THE HISTORY OF LIFE ON EARTH

Evolution and the Natural World

Lecture 13

15/10/2020

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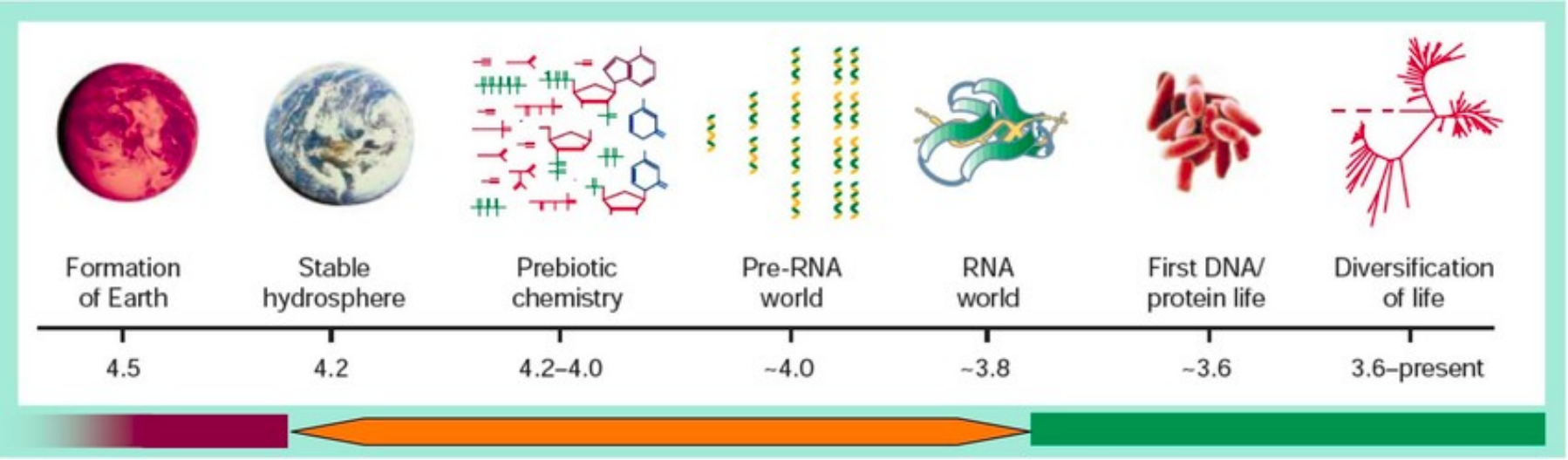
The origin of life



Evolution of life on Earth: questions

- When, how and why did a certain group (animals, mammals, humans) originate?
- When and why did mass extinctions happen?
- Why some groups thrive while others go extinct?
- How do new high order taxa evolve?
- Does **macroevolution** happen gradually?

DESCRIBING THE HISTORY OF LIFE

Information source: fossils

- Hard tissues (bones, exoskeleton, shells)
- Petrification (different tissues incl. those above)
- Casts (imprints)
- Trace fossils

- Fossilization isn’t easy and there is a bias!

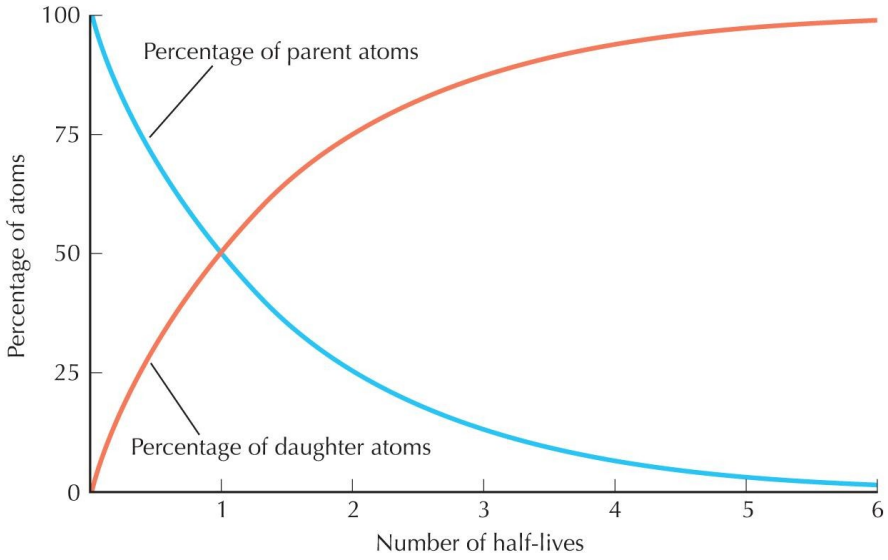
https://www.pinterest.cl/pin/9218374215232630/
http://deanfalk.com/human-brain-evolution-what-fossils-tell-us/
https://teara.govt.nz/en/photograph/9047/fossil-foraminifera

Dating fossils

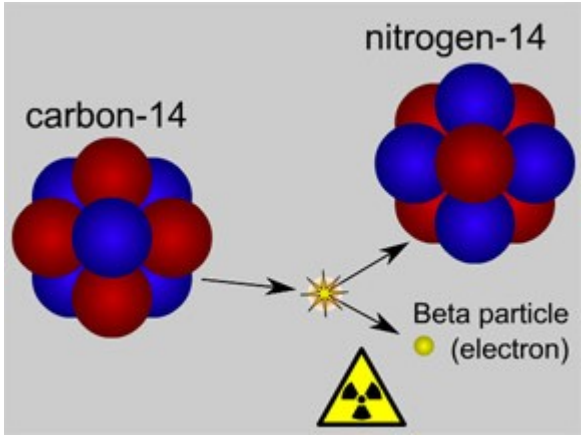
- Relative dating based on stratigraphy – putting sediments layers into chronological order

