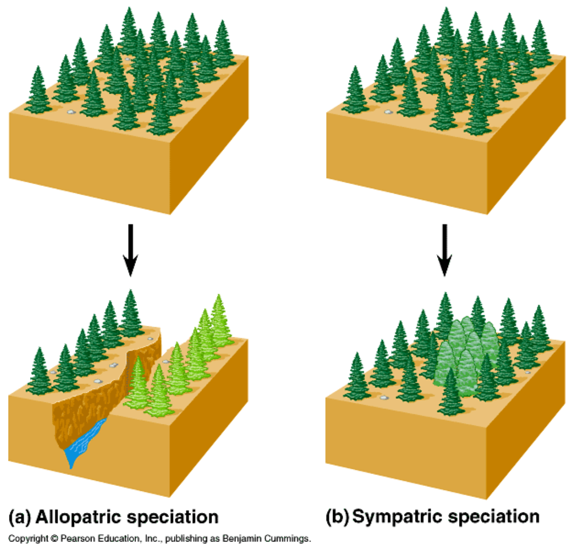
Alternative to BSC: the Phylogenetic Species Concept

- A species is a group of nearest relatives (a clade) that is genetically distinct from other groups by sharing unique alleles inherited from a shared ancestor.
- Problem: how different must two groups be, to qualify as different species?
- Debate: Are two or more species concepts needed?

Speciation

- How does one population get different enough from the others to become a new species?
- How do the members of that population become unable to interbreed with the others?

Allopatric vs sympatric



Allopatric speciation

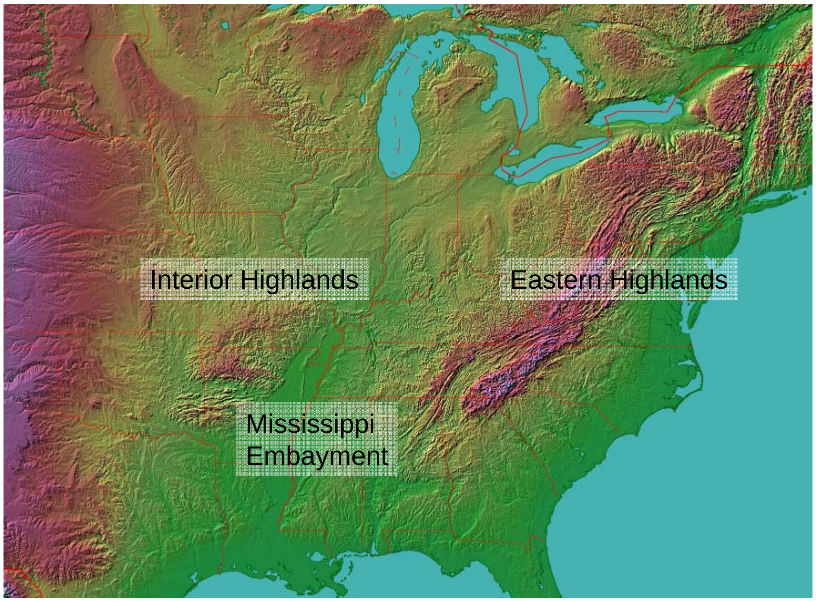
- A geographic barrier separates two populations and prevents gene flow.
- New alleles, different selection pressures, genetic drift cause the two gene pools to diverge
- Differences evolve and eventually lead to reproductive isolation

