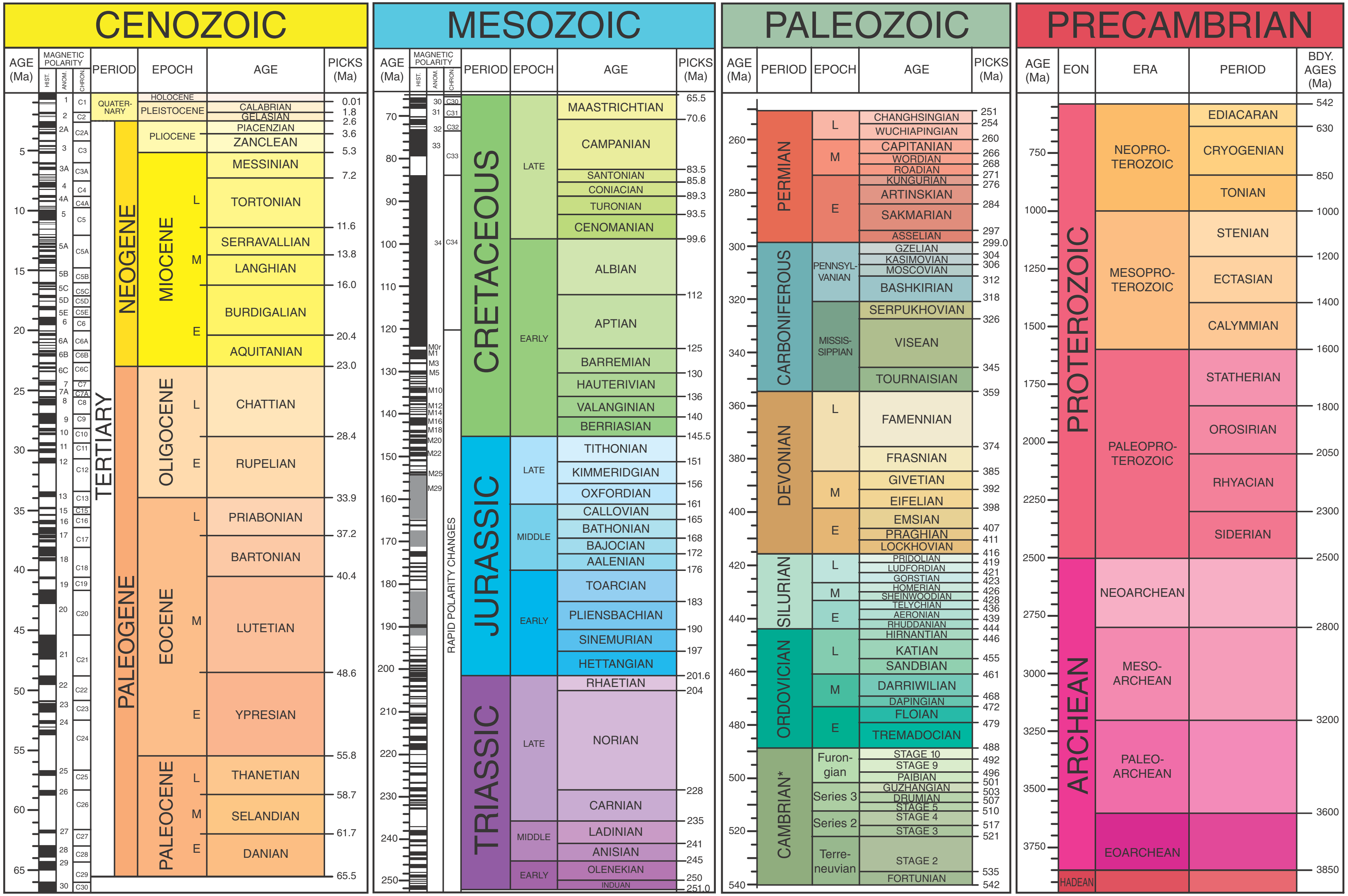
Earth and Life through Time

before and during the Age of the Dinosaurs

2009 GEOLOGIC TIME SCALE



*International ages have not been fully established. These are current names as reported by the International Commission on Stratigraphy.

Walker, J.D., and Geissman, J.W., compilers, 2009, Geologic Time Scale: Geological Society of America, doi: 10.1130/2009.CTS004R2C.

THE GEOLOGICAL SOCIETY OF AMERICA®

Sources for nomenclature and ages are primarily from Gradstein, F., Ogg, J., Smith, A., et al., 2004, A Geologic Time Scale 2004: Cambridge University Press, 589 p. Modifications to the Triassic after: Furin, S., Preto, N., Rigo, M., Roghi, G., Gianolla, P., Crowley, J.L., and Bowring, S.A., 2006, High-precision U-Pb zircon age from the Triassic of Italy: Implications for the Triassic time scale and the Carnian origin of calcareous nannoplankton and dinosaurs: Geology, v. 34, p. 1009–1012, doi: 10.1130/G22967A.1; and Kent, D.V., and Olsen, P.E., 2008, Early Jurassic magnetostratigraphy and paleolatitudes from the Hartford continental rift basin (eastern North America): Testing for polarity bias and abrupt polar wander in

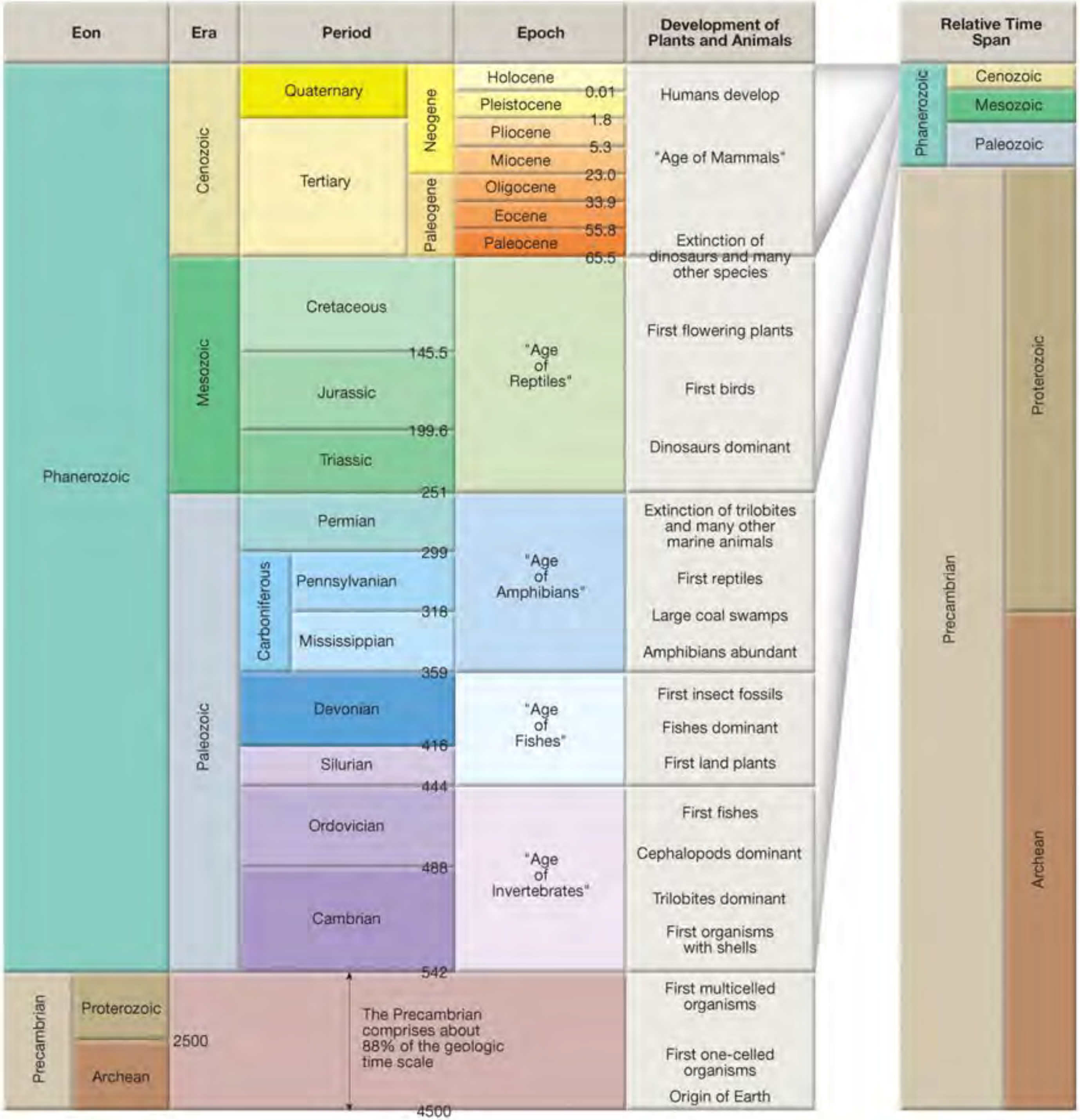
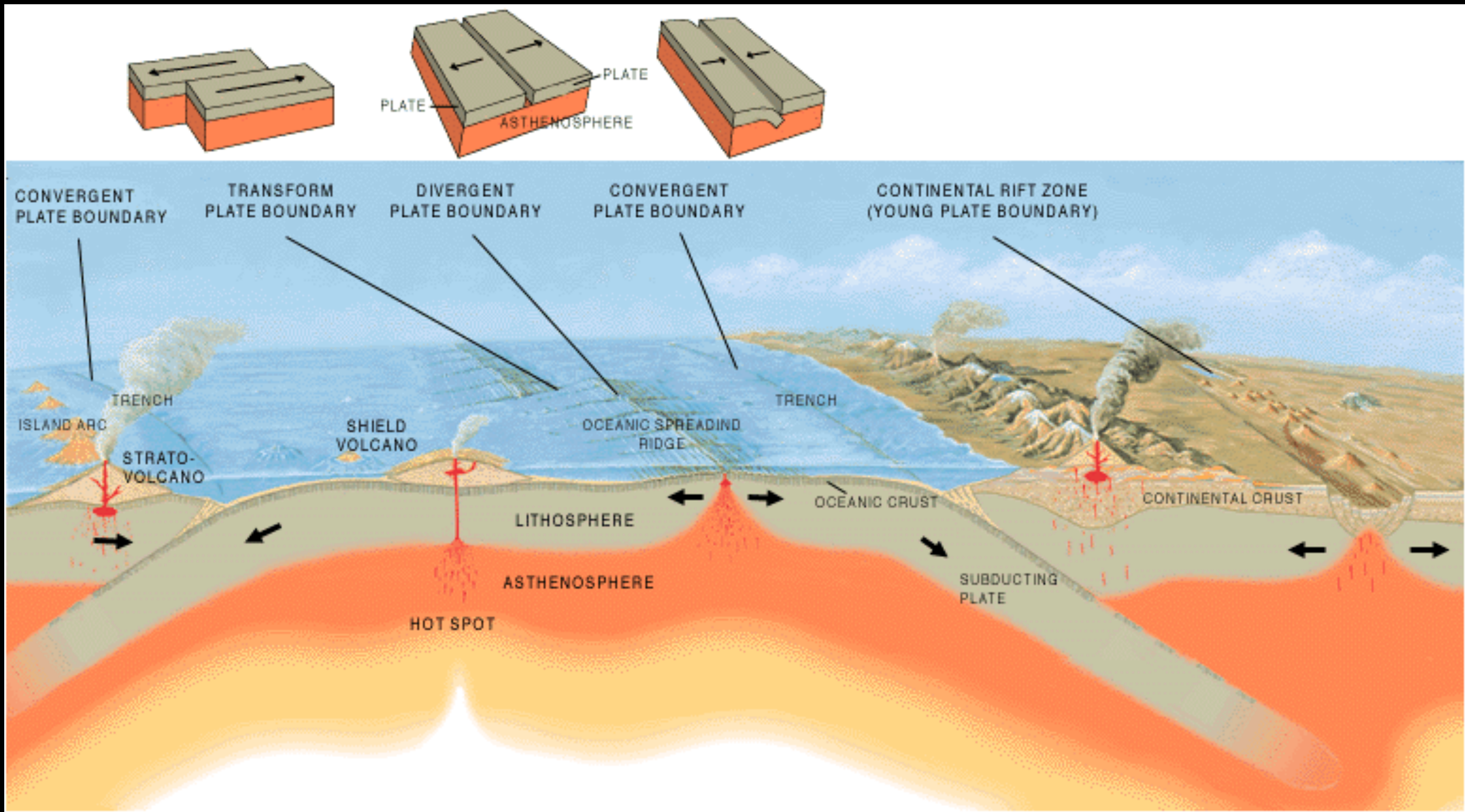
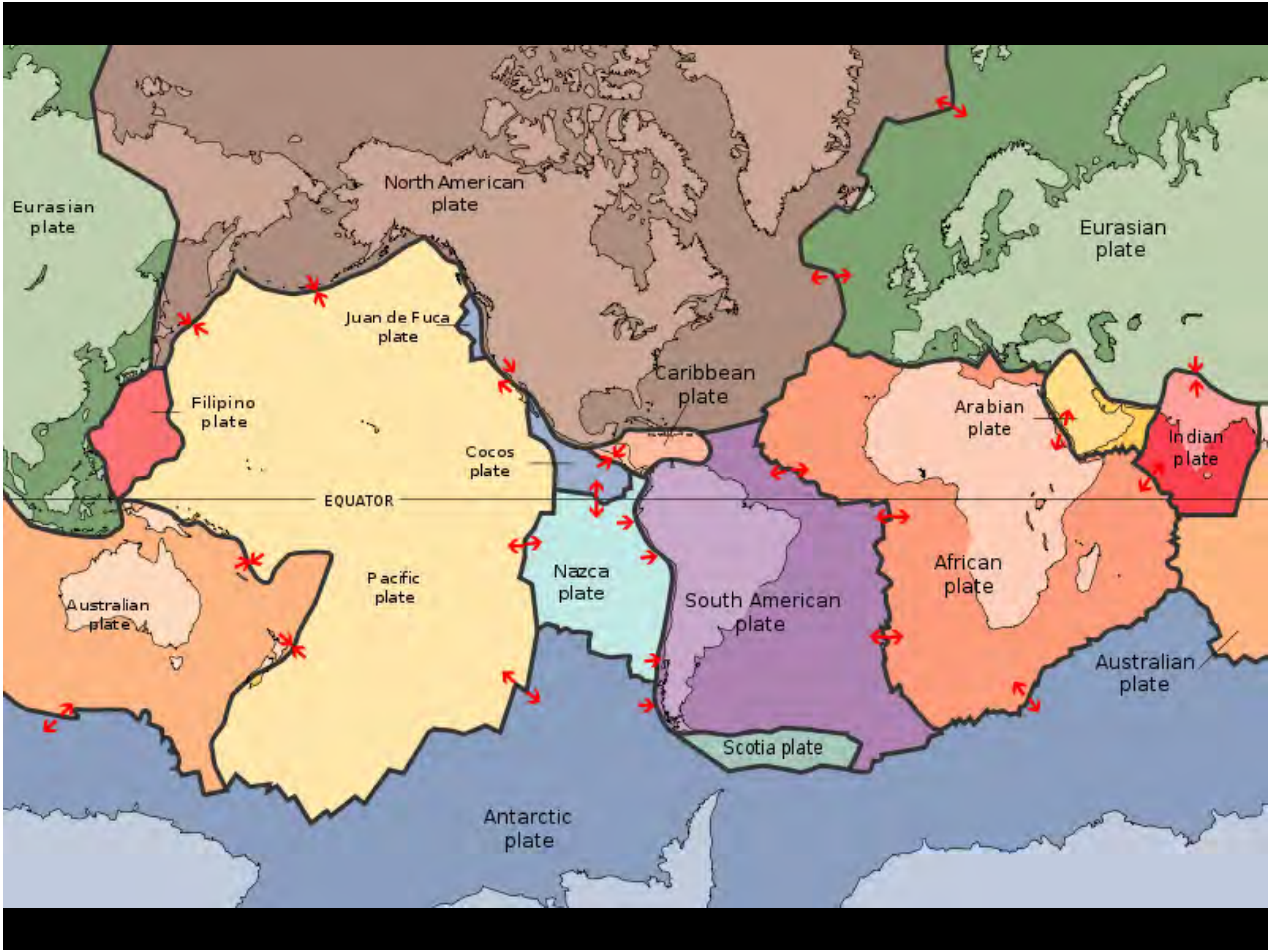
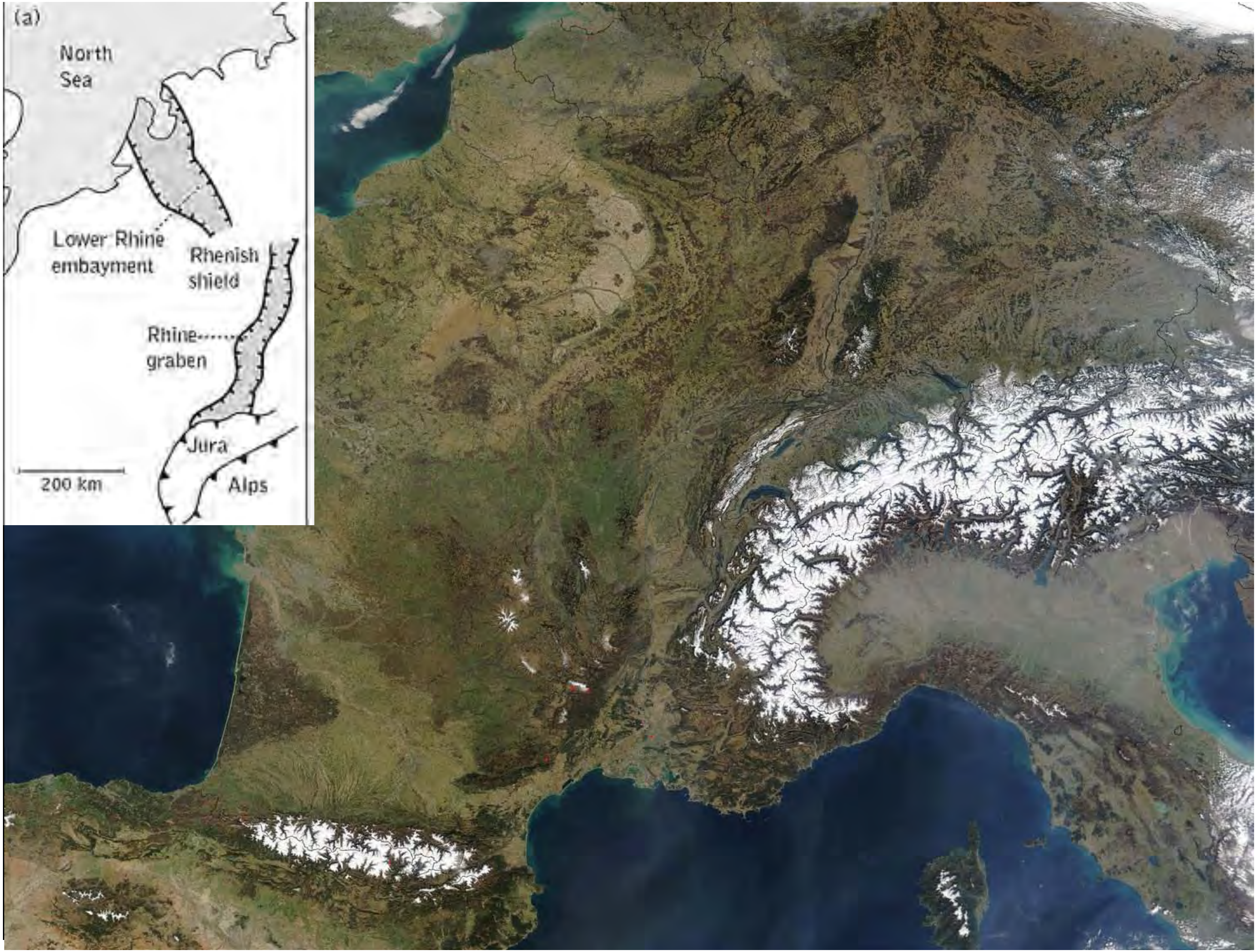

Eon
Era
Period
Epoch
Development of Plants and Animals
Relative Time Span
Phanerozoic
Cenozoic
Quaternary
Neogene
Tertiary
Paleogene
Holocene
Pleistocene
Pliocene
Miocene
Oligocene
Eocene
Paleocene
0.01
1.8
5.3
23.0
33.9
55.8
65.5
Humans develop
"Age of Mammals"
Extinction of dinosaurs and many other species
Mesozoic
Cretaceous
145.5
Jurassic
199.6
Triassic
251
"Age of Reptiles"
First flowering plants
First birds
Dinosaurs dominant
Paleozoic
Permian
299
Carboniferous
Pennsylvanian
318
Mississippian
359
"Age of Amphibians"
Extinction of trilobites and many other marine animals
First reptiles
Large coal swamps
Amphibians abundant
Devonian
416
Silurian
444
"Age of Fishes"
First insect fossils
Fishes dominant
First land plants
Ordovician
488
Cambrian
542
"Age of Invertebrates"
First fishes
Cephalopods dominant
Trilobites dominant
First organisms with shells
Precambrian
Proterozoic
Archean
2500
4500
The Precambrian comprises about 88% of the geologic time scale
First multicelled organisms
First one-celled organisms
Origin of Earth
Phanerozoic
Cenozoic
Mesozoic
Paleozoic
Precambrian
Proterozoic
Archean

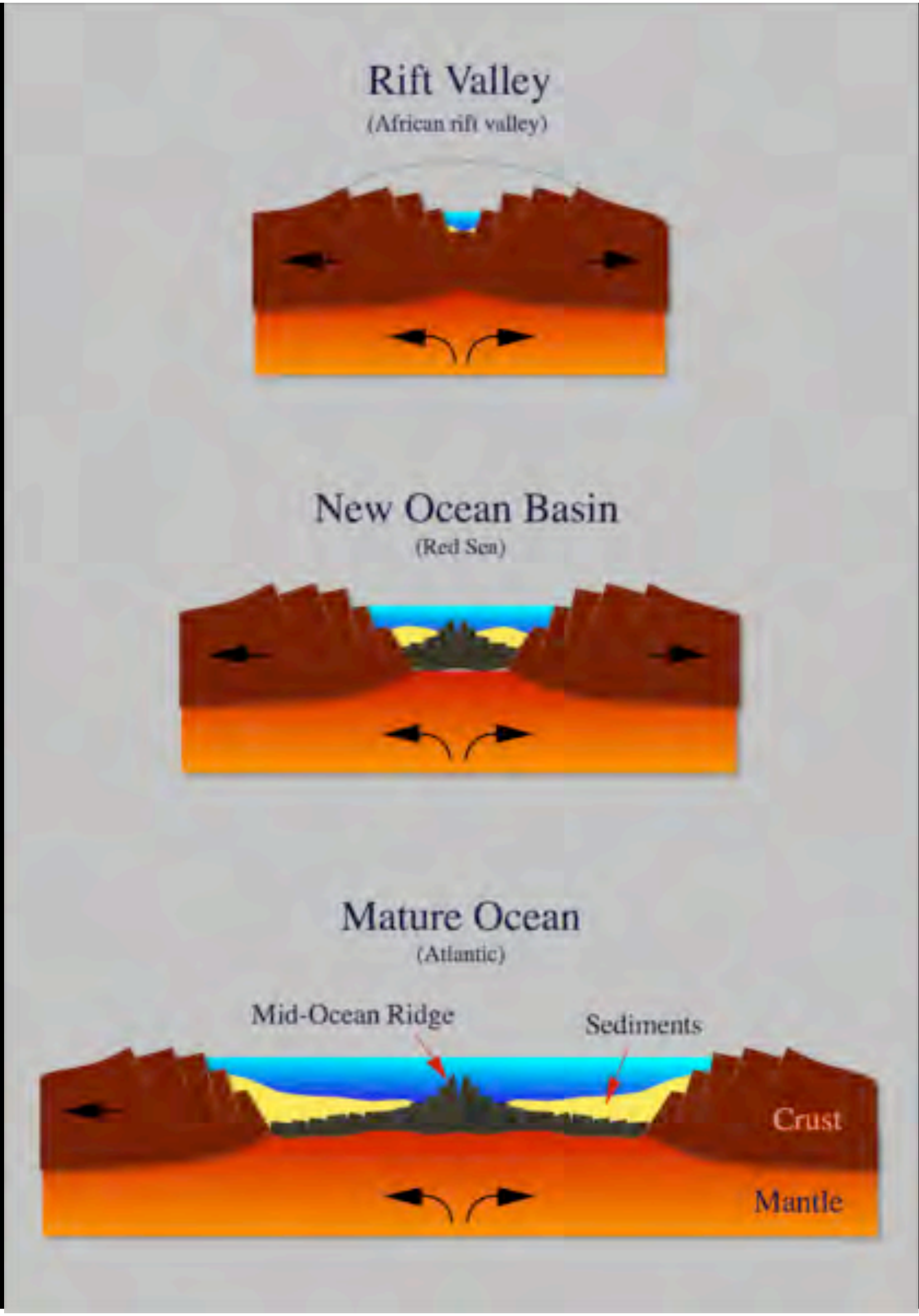
Plate tectonics



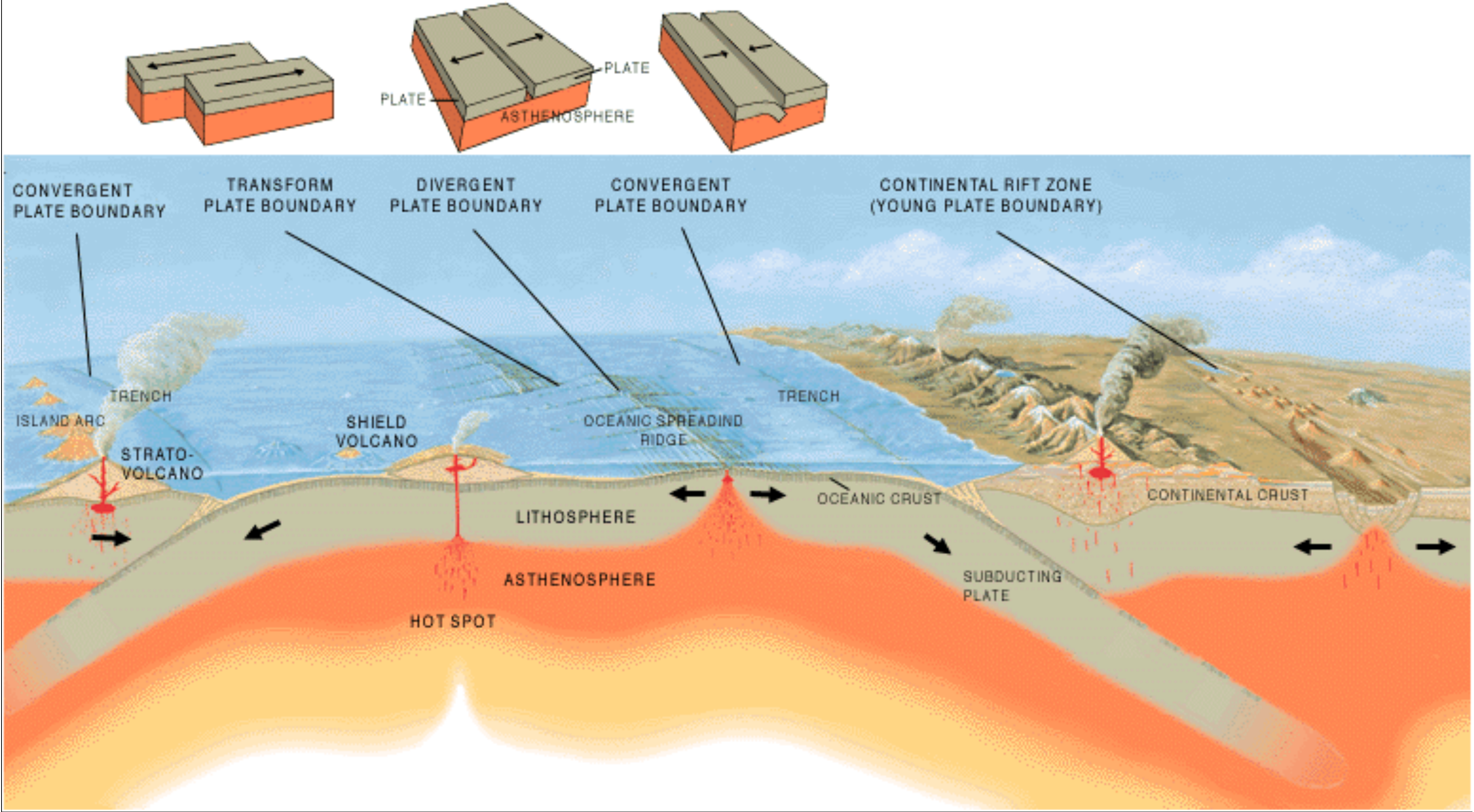

North American plate
Eurasian plate
Eurasian plate
Juan de Fuca plate
Caribbean plate
Filipino plate
Arabian plate
Indian plate
Cocos plate
EQUATOR
African plate
Nazca plate
Pacific plate
South American plate
Australian plate
Australian plate
Scotia plate
Antarctic plate


Fault lines
Tectonic plate boundary
Major active volcanoes
Major dormant or extinct volcanoes
AFRICAN PLATE
ARABIAN PLATE
Erta'ale
Ardoukoba
AFAR DEPRESSION
Lake Albert
Lake Edward
Lake Turkana
EASTERN RIFT VALLEY
Mt. Elgon
Nyamulagira
Nyiragongo
Lake Victoria
Mt. Kenya
Lac Kivu
Volcan Karisimbi
Ol Doinyo Lengai
WESTERN RIFT VALLEY
Kilimanjaro
Mt. Meru
Indian Ocean
Lake Tanganyika
Lake Rukwa
Lake Mweru
Lake Malawi
500 km
mi
N
Views of the Earth, Copyright © 2006 by Christoph Hormann http://earth.imagico.de/


(a)
North Sea
Lower Rhine embayment
Rhenish shield
Rhine graben
Jura
Alps
200 km

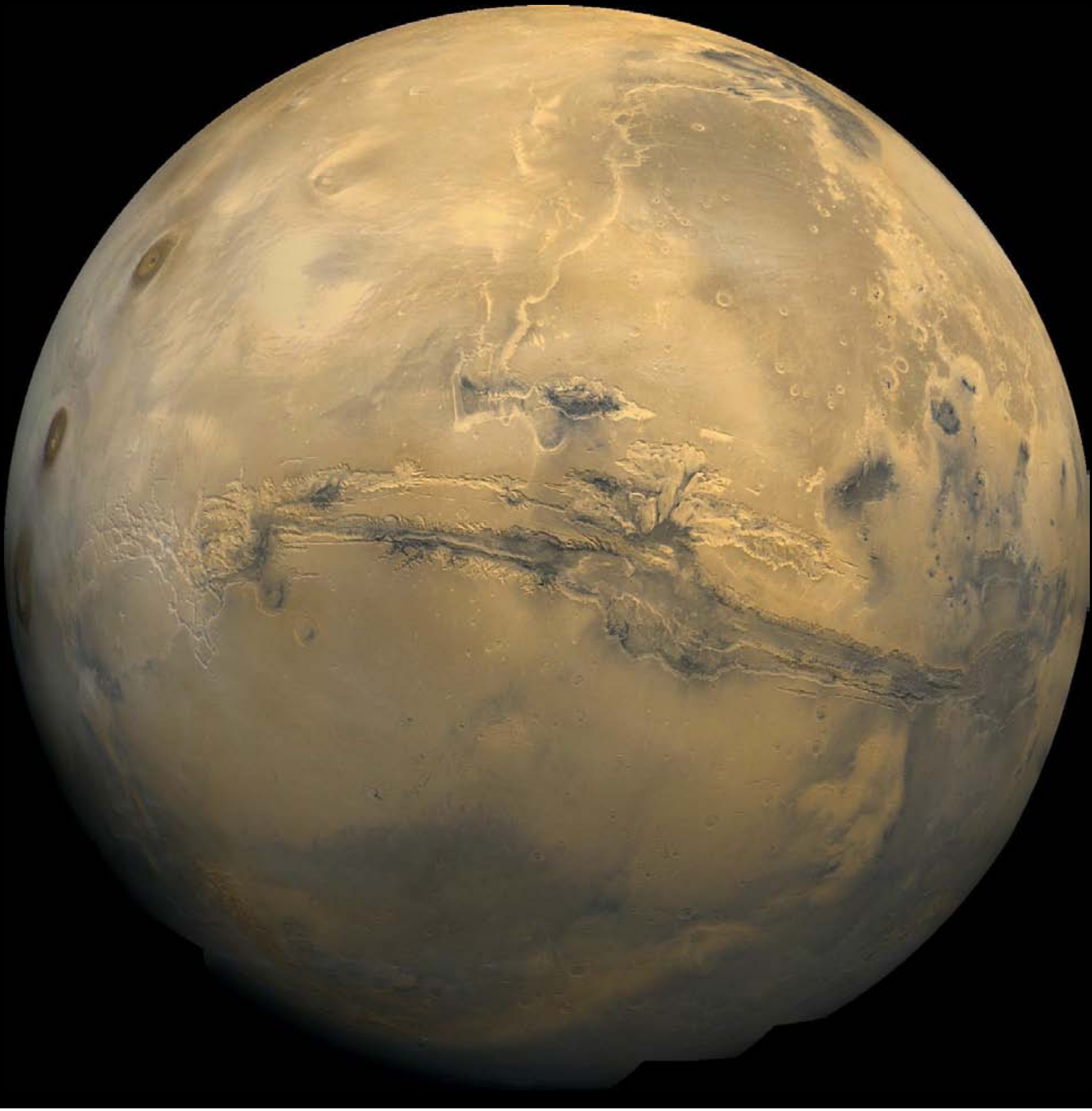


Rift Valley
(African rift valley)
New Ocean Basin
(Red Sea)
Mature Ocean
(Atlantic)
Mid-Ocean Ridge
Sediments
Crust
Mantle

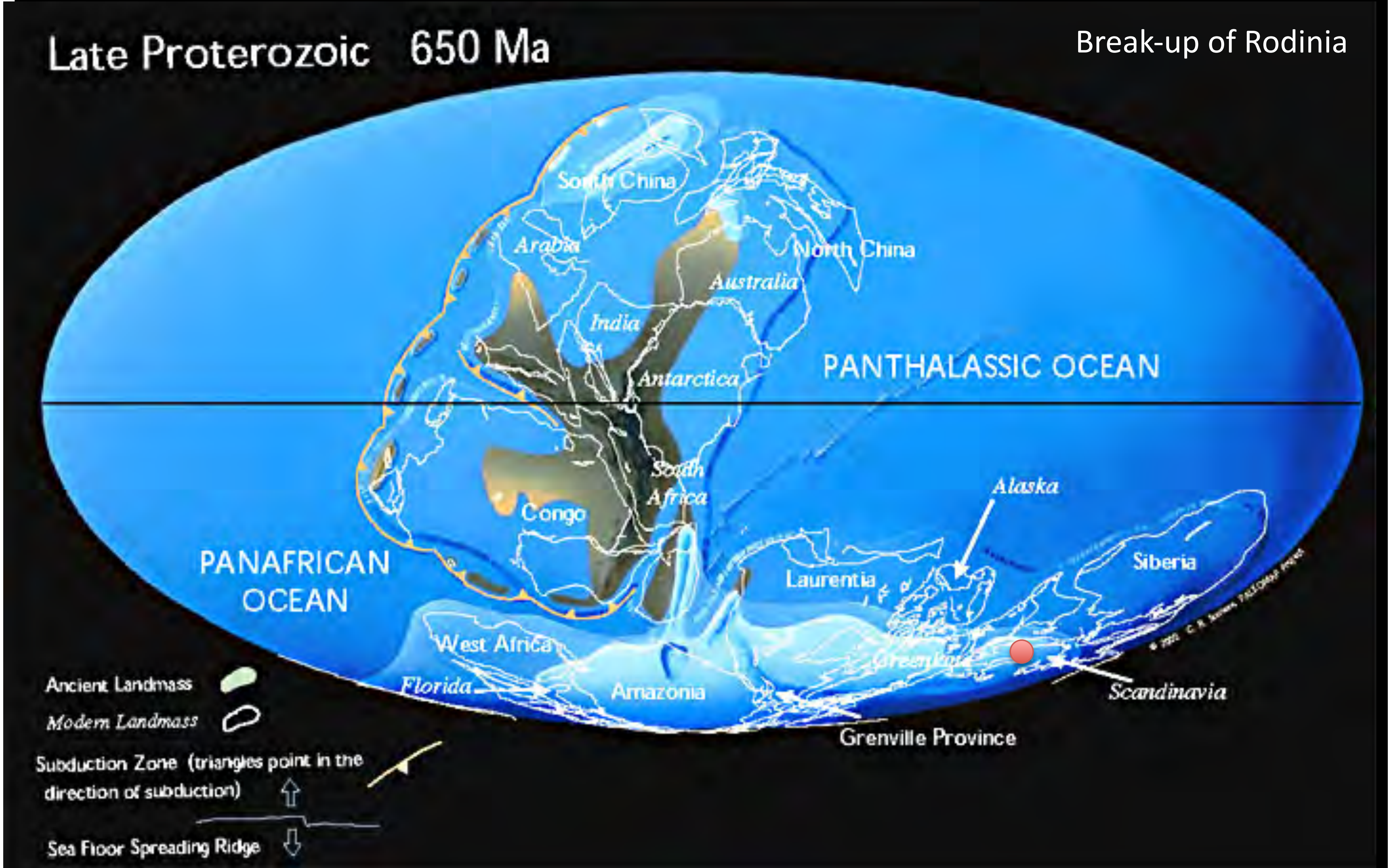


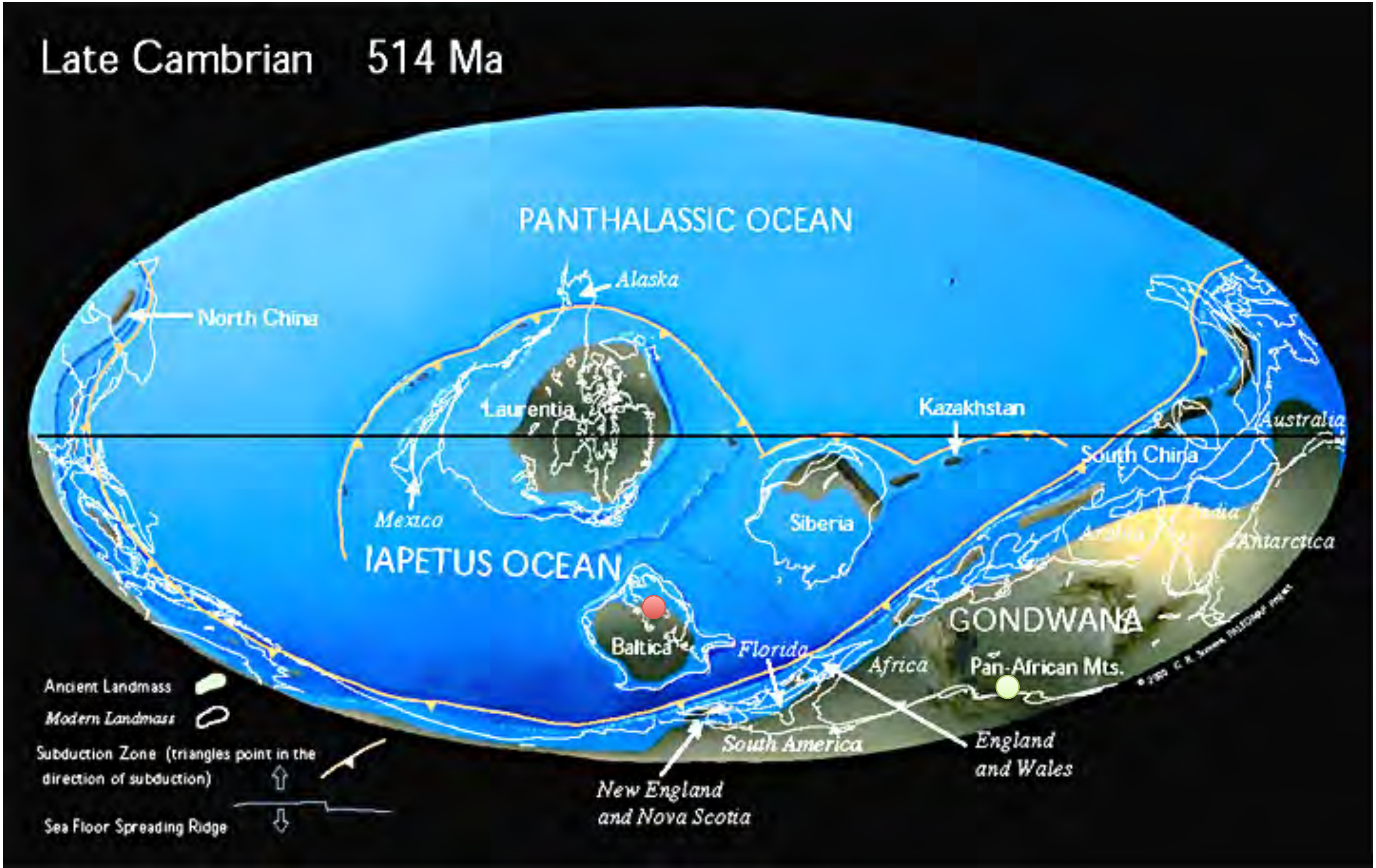
conservative – productive – destructive plate boundaries
continental vs. oceanic crust
shape of continents not stable during earth history (amalgamation vs. breaking apart)
heat in the Earth’s is the driving force

compare Mars' Valles Marineris!

