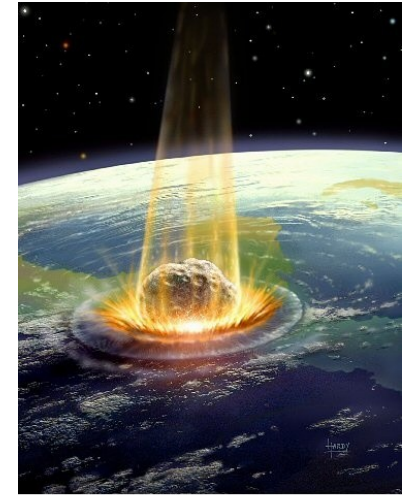
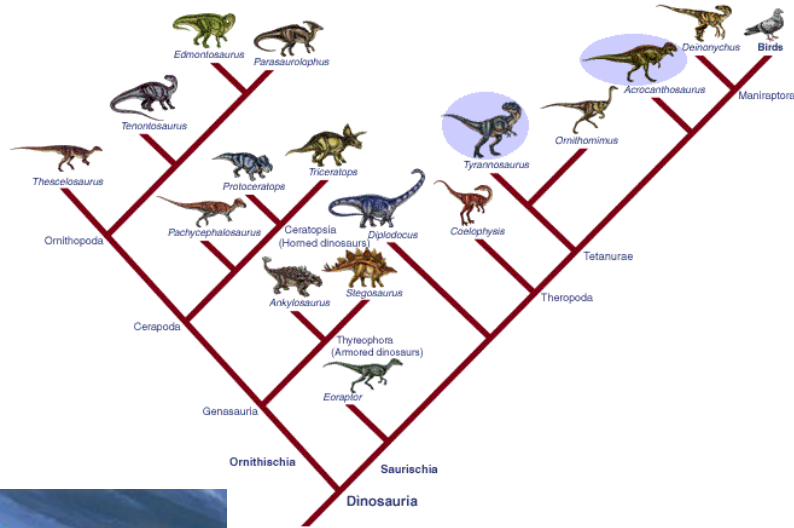
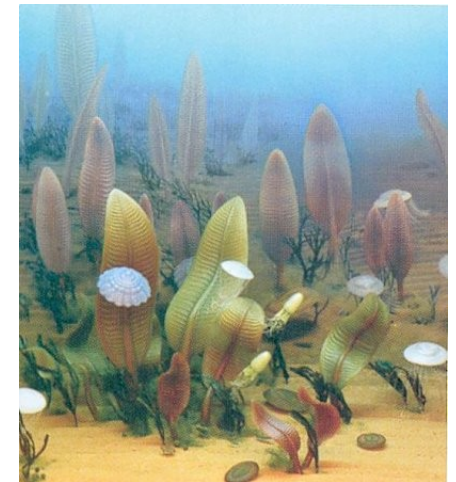


HISTORY OF LIFE ON EARTH



Asteroid Impact

David A. Hardy



Systematics and taxonomy

systematics, paleontology → history of evolutionary changes

systematics = study of relationships between organisms

taxonomy = theory and practice of classification

category: class, order, family, species, ...

taxon: Mammalia, Primates, Hominidae, *Homo sapiens*, ...

1. Before Linnaeus

honeybee = *Apis pubescens, thorace subgriseo, abdomine fusco, pedibus posticis glabris utrinque margine ciliatis*

[Bee with soft short hairs, gray chest, dark brown abdomen, legs with no hair, and small sacs with hair-like outgrowths along the edge]

Acaciae quodammodo accedens, Myrobalano chebulo Veslingii similis arbor Americana spinosa, foliis ceratoniae in pediculo geminatis, siliqua bivalvi compressa corniculata seu cochlearum vel arietinorum cornuum in modum incurvata, sive Unguis cati

[A spiny American tree, in some way resembling Acacia, similar to Vesling's *Myrobalanus chebulae*, with *Ceratonia* leaves in pairs on the pedicle, a silique with two valves, which is compressed, and horn-shaped or curved like the horns of snailshells or ram's horns, or like a cat's claws]

European bison = buffle, urus, bubalus, catoblepas, theur, the bubalus of Belon, Scottish bison

... Aristotle: bonasus → the same?



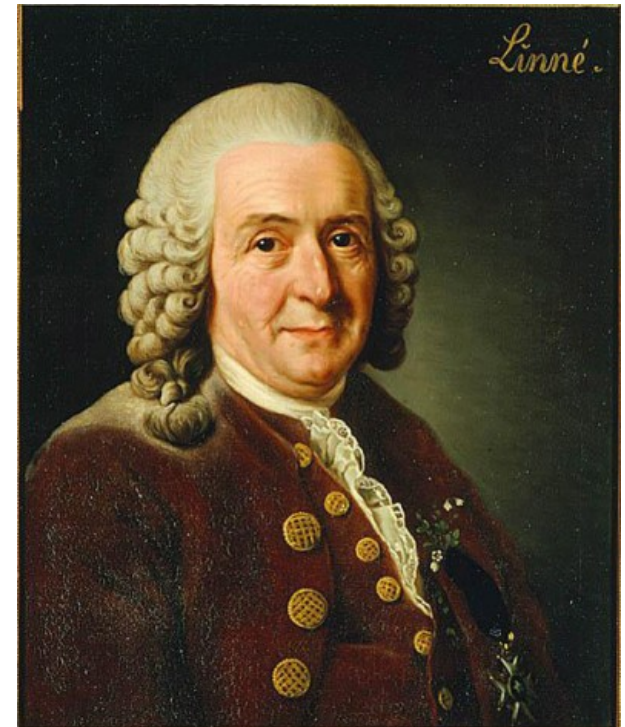
2. Carolus Linnaeus:

1735 *Systema Naturae*

binomial nomenclature: genus + species

hierarchical classification:

kingdom, class, order, genus, species,
(variety/subspecies)



Carolus Linnaeus

3. Darwin:

cladogenesis (branching) and anagenesis (change without branching)

a system should reflect a real phylogeny → but HOW?

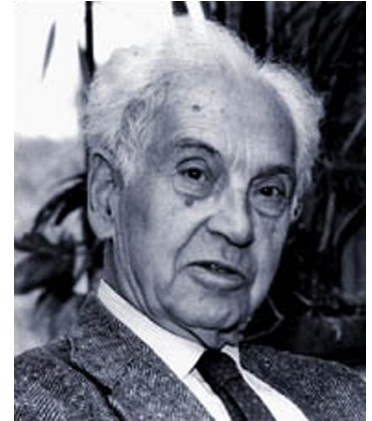
Evolutionary systematics

before 1950: common ancestor + adaptive divergence

discussions if adaptive or neutral traits better

subjective and unclear criteria of choosing and weighing of traits ⇒
taxonomy in crisis (⇒ the word „taxonomy“ itself replaced by
„systematics“)

controversy between splitters and lumpers



E. Mayr

Numerical taxonomy (phenetics)

1957: Charles Michener, Robert Sokal, P.H.A. Sneath



Hoplitis

taxonomy should be based on a total similarity rather than on a small number of „important“ traits

⇒ as many traits as possible

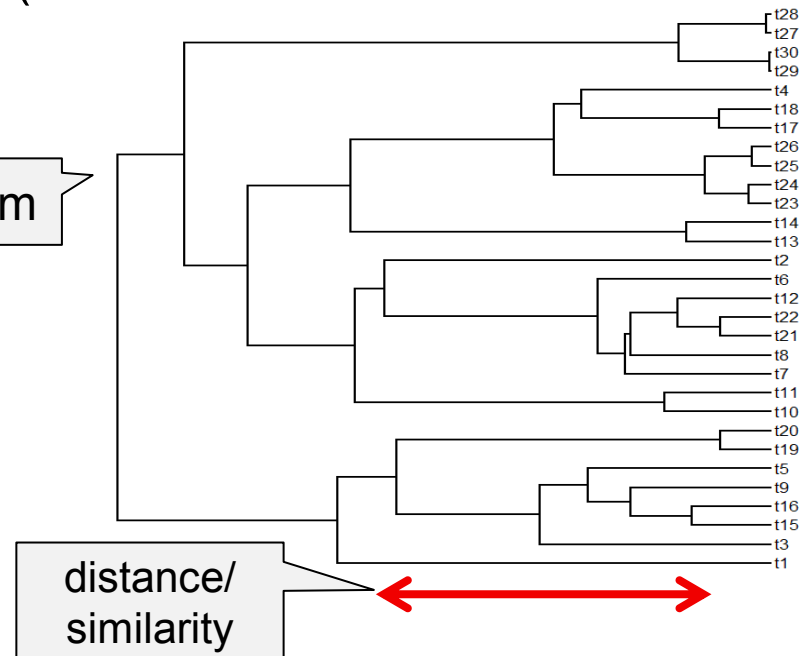
numerical methods: morphological and genetic distances, ordination (PCA, DFA, CVA, MDS, ...), cluster analysis (UPGMA)

phenograms

problems:

- homoplasy (= convergence, parallelism, reversion)
- shared primitive (ancestral) traits
- unequal rate of evolution

phenogram



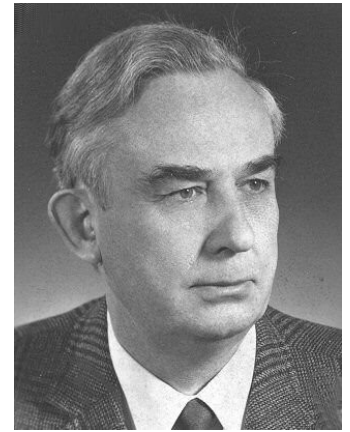
Phylogenetic systematics (cladistics)

1950, 1966: **Willi Hennig**: *Phylogenetic Systematics*

only genealogies, not adaptive divergence

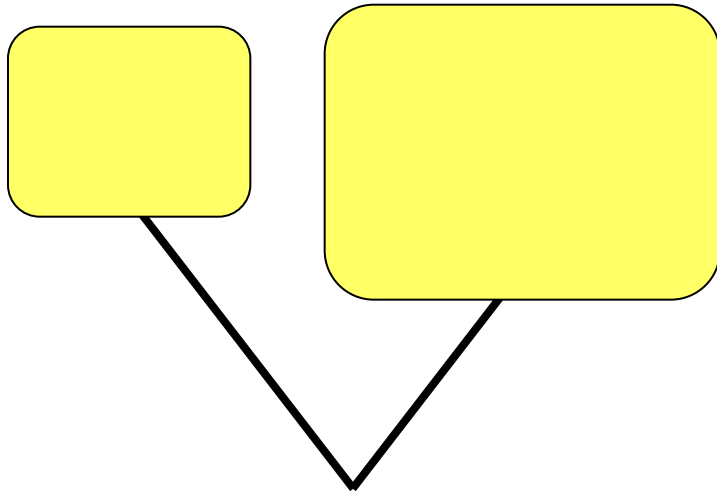
strict monophyly

monophyletic group = **clade**

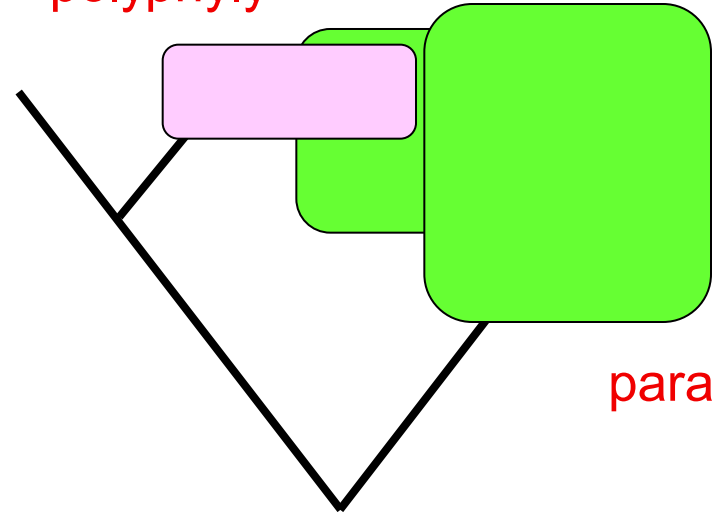


W. Hennig

monophyly



polyphyly



Synapsida

savci

Parareptilia

želvy

Plesiosaoria

Ichthyosauria

haterie

leguáni

agamy

chameleoni

hadi

Mososauria

varani

krokodýli

Pterosauria

Ornithischia

Sauropoda

ostatní teropodi

ptáci

Sphenodontida

Squamata

Lepidosauria

Archosauria

Dinosauria

Saurischia

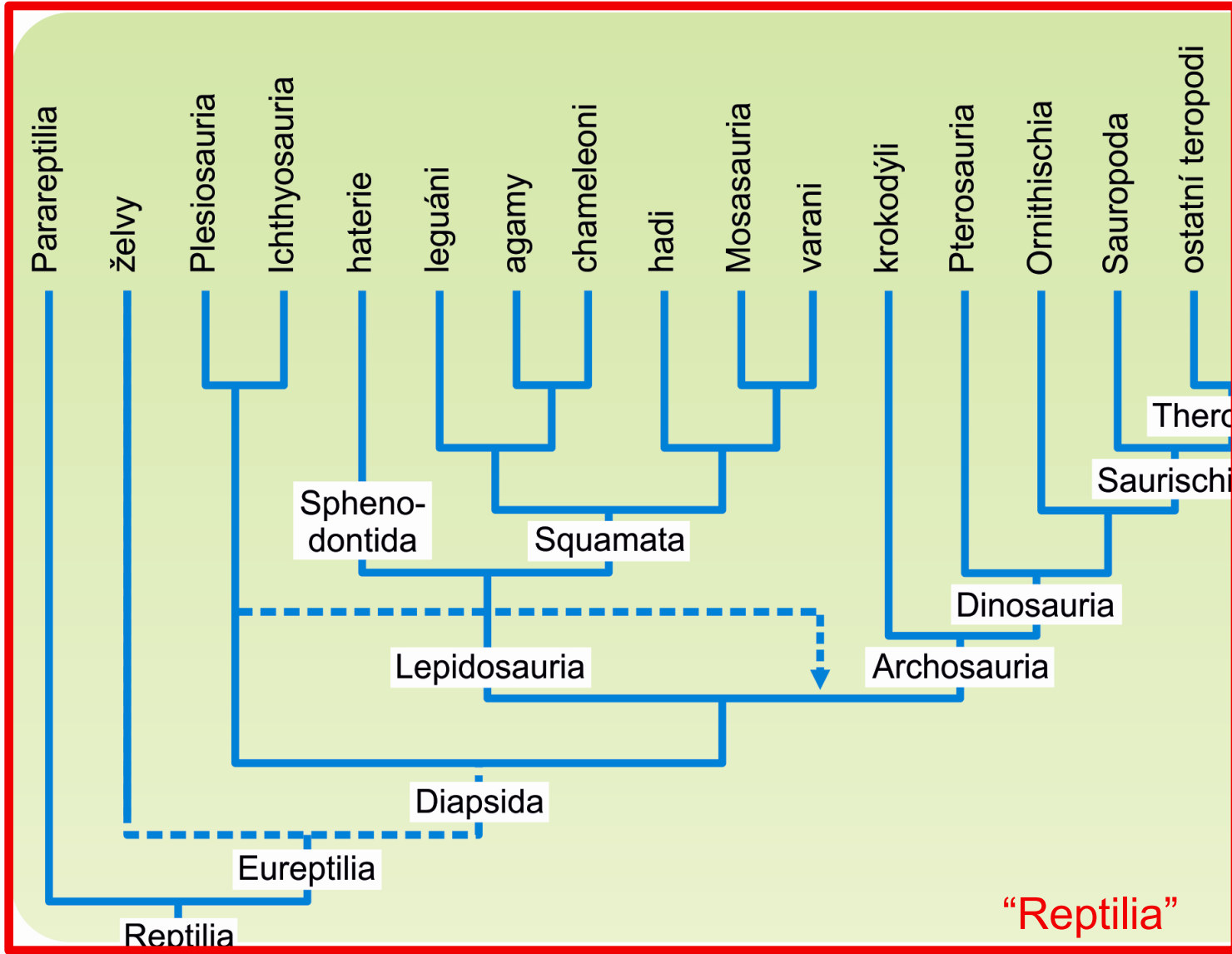
Theropoda

Diapsida

Eureptilia

Reptilia

“Reptilia”



“Pongidae”



Orangutan
48 chromosomes
(24 pairs)



Gorilla
48 chromosomes
(24 pairs)



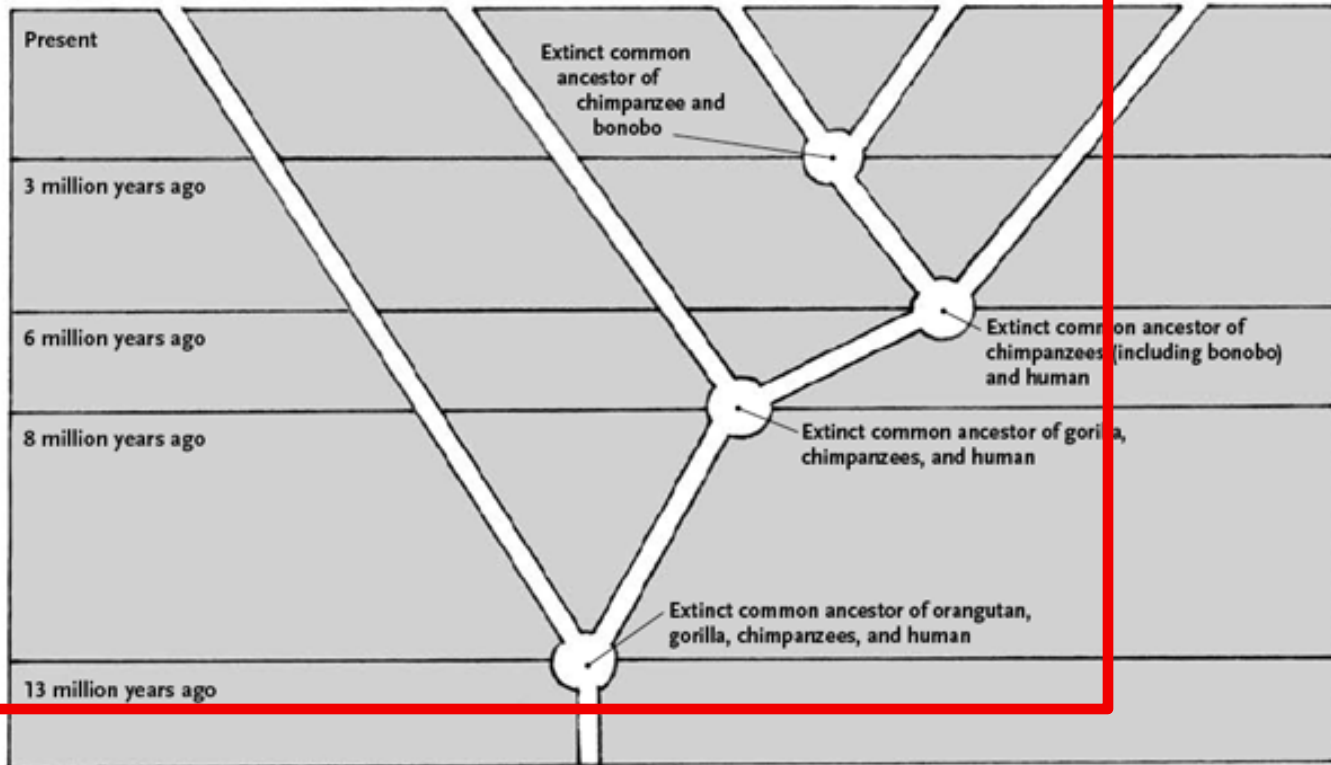
Chimpanzee
48 chromosomes
(24 pairs)