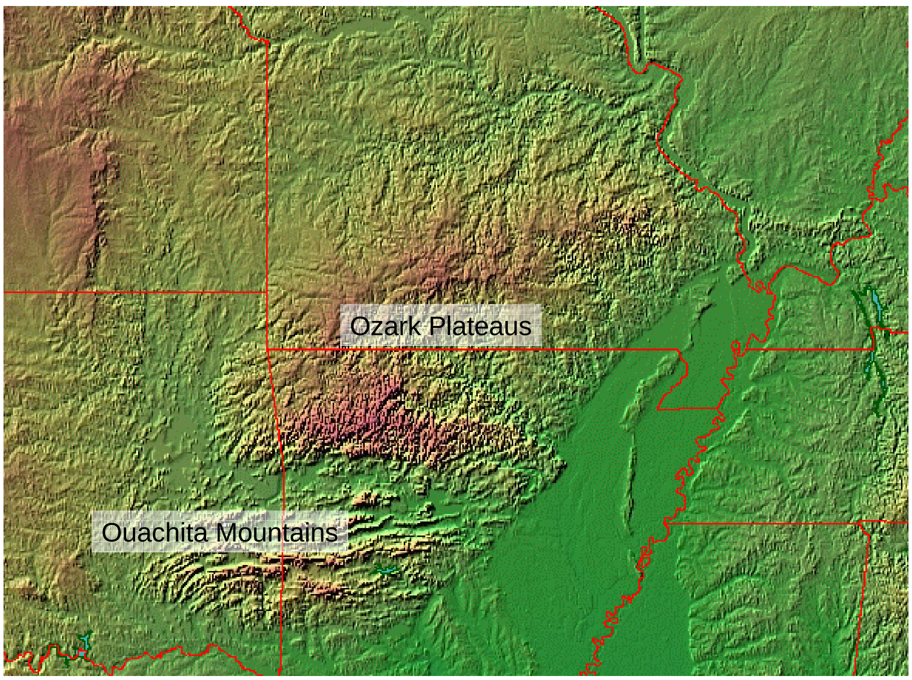
The Grand Canyon- a geographic barrier

Sibling species found on opposite sides of the Grand Canyon

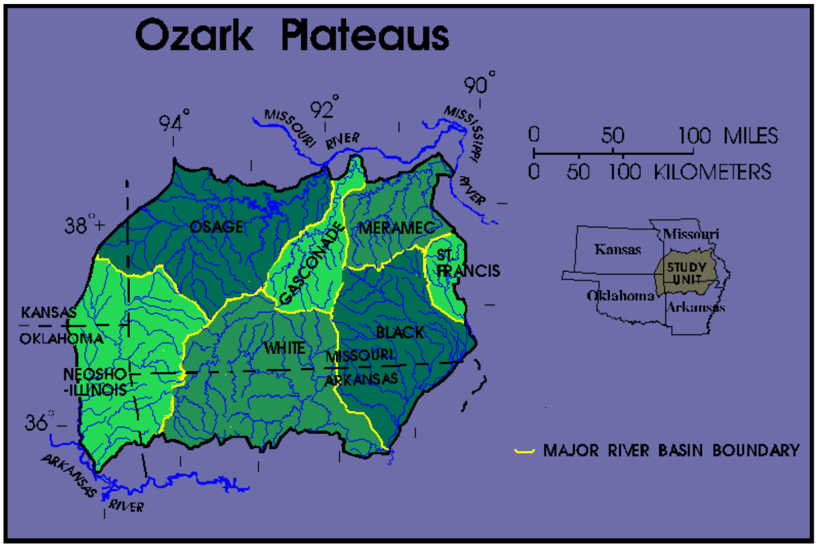
Abert squirrel	Kaibab squirrel
Sciurus aberti	*Sciurus kaibabensis*
South Rim	North Rim

Elevation map of North America





River basins of the Ozark Plateaus

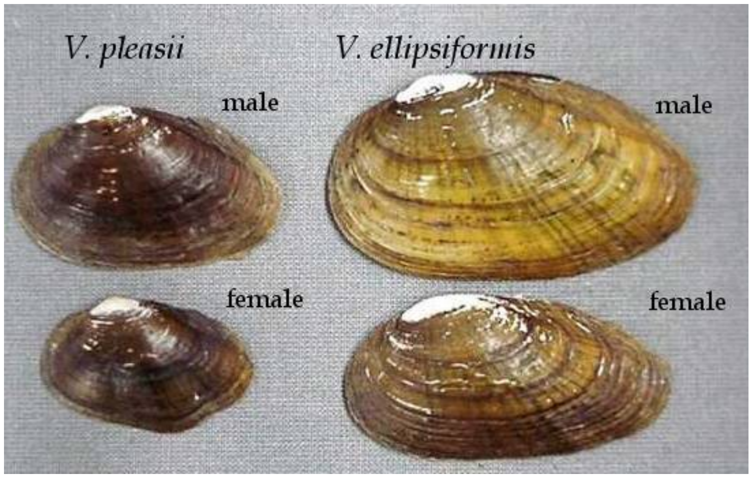


Sibling species in adjacent river basins

Cardinal shiner
Neosho River system

Dusky-stripe shiner
White River system

Sibling species in adjacent river basins



Pleas' mussel
White River system

Ellipse mussel
Neosho River system

Speciation, continued

- Separation of gene pools – loss of gene flow between populations
- Evolution of differences between populations
  - Allele frequencies
  - different alleles
- Evolution of reproductive isolating mechanisms

Sympatric speciation

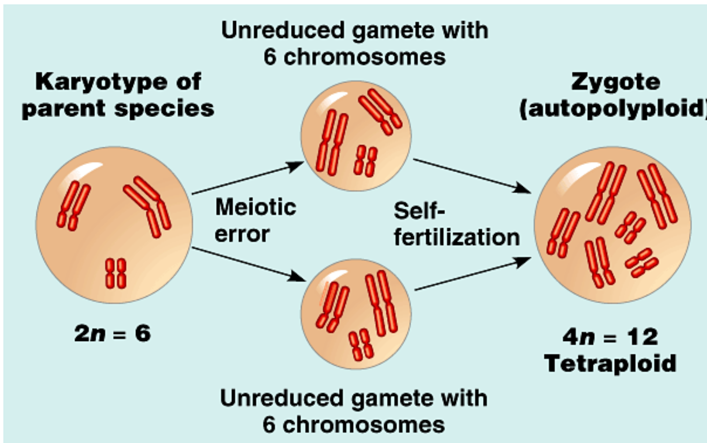
- Sympatric (same place) vs. allopatric (different place)
- A population is separated from the rest by mechanisms other than geography
- probably less common than allopatric speciation but still important

Polyploidy

- can cause instant sympatric speciation in plants and animals
- Extra set(s) of chromosomes (N>2)
- Autopolyploids = extra set(s) from the same species.
- Allopolyploids= extra set(s) from another species

Autopolyploid

- More than 2 sets of chromosomes, all derived from one parent species

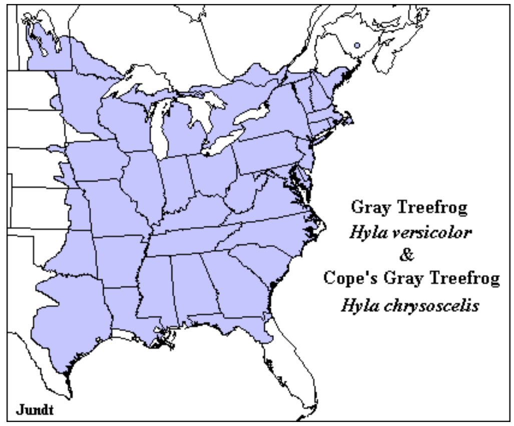


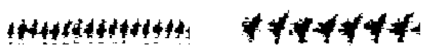
Polyploids are sometimes viable and fertile with other polyploids (= new species)

Polyploidy

- Animal polyploids are nearly always autopolyploids
- In plants, both auto and allopolyploids occur.
- Plant polyploids are often productive- many crops are polyploids, including wheat, oats, potatoes, cotton, coffee, most fruit crops

Sympatric speciation of treefrogs by polyploidy





Missouri treefrogs

- *Hyla chrysoscelis* (Cope's grey treefrog)
  - diploid
    fast trill
    small red blood cells
- *Hyla versicolor* (grey treefrog)
  - tetraploid
    slow trill
    large red blood cells

Ptacek, M., H. Gerhardt, and R. Sage. 1994. Speciation By Polyploidy in Treefrogs: Multiple Origins of the Tetraploid, Hyla versicolor. Evolution 48: 898-908

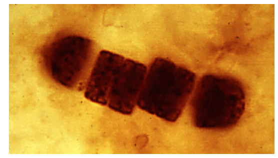
Can man "create" new species?