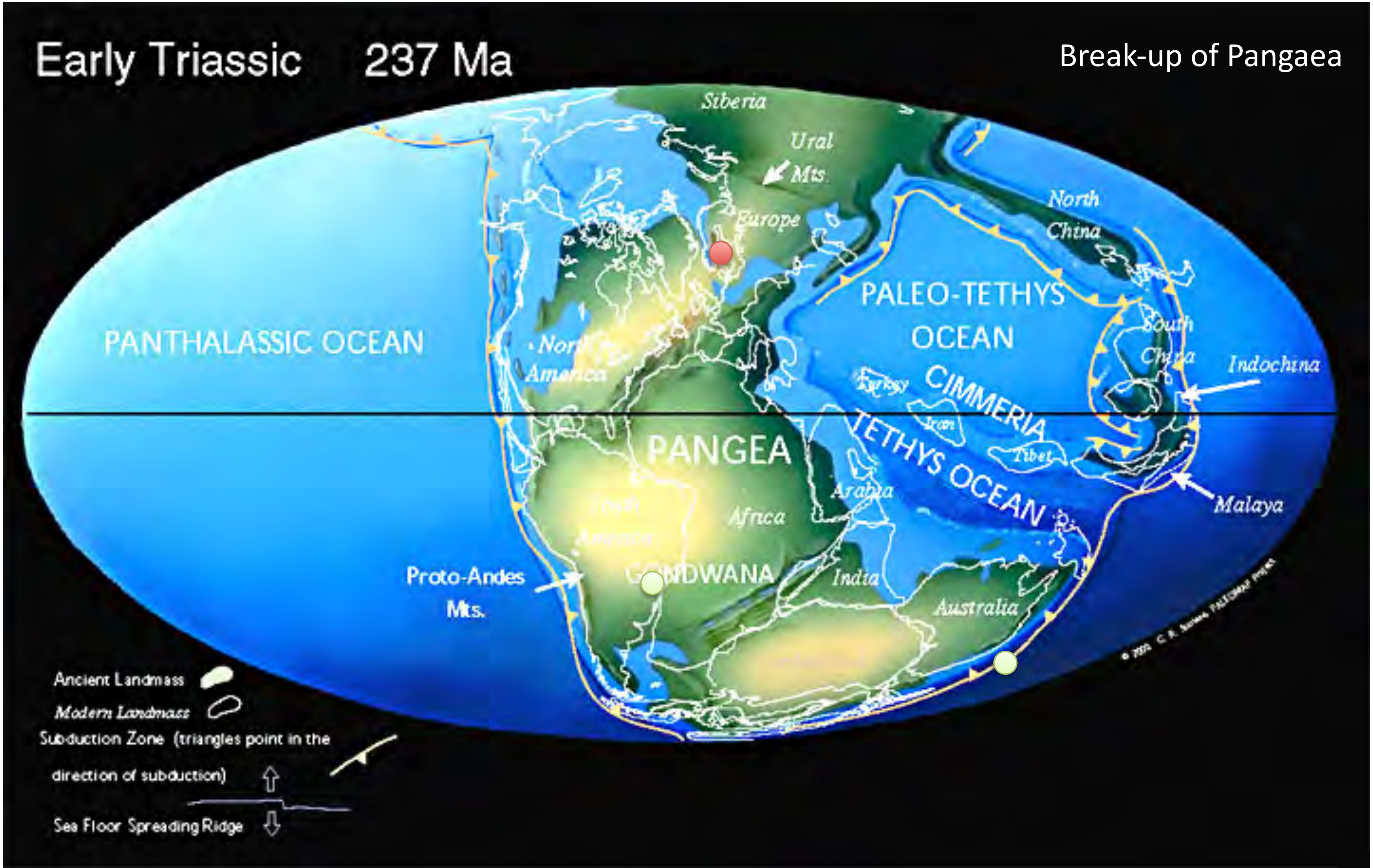


Break-up of Rodinia

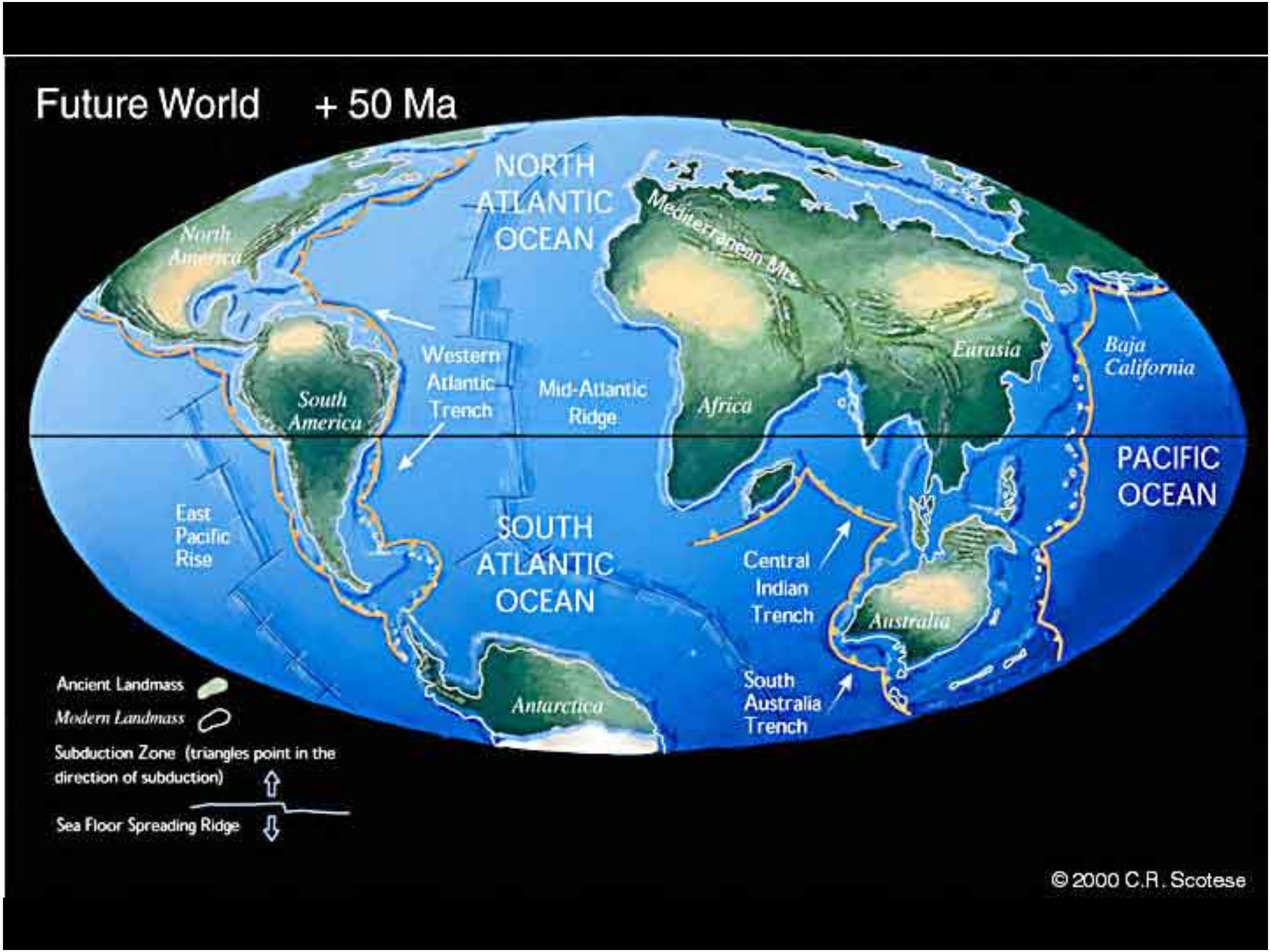



Late Cambrian 514 Ma
PANTHALASSIC OCEAN
Alaska
North China
Laurentia
Kazakhstan
Australia
South China
Mexico
Siberia
India
Arabia
Antarctica
IAPETUS OCEAN
GONDWANA
Baltica
Florida
Africa
Pan-African Mts.
South America
England
and Wales
New England
and Nova Scotia
Ancient Landmass
Modern Landmass
Subduction Zone (triangles point in the direction of subduction)
Sea Floor Spreading Ridge

Break-up of Pangaea

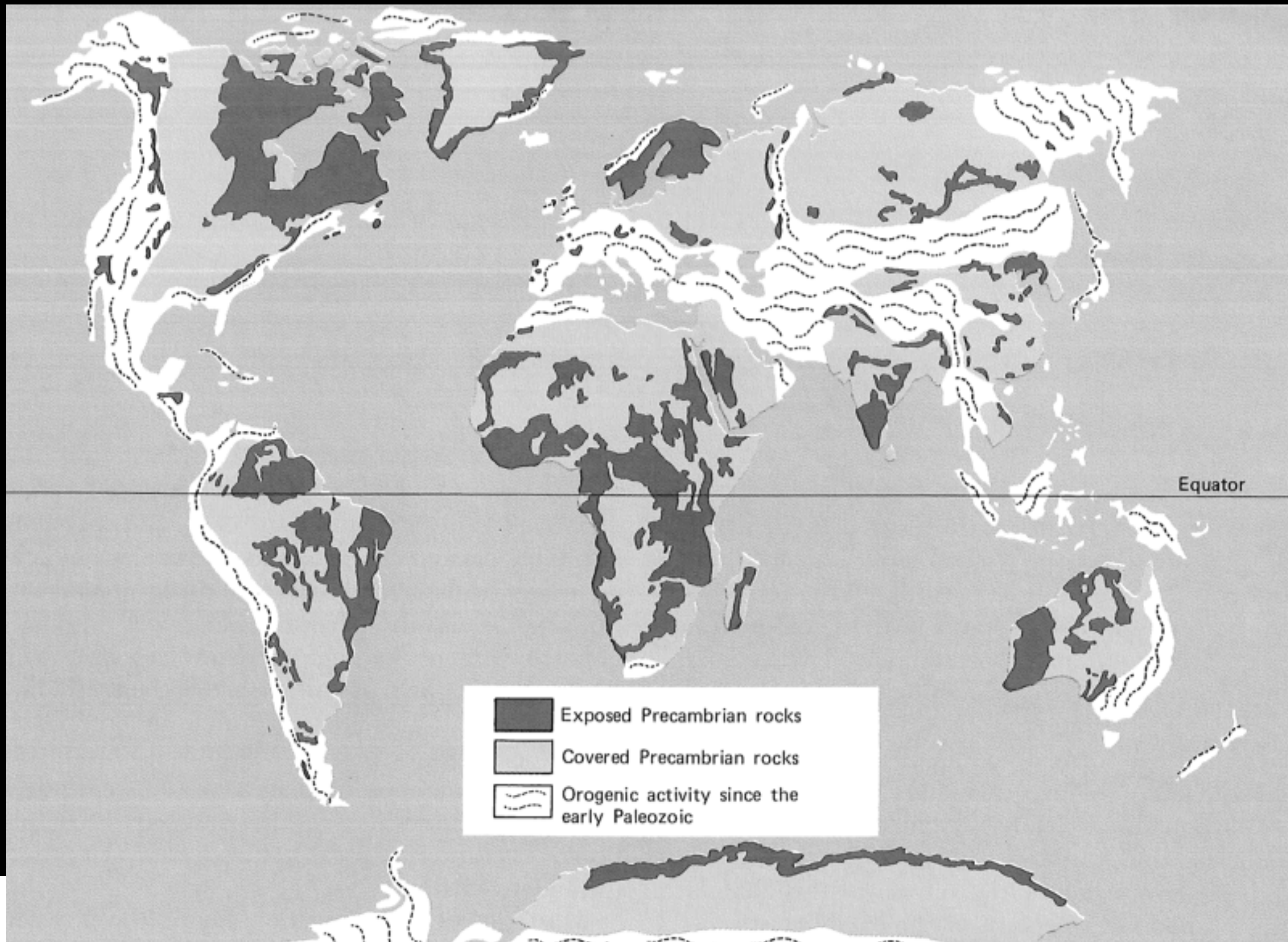


K/T Boundary 66 Ma


Future World + 50 Ma
NORTH ATLANTIC OCEAN
North America
Mediterranean Mts.
Western Atlantic Trench
Mid-Atlantic Ridge
South America
Africa
Eurasia
Baja California
PACIFIC OCEAN
East Pacific Rise
SOUTH ATLANTIC OCEAN
Central Indian Trench
Australia
South Australia Trench
Antarctica
Ancient Landmass
Modern Landmass
Subduction Zone (triangles point in the direction of subduction)
Sea Floor Spreading Ridge
© 2000 C.R. Scotese

Precambrian (4.6 Ga- 0.545 Ga)

- 88% of geological time
- only 20 % of the the rocks exposed

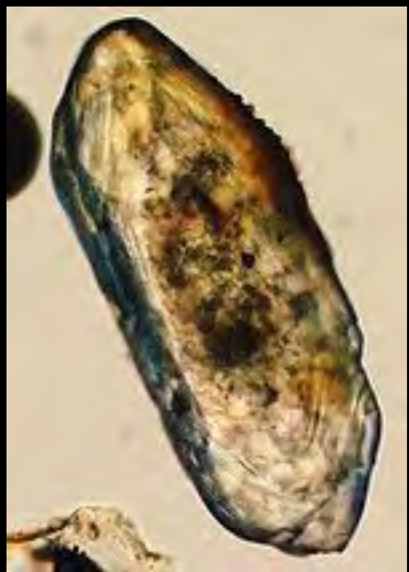


Precambrian

- 3 eons: Hadean – Archaean – Proterozoic

Hadean (4.6-3.8 Ga)

- the time period before the earliest known rocks
- individual minerals (zircon) date from this period (4.4Ga) = oldest material of terrestrial origin
- potentially already liquid water on Earth's surface



Archaean (3.8-2.5 Ga)

- heat flow still high (3x higher than today)
- high volcanic activity
- first continental crust and first proto-continents
- first sedimentary basins by the end of the Archean
- no free oxygen in atmosphere
- presence of liquid water

The Rise of oxygen

- no free oxygen in the Archean, but first BIFs in oceanic basins
- Oldest BIFs date 3.7 Ga → LIFE!
- Great Oxydation Event (2.4 Ga)

Building a banded iron formation

Banded iron formations began as sediments accumulating on the ocean floor of early Earth. The formations record how different both ocean and atmospheric chemistry were from today's, and in what ways they may have dramatically changed. Pictured is one scenario for how the formations may document Earth's transition to an oxygen-rich atmosphere.

1 Iron from the deep
Iron from Earth's interior enters the ocean through hydrothermal vents, which are essentially hot springs on the ocean floor. Modern vents dot spreading ridges, where blocks of ocean crust are moving apart and making room for magma from below to travel upward and create new ocean crust.

2 Iron from the land
Continental crust on land also contains iron. Water and weather break the crust down, and rivers carry dissolved iron particles into the ocean.

3 Oxygen makers
Oxygen could have entered the scene as it was produced in large enough quantities by cyanobacteria, microbes that perform photosynthesis.

4 Iron back down
The ocean of early Earth contained much more dissolved iron than today's ocean. One way iron leaves water is if it reacts with dissolved oxygen. The reaction forms a type of iron that precipitates out of water, falling as iron oxide particles onto the ocean floor.

5 Oxygen up
Being a gas, oxygen can travel between atmosphere and ocean. One question is whether oxygen first built up in the atmosphere, then flooded the water and caused iron to precipitate out; or whether oxygen accumulated in the water and then spent time using up the iron supply until enough oxygen was available to fill the atmosphere.

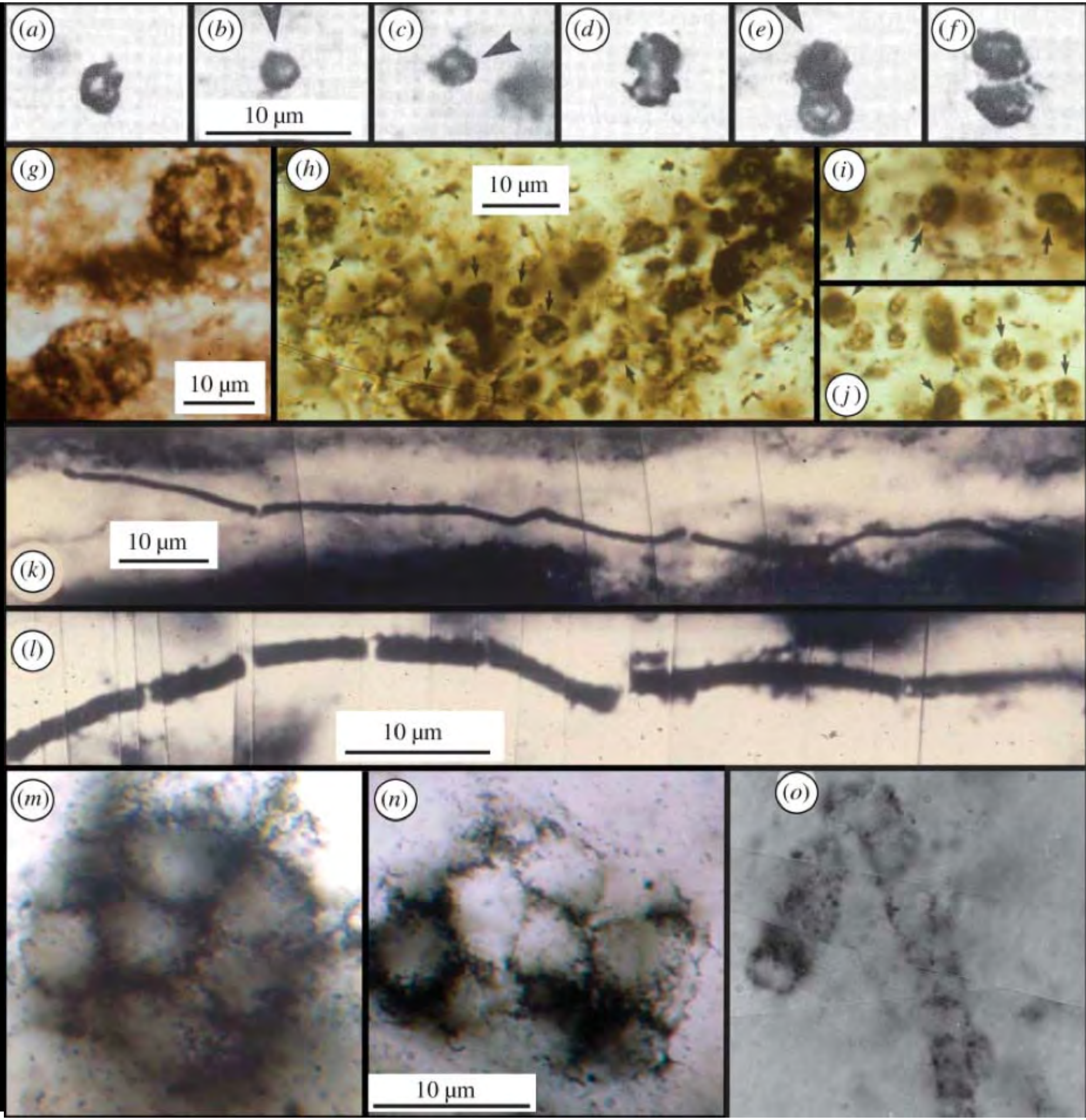
6 Banding beginnings
Particles of silica also drop out of water onto the ocean floor. The layering of banded iron formations shows that sometimes ocean precipitates were mostly silica and other times they were mostly iron. Why remains unclear.

7 Sediment t
Over time, sedime
atop sediments. /
are buried deeper
undergo changes
into rock. Over mi
continents and oc
rocks are uplifted
the continents. Pi
Gorge, part of the
Formation in Wes

First life

- 3.85 Ga: ^{12}C enrichment in fluorit
  → photosynthetic life
- 3.85 Ga: Graphite with kerogen
  → photosynthetic life
- 3.7 Ga: First BIF
- 3.5 Ga: Cyanobacteria (stromatolites)
- 3.45 Ga: Bacteria in chert
- 2.7 Ga: First potential eucaryotes

Other prokaryots



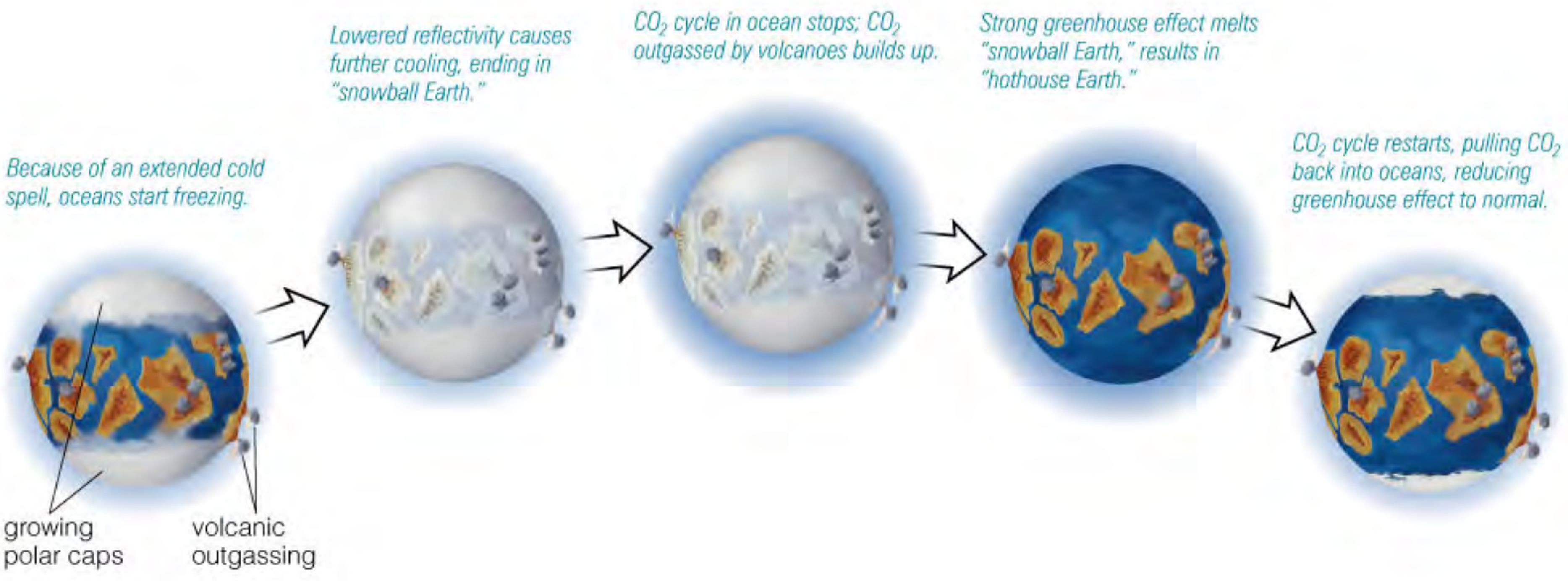
3.3 Ma
Kromberg Formation of South Africa

3.4 Ma Strelley Pool Chert of Australia

Proterozoic (2.5-0.542 Ga)

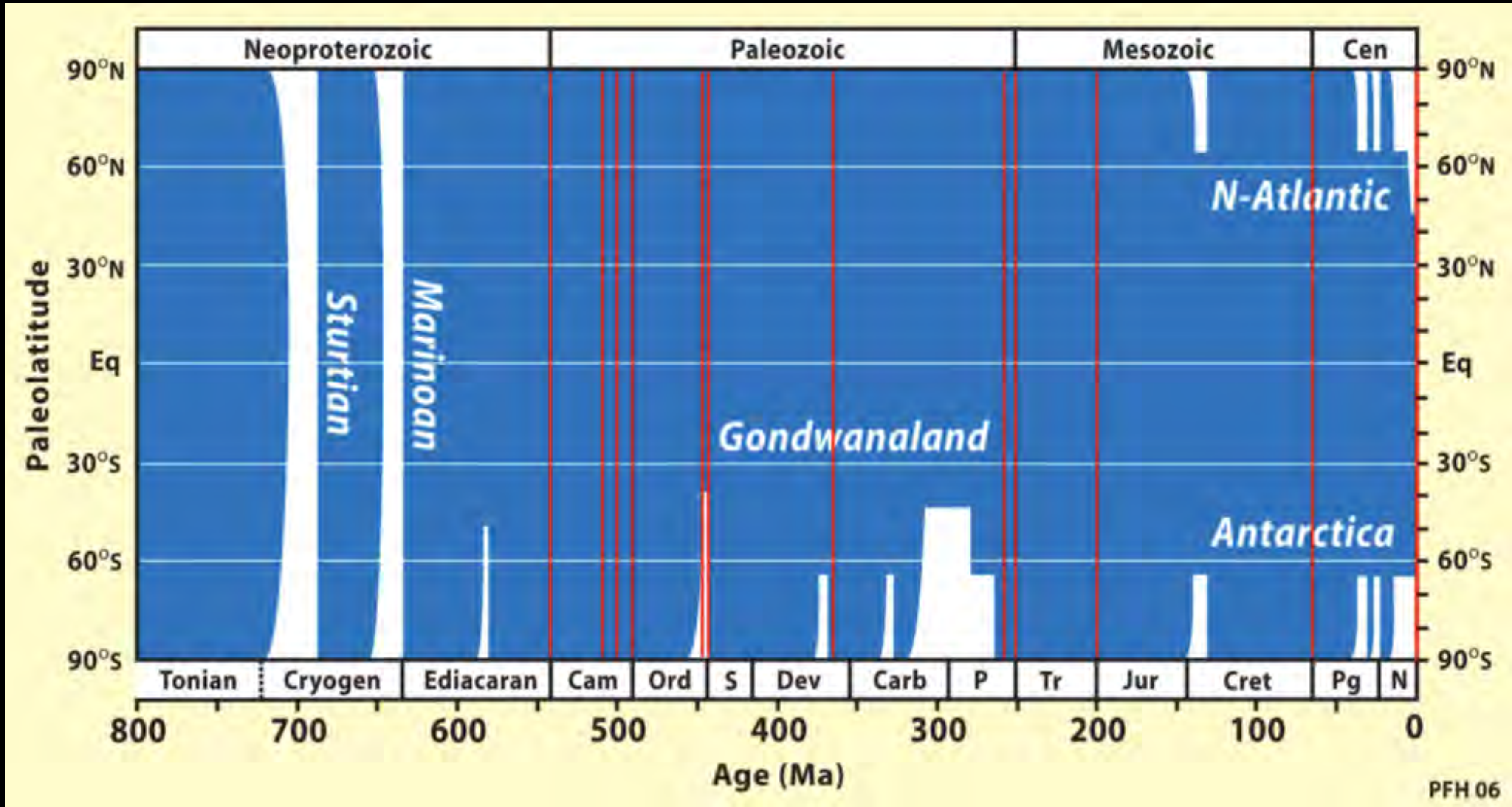
- Much better geologic record than in the Archean (-> much more known)
- Life present, but essentially no complex life yet (eucaryotes, acritarchs, stromatolites)
- first supercontinents (Rodinia)
- various glaciations (climax Snowball Earth)
- First continental red beds → Oxygen in atmosphere

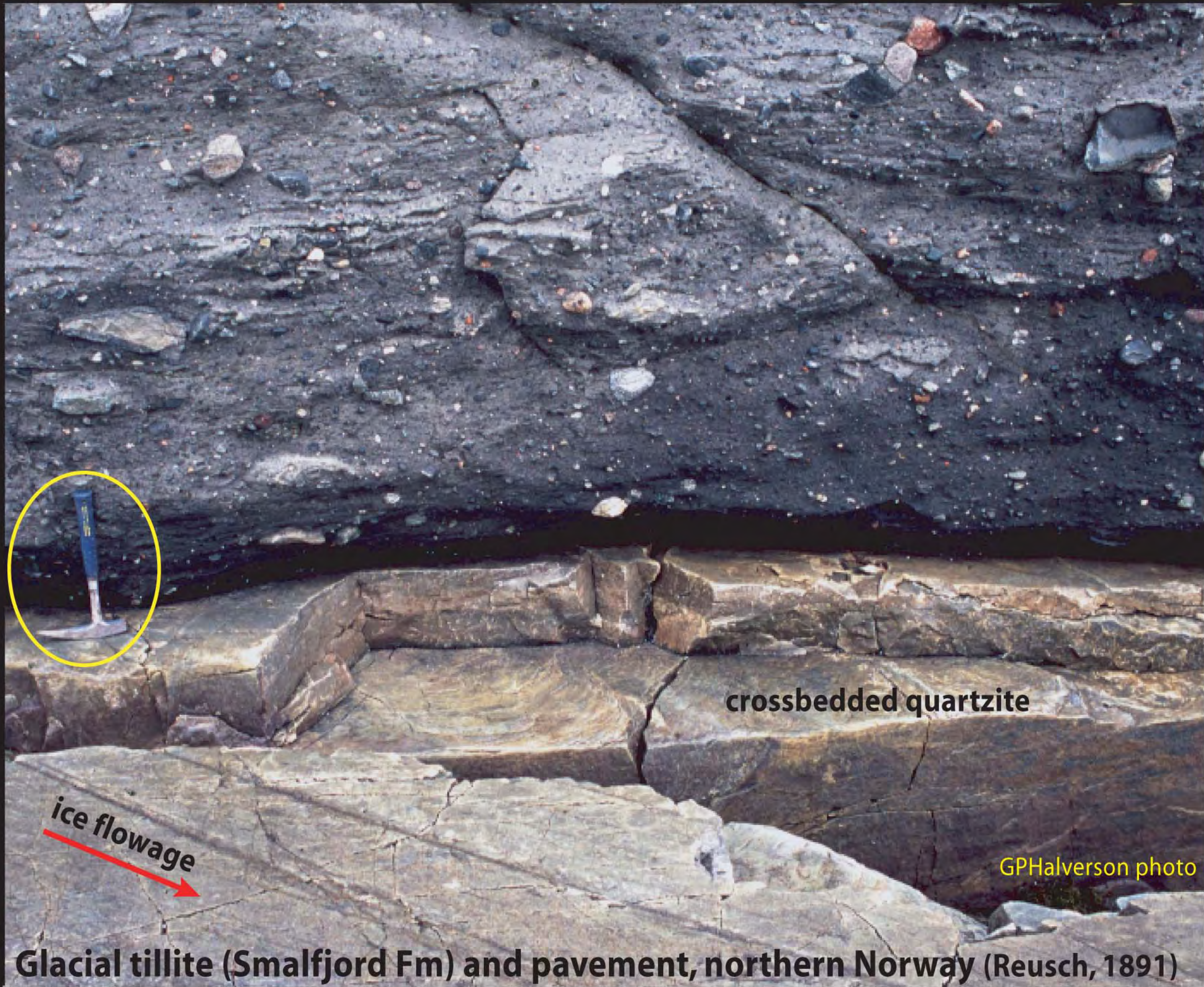
Snowball Earth



Snowball Earth

- Glacier deposits at tropical latitudes
  (dropstones, varves, striations, tillites)



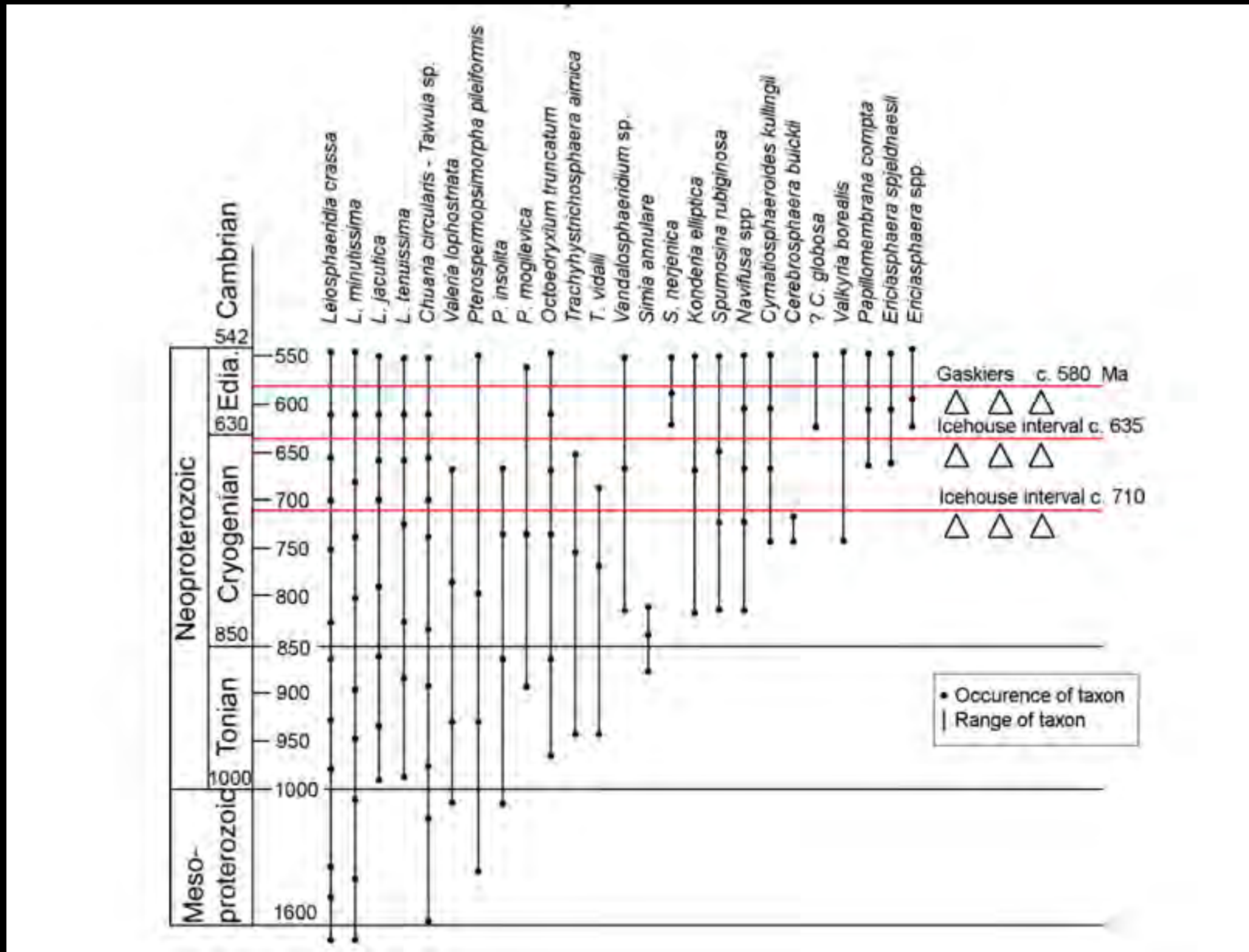


Glacial tillite (Smalfjord Fm) and pavement, northern Norway (Reusch, 1891)

Ice-rafted dropstone in proglacial marine strata, Ghaub Fm lower member, Otavi Group, Namibia

Snowball Earth

- Paleontological evidence does not confirm a totally frozen Earth → Slushball Earth

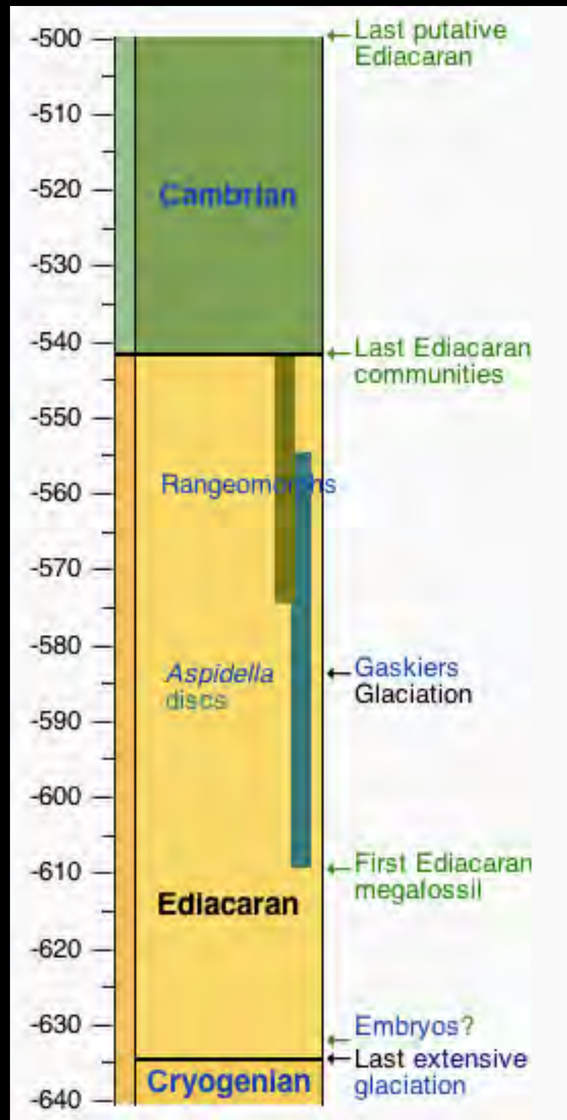


Ediacaran Fauna

- first macroscopic fossils
- fossils are of unknown affinity (ancestors of modern groups?)
- no hard shells or skeletons
- definitive multicellular

Arkarua

Ediacaria



Ediacaran rangeomorphs

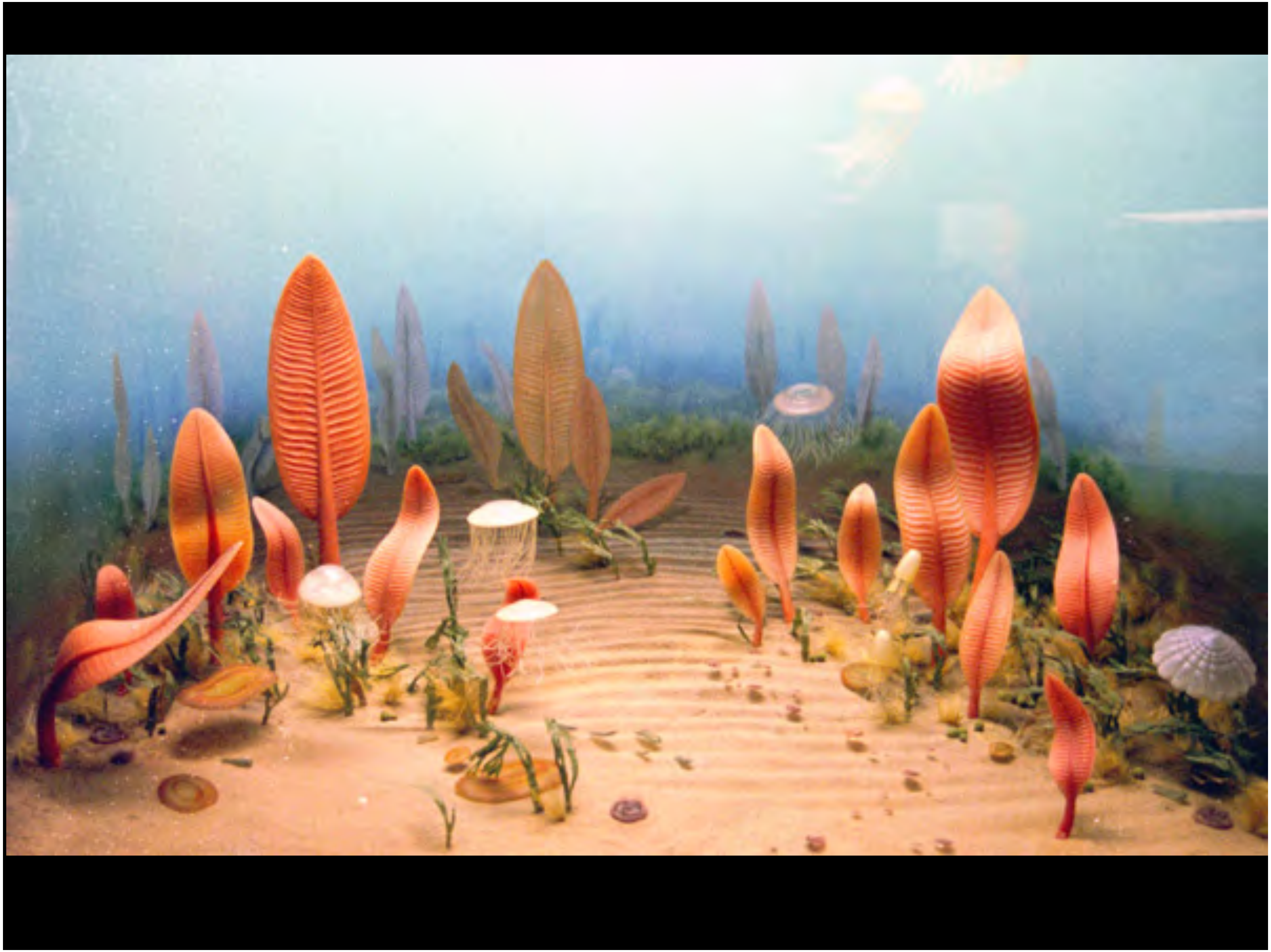
Modern sea feather
(a cnidarian / nässeldjur)

