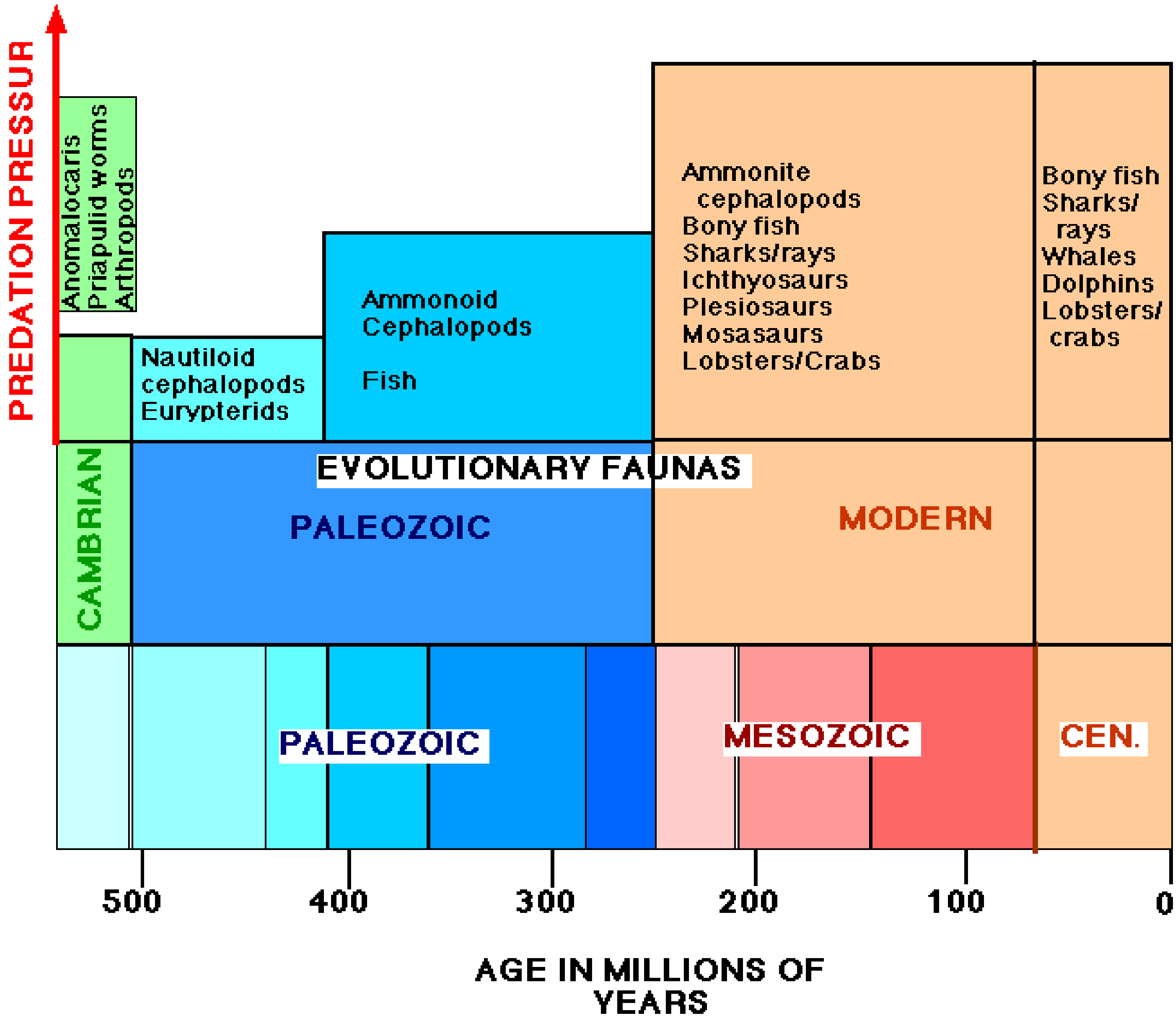


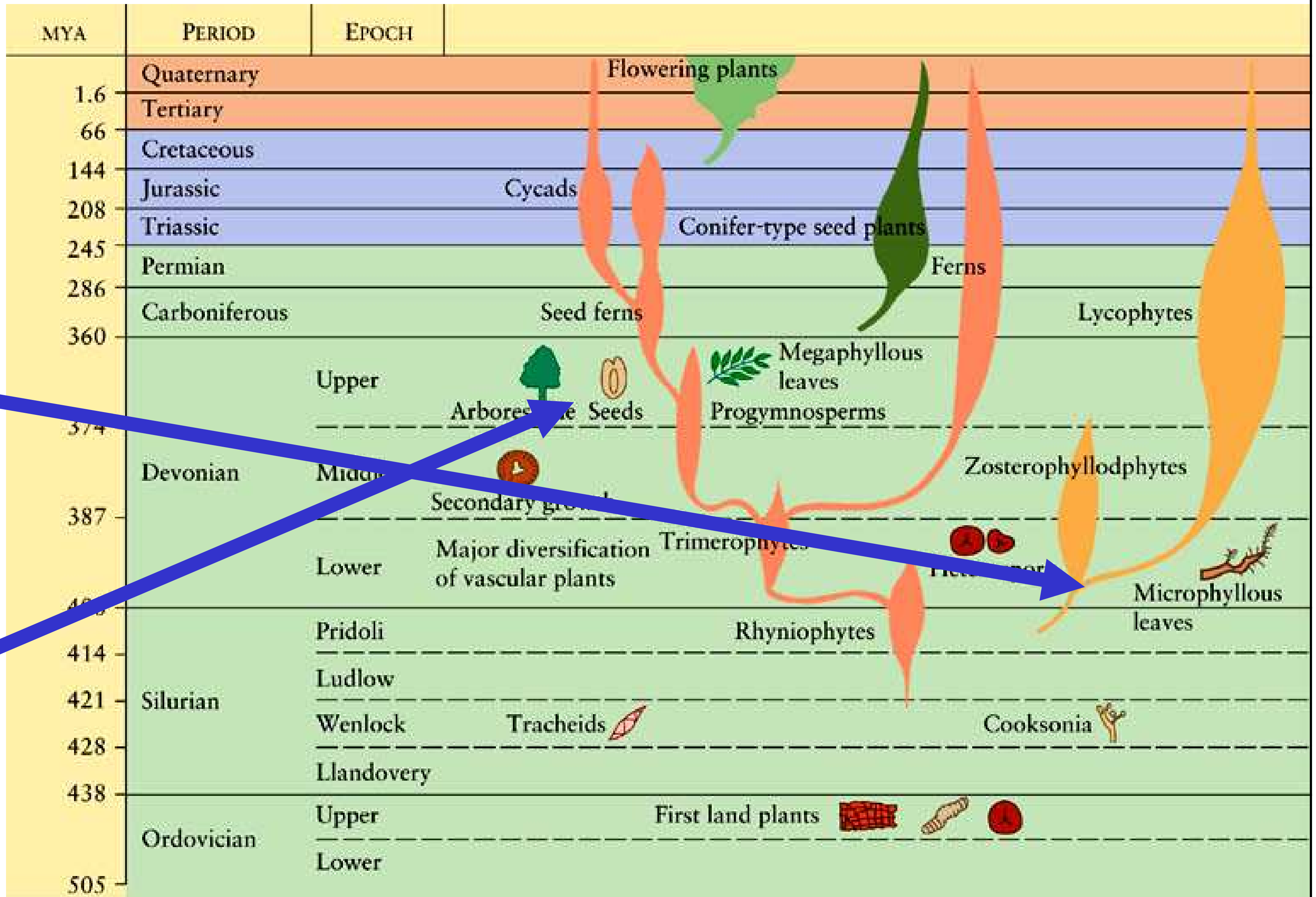
PREDATION PRESSUR
Anomalocaris
Priapulid worms
Arthropods
Nautiloid cephalopods
Eurypterids
Ammonoid Cephalopods
Fish
Ammonite cephalopods
Bony fish
Sharks/rays
Ichthyosaurs
Plesiosaurs
Mosasaurs
Lobsters/Crabs
Bony fish
Sharks/rays
Whales
Dolphins
Lobsters/crabs
CAMBRIAN
EVOLUTIONARY FAUNAS
PALEOZOIC
MODERN
PALEOZOIC
MESOZOIC
CEN.
500
400
300
200
100
0
AGE IN MILLIONS OF YEARS

Plant Evolution

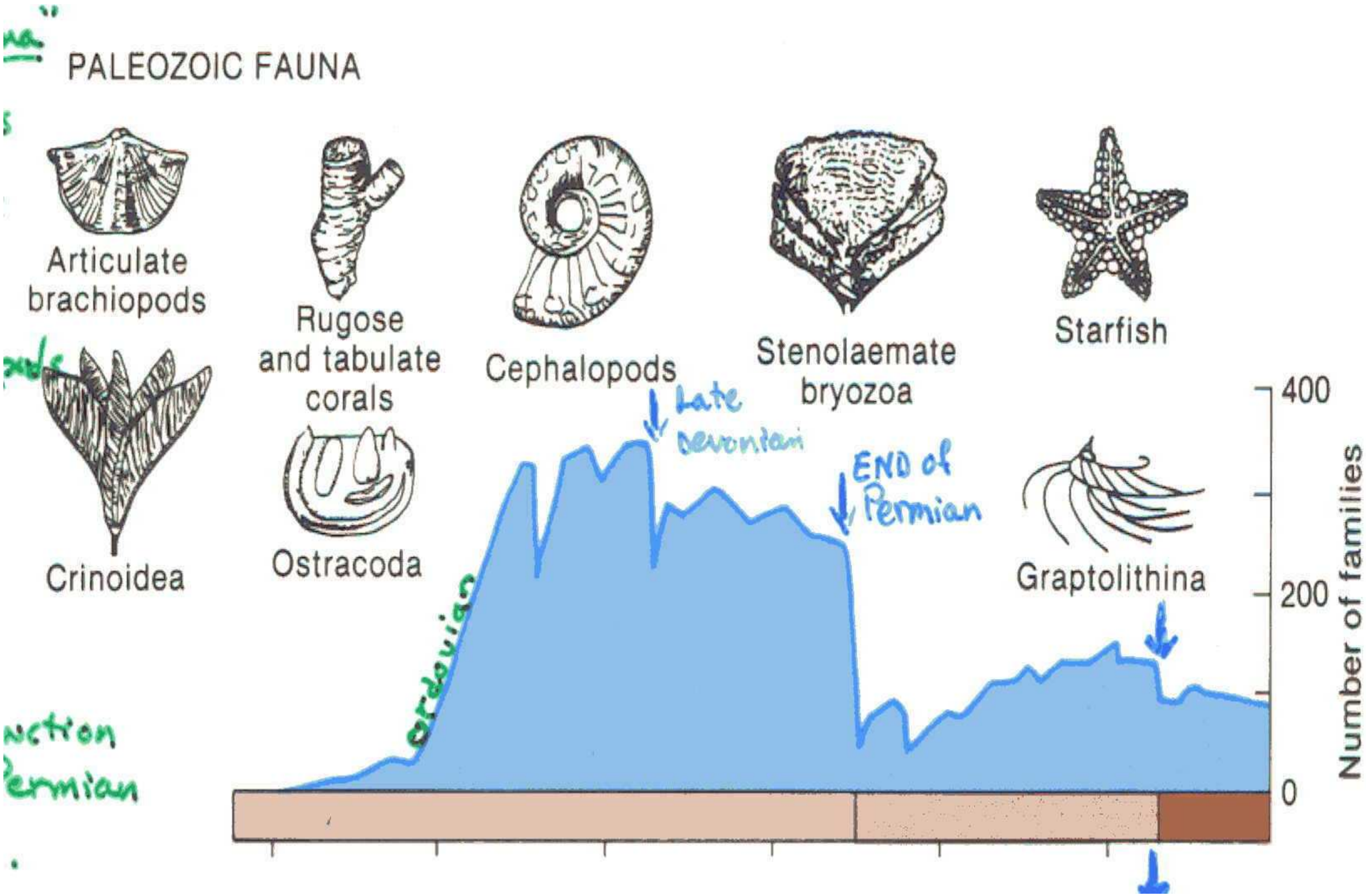
- Major events in the evolution of land plants
  - The Devonian Period was a time of rapid evolution for the land plants

– the appearance of leaves

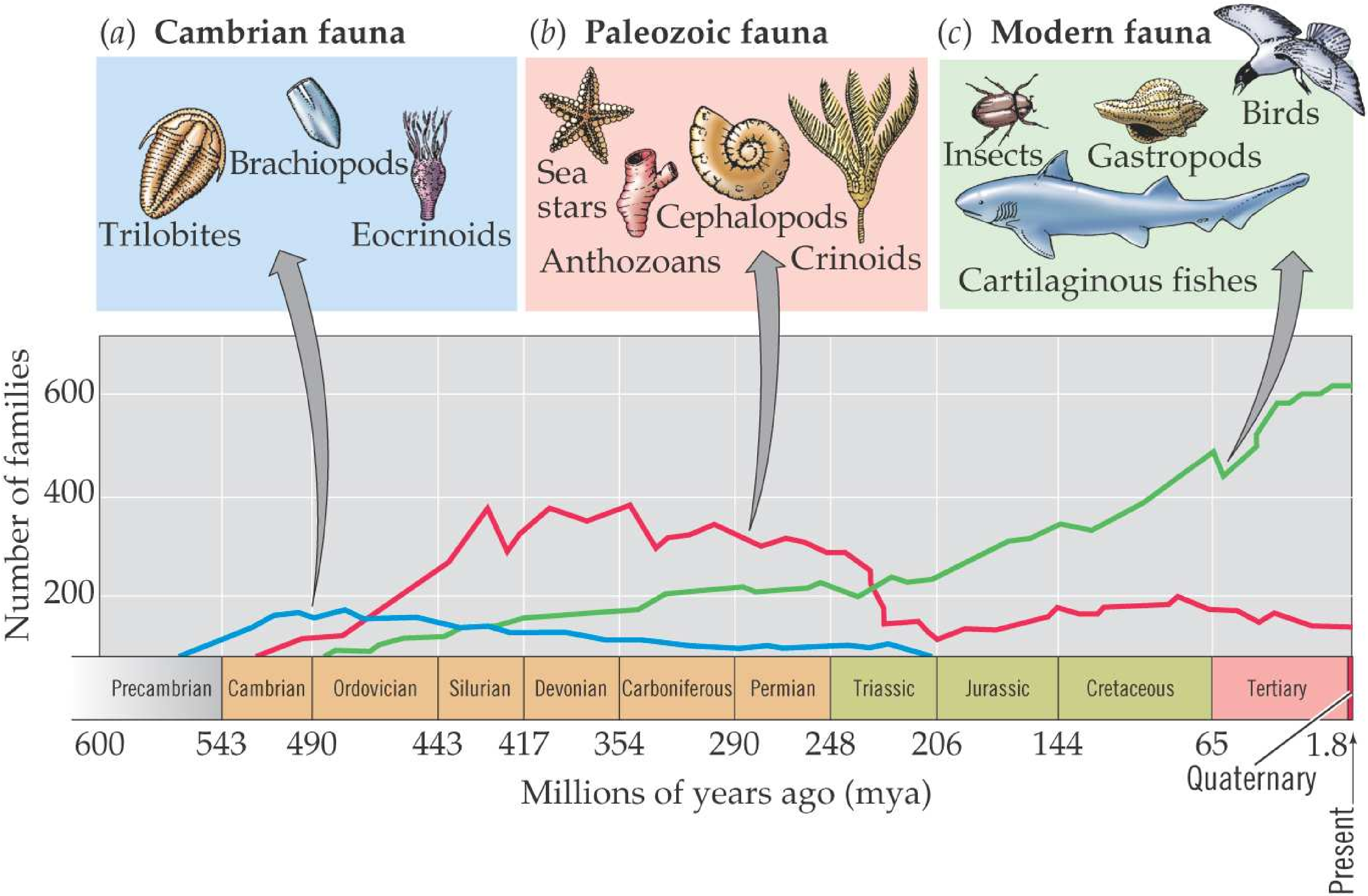
– and emergence of seeds



Paleozoic Fauna



Evolutionary Faunas



LIFE: THE SCIENCE OF BIOLOGY, Seventh Edition, **Figure 22.17 Evolutionary Faunas**

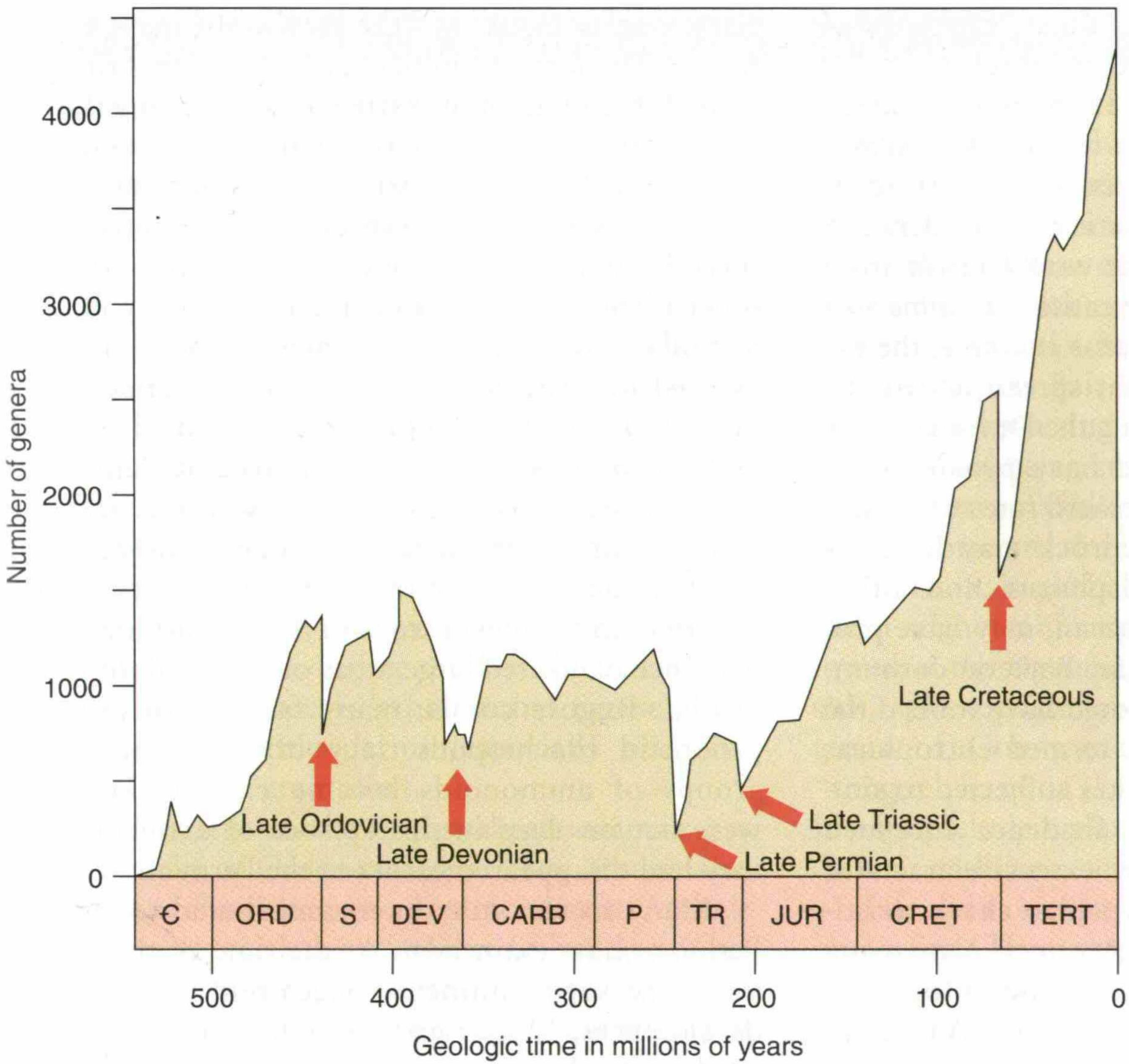


FIGURE 10–84 Diversity of marine animals compiled from a database recording first and last occurrences of more than 34,000 genera. The graph depicts five major episodes of mass extinction (global extinctions over a short span of geologic time). *(Adapted from Sepkoski, J. J., Jr. 1994.* Geotimes *39(3):15–17.)*

The Early Ordovician was a time of **adaptive radiation** of many faunal groups, following the mass extinction of trilobites and nautiloids at end of Cambrian.
Increase in diversity from 150 families -> 400 families

•The **Paleozoic fauna** (or **Brachiopod fauna**): articulate brachiopods, stony and lacy bryozoans, stromatoporoids, cephalopods, crinoids and blastoids, starfish, graptolites