https://www.pinterest.com/pin/725009239987097019/?lp=true

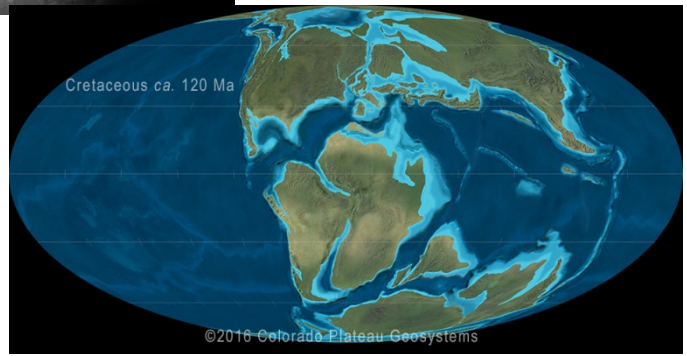
Dating fossils



- Absolute dating using radioactive isotopes – applicable to volcanic rocks



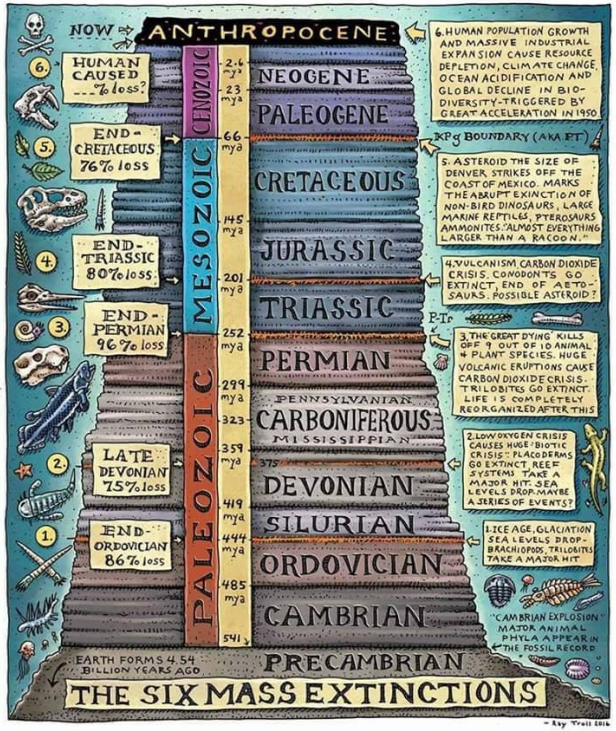
Understanding Earth's past

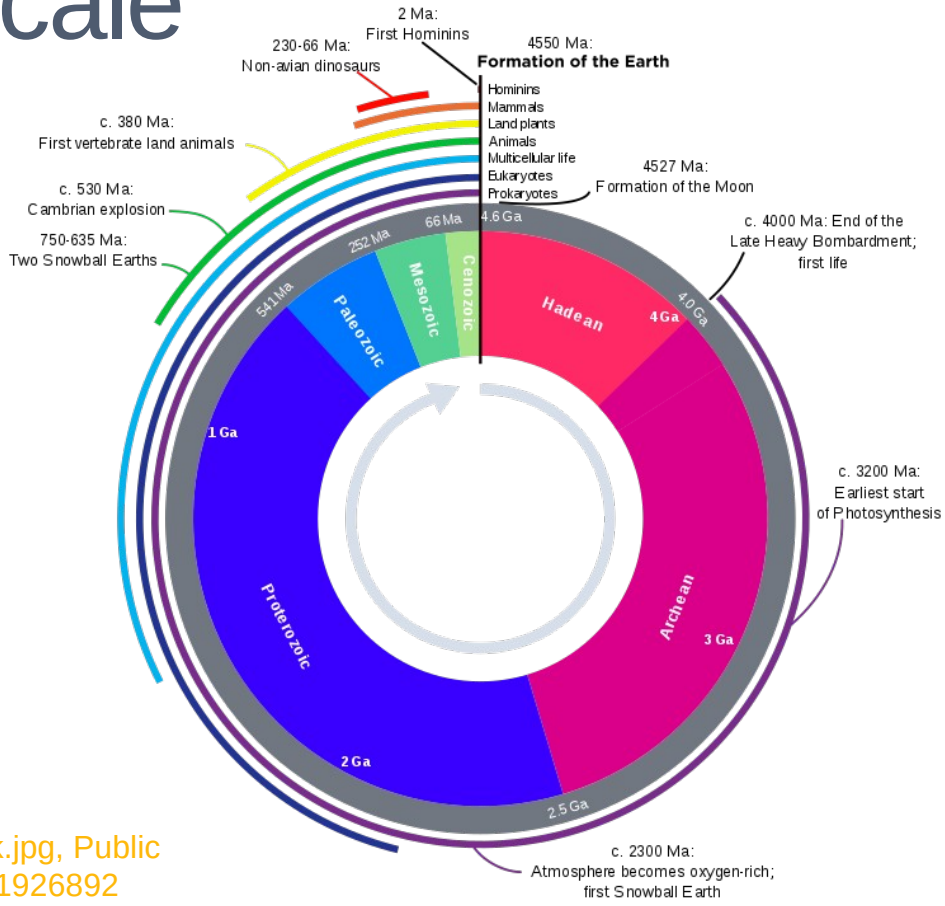


- By studying rocks as well as modern processes we can identify
  - Climate changes (snowball Earth)
  - Massive volcanic eruptions
  - Impact events
  - Plate tectonics

https://www.sciencemag.org/news/2019/04/ancient-snowball-earth-thawed-out-flash
http://deeptimemaps.com/global-series-thumbnails/

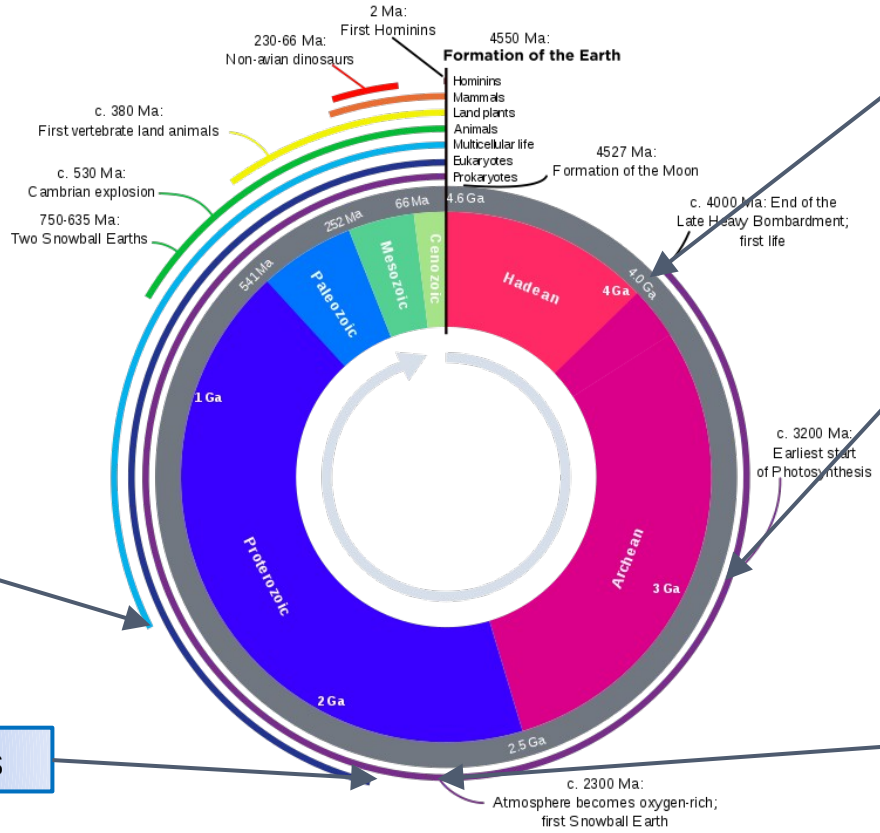
Geological time scale





By WoudloperDerivative work: Hardwigg - File:Geologic_clock.jpg, Public Domain, https://commons.wikimedia.org/w/index.php?curid=11926892