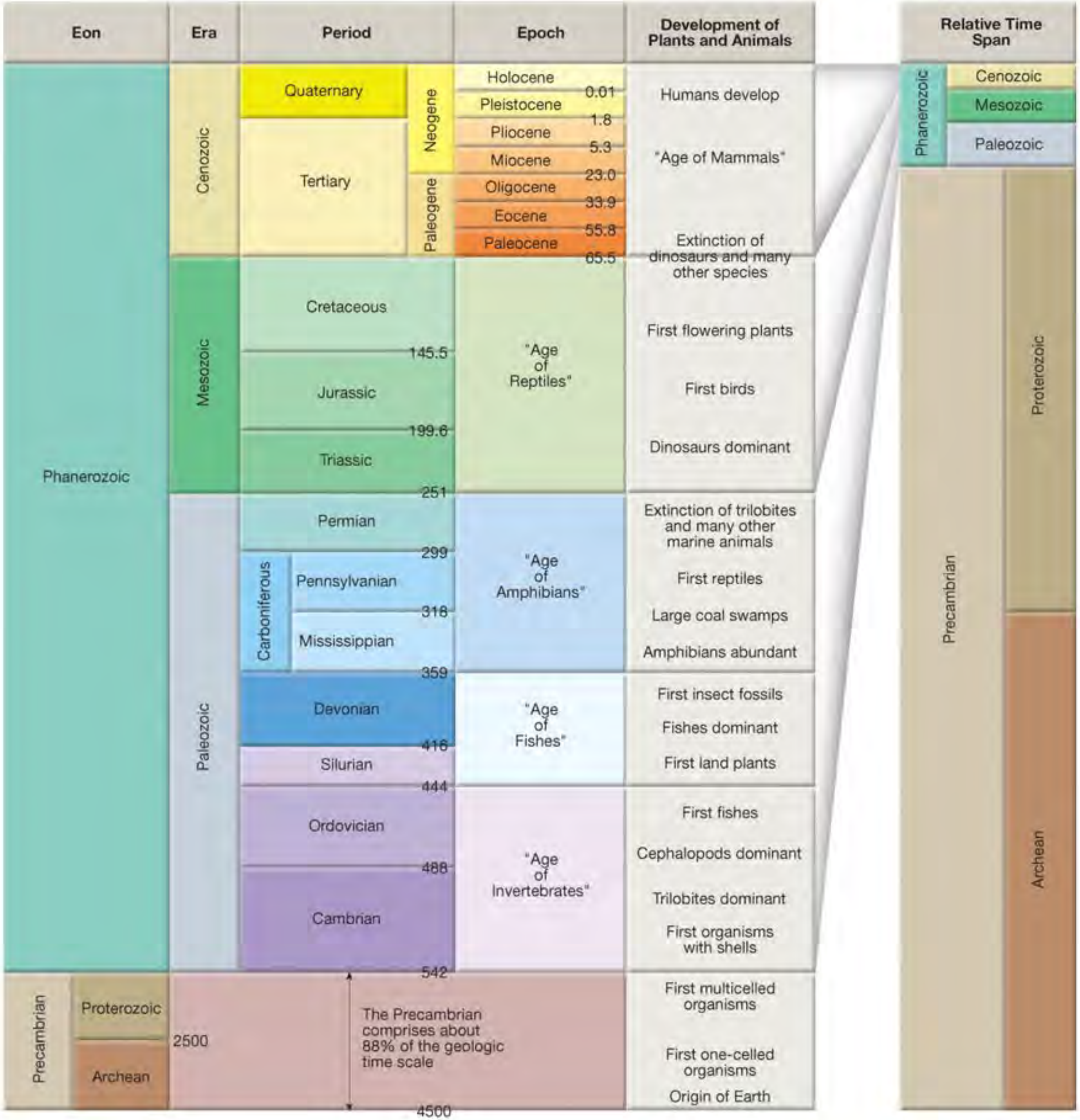
Dickinsonia

modern coral

Spriggina

trilobite




Eon
Era
Period
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Development of Plants and Animals
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Paleogene
Holocene
Pleistocene
Pliocene
Miocene
Oligocene
Eocene
Paleocene
0.01
1.8
5.3
23.0
33.9
55.8
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Humans develop
"Age of Mammals"
Extinction of dinosaurs and many other species
Mesozoic
Cretaceous
145.5
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251
"Age of Reptiles"
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299
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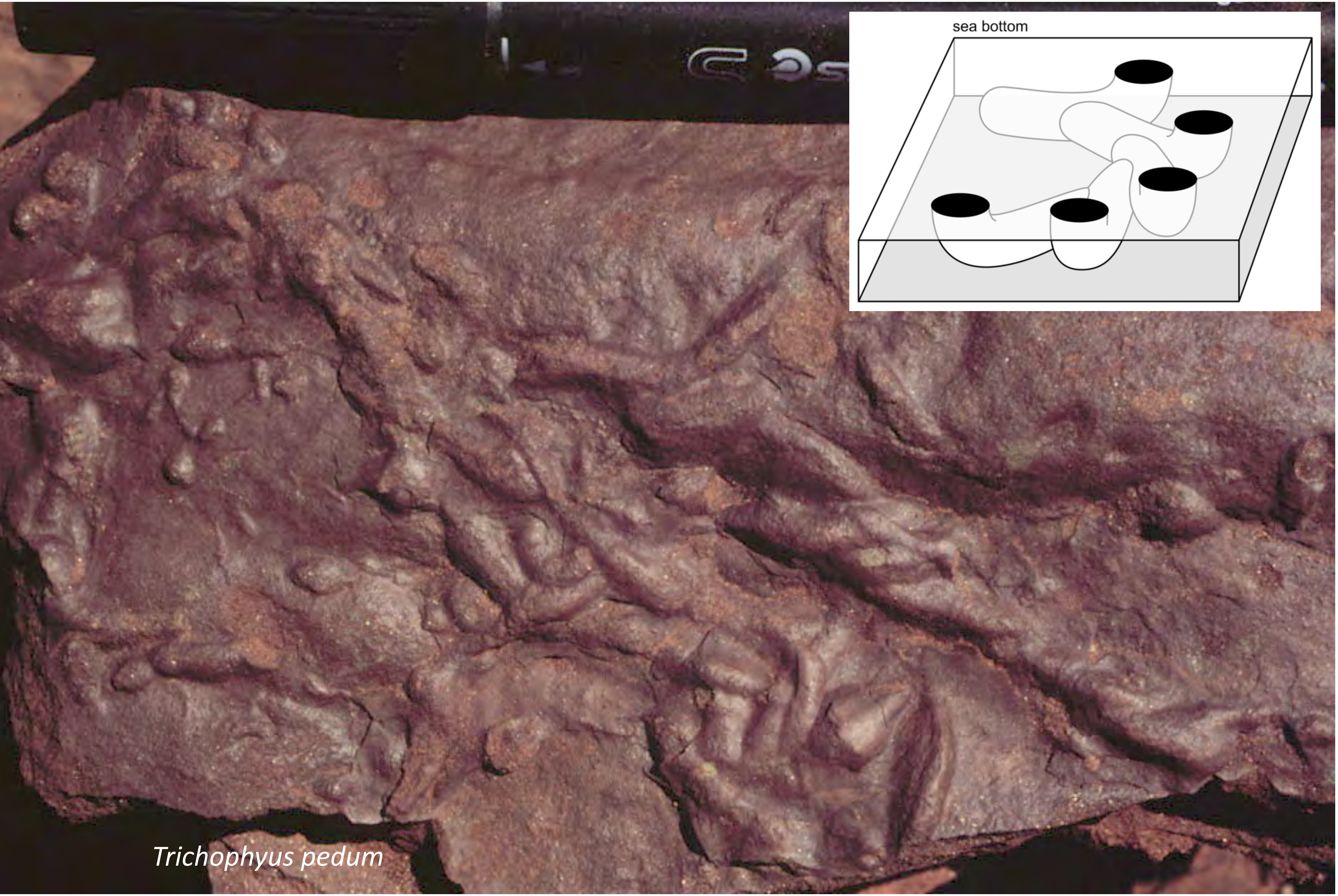
Cenozoic
Mesozoic
Paleozoic
Precambrian
Proterozoic
Archean

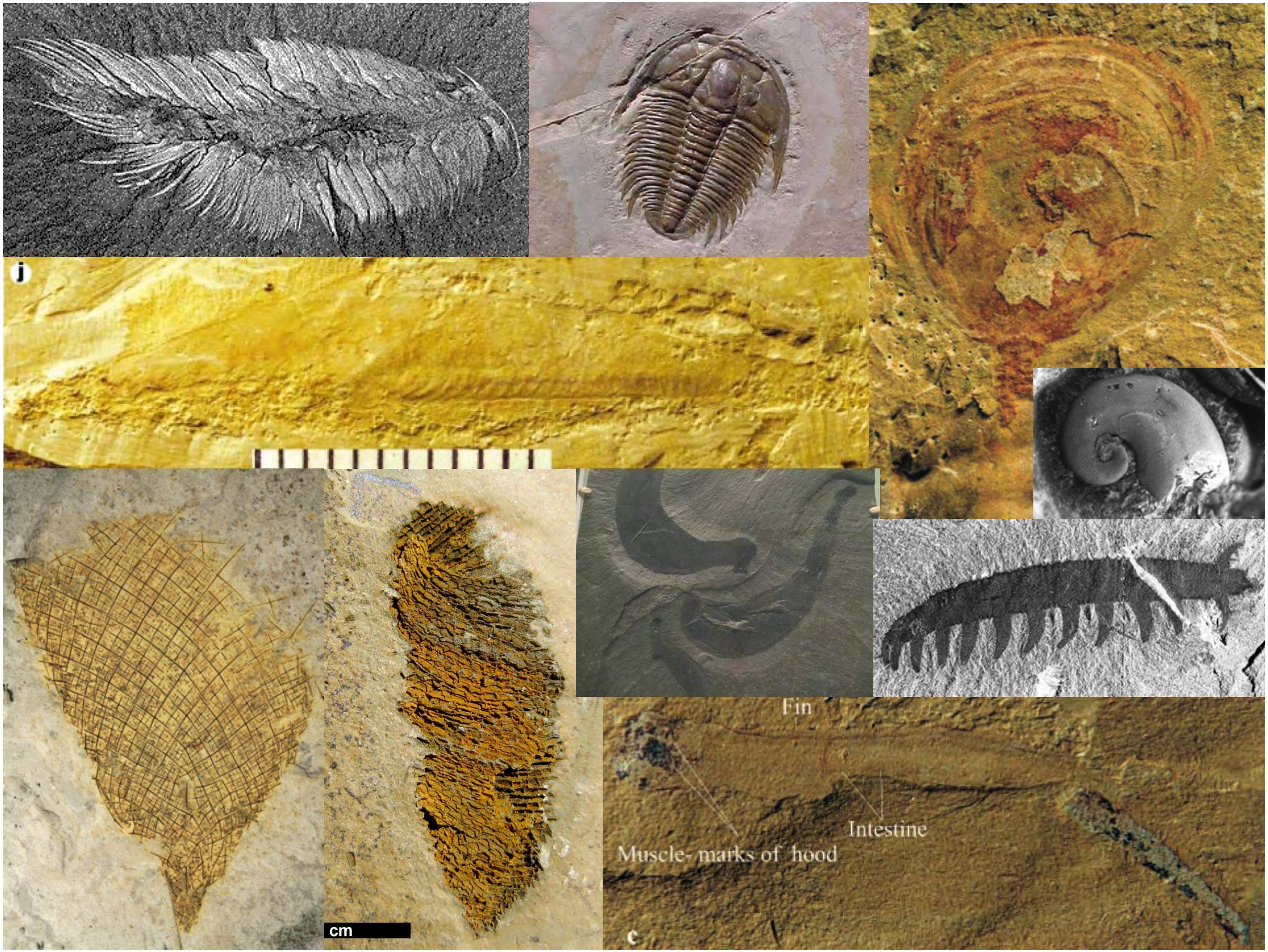
Cambrian (542-488 Ma)

- named after Cambria (Lat. Wales)
- lower boundary defined by the first appearance of complex trace fossils
- time of first appearance of hard parts and essentially all major modern animal phyla

→ Cambrian Explosion

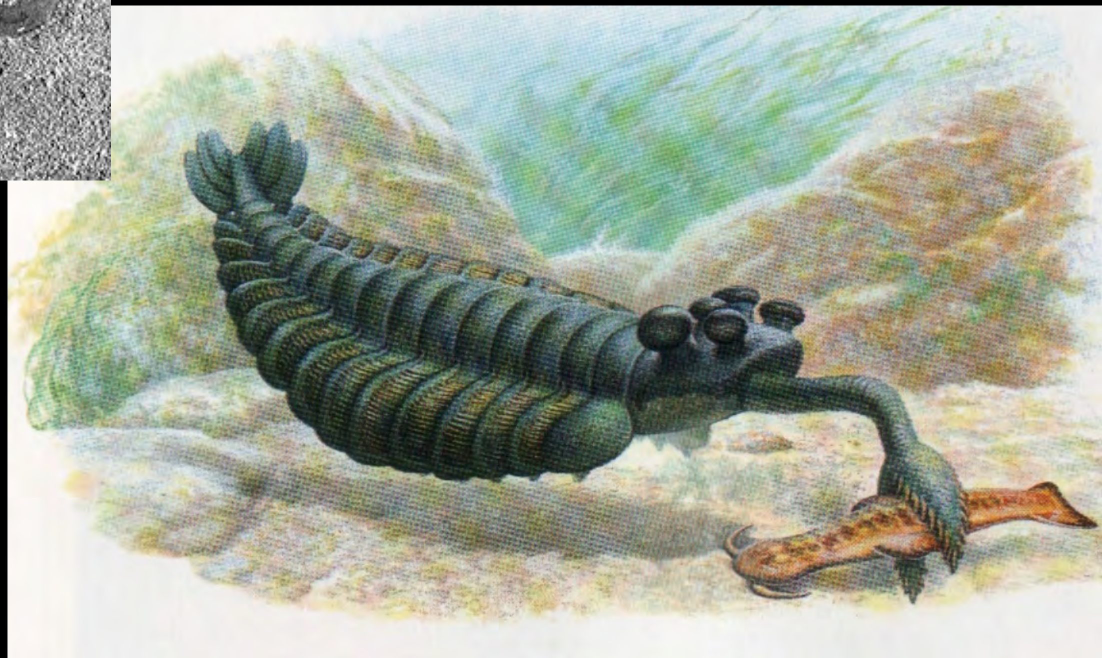


Trichophyus pedum


j
cm
Fin
Intestine
Muscle- marks of hood
c

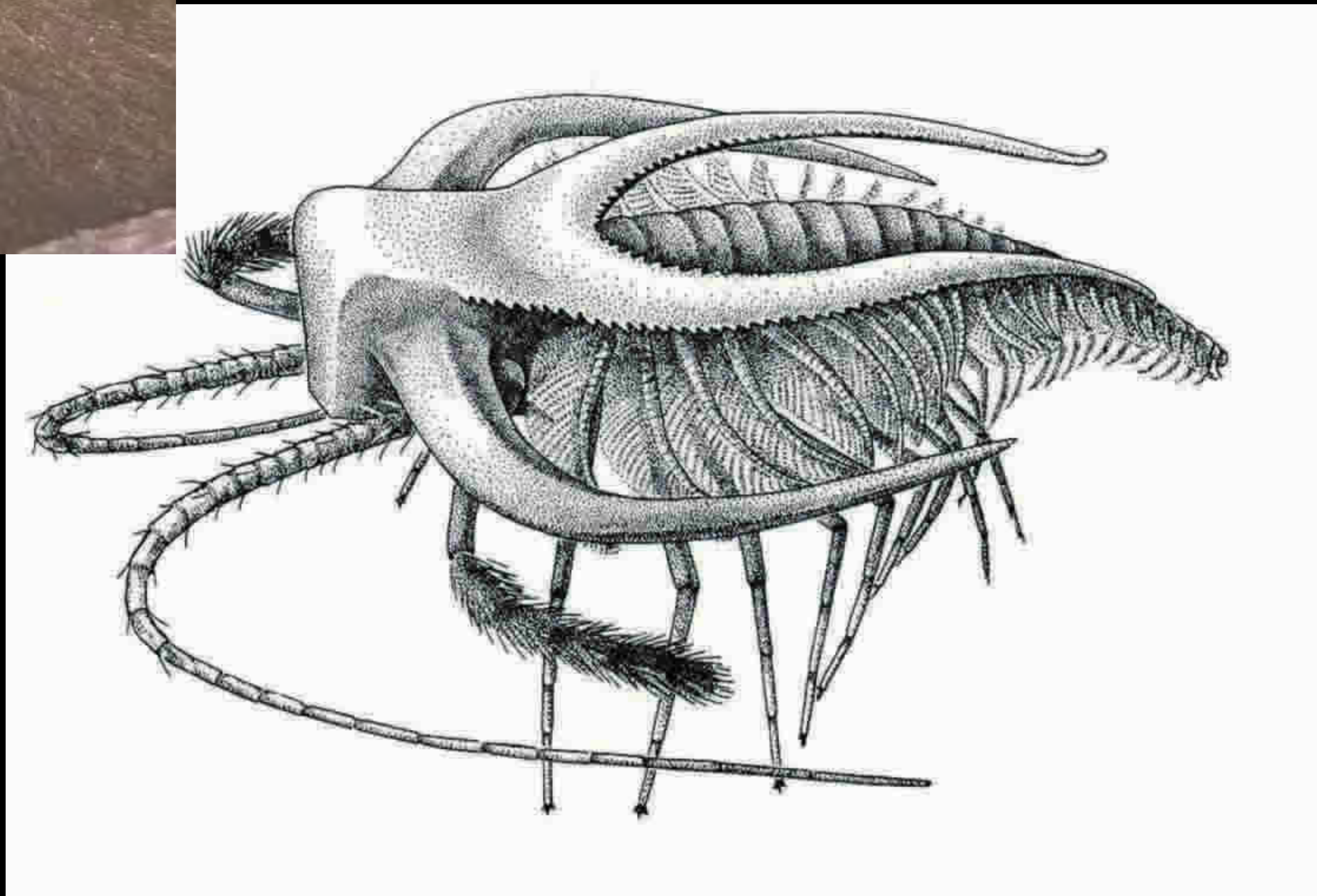
Cambrian Lagerstätten

- Burgess Shale, Sirius Passet & Chengjiang



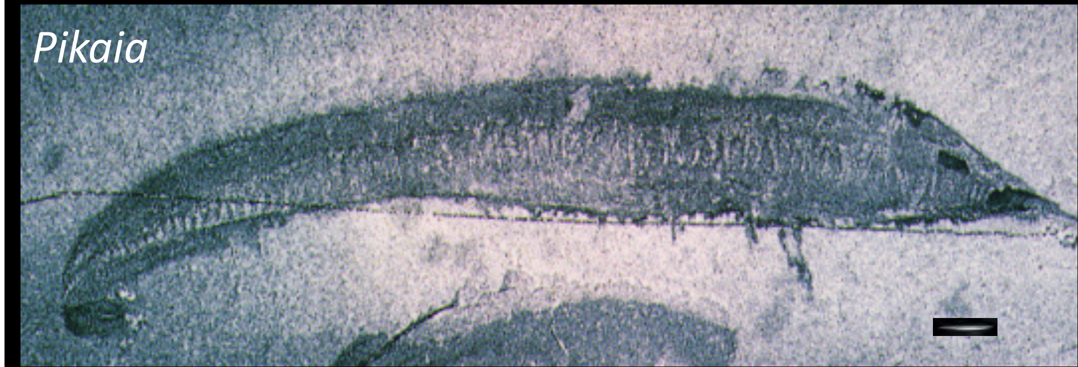
Opabinia

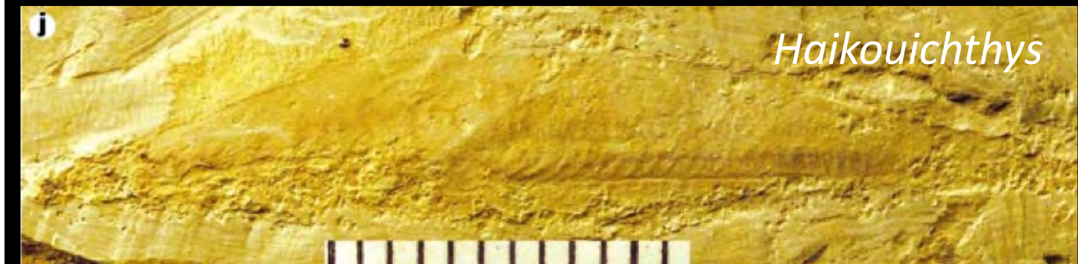
Marrella



Anomalocaris

Our and the dinosaurs' ancestors

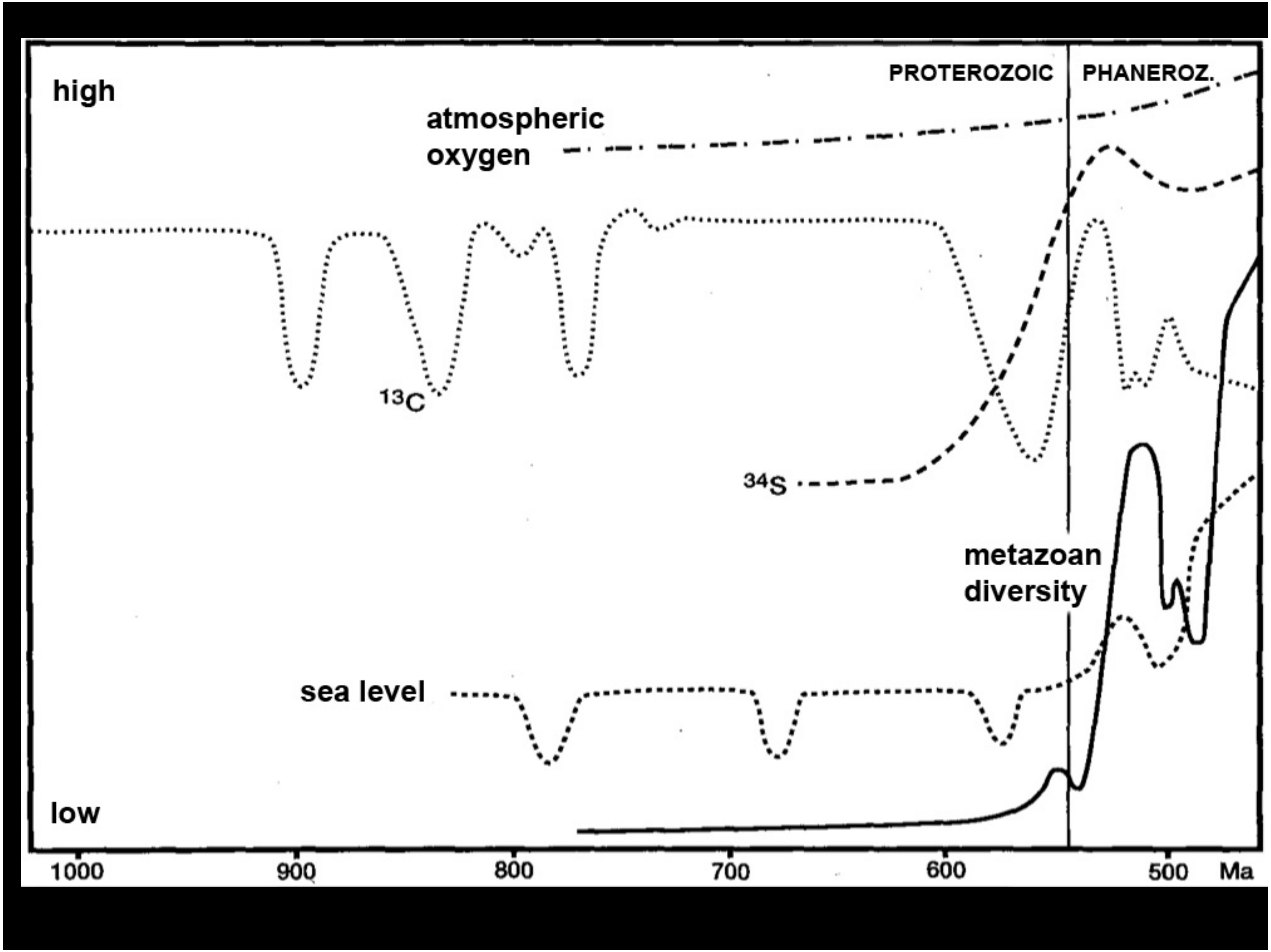




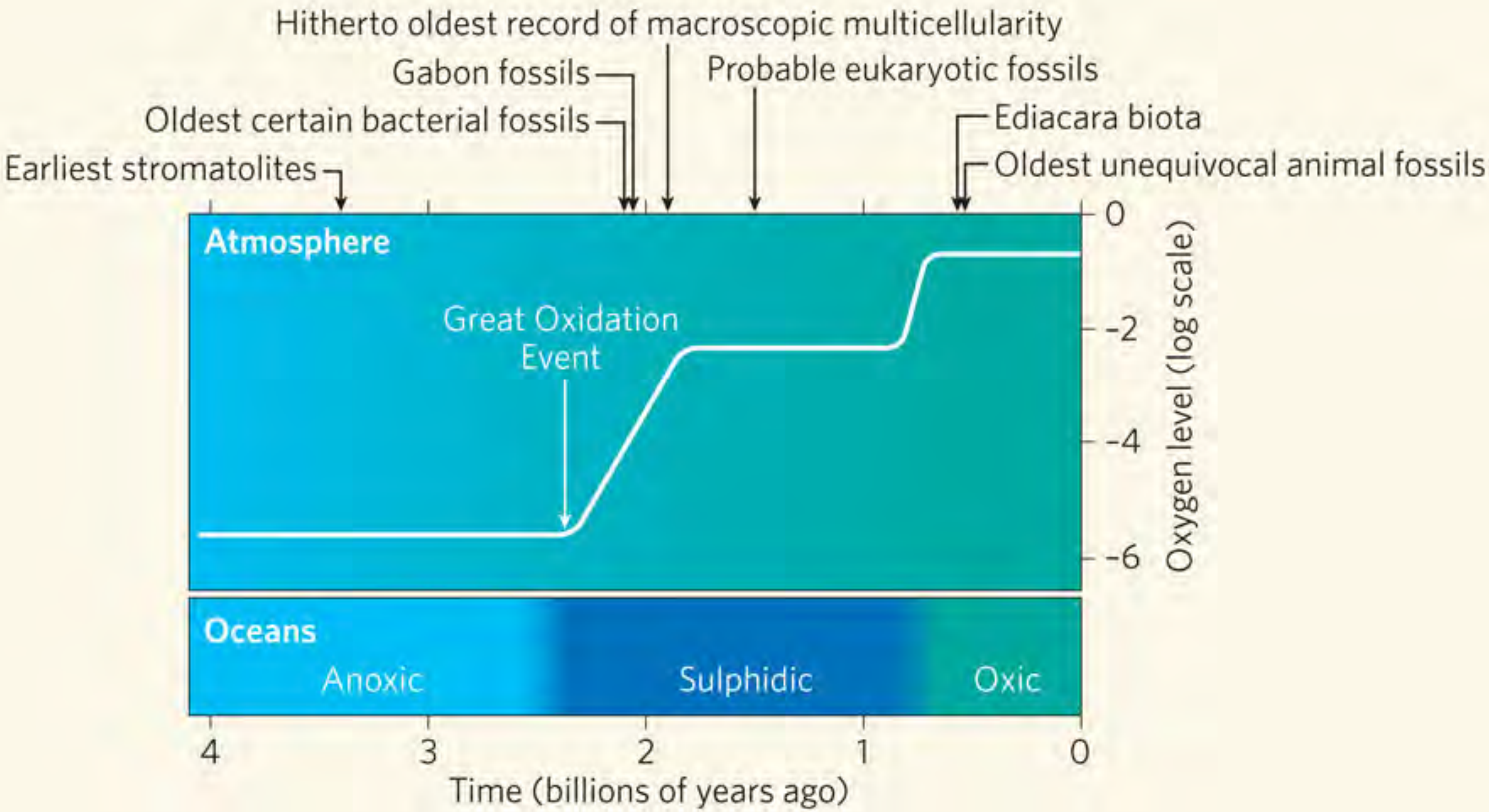
movie break

Reasons for Cambrian explosion

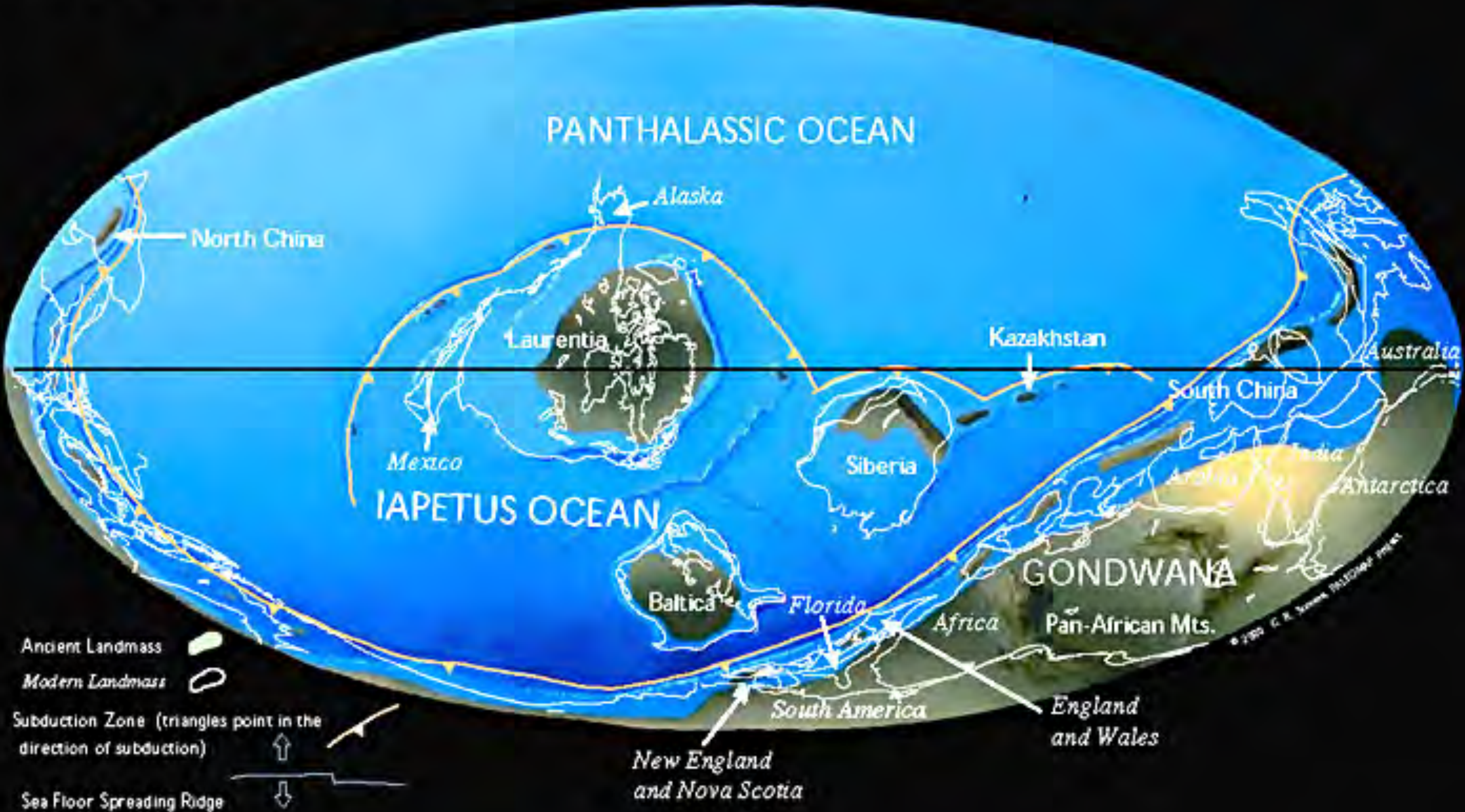
- Oxygen increase in atmosphere
  - shortage might prevent evolution of complex animals
  - certain level needed to maintain a functioning ecosystem
- Evolution of movement and eyes
  - predator-prey competition accelerates evolution



PROTEROZOIC
PHANEROZ.
high
atmospheric
oxygen
13C
34S
metazoan
diversity
sea level
low
1000
900
800
700
600
500
Ma

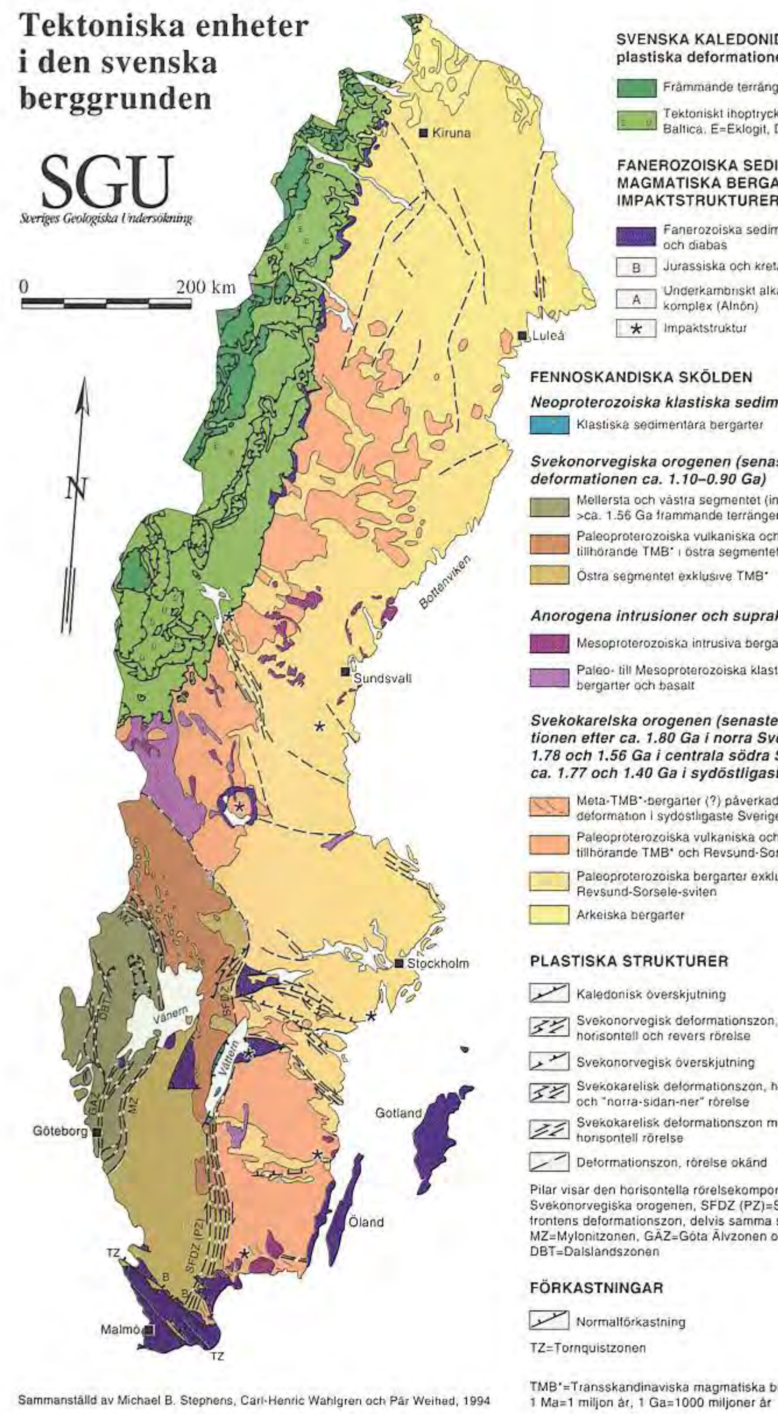

Hitherto oldest record of macroscopic multicellularity
Gabon fossils
Probable eukaryotic fossils
Oldest certain bacterial fossils
Ediacara biota
Earliest stromatolites
Oldest unequivocal animal fossils
Atmosphere
Great Oxidation Event
Oceans
Anoxic
Sulphidic
Oxic
0
-2
-4
-6
Oxygen level (log scale)
4
3
2
1
0
Time (billions of years ago)

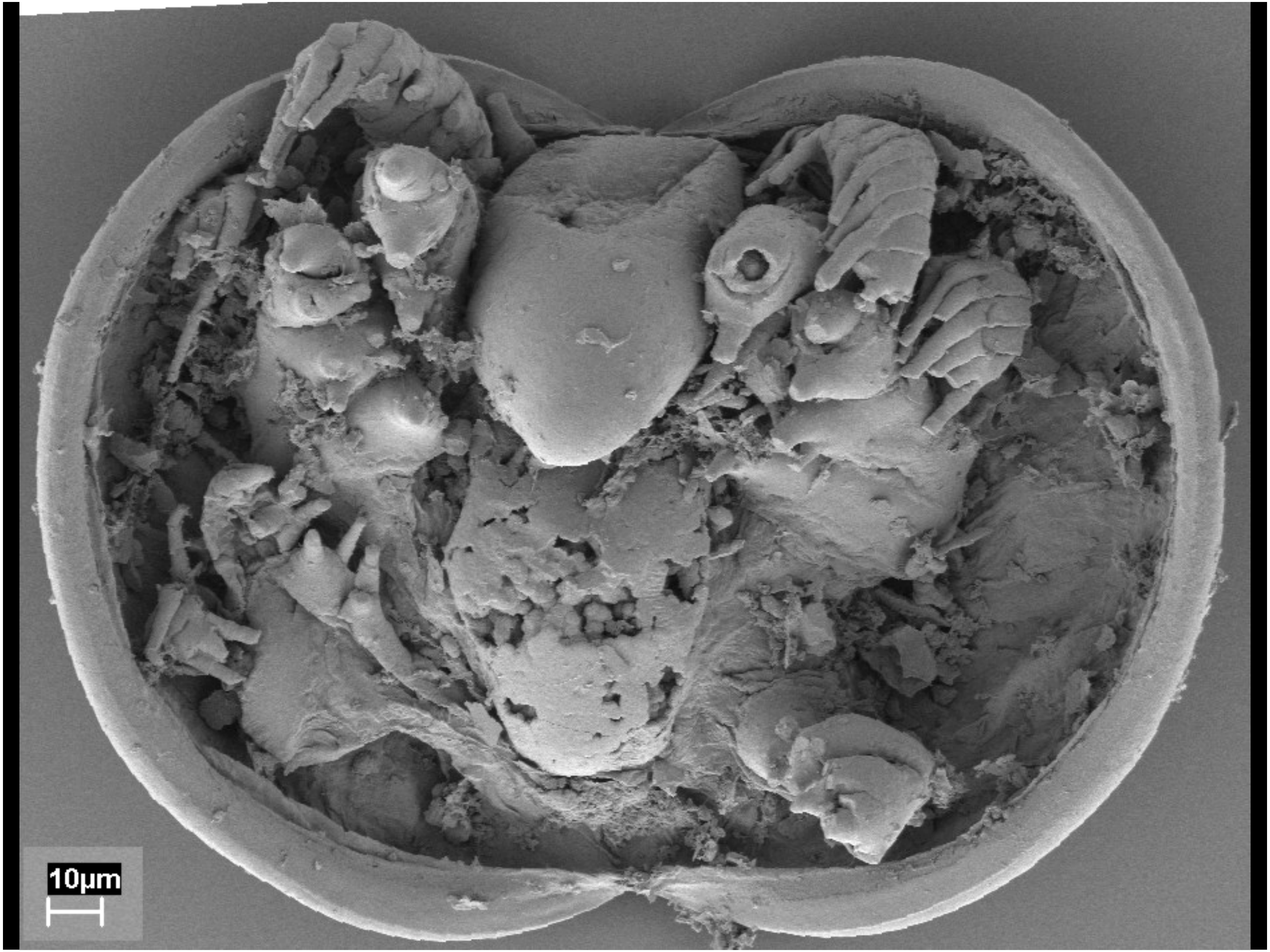
Late Cambrian 514 Ma



Cambrian in Sweden

- quite famous
- sandstones, limestones and alum shale
- Orsten Lagerstätte




10µm

Ordovician (488-444 Ma)