- Sure.
- Artificial selection for characteristics that cause reproductive isolation can create new species.
- If this seems weird, just think about the definition of a species.

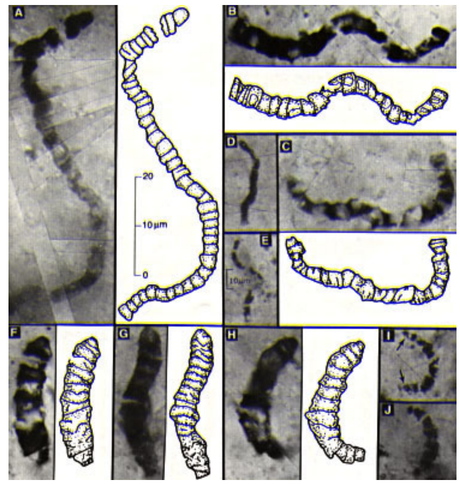
Biodiversity and earth history

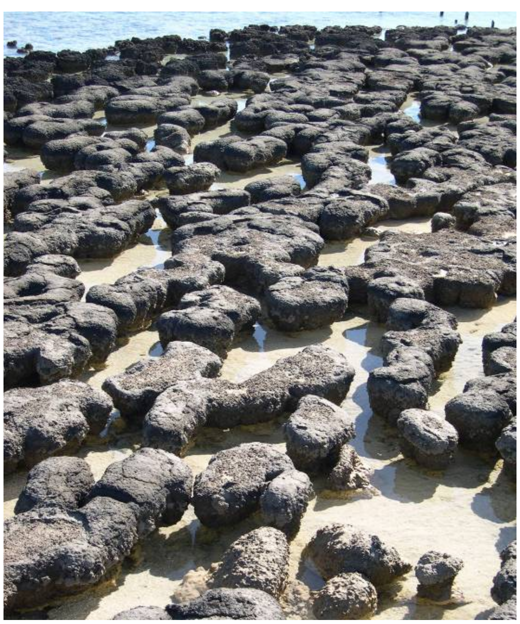
- Life started simple, stayed unicellular for a long time, then multicellular taxa abruptly diversified.
- Subsequently biodiversity has fluctuated- occasional periods of mass extinction are followed by diversification (adaptive radiation)
- These extinctions & radiations mark the boundaries of geological eras and periods.

Earliest fossil cells



- 3.5 billion years old (=3.5 Ga)
- Similar size to modern cyanobacteria (prokaryote algae)
- Prokaryotes do not form complex multicellular organisms





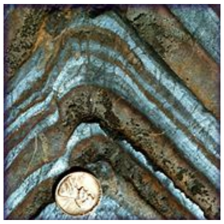
Shark Bay Australia

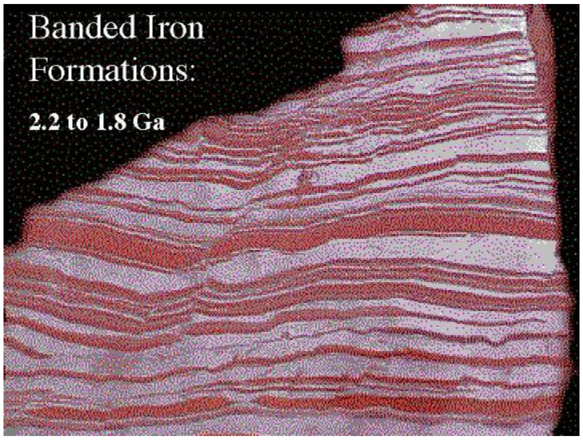
Stromatolites

- Limestone pillars formed by mats of cyanobacteria in shallow water
- Also began ~3.5 Ga
- modern examples form only in hypersaline environments where there are no grazers

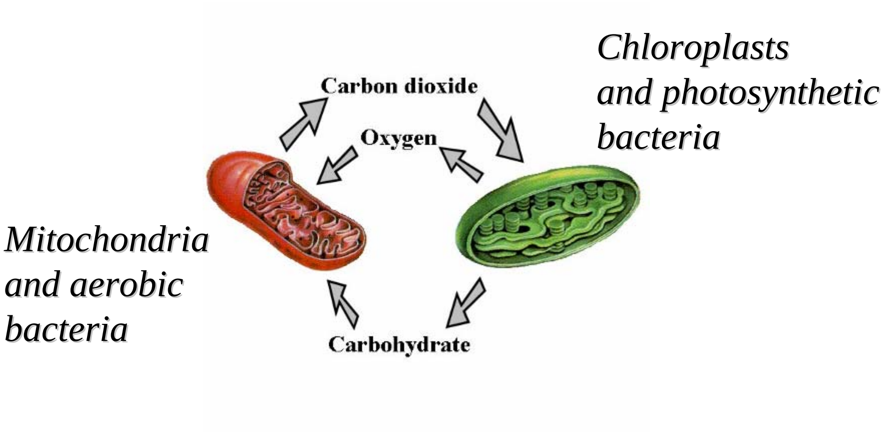
Oxygen production by photosynthesis

- Formation of iron oxide deposits indicates accumulation of oxygen in oceans
- Respiration evolved after oxygen became available





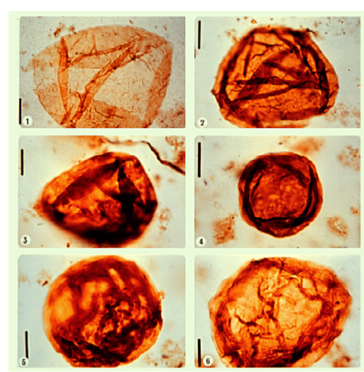
The cycle of life (carbon cycle)… photosynthesis and respiration