A selection of main events



4 bya Origin of life

3.2 bya Start of oxygenic photosynthesis

1.2 bya First multicellular organisms (small algae)

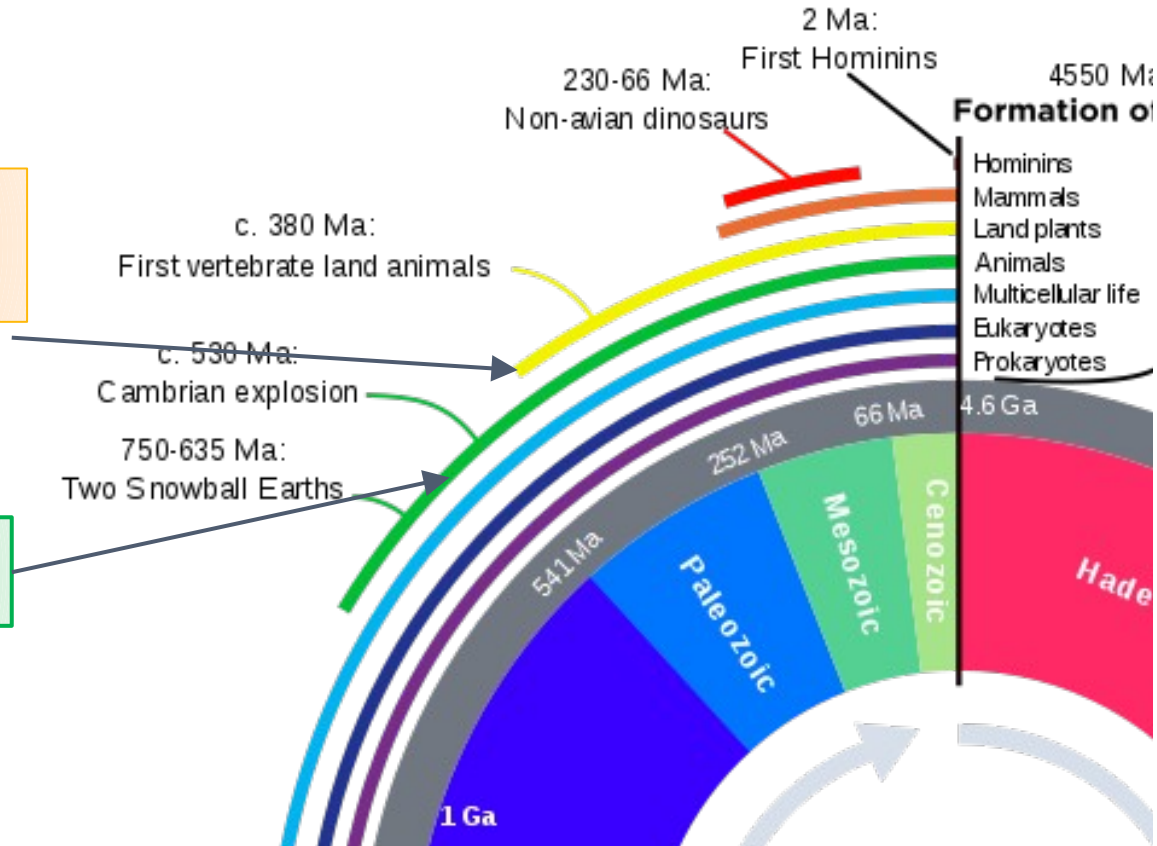
2.1 bya Origin of eukaryotes

2.3 bya “Oxygen revolution”

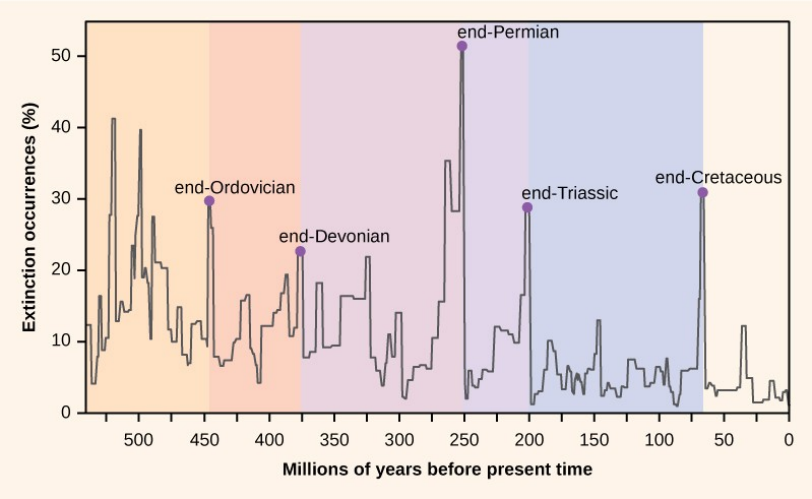
A selection of main events

450-420 mya Earliest land plants and land Arthropods

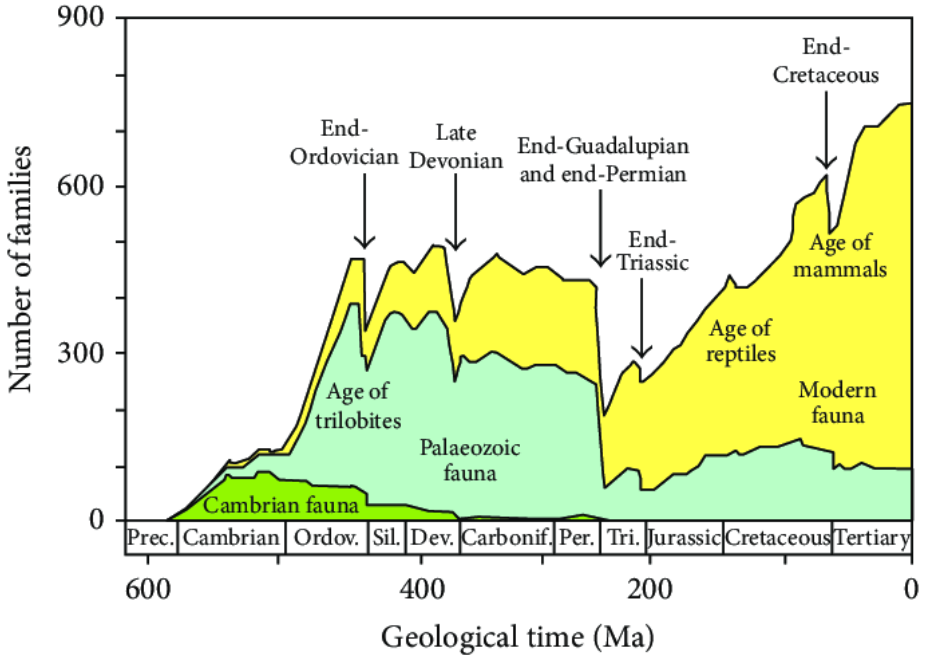
575-535 mya Edicaran biota – first macroscopic animals