- named after the Celtic tribe of the Ordovices
- starts with an extinction event and ends with one

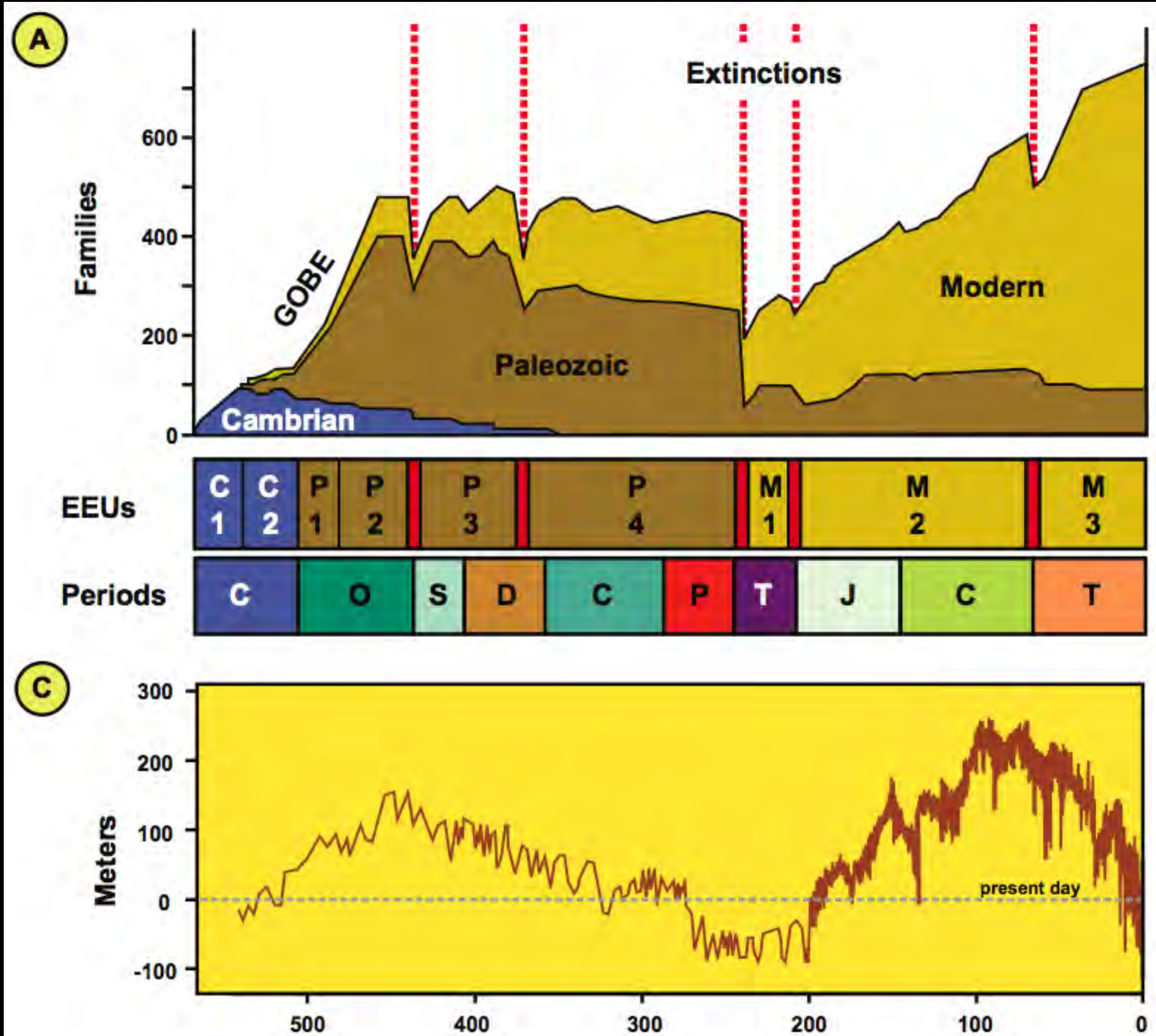
  → first extinction due to sea level drop

  → followed by major radiation and sea level rise

  → second extinction due to glaciation

Ordovician – an extreme time

- highest sea level during the Paleozoic
- huge areas covered by shallow seas (shelf)
- major radiation
  - →Great Ordovician Biodeversification Event (GOBE)
    - →Suspension feeders
    - →Pelagic fauna
    - →Complex food webs



A
Families
600
400
200
0
Extinctions
GOBE
Modern
Paleozoic
Cambrian
EEUs
C 1
C 2
P 1
P 2
P 3
P 4
M 1
M 2
M 3
Periods
C
O
S
D
C
P
T
J
C
T
C
Meters
300
200
100
0
-100
present day
500
400
300
200
100
0

Reasons for the GOBE

- High volcanic activity + high tectonic activity + warm climate -> nutrient rich ecospace
- nutrients rich ecospace + huge shelf areas -> favor diversification

- more controversial: breakup of an asteroid
- impacts on Earth of kilometer-sized asteroids accelerated the biodiversification

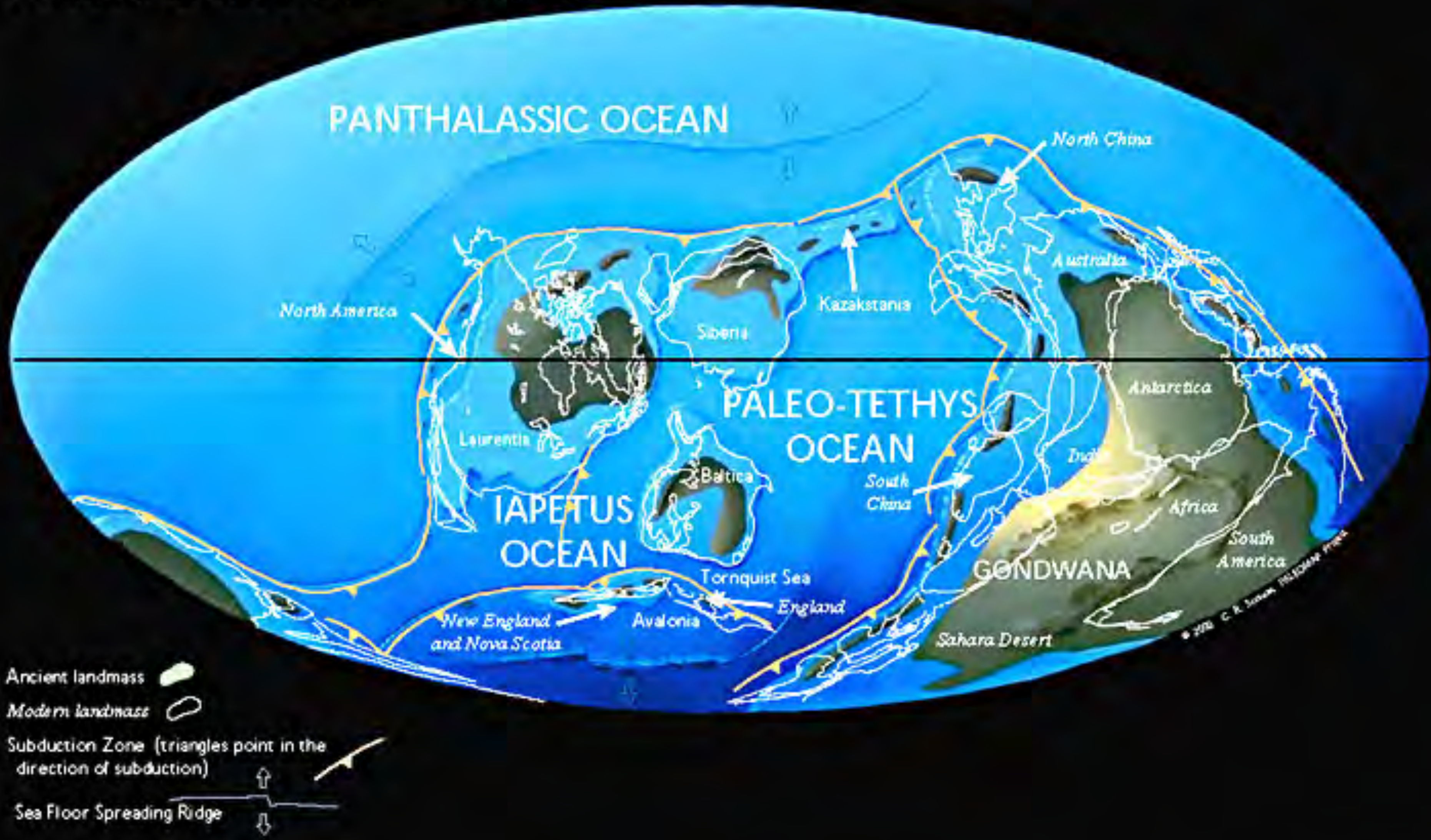
Vertebrates

- first true fish
  - jawless fish in the lower Ordovician (Ostracoderms)
  - jawed fish in the upper Ordovician (Gnathostomata)

Pharyngolepis

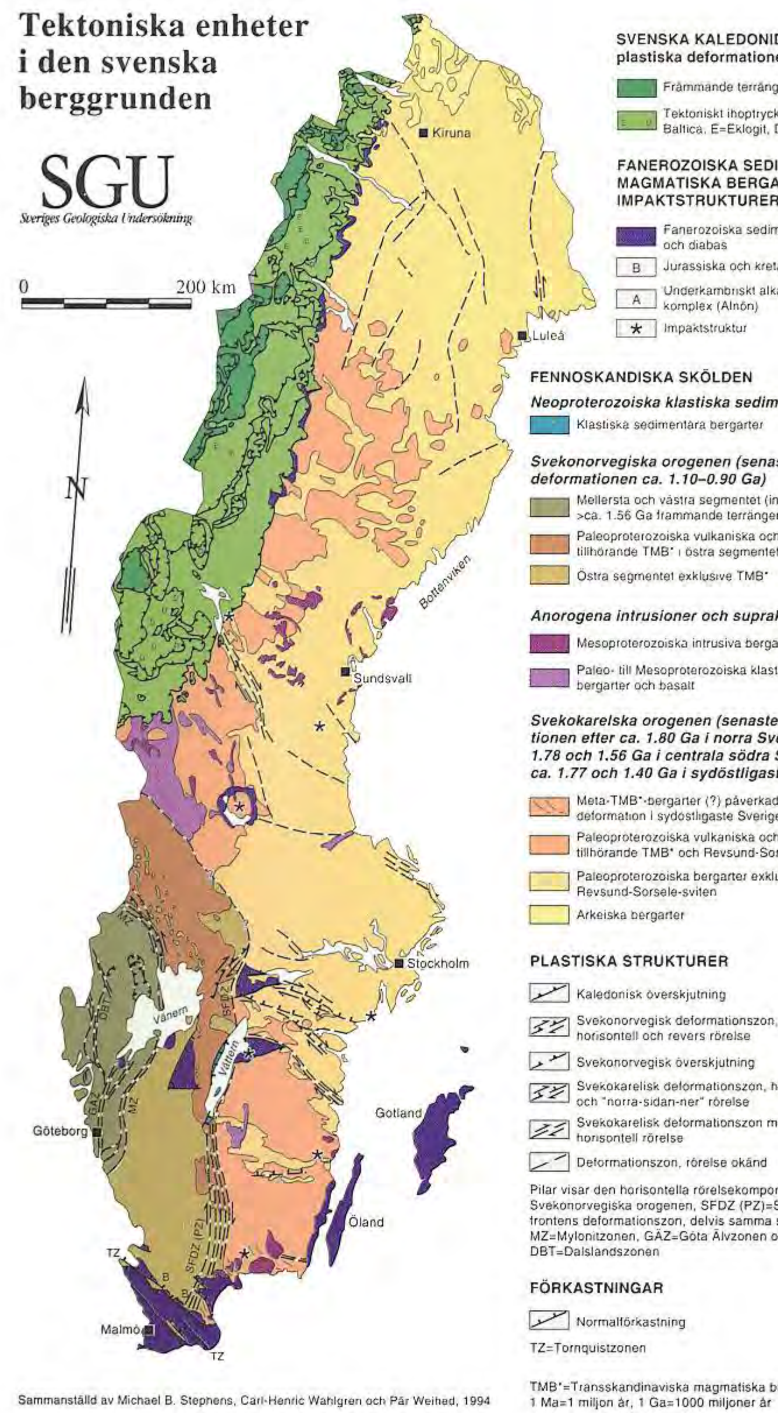
Coocosteus

Middle Ordovician 458 Ma

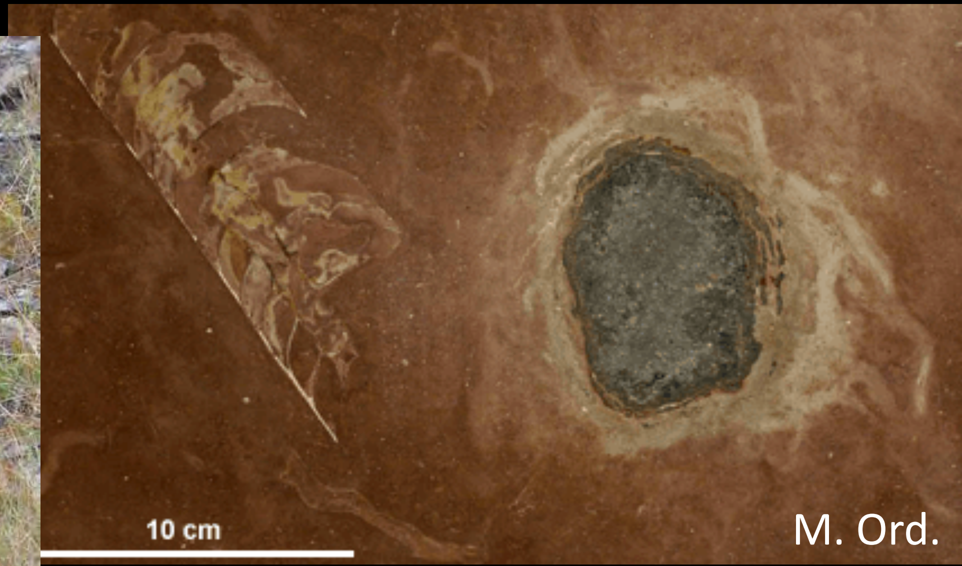


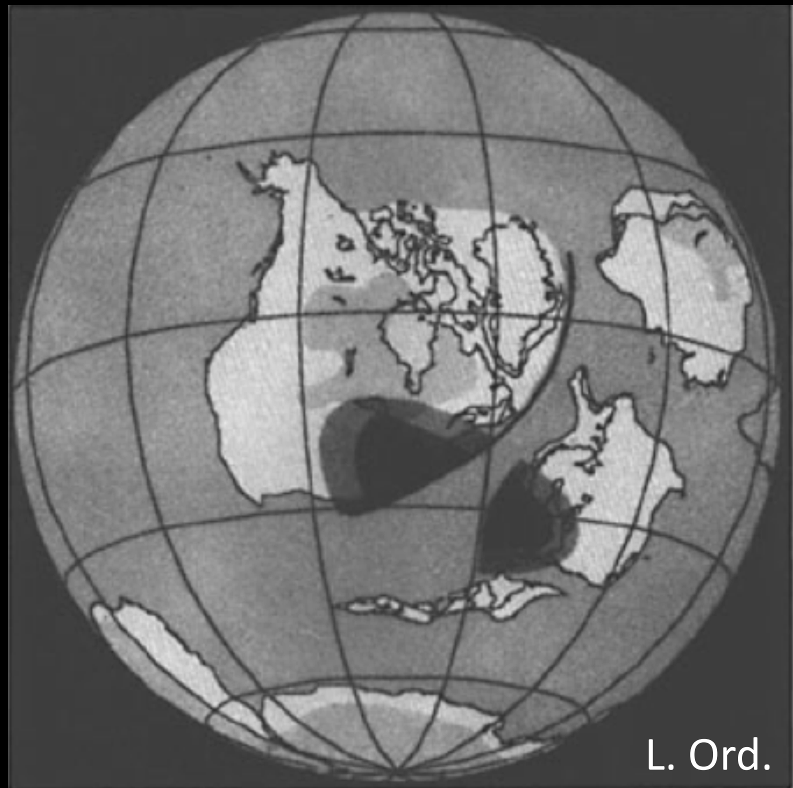
Ordovician in Sweden

- mainly shallow marine limestones
- famous building stones




OSSA
CAROLI A LINNÉ
EQV AVR
MARITO OPTIMO
FILIO VNICO


10 cm
M. Ord.

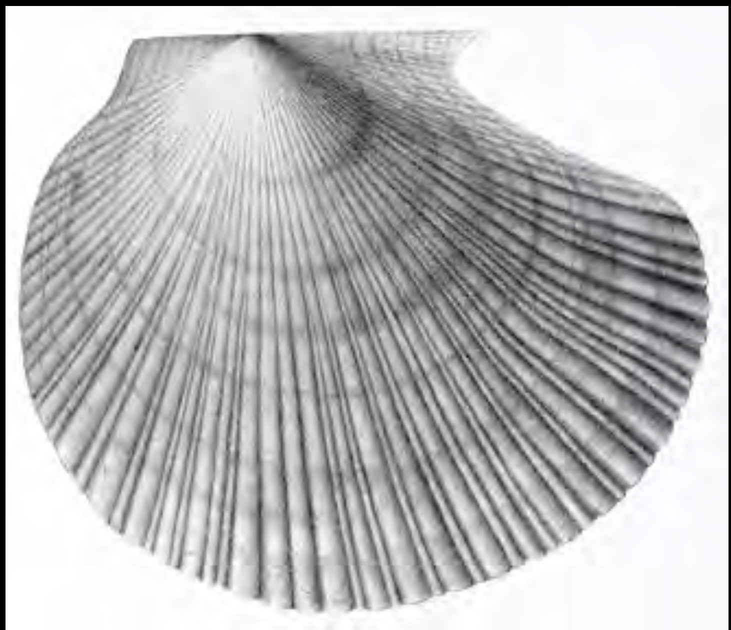

L. Ord.

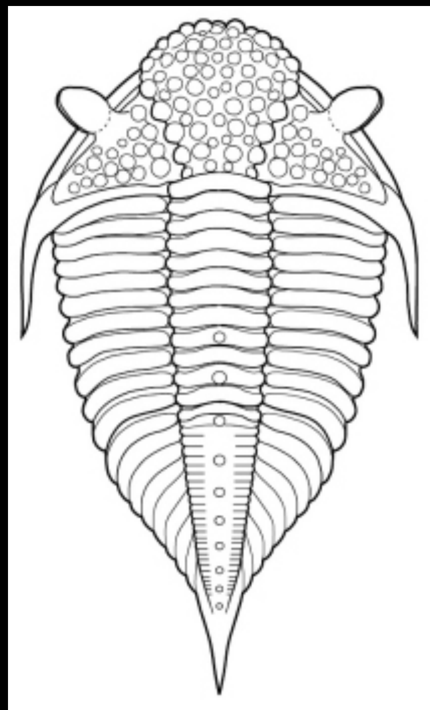
Silurian (444-416 Ma)

- named after a Celtic tribe of Wales, the Silures
- also called Gotlandium
- first land plants
- many reefs
  - warm oceans and continents along equator
- Caledonian orogeny

Life in the Silurian

- starts with recovery of most groups
- bivalves and fish invade freshwater
- graptolites radiate
- reefs

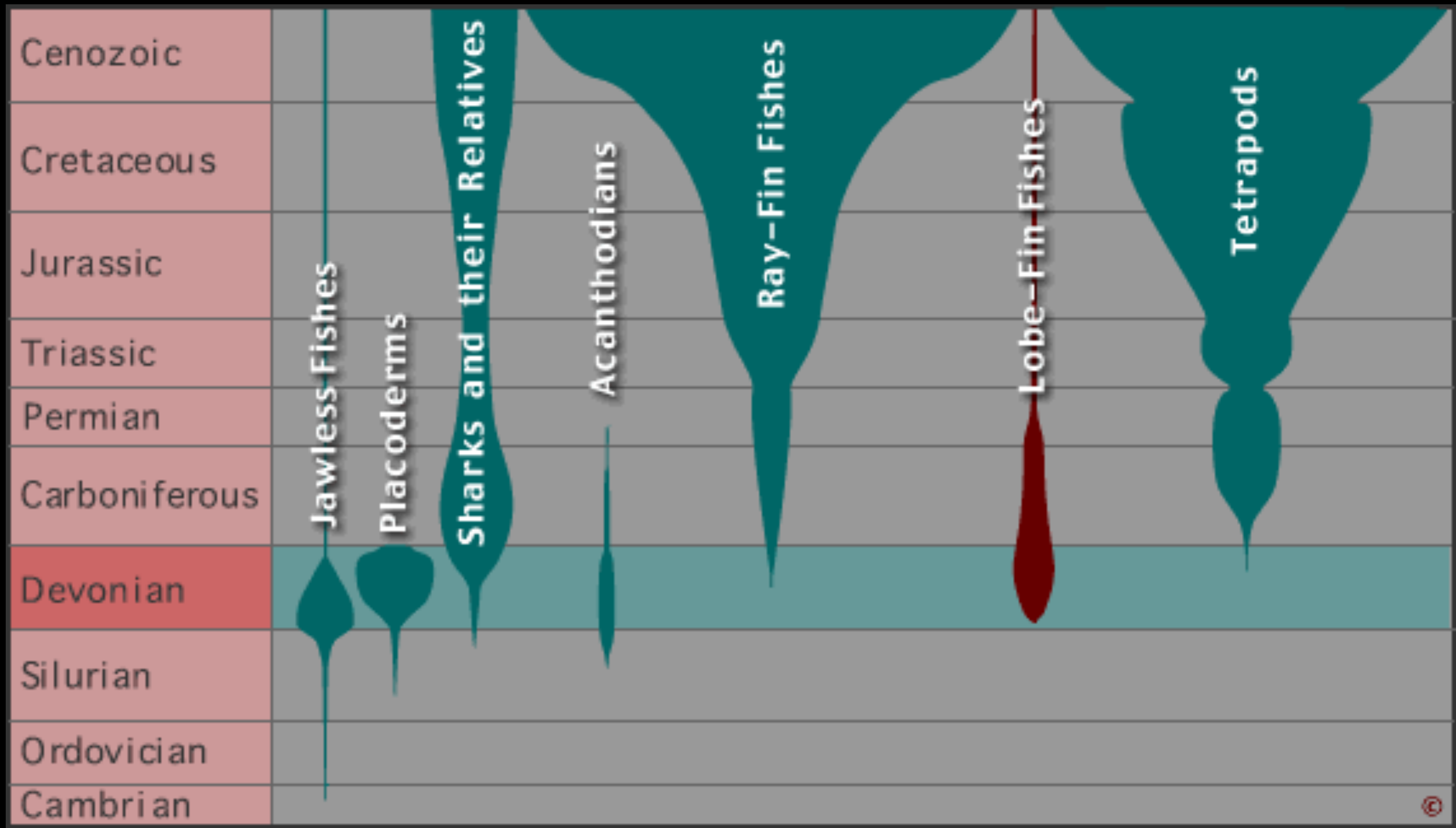




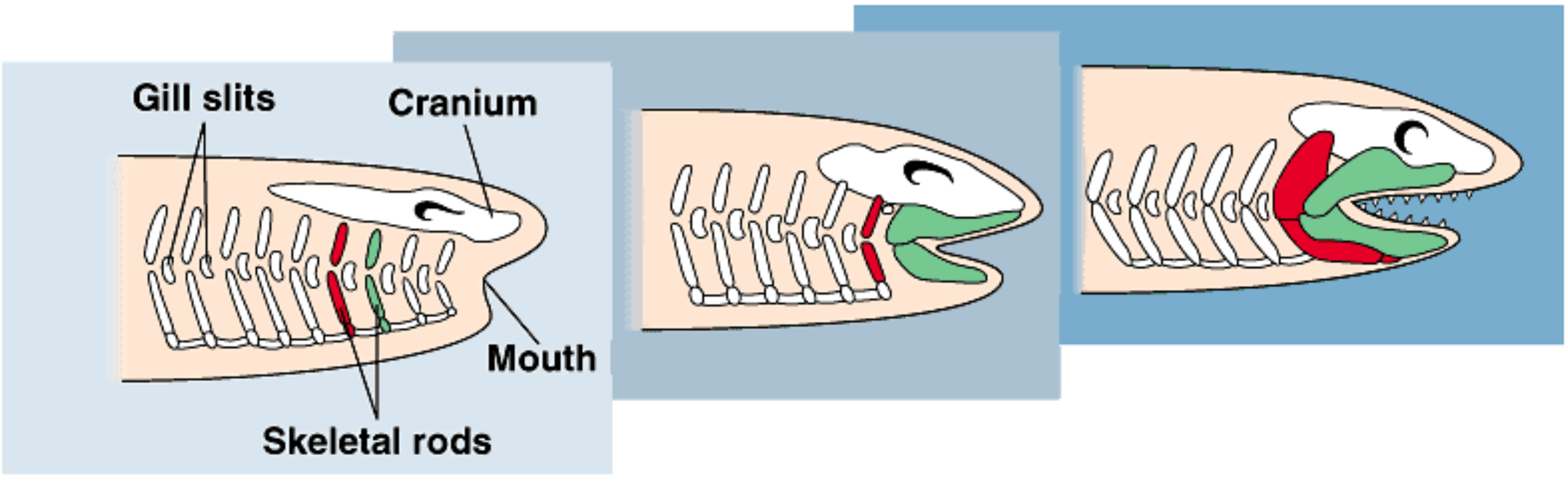
Silurian reefs

Age of the fishes begins

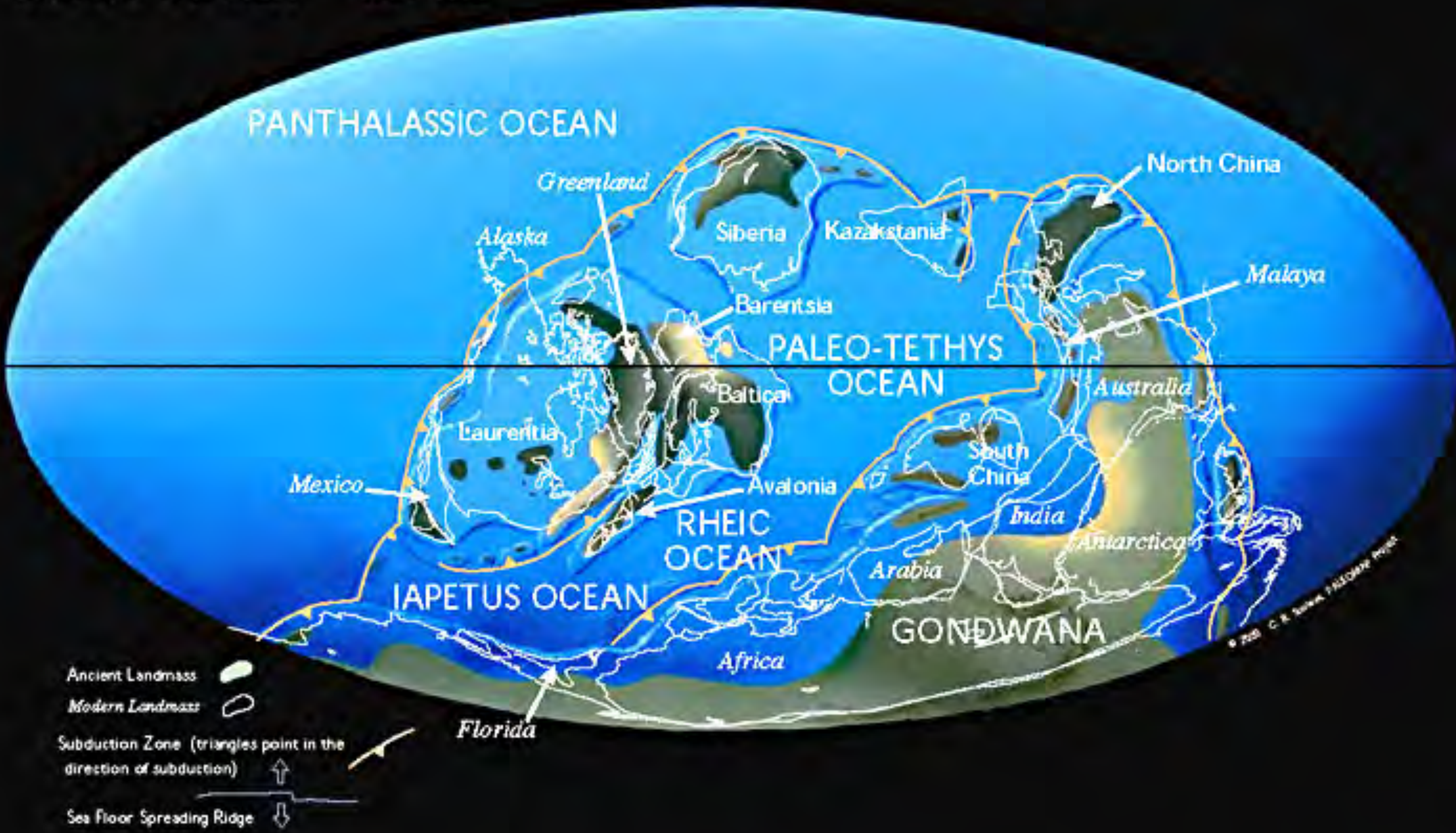
- Ostracoderms and gnathostomes became more common
- mainly in fresh water habitats



Evolution of jaws



Middle Silurian 425 Ma

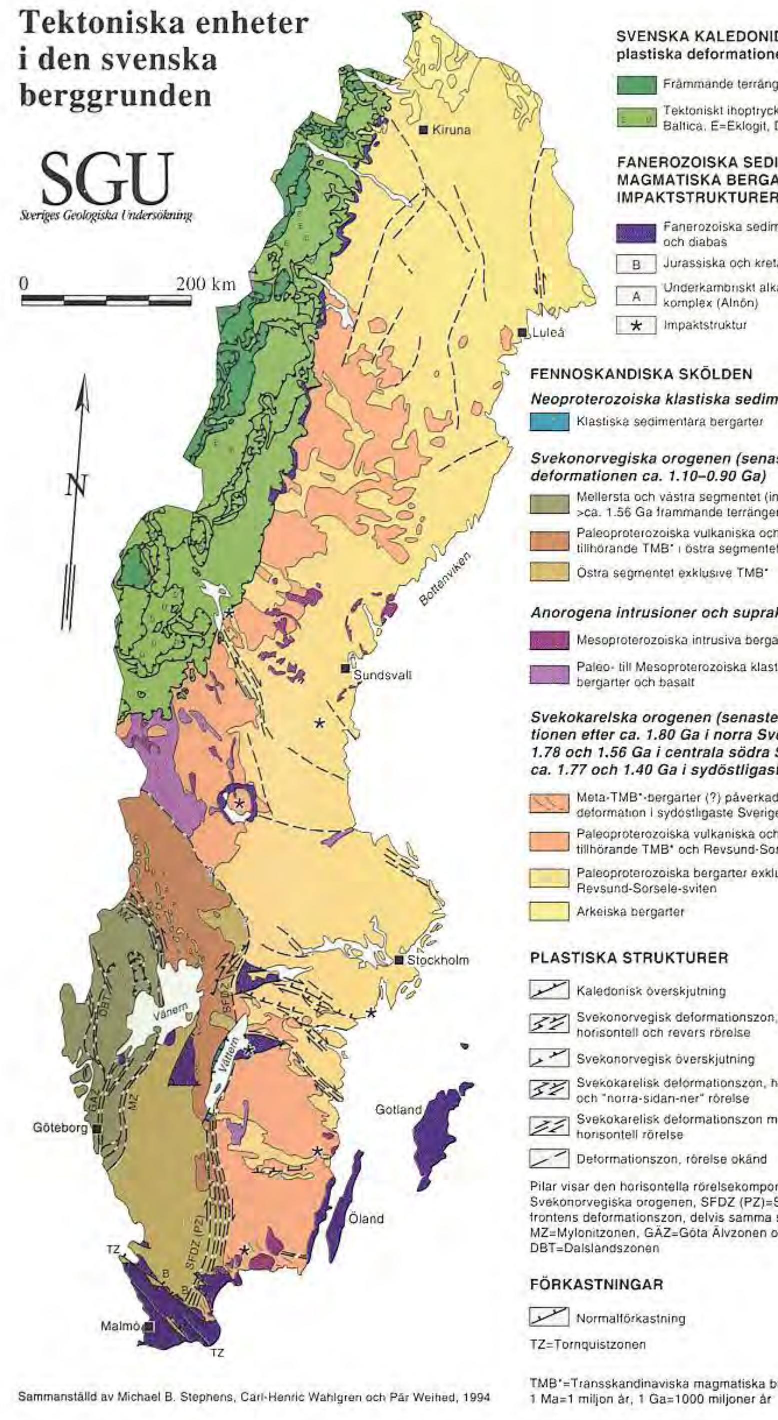


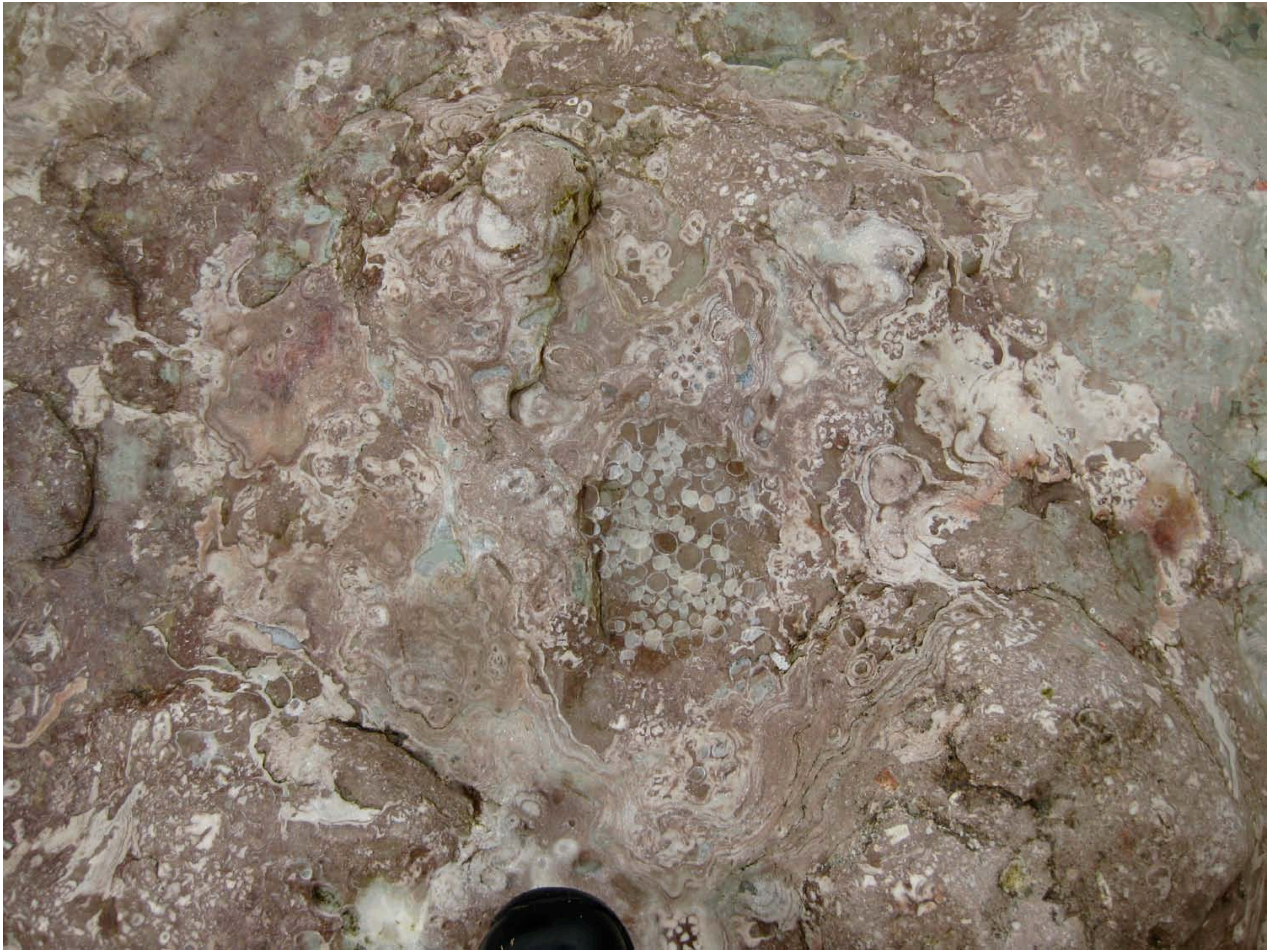

LAURENTIA
BALTICA
AVALONIA
ARMORICA ??
Greenland Caledonides
Scandinavian Caledonides
Scottish
Irish
Caledonides
North-German-Polish Caledonides
Acadian orogeny
Mid-European Caledonides

Silurian in Sweden

- Gotland
- Västergötland
- Scania

Reefs vs. graptolite shales



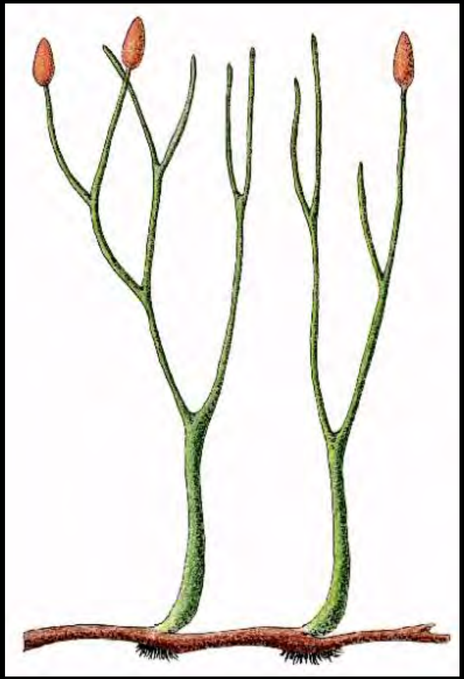


Devonian (416-359 Ma)

- Named after the county Devon, SW England
- Conquering of land
  - First forests (seed bearing plants spread)
  - oldest insects
  - vertebrates go on land

The Devonian Explosion

- plants:



