Tuesday, January 30, 2018 9:03 PM

Lecture 1&2

- Hydrogen and Helium (lithium, boron, beryllium in trace quantities) were created in the Big Bang
- Iron is the heaviest element created in ordinary stars
- Early history of life begins ~3.8 bya
- **Life**: carbon-based, membrane-bound structures (cellular) with controlled energy conversion (metabolism) using ATP; ability to reproduce with variation = ability to evolve (adapt to change)
- **Abiogenesis (spontaneous generation) hypothesis**: "chemical evolution" of a self-replicating energy converting, membrane bound cell
  - 1. **RNA world first**: enzymatic activity (some RNA's can catalyze chemical reactions) and serve as information molecules
  - 2. **Metabolism first**: proteins and structural macromolecules capable of energy conversion reactions attached to surfaces like clays
  - 3. **Membranes (phospholipids) first**: produce "protocell" containers that form spontaneously in solution, trapping other molecules inside them
- Chemical precursors to life
  - **CH4, H2O, CO2, NH3, H2S, PO4 3-**
- 3 steps that must have occurred for life to emerge from inorganic matter
  - **Stage 1: the origin of biological monomers (easiest)**
  - **Stage 2: the origin of biological polymers (macromolecules)**
  - **Stage 3: the evolution from molecules to cells (most difficult stage)**
- Inorganic matter hypothesis
  - **Oparin & Haldane (1920s) "primordial soup hypothesis"**
    - 1. Early earth had a reducing atmosphere
    - 2. Atmosphere exposed to energy in various forms such as lightning, volcanic heat, radiation, produced simple organic compounds (monomers)
    - 3. These compounds accumulated in a dilute organic "soup" of monomer molecules that may have concentrated at various locations (shorelines, oceanic vents, ice formation, evaporating pools, etc) eventually, more complex organic polymers (self assembly) and ultimately life developed in the soup. Mechanisms unknown
  - **Stanley Miller and Harold Urey "life spark experiment"**
    - Confirmed that biomolecules (including amino acids) could form spontaneously when energy is added to simple chemical precursors (water, methane, ammonia, hydrogen)
  - **Sidney Fox "Proteinoid microspheres"**
    - Demonstrated that amino acids could spontaneously form small chains of peptides - although not true proteins)
  - **David Deamer "self assembly"**
    - Proposed biological molecules could have evolved in hydrothermal pools. Lipids

could build up on edges of the pool, trapping chemicals, and facilitate growth of RNA molecules. Lipid bound droplets could peel off, creating RNA-filled proto-cells

- **Exobiology**: current exciting scientific interest in possible life on other planets. But also leads easily into pseudoscience and rank speculation
- **LUCA**: "Last Universal Common Ancestor" (not necessarily the first life form, but the first surviving one)
- Biological evolution begins between ~4 and 3.5 bya, early life populations formed, with RNA variations, setting in motion selection processes that favoured some variations over others. Surviving forms propagated into the nest generations, and a process of natural selection continues… many experimental forms likely disappeared along the way, but LUCA SURVIVED.
  - First fossil remains of more complex microorganisms with photosynthetic ability show up ~3.5 bya (**stromatolites**)

Chapter 1 the virus and the whale

- **Biological evolution**: any change in the inherited traits of population that occurs from one generation to the next (i.e., over a time period longer than the lifetime of an individual in the population)
  - Individuals do not evolve, only populations
  - Gene frequencies may remain stable, or change in subsequent generations (microevolution)
  - Change may be rapid (ie viruses & bacteria) due to rapid reproduction or slow, taking millions of years
  - Changes depend on selection pressures, genomic characteristics, and population structures
- 3 evolution categories
  - 1. **Microevolution**: evolution occurring within populations, including adaptive and neutral changes in allele frequencies from one generation to the next
    - Viruses: simplest known life forms, with only 8 pieces of RNA that make only 13 proteins (all are parasitic on other life)
      - Changed surface proteins: host antibodies do not recognize the new mutants: no resistance and may become pathogenic → rapid evolution
      - **Viral reassortment**
        - all human influenzas begin in birds and/or mammals (often pigs=swine)
        - occurs when genetic material from different strains gets mixed into new combinations within a single individual
  - 2. **Macroevolution**: evolution occurring above the species level, including the origination, diversification, and extinction of species over long periods of evolutionary time
    - How do we know whales are mammals?