Mass extinctions



Geological Period	Mass Extinction Name	Time (MYA)
Ordovician–Silurian	end-Ordovician or O–S	450–440
Late Devonian	end-Devonian	375–360
Permian–Triassic	end-Permian	251
Triassic–Jurassic	end-Triassic	205
Cretaceous–Paleogene	end-Cretaceous or K–Pg (K–T)	65.5



Percentage of extinct families: late Ordovician 12%, late Devonian 14%, late Permian 52%, late Triassic 12%, late Cretaceous 11%

http://bio1520.biology.gatech.edu/biodiversity/mass-extinctions-and-climate-variability-2/
https://www.researchgate.net/figure/Number-of-families-as-a-function-of-geologic-time-showing-the-five-major-extinction_fig4_304032154

Permian extinction

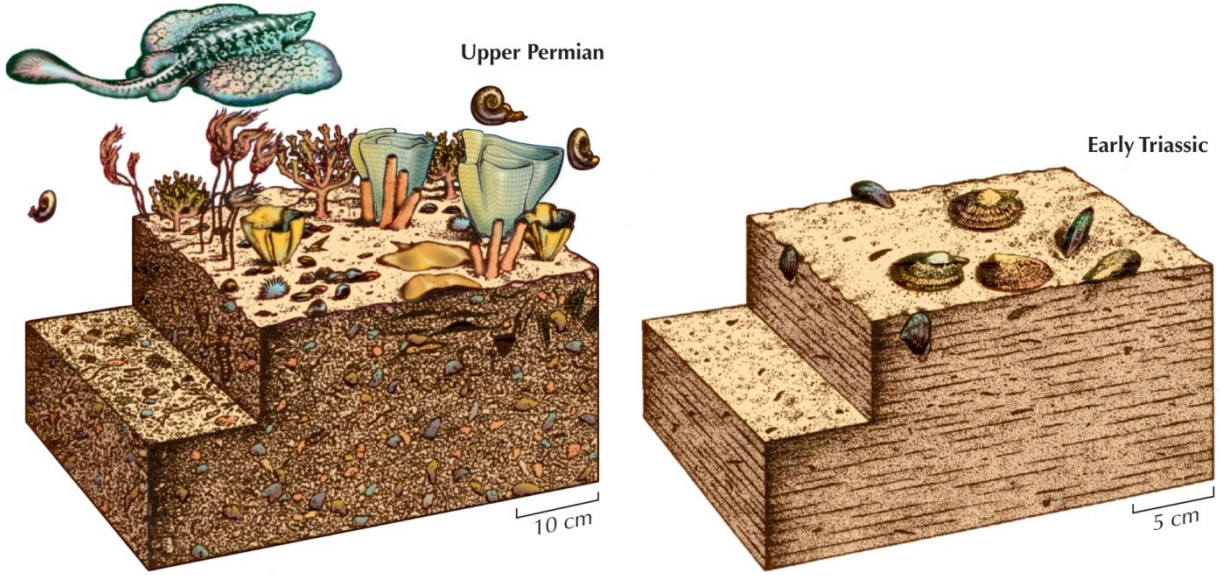


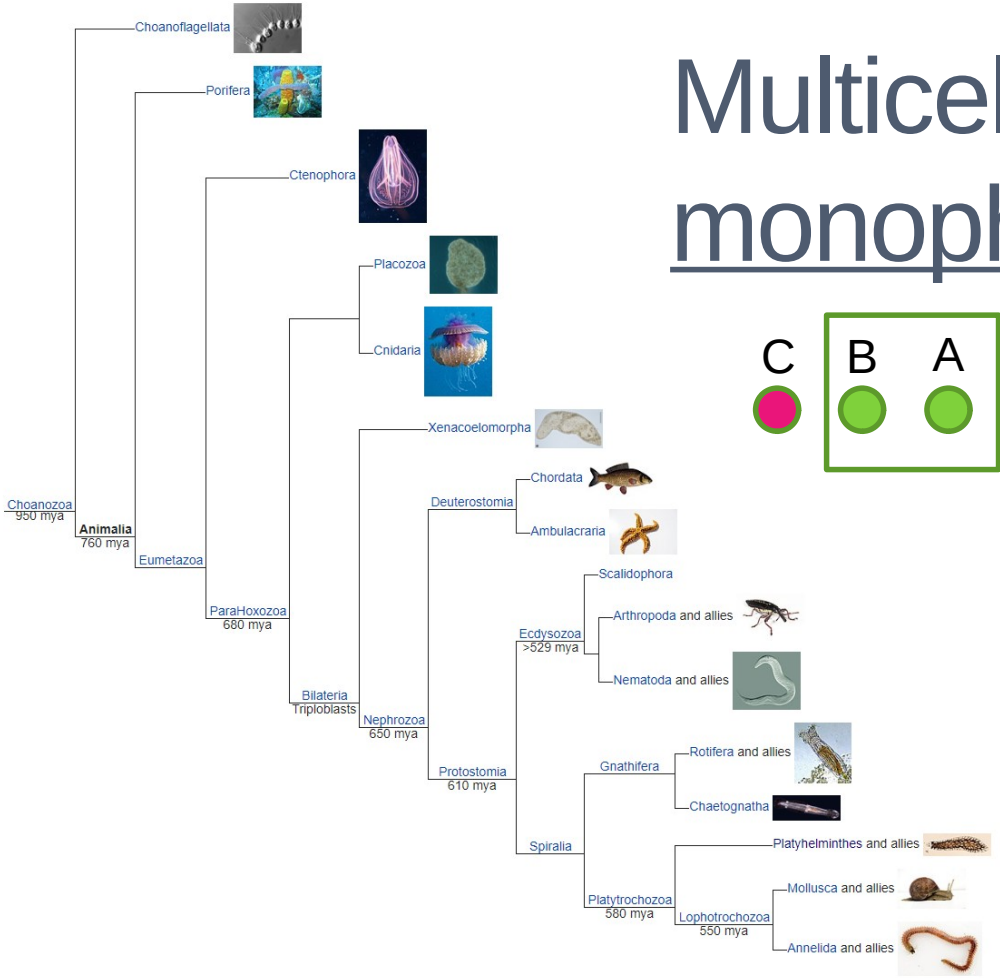
FIGURE 10.37. Effects of the Permian extinction. The latest Permian tropical seafloor compared with that of the Early Triassic, based on the section at Meishan, China, showing the loss of reef-dwelling organisms.