Bonobo
48 chromosomes
(24 pairs)



Human
46 chromosomes
(23 pairs)



characters:

plesiomorphic (= ancestral, „primitive“)

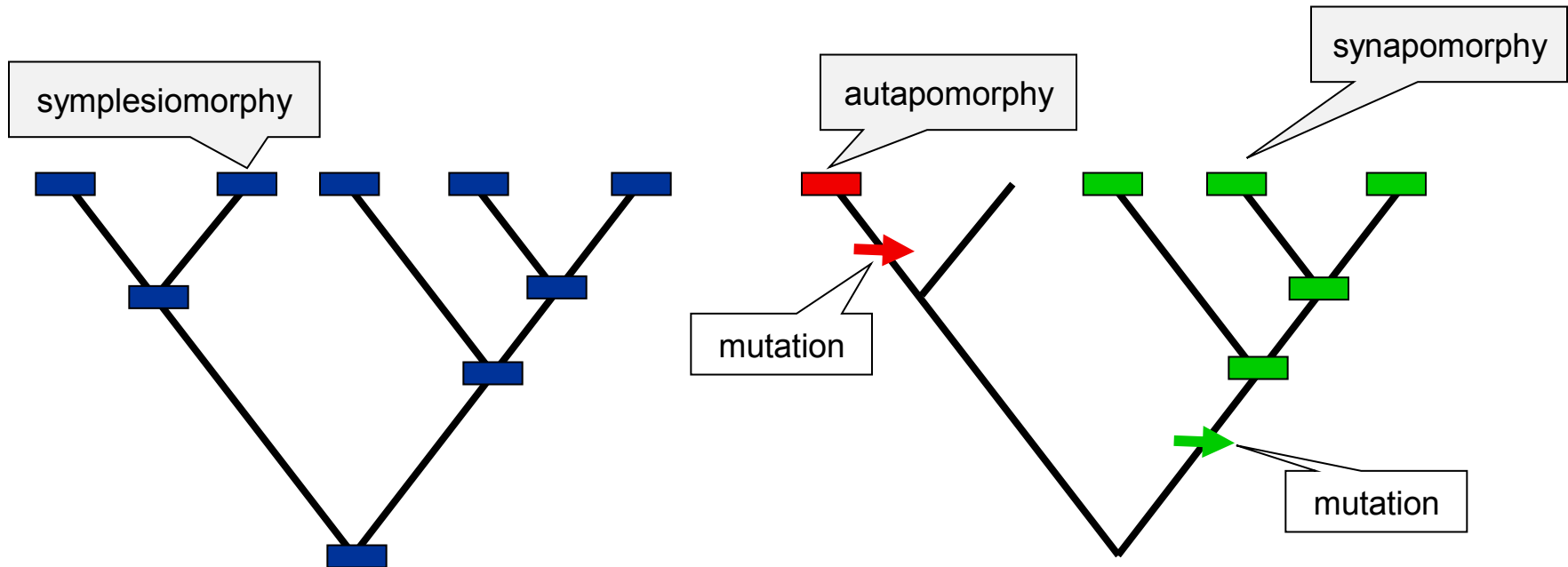
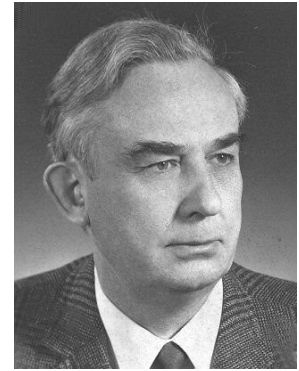
symplesiomorphic (= shared ancestral)

apomorphic (= derived)

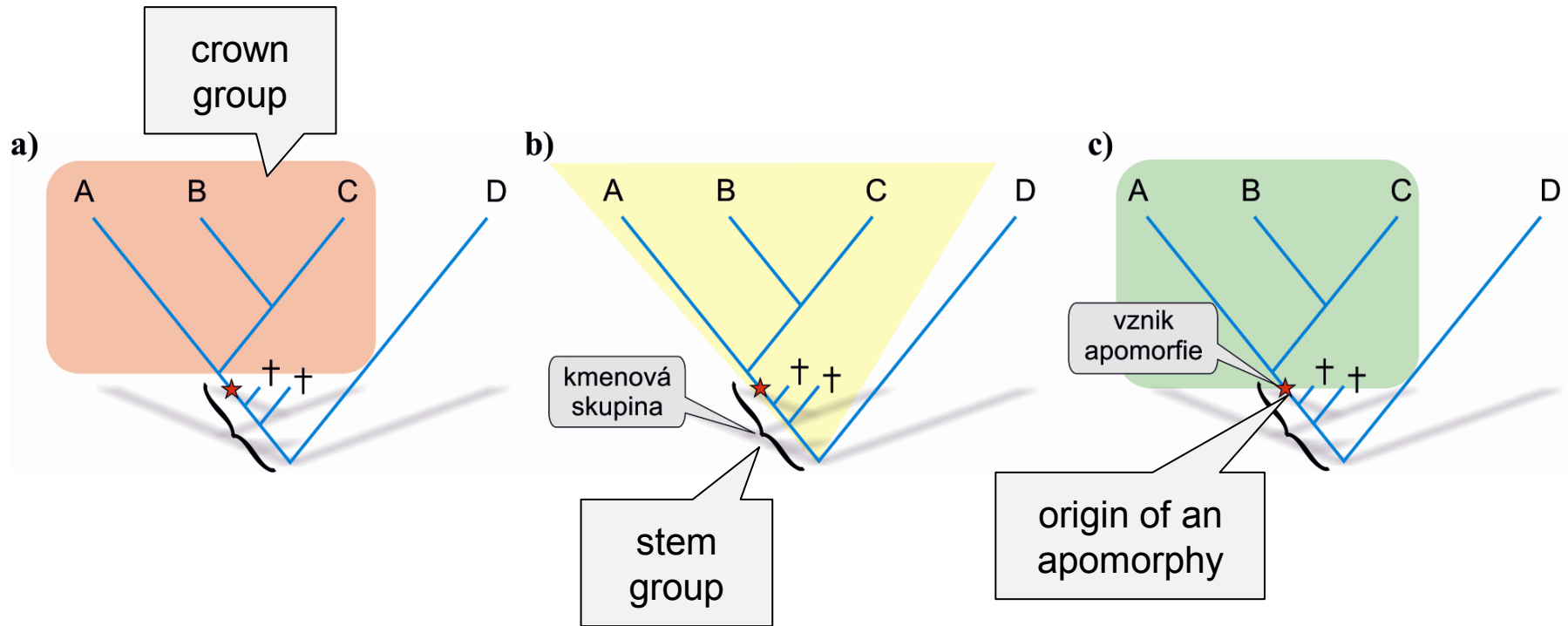
synapomorphic (= shared derived)

autapomorphic (= unique derived)

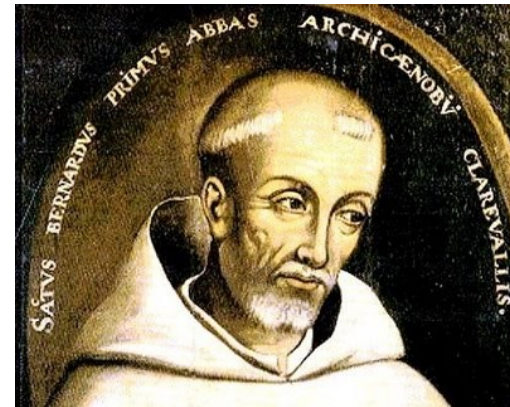
clades defined only by synapomorphies



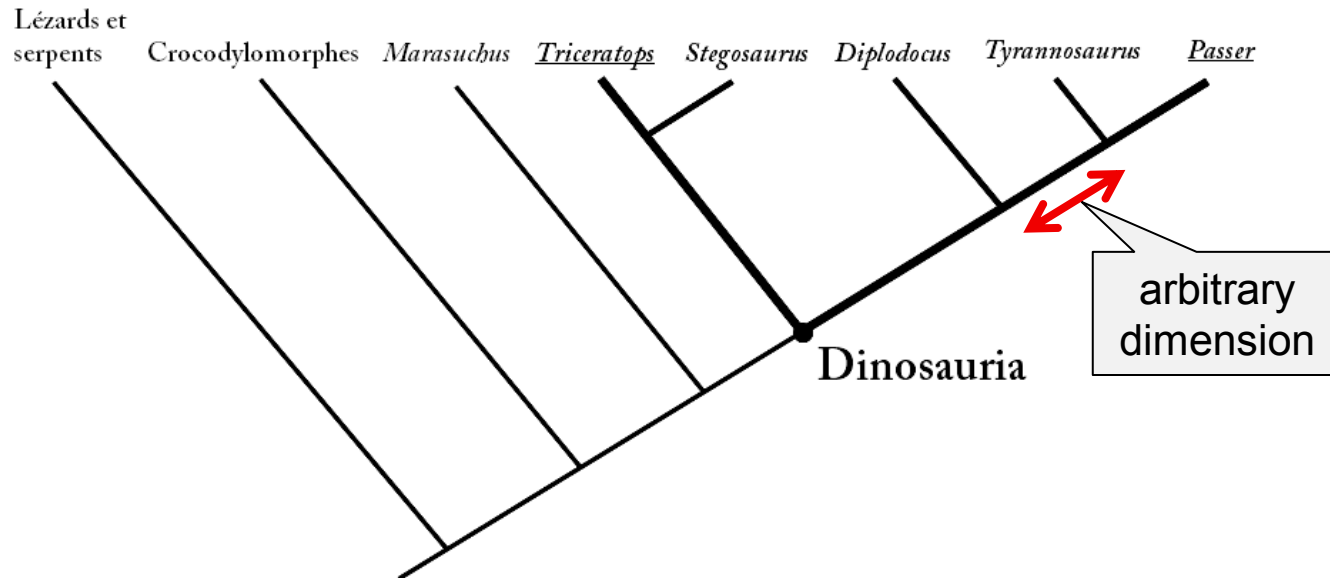
Definition of clades and classification of extinct taxa:



principle of parsimony: Occam's razor
(William of Ockham, 14th century)



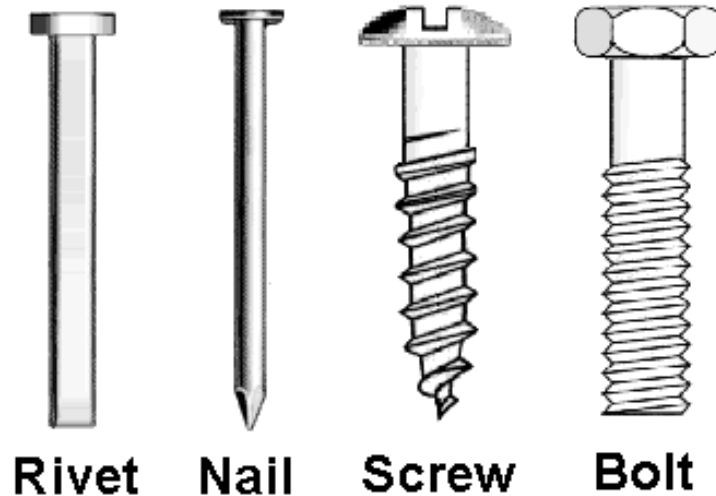
cladograms



PhyloCode (*International Code of Phylogenetic Nomenclature*)
till now somewhat controversial and impractical

problems: homoplasy, rapid evolution

Cladistics and phenetics exemplified by the „evolution“ of fasteners



Rivet: the simplest structure \Rightarrow we suppose that it is the most similar to the common ancestor of all modern types of fasteners

We can define 7 derived character states (ie. those nonexistent in rivets):

- 1) notched heads,
- 2) rounded heads,
- 3) hex heads,
- 4) threaded shafts,
- 5) tapered shafts,
- 6) pointed tips,
- and 7) thick diameter.

Cladistics and phenetics exemplified by the „evolution“ of fasteners

Character states of all 4 types are listed in the following table where

„0“ = plesiomorphic („rivet-like“) state

„1“ = apomorphic (derived) state

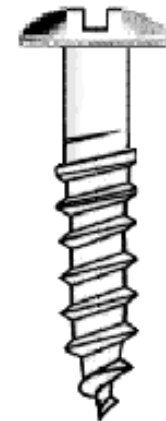
Character	Rivet	Nail	Screw	Bolt
Head notch	0	0	1	0
Rounded head	0	0	1	0
Hex head	0	0	0	1
Threaded shaft	0	0	1	1
Tapered shaft	0	0	1	0
Pointed tip	0	1	1	0
Thick diameter	0	0	1	1



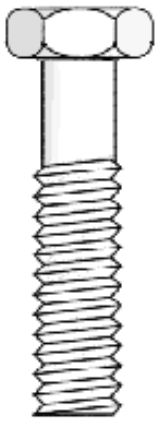
Rivet



Nail



Screw



Bolt

Cladistics and phenetics exemplified by the „evolution“ of fasteners

Character	Rivet	Nail	Screw	Bolt
Head notch			1	0
Rounded head			1	0
Hex head			0	1
Threaded shaft			1	1
Tapered shaft			1	0
Pointed tip			1	0
Thick diameter			1	1

Phenetic Comparison (Total of all shared states)				
	Rivet	Nail	Screw	Bolt
Rivet	-	6	1	4
Nail		-	2	3
Screw			-	2
Bolt				-

If we use the **phenetic** approach we count the total number of shared states (both ancestral and derived).

For example rivet vs. nail: 6 similarities, 1 difference

Cladistics and phenetics exemplified by the „evolution“ of fasteners

Character	Rivet	Nail	Screw	Bolt
Head notch	0	0	1	0
Rounded head	0	0	1	0
Hex head	0	0	0	1
Threaded shaft	0	0	0	0
Tapered shaft	0	0	1	0
Pointed tip	0	0	0	0
Thick diameter	0	0	0	0

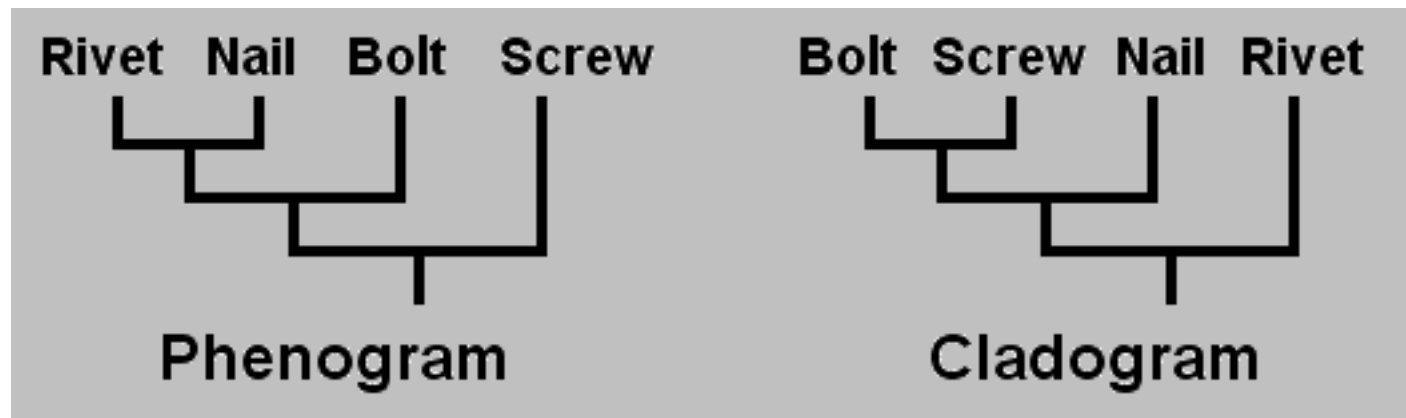
Cladistic Comparison (Total of derived states only)				
	Rivet	Nail	Screw	Bolt
Rivet	-	0	0	0
Nail		-	1	0
Screw			-	2
Bolt				-

If we use the **cladistic** approach we take into account only shared derived states.

For example. screw vs. bolt: 2 **synapomorphies**

Cladistics and phenetics exemplified by the „evolution“ of fasteners

Phenetic Comparison (Total of all shared states)					Cladistic Comparison (Total of derived states only)				
	Rivet	Nail	Screw	Bolt		Rivet	Nail	Screw	Bolt
Rivet	-	6	1	4	Rivet	-	0	0	0
Nail		-	2	3	Nail		-	1	0
Screw			-	2	Screw			-	2
Bolt				-	Bolt				-



Evolutionary systematics – a response

phylogenetic relationships + degree of divergence \Rightarrow combination
of phenetic and cladistic approach

reflection of both clades and grades

An evolutionary grade is a group of similar species that has given rise
to another group that differs markedly from the ancestral condition,
and is thus not considered part of the ancestral group.