- Whales share several **synapomorphies** (shared derived characters from a common ancestor) with others in order Mammalia
  - Ex_ mammary glands and milk production
  - Three middle ear bones
  - Hair (in developing embryos) & other features
- Similarities with fish (shape, fins) arose through convergent evolution (adaptations to living in an aquatic environment, not ancestry)
- Early fossil whales (**archaeocetes**) share synapomorphies with modern cetaceans (teeth, inner ear, ankle bones)

- **Synapomorphy**: shared derived characters from a common ancestor
  - **Birds - feathers, wings, toothless beak**
  - **Apes- lack of tail, forward facing eyes, larger brain size, similar dentition (32 teeth)**
- **Dorudon** (40 mya late Eocene) archaeocete with aquatic morphology (reduced legs)
- **Pakicetus & Indohyus** (50 mya Early Eocene) terrestrial fossils from Eocene Indian Continent
- **Ambulocetus** "link" or transitional form b/t terrestrial and aquatic fossil whale

- **Clades**: taxonomic "groups" with a shared common ancestor
- **Artiodactyl**: cows, goats, camels, hippos
  - old order Cetacea now included in Artiodactyla
  - hippos & cetaceans shared a fossil common ancestor (4 unique DNA homologies are synapomorphies linking them
- **Evo-Devo (embryology)**: Embryos of cetaceans develop hind limbs but are then lost 4-9 weeks into development.
- Sociality promoted the evolution of large brains
- Behavior can evolve
  - Form lasting alliances
  - Competition for mates
  - Complex communication

  - 3. **Speciation**: the evolutionary process by which new species arise. Speciation causes one evolutionary lineage to split into two or more lineages

Chapter 2 natural philosophy to Darwin

✓ **"theory" of evolution**
- An explanation of the natural world that has been extensively tested and supported by observation and experiment (and not falsified) but always open to change or even destroyed in light of new evidence

➢ Evolution and religions
- **Science,** including evolutionary biology, is limited to understanding the natural world based on testable facts (data) from observations and experiments, and theories or hypothesis that try to explain them

- **Religions**, on the other hand, deal mostly with faith-based revealed knowledge (scriptures, prophets) and supernatural phenomena (GOD, angels, souls, heaven & hell, etc) that are usually not testable using scientific methods

- natural philosophy
  - **Carl Linnaeus** "father of modern taxonomy"
  - **Nicolas steno** "father of geology and stratigraphy"
    - Recognized similarities b/t tongue stones and sharks' teeth
    - First naturalist who realized life is transformed into stone
    - Stratigraphy: study of layering in rock (stratification)
  - **Georges Buffon**
    - Earth formed according to laws of physics and chemistry
      - older than previously thought
    - Life emerged as distinct types
      - Could transform when environment changed (new idea)
  - **Georges Cuvier**
    - **Paleontology**: the study of prehistoric life
    - Fossils resemble but are not exactly the same as modern species
    - Animal extinctions are a fact

- Geologist
  - **James Hutton**
    - Observable processes produce small changes that accumulate over time
    - The earth must be old
    - Long time was critical for Darwin's ideas on change mechanisms
  - **William Smith** (Canal surveys)
    - Different rock layers contain distinct fossils: can correlate them in space, and map them

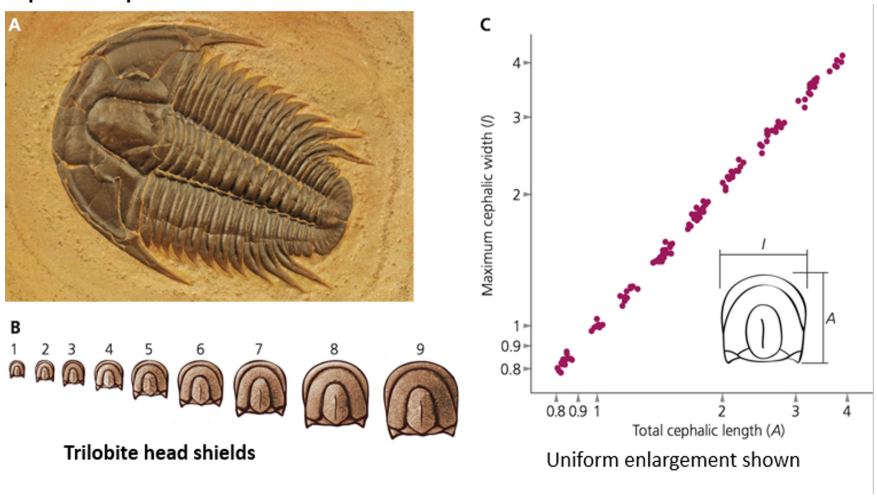
- **Lamarck**
  - Life driven from simple to complex
    - Complex species descended from microbes
    - Microbes continually generated spontaneously
  - Adaptation occurs through inheritance of acquired changes through "needs" and "use and disuse"… neck of giraffe