10.37, © John Sibbick

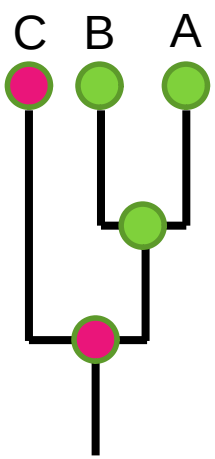
SOME EXAMPLES OF MACROEVOLUTION

Evolution beyond speciation (origin of large taxa like phyla)

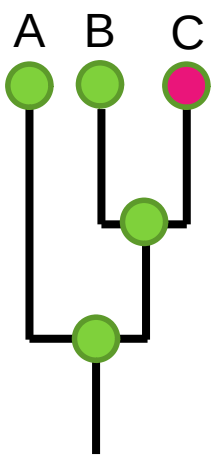
Multicellular animals are monophyletic



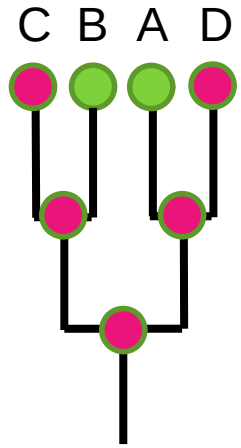
Mono-



Para-



Poly-



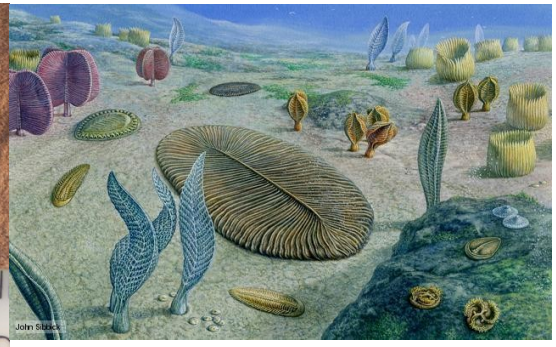
Key notes

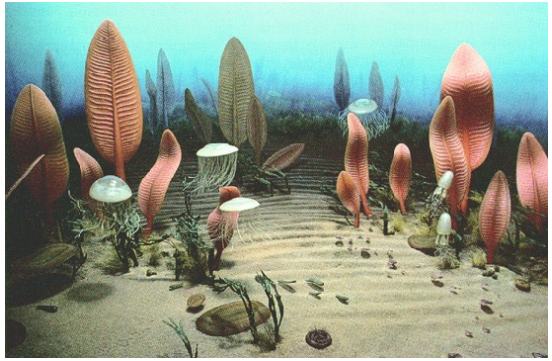
- 635-551 mya – oldest fossils of animal embryos (?)

https://jgs.lyellcollection.org/content/174/5/793

- 575-541 mya – Edicaran fauna
- 541 mya – Cambrian explosion
- Appearance, diversification and movement to land of major groups
  - arthropods incl. insects,
  - vertebrates incl. tetrapods which in turn include reptiles and mammals

Edicaran fauna

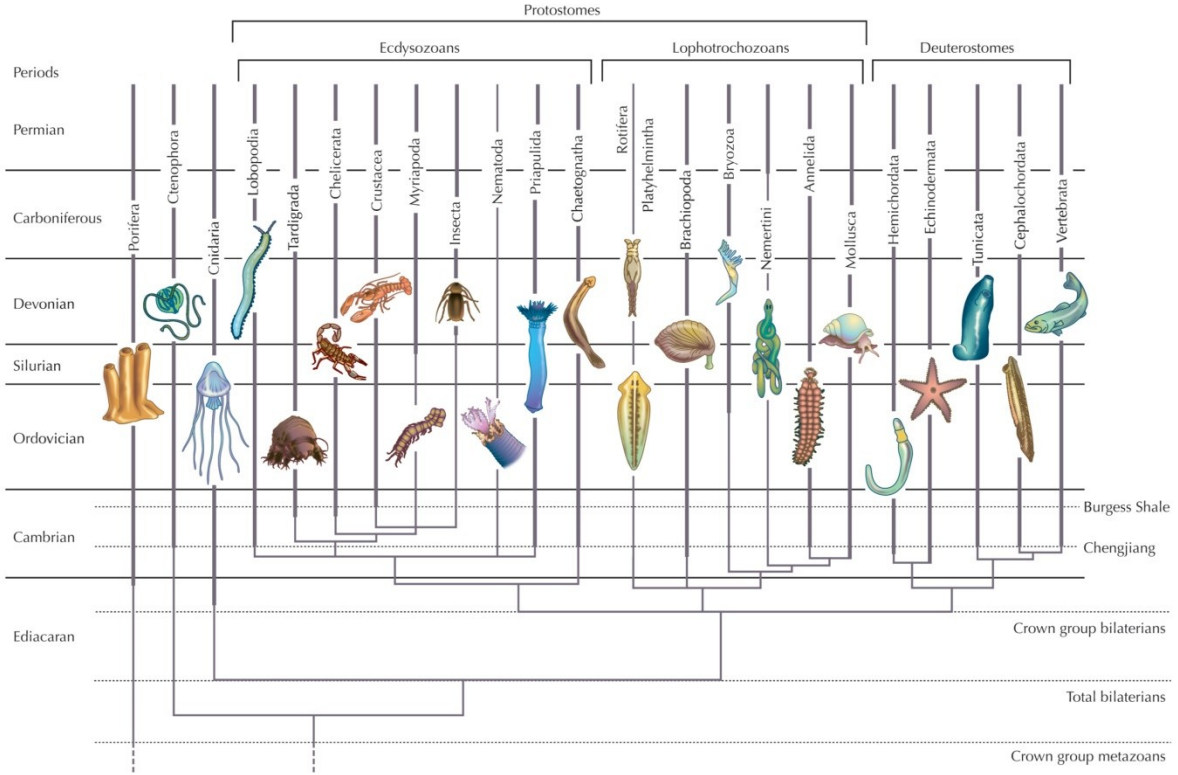




- The oldest fossils of large (up to 1 m) soft-bodied animals
- Some are so strange that may even not belong to any extant phyla

http://evolution-textbook.org/content/free/figures/10_EVOW_Art/10_EVOW_CH10.jpg

Cambrian explosion



- Sudden appearance of almost all modern phyla as well as some extinct ones
- Chengjiang and Burgess Shale sites with soft- and hard-bodied animals