Important Groups of Paleozoic Invertebrates

- Porifera – Sponges
- Cnidaria – Corals (Rugosa and Tabulata)
- Bryozoa – Moss animals
- Brachiopoda – Lamp shells (Articulata and Inarticulata)
- Arthropoda – Trilobites, Crustaceans, Insects
- Mollusca – Snails, Bivalves, Cephalopods
- Echinoderms – Crinoids and Blastoids

EARLY PALEOZOIC LIFE

Unicellular Organisms (Protistans)

Foraminifera

First appeared in the Cambrian
Survive to present

Platysolenites, a **Cambrian foram**
Agglutinated form
Calcareous skeleton

Nanicella – middle to late Devonian

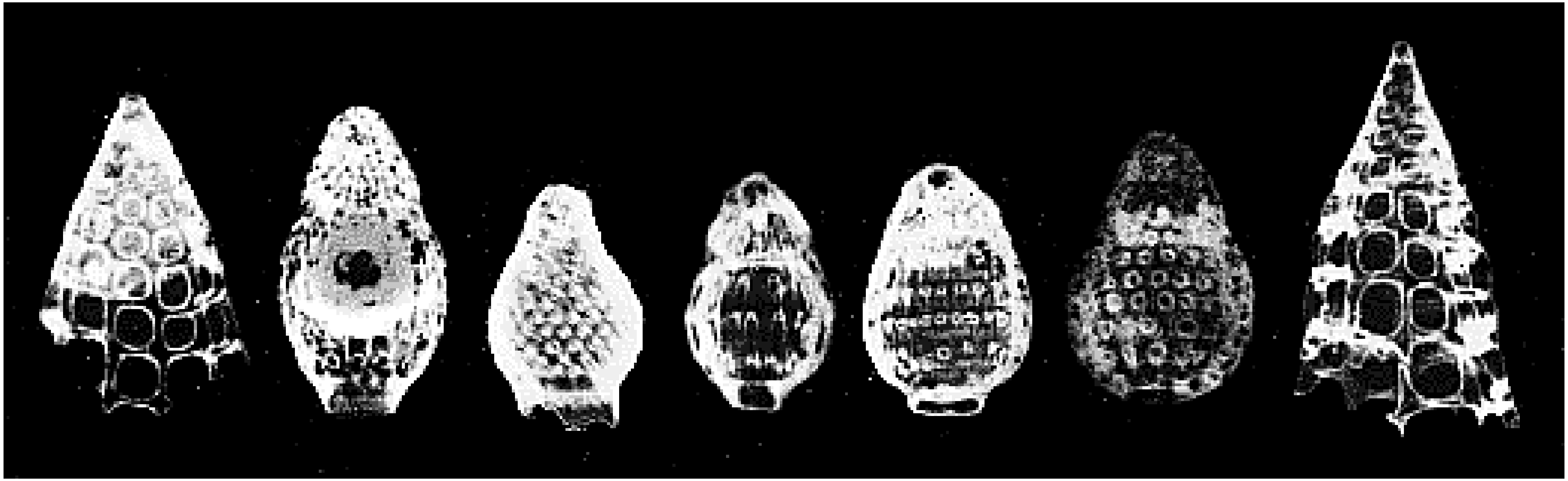
Late Frasnian – Eogeinitzina, Eonodosaria
Late Famennian - Quasiendothyra

EARLY PALEOZOIC LIFE

Unicellular Organisms (Protistans)

Radiolaria

First appeared in the Cambrian, more abundant in mid-Paleozoic
Survive to present
Have a siliceous skeleton

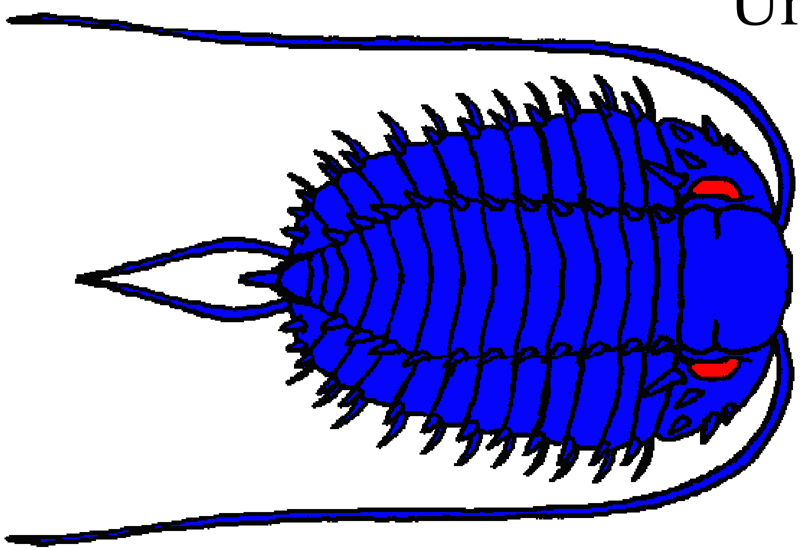


In Paleozoic only Nasselaria. Rock-forming role in the Devonian – radiolarites. E.g. Ponikev Formation

Trilobites

Still abundant and stratigraphically important. Second and last prime in early Devonian, since middle Devonian on retreat

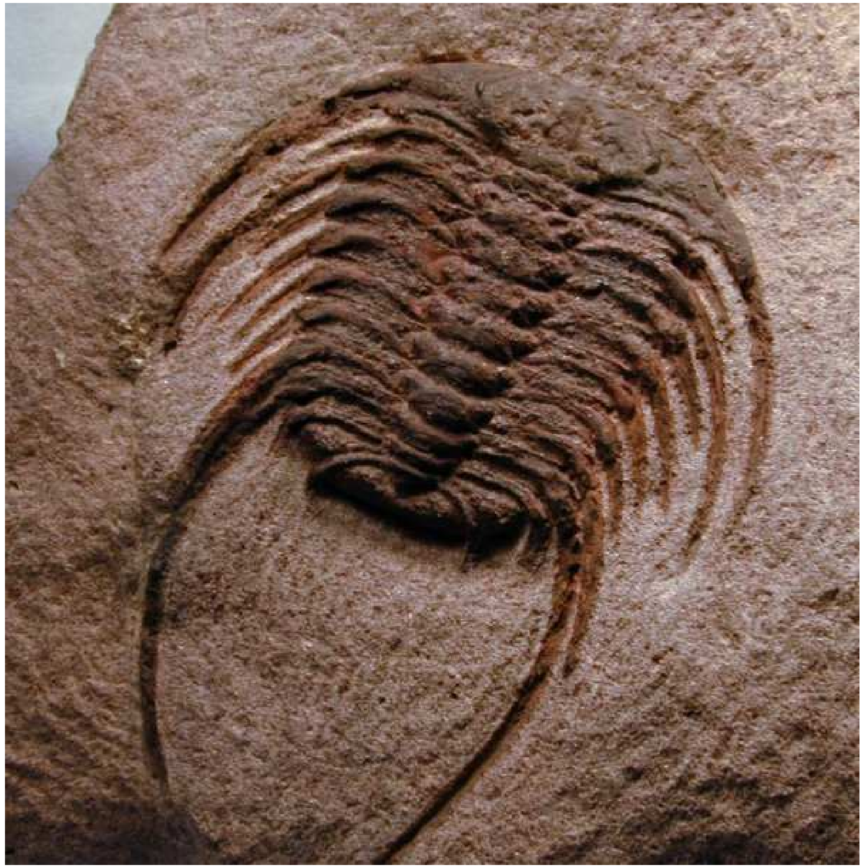
Uralichas



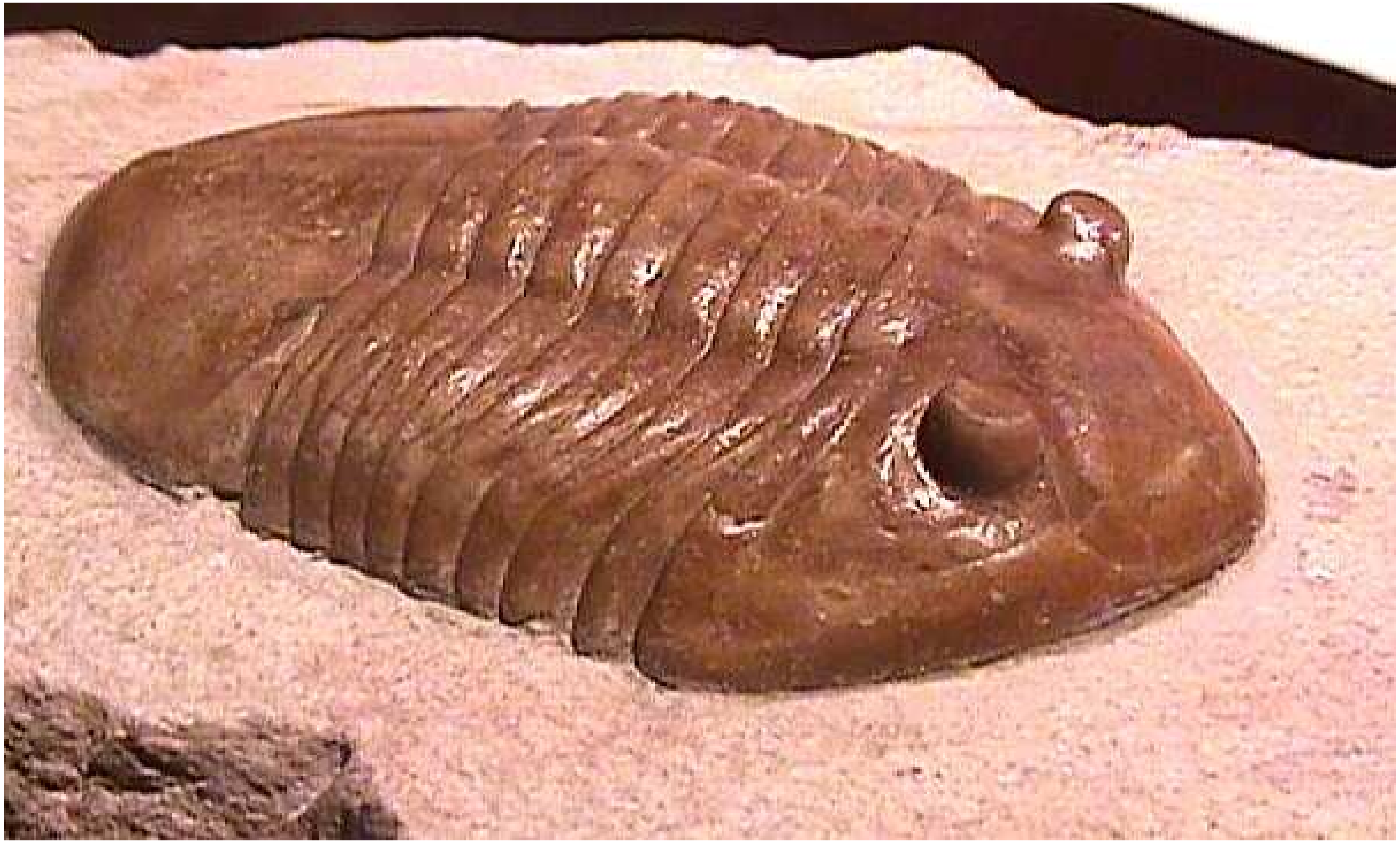
Ordovician

Selenopeltis province - Perigondwama

Selenopeltis



Ordovician



Asaphus

Asaphus province - Baltica

Aulacopleura konincki,
Silur,

Phacops

DEVONIAN

Reedops

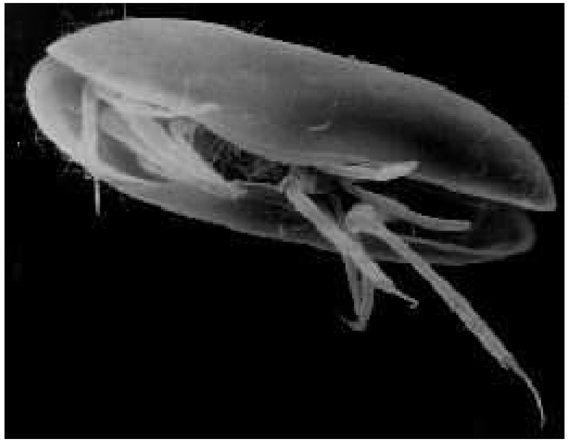
•

Odontochile

EARLY PALEOZOIC LIFE

Metazoan Invertebrates

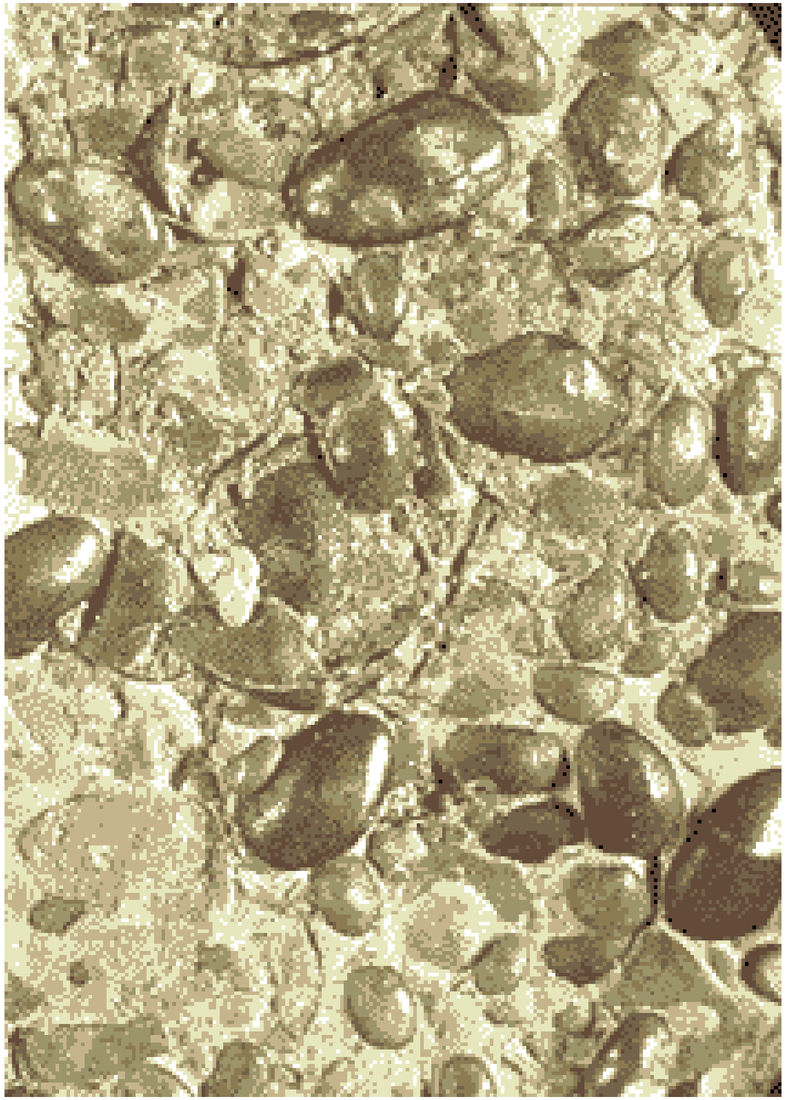
Arthropoda Ostracodes



Look like beans
Segmented body enclosed
in $CaCO_3$ and chitin
carapace
Marine and freshwater
Useful in biostratigraphy
Early Cambrian to Recent

Ostracodes

Since Ordovician diversification of ostracodes



- ***Eoleperditia fabulites* Conrad**
- Middle Ordovician, Rutherford Co., Tennessee
- Shells are bivalved, small (1 to 10 mm) and oval
- Recrystallization

Arthropoda

Subphyla Trilobita

Trilobites (extinct)

UCMP - Trilobita

Subphyla Crustacea

Shrimp, lobsters, crabs, barnacles, cladocerans, ostracoids, crayfish, water fleas, and copepods

Characteristics

- **Branched antennae**
- **Mandibles (chewing mouth parts)**

Encarta Online - Crustacea - korýši

Subphyla Chelicerata - klepítkatci

Spiders, scorpions, ticks, mites, sea spiders, and horseshoe crabs

Characteristics

- **Lack antennae**
- **Chelicerae (pincerlike mouth parts)**

UCMP - Chelicerata

Encarta Online - Chelicerata

Subphyla Uniramia

Insects, centipedes, and millipedes

Characteristics

- **Antennae**
- **Mandibles**
- **Unbranched appendages**

Branchiopoda (lupenonožci) je skupina primárně sladkovodních korýšů - devon

First **Decapoda (shrimps)** in the late Devonian

Merostromata

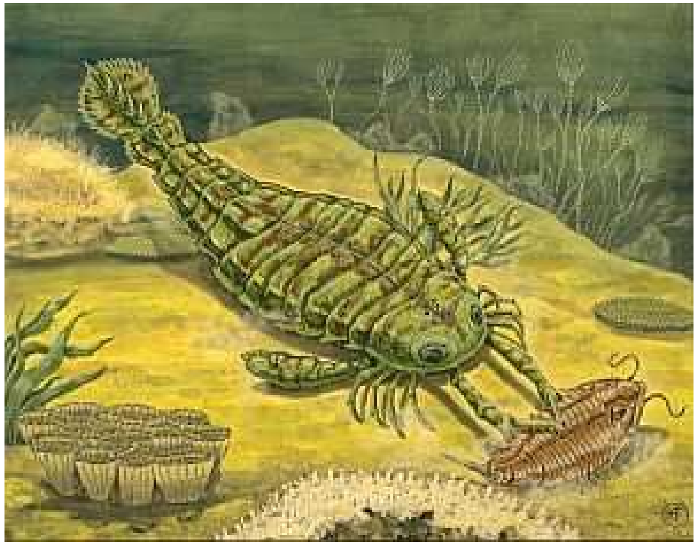
EARLY PALEOZOIC LIFE

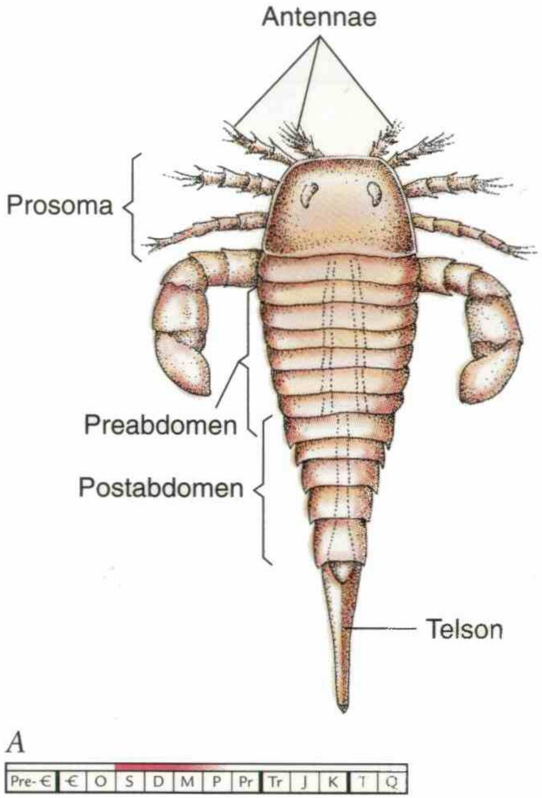
Metazoan Invertebrates

Arthropoda Eurypterids

Swimming or crawling arthropods
Some up to 3 m in length

Ordovician to Permian
Mostly Silurian and Devonian





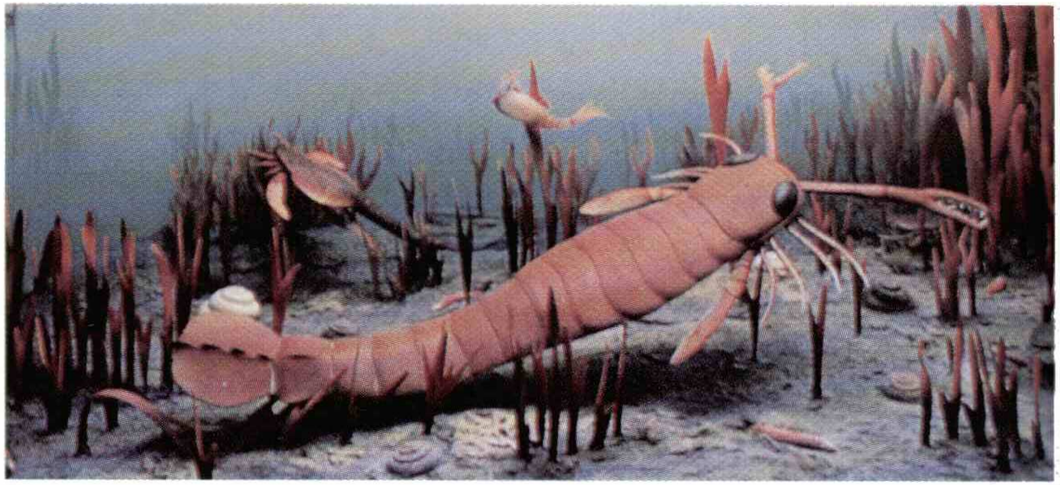
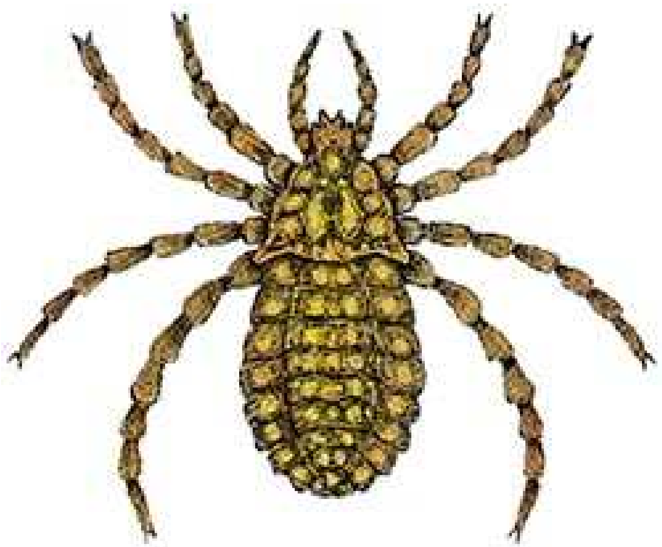