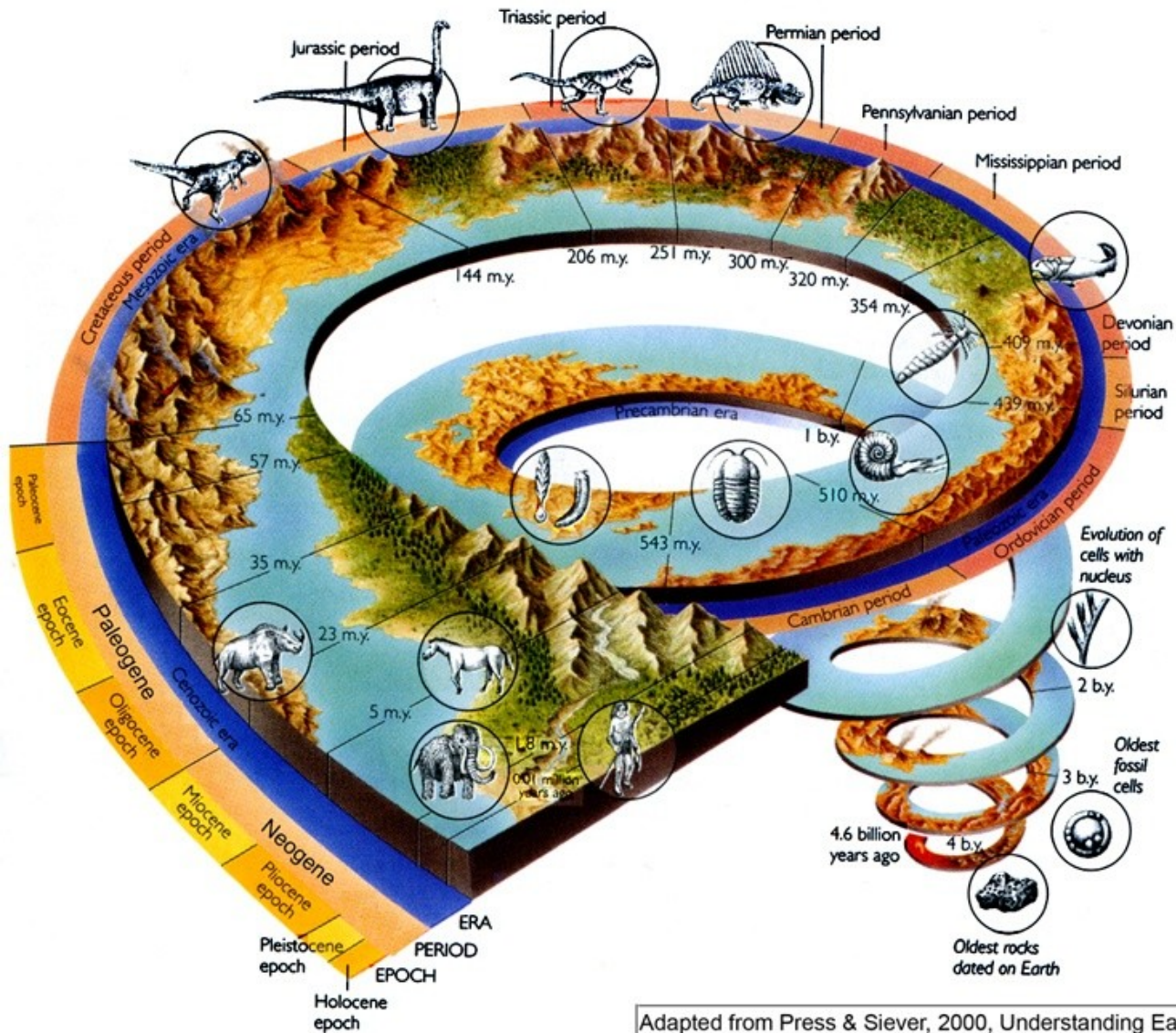
\Rightarrow the ancestral group is then paraphyletic

eg. reptiles (without birds),
fishes in a traditional sense

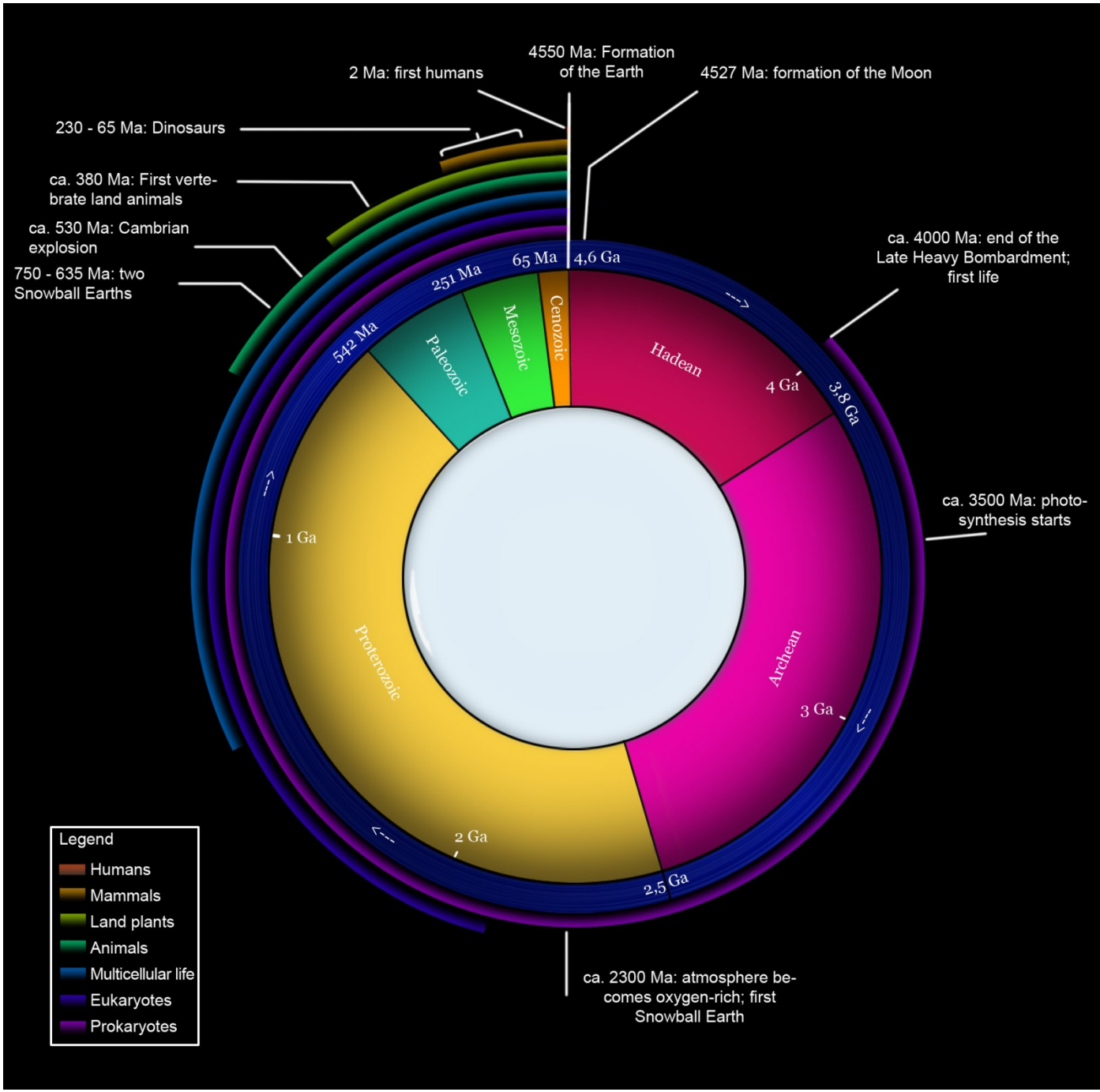


E. Mayr

HISTORY OF LIFE ON EARTH

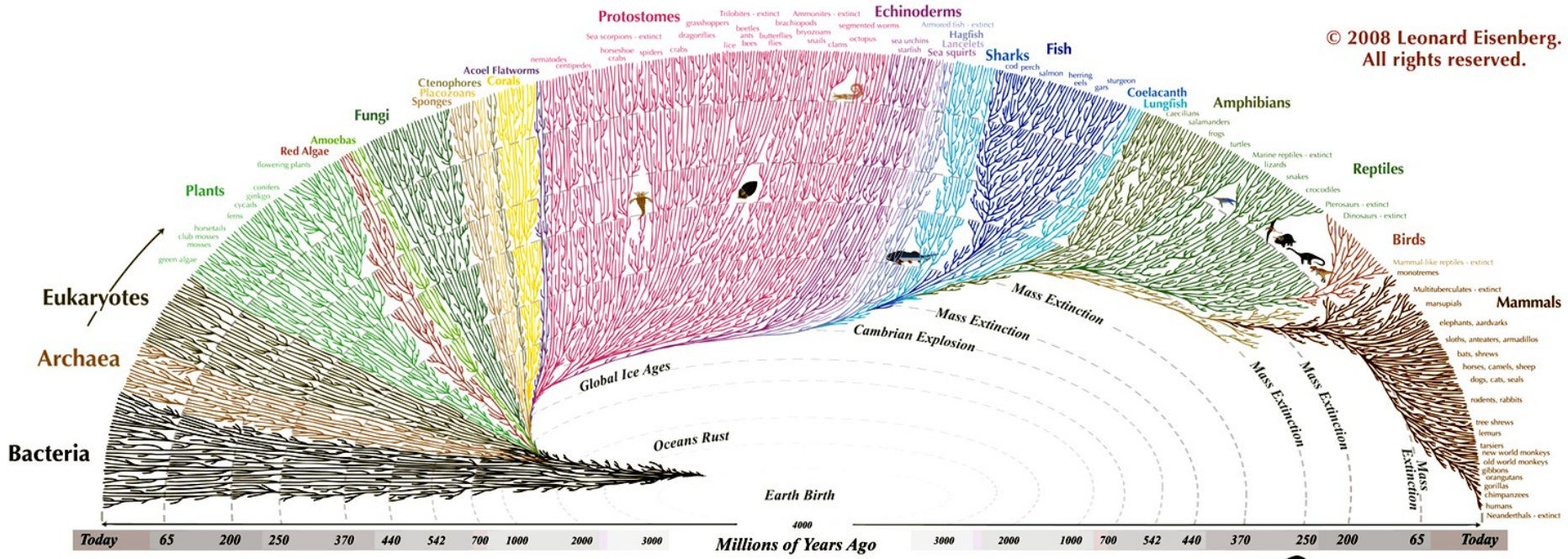



Adapted from Press & Siever, 2000, Understanding Earth



- Legend**
- Humans
 - Mammals
 - Land plants
 - Animals
 - Multicellular life
 - Eukaryotes
 - Prokaryotes

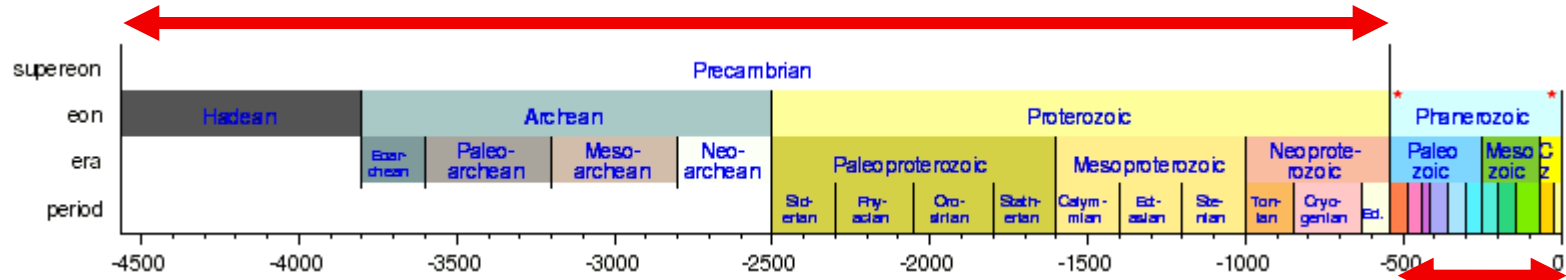
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All the major and many of the minor living branches of life are shown on this diagram, but only a few of those that have gone extinct are shown. Example: Dinosaurs - extinct 

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evogenes.com

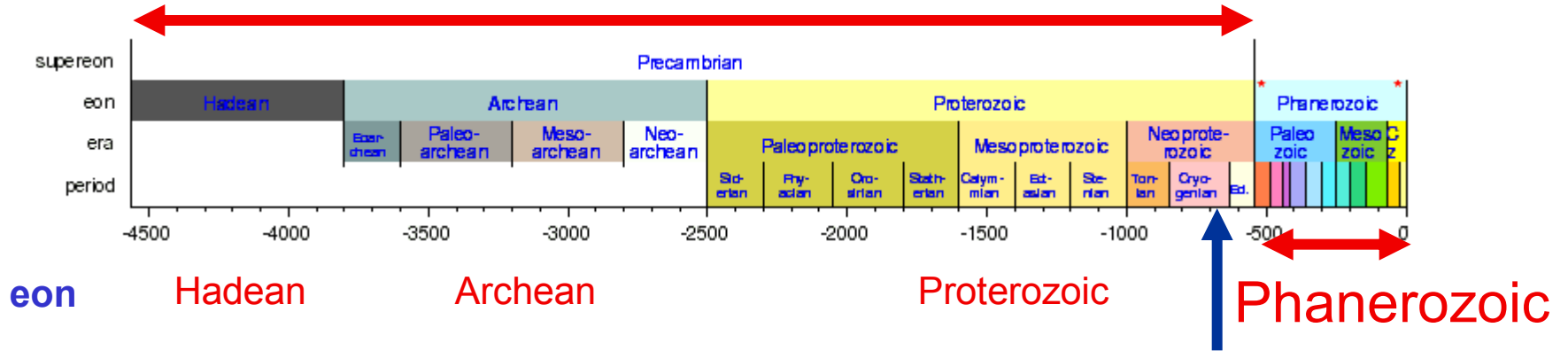
Precambrian



eon Hadean Archean Proterozoic Phanerozoic

EON	ERA	PERIOD	MILLIONS OF YEARS AGO	KEY EVENTS
Phanerozoic	Caenozoic	Quaternary	1.6	Humans evolve
		Tertiary		
	Mesozoic	Cretaceous	138	Extinction of Dinosaurs
		Jurassic		
		Triassic		
	Paleozoic	Permian	240	Permian mass extinction
		Carboniferous	330	
		Devonian	410	Invertebrates become common
		Silurian		
		Ordovician		
Cambrian	500			
Proterozoic	Also known as Precambrian	3500	Earliest life	
Archean				
Hadean				

Precambrian



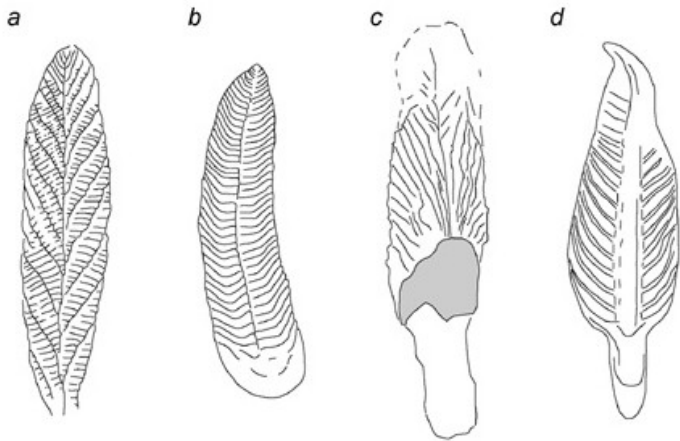
Ediacaran (Vendian) fauna
~635-542 M



Charnwood,
Leicestershire
~ 560 M

Mistaken Point,
Newfoundland
~ 565 M





Charnia

Charnia

Spriggina

Stromatoveris

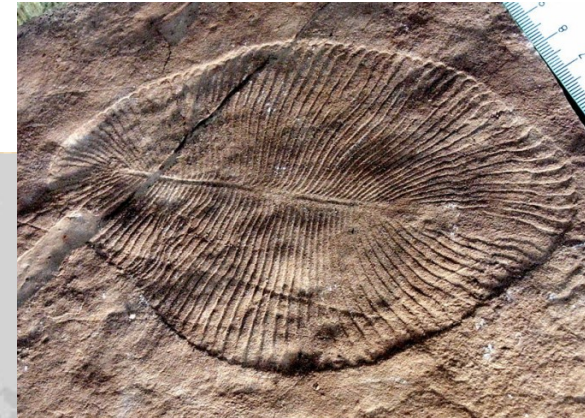
Thaumaptilon



Ediacara Hills,
Australia



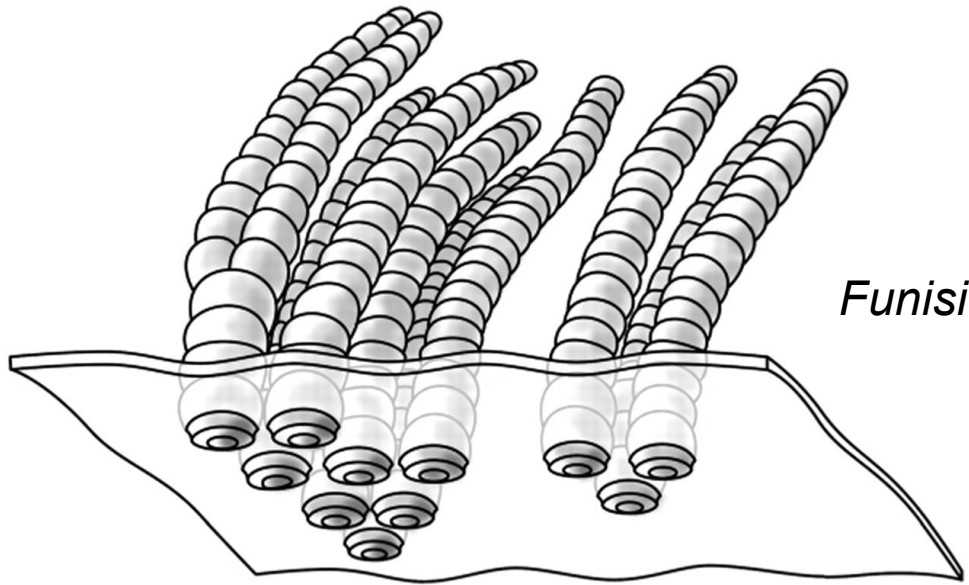
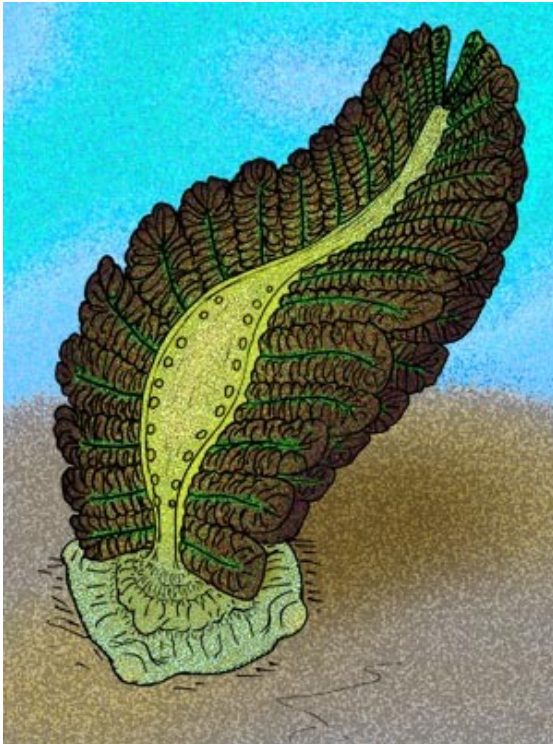
Spriggina



Dickinsonia
~ 580 M

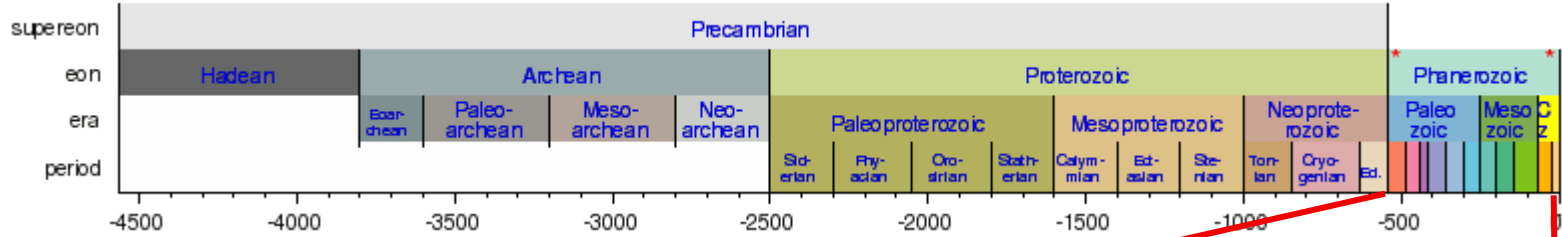


Spriggina



Funisia: sex?