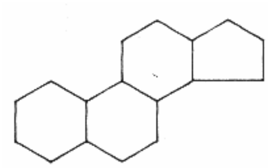
Oxygen was critical in the evolution of animals and plants

- Early earth lacked free oxygen – it was eventually produced by photosynthetic organisms.
- Free oxygen allowed evolution of respiration, which led to eukaryotes and multicellularity.
- Eukaryotic cells originated when prokaryotes with the respiratory pathways (aerobic prokaryotes) joined forces with larger phagocytotic host cells, probably members of the Domain Archaea.
- Multicellular animals and plants are all eukaryote

Early eukaryotes



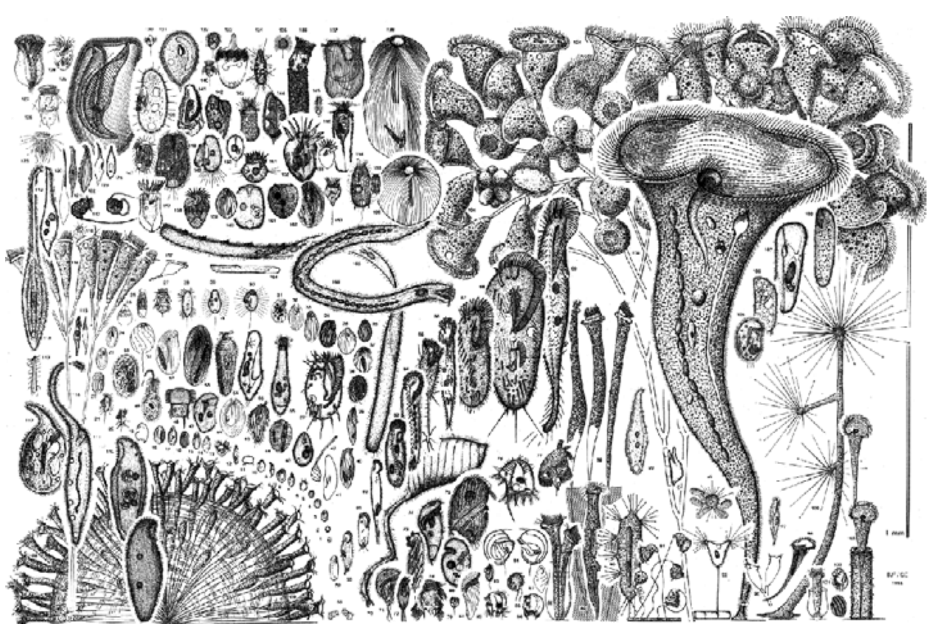
- Fossils of eukaryote size appear 1.8 billion years ago.
- Chemical evidence for eukaryotes appears earlier- 2.7 billion yr ago
- Steranes are "fossil lipids" derived from cholesterol (cholesterol is abundant in eukaryote membranes, not prokaryotes)



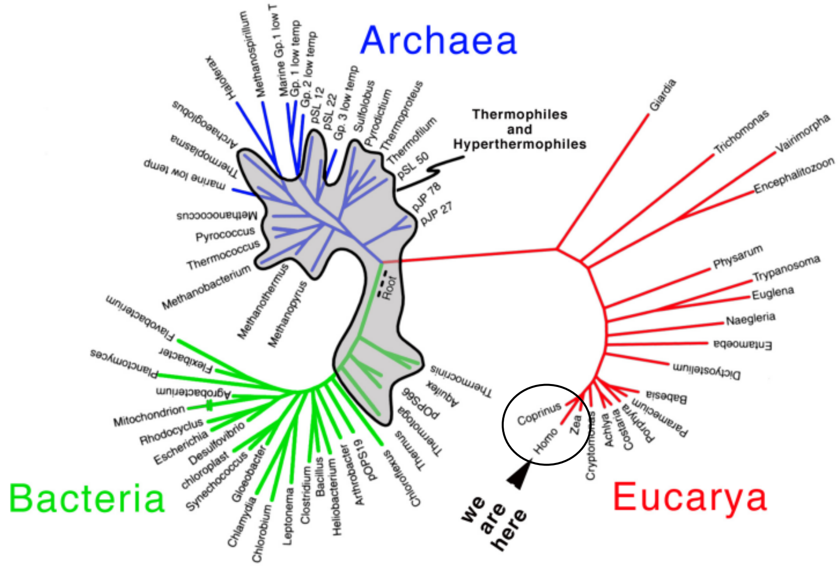
Protista

- Eukaryotes diversified into a huge variety of “single celled” taxa, collectively referred to as Protista
- Life remained unicellular or colonies of cells for another billion years
- Complex multicellular animals don’t appear in the fossil record until about 600 million years ago

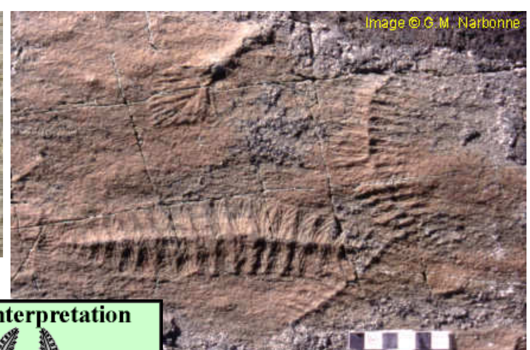
Diversity in just one clade of Protista- the ciliates

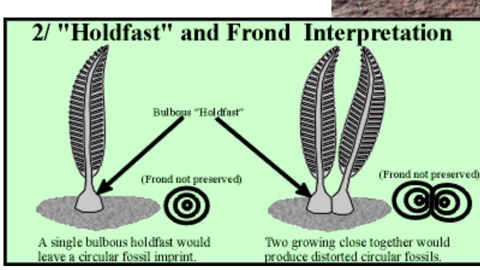


The evolutionary distance among rRNA sequences reflects the time since divergence… the circle indicates multicellular organisms, including us