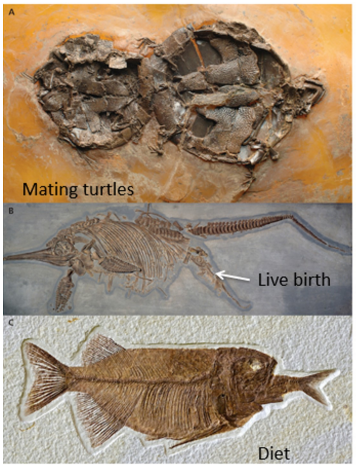
- **Charles Darwin**
  - Voyage of the beagle
  - **Four postulates**
    1. Individuals in a species vary in their traits
    2. These variable traits can be passed on from parents to offspring
    3. More individuals are born that can survive in a given population
    4. Individuals compete for resources and struggle for survival
  - 3 ways in which Charles Darwin and Alfred Russell Wallace changed the way scientist think about biology

    - **"decent with modification"**
    1. All species share a common ancestor
    2. Heritable variations are present in all organism
    3. Changes occur through natural selection favouring certain variations of a trait over others
- **"common descent"**
    - Homologous trait: similar structures resulting from inheritance from a common ancestor
        - Ex) homologou forlimb bones of tetrapods: vertebrates with 4 limbs
    - Common descent also seen in embryos
- **Natural selection**: a mechanism that can lead to adaptive evolution, whereby difference in the phenotypes of individuals cause some of them to survive and reproduce more effectively than others
- **Adaptations**: inherited aspects of an individual that allow it to outcompete other members of the same population that lack the trait
    - Trais that have evolved through the mechanism of natural selection
- **Sexual selection**: a process different from natural selection that differentiates males and females of the same taxon, and affects breeding success
- **Genetic drift**: random changes to the gene pool resulting from chance events in small populations (rapid genetic changes and possible) can play a role in evolution
- The 2 most widely used anti-evolutionary arguments
    1. The argument from design
        - Robert Hooke
        - William paley
            - "watch-maker"
        - Behe's books
    2. "gaps" in the fossil record

Chapter 3 what the rocks say

- Sanning electron microscopy
    - Structure of fossil melanosomes on feathers suggests strikng plumage colours in Chinese fossil feathered dinosaur Anchiornis (late jurassic, like Archaeopteryx)
- Age of Earth debates
    - **Lord Kelvin**
        - Proposed earth was no more than 20million years old based on the temperature of rocks (cooling rates)
        - Kelvin estimated the age of the earth based on the cooling rate and temperatures of rocks. He made the assuption that the earth was a molten ball that cooled at a predictable rate. He had no idea that the interior of the earth was radioactively heated, with movements of lava that drive continental drift. Radiometric dating techniques using Uranium, and Rubidium has proven that the earth is 4.5 billion years old
- Radiometric dating: a technique that allow geologists to estimate the precise ages at which one geological formation ends and another begins

- **Fossils:** key evidence for change
  - Most organisms do not fossilize well
    - Those with hard parts (teeth, bones, shells, etc) have best chance, as well as those that live near sedimentary environments, oceans, lakes, rivers) and those who are numerically abundant and with broad distriutions
  - **Lagerstatte**: sites with an abundant supply of unusually well-preserved fossils - often including soft tissues - from the same period of time
    - Ex) burgess shale (cambrian period) : a lagerstatte in canada that preserved fossils from the cambrian period
      - 505mya
      - Rapid burial in oxygen-poor ocean sediments accounts for preservation --> created unusual good preservation "lagerstatte"
  - Fossils can provide clues about behaviour in extinct animals and growth & development patterns in extinct taxa
    - 

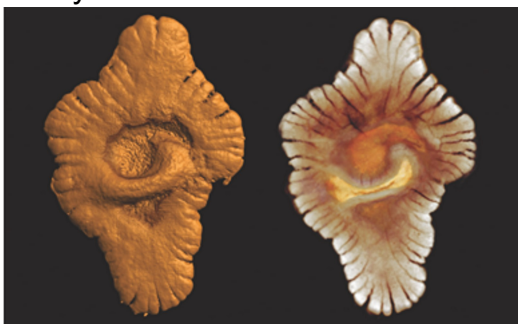
    - 

    - 
Dinosaur nesting, egg-laying, herding
    - 
- CT scans help determine function of hadrosaur (duck-billed dinosaur) crests
  - Crest connected to nasal cavity
    - Sound generated by blowing air (trumpet-like)
  - Ears tuned to this frequency
  - Crest/vocalizations likely had display functions (sexual selection and communication)
- Earliest signs of life
  - **Biomarkers**: molecular evidence of life in the fossil record. Biomarkers can include fragments of DNA, molecules such as lipids, or specific isotopic ratios
    - Oldest potential evidence of life dates to ~3.7 bya (carbon "biomarkers"-->