http://evolution-textbook.org/content/free/figures/10_EVOW_Art/16_EVOW_CH10.jpg

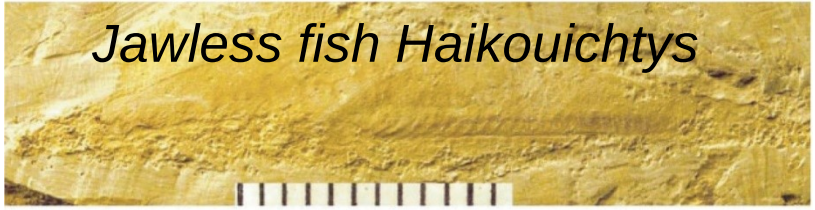
Cambrian explosion: interpretations

trilobites

soft-bodied worms

nautiloids

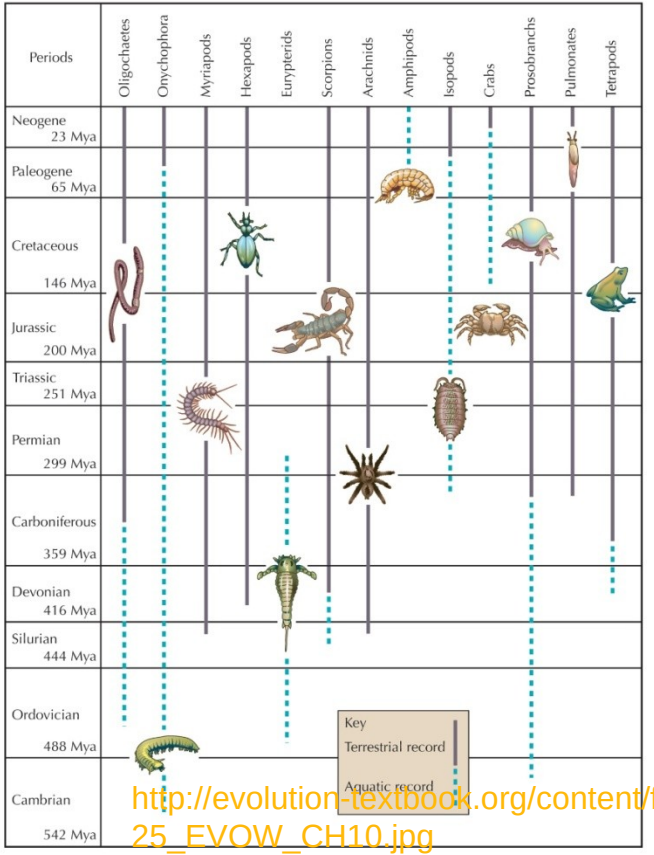
Hallucigenia



- Molecular data suggest pre-Cambrian divergence

- Better fossilization?
- Diversification driven by predator-prey interaction?
- Adaptive radiation after a previous mass extinction?
- Early evolution of developmental pathways?

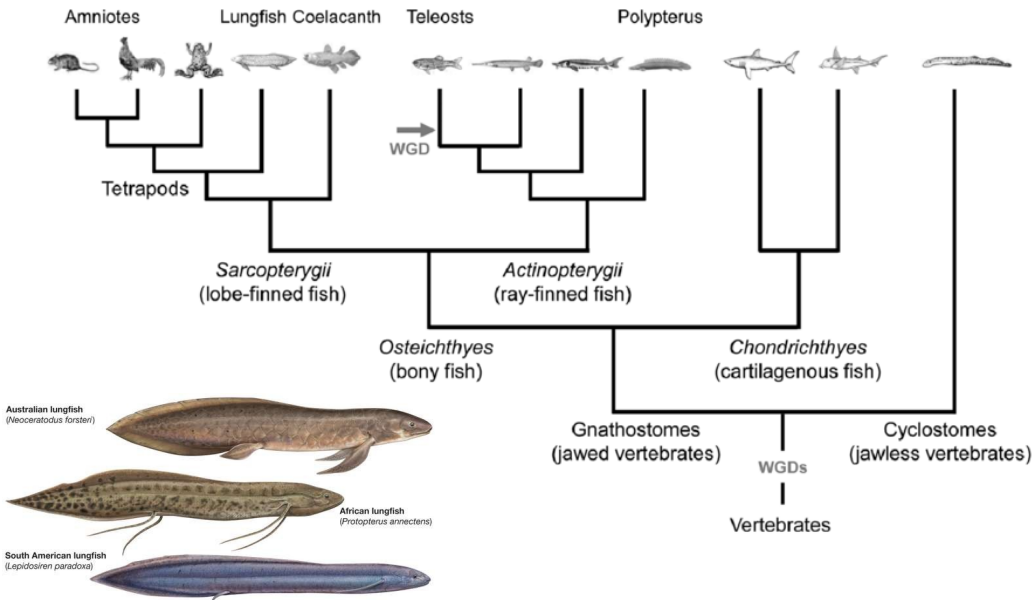
Colonization of land



http://evolution-textbook.org/content/free/figures/10_EVOW_Art/25_EVOW_CH10.jpg

- Different groups moved to land independently
- Nowadays, arthropods, vertebrates, annelids and mollusks are the main land animals
- Let’s focus on vertebrates as an example

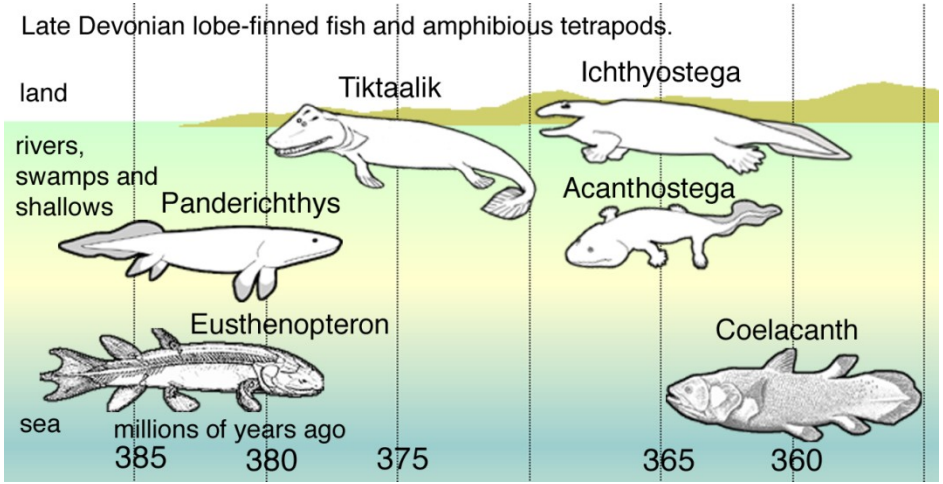
Tetrapods – land vertebrates



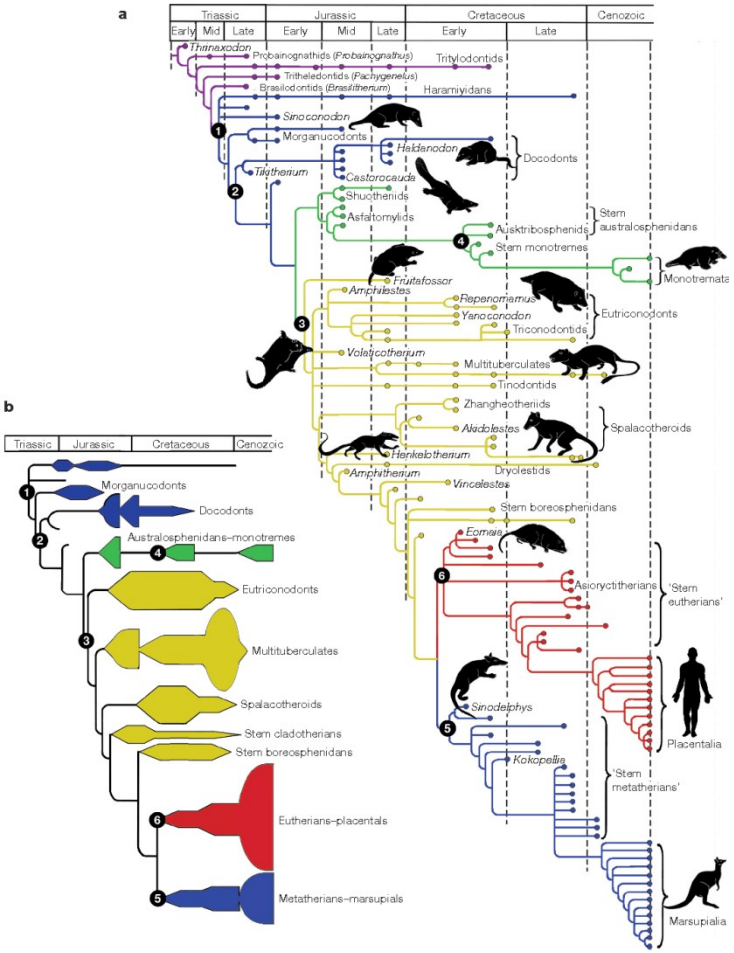
- Fishes and fish-like animals comprise most of vertebrates in terms of species number and phylogenetic diversity
- The closest fish relatives of tetrapods are lungfishes