FIGURE 8–31 **Two genera of eurypterids.** *Eurypterus* (A) is noted for its broad, flipperlike paddles and blunt frontal margin. *Pterygotus* (B) is distinguished by a pair of formidable-looking frontal pincers. The animal swimming in the center background is a primitive jawless fish. *(Drawing and model of* Eurypterus, × 1/3. *Reconstruction of* Pterygotus *courtesy of the National Natural History Museum, Smithsonian Institution.)*

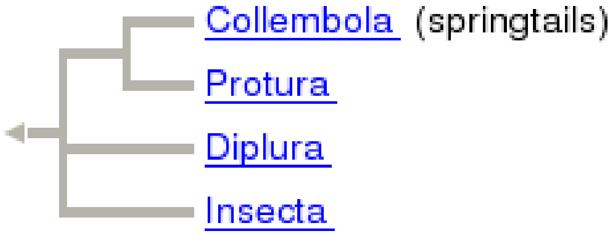
Arachnids

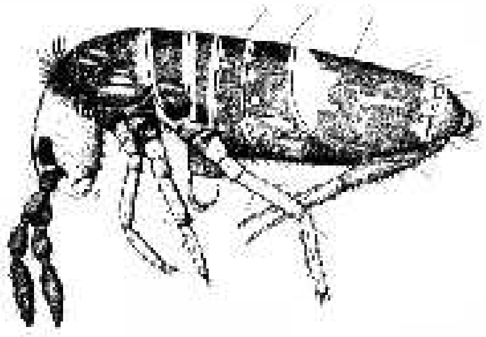
Silurian, Devonian



Gigantocharinus

Insects – Apterygota (Colembola Chvostoskoci)

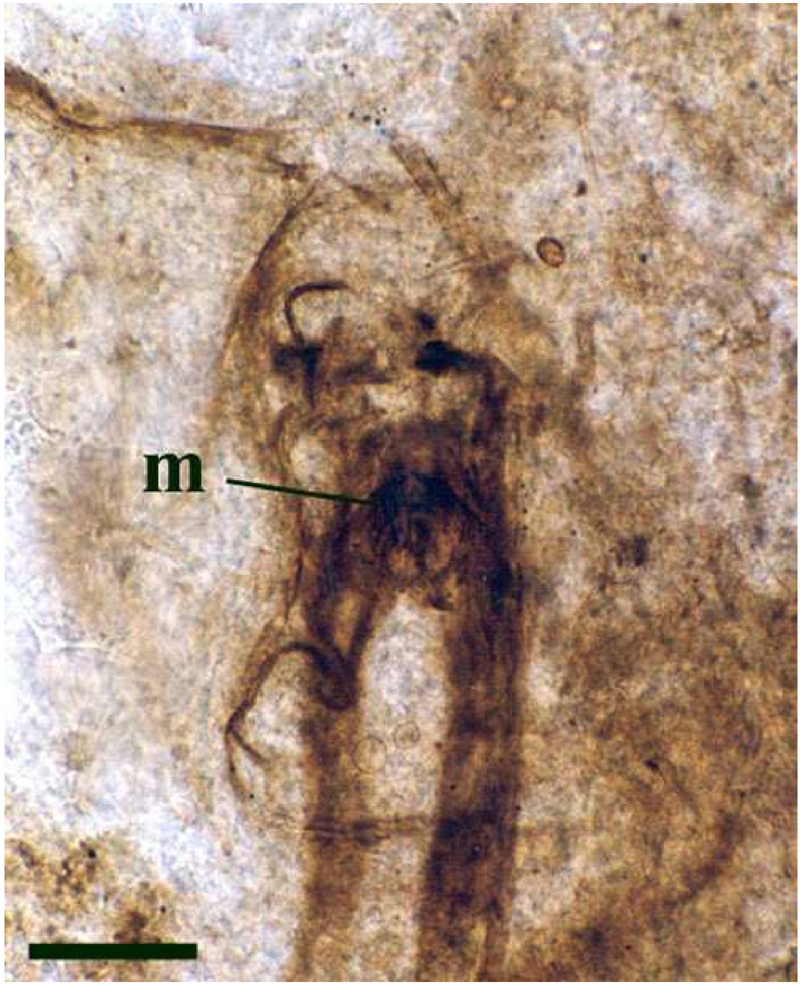




Insect evolution: Six legs good
Primitive **insect-like creatures** called springtails were among the earliest known animals to colonize the land, early in the Devonian period almost **400 million years ago**.

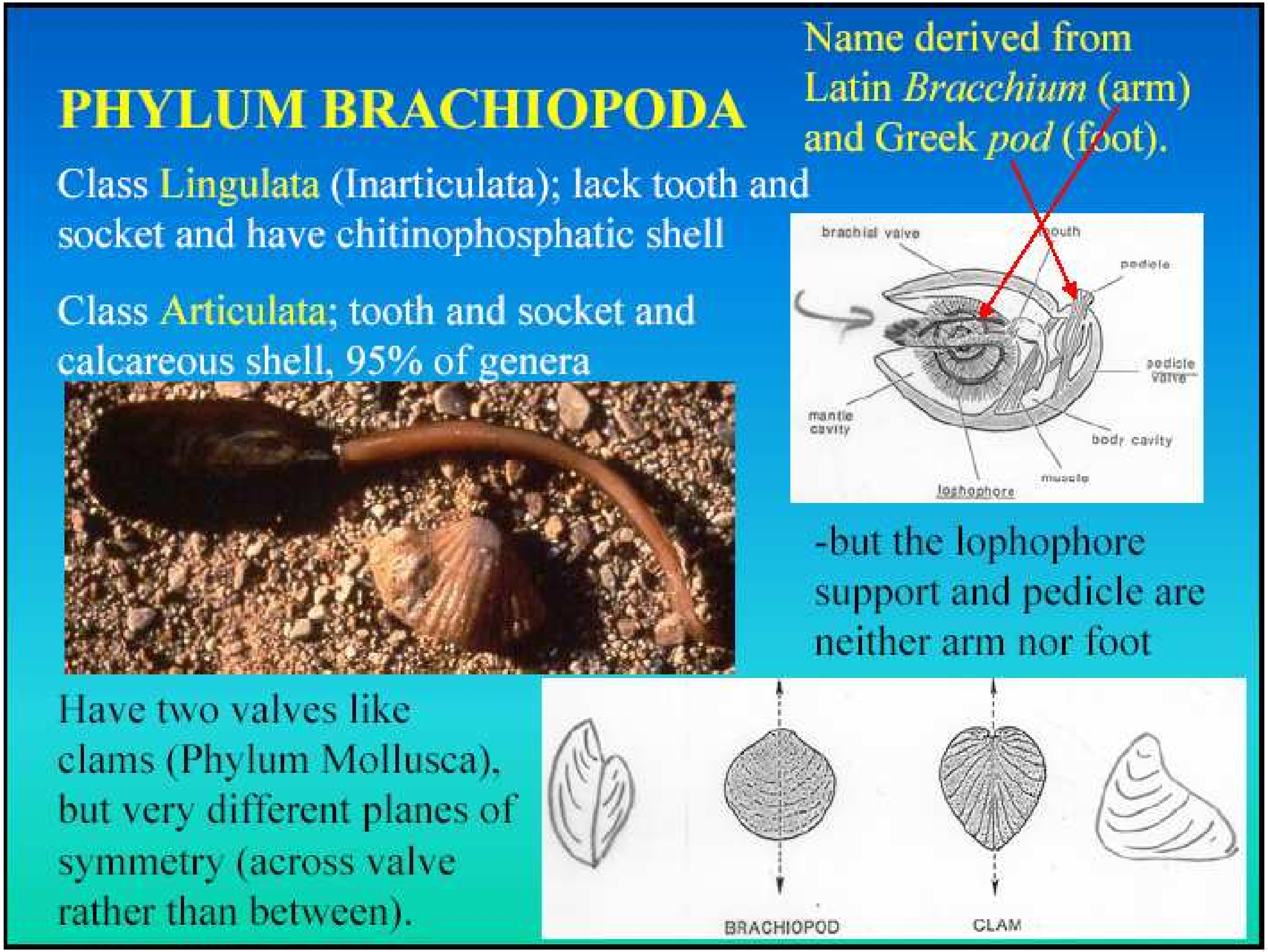
New light shed on the oldest insect
MICHAEL S. ENGEL & DAVID A. GRIMALDI
Nature **427,** 627–630 (2004); doi:10.1038/nature02291

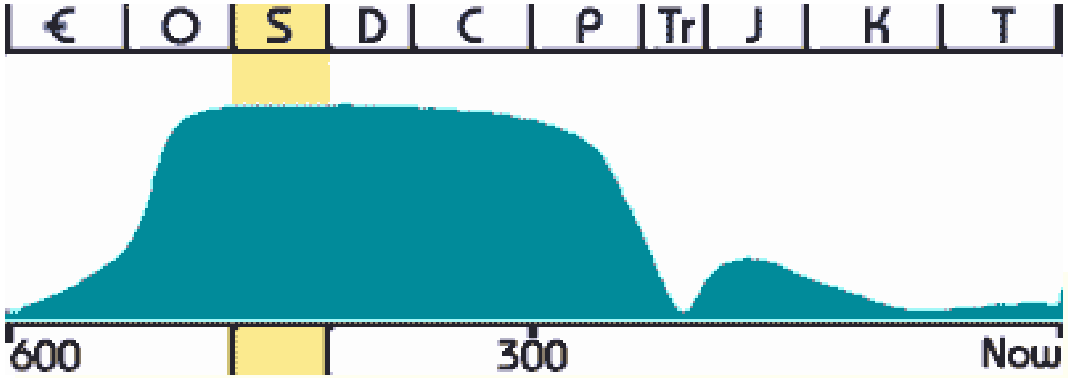
In contrast, fossils of the earliest known **true insects** are known from later on in the Devonian period. However, reinterpretation of a fragmentary insect fossil from the important **early Devonian** Rhynie cherts of Scotland shows that the enigmatic ***Rhyniognatha hirsti*** was not only a **true insect**, **but relatively derived** — that is it had been around long enough to have accumulated some uniquely insect-like features. Although only the mandibles are preserved, it is possible that they once belonged to a winged insect. In any case, the fossil shows that the origin of insects was much earlier than previously thought. The discovery suggests that **insects almost certainly evolved in the Silurian Period**, some 438-408 million years ago.



Brachiopods

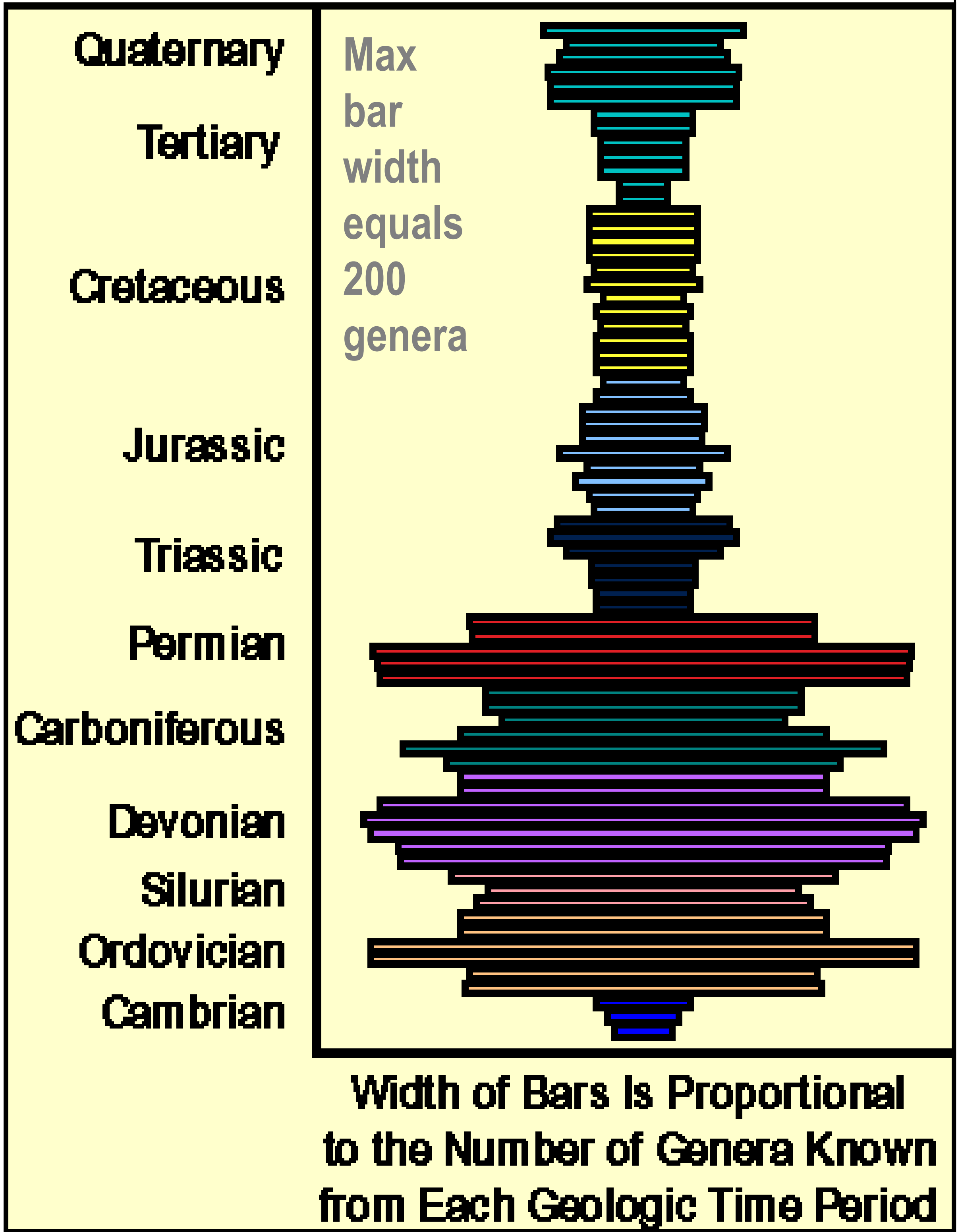
Diversification of articulates

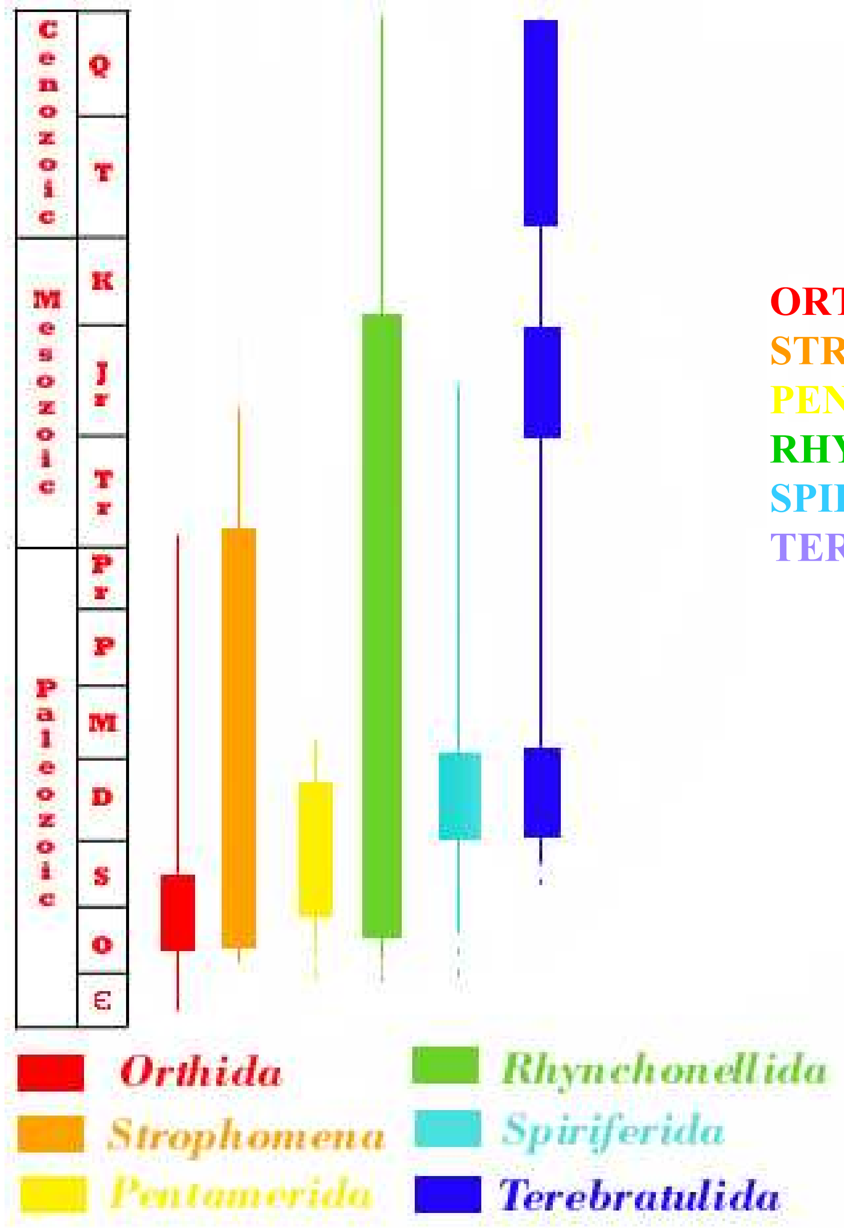




Ordovician-There was an enormous radiation of brachiopods.