Rhynia

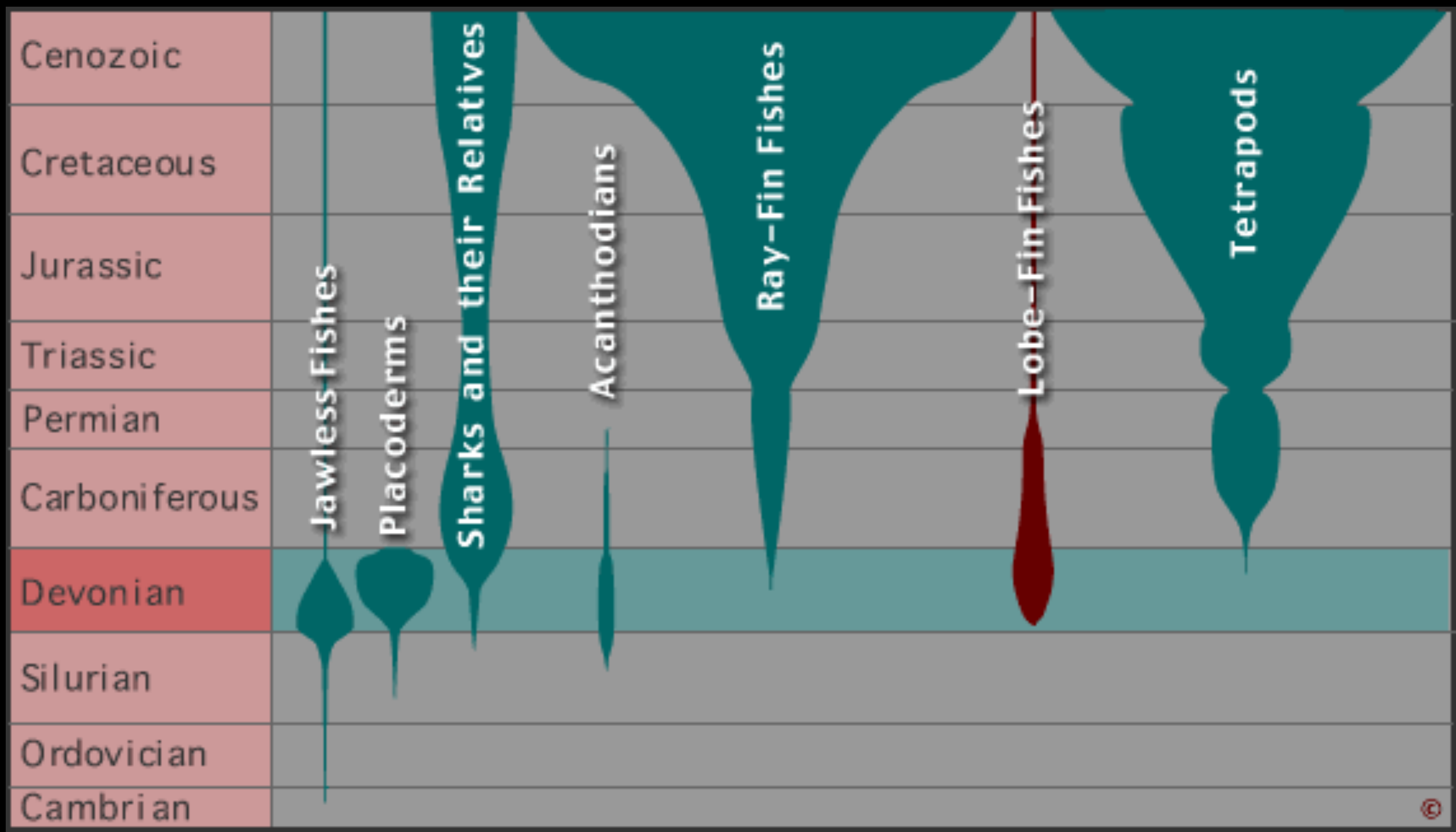
Life in the Devonian

• Oldest insect from the Rynie Chert
→ by the end of Devonian arthropods were established on land
→ co-evolution of vegetation and arthropods
→ incentive for “fish” to go on land for food

• Development of coilded ammonoids

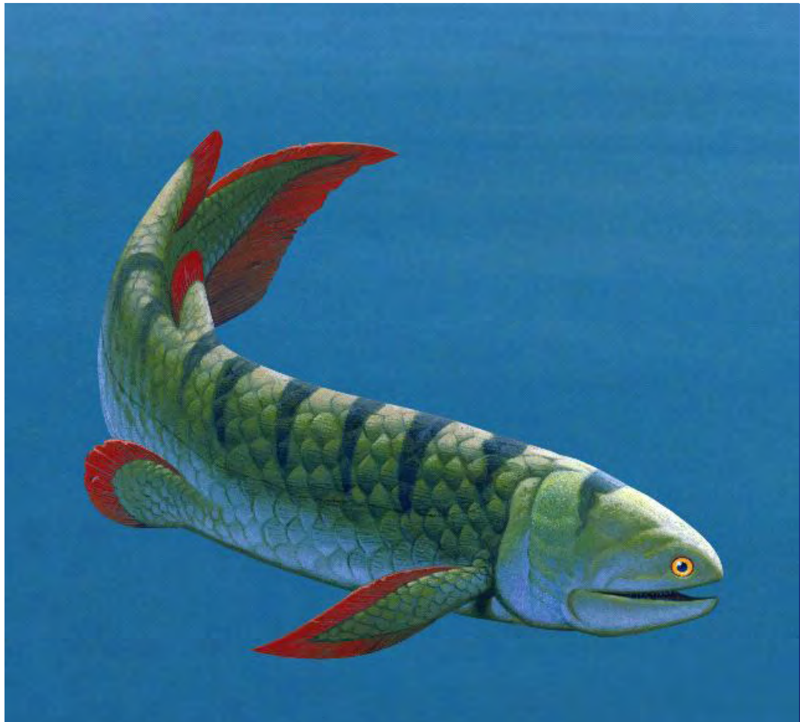
Vertebrate Life in the Devonian

- Age of fishes



Dunkleostes - a placoderm

Diplacanthus - an acanthodian



Holoptychius – lobe-finned fish

Stethacanthus – a early shark

End Devonian Extinction

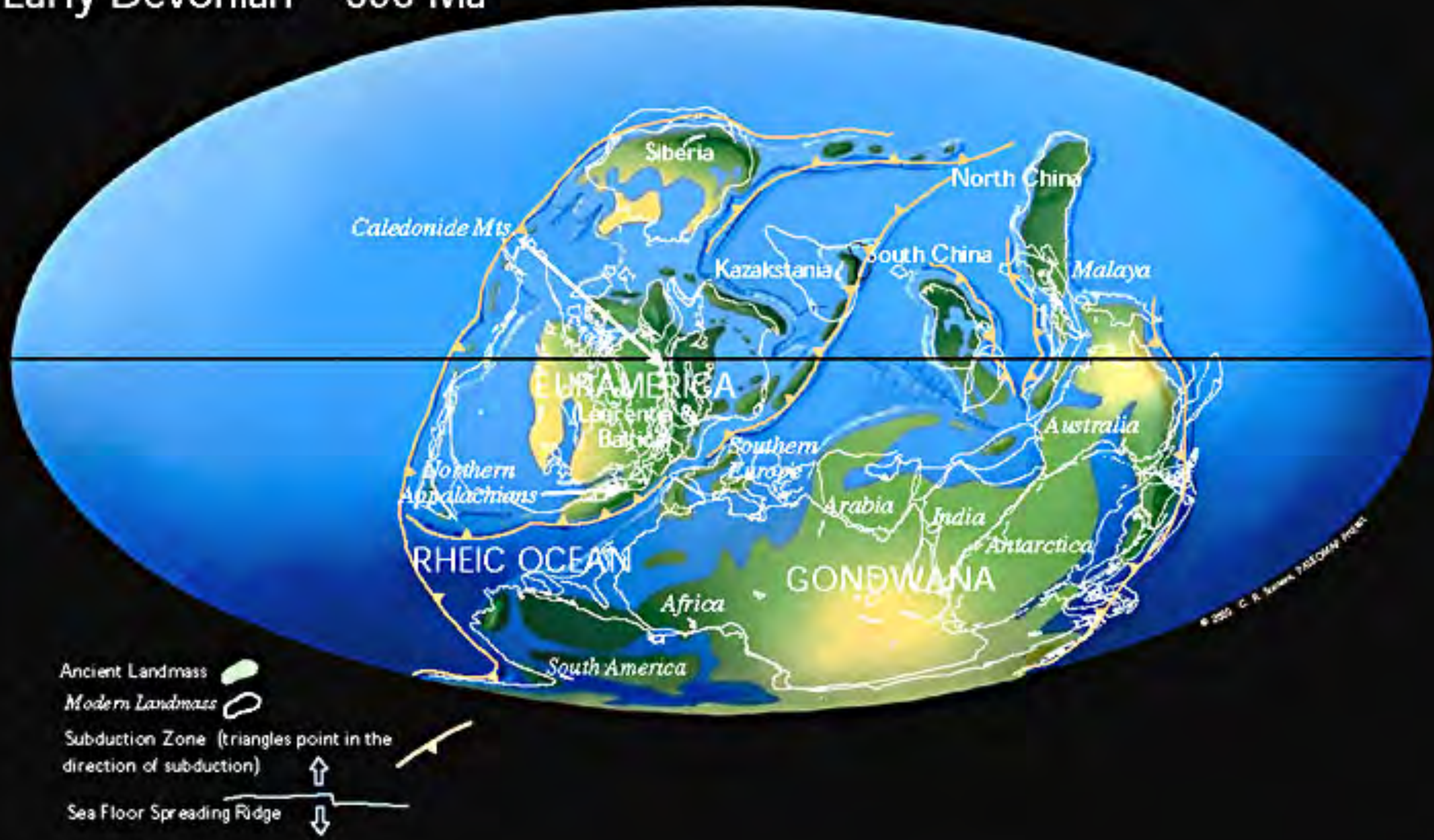
- One of the big 5!
- 2 events
- 1st event: corals, brachiopods, trilobites, ammonites, conodonts, and acritarchs
- 2nd event: tetrapod ancestors, all placoderms and most sarcopterygians

  → establishment of the modern vertebrate fauna (ray-finned fish, sharks, and tetrapods)

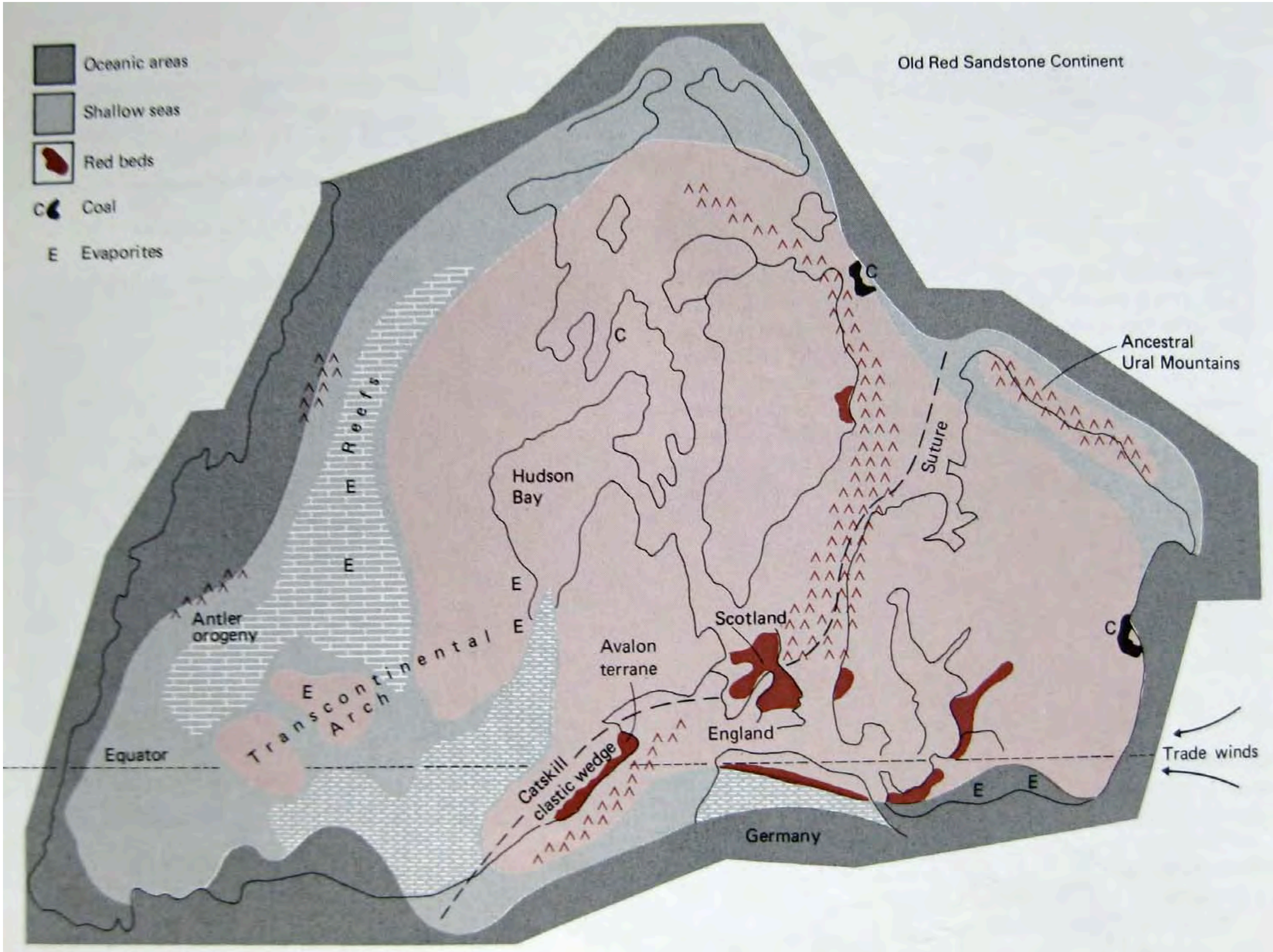
Reasons for extinction

- Diversification of plants
  - → Intensified weathering and nutrient run off
    - → Anoxia
  - → Consumption and binding of CO_2
    - → Cooling / glaciation
- Impacts
  - → Alamo + Siljan (1st event) / Woodleigh (2nd event)

Early Devonian 390 Ma




Laurentia
Baltica
Orkney
0
30S
60S


Oceanic areas
Shallow seas
Red beds
C Coal
E Evaporites
Old Red Sandstone Continent
Ancestral Ural Mountains
Reefs
Suture
Hudson Bay
C
E
Antler orogeny
Transcontinental Arch
Scotland
Avalon terrane
England
Catskill clastic wedge
Equator
Trade winds
Germany

Devonian in Sweden

- Nope!

  but...

Norway:

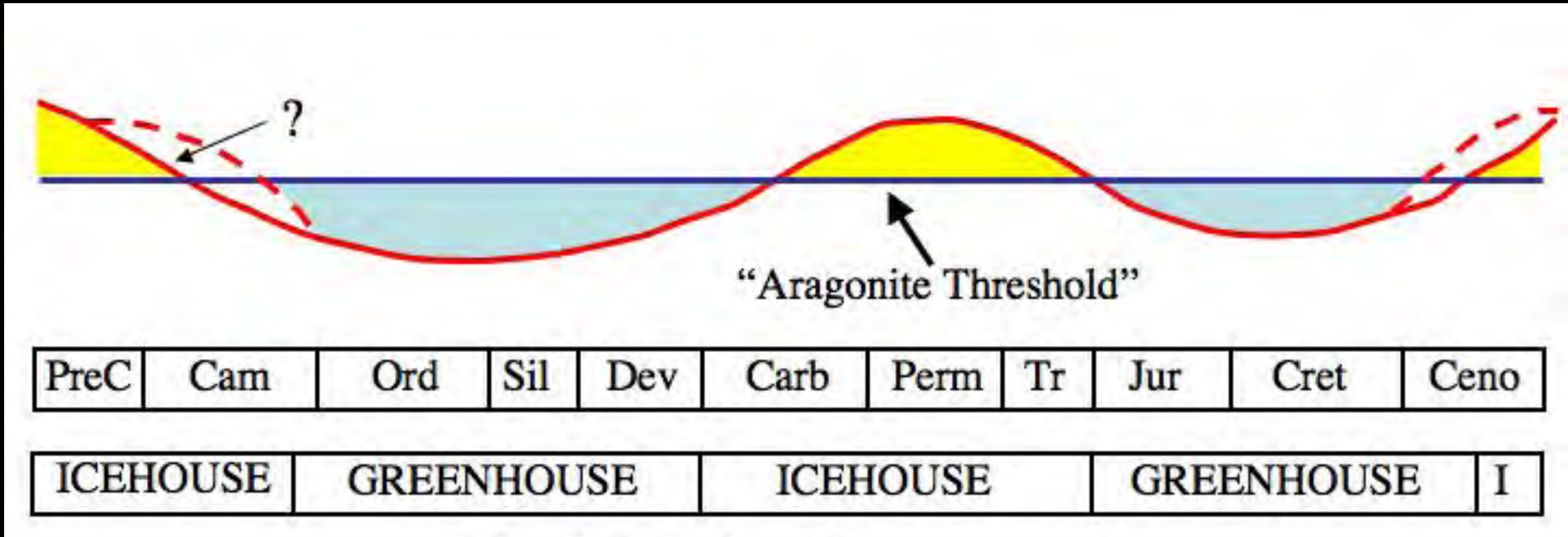
- Hornelen Basin (western Norway)
- Svalbard

Carboniferous (359- 299 Ma)

- Named after the common coal deposits
- Diversification of plants
- swamps
- Time of glaciation (Permo-Carboniferous Glaciation)
- Pangea is formed → active mountain building

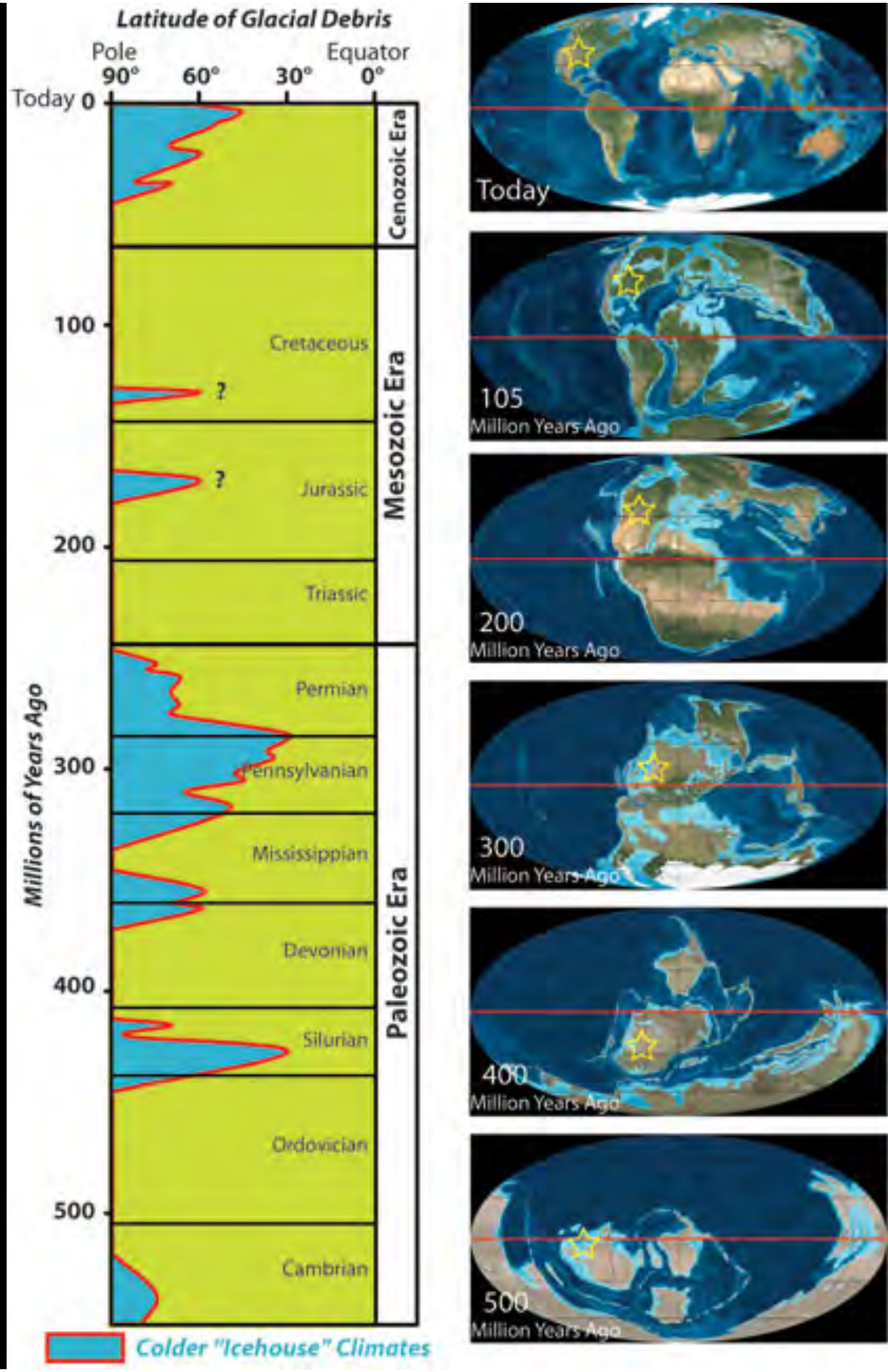
[Note!]

Glaciations / Ice ages



Icehouse stage: presence of continental ice sheets, less greenhouse gases, lower global temperatures

Greenhouse stage: no continental ice sheets, high levels of CO2 and other greenhouse gases, higher global temperaturs, rapid sea floor spreading

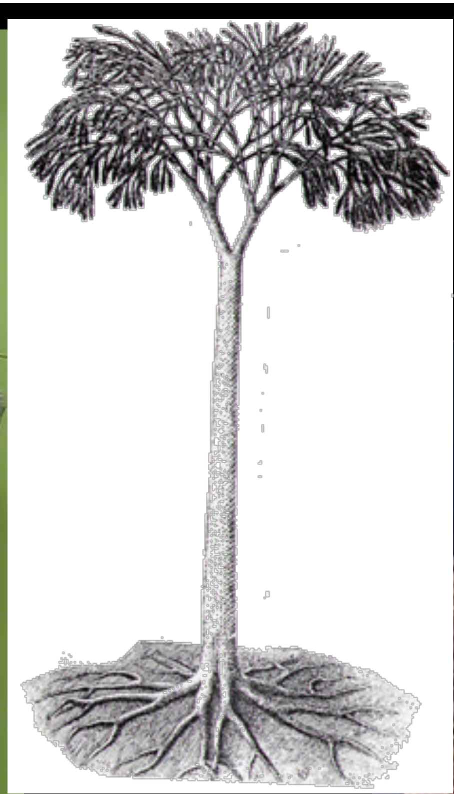


Latitude of Glacial Debris
Pole
Equator
90°
60°
30°
0°
Today 0
100
200
300
400
500
Millions of Years Ago
Cenozoic Era
Mesozoic Era
Paleozoic Era
Cretaceous
Jurassic
Triassic
Permian
Pennsylvanian
Mississippian
Devonian
Silurian
Ordovician
Cambrian
?
?
Colder "Icehouse" Climates
Today
105
Million Years Ago
200
Million Years Ago
300
Million Years Ago
400
Million Years Ago
500
Million Years Ago

Fauna

- Radiation/recovery of most groups after extinction

  Corals, brachiopods, mollusks, sea lilies
- foraminiferas become a significant part of the marine life

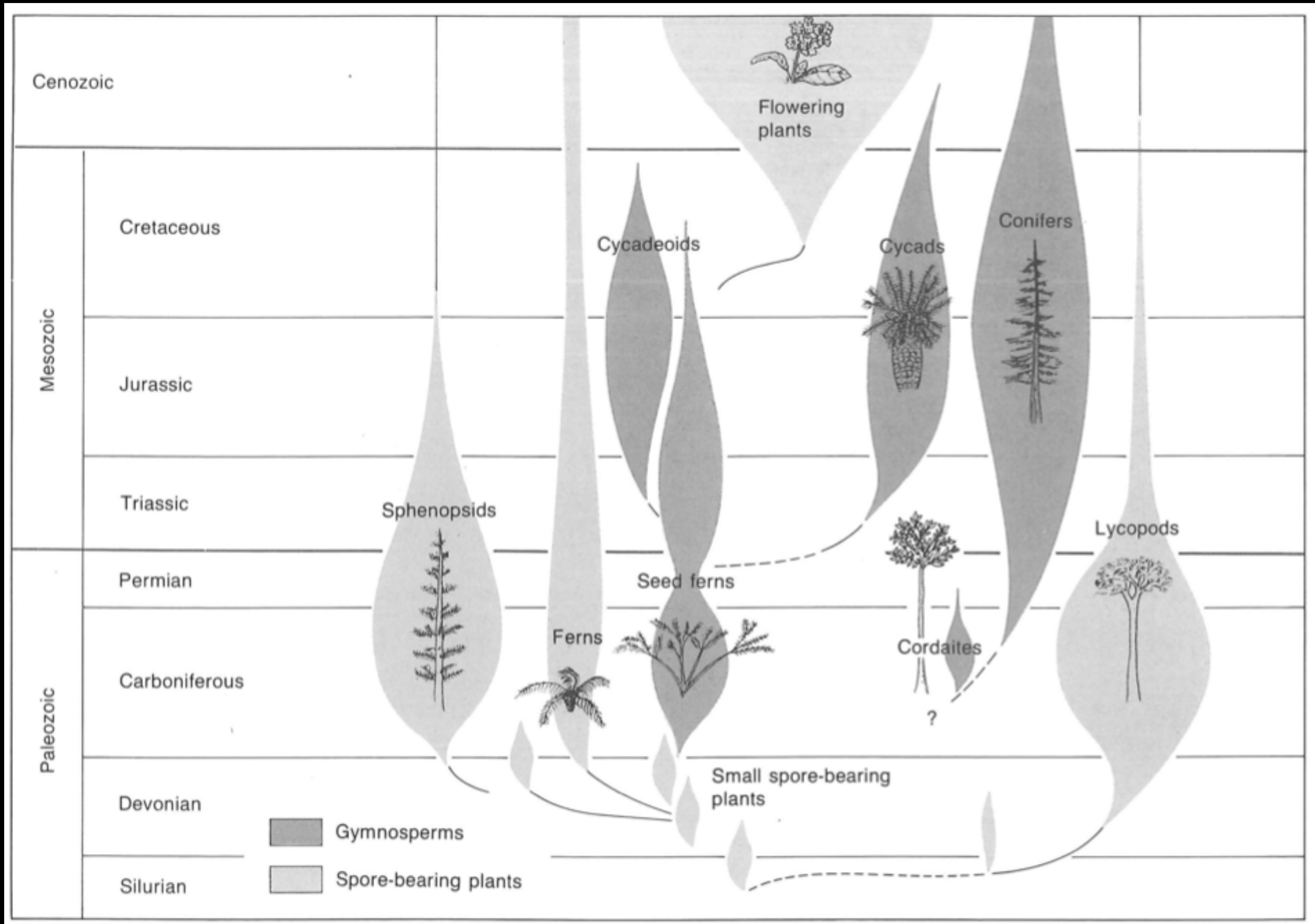


Lepidodendron
scale tree, up to 30 m

Lycopodium
club moss, 30 cm

Sigillaria

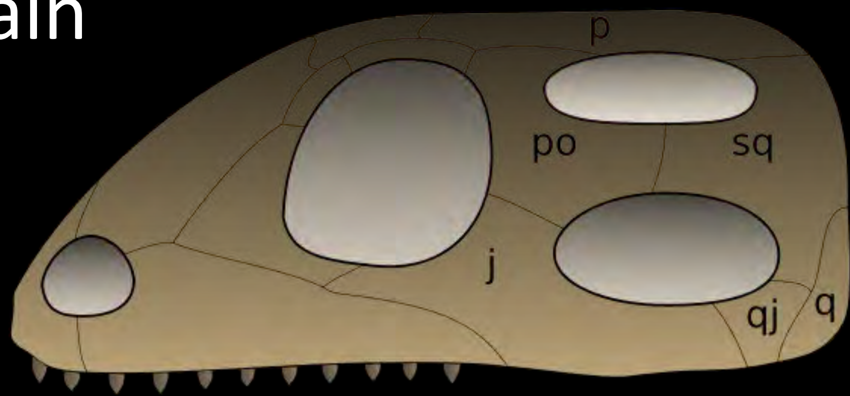
Flora



Cenozoic
Mesozoic
Cretaceous
Jurassic
Triassic
Paleozoic
Permian
Carboniferous
Devonian
Silurian
Flowering plants
Cycadeoids
Cycads
Conifers
Sphenopsids
Seed ferns
Ferns
Cordaites
?
Lycopods
Small spore-bearing plants
Gymnosperms
Spore-bearing plants

Tetrapods

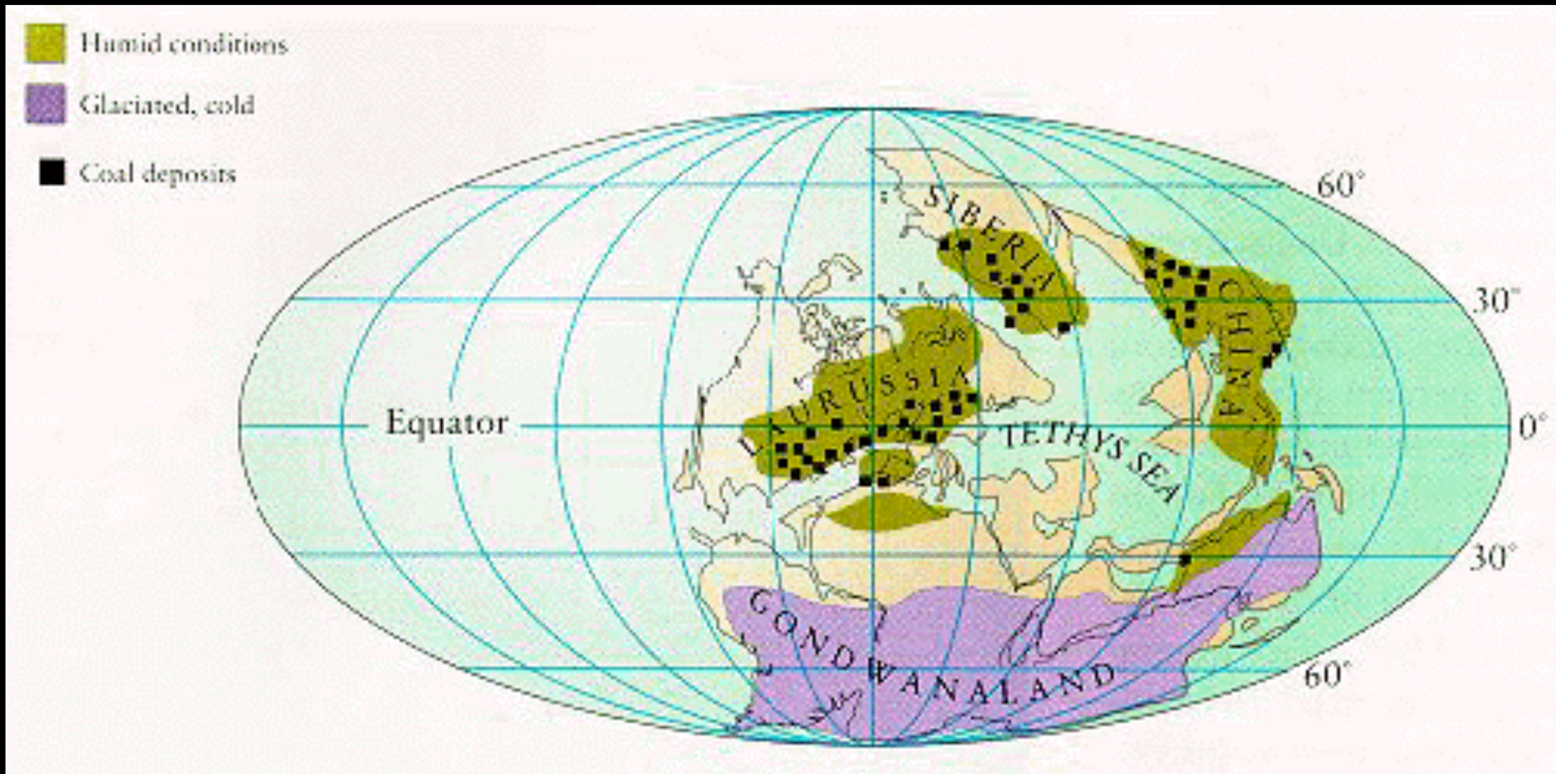
- Carboniferous: main phase of tetrapod evolution
- evolving plants and terrestrial arthropods supported the radiation
- 40 families
- secondarily aquatic again
- first reptiles
- first diapsides



[handout]

Coal deposits

- Coal deposits world wide
  - China, Siberia, Eastern Europe, USA etc



Climate

- changed from warm and moist to cool and arid in the Late Carboniferous

  → glaciations and forming of Pangea

  → extinction event

  Carboniferous Rainforest Collapse

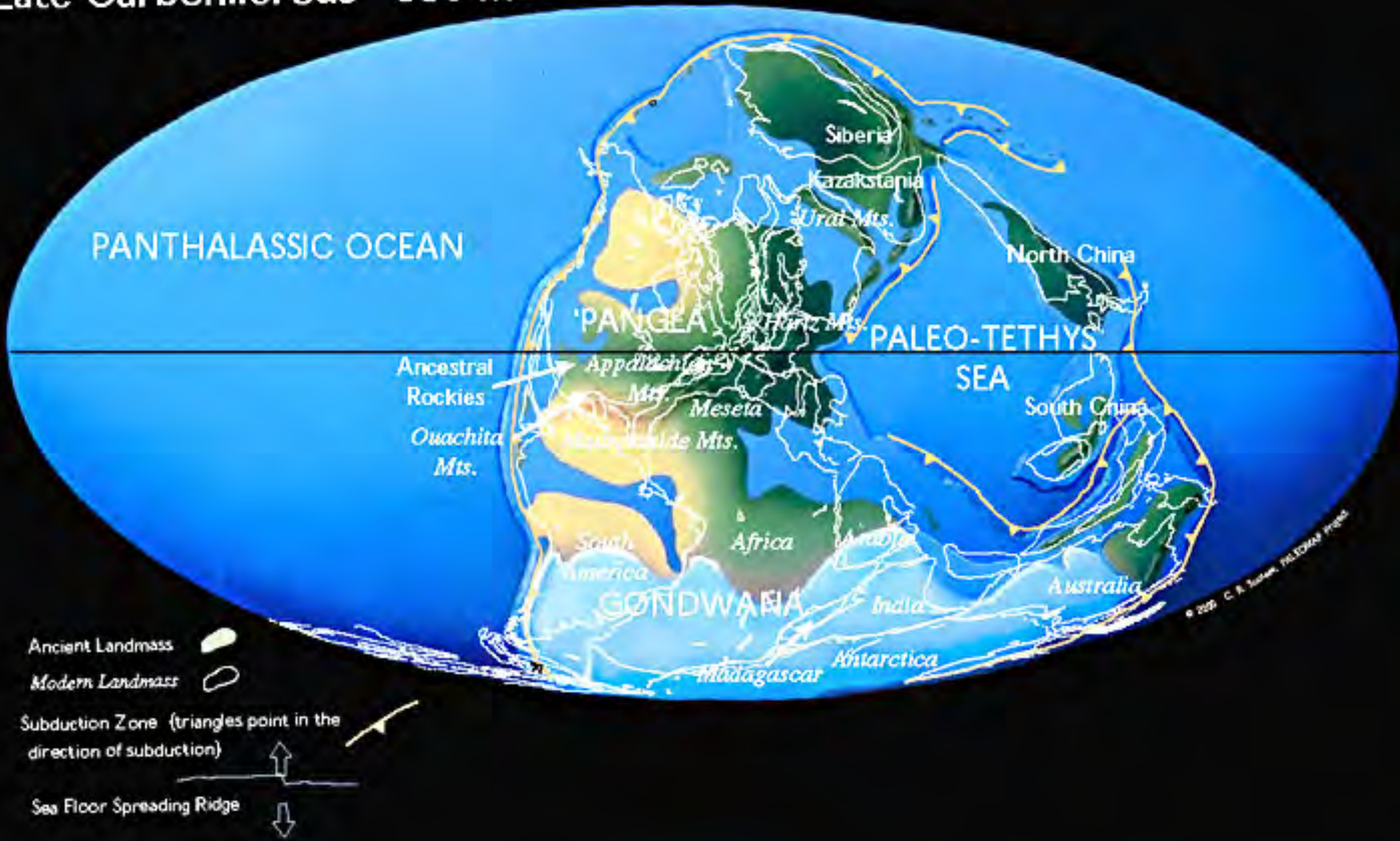
  However:

  → isolated populations of reptiles

  → each community evolved in separate directions → increase in diversity

Rainforest collapse kickstarted reptile evolution

Late Carboniferous 306 Ma



Carboniferous in Sweden

- no sediments, potentially some volcanic rocks
- Sweden was above sea level

Permian (299-251 Ma)

- named after the city Perm (Russia, near Ural Mountains)
- diversification of early amniotes

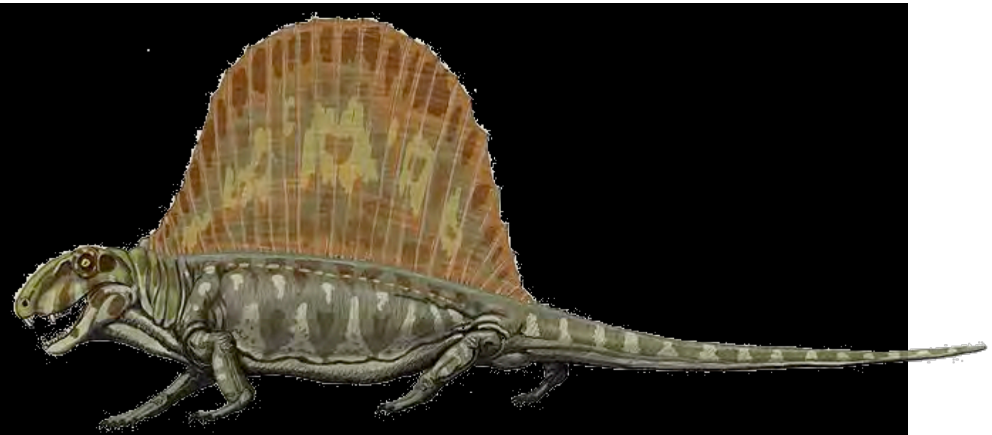
  → ancestral groups of the mammals, turtles, lepidosaurs and archosaurs evolve
- ends with largest extinction event
- Pangea
- Large continental landmasses create climates with extreme variations of heat and cold

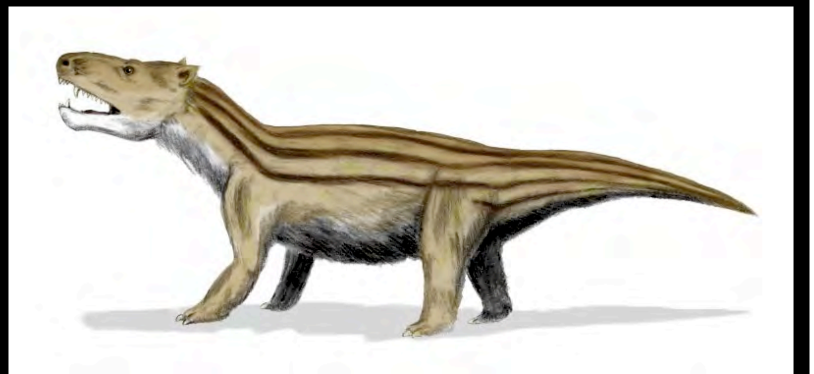
Fauna

- Mollusks, echinoderms, and brachiopods
  – brachiopods formed reefs
- Trilobites
- Fusulinides