carbon isotopes in rocks)
    - **Purple sulfur bacteria**
        - Produces a pigment biomarker "okenane" that can preseve in ancient rocks (1.6 billion year old rock in Australia) , period of low free oxygen in oceans
- **Oldest stromatolite fossils (3.5 bya)**
    - Sedimentary rocks formed by sticky cyanobacterial "biofilms" that slowly trapped fine sediments in layers
    - Photosynthesis by stromatolite formers is key metabolic process that produced oxygen in abundance

➢ **3 domains of life**
- Microbes
    - Bacteira
        - Cyanobacteira
        - Free oxygen from photosynthesis by cyanobacteria formed iron precipitates, and increased later. Toxic to anaerobic early life froms
    - Archaea
        - Ancient bacteria
        - No photosynthetic species
        - Contain unique proteins for transcribing DNA to RNA, similar to Eucaryotes
        - Most probable ancestors of all Eucaryotes
- Eukaryotes

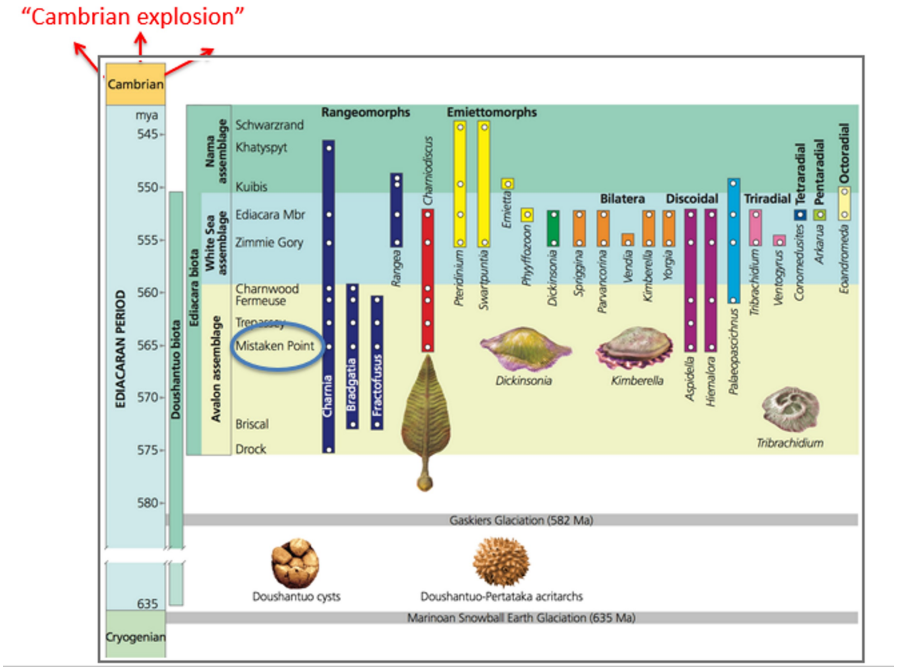
➢ Oldest fossils of multicellular life
- 2.1 bya



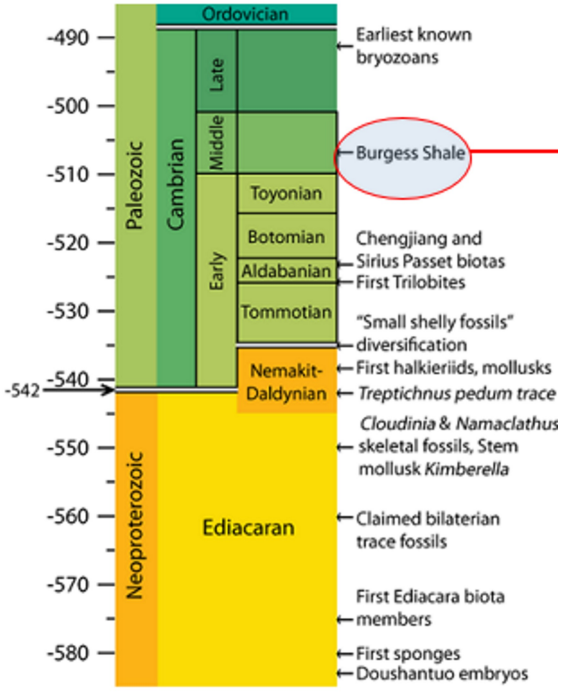
➢ Eukaryotic multicellular life (membrane bound nucleus)
- Earliest fossils of algae date to ~1.6 bya
- Red algae: 1.2 bya
- Green algae: appear 750 Ma; ancestors of green plants