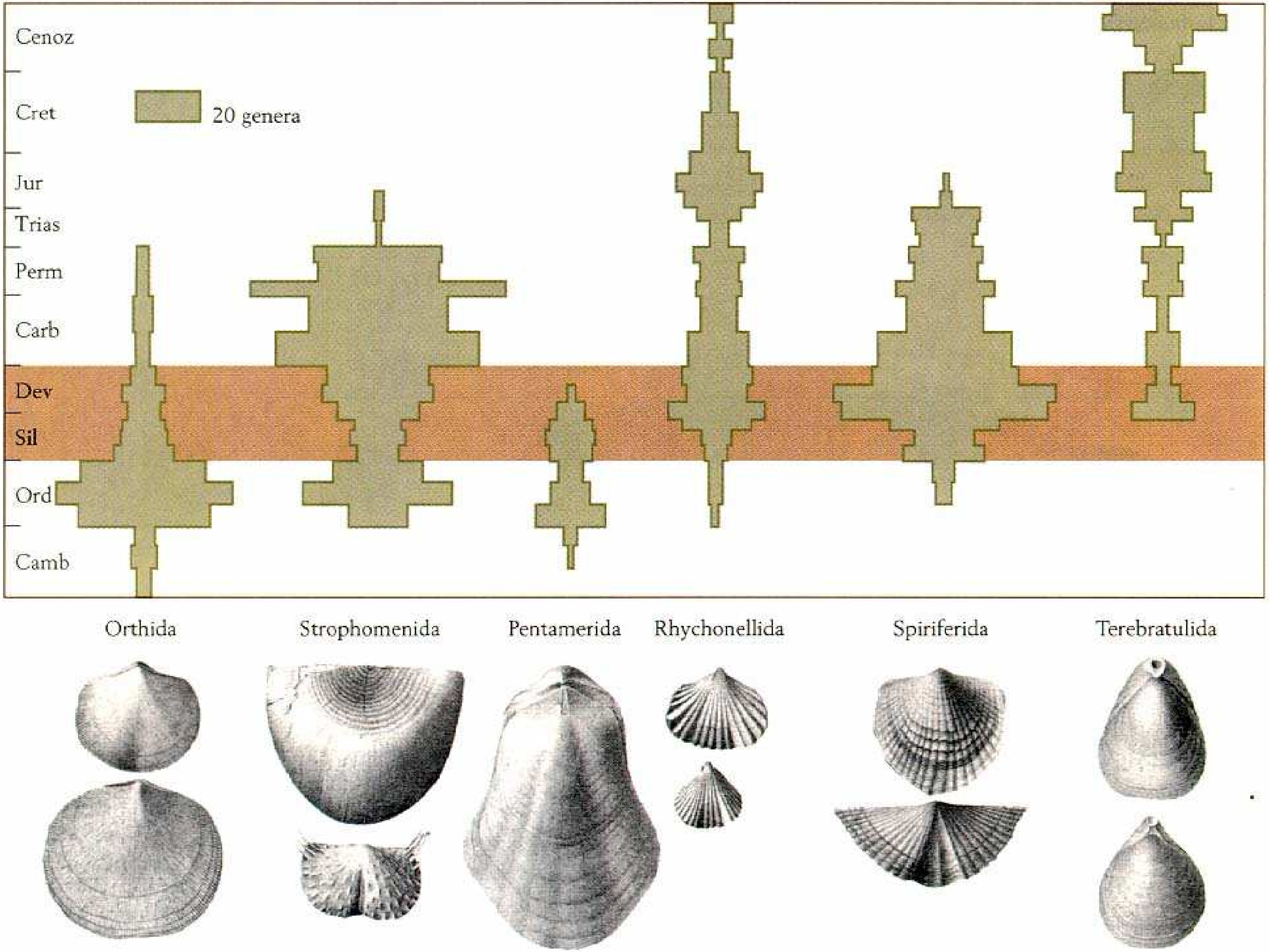
Brachiopod abundance through geologic time





ARTICULATA

ORTHIDA- Lower Cambrian to Upper Permian
STROPHOMENA- Lower Ordovician to Lower Jurassic
PENTEMERIDA- Middle Cambrian to Upper Devonian
RHYNCHONELLIDA- Middle Ordovician to Recent
SPIRIFERIDA- Middle Ordovician to Jurassic
TEREBRATULIDA-Upper Silurain to Recent

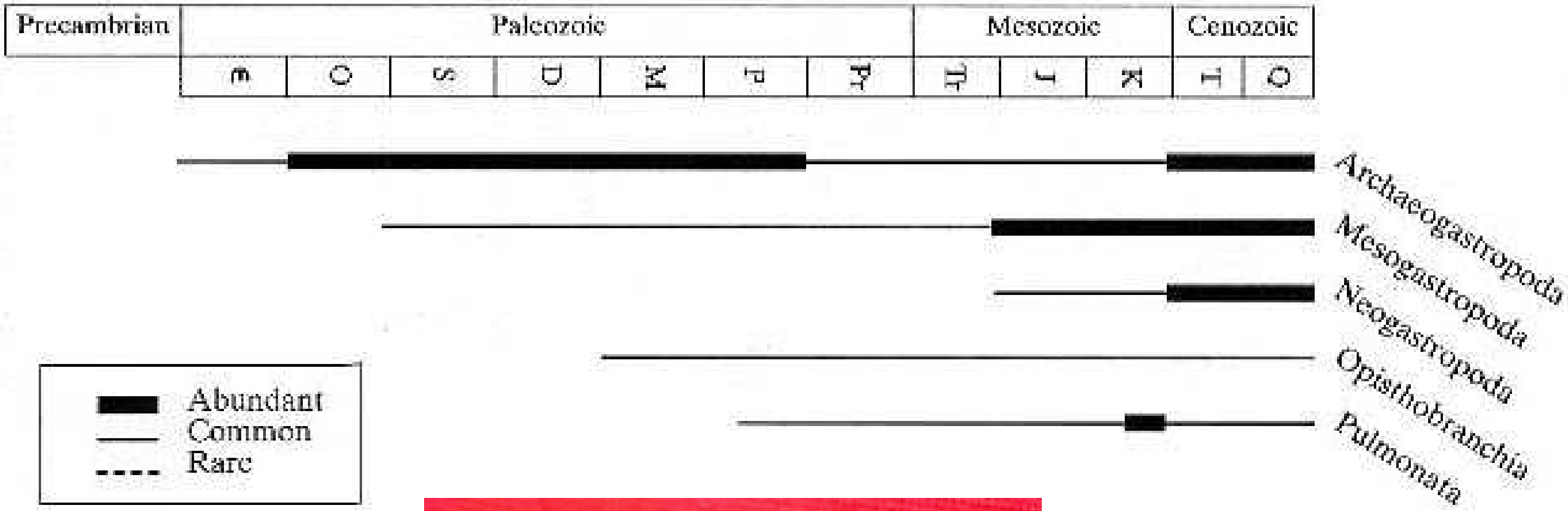

Cenoz
Cret
20 genera
Jur
Trias
Perm
Carb
Dev
Sil
Ord
Camb
Orthida
Strophomenida
Pentamerida
Rhychonellida
Spiriferida
Terebratulida

Strophomena

Stringocephalus

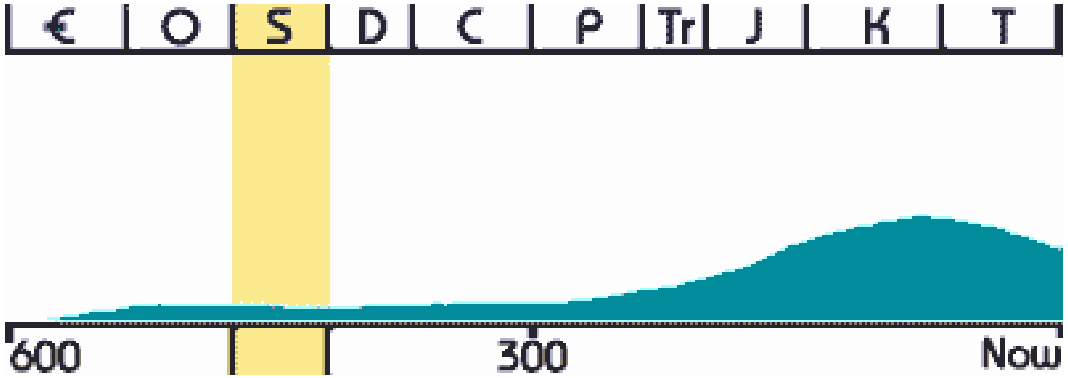
Gastropoda

Gastropods - they appear in the Cambrian but are not abundant until the Late Paleozoic.

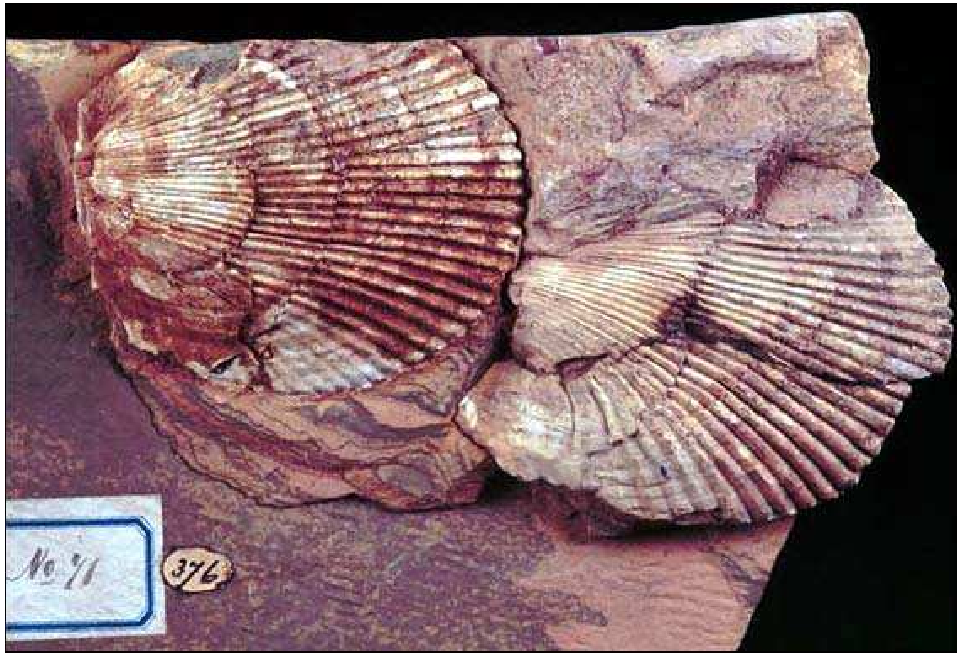


Platyceras

BIVALVES

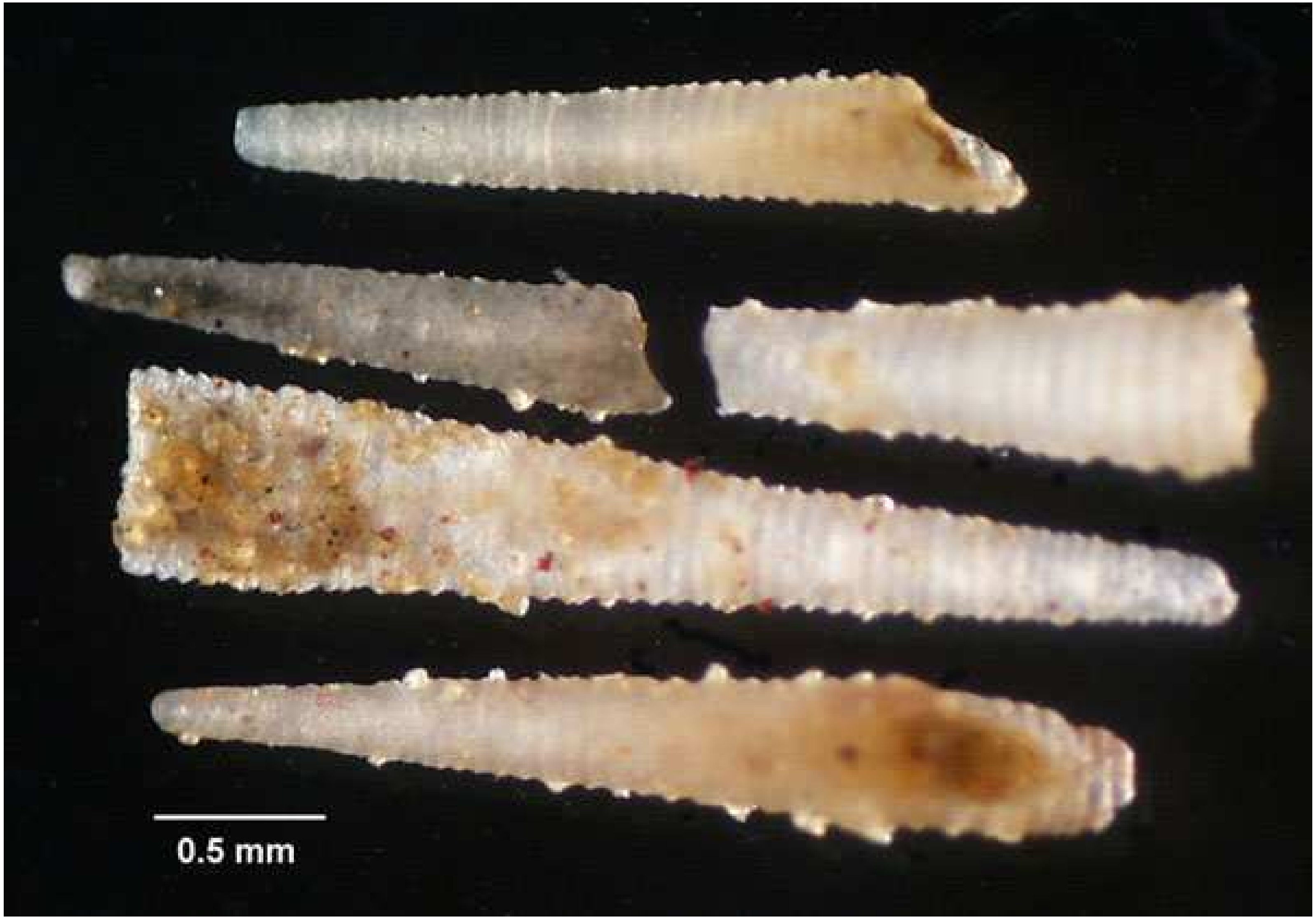


Cardiola



Panenka

Tentaculites



CLASS: Cephalopoda- This class of the order Molluska is divided up into 7 subclasses **SUBCLASSES:**

•**NAUTILOIDEA-**These were the first cephalopods to appear in the fossil record. They appeared in the Late Cambrian and quickly expanded. The only surviving Nautiloidea are members of the genus *Nautilus* (picture in heading of page). The members of the subclass Nautiloidea have orthoconic or coiled shells. Many of the straight Nautiloidea secreted deposits in their older chambers to make their shells neutrally bouyant. For more information on this subclass see this page.

•**ENDOCERATOIDEA-** The most noticeable thing about this subclass is the enormous size of its members. The largest Paleozoic fossils, they had orthoconic shells that could reach up to 9m. They had a "short" stratigraphic range, entering the fossil record in the Ordovician and leaving in the Silurian.

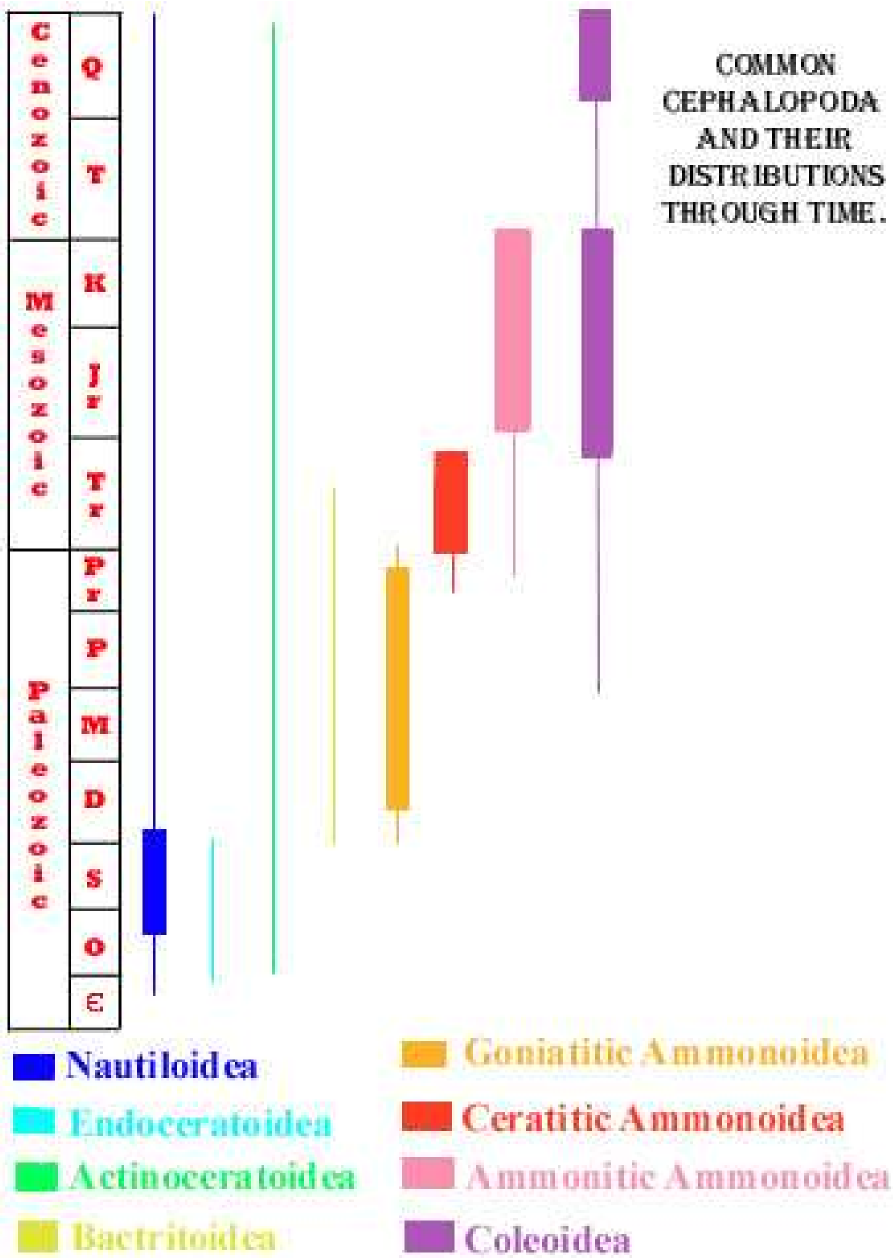
•**ORTHOCERATOIDEA-** The members of this subclass are known for the particular ornamentation on their shells. Their orthoconic or cyrtocone (slightly curved) shell have rings, grooves, and/or color. Secondary deposits in the shell are well developed. They entered the fossil record in the Ordovician and left in the Carboniferous. They are the probable ancestor to other cephalopoda.

•**ACTINOCERATOIDEA-** They had large straight shells with a blunt end (apex). The siphuncle has inflated connective rings. They entered the fossil record in the Ordovician and left in the Carboniferous.

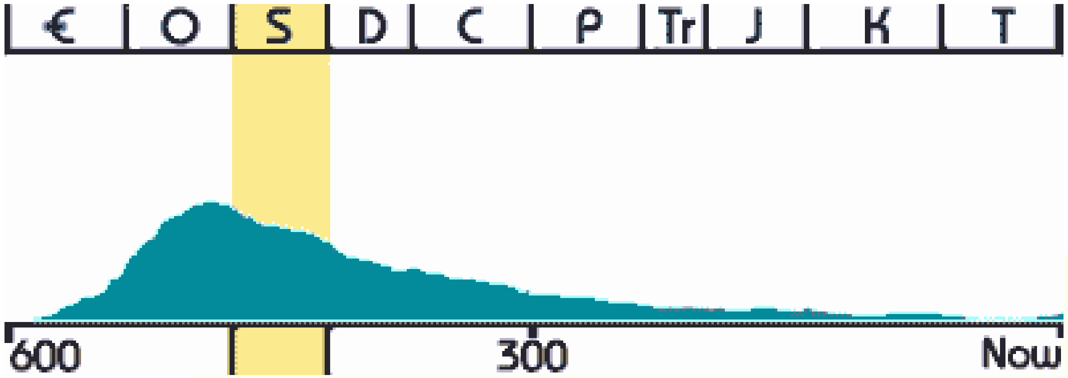
•**BACTRITOIDEA-** They have shells that are either straight or slightly curved. Members of this subclass resemble members of the ammonoidea subclass in that they have a bulbous protoconch and a small marginal siphuncle. They entered the fossil record in the Devonian and left in the Triassic.

•**AMMONOIDEA-** Their shells are tightly spiraled with complex sutures. Like the bactritoids, they have have a bulbous protoconch and a marginal siphuncle. They entered the fossil record in the Devonian and left in the Cretaceous at the famous K/T boundary.

•**COLEOIDEA-** The common Cephalopoda of today, which include squids, octopuses, and cuttlefish. They have either internal shells or no shell at all. Coleoidea differ from other cephalopods by having only one pair of gills and one pair of nephridia (kidneys); all other cephalopods have 2 pairs of both gills and nephridia. Coleoidea entered the fossil record during the Devonian and are still around today.