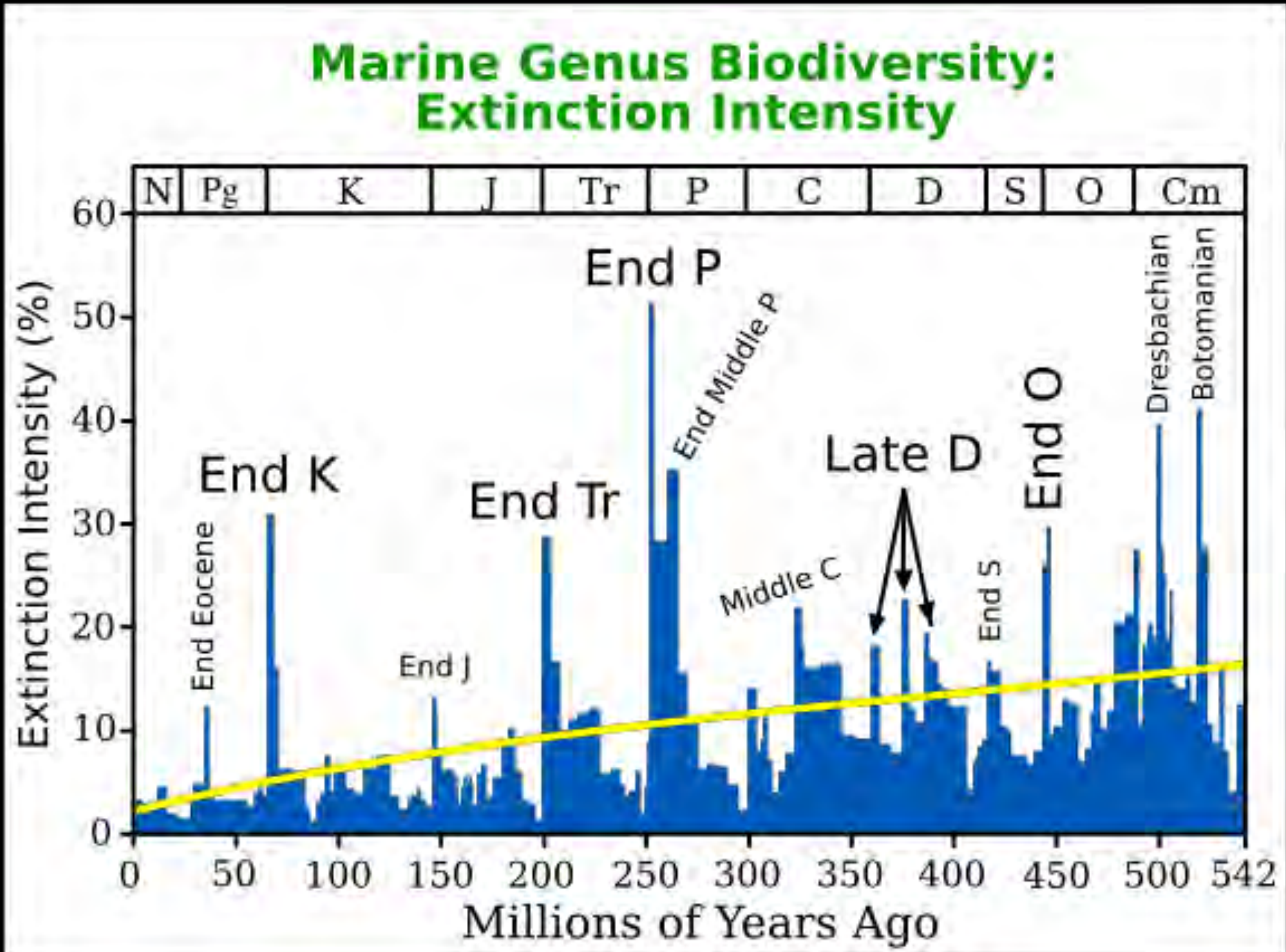
Vertebrates

- Synapsida radiated
  - pelycosaurs
  - therapsids
    - dinocephalia
    - cynodonts
- First archosaurs
- Permian anapsids
- Amphibians





End Permian Extinction



Marine extinctions	Genera extinct	Notes
Marine invertebrates		
Foraminifera	97%	Fusulinids died out, but were almost extinct before the catastrophe
Radiolaria (plankton)	99%[37]	
Anthozoa (sea anemones, corals, etc.)	96%	Tabulate and rugose corals died out
Bryozoans	79%	Fenestrates, trepostomes, and cryptostomes died out
Brachiopods	96%	Orthids and productids died out
Bivalves	59%	
Gastropods (snails)	98%	
Ammonites (cephalopods)	97%	
Crinoids (echinoderms)	98%	Inadunates and camerates died out
Blastoids (echinoderms)	**100%**	May have become extinct shortly before the P–Tr boundary
Trilobites	**100%**	In decline since the Devonian; only 2 genera living before the extinction
Eurypterids ("sea scorpions")	**100%**	May have become extinct shortly before the P–Tr boundary

marine vertebrates:
- Acanthodians 100%

terrestrial invertebrates:
- Insects 83 %

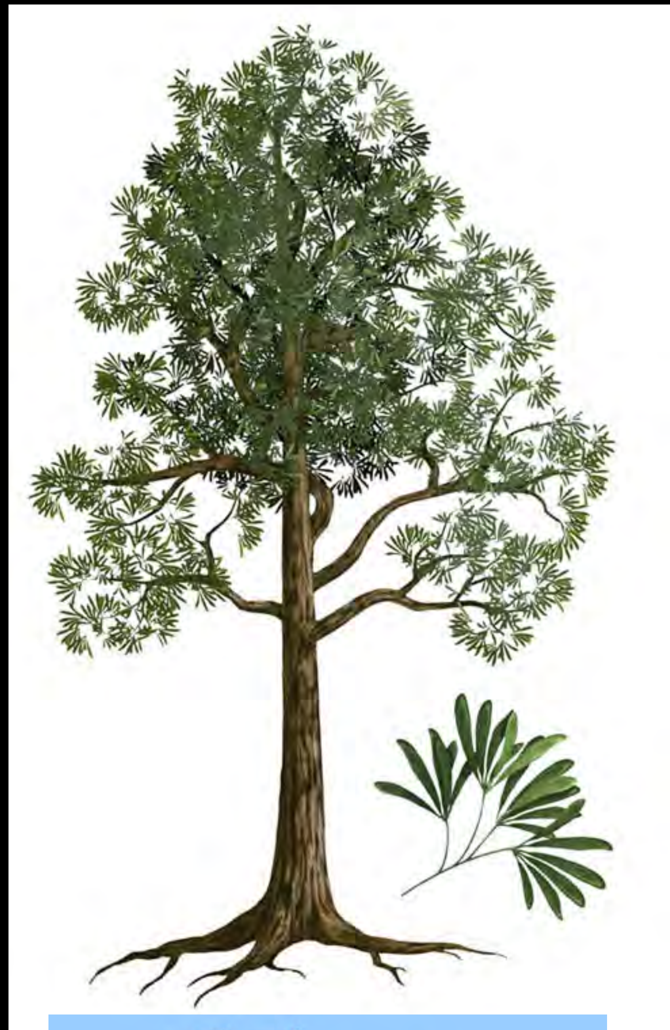
terrestrial vertebrates:
- heavy losses (2/3 of families)

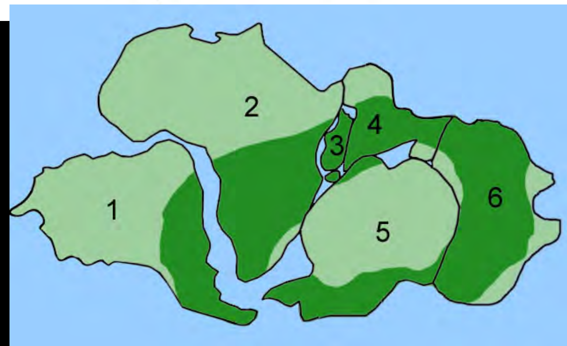
Plants

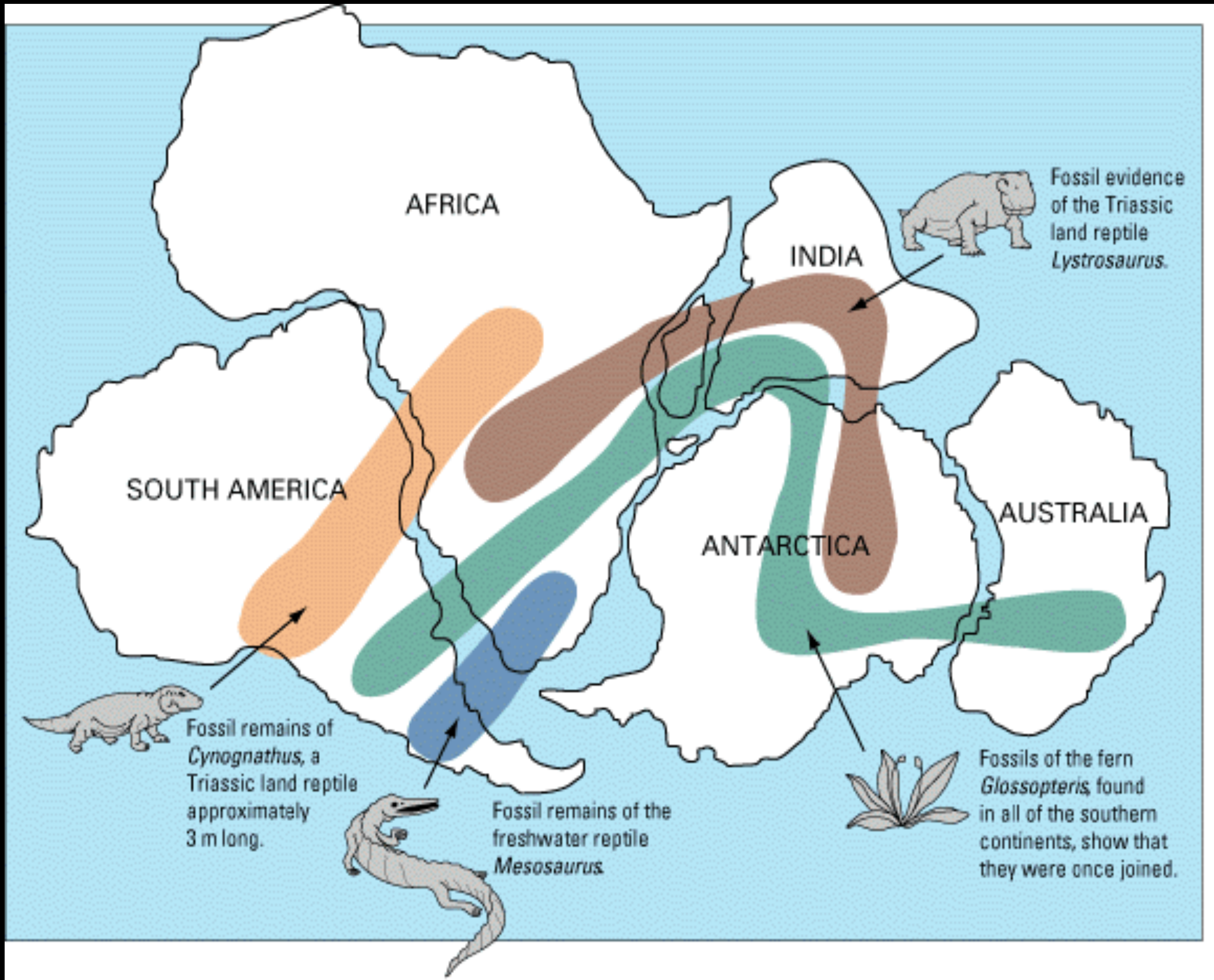
- typically unaffected by extinctions
- change of dominant floral groups

→ many groups of land plants decline, such as gymnosperms and the Glossopteridales, the seed ferns)

→ gymnosperm genera were replaced by lycophytes






AFRICA
INDIA
SOUTH AMERICA
ANTARCTICA
AUSTRALIA
Fossil evidence of the Triassic land reptile *Lystrosaurus*.
Fossil remains of *Cynognathus*, a Triassic land reptile approximately 3 m long.
Fossil remains of the freshwater reptile *Mesosaurus*.
Fossils of the fern *Glossopteris*, found in all of the southern continents, show that they were once joined.

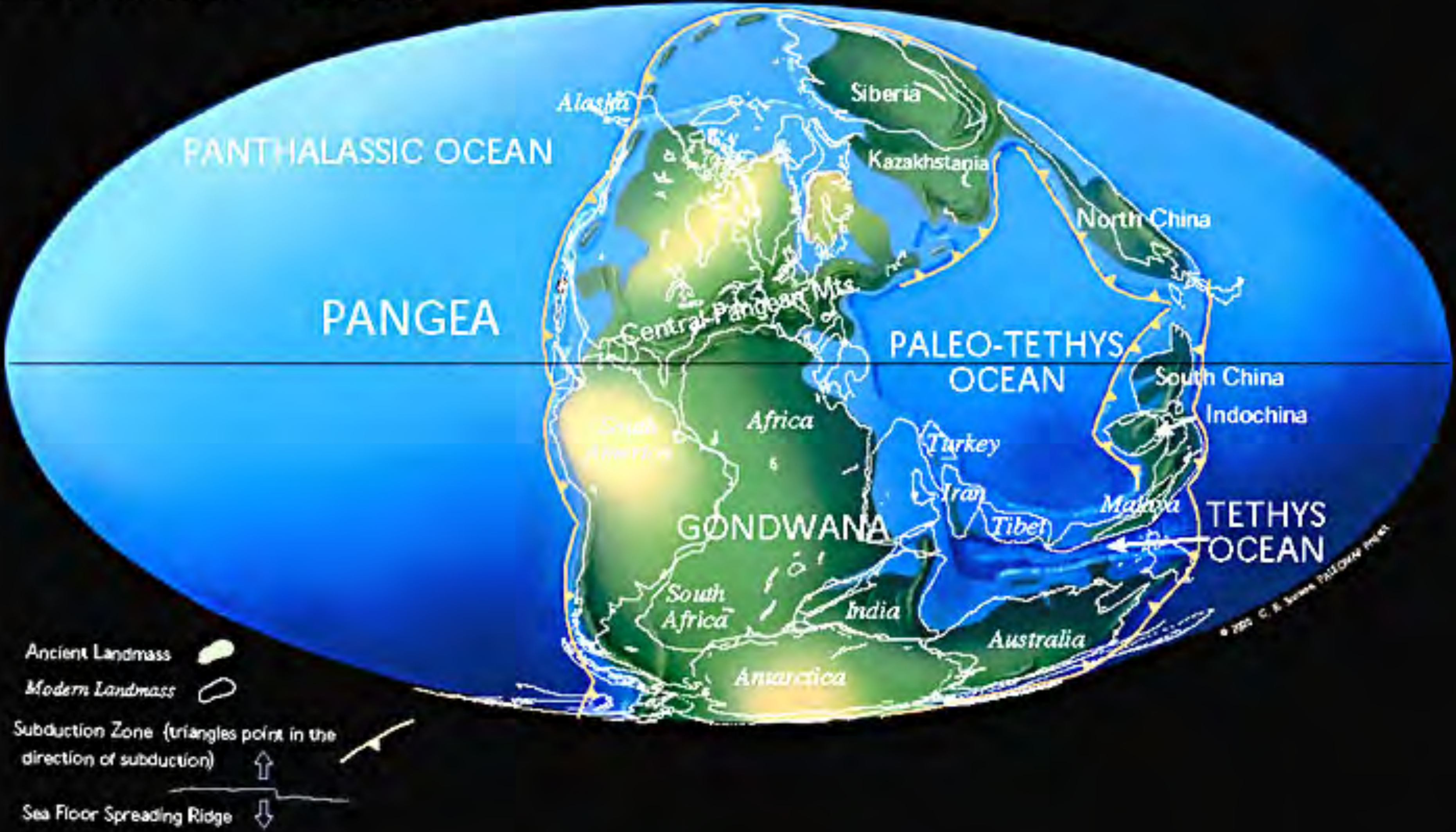
Reasons for P-Tr extinction

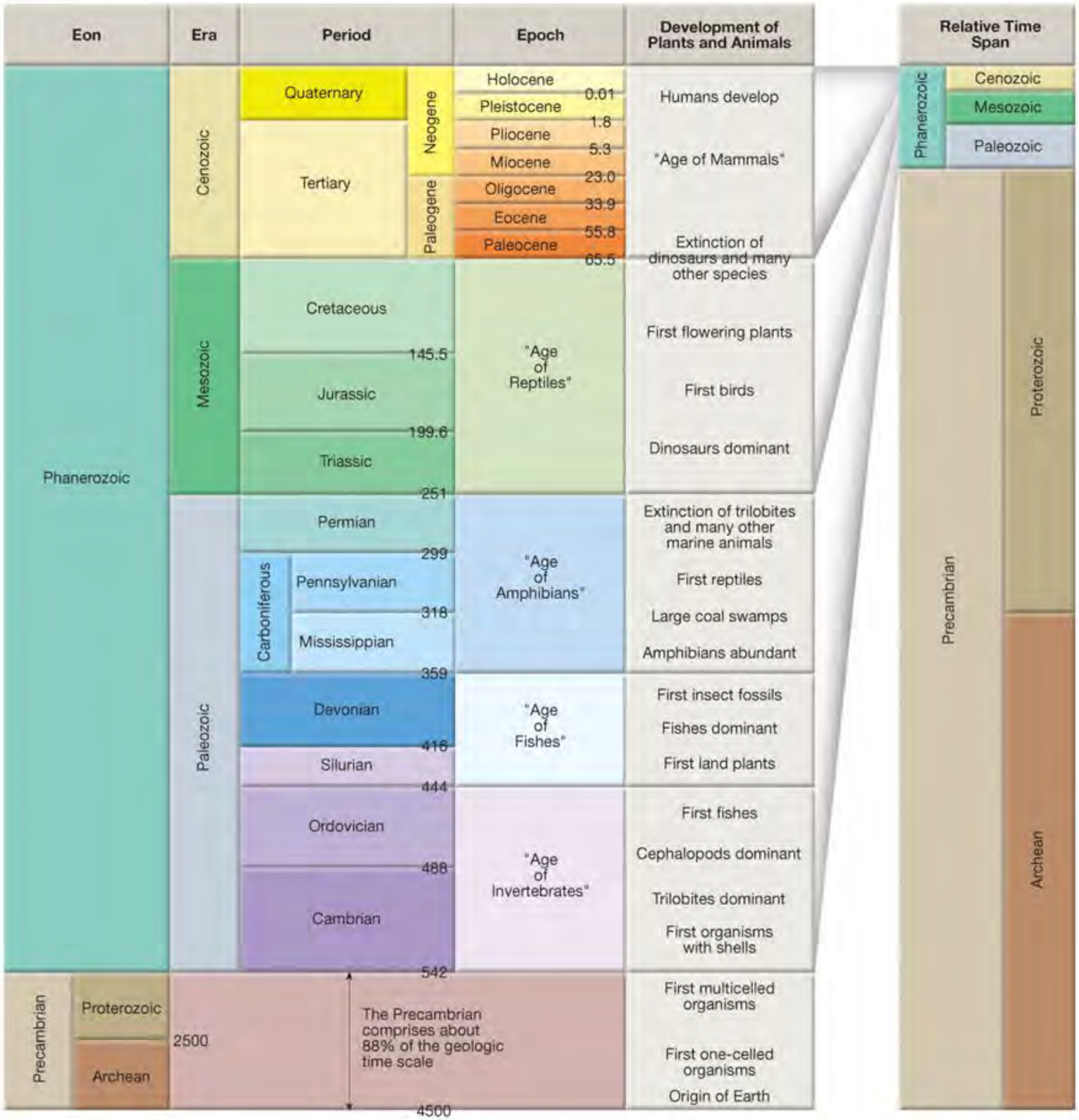
- **Impact event**
- **Volcanism**
- **Methane hydrate gasification**
- **Sea level fluctuations**
- **Anoxia**
- **Hydrogen sulfide emissions**

Climate

- variable and extreme
- early Permian : glaciations
  - →cold at poles, but quite hot at equators
- vast land masses separated by mountain chains
  - →distinct climate and flora provinces
- drier conditions towards the end of the Permian
  - →documented by flora
  - →evaporites

Late Permian 255 Ma





Eon
Era
Period
Epoch
Development of Plants and Animals
Relative Time Span
Phanerozoic
Cenozoic
Quaternary
Tertiary
Neogene
Paleogene
Holocene
Pleistocene
Pliocene
Miocene
Oligocene
Eocene
Paleocene
0.01
1.8
5.3
23.0
33.9
55.8
65.5
Humans develop
"Age of Mammals"
Extinction of dinosaurs and many other species
Mesozoic
Cretaceous
145.5
Jurassic
199.6
Triassic
251
"Age of Reptiles"
First flowering plants
First birds
Dinosaurs dominant
Paleozoic
Permian
299
Carboniferous
Pennsylvanian
318
Mississippian
359
"Age of Amphibians"
Extinction of trilobites and many other marine animals
First reptiles
Large coal swamps
Amphibians abundant
Devonian
416
Silurian
444
"Age of Fishes"
First insect fossils
Fishes dominant
First land plants
Ordovician
488
Cambrian
542
"Age of Invertebrates"
First fishes
Cephalopods dominant
Trilobites dominant
First organisms with shells
Precambrian
Proterozoic
Archean
2500
4500
The Precambrian comprises about 88% of the geologic time scale
First multicelled organisms
First one-celled organisms
Origin of Earth
Phanerozoic
Cenozoic
Mesozoic
Paleozoic
Precambrian
Proterozoic
Archean

Triassic (251-200 Ma)

- Entering the Mesozoic – The time of the dinosaurs
- named after the tri-partition of the period
- adaptive radiation following end-Permian extinction
- modern faunas become dominant
- first dinosaurs!

Fauna

- impoverished biosphere in Lower Triassic
- adaptive radiation
- recovery took longer than after other extinctions

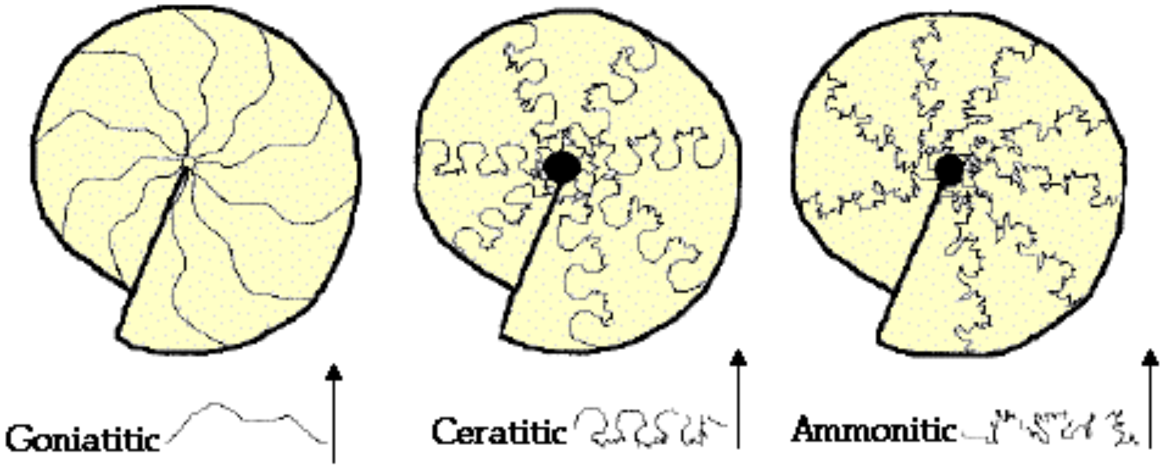
  → appearance of modern corals

  → ammonites diversified

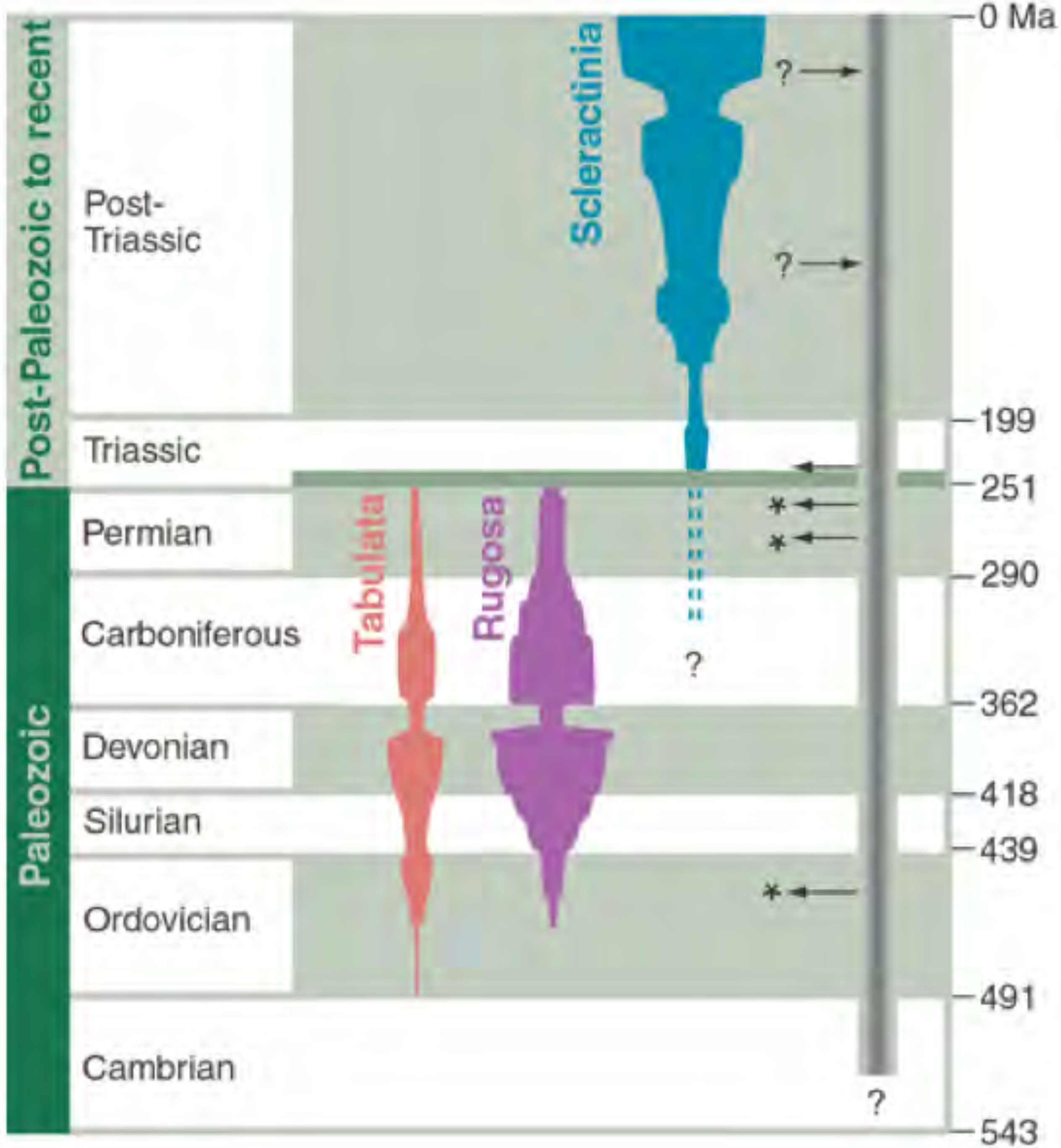
  → diverse marine reptiles

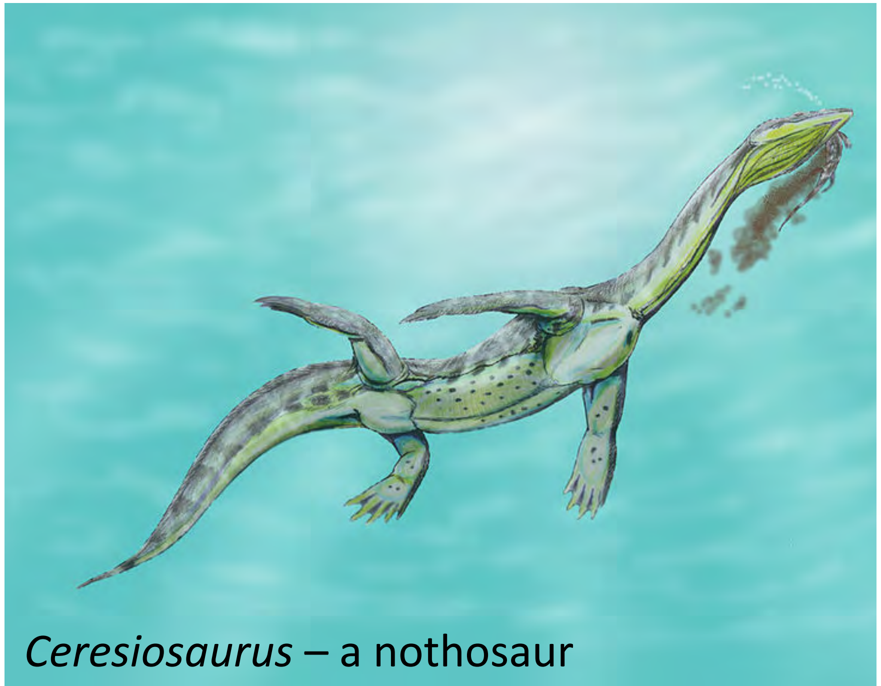
  → first mammals

  → archosaurs diversify

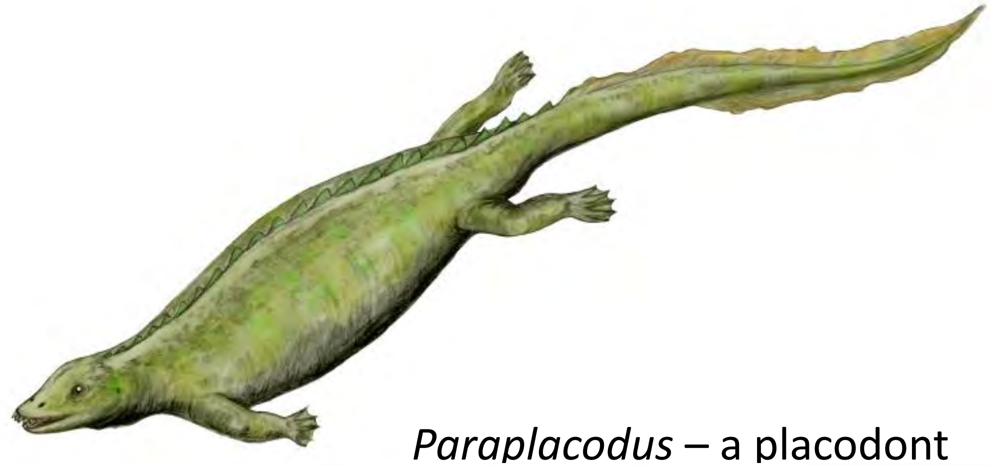


arrow indicates direction of aperture

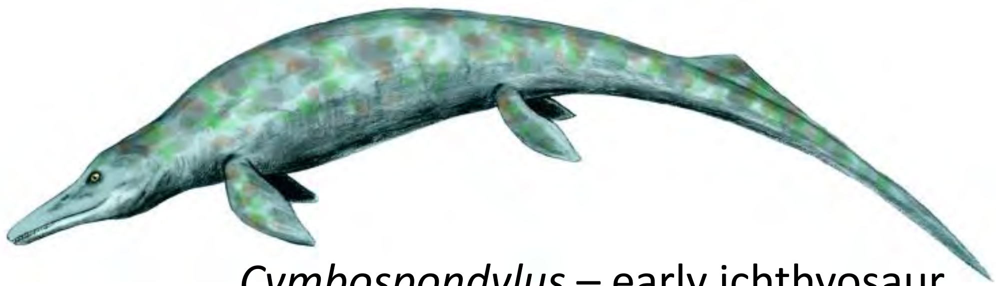

Post-Paleozoic to recent
Paleozoic
Post-Triassic
Triassic
Permian
Carboniferous
Devonian
Silurian
Ordovician
Cambrian
Tabulata
Rugosa
Scleractinia
?
?
?
?
*
*
*
0 Ma
199
251
290
362
418
439
491
543



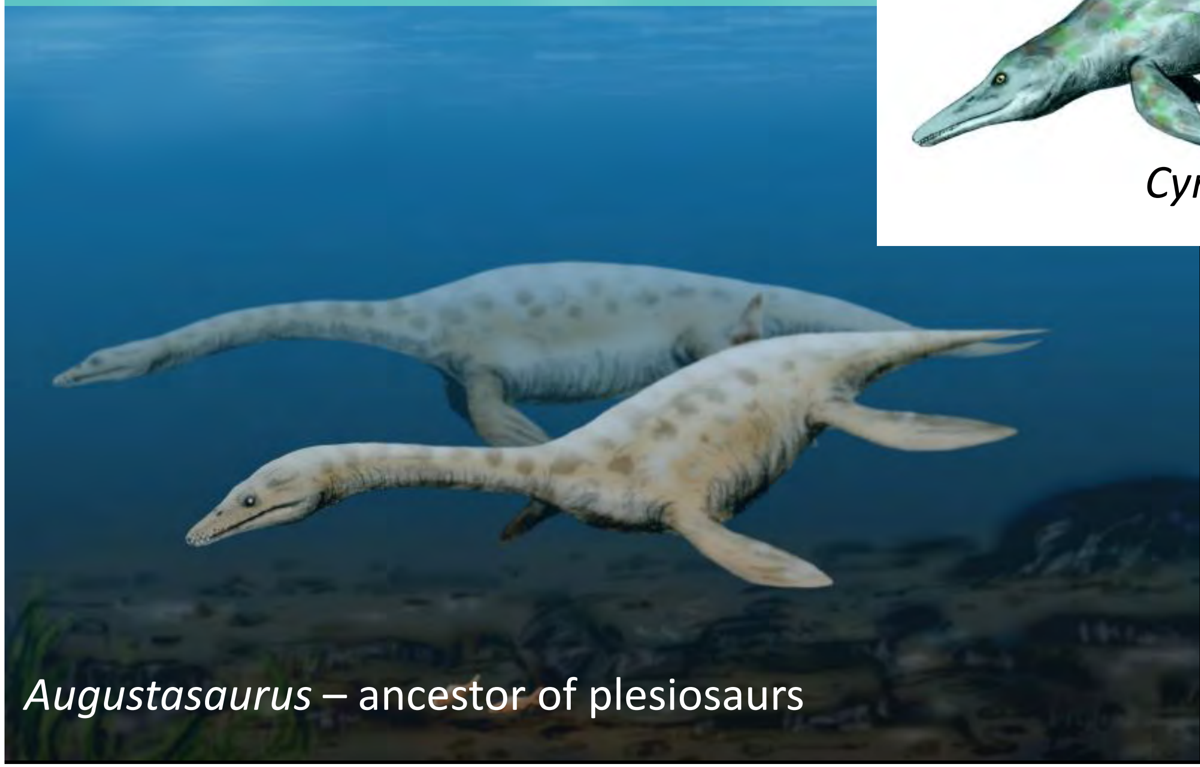
Ceresiosaurus – a nothosaur



Paraplacodus – a placodont



Cymbospondylus – early ichthyosaur

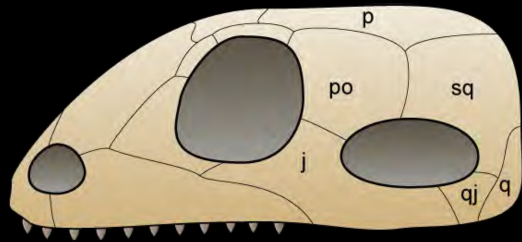


Augustasaurus – ancestor of plesiosaurs

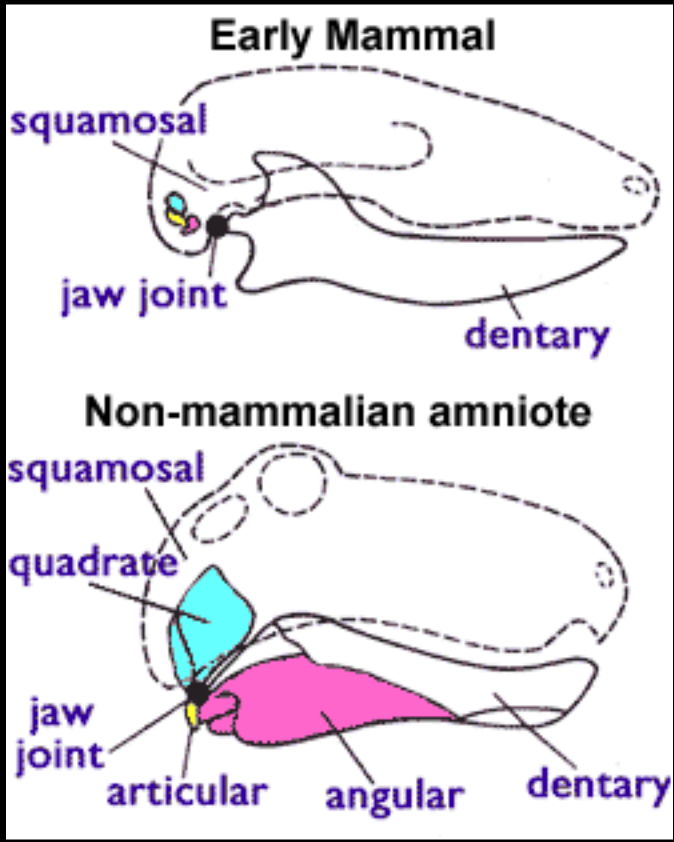
Marine reptiles from the

Middle Triassic

First mammals



- true mammal = middle ear + jaw joint
- candidates:
  - *Hadrocodium*
  - *Morganucodon*
  - *Megazostrodon*



First dinosaurs

Eoraptor - an agile, omnivore from the Late Triassic of Argentina
- ran upright on its hind legs
- five digits on hand, with three of them enlarged and clawed

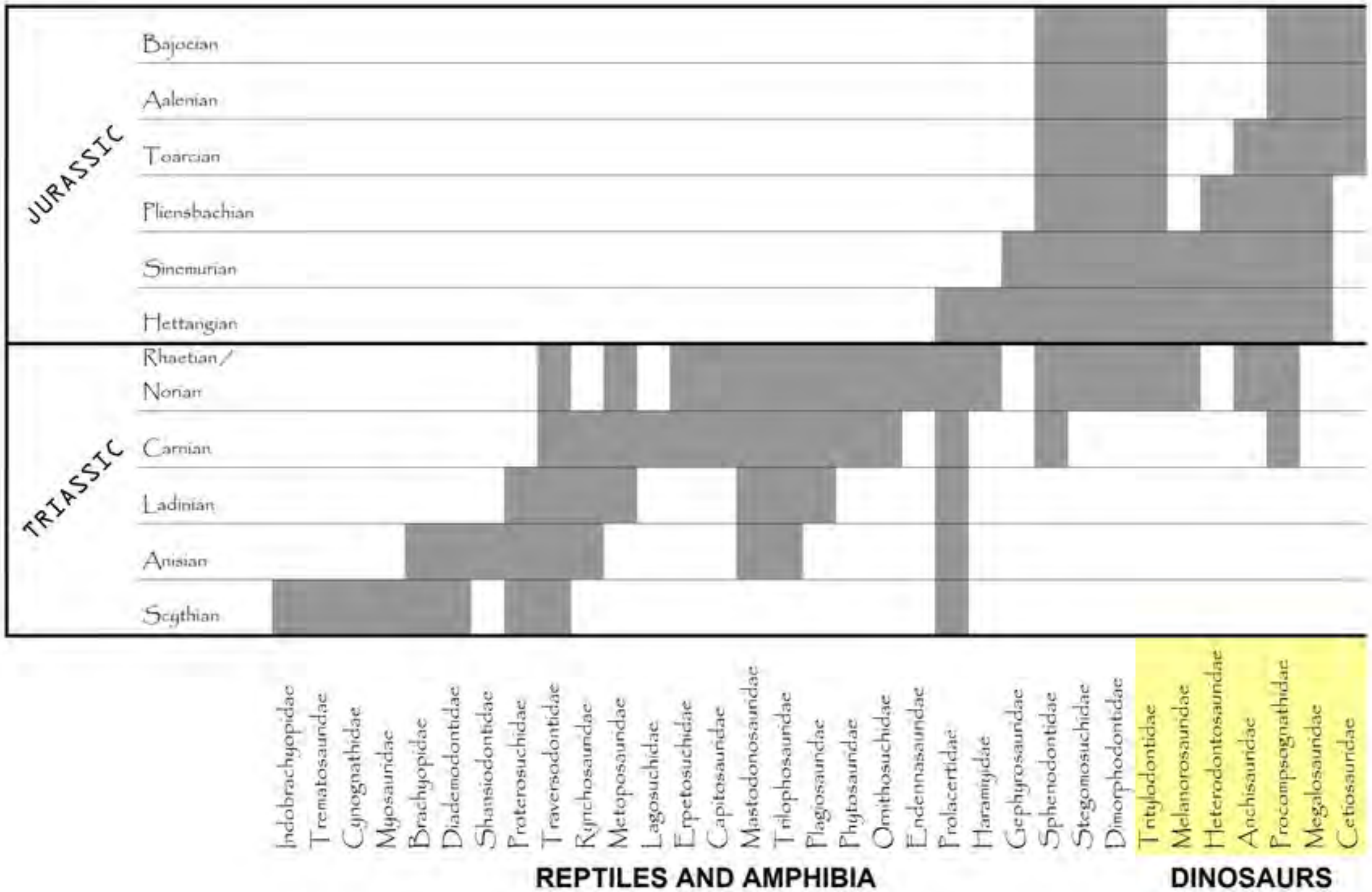
Coelophysis – similar to *Eoraptor*; agile, carnivorous, good eye sight

Eoraptor

End Triassic Extinction

- also one of the Big 5.
- marks the end of the Triassic
- reasons debated
- affected marine and terrestrial fauna
- Results:
  - conodonts disappeared
  - large crurotarsans (non-dinosaurian archosaurs) other than crocodilians, some remaining therapsids, and many of the large amphibians go extinct

→ opening up niches for the dinosaurs to diversify and dominate the Earth



Ranges of families tetrapods through the Triassic and Early Jurassic depicted at the stage level.