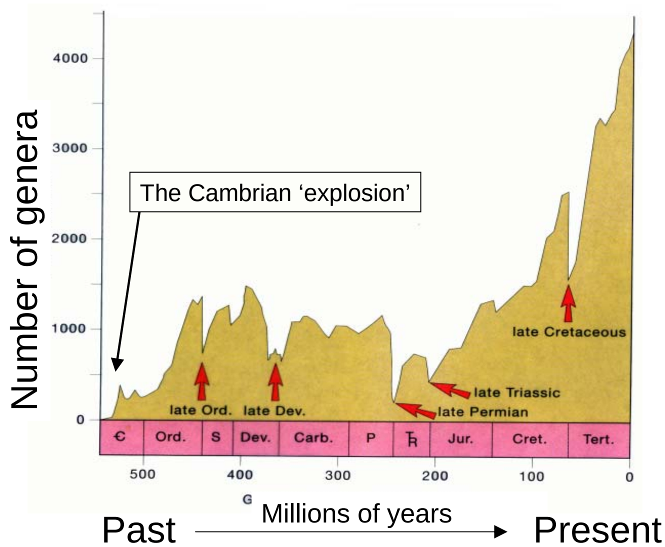
Early animals – the "Ediacaran fauna"



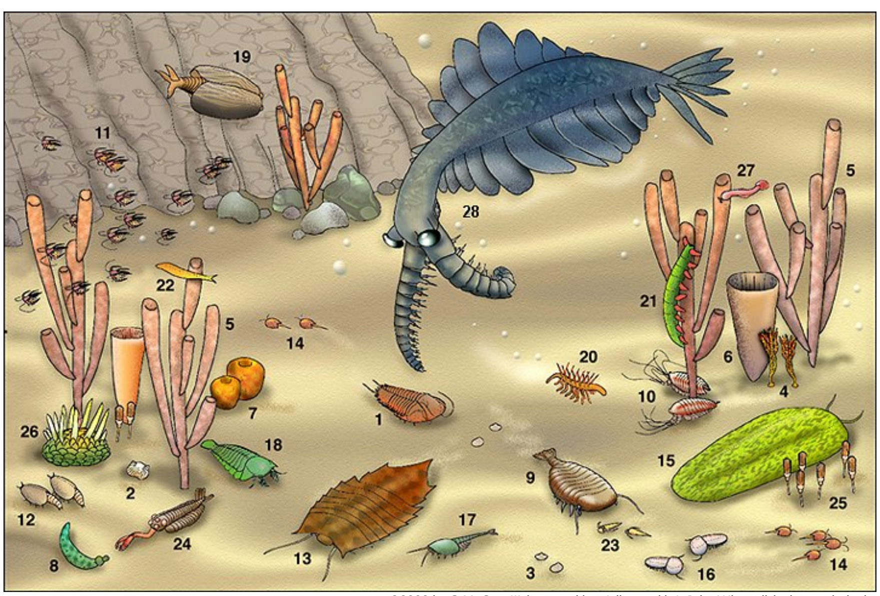


~600 million years ago..
The first animals – complex multicellular heterotrophs

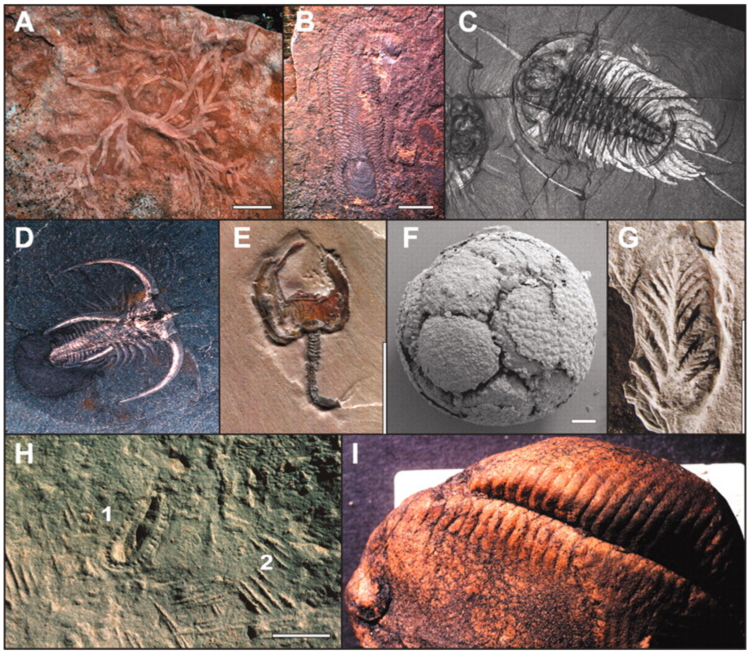
Change in animal biodiversity over time
(based on fossil aquatic invertebrates)



Reconstruction of a Cambrian marine community



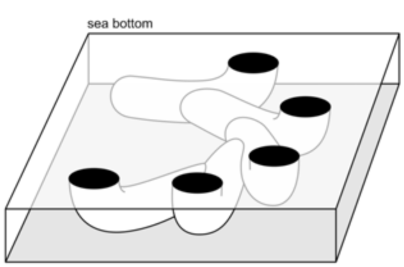
Erwin et al. 2011 Cambrian conundrum Science 334:1091

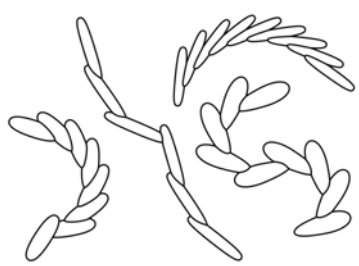


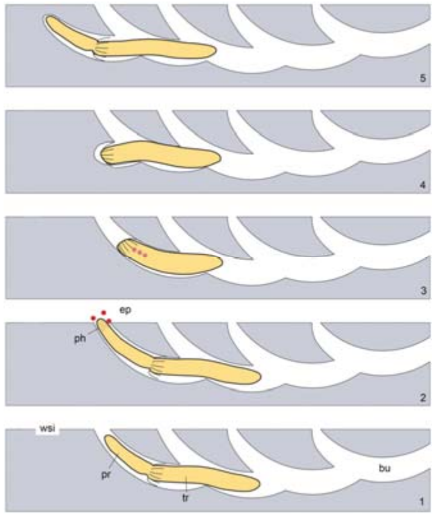
A recent article addressing the timing of evolution of the animals. They used molecular phylogeny, molecular clocks, and fossils to date the animal family tree from about 800 million years ago

Treptichnus pedum

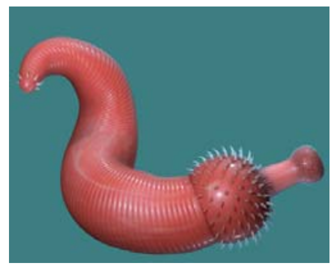
- Geographically widespread trace fossil
- Earliest appearance used to distinguish the Ediacaran and Cambrian Periods.