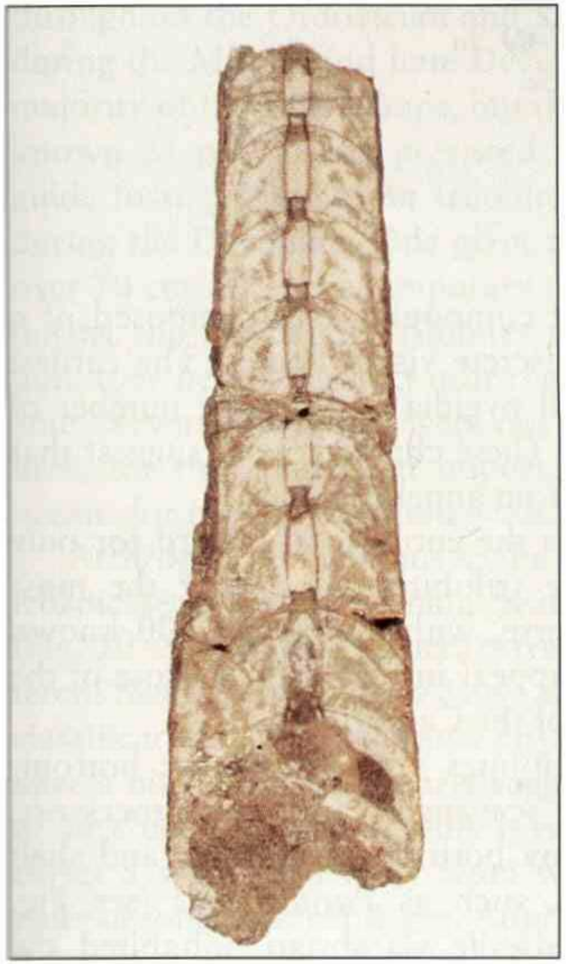

COMMON CEPHALOPODA AND THEIR DISTRIBUTIONS THROUGH TIME.
Cenozoic
Mesozoic
Paleozoic
Q
T
K
Jr
Tr
Pr
P
M
D
S
O
Є
Nautiloidea
Endoceratoidea
Actinoceratoidea
Bactritoidea
Goniatitic Ammonoidea
Ceratitic Ammonoidea
Ammonitic Ammonoidea
Coleoidea

Nautiloids

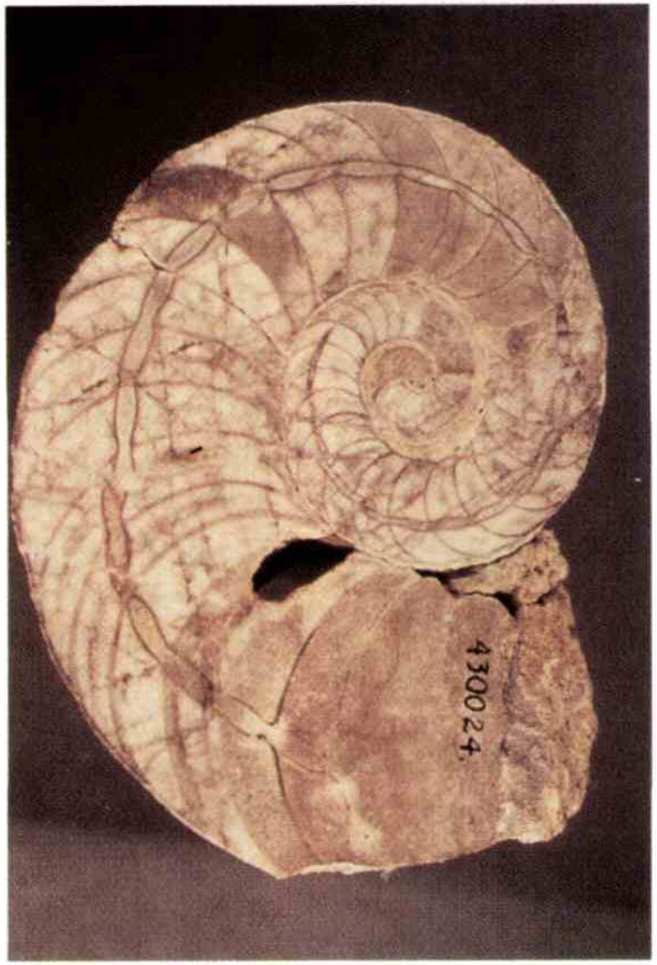


Lituites littuus, an odd nautiloid fossil from the Ordovician of China.

Reconstruction of the Silurian sea



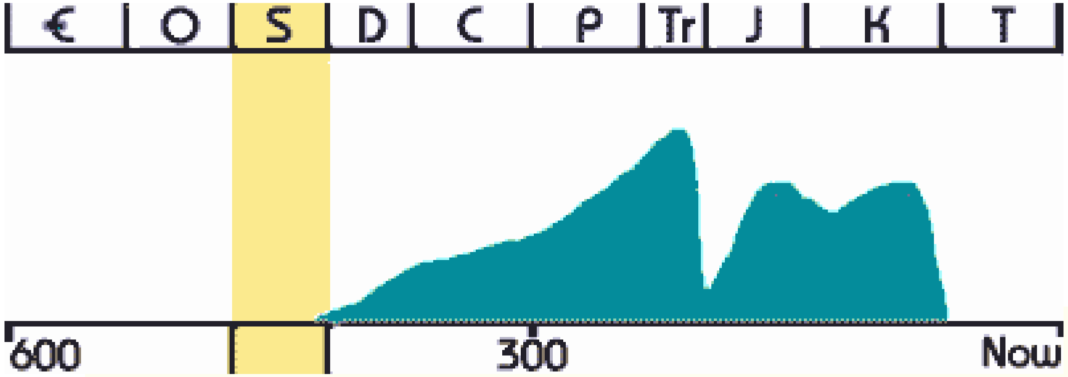
A



B

FIGURE 10–46 Variation in conch shape among early Paleozoic nautiloid cephalopods. Both of these specimens are from the Silurian of Bohemia. (A) A sawed and polished section of the straight conch of *Orthoceras potens* showing septa and siphuncle. (B) Sawed and polished section of *Barrandeoceras,* exhibiting a coiled form. Specimen A is 22.5 cm in length; B has a diameter of 18 cm.

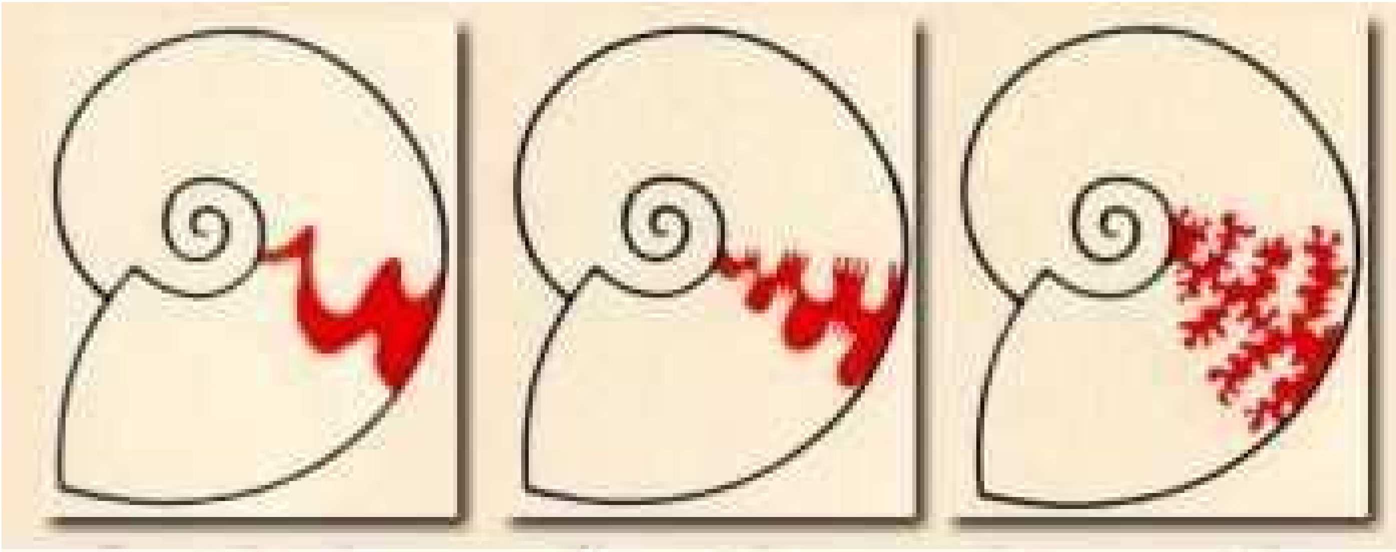
Ammonites



First occurrence in Pragian

Polished Devonian goniatite Tomoceras

Clymenia



Goniatites Ceratites Ammonites

The goniatite *Goldringia* is at center. Behind, the straight-shelled cephalopod *Michelinoceras* is can be seen. At front left, the trilobite *Phacops* is moving near a cluster of *Paraspirifer* brachiopods

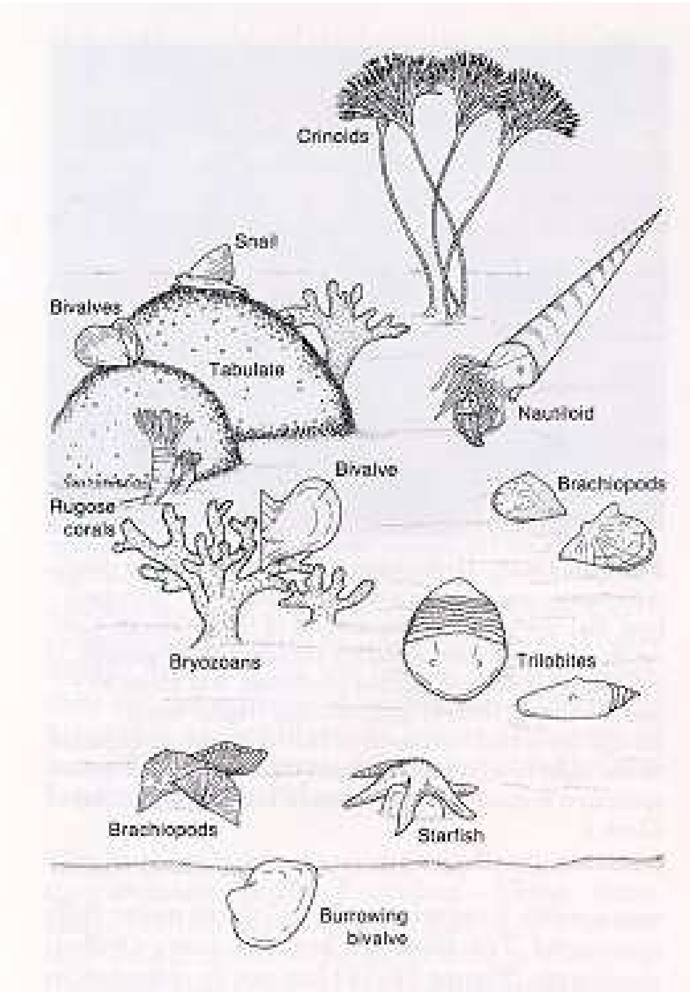
Coleoidea

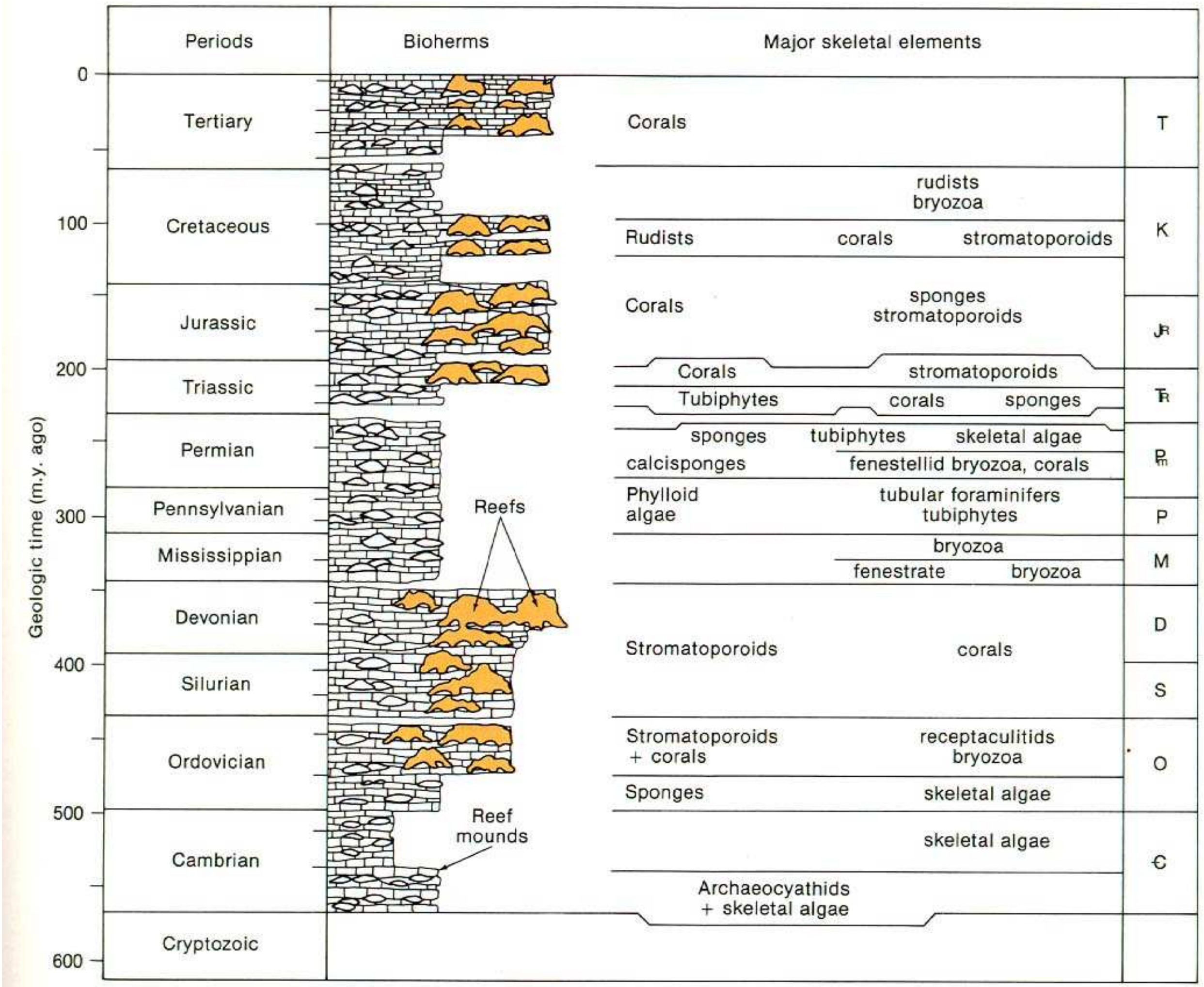
Devonian Eoteuthis

Alloteuthis

Ordovician reefs

First True Reefs





BRYOZOANS

The phylum **Bryozoa** is a diverse one with approximately 4000 living species known, and almost four times that amount are found in the fossil record (Levin, 1999). These "moss animals" are often mistaken for corals due to their structural similarities but bryozoans have a much more complex anatomy. Bryozoans are also mistaken for plants, hence the term 'moss animal'. Bryozoans (sometimes referred to as Entoprocta and Ectoprocta) are microscopic sea animals that live in **colonial structures** that are much larger than the individual animal. Because these structures are usually composed of secreted **calcite**, they commonly form fossils.

Bryozoa **Moss Animals, Sea Mats,**

Stenolaemata - Cyclostomata Fenestrata Cryptostomata Cystoporata Trepostomata

Gymnolaemata - Ctenostomata Cheilostomata

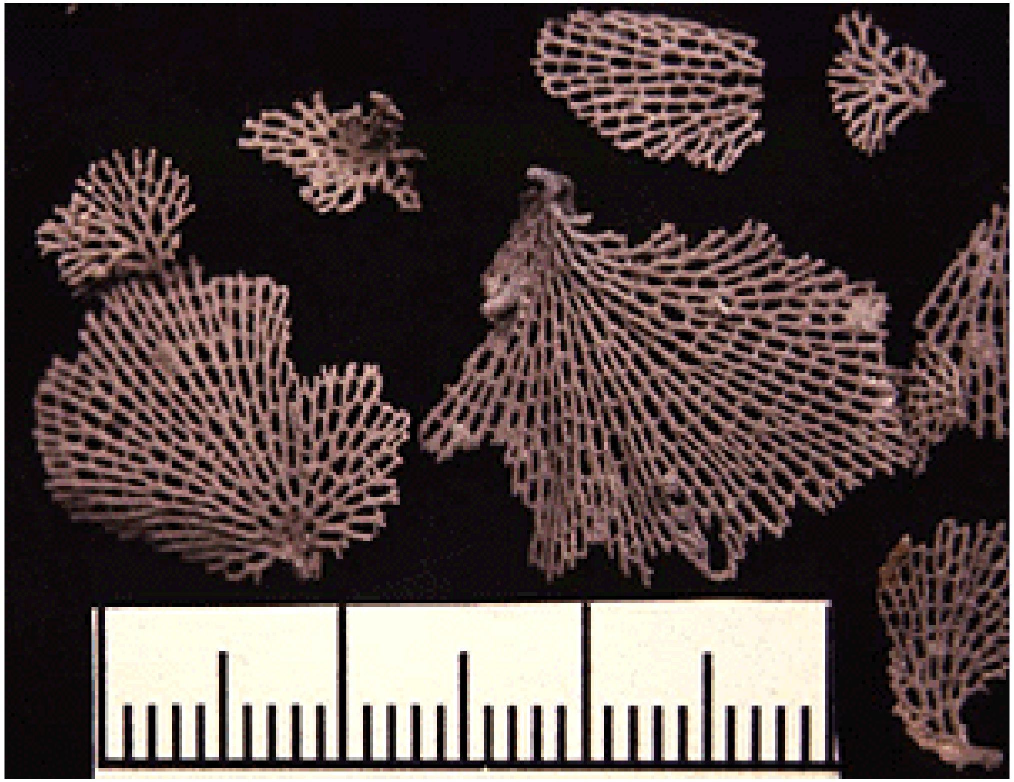
Phylactolaemata

Bryozoan Classification - **Class Stenolaemata**

Marine bryozoans with tubular zooids with calcified walls. Lophophore is protruded by action of annular muscles. Includes five sub-groups:

- **Trepostomata:** Colonies generally robust; dendroid, encrusting, or massive. (Ordovician - Triassic)
- **Cystoporata:** Colonies robust or delicate. (Ordovician - Triassic)
- **Cryptostomata:** Colonies typically delicate; foliate or dendroid. (Ordovician - Permian)
- **Fenestrata:** Colonies typically delicate; reticulate (net-like) or pinnate. (Ordovician - Triassic)
- **Tubuliporata**, or **Cyclostomata** (Ordovician - Recent)

Bryozoa – Order Fenestrata



- ***Fenestella althaea* Hall**
- **Flat colonies of "lacy" bryozoa**
- Early Devonian, Albany Co., New York
- Silica replacement