Phanerozoic

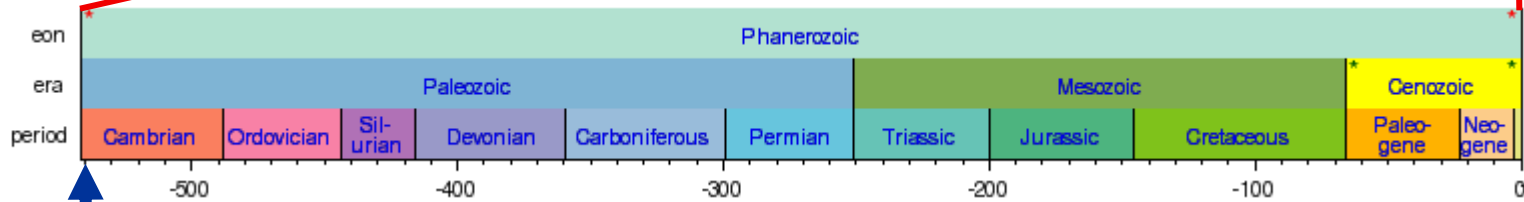


era

Paleozoic

Mesozoic

Cenozoic



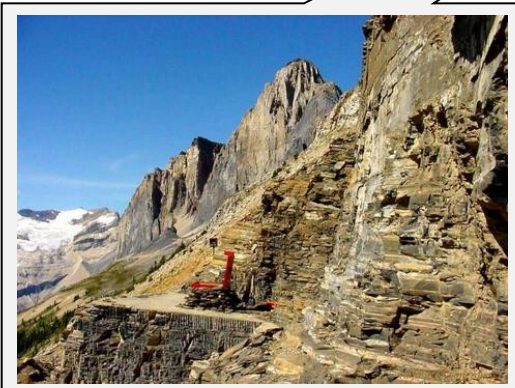
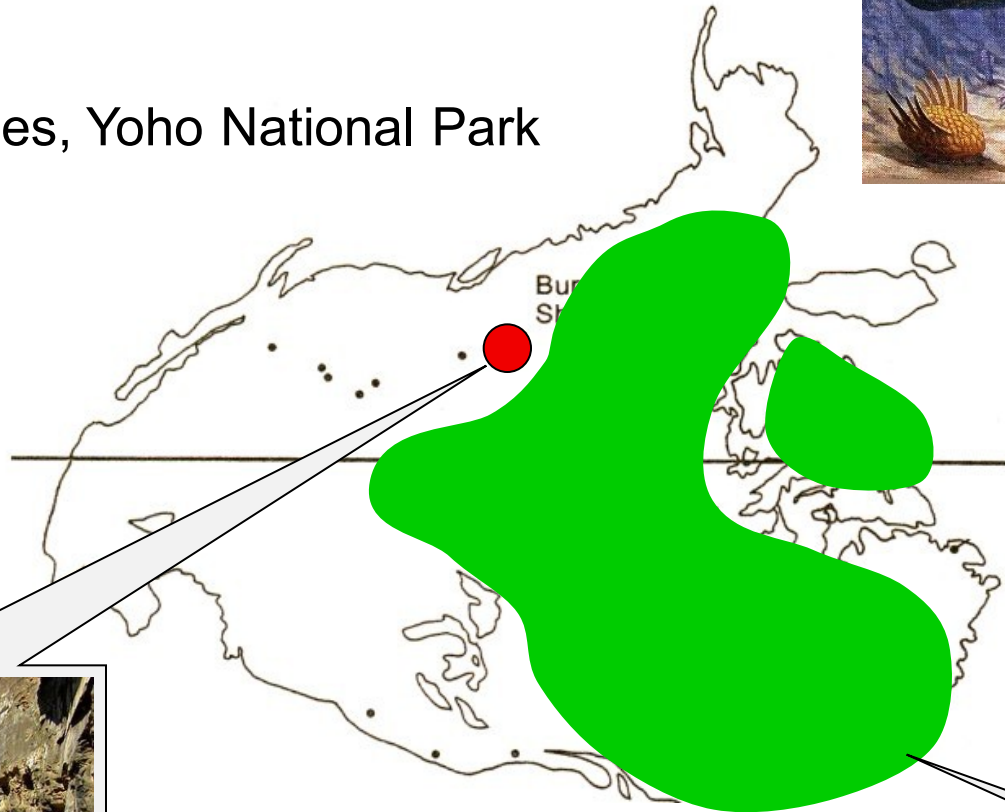
Cambrian explosion
~ 542-520 M

Cambrian explosion

Burgess Shale

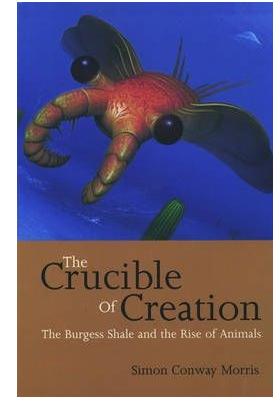
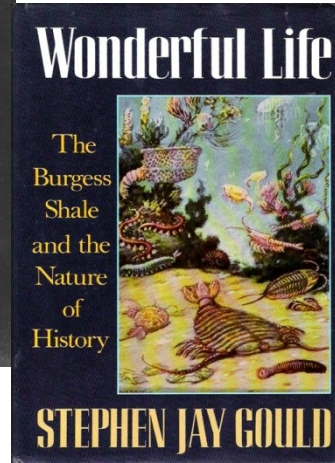
~ 542-520 M

Canadian Rockies, Yoho National Park

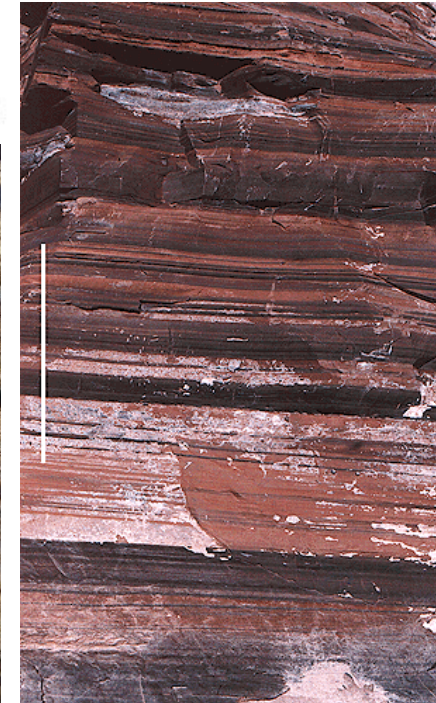


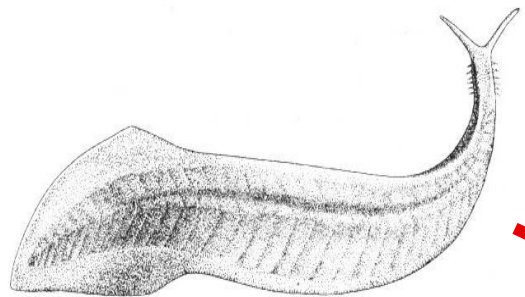
continent

Charles Doolittle Walcott (1909)



Simon Conway Morris

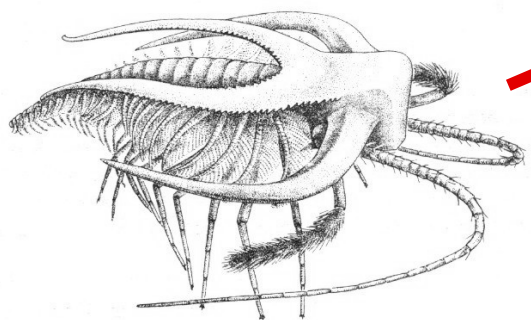
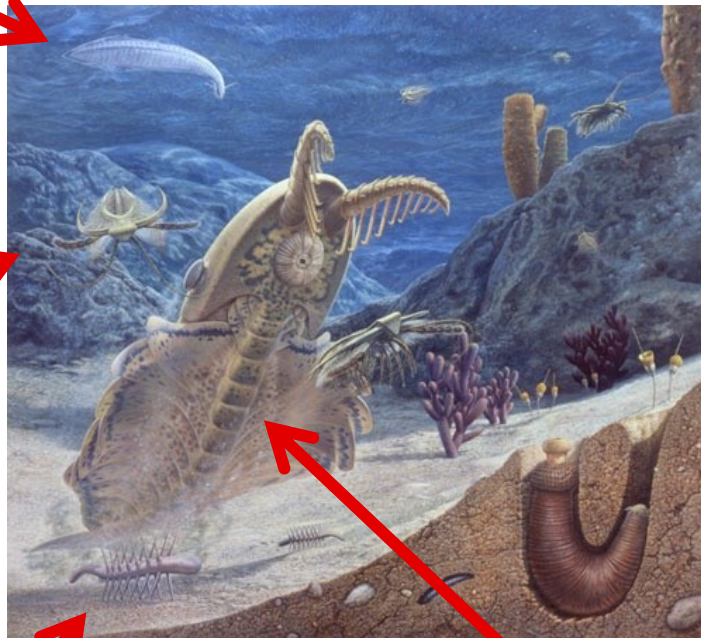




Pikaia gracilens

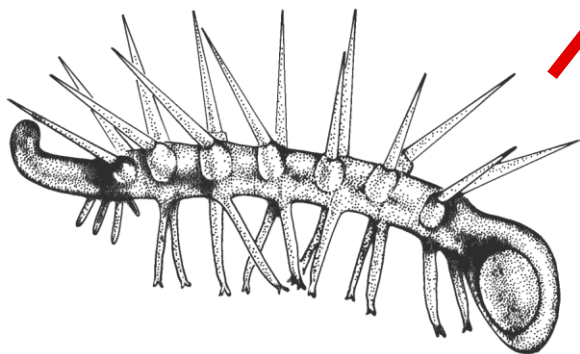


Yohoia

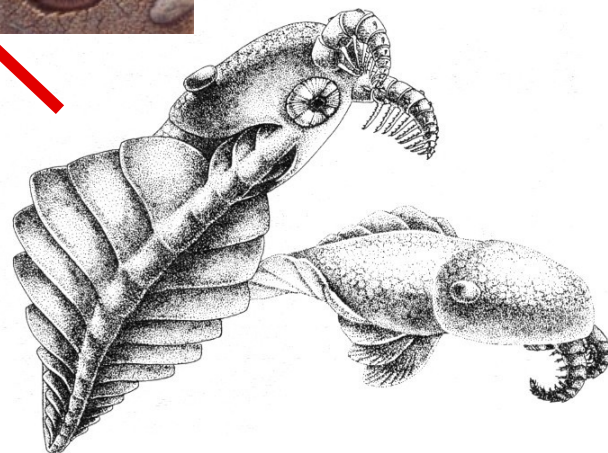


Marella

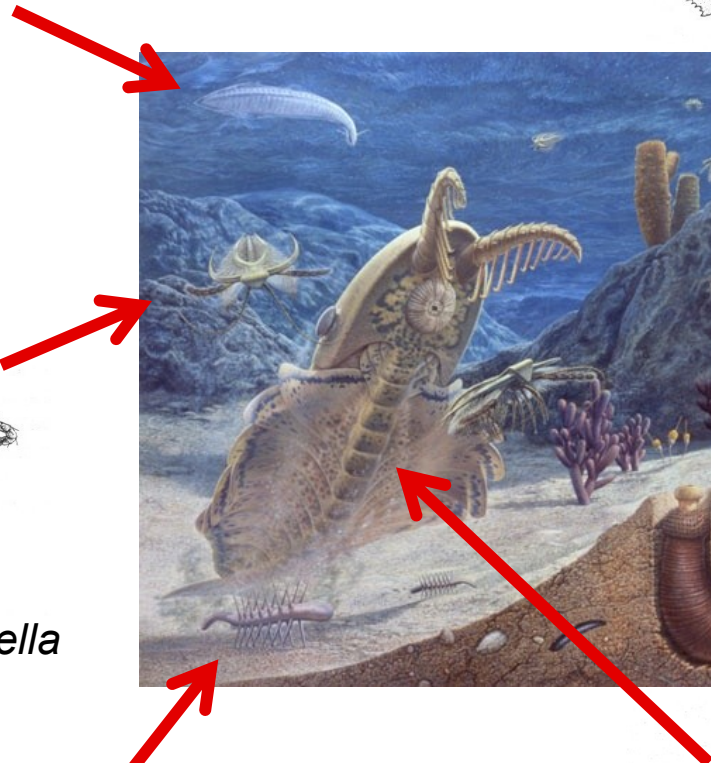
Anomalocaris nathorsti



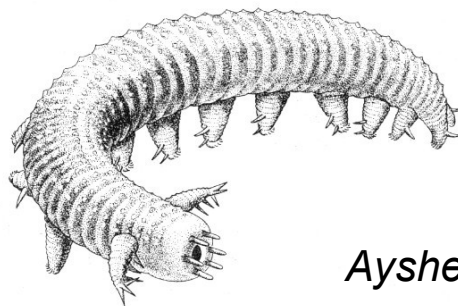
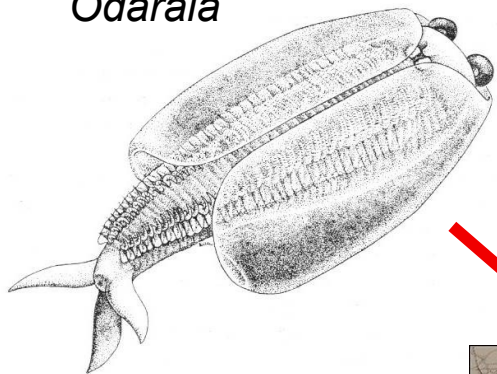
Hallucigenia



A. canadensis



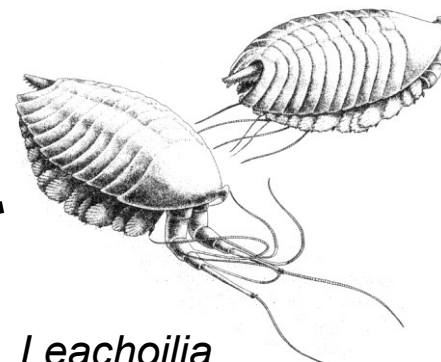
Odaraia



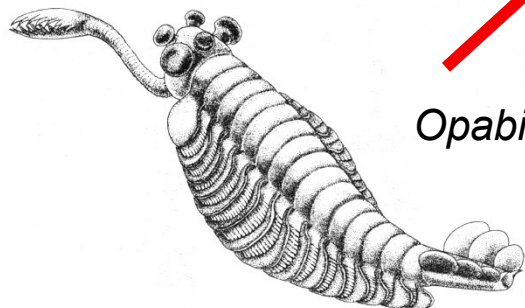
Aysheaia



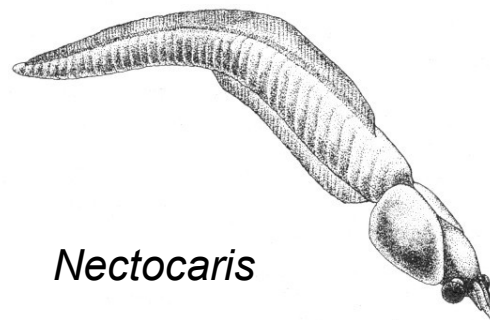
Wiwaxia



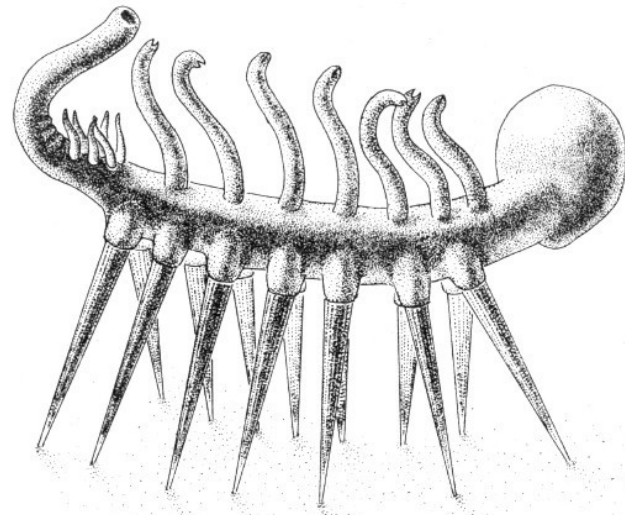
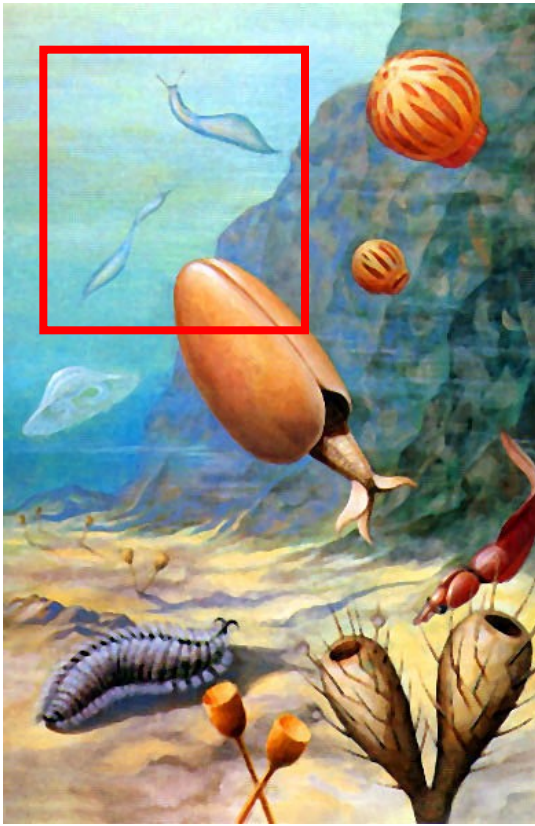
Leachoilia