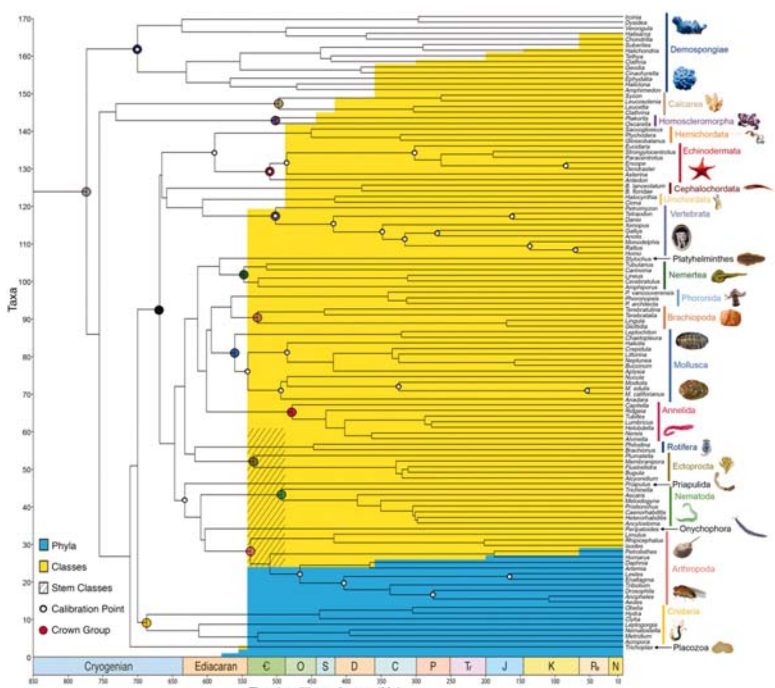






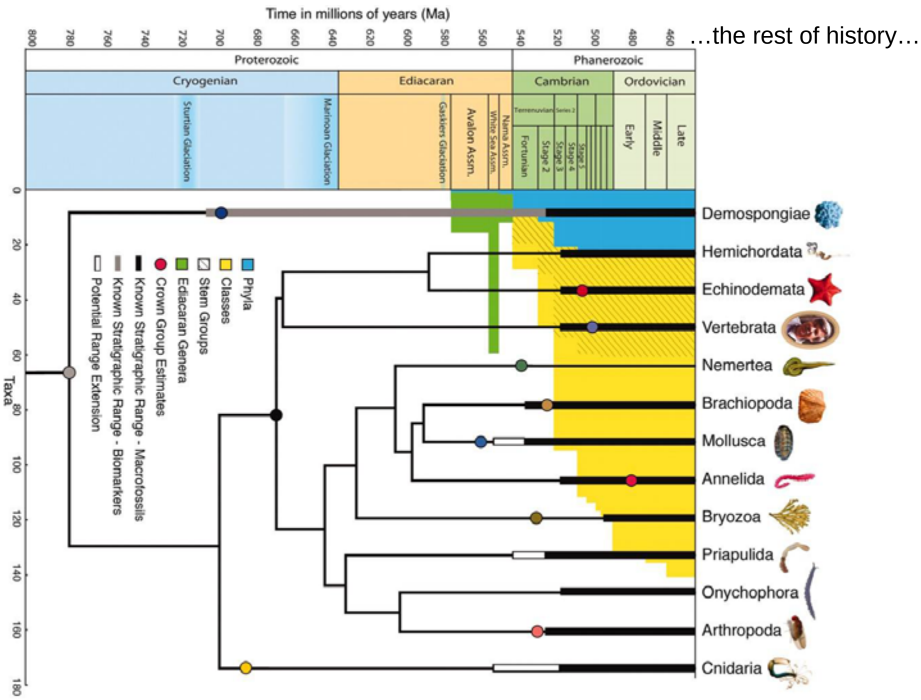
Vannier, et al. 2010. Priapulid worms: Pioneer horizontal burrowers at the Precambrian-Cambrian boundary. Geology 38:711-714





Time on the X-axis, indicating the timing of the branch points in the tree.