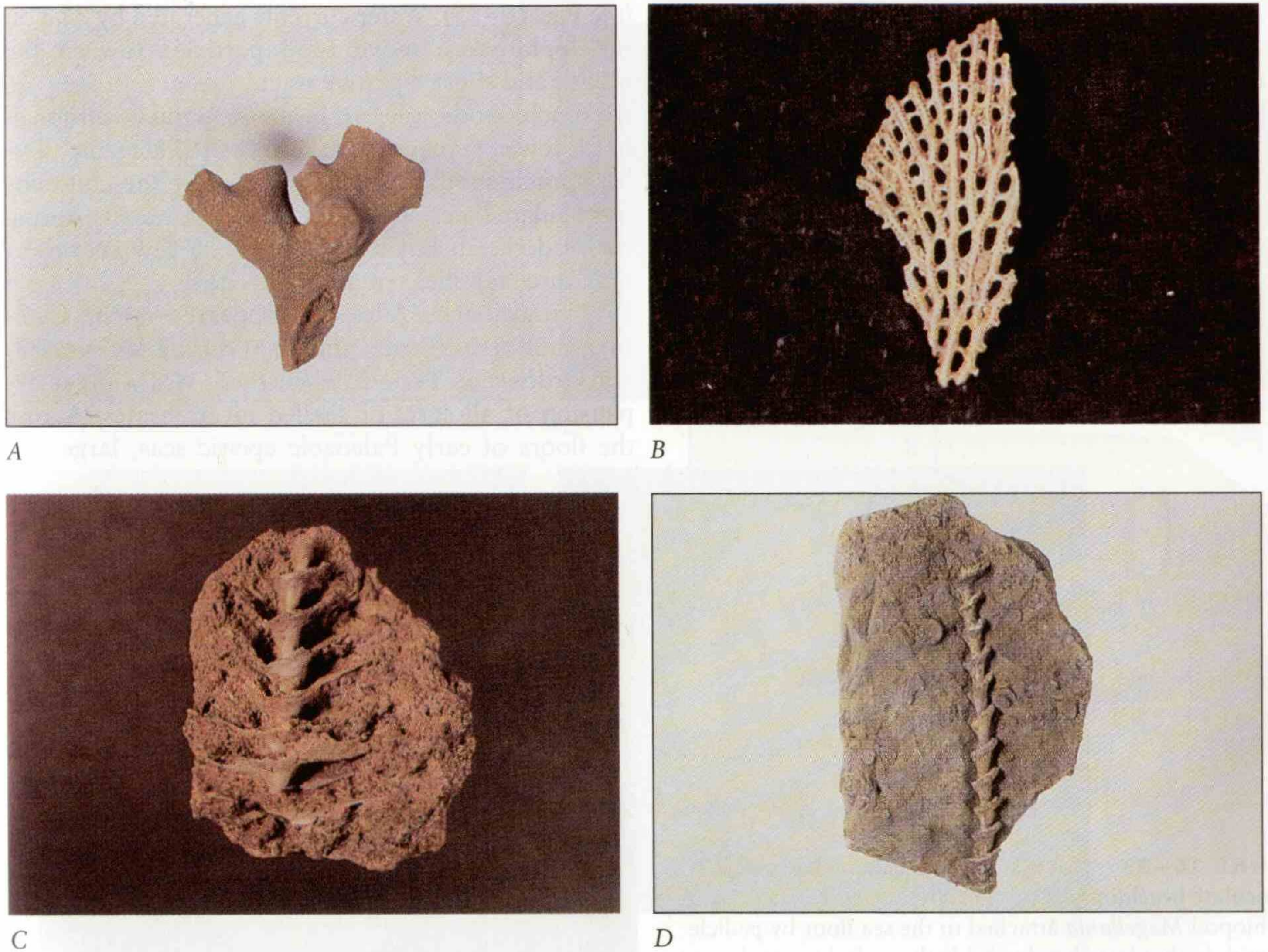
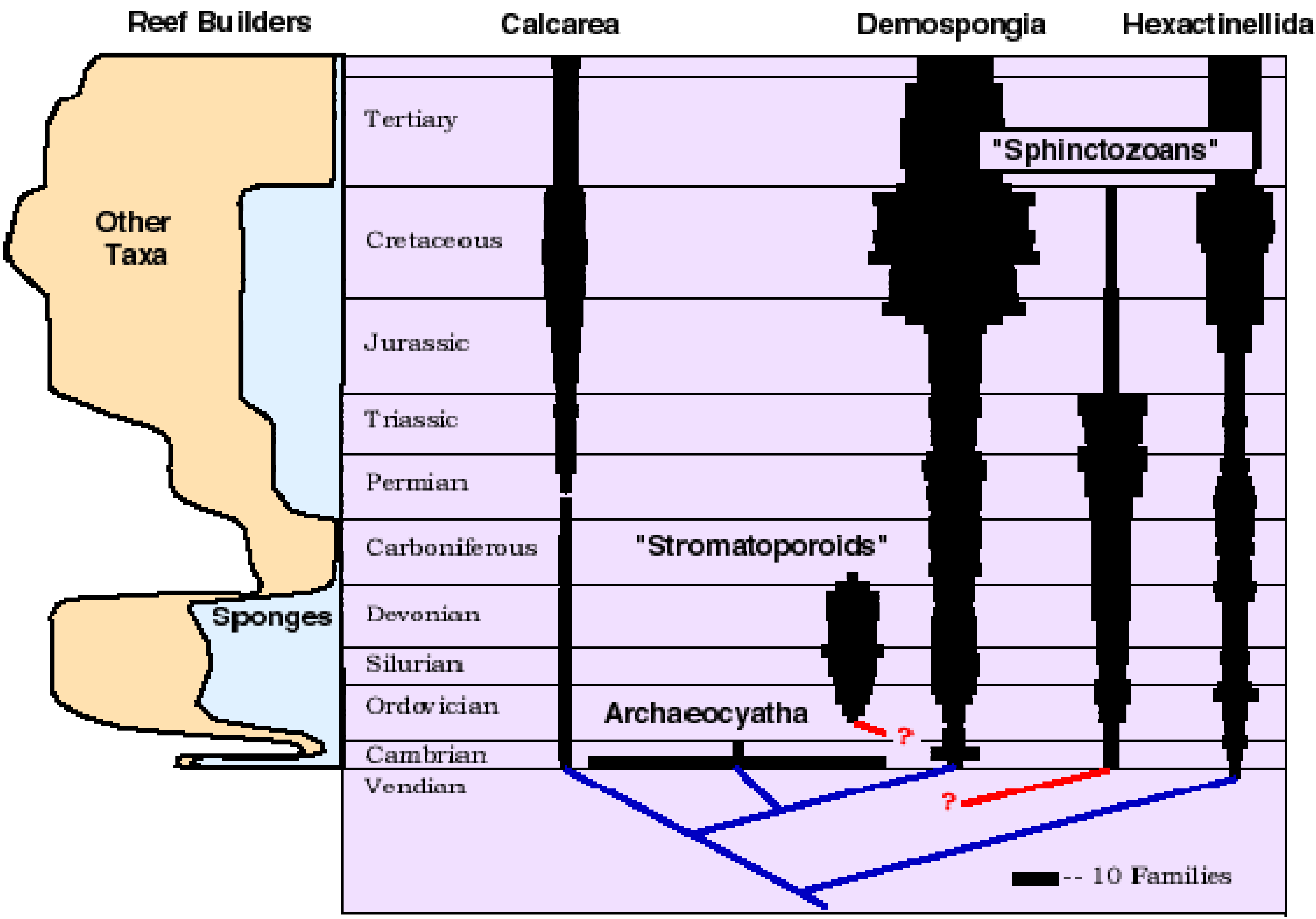
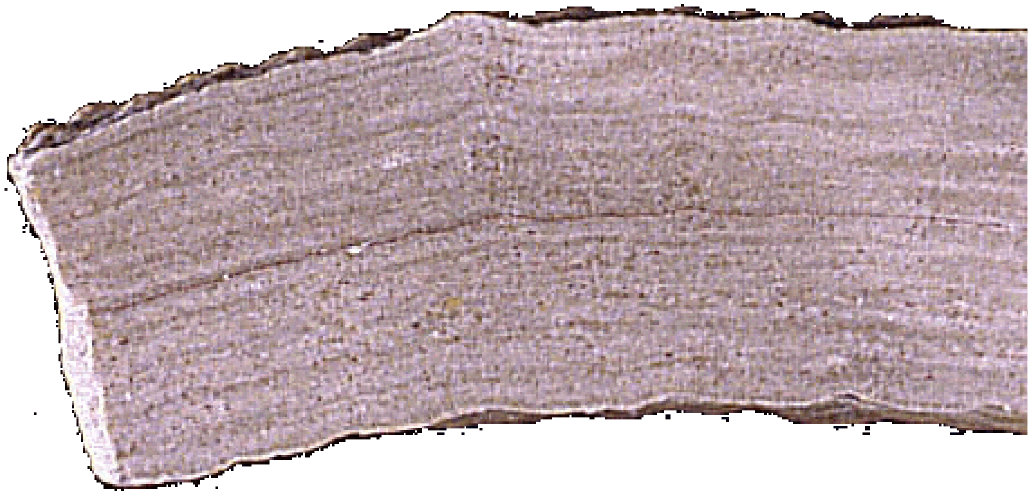


FIGURE 10–34 **Paleozoic bryozoans.** (A) The branching twig bryozoan *Hallopora* from the Ordovician of Kentucky. (B) *Fenestella,* a lacy bryozoan from Devonian limestones at the Falls of the Ohio River. (C) *Archimedes,* with part of the spirally encircling frond of lacy bryozoan colony attached and visible. (D) The central axis of *Archimedes*. Where were the zooecia located in this zoarium?

Porifera Family Tree



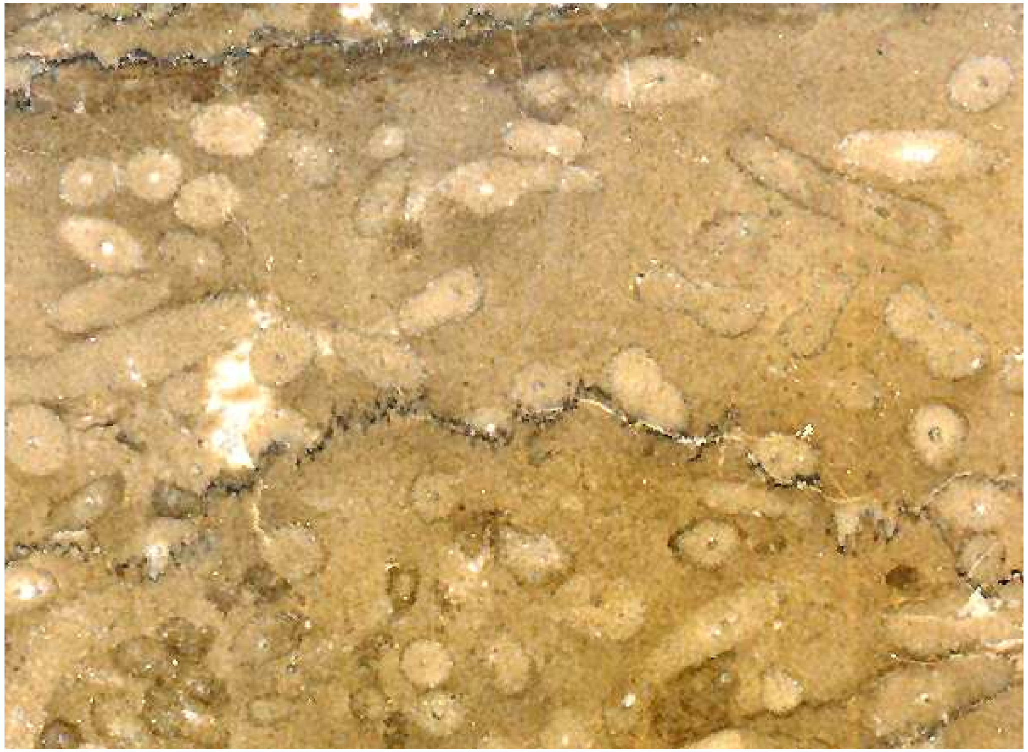
Stromatoporoids



Sponge-like, grew in sheet-like calcareous layers.

Dominant reef builders, Ordovician Period through the Devonian Period, a period of about 100 million years.

Stromatoporoids were marine colonial forms with a calcareous skeleton. They were important contributors to reef building during the Silurian and Devonian. Their relationship to other creatures is uncertain but they show some affinities with Porifera.
They consist of calcareous layers which, when weathered, show a charecteristic contour line pattern as seen in the specimen above.



Amphipora floatstone in
peloidal line mud matrix; note
common stylolites"
Upper Devonian
Leduc Formation
Alberta

Calcareous sponges

Geologic range: Ordovician to Present

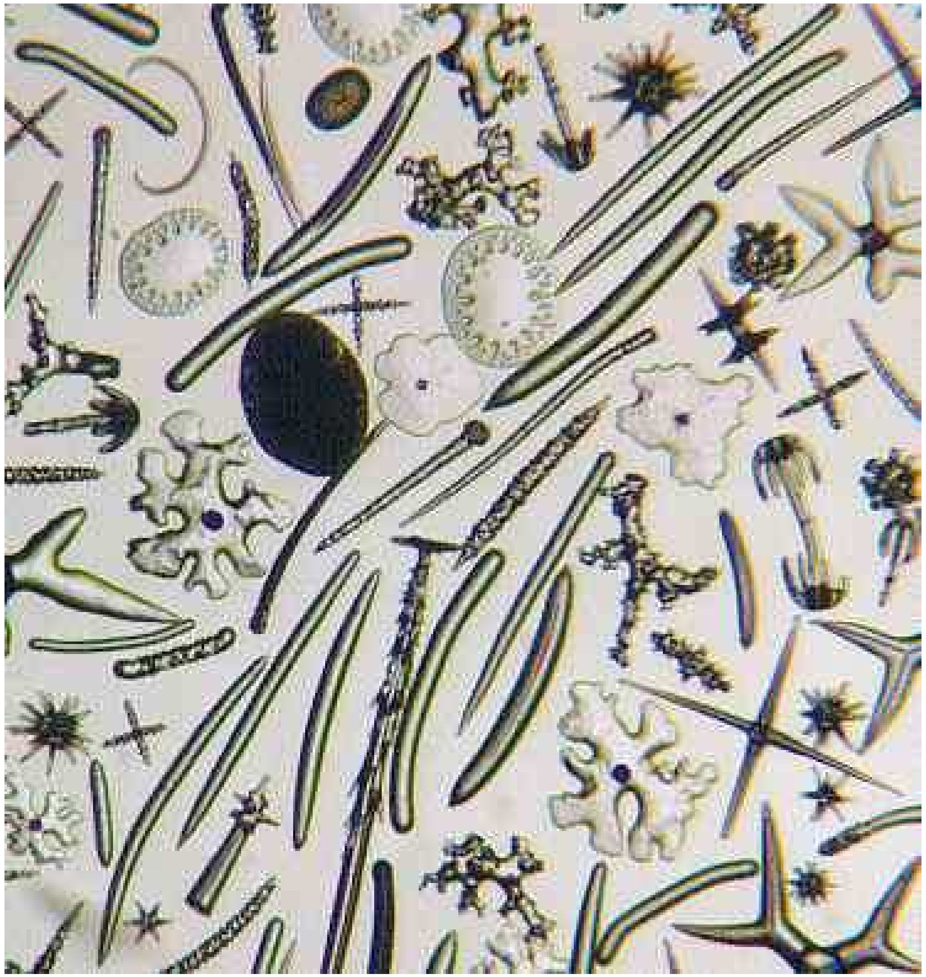
Built reefs in the Silurian (Michigan Basin)

Found in Caribbean Sea, Mediterranean Sea and Pacific Ocean

EARLY PALEOZOIC LIFE

Metazoan Invertebrates

Phylum Porifera (sponges) **SPICULES**



Spicules –

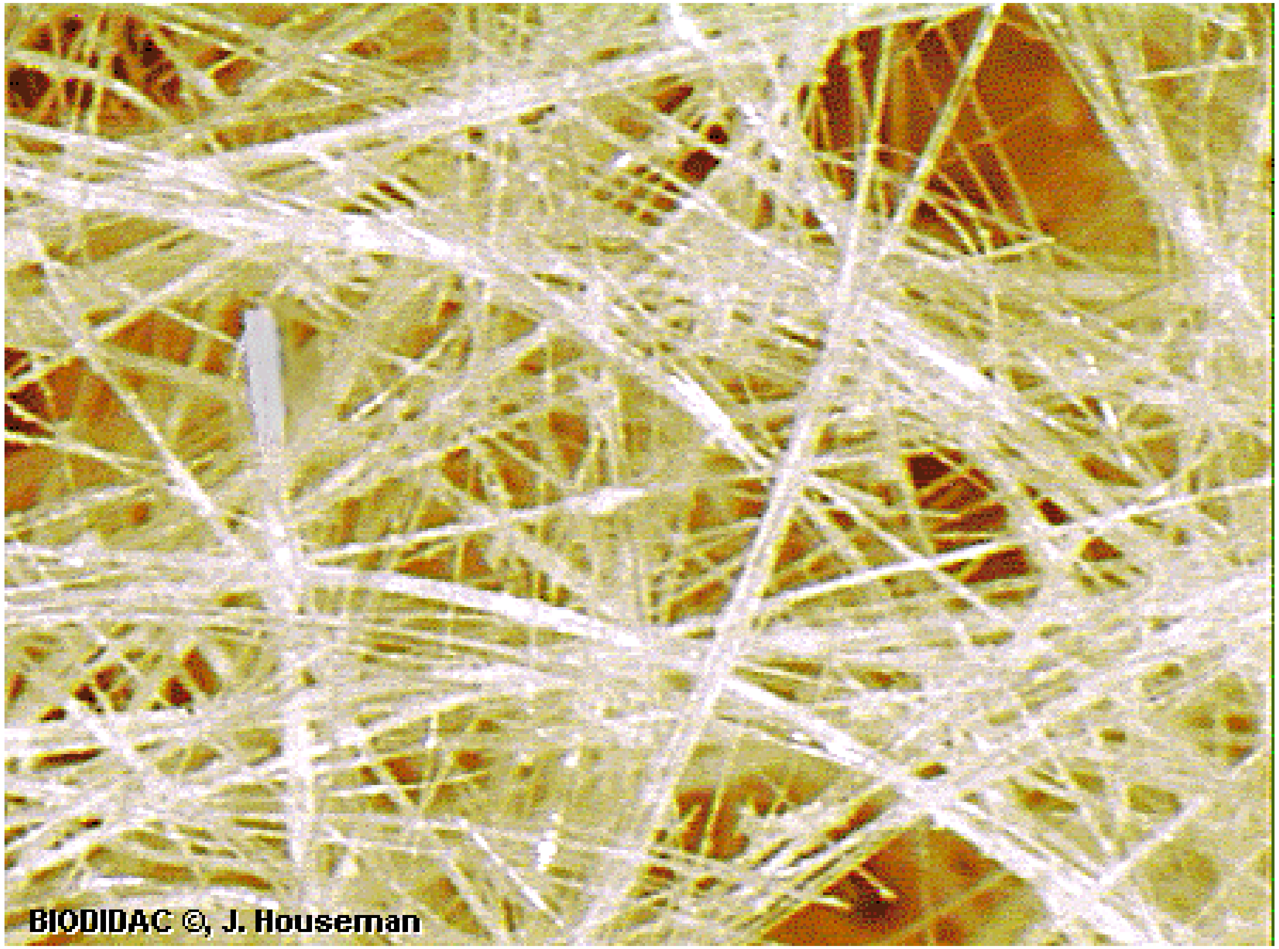
Composed of

Calcium carbonate

EARLY PALEOZOIC LIFE

Metazoan Invertebrates

Phylum Porifera (sponges)   SPICULES



Spicules –

Composed of

Silica

EARLY PALEOZOIC LIFE

Metazoan Invertebrates

Phylum Porifera (sponges)
Silurian

Caryospongia

Astylospongia

Cnidaria – Rugosa (solitary)

- Rugosa are an extinct group of corals that were abundant in **Middle Ordovician to Late Permian**
- Solitary rugosans are often referred to as "horn corals"
- Rugosa can also be colonial
- extinct at the end of the Permian, about 245 million years ago

Cnidaria – Rugosa (solitary)

- ***Cystiphyllum conifollis***
- Solitary Rugose coral
- Middle Devonian, Ontario, Canada
- Recrystallization

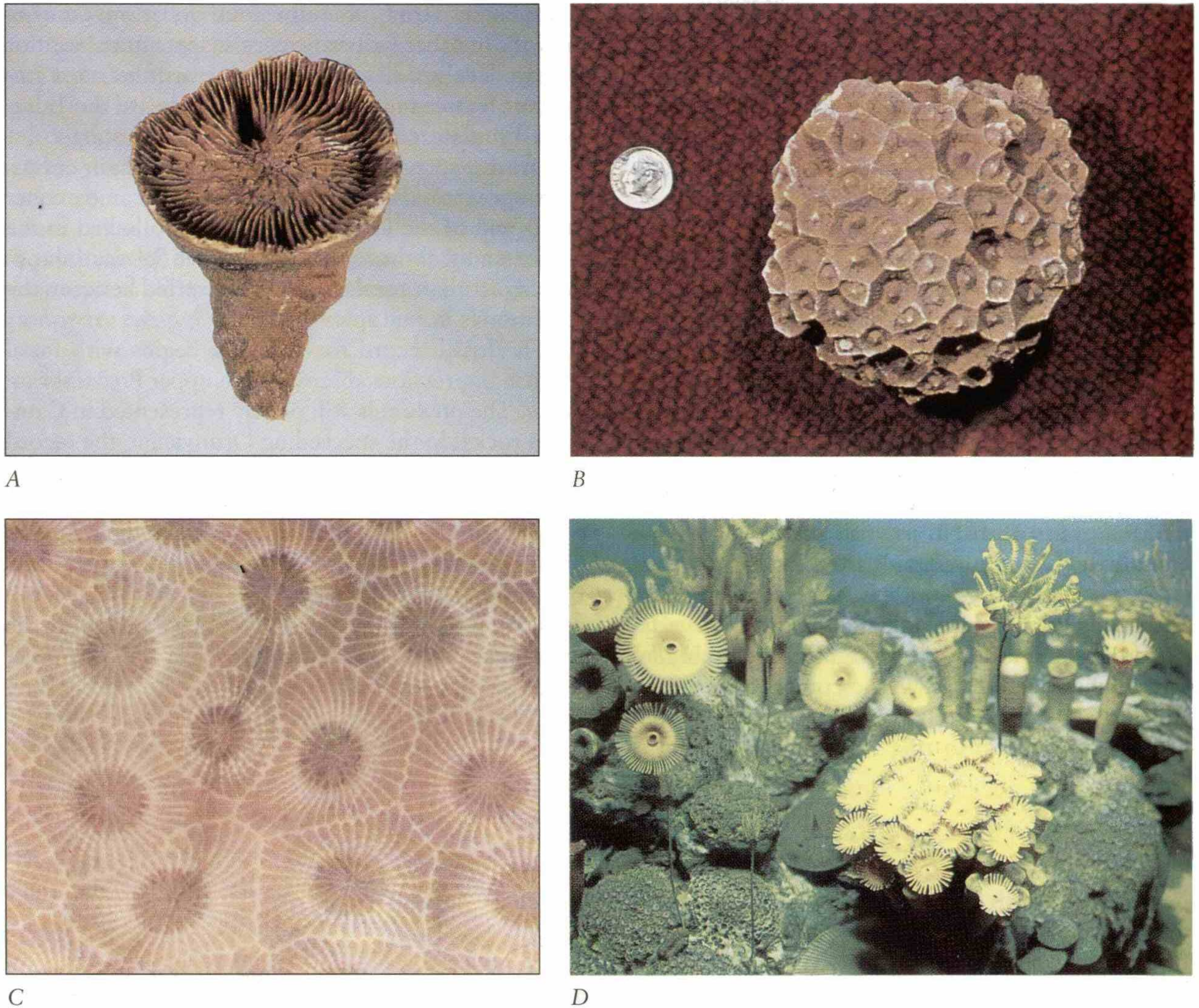
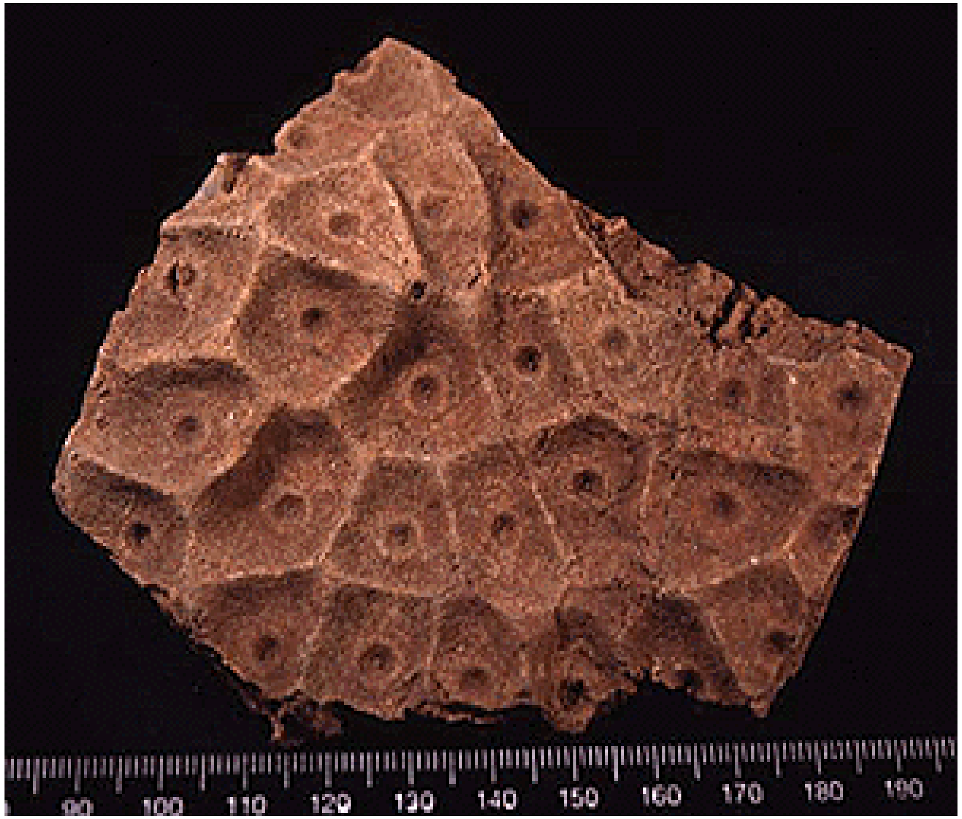