Red algae fossil; 1.2 bya

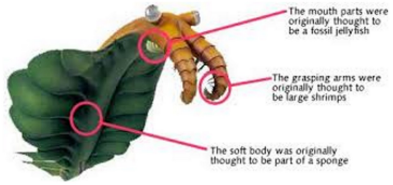
- **Ediacaran fauna**
  - Diverse and unique animals dominated global oceans from 575-535 mya
  - Fossil sponges: some early forms back to Ediacaran ~650 Ma
    - Sponges, the simplest animals, have long fossil records, and still common in modern oceans nd fresh waters
    - Sponges first animals?
  - **Charnia, spidella, springgina, dickinsonia, charniodiscus, tribrachidium, kimberella, p.reticulata,**



- **Cambrian fauna**: appearance of many familiar animal lineages 520 Ma
  - Beginning of **phanerozoic eon**
  - **"cambrian explosion" is common term for relatively sudden appearance of many new animal lineages**
    - Rapid diversification of early multicellular marine animal fossils
  - Burgess shale



- Lineages of Molluscs, crustaceans, worms
- Anomalochris
    - Large swimming Cambrian predator discovered in stages



- First known Chordates emerged during early Cambrian
    - Vertebrate origins?
    - Chordates: animals with a notochord (stiffening rod) along back
    - Vertebrates: with vertebrae forming a backbone

➢ Key concepts

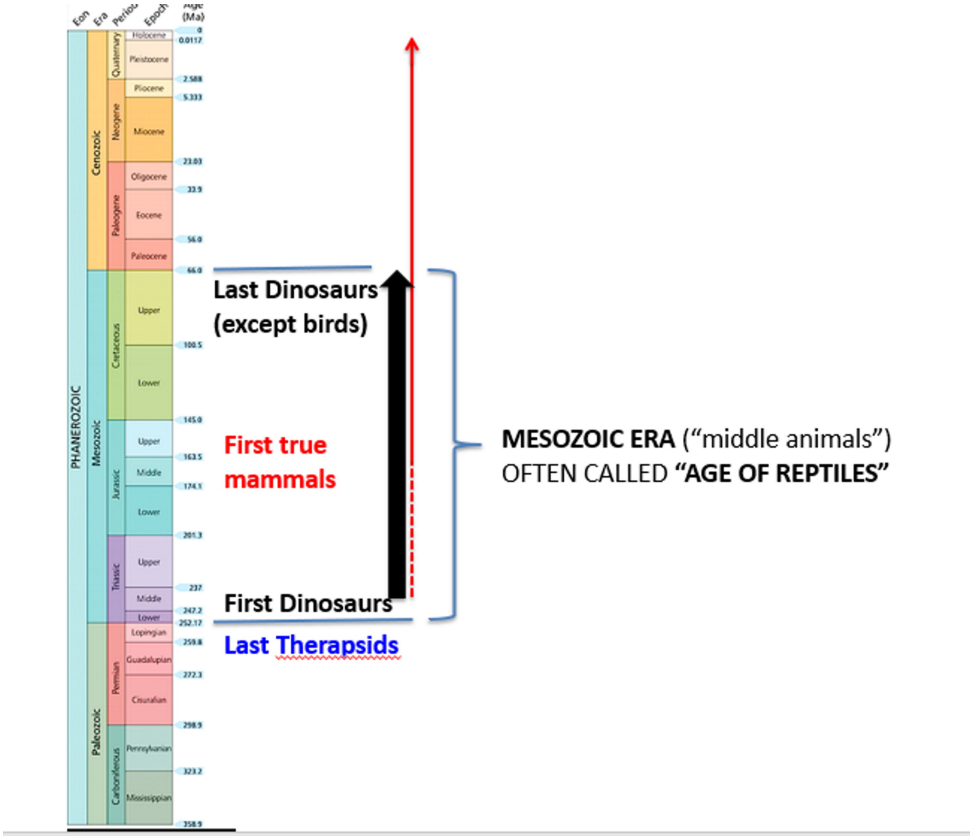
- Only a fraction of Ediacaran fauna share traits with existing lineages
    - Almost all extinct within 40my
- Most existing lineages are found in the fossil record during the Cambrian period
    - Includes our own lineage, the chordates