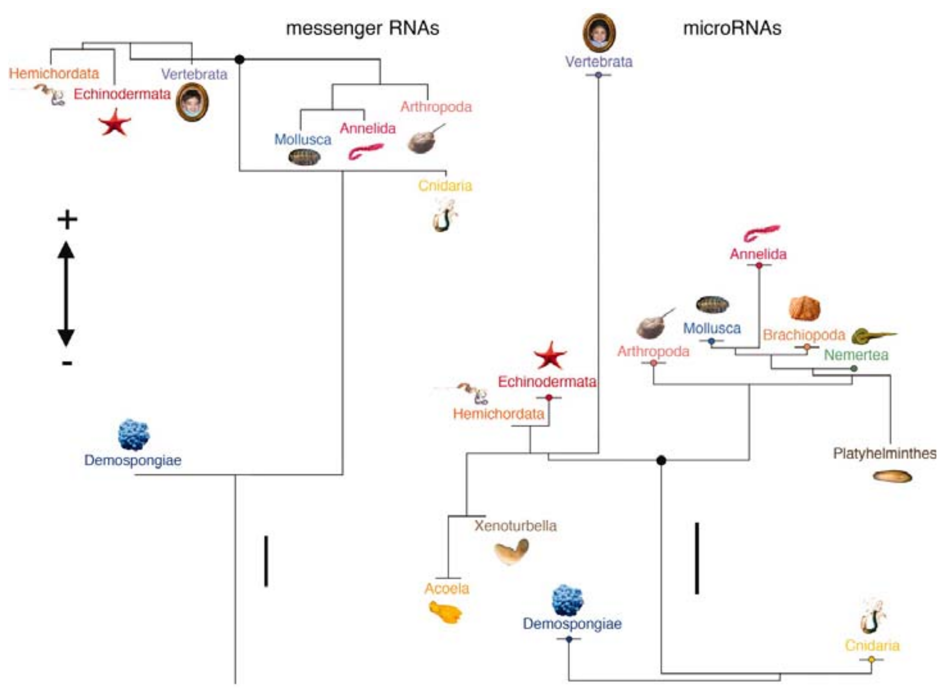
The blue and yellow bars are the numbers of phyla (blue) and classes (yellow) of animals known from fossils vs time. Note abrupt jump at the beginning of the Cambrian period



Erwin et al. 2011 Cambrian conundrum Science 334:1091

- Phylogeny and molecular clocks suggest slow diversification of animals long before the Cambrian
- Fossils of most animal phyla and classes appear abruptly near the base of the Cambrian.
  - Probably partly reflects better fossilization with evolution of mineralized shells
  - Probably partly a real acceleration of diversification

- All living animal phyla have similar protein-coding (structural or mRNA) gene families
  - This basic ‘toolkit’ had apparently evolved by 660 mya in the ancestors of the living phyla
- Later diversification of animals involved mainly changes in mi-RNA genes
  - Micro-RNA’s control expression of the structural genes
- Diversification might have accelerated for ecological reasons
  - New niches were created by burrowers, by evolution of predators and defensive structures (hard parts).



Big Events in Biodiversity

- Cambrian radiation ~544 mya
  - Most animal phyla appear in the fossil record
- Permian extinctions 245 mya
  - 52% of families extinct: infer that 88% of genera, 96% of species were lost
- Cretaceous (K-T) extinctions ~65 mya
  - 11% of marine families went extinct, as well as the last of dinosaurs

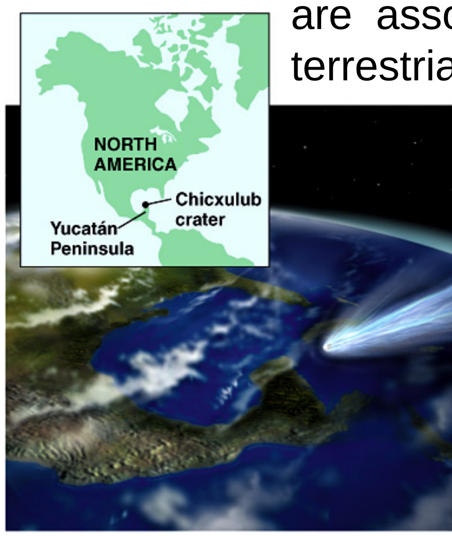
Geological eras

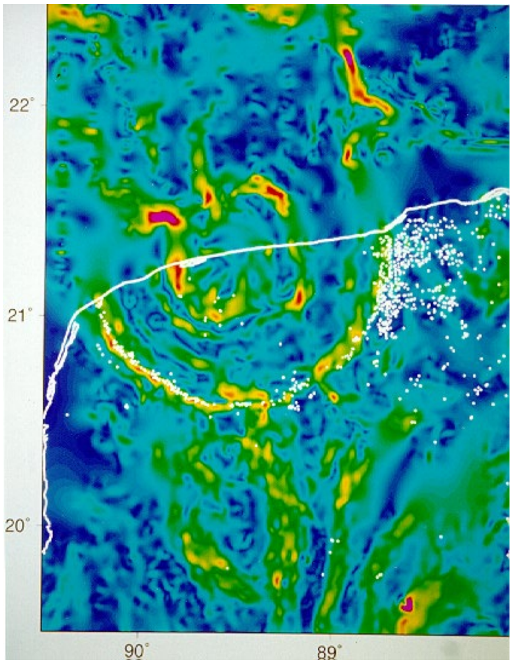
- <u>Precambrian</u> 4,600-540 million years ago
- <u>Paleozoic</u>, 543-245 mya
  Cambrian radiation to Permian extinction
- <u>Mesozoic</u>, 245-65 mya
  Permian extinction to K-T extinction
- <u>Cenozoic</u>, 65 million years ago to present
  Cretaceous extinction to present

Mass extinctions

- Causes are debated, but extinctions are often linked to:
  - – Impacts by comets or meteors
  - – Periods of volcanism
  - – Continental drift
- All of these caused widespread <u>climate change</u>

Some mass extinctions (e.g KT) are associated with extra-terrestrial impact events





Gravity Map (A.Hildebrandt)

The KT extinction is associated with Chicxulub impact structure- imaged by gravity anomaly (white line is the coastline, dots are cenotes)

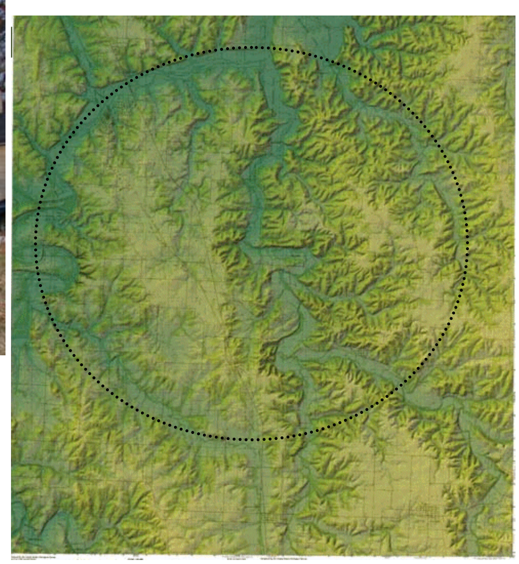
The structure is over 100 miles in diameter.