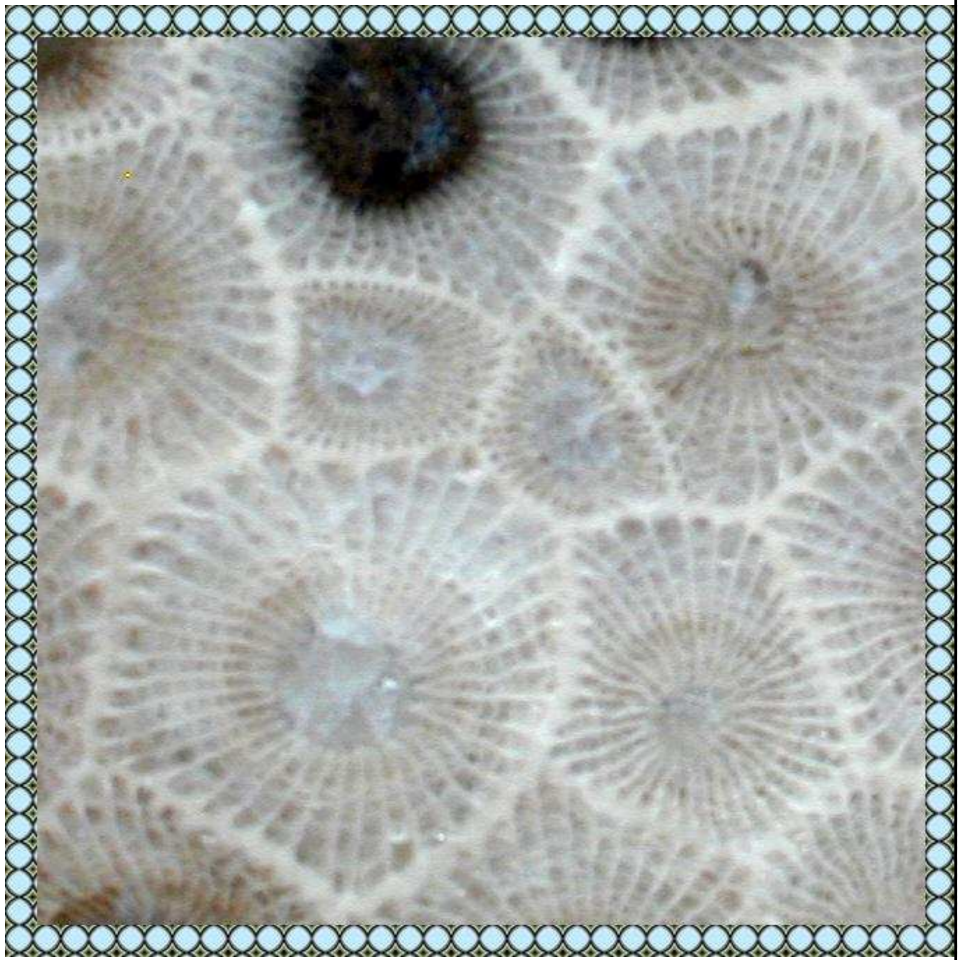
FIGURE 10–33 Devonian rugose corals. (A) The solitary horn coral *Zaphrenthis* with clearly visible radiating septa in the hornlike theca. (B) The compound (colonial) rugose coral *Lithostrotionella.* (C) A polished slab of the compound coral *Hexagonaria.* Water-worn fragments of this coral are found along the shore of Lake Michigan at Petoskey, Michigan, and this accounts for its being called Petoskey stone. Although not a rock, Petoskey stone is the designated state rock of Michigan. (D) Reconstruction of compound and solitary rugose corals on the floor of a Devonian epeiric sea. *(Diorama photograph courtesy of the U. S. National Museum of Natural History, Smithsonian Institution.)* What was the purpose or function of the septa in rugose corals?

Cnidaria – Rugosa (colonial)



- ***Arachnophyllum pentagonum* Goldfuss**
- Colonial rugose coral
- Middle Silurian, Kentucky
- Silica replacement

Petoskey Stones – recrystallized colonial Devonian rugose corals



EARLY PALEOZOIC LIFE

Metazoan Invertebrates

Tabulata (Tabulate Corals)

- **Ranged from Ordovician to Permian**
- **Major reef formers, Silurian and Devonian reefs**
- **Always colonial**

EARLY PALEOZOIC LIFE

Metazoan Invertebrates

Tabulata (Tabulate Corals)

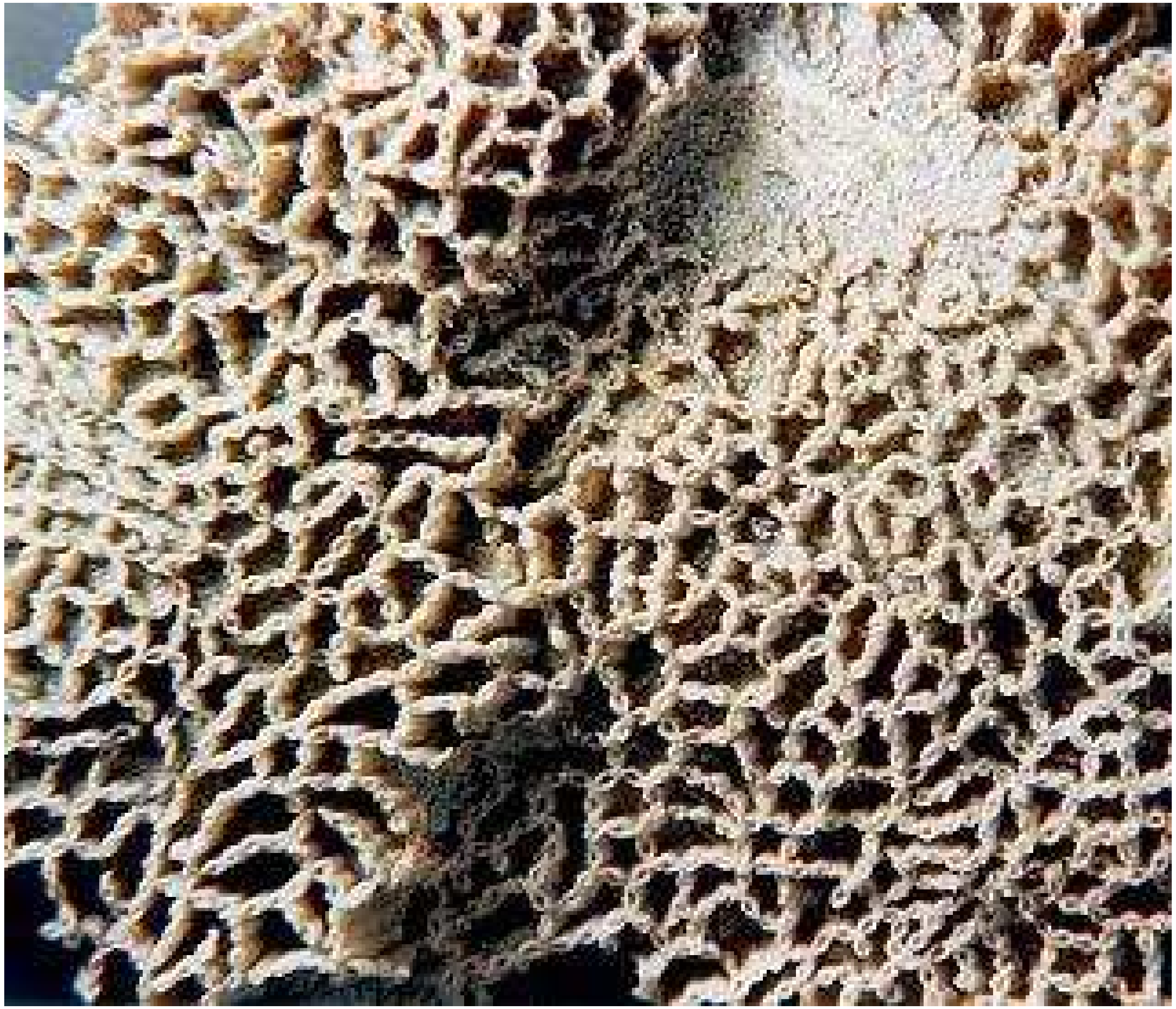
Favosites

EARLY PALEOZOIC LIFE

Metazoan Invertebrates

Tabulata (Tabulate Corals)

Halysites



Phylum Echinodermata

Subphylum Blastozoa

..........Class Eocrinoidea (**Cambrian** - Silurian, 30-32 genera)
..........Class Parablastoidea (Ordovician, 3 genera)
..........Class Rhombifera = Cystoidea in part (Ordovician - Devonian, 60 genera)
..........Class Diploporita = Cystoidea in part (Ordovician - Devonian, 42 genera)
..........Class Blastoidea (Silurian - Permian, 95 genera)

Subphylum Crinozoa

..........Class Crinoidea - sea lilies (**Cambrian?** Early Ordovician - Recent, 1005 genera)
..........Class Paracrinoidea (Ordovician - Silurian, 13-15 genera)

Subphylum Echinozoa

..........Class Echinoidea (Sea Urchins) (Ordovician - Recent, 765 genera)
..........Class Holothuroidea (Sea Cucumbers) (Ordovician - Recent, 200 genera)
..........Class Edrioasteroidea (**Early Cambrian** - Carboniferous, 35 genera)
..........Class Edrioblastoidea (Ordovician, 1 genus)
..........Class Helicoplacoidea (**Cambrian**, 3 genera)
..........Class Cyclocystoidea (Ordovician - Devonian, 8 genera)

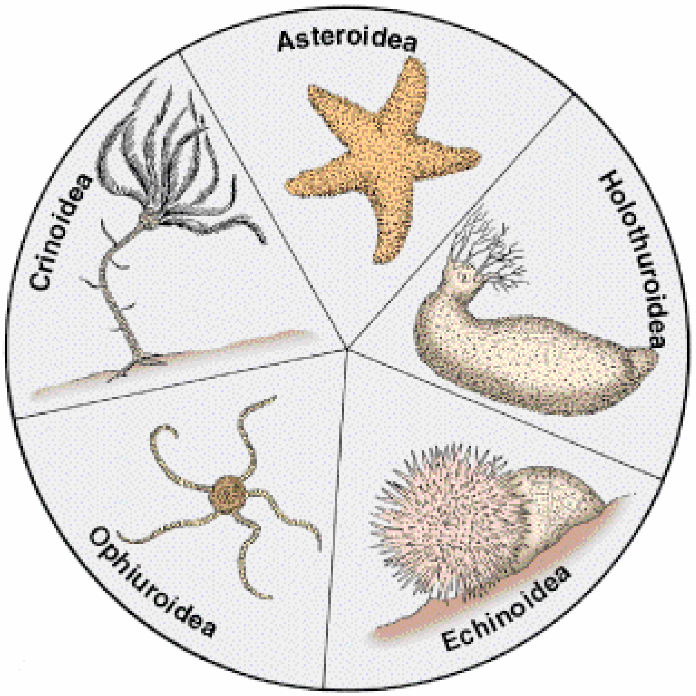
Subphylum Asterozoa (= Stelleroidea)

..........Class Asteroidea - starfish - (Early Ordovician - Recent, 430 genera)
..........Class Ophiuroidea - Brittle Stars -(Ordovician - Recent, 325 genera)

Subphylum Homalozoa

..........Class Stylophora (Cambrian - Devonian, 32 genera)
..........Class Homoiostelea (Cambrian - Devonian, 12-13 genera)
..........Class Homostelea (Cambrian, 3 genera)
..........Class Ctenocystoidea (Cambrian, 2 genera)