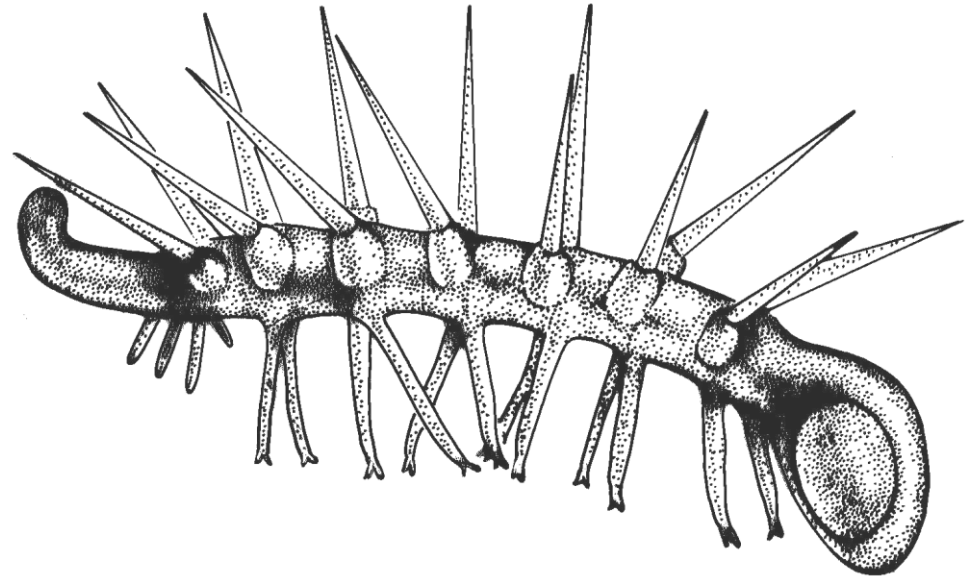
Opabinia



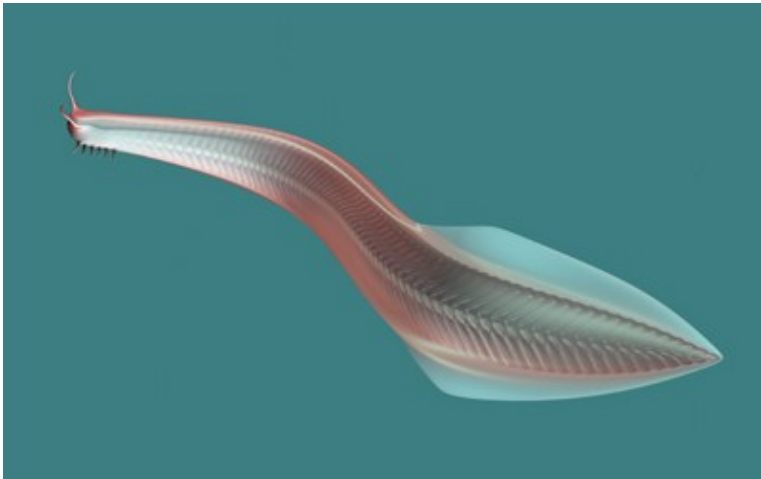
Nectocaris

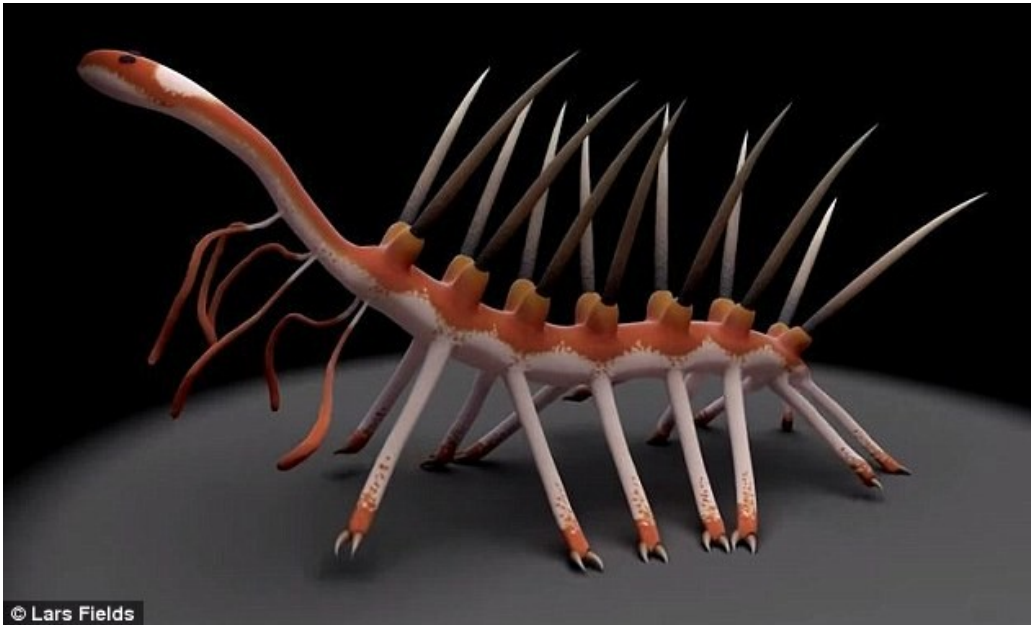


Hallucigenia



Pikaia gracilens (Chordata)





© Lars Fields



Aysheaia

Transition from sea to land?



Onychophora

diversity and disparity:

interpretation of Burgess fossils

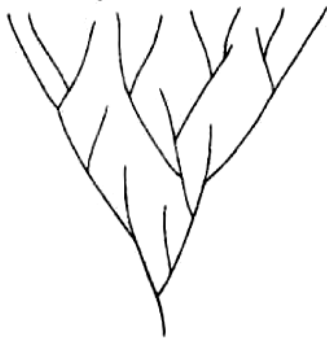
Stephen Jay Gould vs. Simon Conway Morris

diversity = number of species

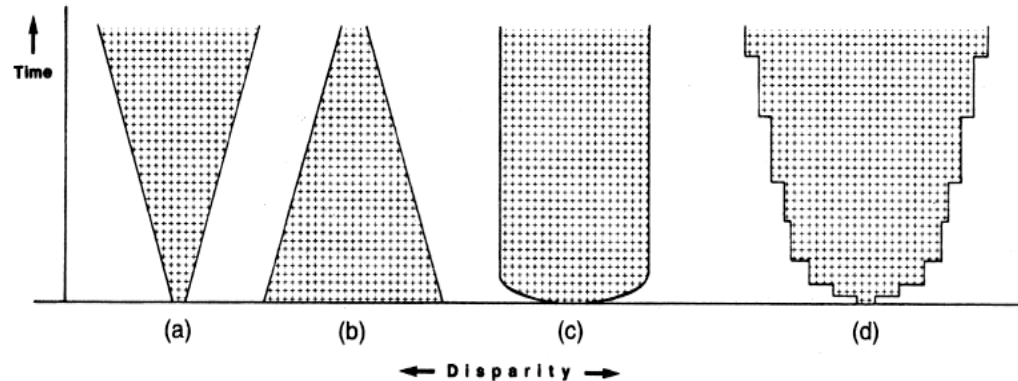
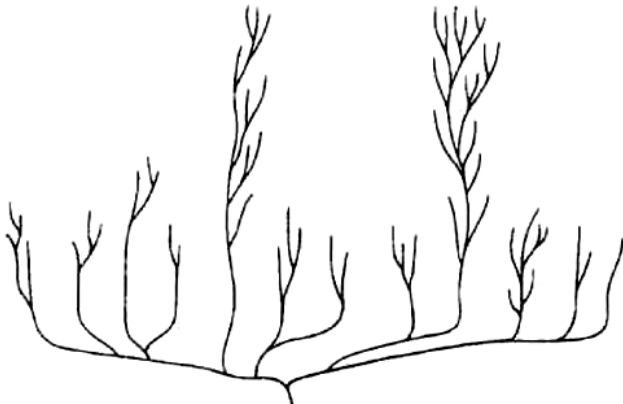
disparity = number of „Bauplans“



The Cone of Increasing Diversity



Decimation and Diversification



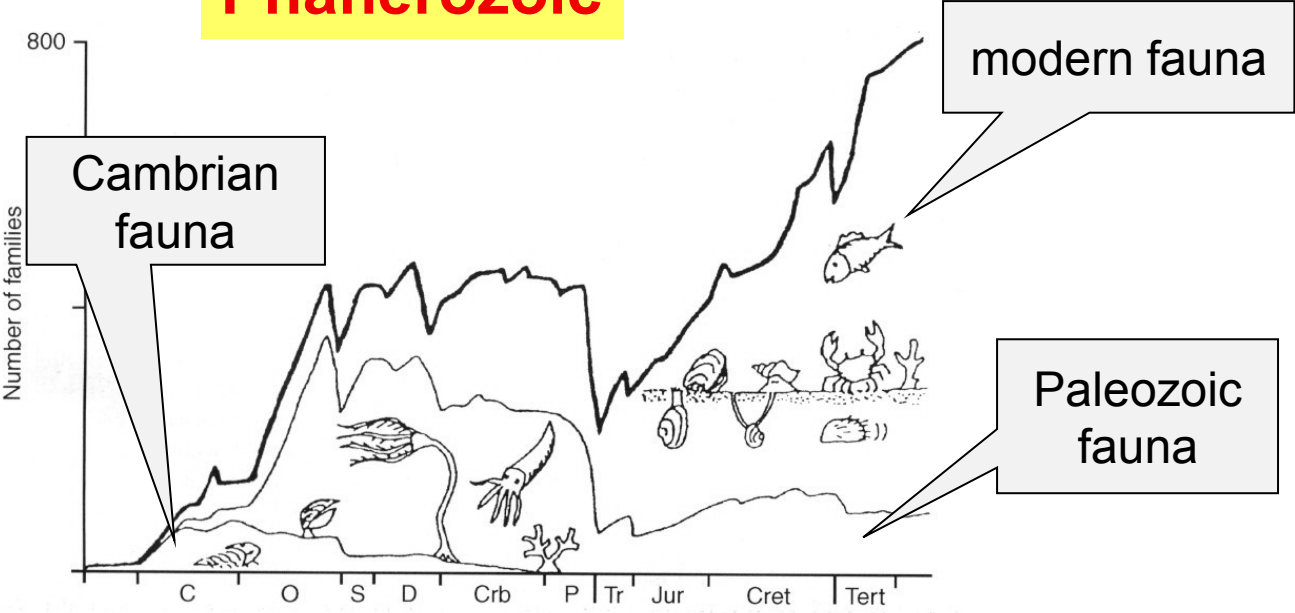
traditional

Gould

Conway Morris

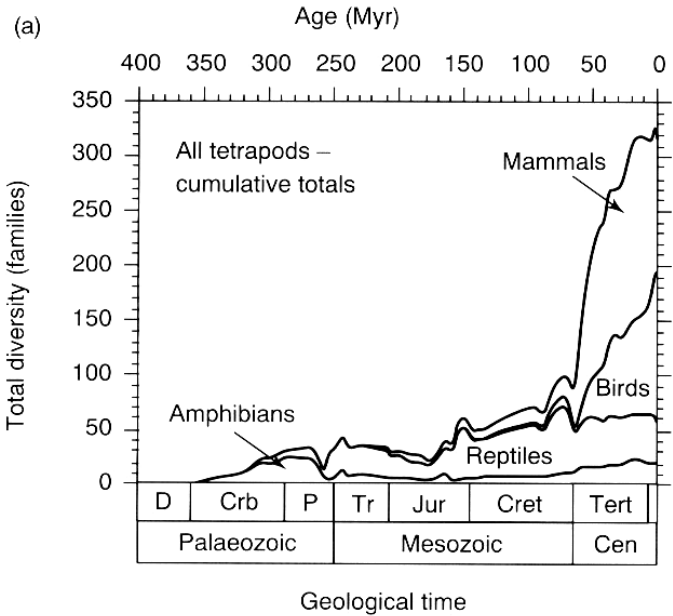
Phanerozoic

increasing
diversity

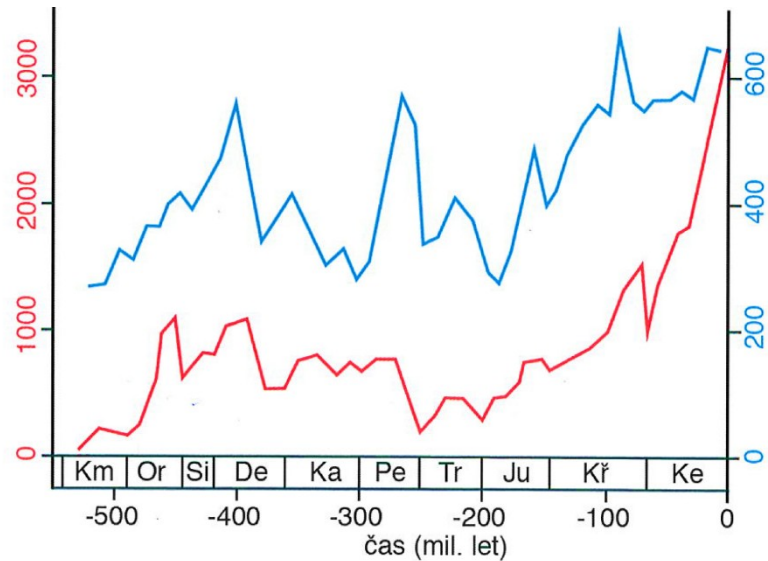
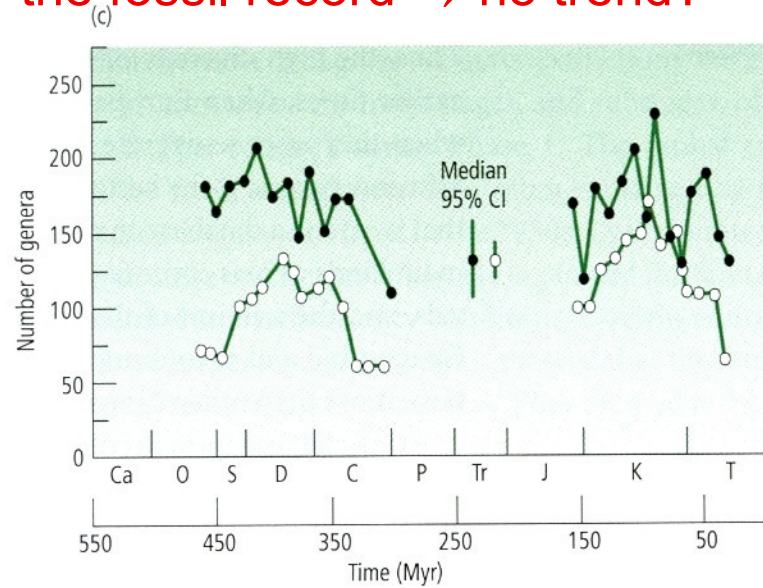
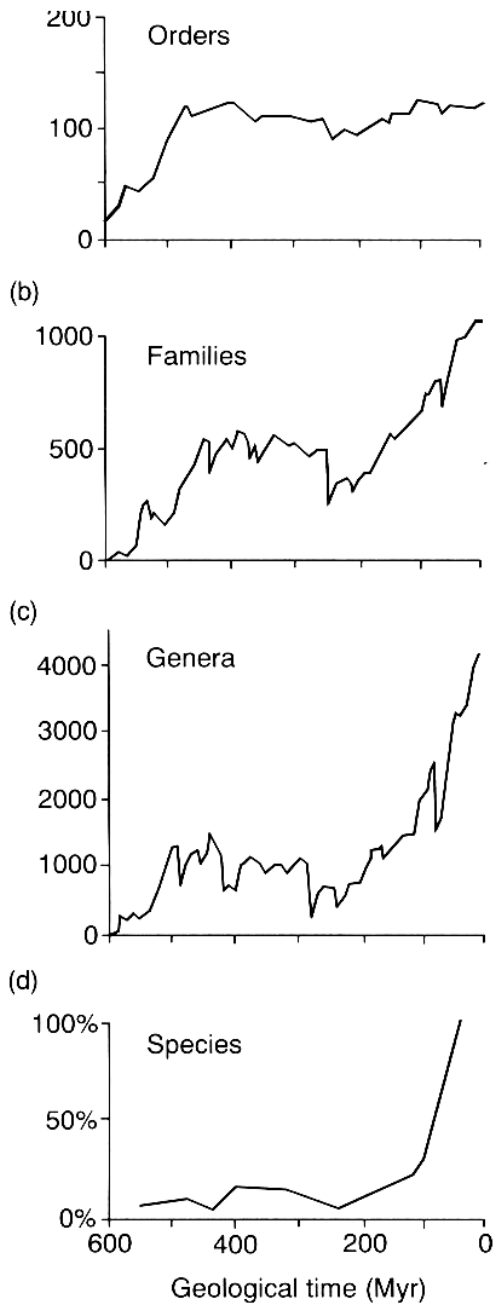


Jack J. Sepkoski (1981): logistic model

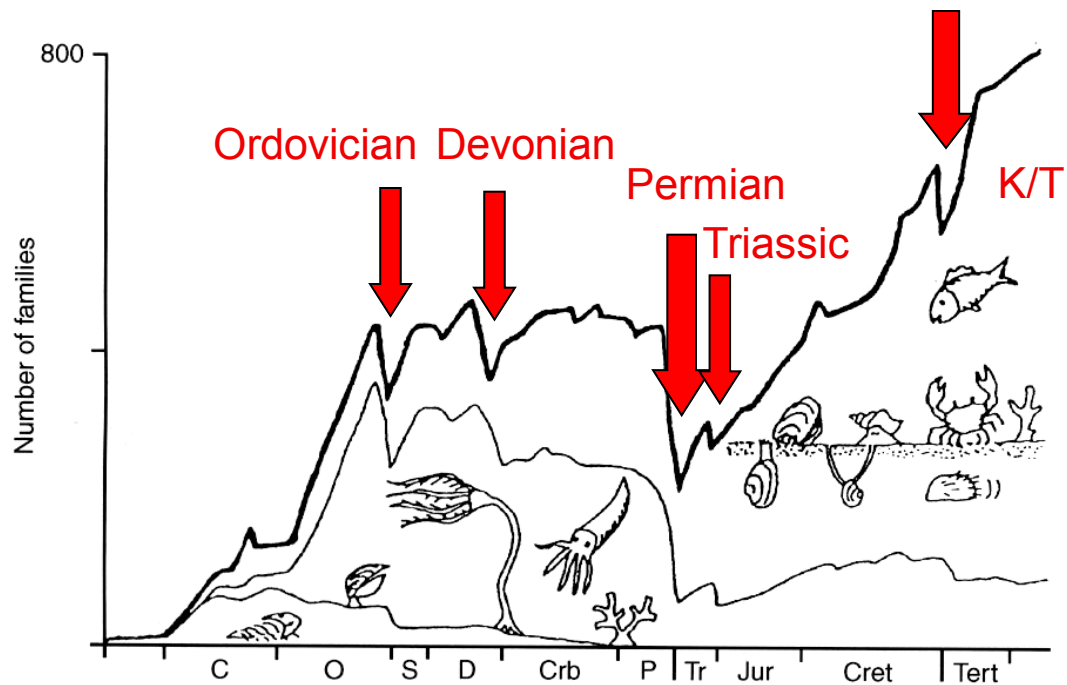
Michael J. Benton (1997):
curve for terrestrial organisms differs
exponential model



If we take into account incompleteness of the fossil record → no trend?