https://www.researchgate.net/figure/Phylogenetic-tree-of-vertebrates-A-simplified-phylogenetic-tree-focusing-on-the_fig1_316690258
https://www.britannica.com/animal/lungfish

Early evolution of tetrapods



- Most likely the earliest tetrapods lived in shallow drying out fresh waters
- Maybe similar traits evolved in parallel in different groups but only one of them gave rise to extant tetrapods

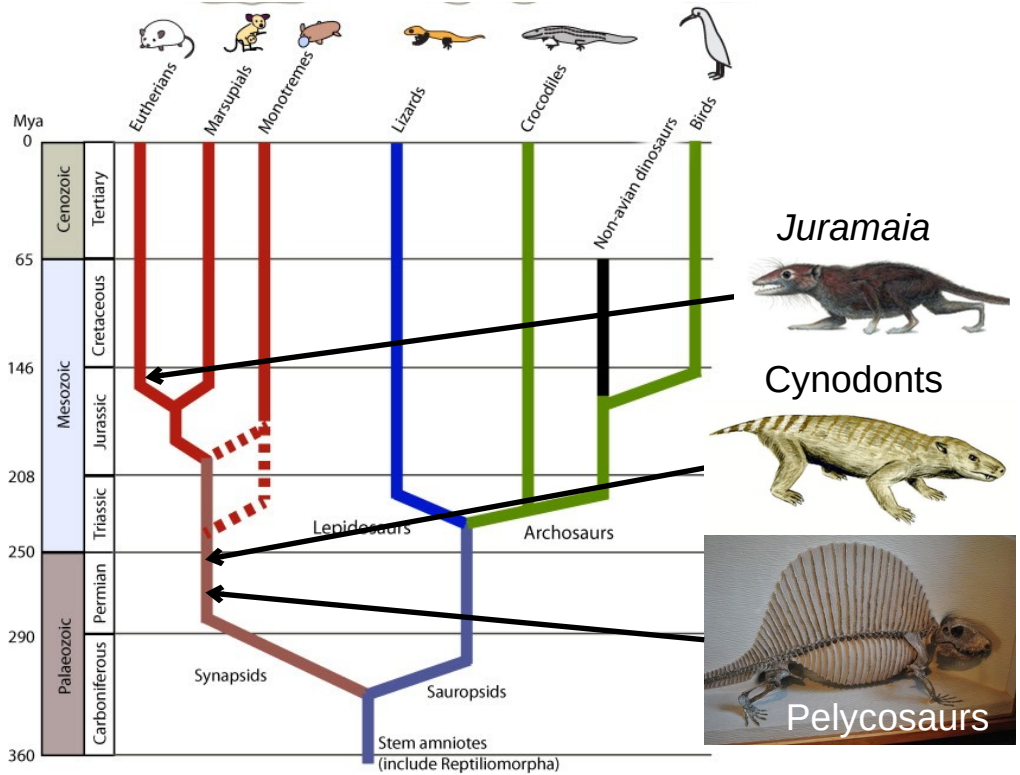


https://www.nature.com/articles/nature06277

Evolution of mammals

- Modern mammals are represented by monotremes, marsupials and placental mammals
- But there were many mammals and related groups

Evolution of mammals



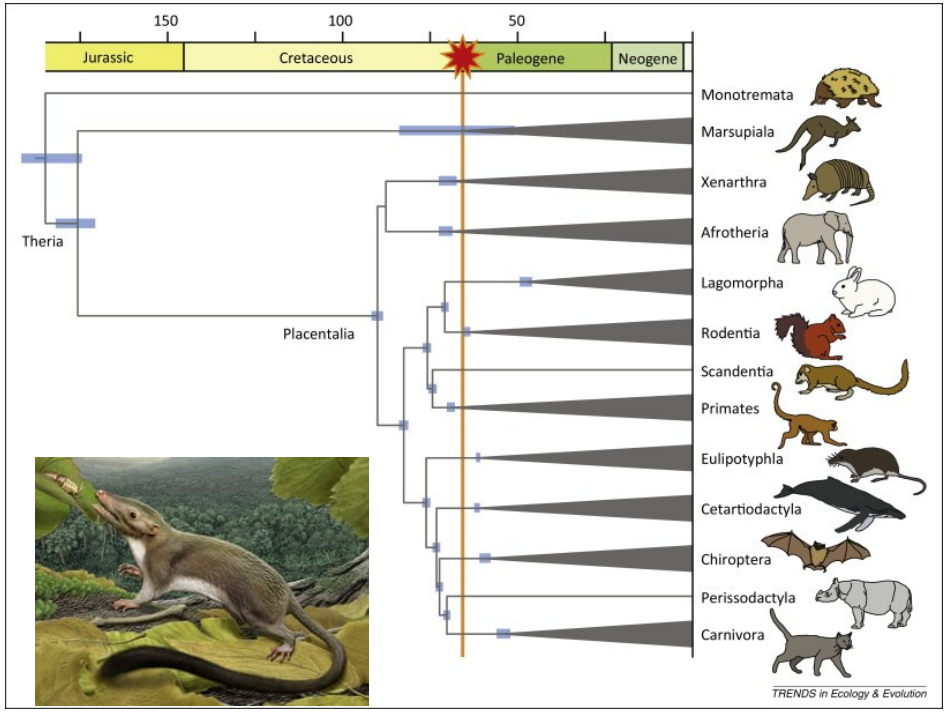
Juramaia

Cynodonts

- Mammals belong to a group distinct from modern reptiles and birds, but their ancient ancestors were reptiles-like
- Some mammalian features appeared early and perhaps in parallel in different lineages

https://www.researchgate.net/figure/Phylogenic-tree-of-amniotes-The-first-amniotes-appeared-approximately-350-million-years_fig3_260997108

Diversification of mammals



- During the Mesozoic era there were different groups of mammals, but most of them were small nocturnal insectivores
- Diversification of modern groups and evolutions of modern phenotypes started after the extinction of dinosaurs