➢ Devonian period

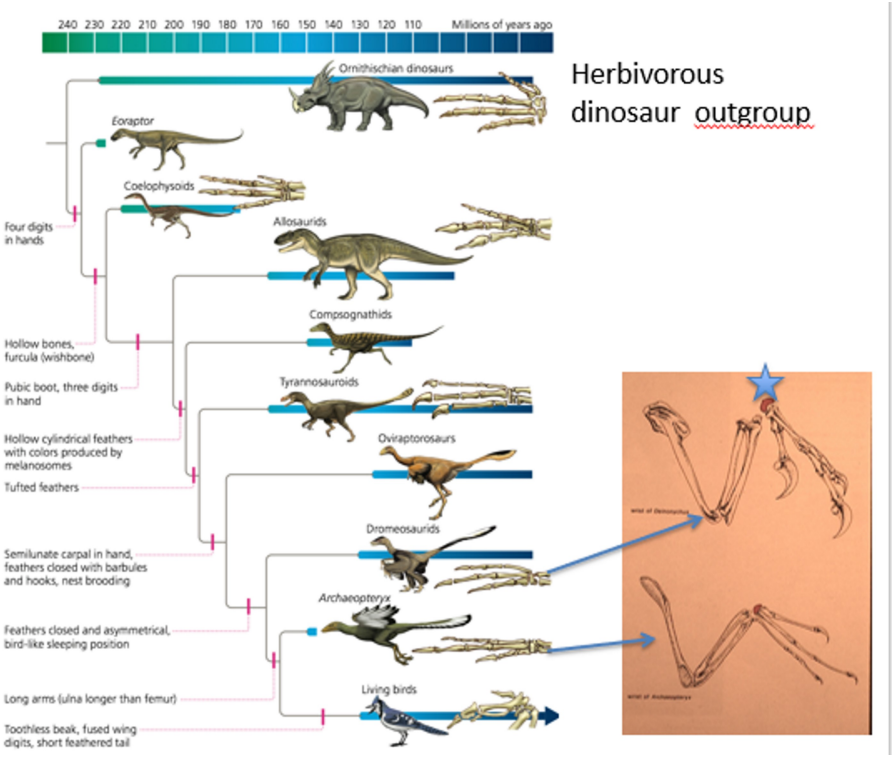
- First terrestrial plant and fungal life
    - Oldest terrestrial plant fossils 475 ma, earliest fossil plants resembled mosses and liverworts (small, simple structures)
    - Large forest ecosystems develop within 100 million years in Devonian period
    - **Fungi appear ~400 myo**
        - Associated with plants

- First terrestrial animal life
  - Invertebrate trackways date to 480 mya
    - Probably relatives of insects and spiders
    - Not clear whether they lived on land permanently
  - Oldest fossil of fully terrestrial animal (**millipede**) dates to 428 mya (**silurian)**
- **First terrestrial vertebrates**
  - Oldest trackways date to 390mya (devonian)
  - Oldest fossils of tetrapods date to 370 mya
  - **Tetrapods**: vertebrates with four limbs (or, like snakes, descended from vertebrates with four limbs). Living tetrapods include mammals, birds, reptiles, and amphibians
- **Homologies**: homologous structures are similarities that were inherited from a common ancestor of the taxa in question
  - Comparative anatomy
  - Embryology
  - Behaviour
  - Biochemistry (amino acids, enzymes, metabolic byproducts, pigments, etc)
  - **DNA molecular evolution**
    - Homologous genes and other nucleotide sequences
- **Evolution of mammals**
  - Mammals evolved from **synapsid retiles called therapsids (not dinosaurs)**
    - **"mammal-like reptiles" therapsids**
    - Dominant land vertebrates around 280 mya (late permian period), prior to big extinction event
    - Some were huge, many small; dominant land animals in permian
    - They all died out during the end-permian mass extinction event
    - Small mammals had evolved by late permian
    - ✓ Jaw bones to inner ear bones??
      - 3 inner ear bones of mammals
        - proven by fossil evidence
      - Embryological evidence
        - bones that start out attached to back of jaw, become smaller and turn into the 3 inner ear bones
      - Human inner ear bones also homologous to ancestors
        - Living reptiles do not have this inner ear arrangement (homology), therapsids are almost certainly the distance ancestors of all mammals, including humans

  - First dinosaurs appear later ~230 mya (triassic)
    - **First true mammals emerged ~150 mya (mid-jurassic)**