Climate

- generally hot and dry

  → typical red bed sandstones and evaporites
- no evidence of glaciation at or near either pole

  → polar regions were moist and temperate
- Pangaea's large size limited the moderating effect of the global ocean

  → highly seasonal continental climate

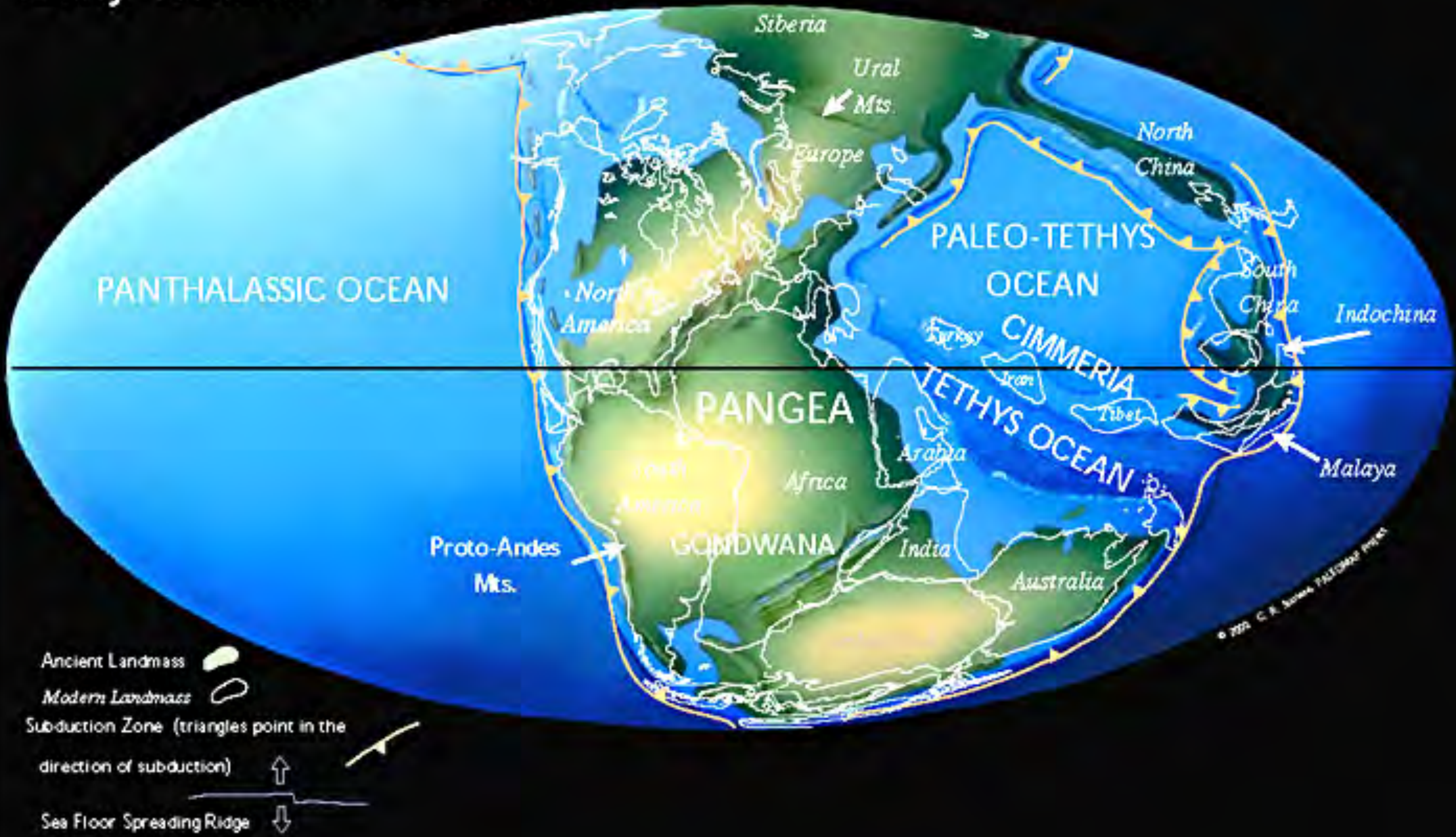
Dinosaur localities

Chinle Formation – Arizona (Late Triassic)

Ischigualasto Formation – Late Triassic (Argentina)

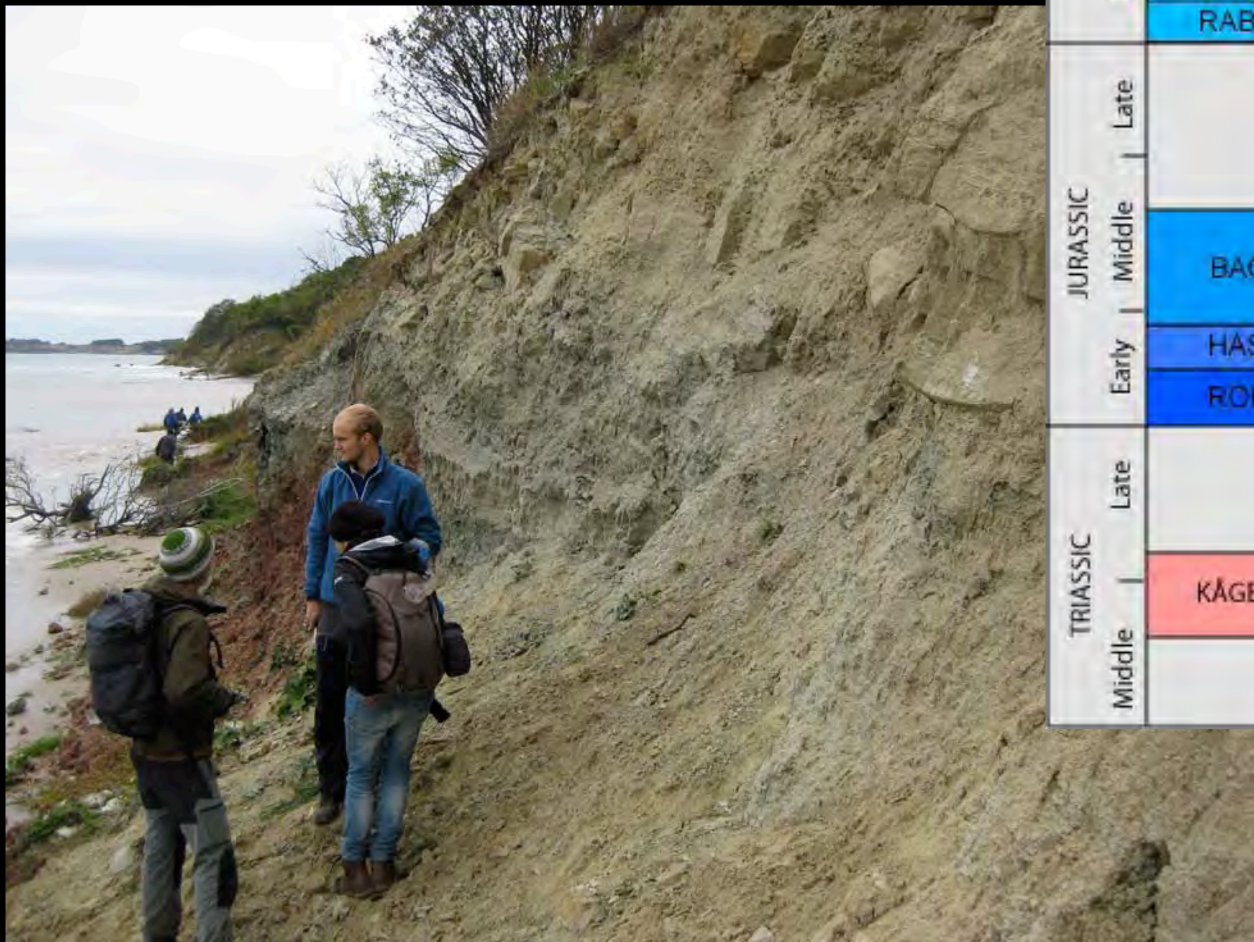
Grabfeld Formation – Late Triassic (Germany)

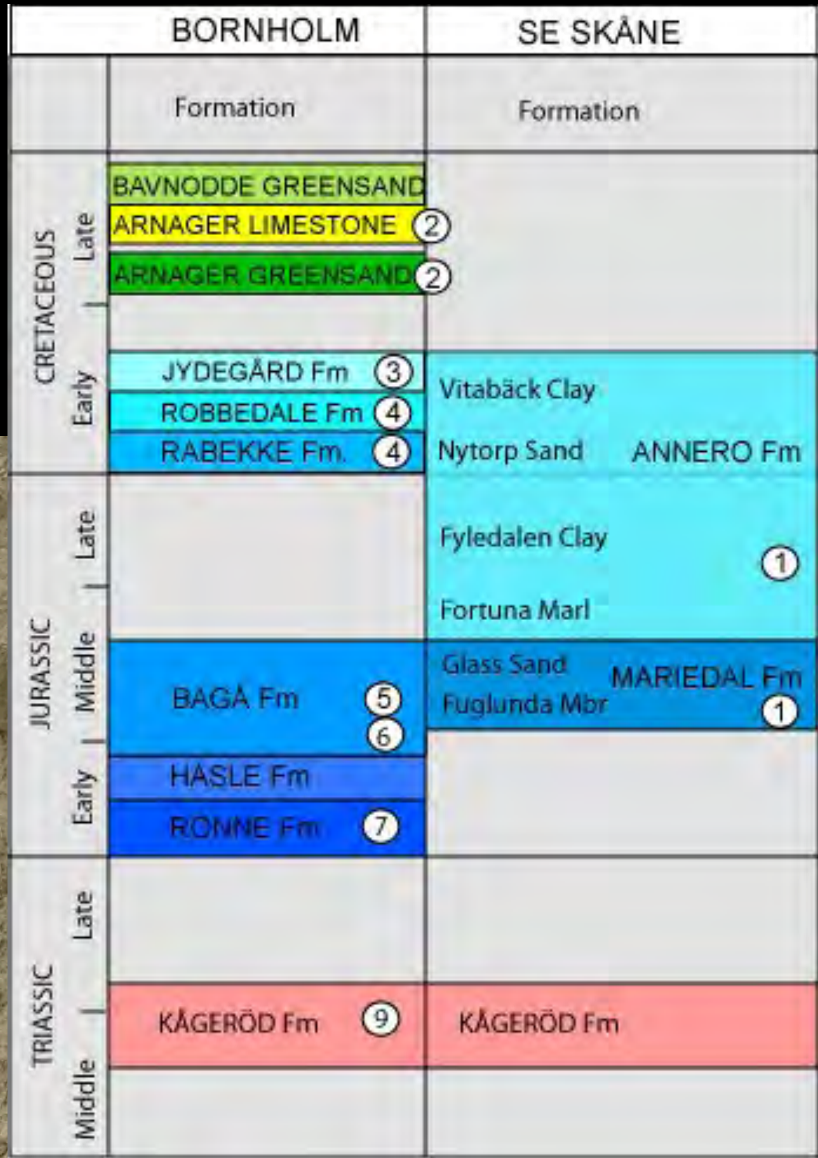
Early Triassic 237 Ma



Triassic in Sweden

- Scania (& Bornholm)

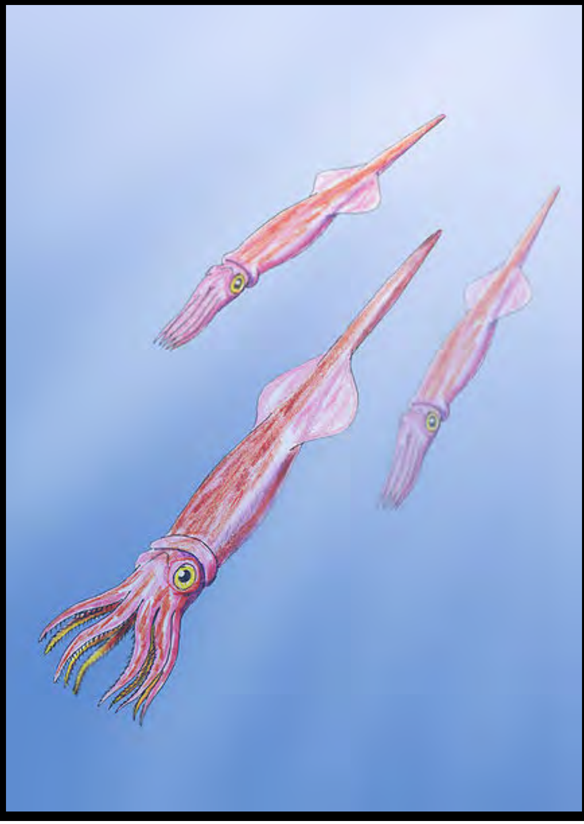


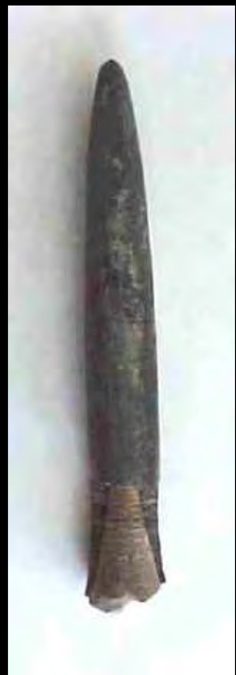


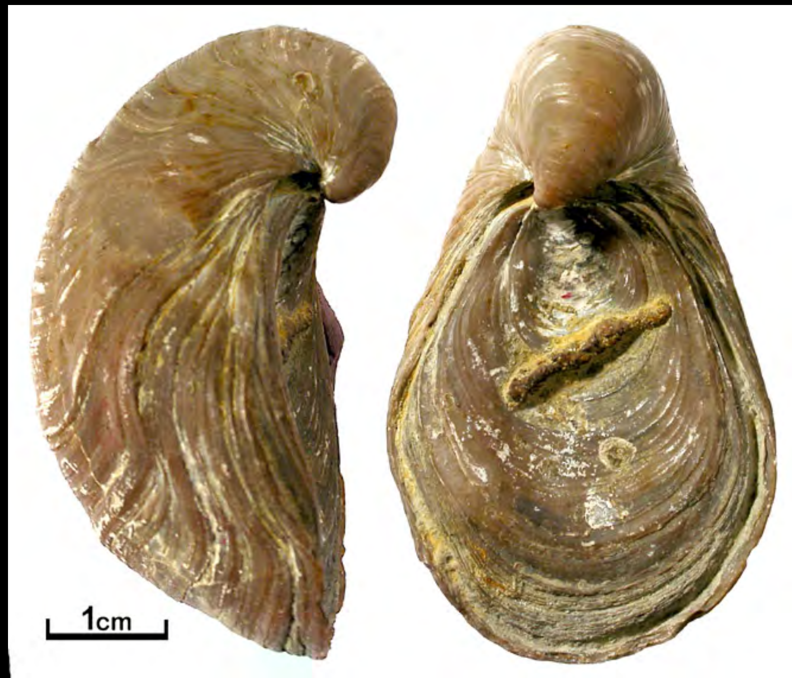
Jurassic (200-146 Ma)

- named after the Swiss Jura Mountains
- Age of the reptiles
- Pangea is breaking apart
- many shallow epicontinental seas
  - Sundance Sea; central Europe
- famous lagerstätten

Marine invertebrate fauna

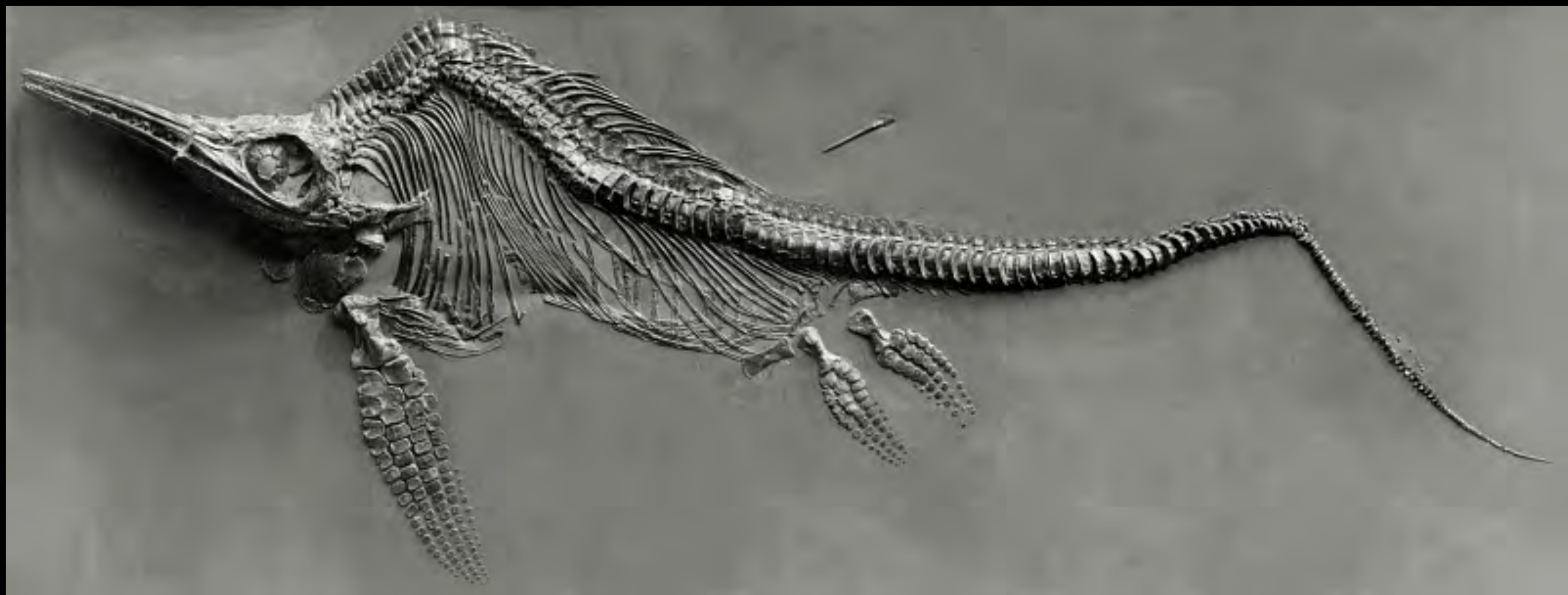






Marine vertebrate fauna

- various marine reptiles
- more advanced than in Triassic
- ichthyosaurs, plesiosaurs, pliosaurs, and marine crocodiles



Terrestrial fauna

- dinosaurs diversify / increase in size
- first birds at the end of the Jurassic

	theropods	sauropods	ornithopods	thyreophors	marginoceph.
Upper Jurassic	carnosaurs (*Allosaurus*)	large (*Diplodocus*, *Brachiosaurus*)	medium (*Iguanodon*)	large stegosaurs	
Middle Jurassic		large	small	small stegosaurs	
Lower Jurassic		small	small	primitive forms	




Climate

- arid, continental conditions characteristic of the Triassic steadily eased during the Jurassic period, especially at higher latitudes
- a warm, humid climate allowed lush jungles to cover much of the landscape

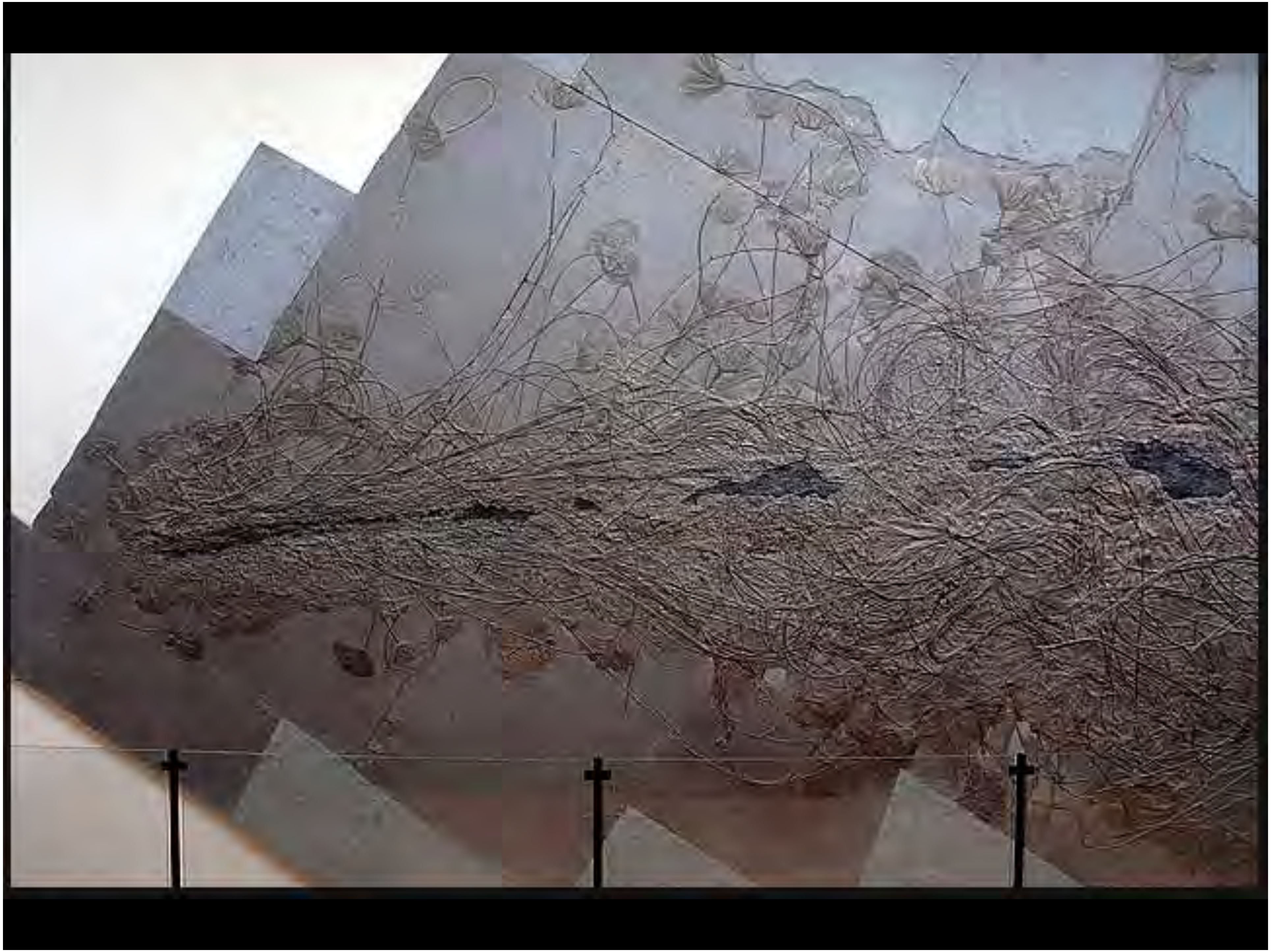
Lagerstätten & dinosaur localities

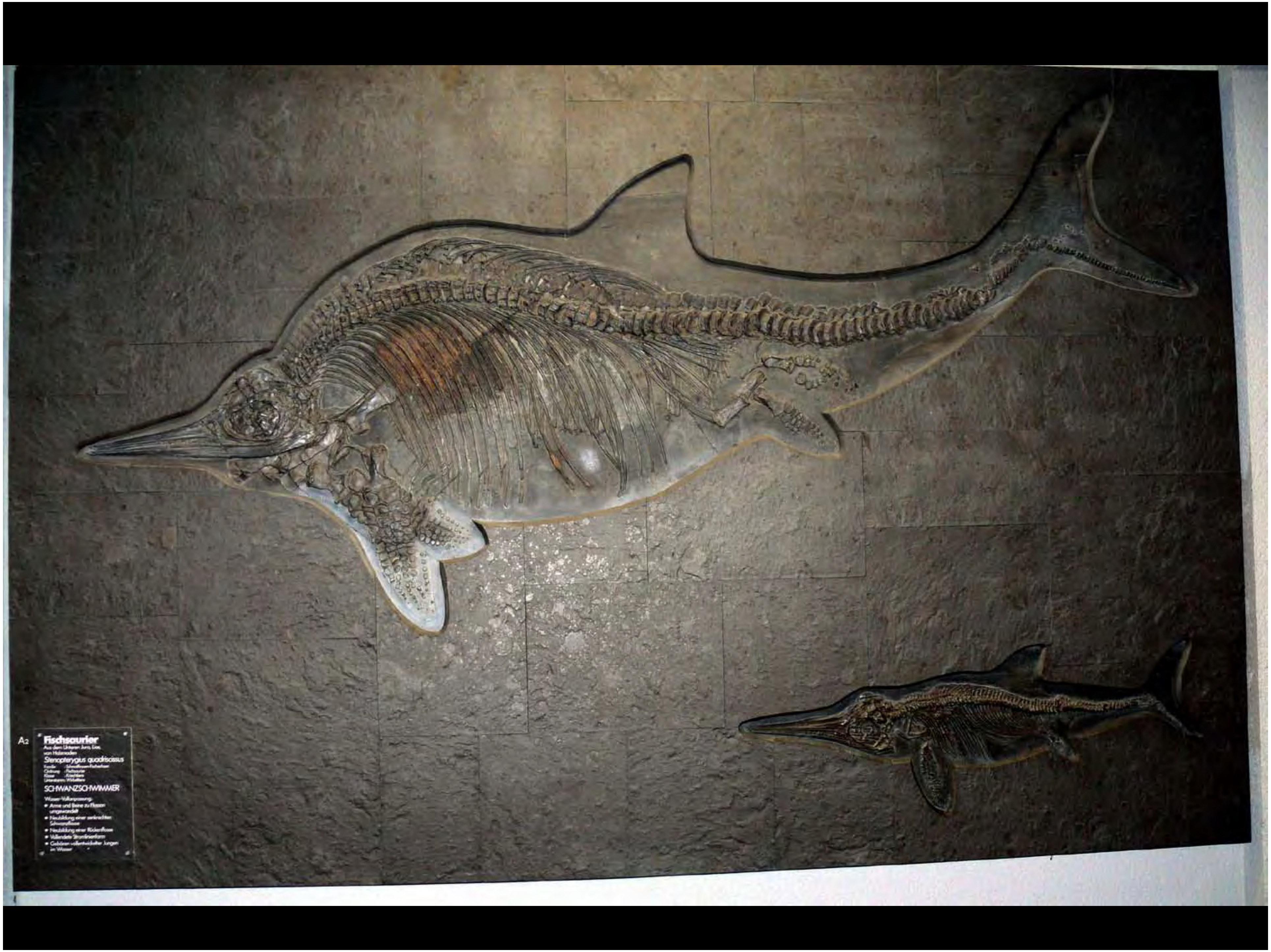
- Holzmaden, southern Germany
  - *Posidonia* Shale, Lower Jurassic
    - → marine reptiles
- Solnhofen, southern Germany
  - Solnhofen Formation, Upper Jurassic
    - → *Archaeopteryx*, pterosaurs, and fish
- Western USA, Colorado, Utah, Wyoming
  - Morrison Formation, Upper Jurassic
    - →richest dinosaur locality of the Jurassic
- Tanzania
  - Tendaguru Formation
    - → age equivalent to Morrison Fm.

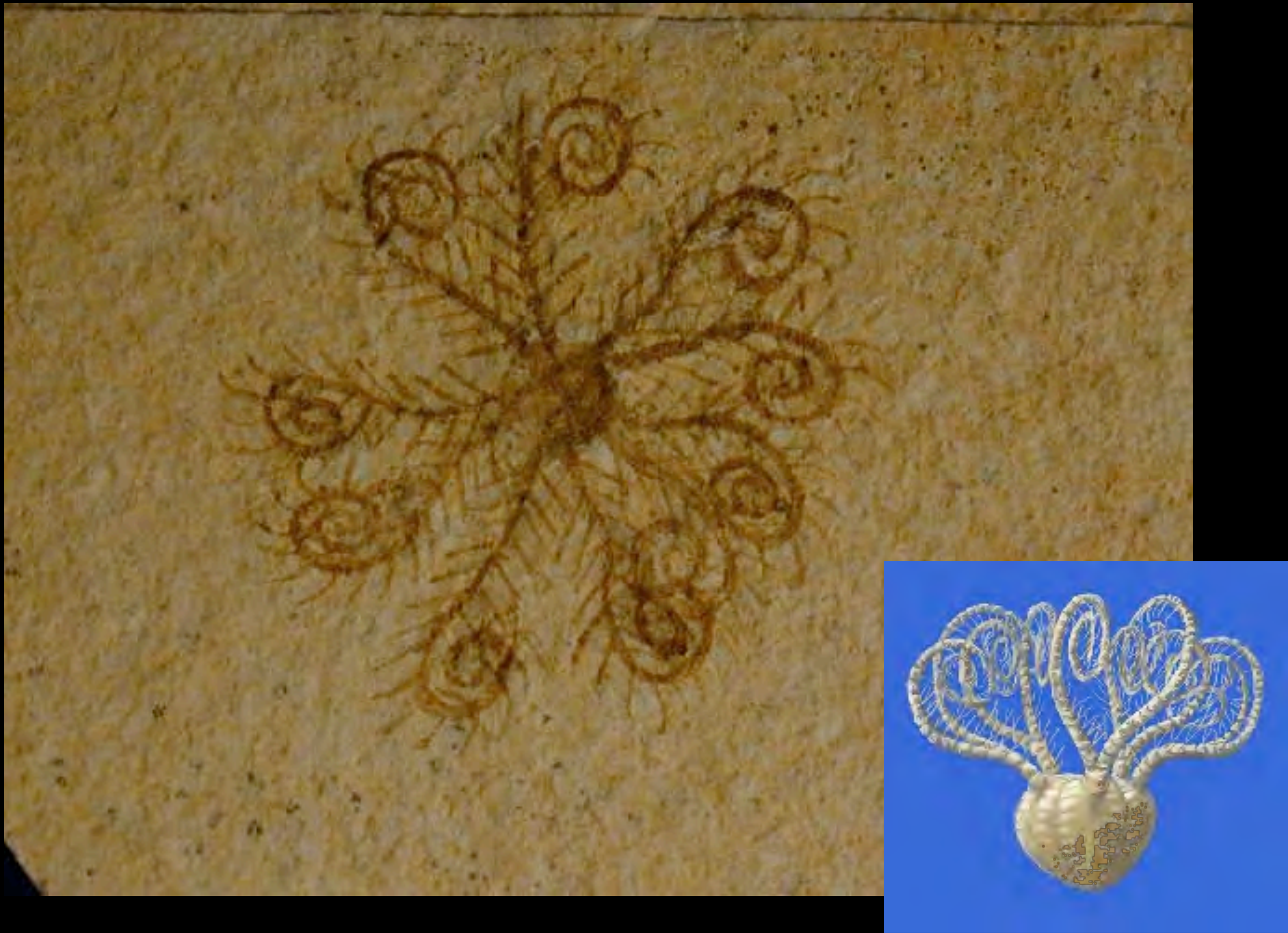
marine sediments

terrestrial deposits


Posidonienschiefer

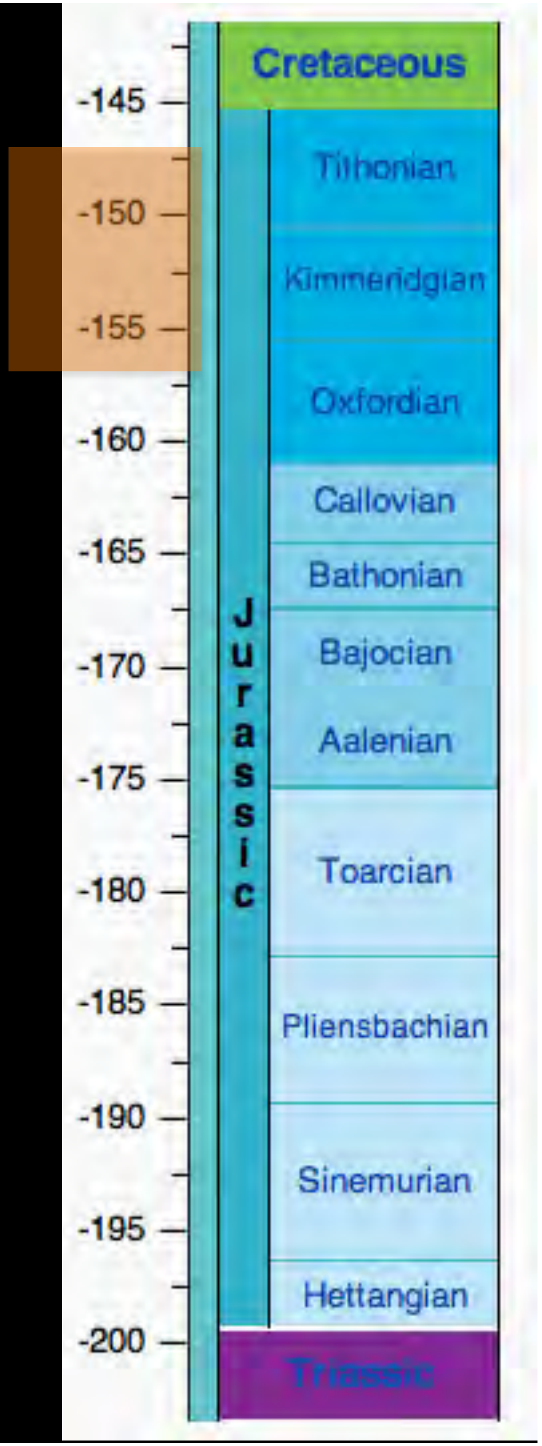



A2
Fischsaurier
Stenopterygius quadriscissus
SCHWANZSCHWIMMER



Morrison Formation

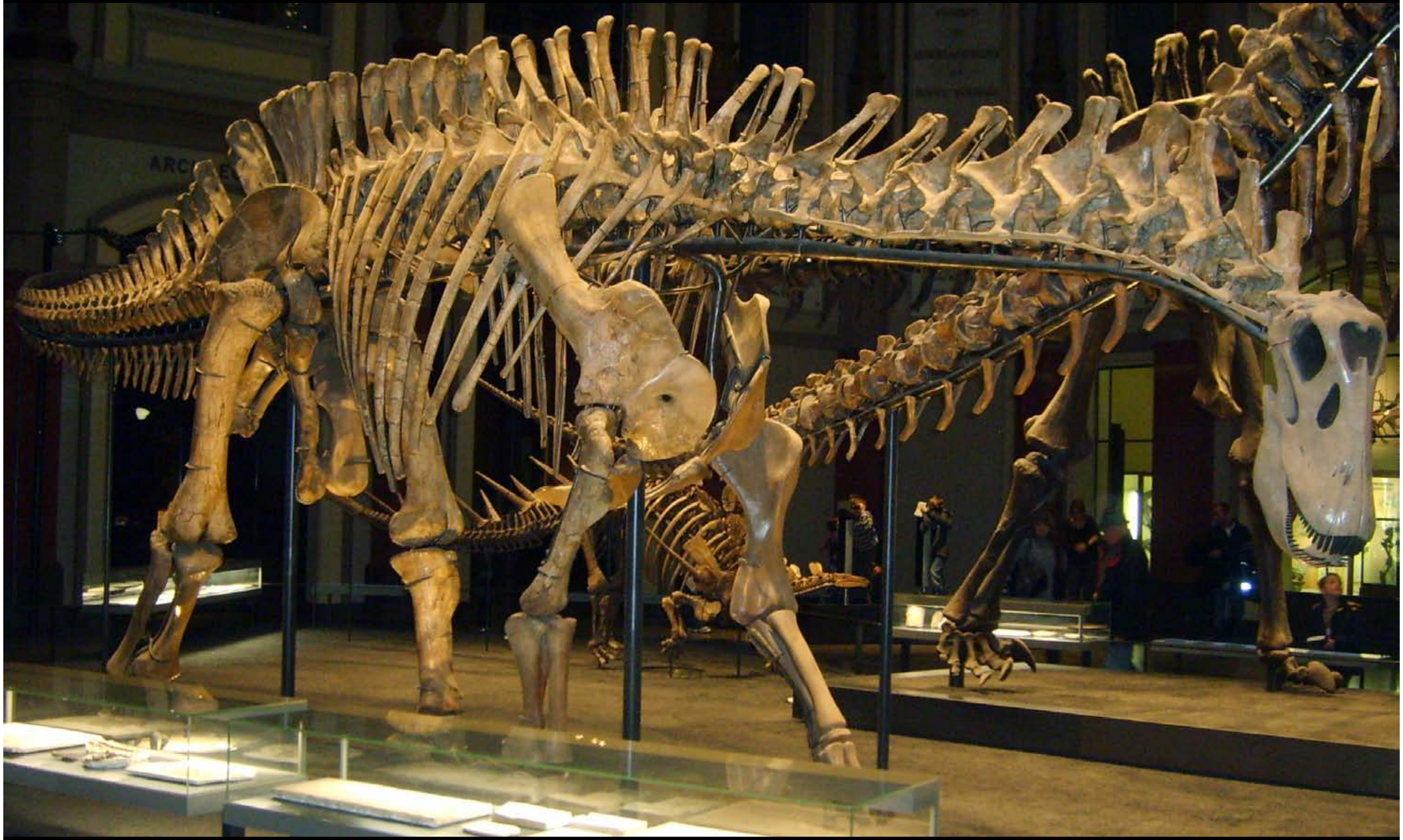
- covers an area of 1.5 million square km
- only small parts are exposed
- dates from 156.3 ± 2 Ma to 146.8 ± 1 Ma
- sediments of rivers and floodplains