Obr. 7.27: Růst globální diverzity: červená křivka popisuje růst počtu „rodů“ na základě prvního a posledního výskytu ve fosilním záznamu, modrá křivka počet „rodů“ po odstranění „tahu přítomnosti“ (viz text).

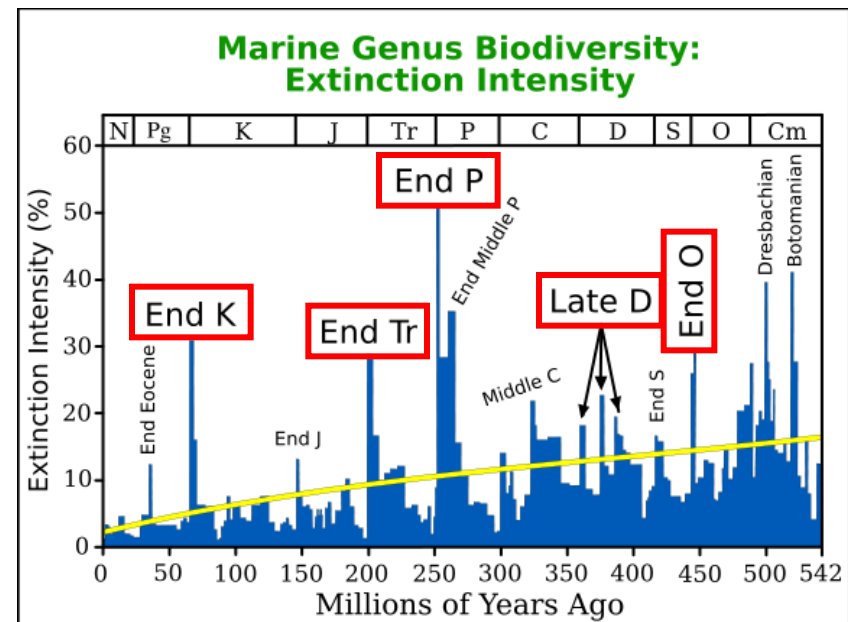


Extinction:

background extinctions

mass extinctions → „Big Five“

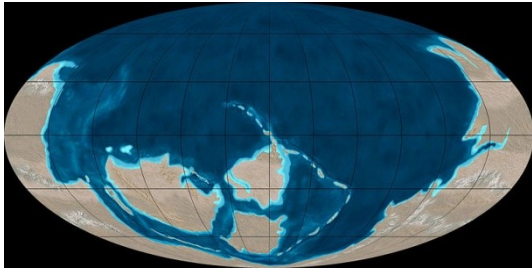
greatest: end of the Permian



Paleozoic

Cambrian:

single supercontinent Rodinia (Proterozoic) → Gondwana, Laurentia, Baltica, Angara (Siberia), Avalonia ...



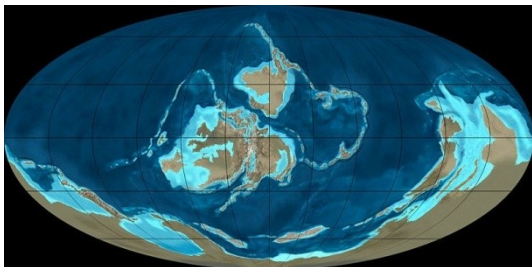
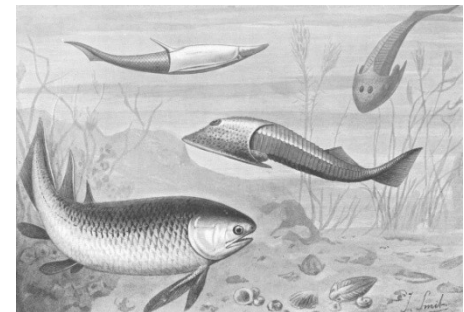
Ordovician:

increase of diversity (marine organisms)
the end: 1st mass extinction

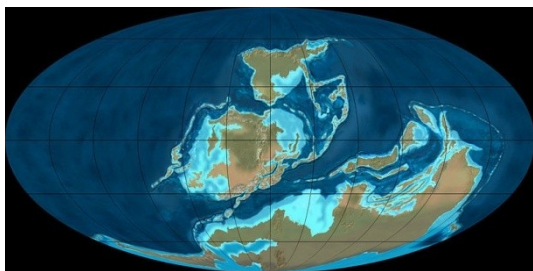


Silurian:

gnathostomes
first terrestrial o.
(plants, scorpions)



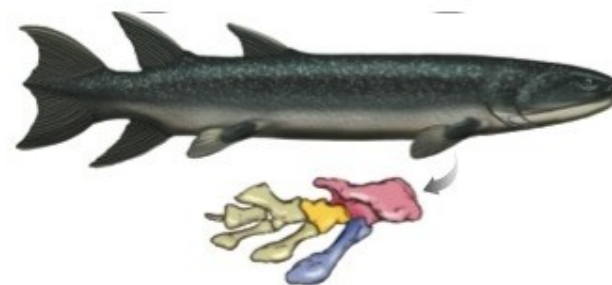
Laurentia+Baltica = Laurasia



Devon:

radiace ryb, první žraloci, lalokoploutví, obojživelníci
na konci 2. masová extinkce

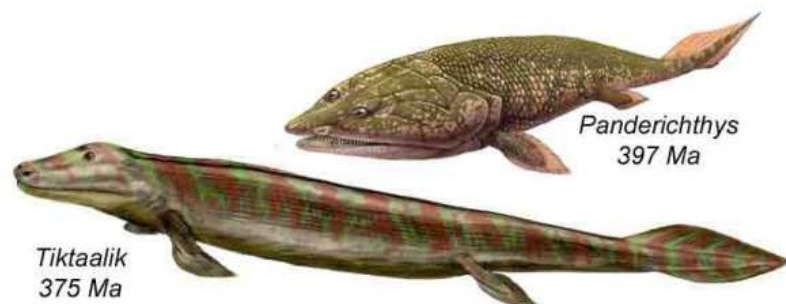
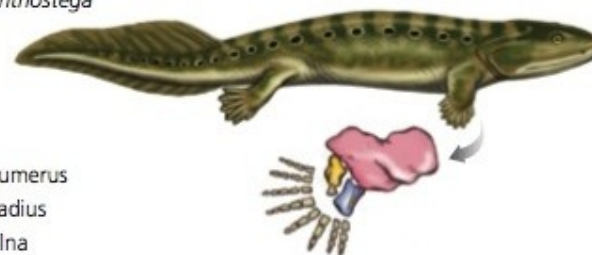
Eusthenopteron



Tiktaalik



Acanthostega



Panderichthys
397 Ma

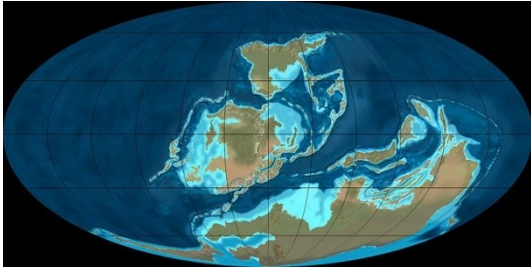
Tiktaalik
375 Ma



Acanthostega
360 Ma

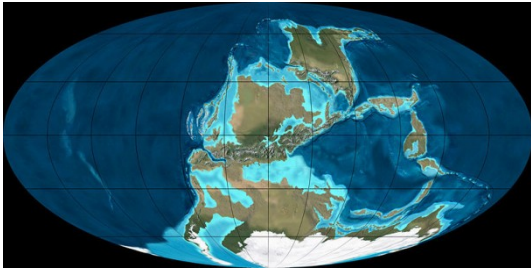


Ichthyostega
365 Ma



Devon:

radiace ryb, první žraloci, lalokoploutví, obojživelníci
na konci 2. masová extinkce

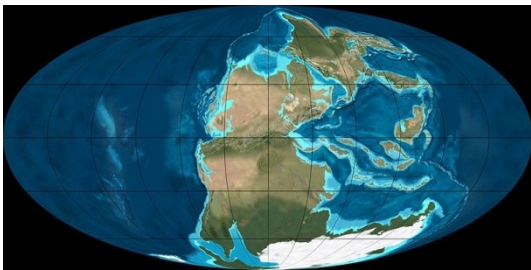


Karbon:

přesličky, hmyz, první plazi



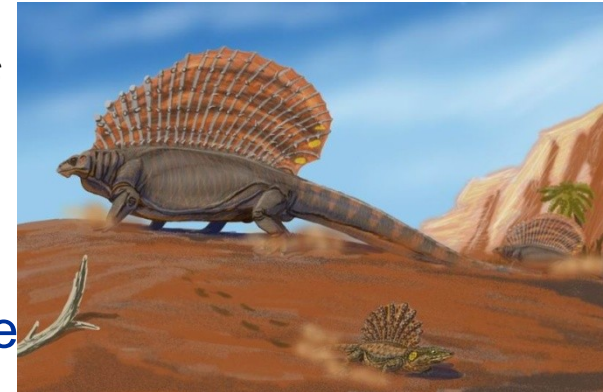
Archaeothyris
(Synapsida)



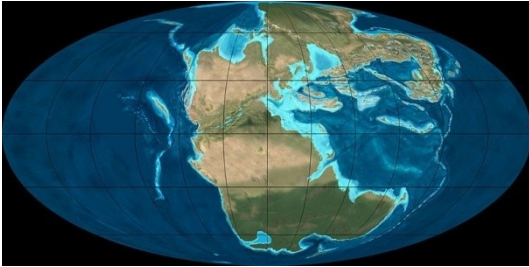
Perm:

Pangea
Therapsida (→ savci)
na konci 3. masová extinkce

Edaphosaurus
(Pelycosauria)



Mesozoic



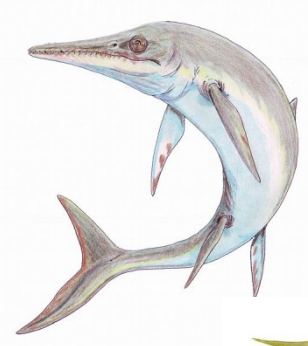
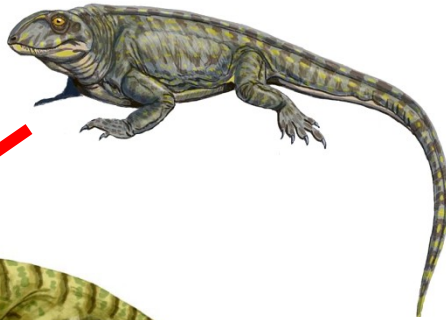
Triassic:

butterflies, dipterans

radiation of reptiles (tortoises, ichthyosaurs, plesiosaurs, pterosaurs)

the end: dinosaurs, mammals, 4th extinction

synapsid
Pelycosauria
(*Palaeohatteria*)



ichthyosaurs

plesiosaurs



Therapsida



cynodont
(*Cynognathus*)



pterosaurs



primitive mammal (*Castorocauda*)

Evolution of mammals

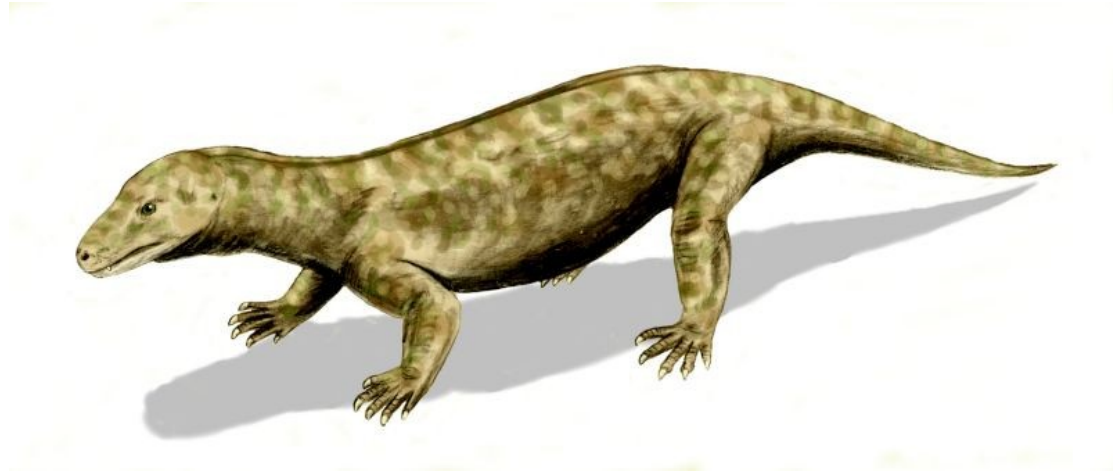
Sphenacodon: Lower Permian (270 M) – mandible from several bones, reptile-like articulation, no eardrum

Biarmosuchia: Upper Permian – one of the first therapsids, articulation already more mammal-like, knit upper jaw, hind legs more upright

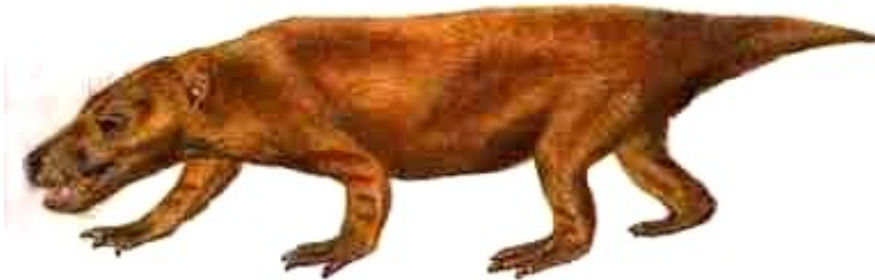


Biarmosuchus

Procynosuchus: end of Permian – primitive cynodont



Thrinaxodon: Lower Triassic – more derived cynodont, eardrum in the lower jaw



Probainognathus: Middle Triassic (~ 235 M) – 2 joints: mammalian+reptilian

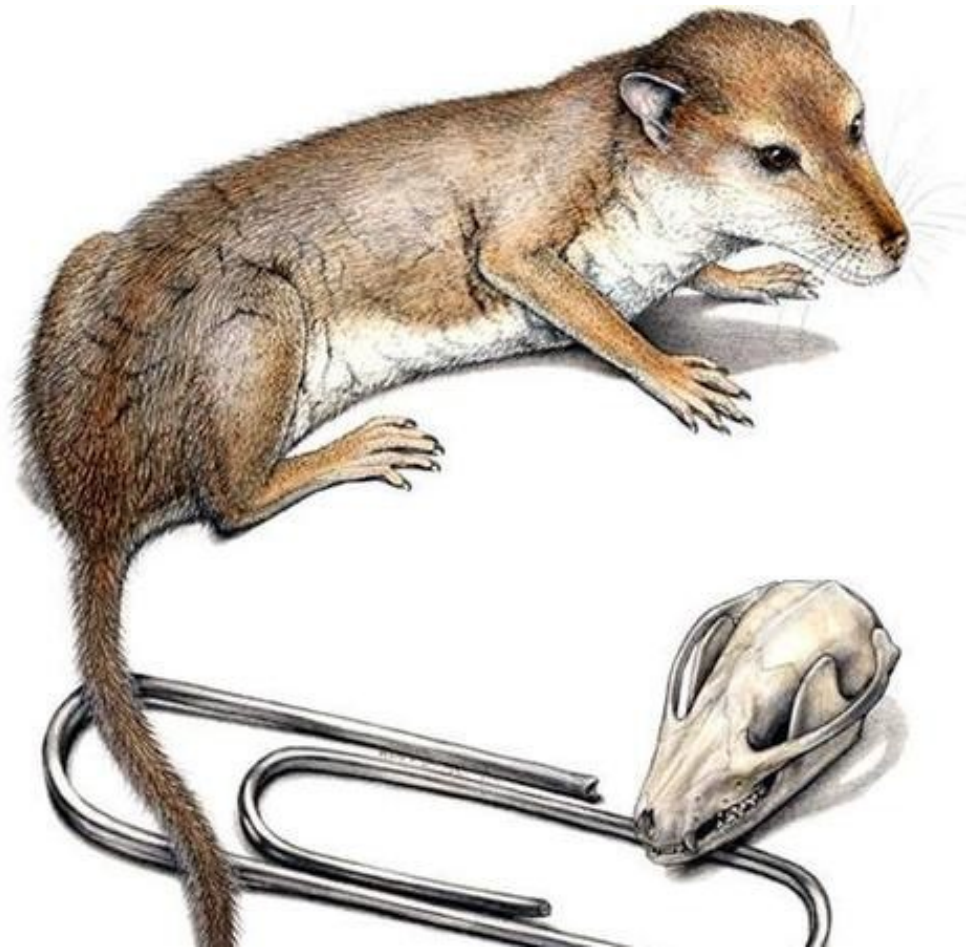


Diarbrognathus: Lower Jurassic (~ 209 M) – advanced cynodont, although still 2 joints, but the reptilian one used almost entirely for hearing

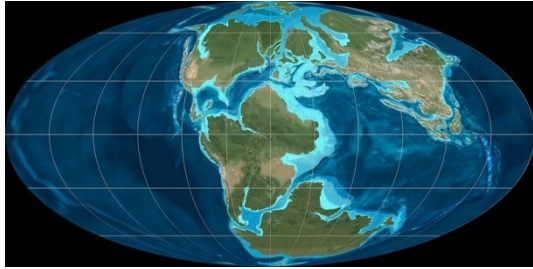
Morganucodon: Lower Jurassic (~ 220 M)
– still a residue of the reptilian joint