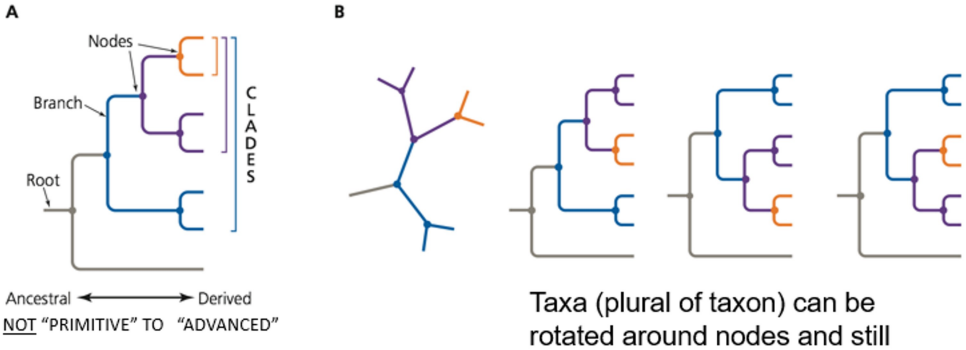
- Diversification of mammals
  - **Mammals diversified after dinosaurs went extinct (~66mya)**
  - Whales, bats, and primates all emerged around 50 mya (**Eocene period)**
  - Primates appear in Eocene, but do not develop into monkey and ape forms until much later in Miocene
  - *Sahelanthropus* (oldest known bipedal hominid fossil)
  - **Oldest human (homo sapiens)**
- **Homoplasy**: convergent or parallel evolution
  - Ex) turtles have a different ancestor than mammals,
  - whales have similarities with fish (shape, fins) arose through convergent evolution (adaptations to living in an aquatic environment, not ancestry)
  - Homoplasy between birds and humans --> Bipedal
- **Homology:** homologous structures are similarities that were inherited from a common ancestor of the taxa in question
  - Ex) homology b/t human and chimpanzee hands and feet is obvious (bones, muscles, ligaments, etc)
  - Human and apes
    - Bipedality
    - Larger brain size
    - Smaller canine teeth
- **Birds are theropod (meat eating dinosaurs)**
  - Archaeopteryx (~145 mya near the jurassic/cretaceous boundary)
  - Feathers evolved before flight in theropods
    - Fingers & claws in some living birds



- **Exaptation:** natural selection co-opts a trait for a new function, like flight (not necessarily evolved as adaption for flight)
- **Examples: Velociraptor**

Chapter 4 the tree of life: phylogeny

- **Phylogeny:** a visual representation of the evolutionary history of populations, genes, or species
- Reading a phylogenetic tree



EACH NODE IS A "BRANCH POINT" DEFINED BY THE APPEARANCE OF A NEW SHARED TRAIT (**SYNAPOMORPHY**)

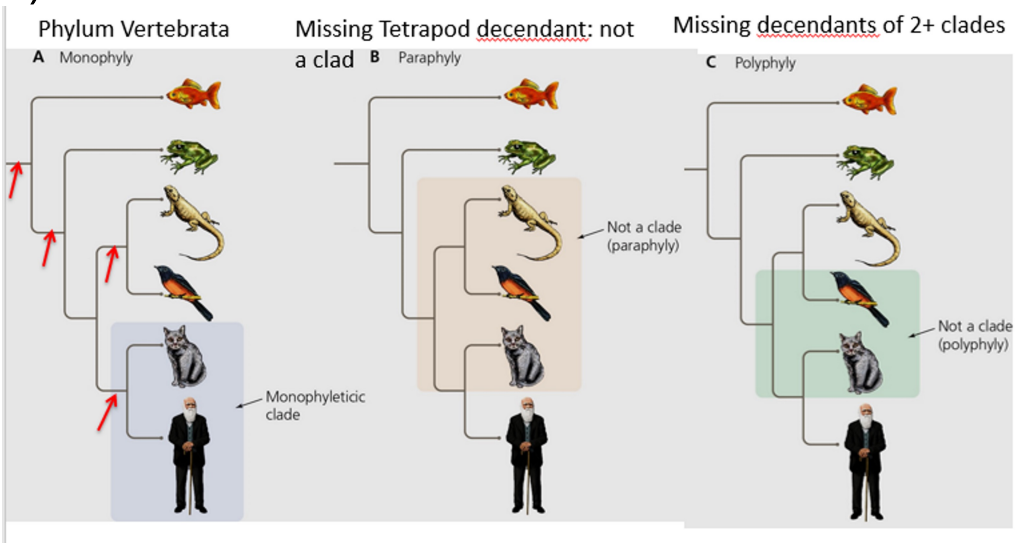
CLADES CAN BE ANY **TAXON** (TAXONOMIC CATEGORY: SPECIES, GENERA, FAMILY, ORDER, ETC.): *ANCESTOR + ALL DECENDANTS*

- Branches: lineages evolving through time that connect successive speciation or other branching events
- Nodes: points in a phylogeny where a lineage splits (a speciation event or other

branching event, such as the formation of subspecies)