The impactor may have been 6 miles in diameter

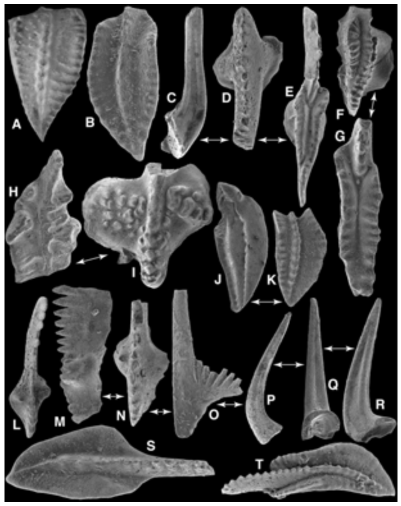
A worldwide layer of dust rich in iridium is linked to this impact

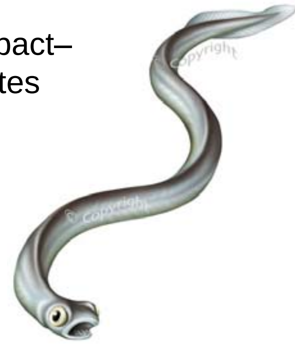
Kevin Evans
(MSU Geology)

Weaubleau impact near Osceola, MO ~300 mya



Conodont fossils from the Wableau impact–
These tiny marine relatives of vertebrates
had complex “teeth” that are excellent
indicator fossils





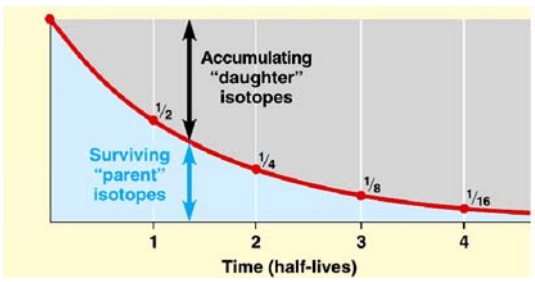
On the head of a pin

Relative dating

- Relative dating is based on stratigraphy- older rocks lie below younger ones
- Life changes through time- rocks with similar fossils are of similar age
- <u>Index fossils</u> are widespread, common, rapidly evolving species - presence indicates rocks of particular age

Absolute dating

- uses change in physical constants
- radiometric methods (isotope decay) such as the decay of carbon-14 or uranium-238
- constant rates, unaffected by temperature



Should (and does) evolution result in "progress"?

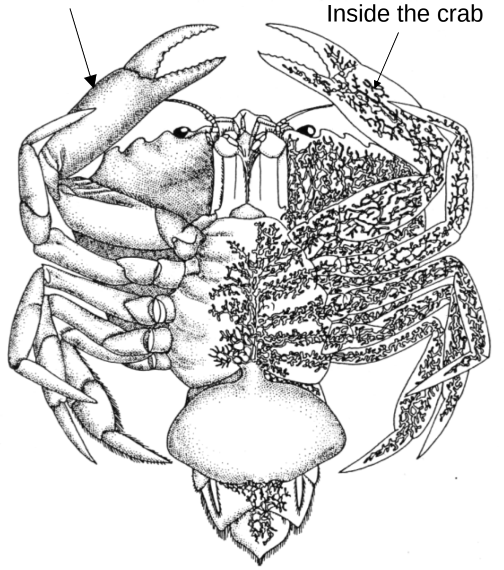
- Fossils show that earliest organisms were small and simple.
- Many modern organisms are big and complex.
- However, many are still small and simple.
- Some organisms, particularly parasites, evolve simpler body forms from complex ancestors

“Devolution”?

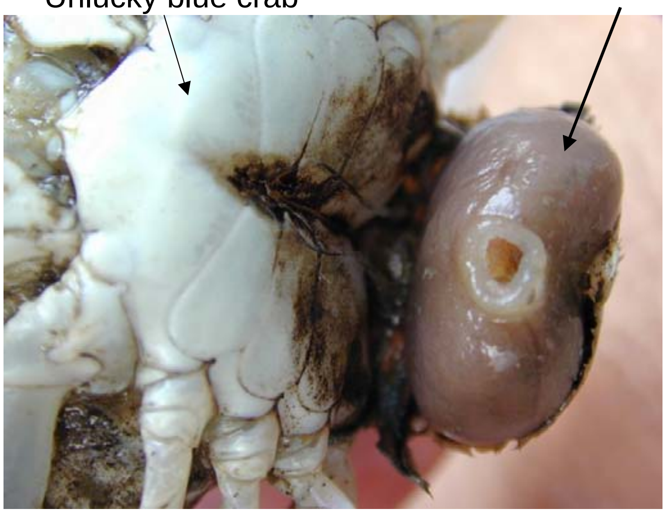
Sacculina is a parasite of blue crabs.

The parasite consists of a network of tissue inside the host crab, and an external egg sac under the crab’s tail.

The genes and larva of *Sacculina* show that it is a crustacean, but the adult looks more like a fungus.



Sacculina – the “devolution” of a crustacean to a web of filaments and an egg sac



As humans become more dependent on machines, will our morphology (d)evolve too?

What about the usual sci-fi depiction of future humans with bigger brains? Does that make any sense, evolutionarily speaking? In modern society, do big-brained people have more babies?

Are humans the purpose or goal of evolution?

- Physicists point out that if physical laws were not just as they are, we couldn't be here.
- Paleontologists point out that our ancestors, from Paleozoic worms on up, were hugely lucky to have survived
- So do we have a destiny, or are we just floating about on the breeze?

A few parting comments

- One semester is not long enough to introduce biology – I hope that you will continue on to Bio 122 and learn more
- Biology really is the most fascinating and important human endeavor - don’t stop learning about it.
- If you want to talk about coursework or careers or whatever, don’t hesitate to call or stop by.