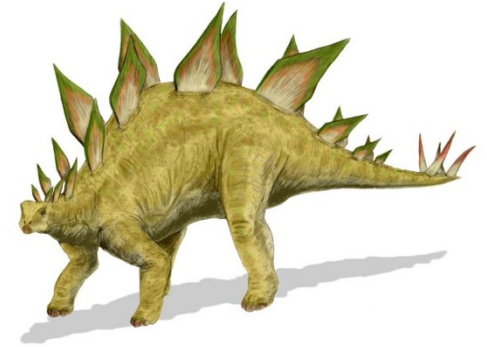
Hadrocodium: Lower Jurassic – transition of the middle ear ossicles from the jaw to the cranium



Mesozoic



Jurassic:
bone fishes
bird evolution

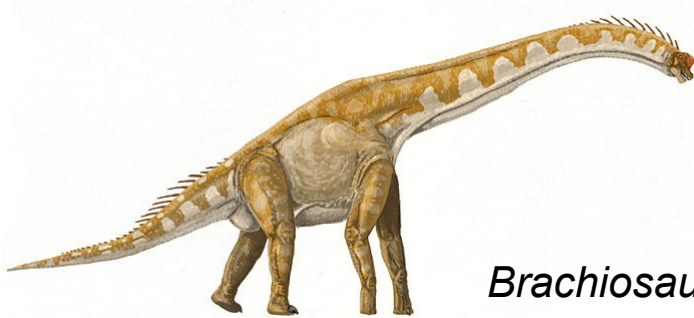


Stegosaurus

Saurischia

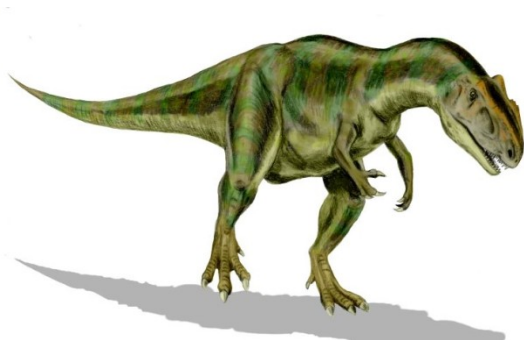
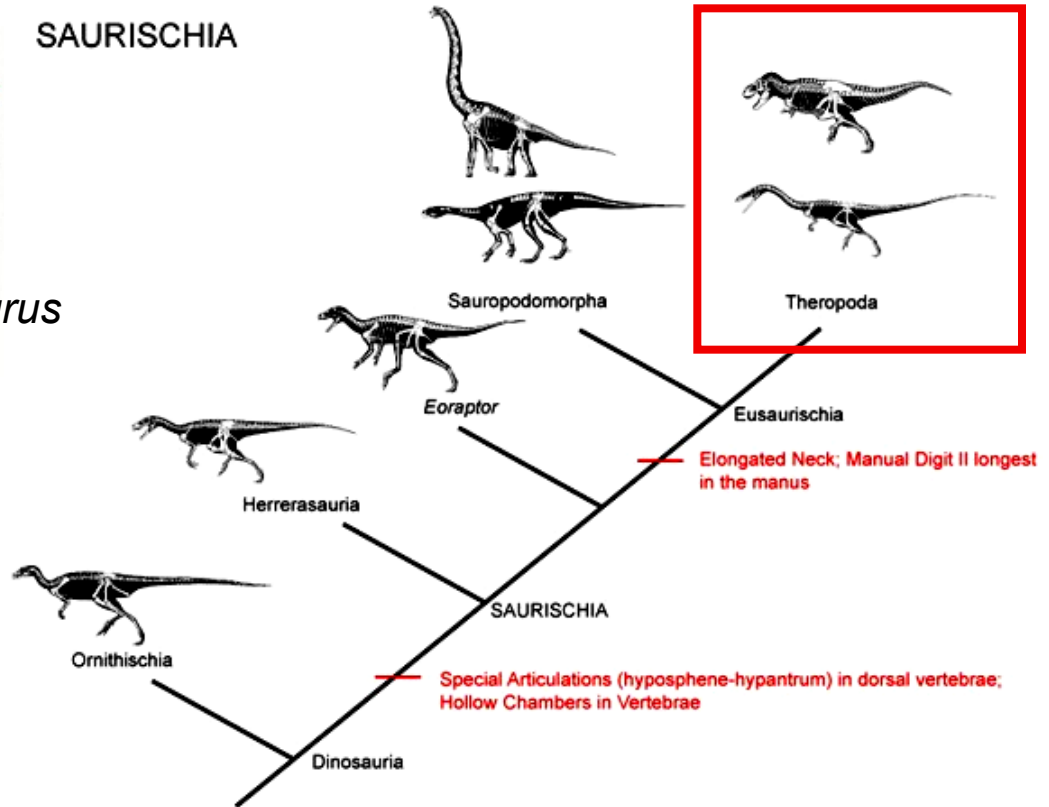
dinosaurs

Ornithischia



Brachiosaurus

SAURISCHIA

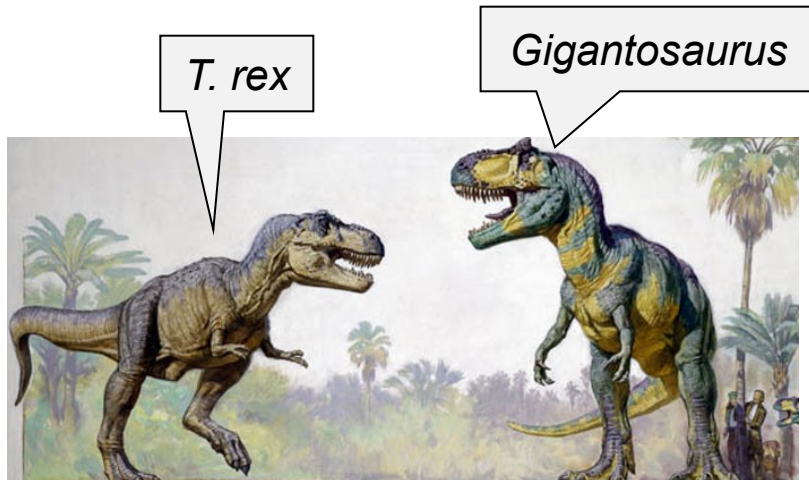


Allosaurus

Mesozoic



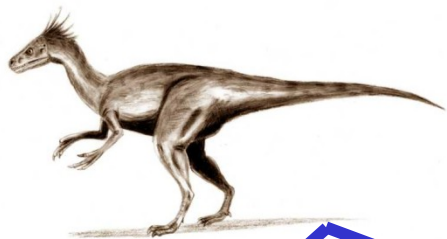
Jurassic:
bone fishes
bird evolution



theropod dinosaurs

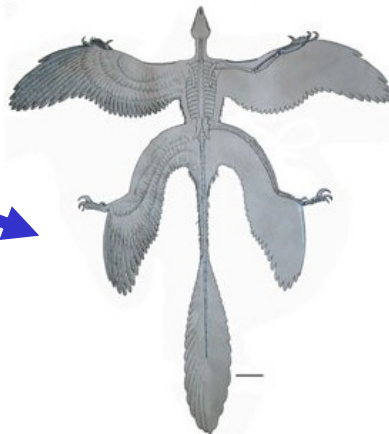


Maniraptora



Archaeopteryx lithographica

tyrannosaurs
(Cretaceous)



Microraptor gui



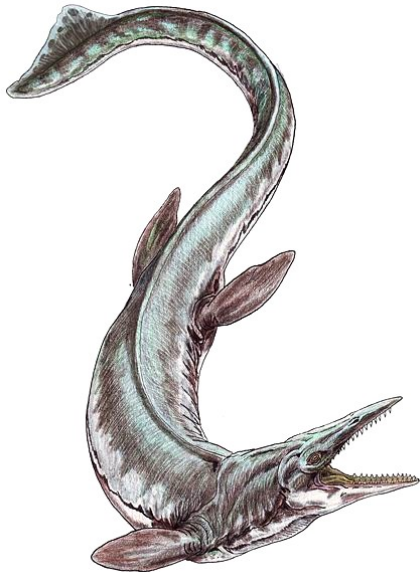
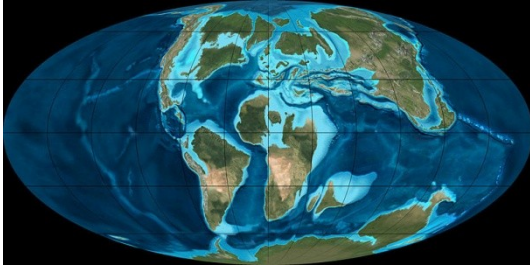
Mesozoic

Cretaceous:

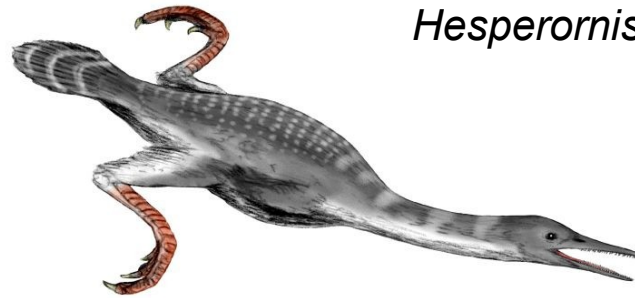
angiosperms

modern sharks and rays, mosasaurs, first snakes,
birds

mammals: divergenc of marsupials and placentals



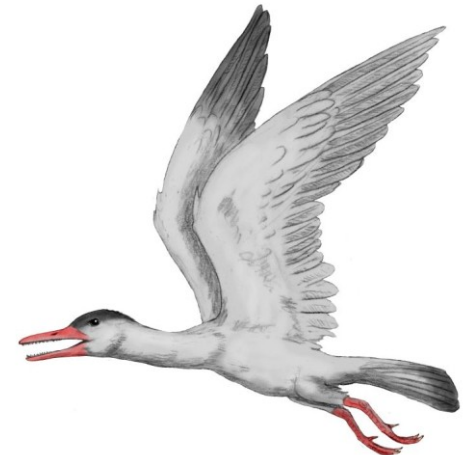
mosasaurs



Hesperornis

the end: **5th extinction**, 66 M

→ the cause??



Ichthyornis

Extinkce na K/T* (K/Pg**) boundary:

*) Cretaceous/Tertiary
**) Cretaceous /Paleogene

1980 Louis Alvarez et al.:

catastrophic hypothesis – asteroid 10 km in diameter
 $10^9 \times$ more than Hiroshima



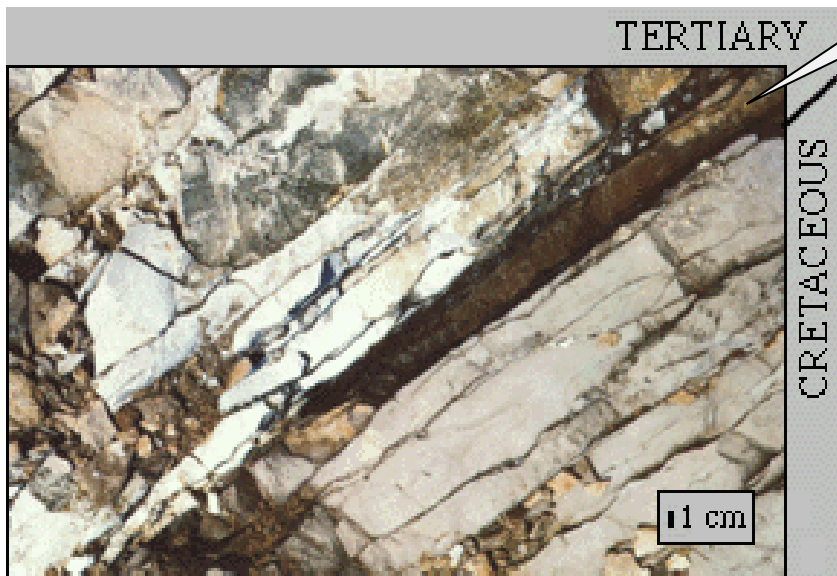
L. Alvarez



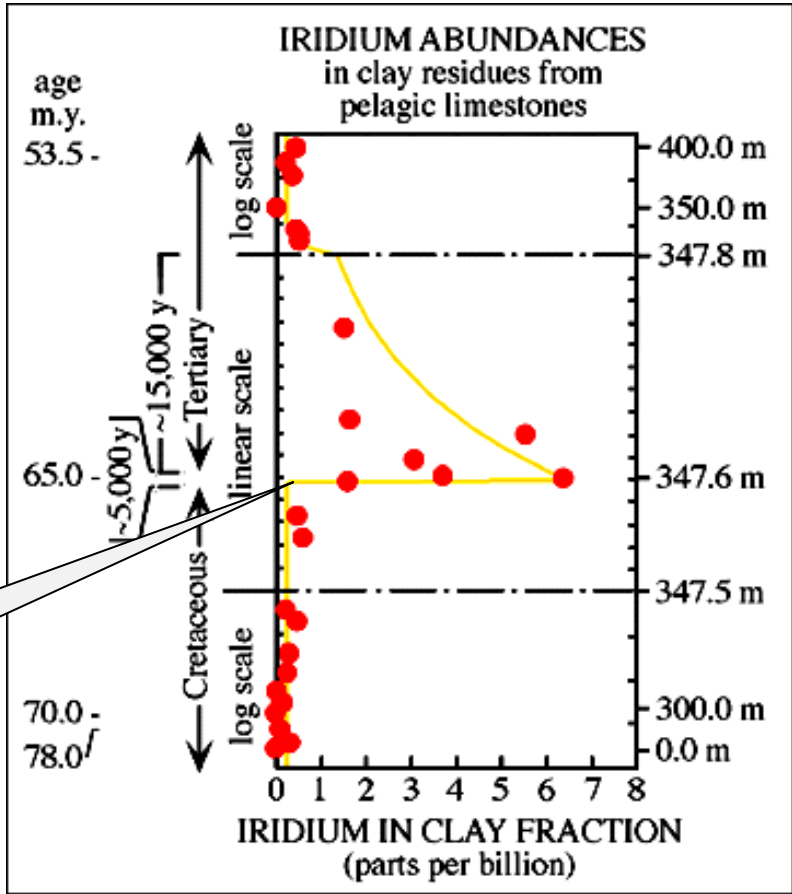
Extinction on the K/T (K/Pg) boundary:

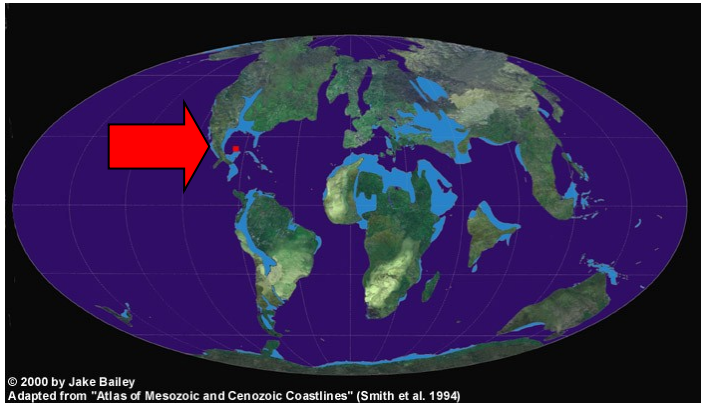
iridium on the boundary

K/T boundary



cca. 100-fold increase of the amount of iridium

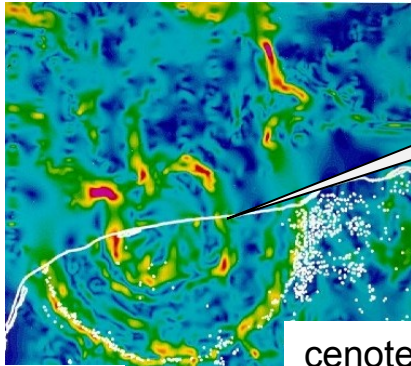




Chicxulub crater (Mexico)

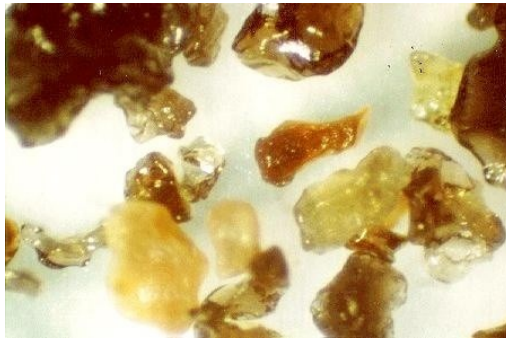


map of gravitational field

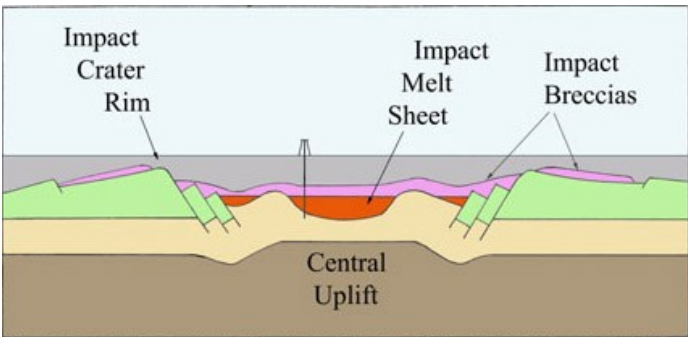
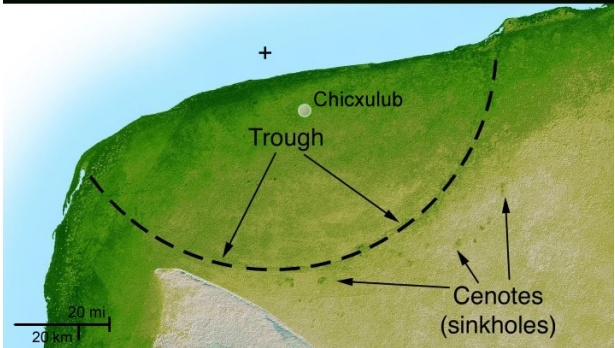


cenotes

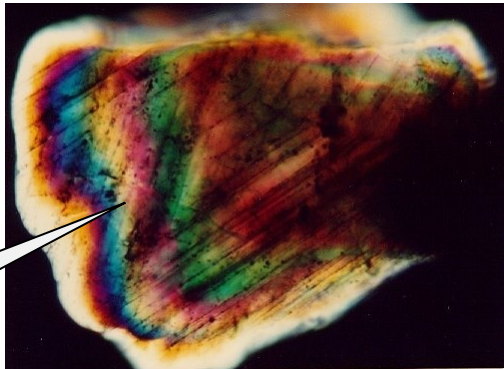
syncline



tektites from the K/T



shock crystal



Problems of the impact theory:

extinctions not that sudden for most animals, occurring before the impact
species have been disappearing in several phases from more thermophilic
to less thermophilic

the impact by ca. 300 ky older than the extinction (but it may have trigger
tsunamies and earthquakes \Rightarrow mixing of layers)

locality El Penon (Mexico): same species above and below the „impact“
layer)

Alternative hypothesis:

gradual cooling caused by giant volcano erruptions on the Deccan Plateau
in India

basalt layer 1200-1800 m thick, 100 000 km² \Rightarrow during 1 MY
 \rightarrow min. 1,5 mil. km³ of basalts

the origin of the plateau at the turn of the Cretaceous and Tertiary

Recent findings:

According to new dating the Deccan event appeared before the impact –
problém: inaccurate dating of the Indian event

More precise dating: the Chicxulub crater corresponds with the extinction

~ 100 ky before the impact cooling by 6–8 °C, probably as a consequence
of the Deccan catastrophe – the impact then as the „coup of grace“

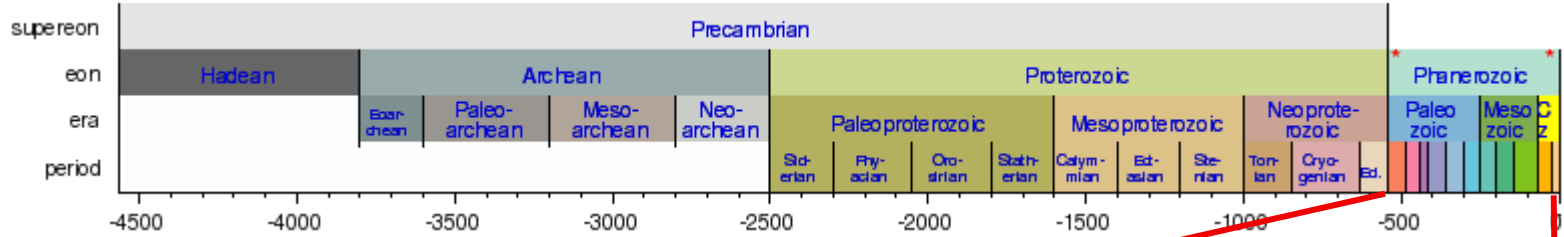
Cyanobacteria as a result of the greenhouse effect?