- Tips: the terminal ends of an evolutionary tree, representing species, molecules, or populations being compared
- Internal nodes: nodes that occur within a phylogeny and represent ancestral populations or species
- Clades: single "branches" in the tree of life; each clade represents an organism and all of its descendants

➢ **Monophyletic groups: must include all the descendants of an ancestor (one "snip" to detach)**



➢ **Polyphyletic** : a taxon that does not include the common ancestor of all members of the taxon

➢ **Paraphyletic:** a group of organisms that share a common ancestor although the group does not include all the descendants of that common ancestor

➢ **Characters:** heritable aspects of organisms that can be compared across taxa

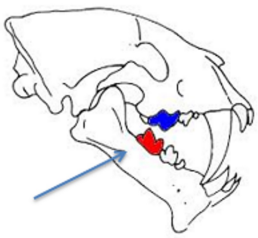
➢ **Taxa (singular, taxon):** groups of organisms that a taxonomist judges to be cohesive taxonomic units, such as a species or order

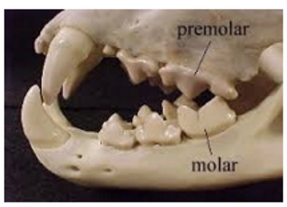
➢ **Outgroups:** groups of organisms that are outside of the monophyletic group being considered. In phylogenetic studies, outgroups can be used to infer the ancestral states of characters.

➢ **Cladistics:** modern method of constructing phylogenies of clades: "nested hierarchies" of organisms according only to their shared derived characters, or synapomorphies

➢ **Order carnivora "flesh eaters"**

- Share "characters" that define this mammal clade. One synapomorphy found only in carnivores is **carnassial teeth** (upper premolar & lower molar = flesh shears)





PUMA (cat)


Dog using carnassials

➢ **Parsimony rule:** principle that guides the selection of alternative hypotheses; the alternative requiring the fewest assumptions or steps is usually (but not always) best. In

cladistics, scientist search for the tree topology with the least number of character-state changes- the most parsimonious

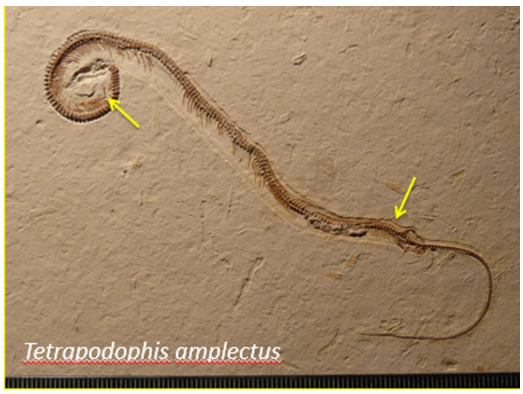
- **Homoplasy**: character state similarity *not* due to common descent (may be difficult to detect)
  - CONVERGENT EVOLUTION: independent evolution of similar trait (streamlined shape of whales, sharks, Ichthyosaurs)

➢
  - **EVOLUTIONARY REVERSALS**: reversion back to an ancestral character state (many vestigial structures) (ie no legs in snakes, although they are tetrapods like lizard ancestors)

  - SNAKE EVOLUTION FROM 4-LIMBED REPTILE ANCESTORS
  - LONG HISTORY OF SPECULATION? **EVIDENCE**?

➢ Marine mosasaurs (extinct reptiles, not dinosaurs)
- Possible snake ancestors with 4 legs
- 120 Ma old (cretaceous)
- 

UNRESOLVED QUESTION: ARE SNAKES DERIVED FROM 4-LIMBED MARINE MOSASAURs OR TERRESTRIAL ANCESTORS?



The combination of a snake-like body with complete forelimbs and hindlimbs suggests a snake version of *Archaeopteryx*."

- Snake hips in boas
  - "spurs" are vestigial hind leg bones still attached to vestigial "hips" or pelvic girdle

KEY CONCEPTS

- **Phylogenies ("Evolutionary trees")** are created by identifying synapomorphies. (Such traits can help confirm homologies among taxa)

- Homoplasy can create the mistaken impression that
➢ two species are closely related when they are not (convergence)

- **Phylogenetic trees are hypotheses** based on best available data (often missing or incomplete in fossils): Often revised/updated as new data becomes available and trees redrawn

- **Water to land transition**
  - *Coelacanths* ("living fossils") : closest living relatives of tetropods (vertebrates with 4 limbs)
    - Fins are homologous to tetrapod forelimb
  - *Eusthenopteron* fossil: devonian
  - *Tiktaalik:* transitional fossil b/t ancient lungfish and tetrapods
    - Devonian
  - *Ichthyostega:* first true amphibian tetrapod