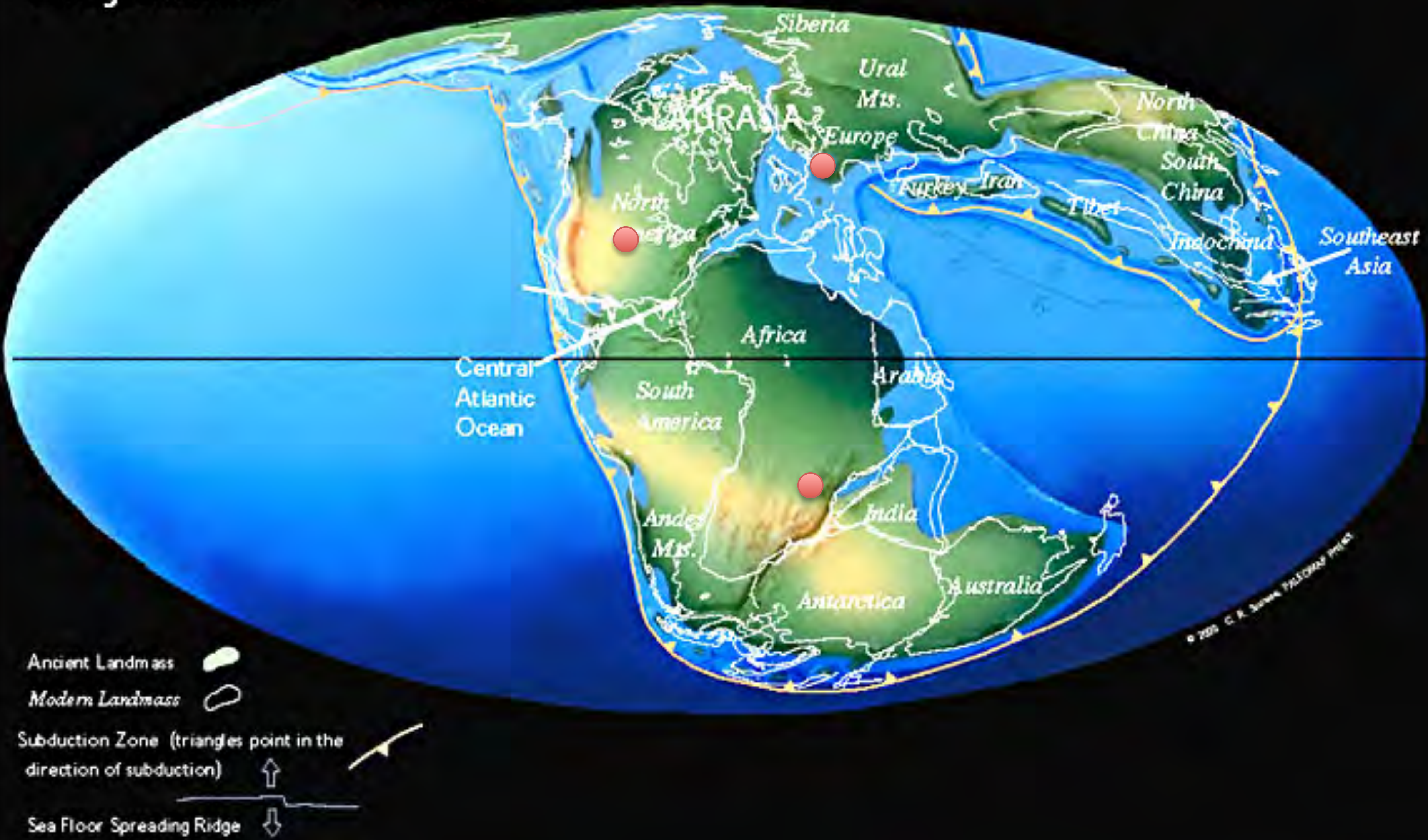

Brushy Basin Member

Tendaguru Formation

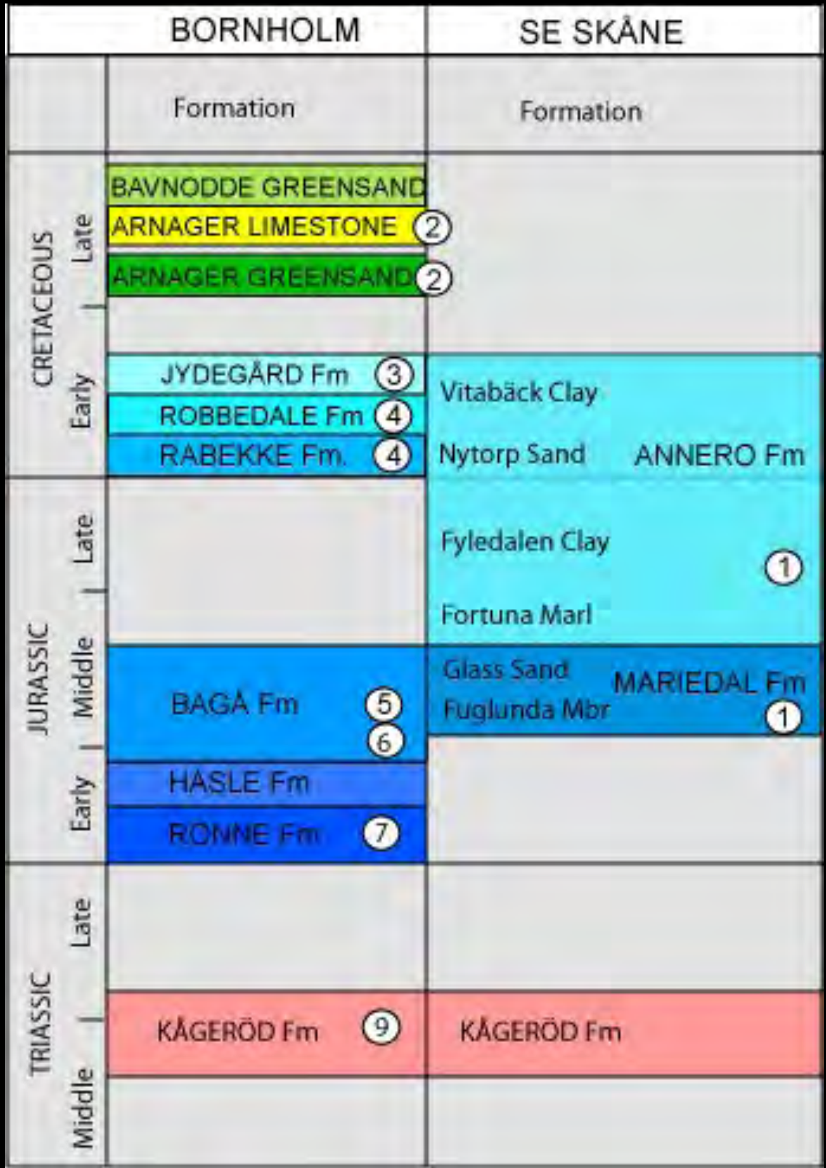
- time equivalent as Morrison Formation
- equally rich in fossil diversity
- but only one large predator (*Allosaurus*?)
- discovered 1906 by chance

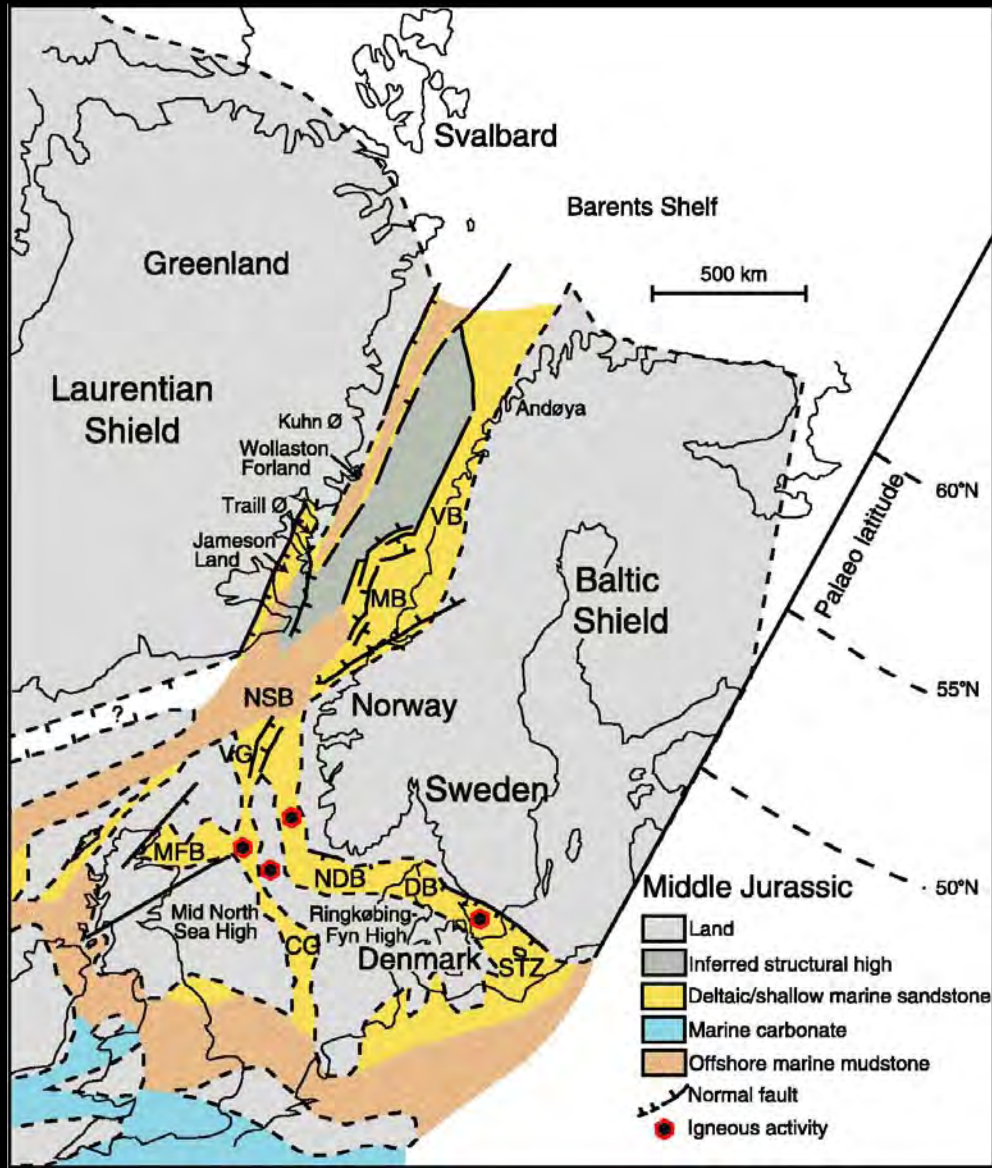


Early Jurassic 195 Ma



Jurassic in Sweden



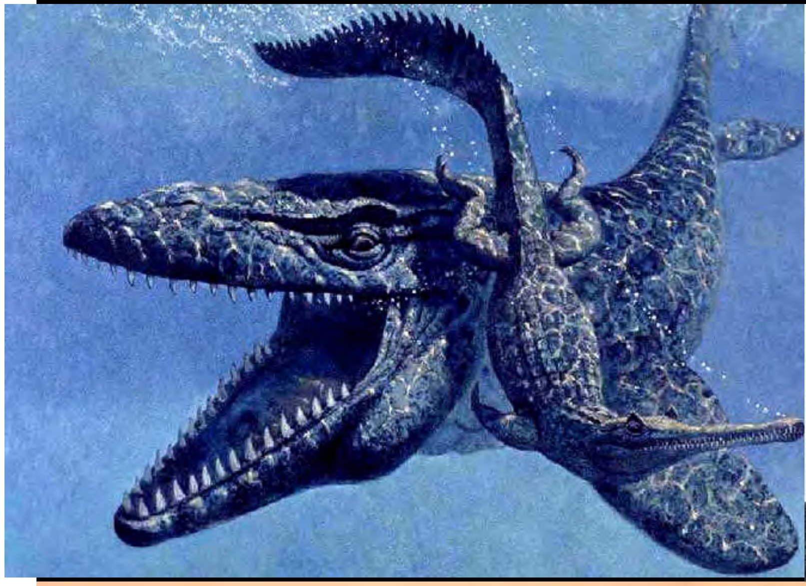


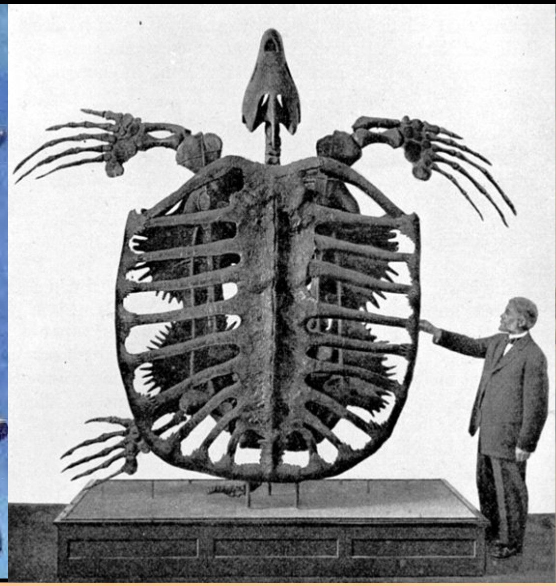
Cretaceous (146-65 Ma)

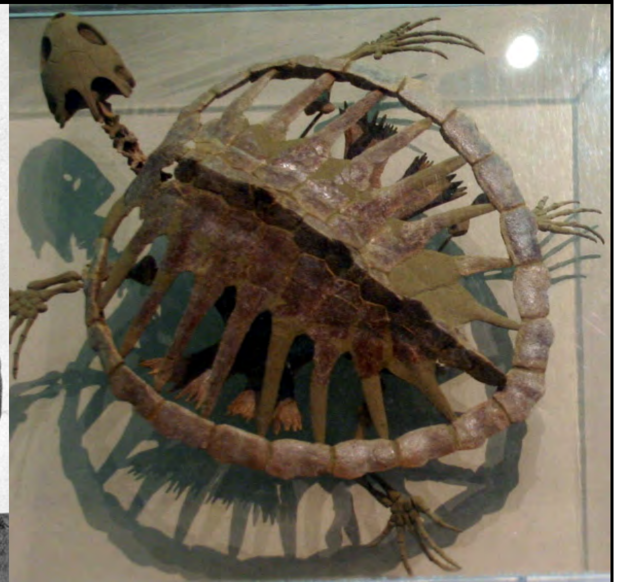
- Named after *creta* (Lat.), = chalk
- Oceans filled with marine reptiles
- Land dominated by dinosaurs
- Warm climate with high sea level
- Flowering plant appear
- ends with major extinction

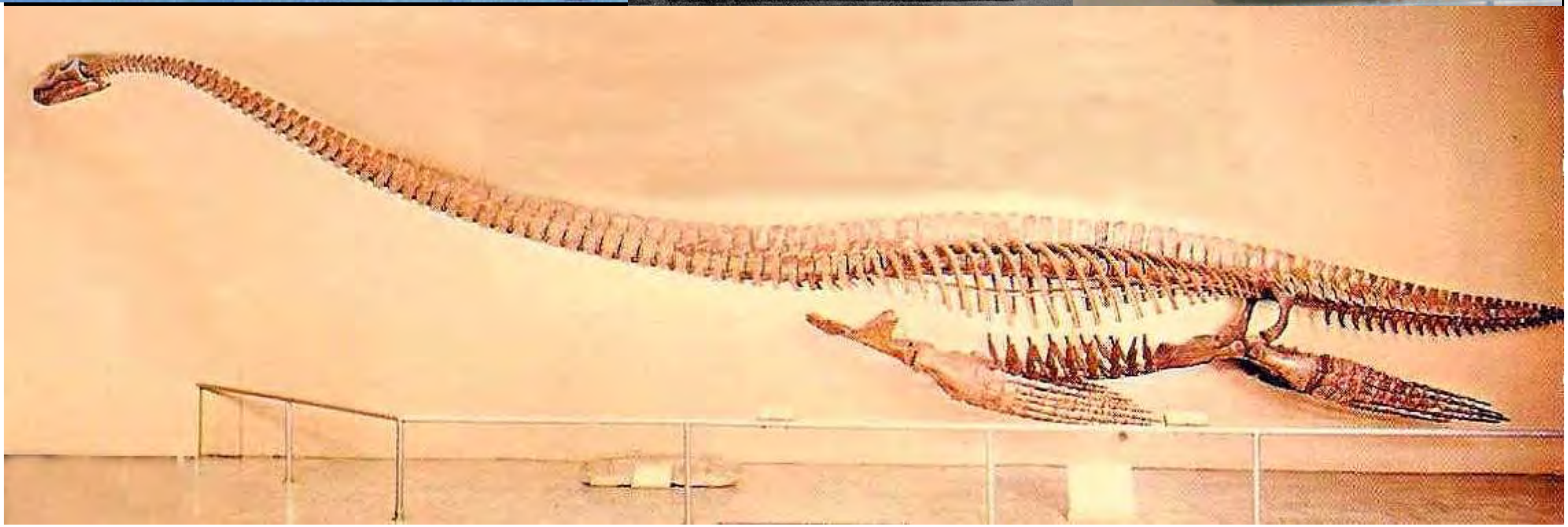
Invertebrate marine fauna

Marine vertebrate fauna









Terrestrial vertebrate fauna

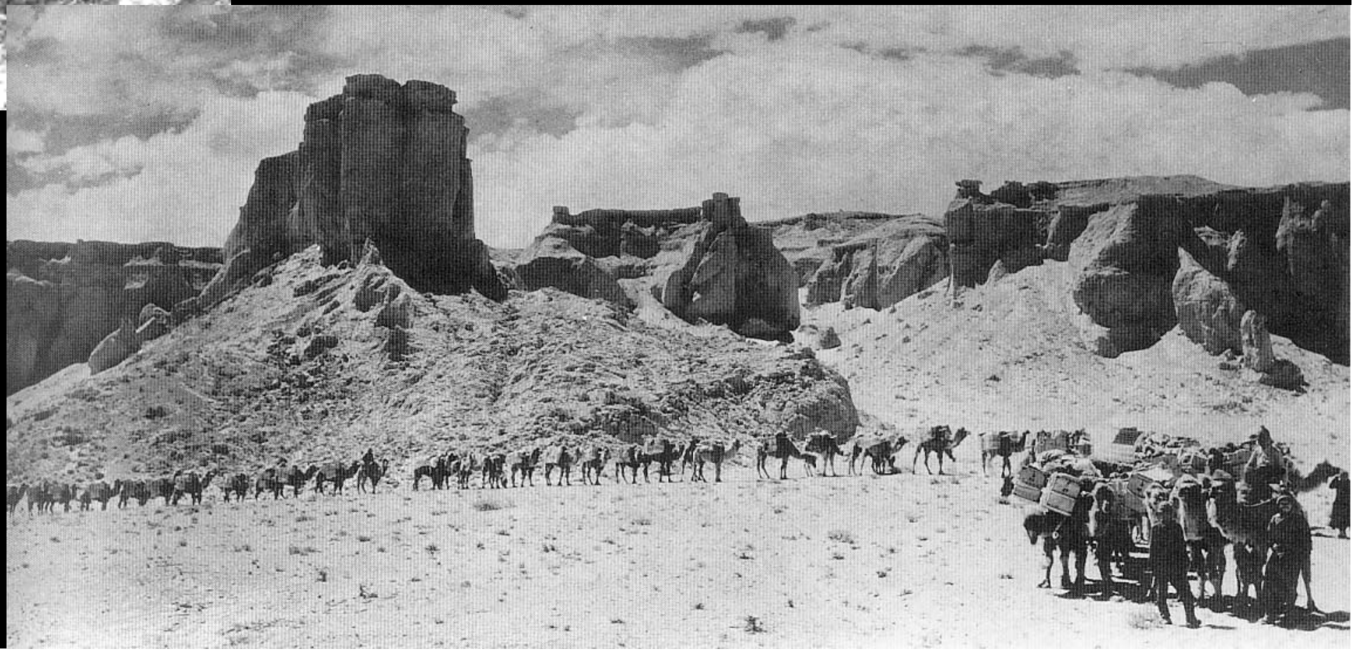
	theropods	sauropods	ornithopods	thyreophors	marginoceph.
Upper Cretaceous	T. rex a. o. coelurosaurs		hadrosaurs	ankylosaurs	ceratopsians
Lower Creaceous		smaller	Iguanodons	ankylosaurs stegosaurs	

Climate

- starts with a cooling trend, however no major glaciations
- during the early Cretaceous temperatures rose, and the climate stayed warm until the end of the Cretaceous
  - high volcanic activity → Greenhouse gases
  - extensional tectonics, mantle plumes → sea level rise → epicontinental seas
  - gentle temperature gradient between equator and poles → weaker wind, less upwelling, stagnant oceans, anoxia, black shales
  - tropical sea surface temperatures averaged around 37 °C,

Roy Chapman Andrews

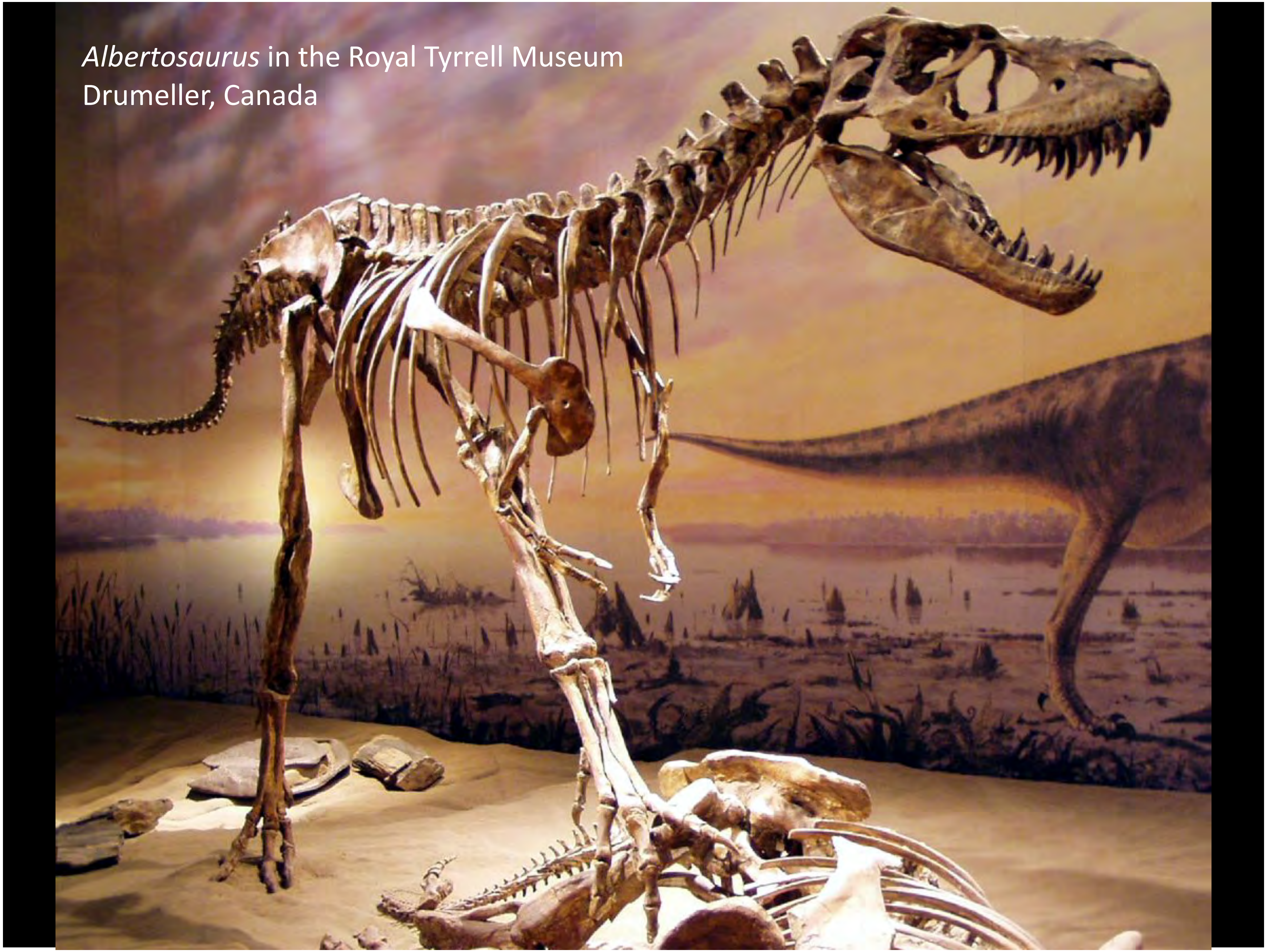
Mongolia expeditions
1920-1925

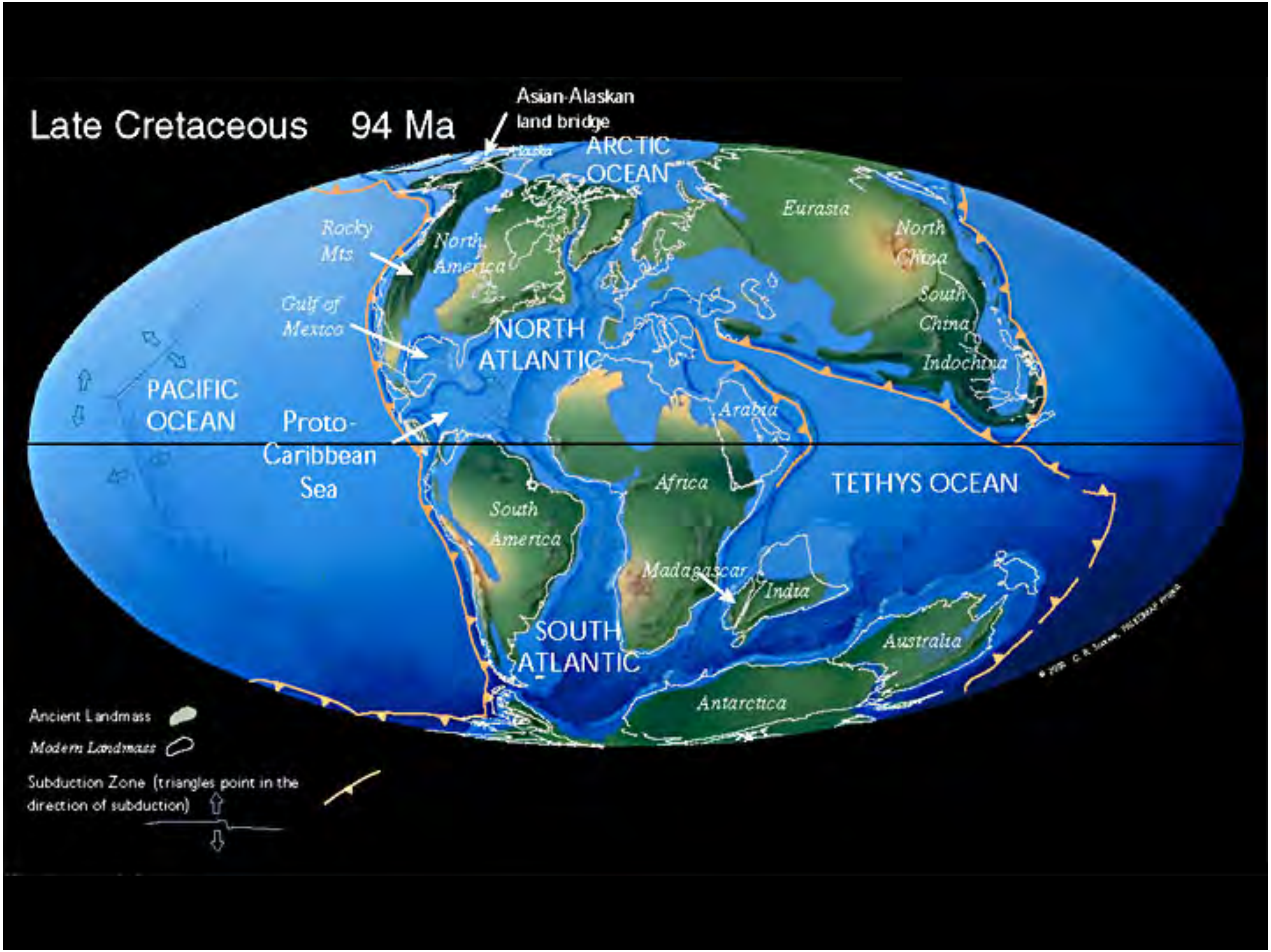


Hell Creek Formation , Late Cretaceous, Montana

“Sue” in the Field Museum of Natural History in Chicago, Illinois

Horseshoe Canyon Formation, Alberta, Canada

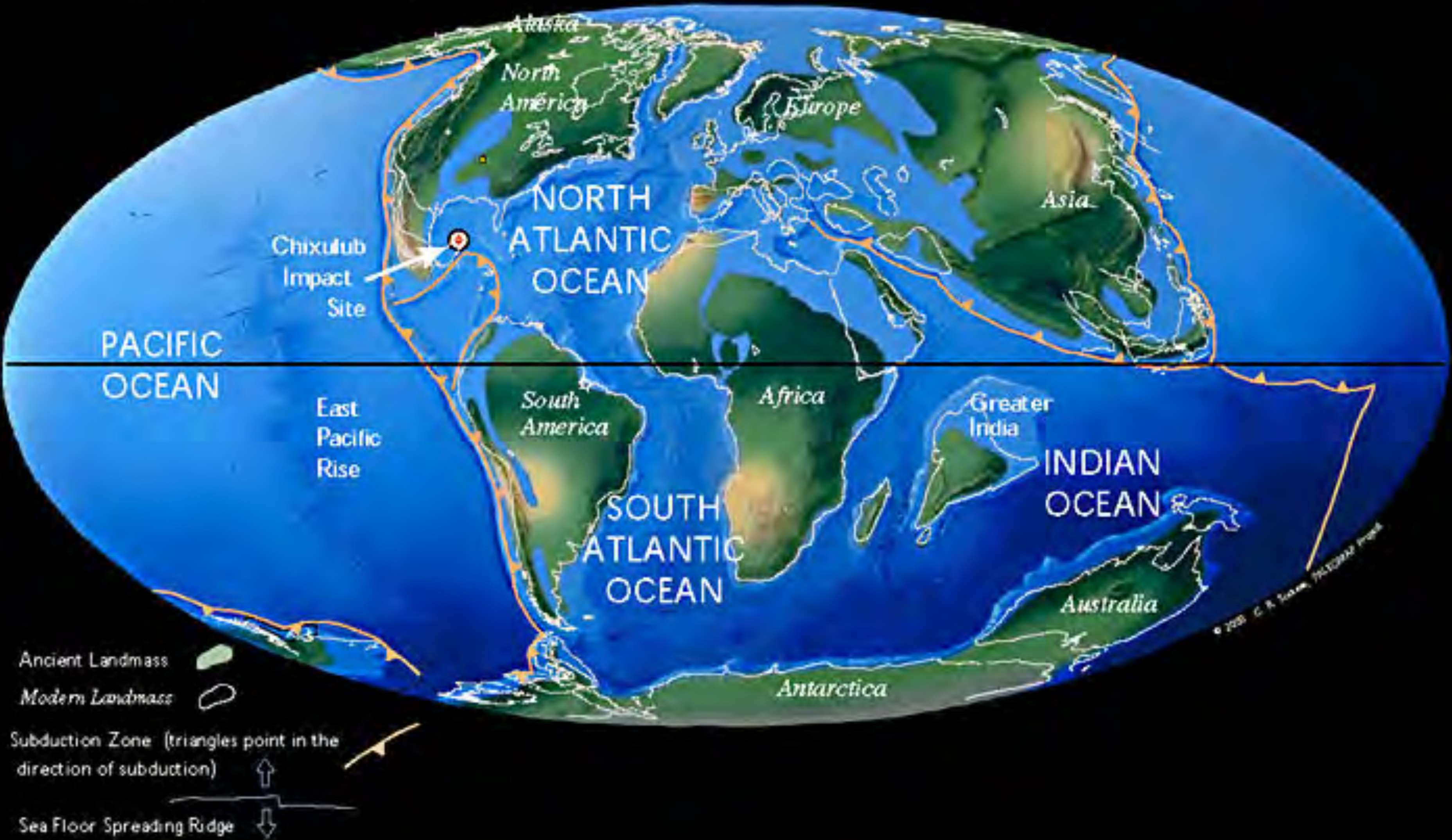

Albertosaurus in the Royal Tyrrell Museum
Drumeller, Canada



Late Cretaceous 94 Ma
Asian-Alaskan land bridge
ARCTIC OCEAN
Eurasia
North China
South China
Indochina
Rocky Mts
North America
Gulf of Mexico
NORTH ATLANTIC
PACIFIC OCEAN
Proto-Caribbean Sea
Arabia
Africa
TETHYS OCEAN
South America
Madagascar
India
SOUTH ATLANTIC
Australia
Antarctica
Ancient Landmass
Modern Landmass
Subduction Zone (triangles point in the direction of subduction)

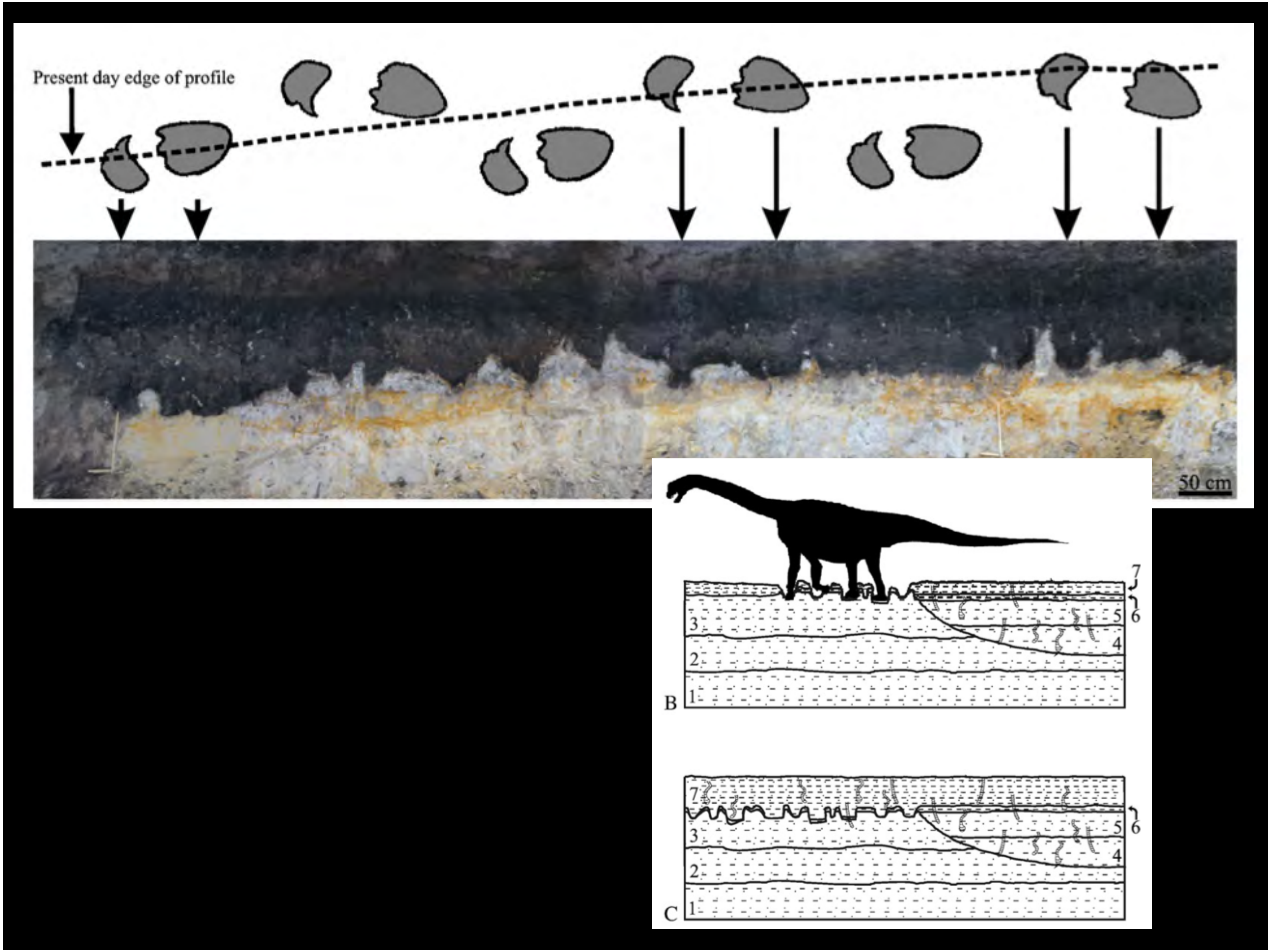

WESTERN
INTERIOR
SEAWAY
LARAMIDIA
APPALACHIA

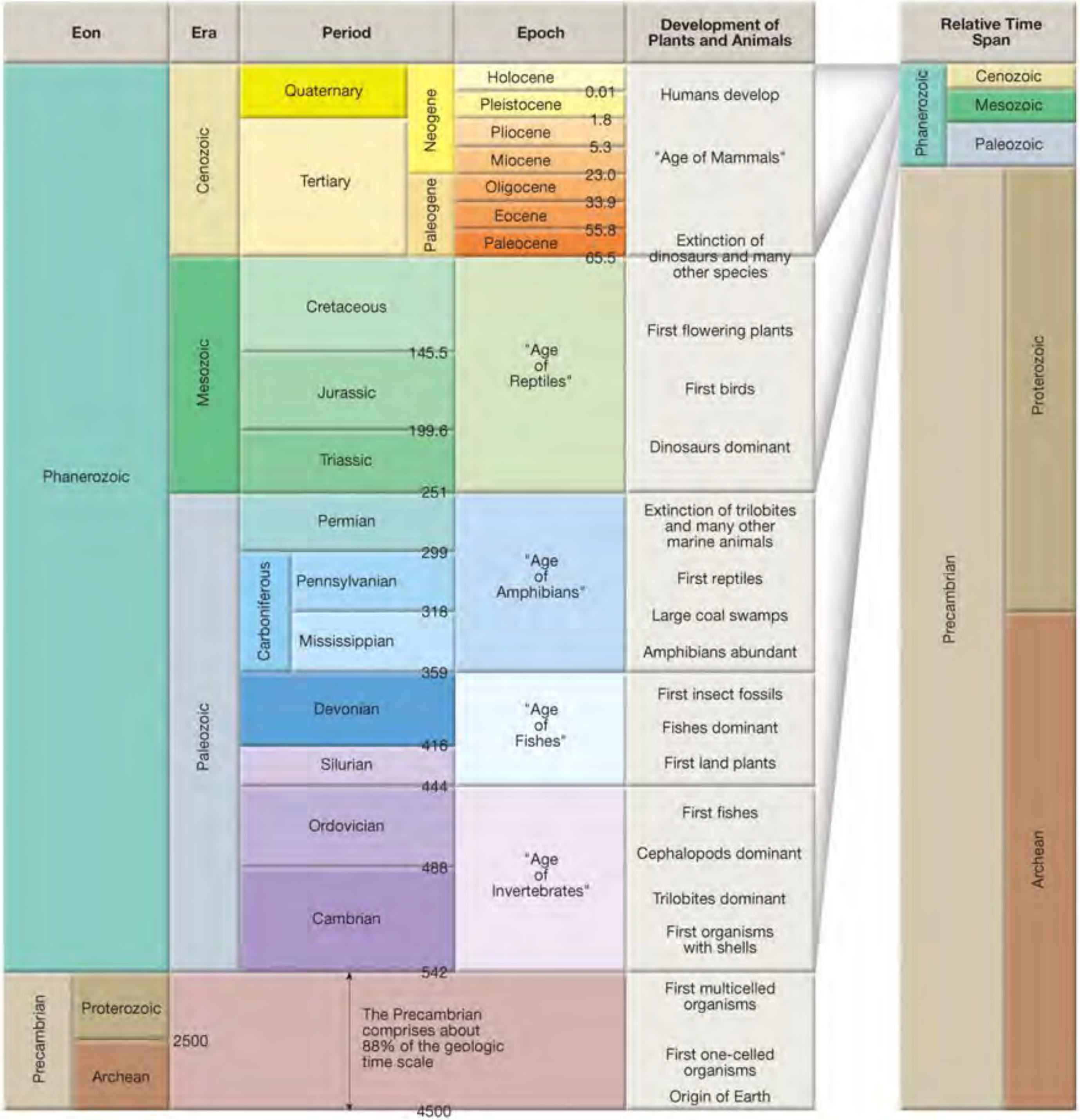
K/T Boundary 66 Ma



Cretaceous in Sweden

- Scania (Skåne), Kristianstad basin
  - →shark, amphibians, ceratopsians
- Bornholm


Present day edge of profile
50 cm
7
6
5
4
3
2
1
B
C



Eon
Era
Period
Epoch
Development of Plants and Animals
Relative Time Span
Phanerozoic
Cenozoic
Quaternary
Tertiary
Neogene
Paleogene
Holocene
Pleistocene
Pliocene
Miocene
Oligocene
Eocene
Paleocene
0.01
1.8
5.3
23.0
33.9
55.8
65.5
Humans develop
"Age of Mammals"
Extinction of dinosaurs and many other species
Mesozoic
Cretaceous
145.5
Jurassic
199.6
Triassic
251
"Age of Reptiles"
First flowering plants
First birds
Dinosaurs dominant
Paleozoic
Permian
299
Carboniferous
Pennsylvanian
318
Mississippian
359
"Age of Amphibians"
Extinction of trilobites and many other marine animals
First reptiles
Large coal swamps
Amphibians abundant
Devonian
416
Silurian
444
"Age of Fishes"
First insect fossils
Fishes dominant
First land plants
Ordovician
488
Cambrian
542
"Age of Invertebrates"
First fishes
Cephalopods dominant
Trilobites dominant
First organisms with shells
Precambrian
Proterozoic
Archean
2500
The Precambrian comprises about 88% of the geologic time scale
4500
First multicelled organisms
First one-celled organisms
Origin of Earth
Phanerozoic
Cenozoic
Mesozoic
Paleozoic
Precambrian
Proterozoic
Archean