Some theories: two consecutive impacts

Animations:

eg. <https://www.youtube.com/watch?v=bU1QPtOZQZU>

eon: Phanerozoic

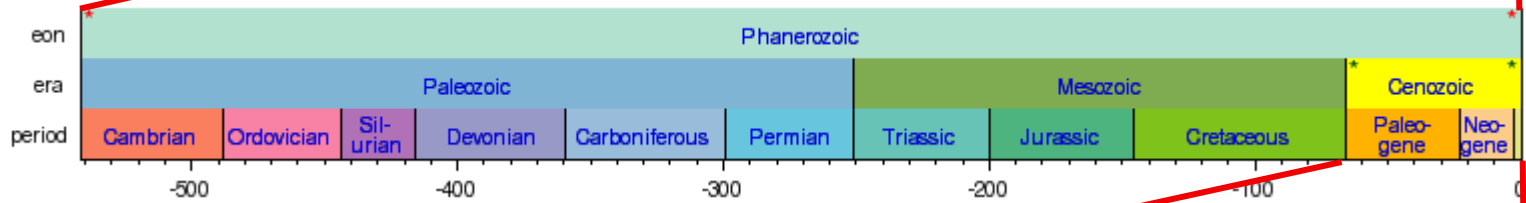


era

Paleozoic

Mesozoic

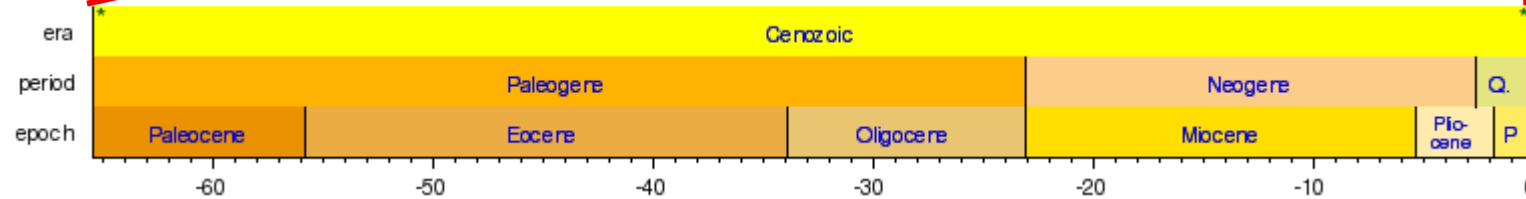
Cenozoic



period

Paleogene

Neogene



epoch

Paleocene

Eocene

Oligocen

Miocene

Plio- Pleisto-

Paleontological vs. molecular data

When have animal phyla and mammalian/bird orders emerged?

Cambrian explosion?

molecular data (Wray et al. 1996):

Protostomia-Deuterostomia ~ 1200 M

Chordata-Echinodermata ~ 1000 M

„phylogenetic fuse“?

Paleontological vs. molecular data

When have animal phyla and mammalian/bird orders emerged?

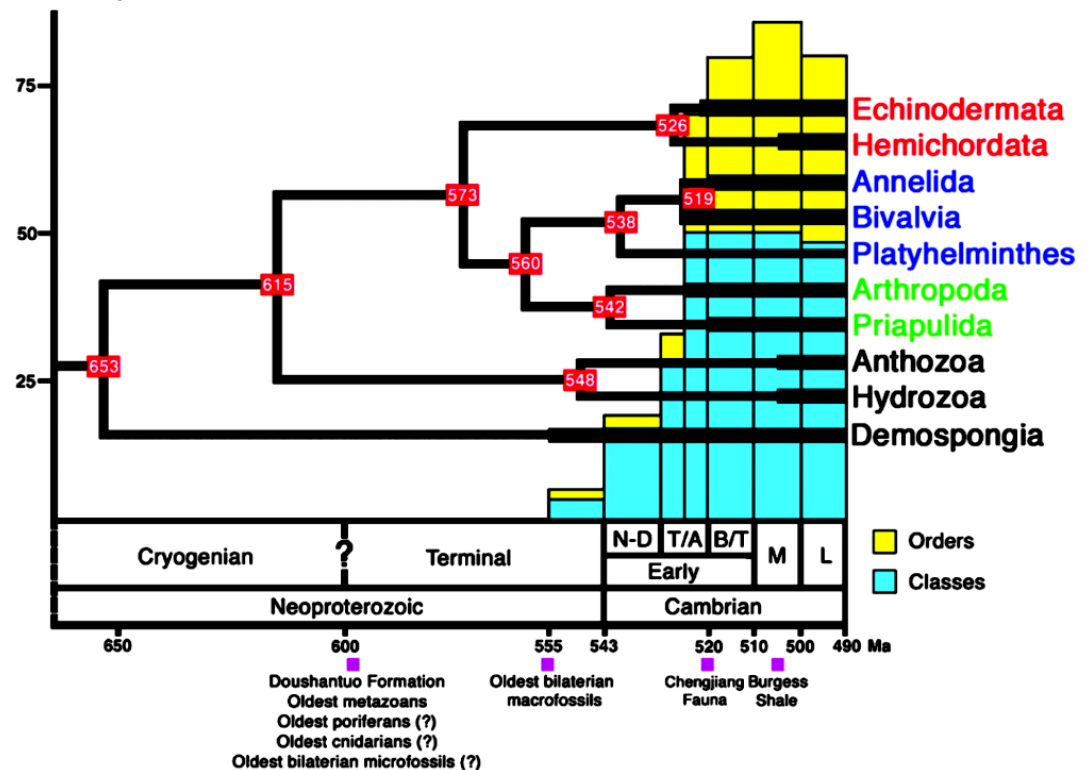
Cambrian explosion?

recent molecular estimates closer to the Cambrian explosion:

Metazoa ~ 650 M (Peterson et al. 2004)

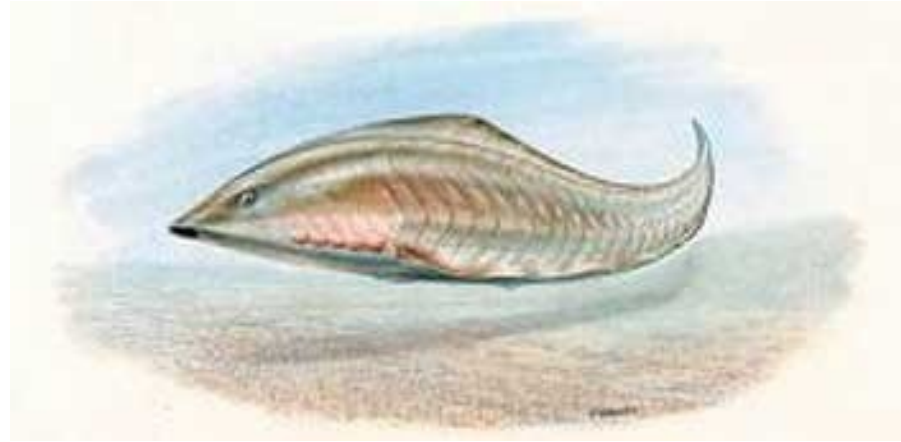
Protostomia-Deuterostomia ~ 582 M

(Aris-Brosou and Yang 2003)



Cambrian explosion?

fauna of Chengjiang (China) ~ 525 M



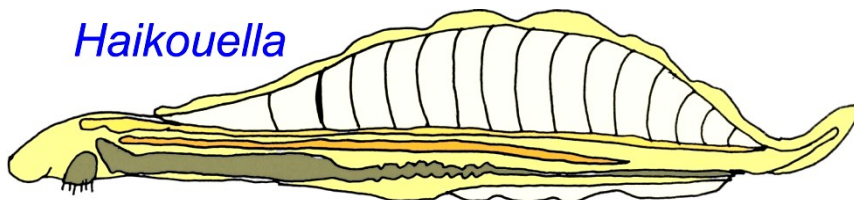
Myllokunmingia



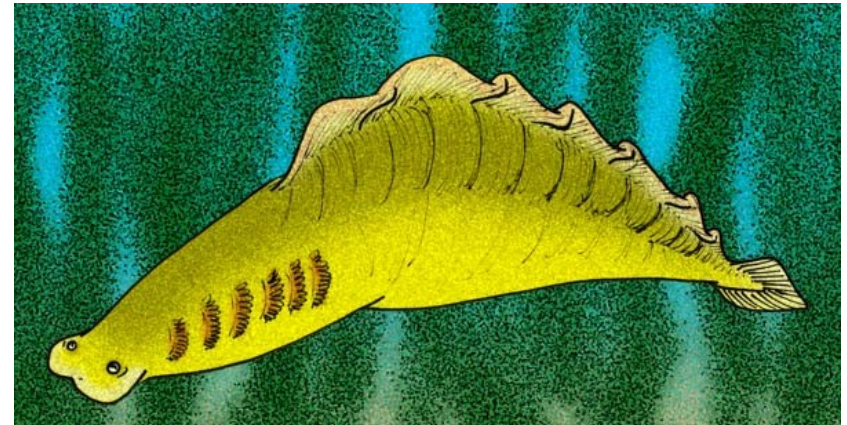
Yunnanozoon lividum



Haikouella lanceolata



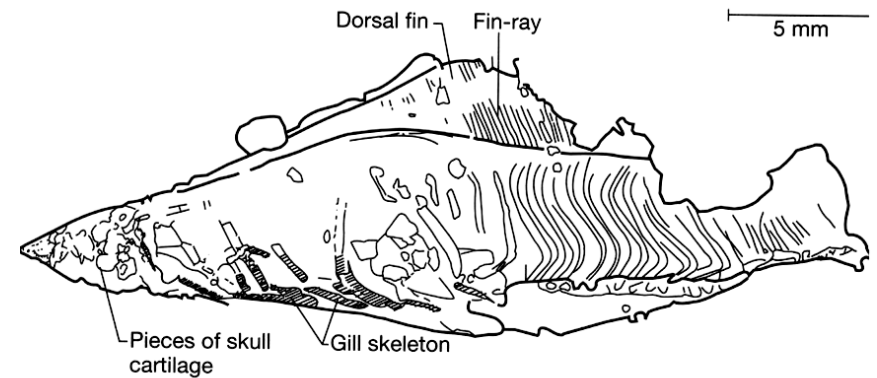
Haikouella



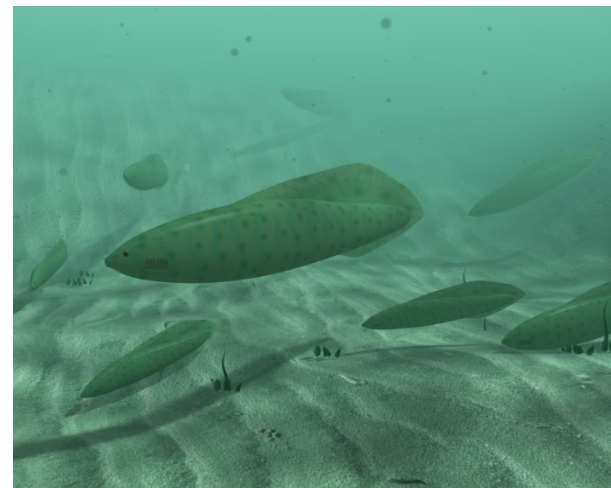
Cambrian explosion?

fauna of Chengjiang (China) ~ 525 M

Doushantuo formation (S China),
590–560 M: many species



early embryonic stages?



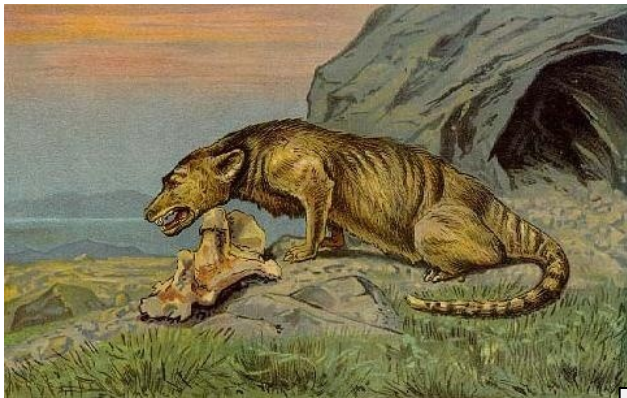
*Haikouichthys
ercaicunensis*
525 M

Paleontological vs. molecular data

When have animal phyla and mammalian/bird orders emerged?

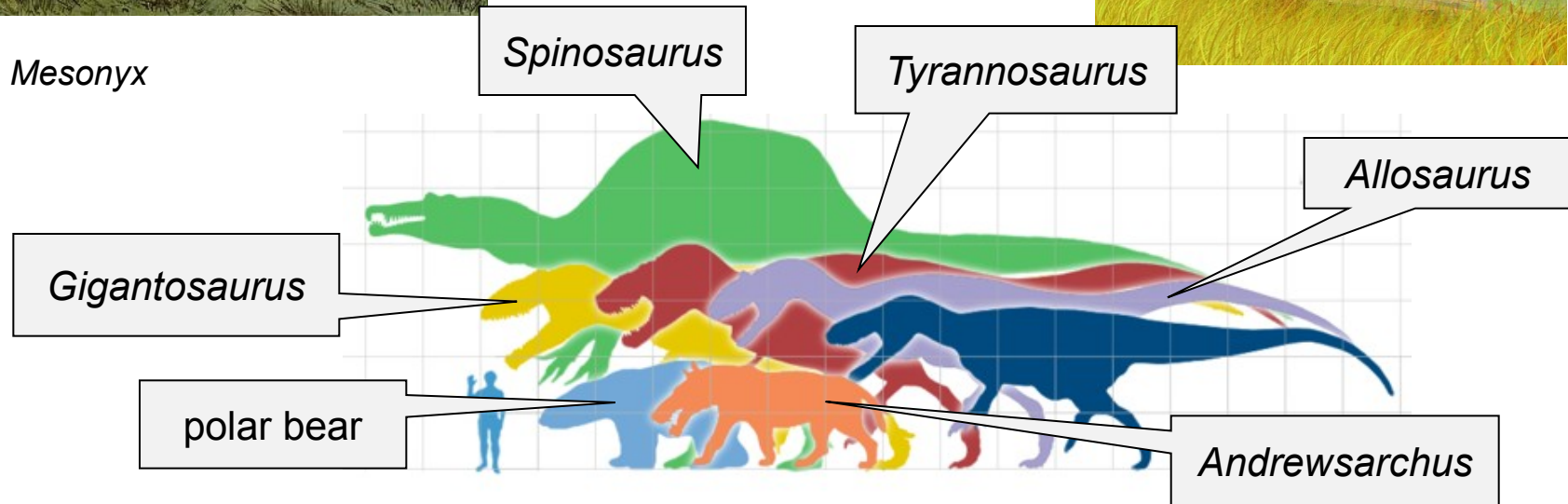
recent groups of mammals and birds and the K/T boundary

cetacean evolution: mesonychids → moving to water → cetaceans



Mesonyx

Andrewsarchus mongolicus



Spinosaurus

Tyrannosaurus

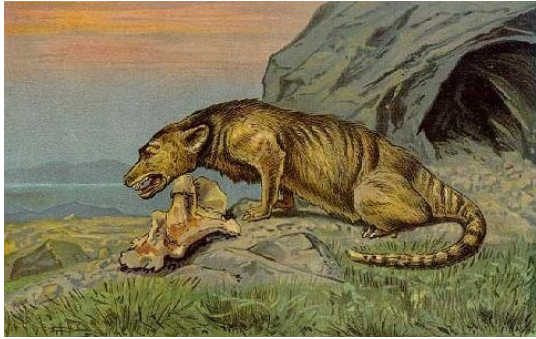
Allosaurus

Gigantosaurus

polar bear

Andrewsarchus

cetacean evolution



mesonychids ~ 56 M



Pakicetus 56-34 M

Ambulocetus 50-49 M



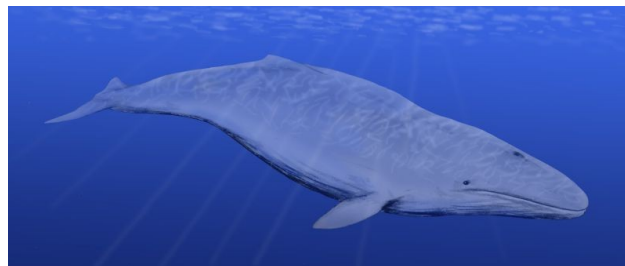
Dorudon 41-33 M



Rodhocetus 47 M



Basilosaurus 40-34 M



Cetotherium 15 M



General principles

diversity: stock market analogy

extinction: foot soldier model

lifetime of lineages: gambler's bankruptcy model

random walk

David Raup, Jack Sepkoski:
periodicity? (26 M)



D. Raup



J. J. Sepkoski