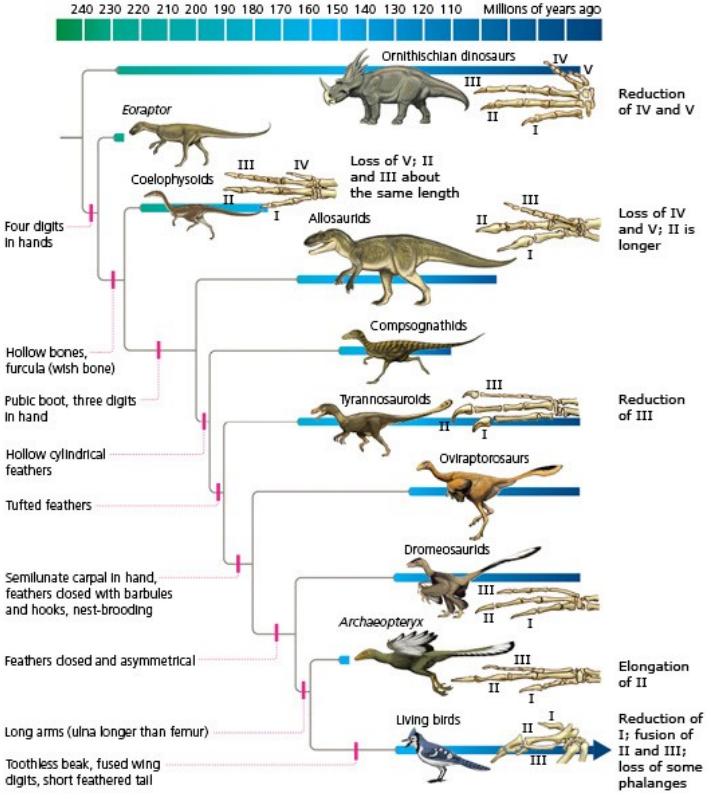
https://www.cell.com/trends/ecology-evolution/fulltext/S0169-5347(14)00155-4
https://www.theguardian.com/science/2017/nov/07/teeth-discovered-in-dorset-reveal-secrets-of-the-origins-of-modern-mammals

Evolution of birds

- Now we have quite some fossils elucidating the evolution of birds
- Archaeopteryx is an iconic example, but not the only one

https://evolution.berkeley.edu/evolibrary/article/evograms_06
https://www.cell.com/current-biology/fulltext/S0960-9822(15)00945-8

Evolution of birds



- The were feathered dinosaurs
- Feathers initially didn’t evolve for flight, but for thermal insulation => feathers are not an adaptation for flight but an exaptation (=‘preadaptation’)
- Maybe parallel evolution of usage of feathers for flight?

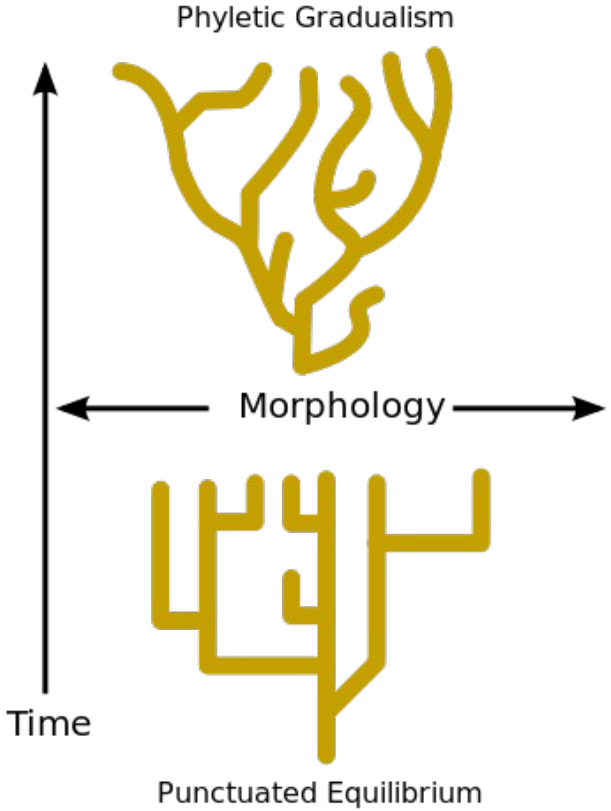
https://evolution.berkeley.edu/evolibrary/article/evograms_06

MECHANISMS AND TRENDS IN MACROEVOLUTION

Origin of species vs origin of phyla?

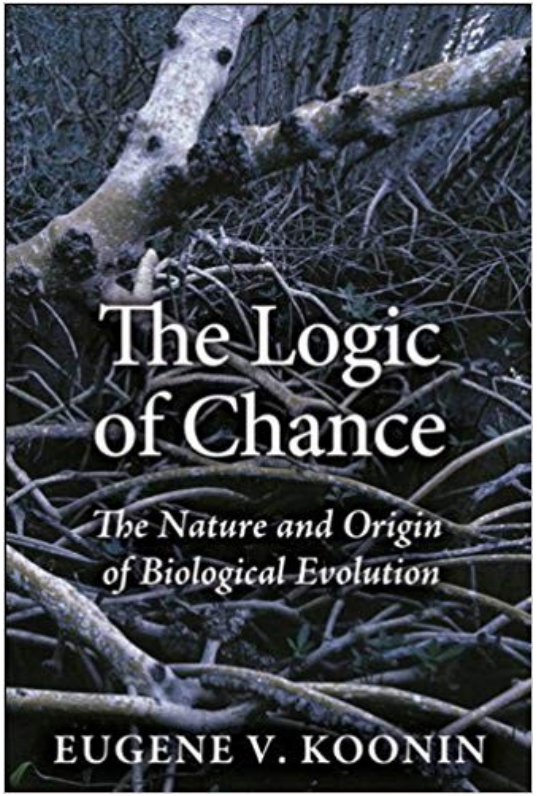
- No difference: mutations + drift + selection, just more time
- Something special:
  - Symbiosis – eukaryotes, different algae
  - Macromutations
    - Developmental genes?
    - Whole genome duplications – in early evolution of vertebrates and seed plants

Pace of macroevolution



- Classical view: very slow but constant (gradualism)
- Alternative view: “jumpy”, perhaps via macromutations (saltationism)
- Synthesis: changes occur relatively quickly (100-1000s generations) and are followed by long stasis when equilibrium between phenotype and environment is reached (punctuated equilibrium)

Trends in macroevolution



- No general trend for complexity – most lineages didn't increase dramatically in complexity
- Adaptive radiation happens when life enters new environment with many niches (like land) or niches get free due to mass extinctions
- Parallel evolution (convergence) indicates certain trends
- What's the role of randomness?

http://www.evolocus.com/Textbooks/Koonin2011.pdf

Key points

- Combining geological data, fossils (many are only recently discovered) and molecular data enables us to reveal evolutionary history of life in general and of certain groups in particular
- But there are still many open questions
- Describing evolutionary history helps to better understand fundamental trends and mechanisms of macroevolution