Levin, The Earth Through Time, 6/e
Figure 10-52

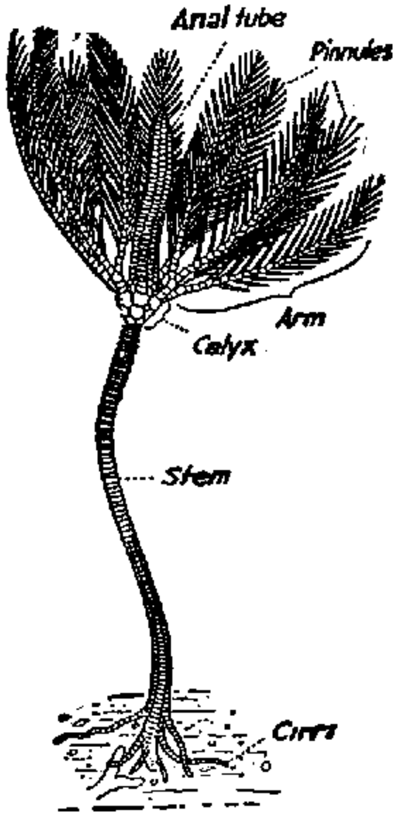


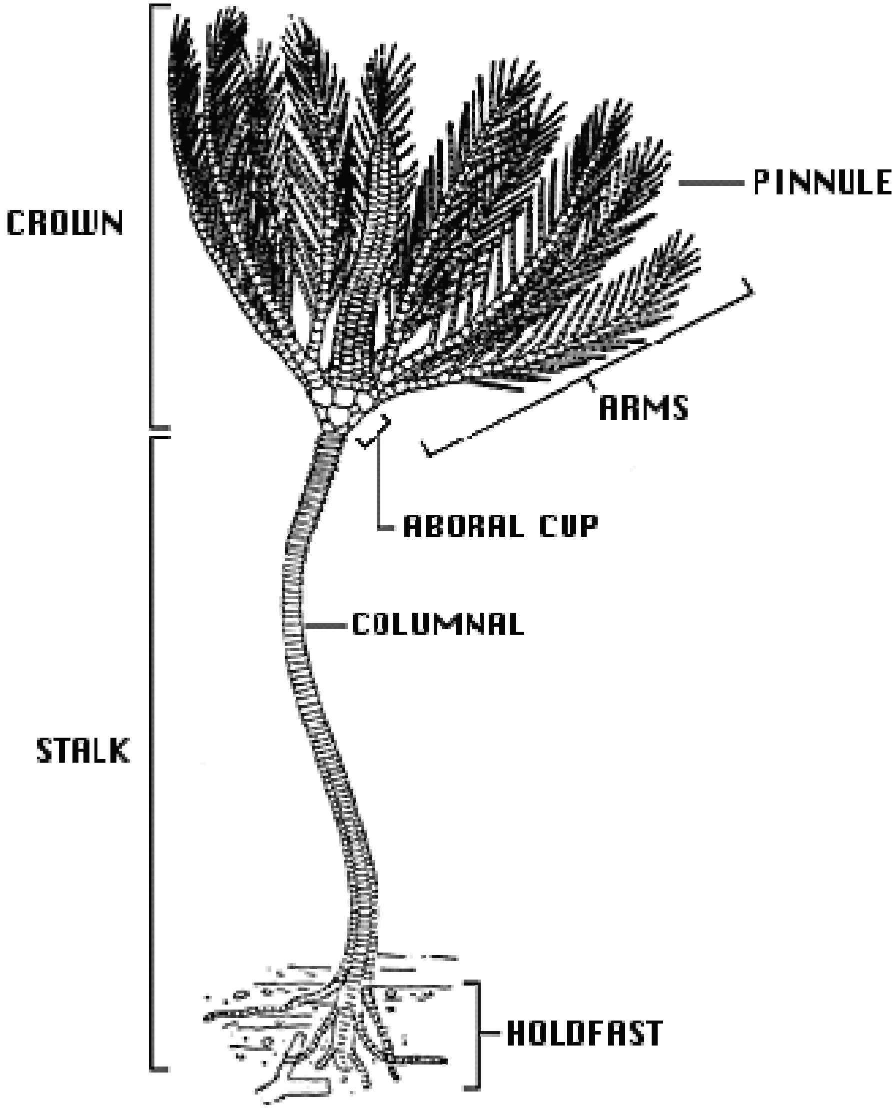
EARLY PALEOZOIC LIFE

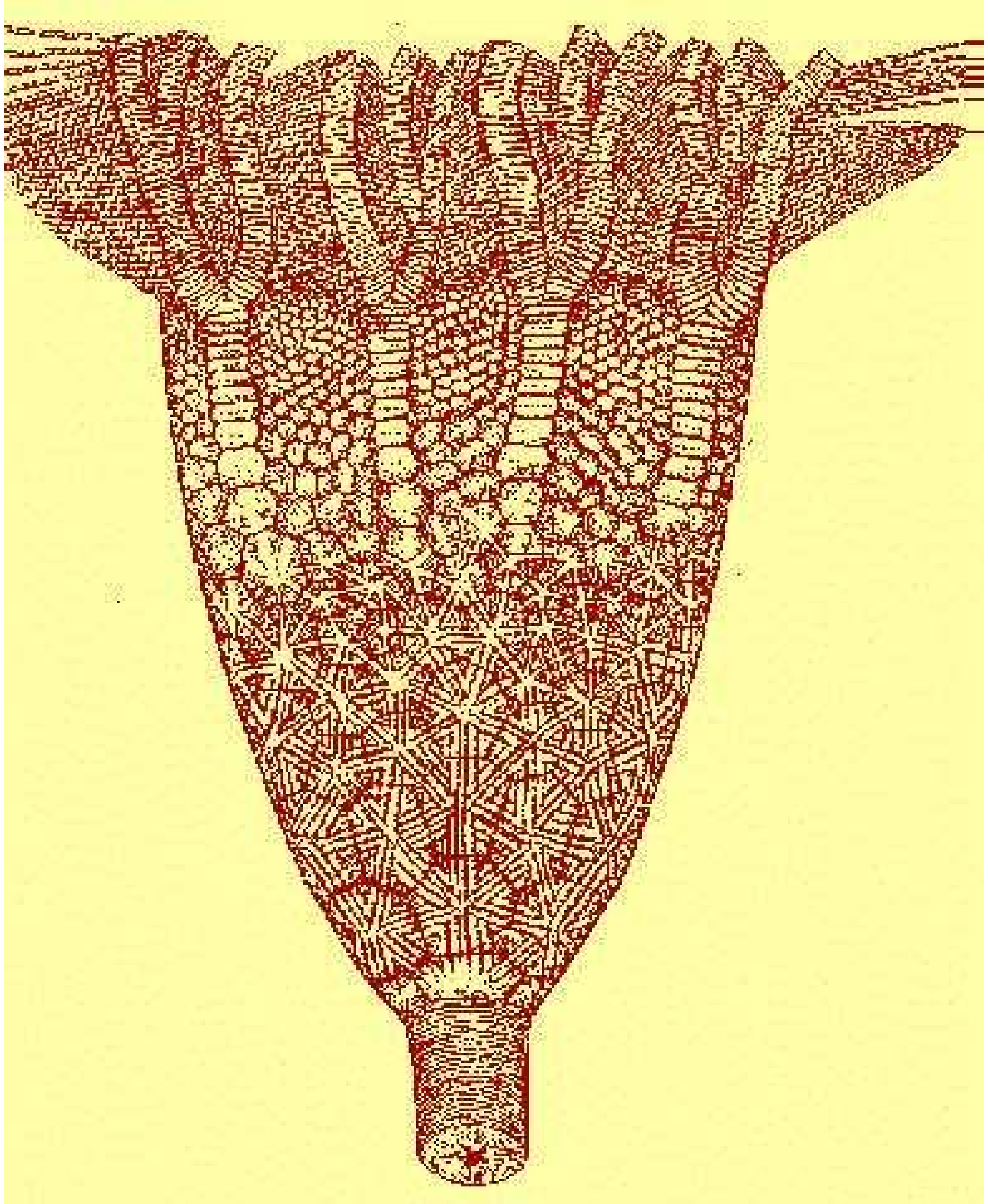
Metazoan Invertebrates

Echinodermata   Crinoidea

Crinoids
Middle Cambrian
to Recent




CROWN
PINNULE
ARMS
ABORAL CUP
COLUMNAL
STALK
HOLDFAST



Scyphocrinites

EARLY PALEOZOIC LIFE

Metazoan Invertebrates

Echinodermata   Blastoidea

Blastoids
Early Cambrian
to Permian

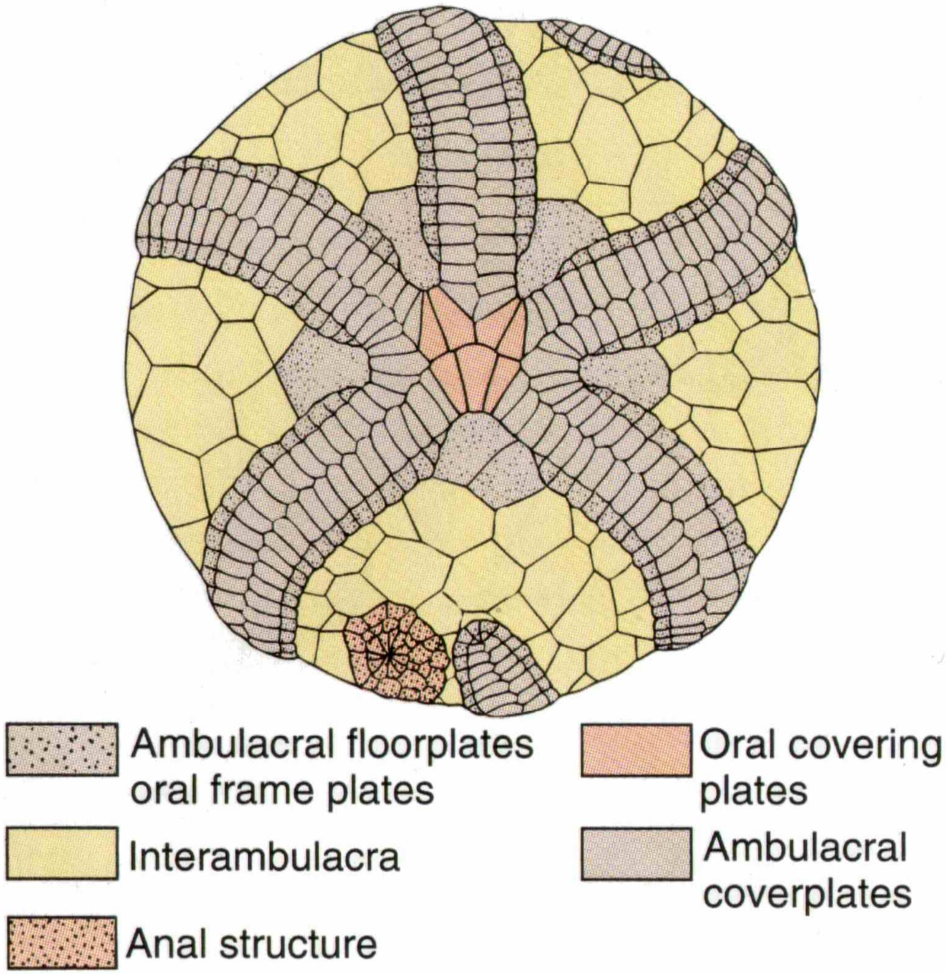


FIGURE 10–54 ***Edrioaster bigsbyi*, a Middle Ordovician edrioasteroid.** Specimen is 45 mm in diameter. *(From Bell, B. M. 1977.* J. Paleo. *51(3):620.)*

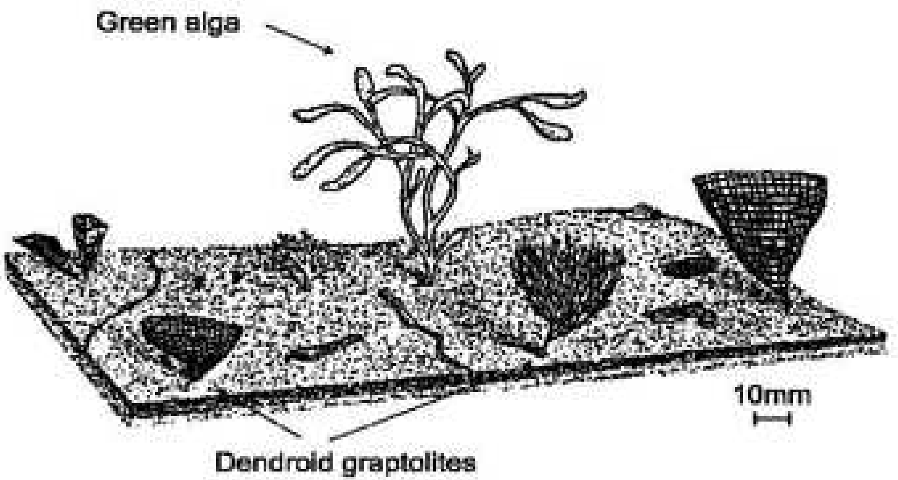
Echinodermata - Asterozoa

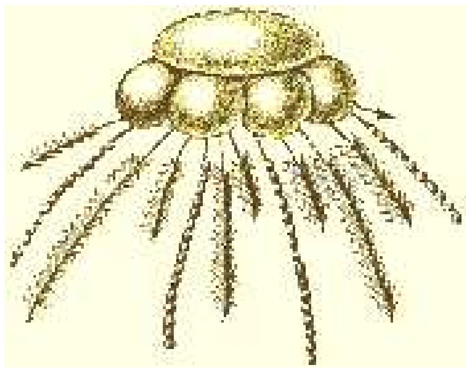
- ***Devonaster eucharie* (Hall**
- **Middle Devonian, Ulster Co., New York**
- **External Mold in shale**


5mm
Scale

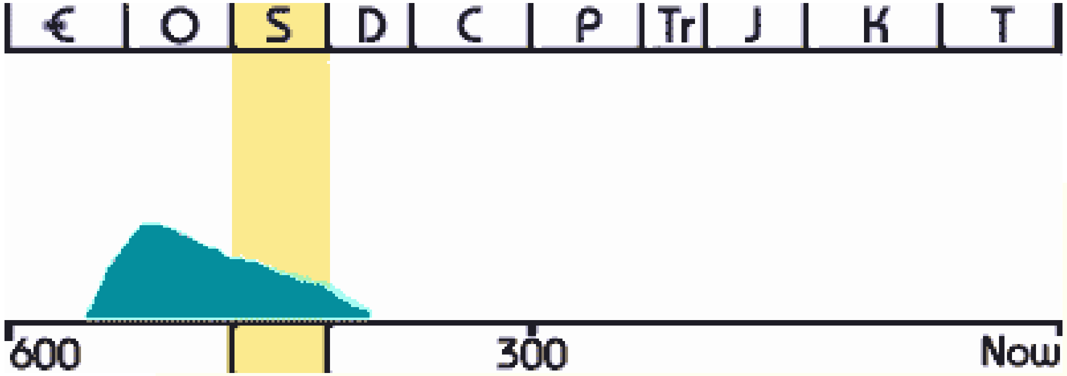
Graptolites

Graptolites range from the middle Cambrian to the Carboniferous. **Dendroidea** are found across this entire span while **Graptoloida** are found from the Ordovician until the earlyDevonian. Graptolites are most commonly found in deep water, dysoxic facies (black shales), but do extend into shallow facies. Because they did not biomineralize an easily preservable skeleton they are nearly always carbonized. The process of carbonization combined with the highly compressible nature of shales made most graptolite fossils extremely flat and therefore difficult to study.





Graptoloidea

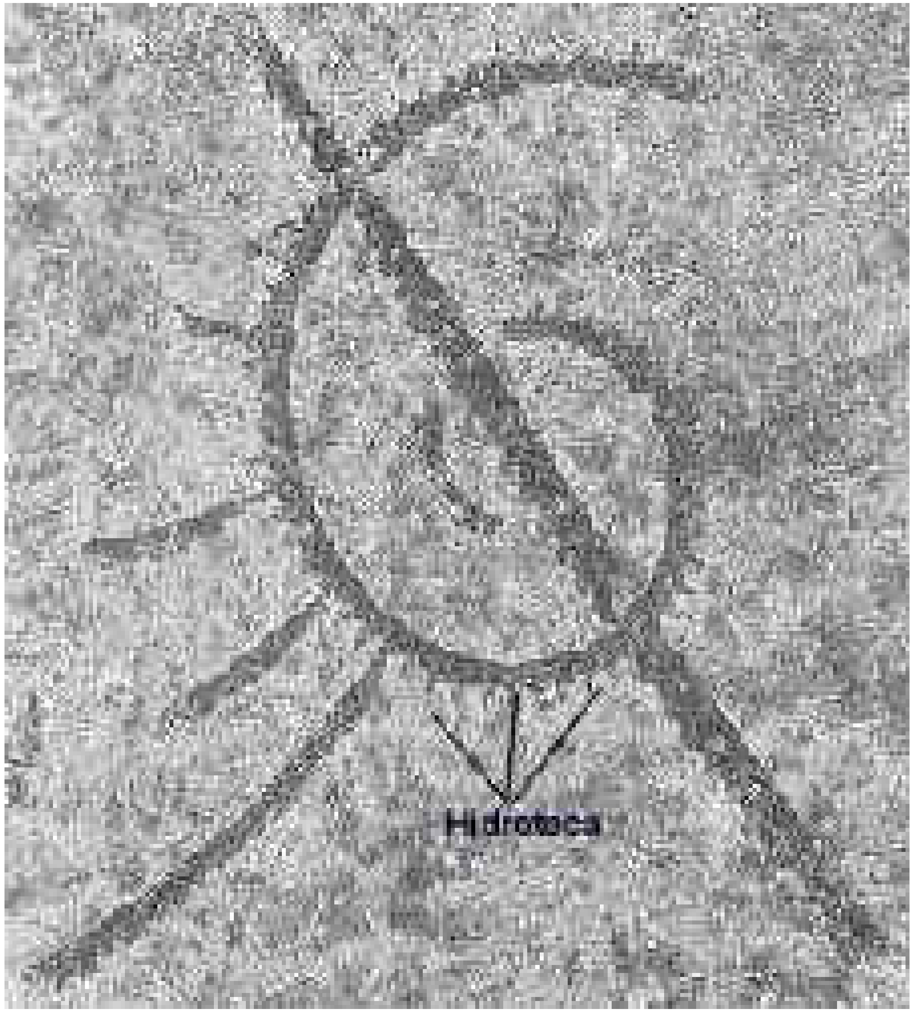


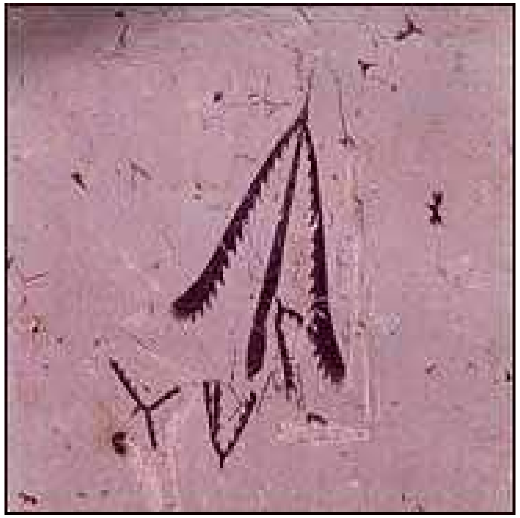
EARLY PALEOZOIC LIFE

Metazoan Invertebrates

Graptolithina (Graptolites)

Marine
Planktonic or epiplanktonic
Sessile benthonic
Chitin skeleton
Cambrian to Mississippian?



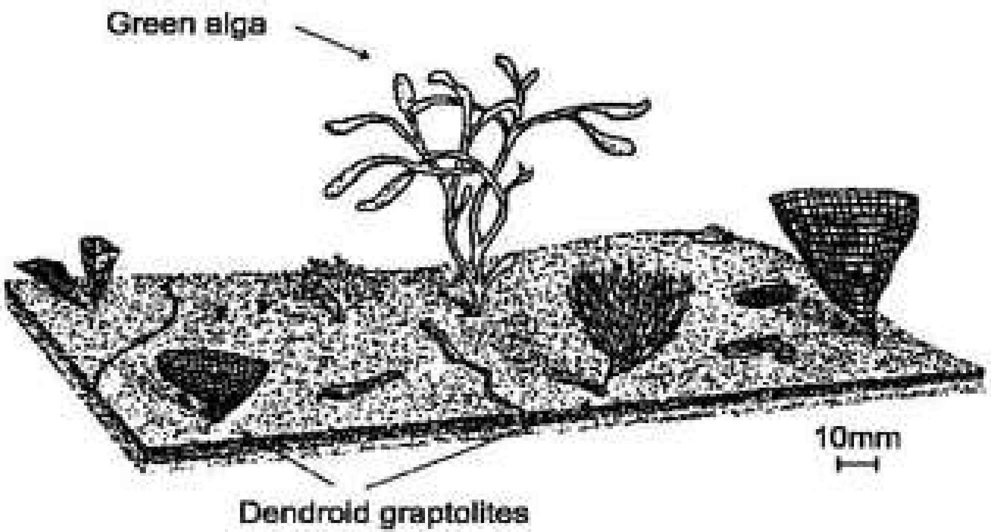


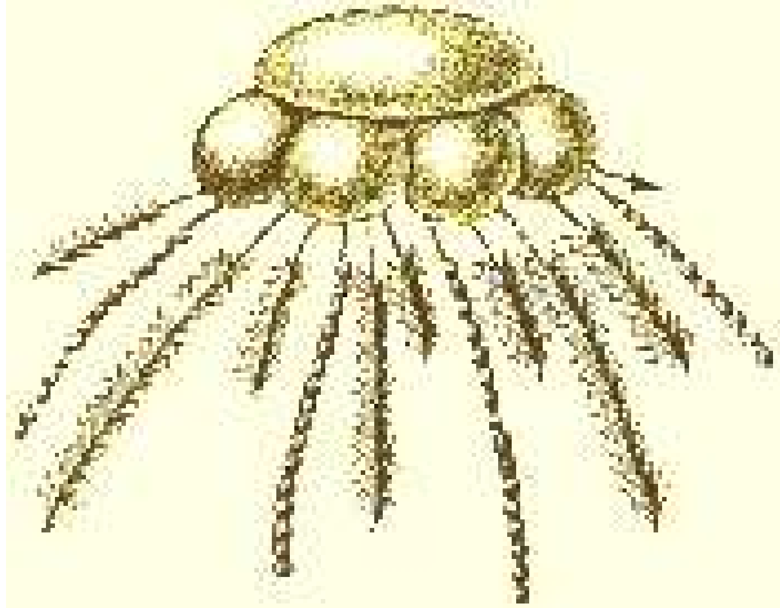
Good index fossil for Ord-Sil

EARLY PALEOZOIC LIFE

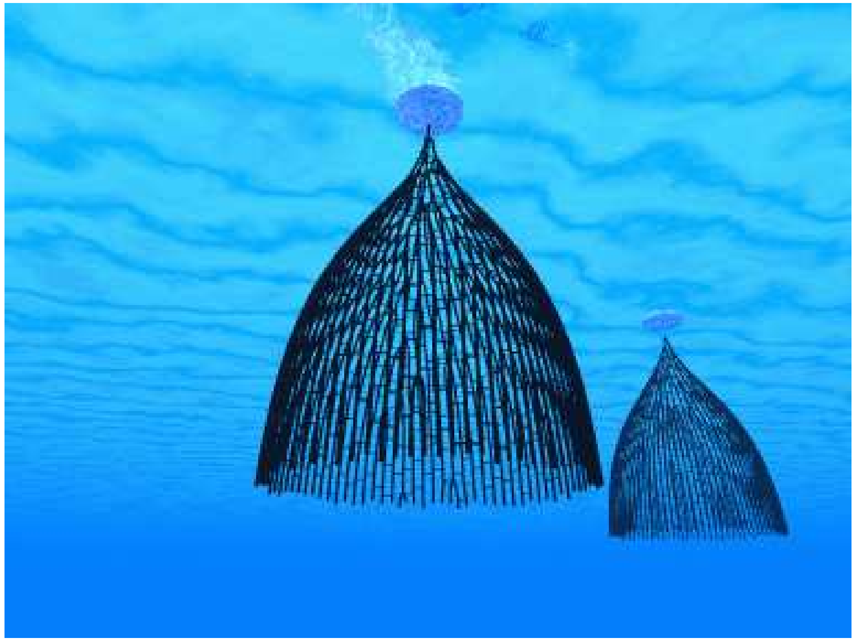
Metazoan Invertebrates

Graptolithina (Graptolites)





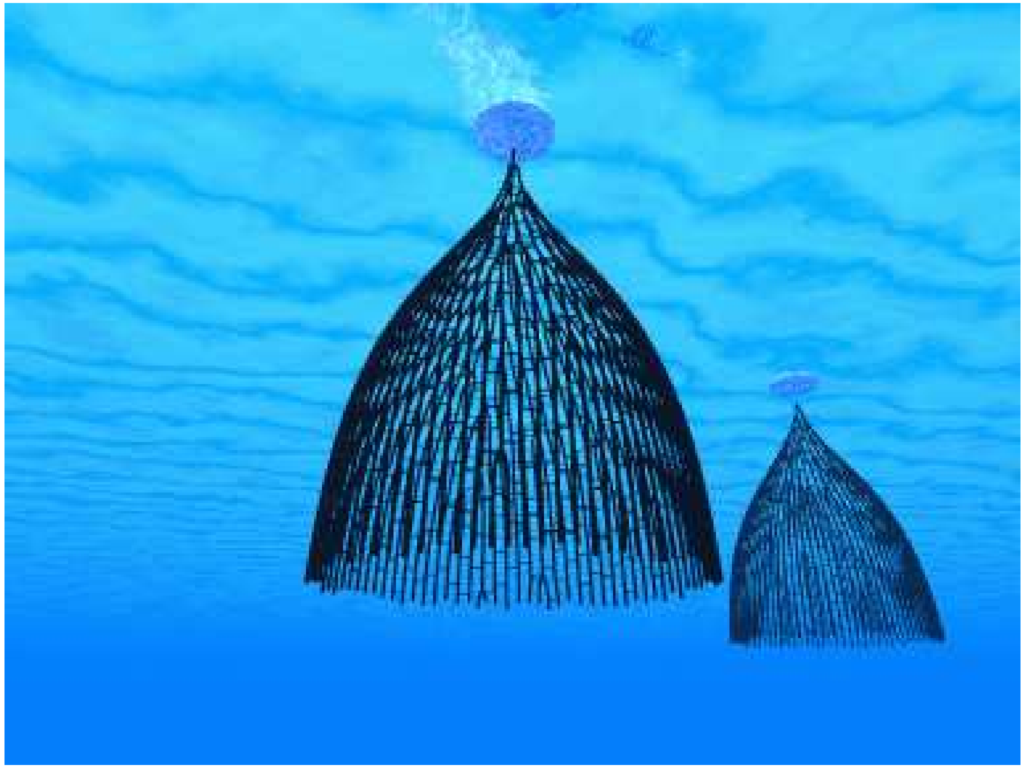
MONOGRAPTUS



- **Silurian graptolite shales**

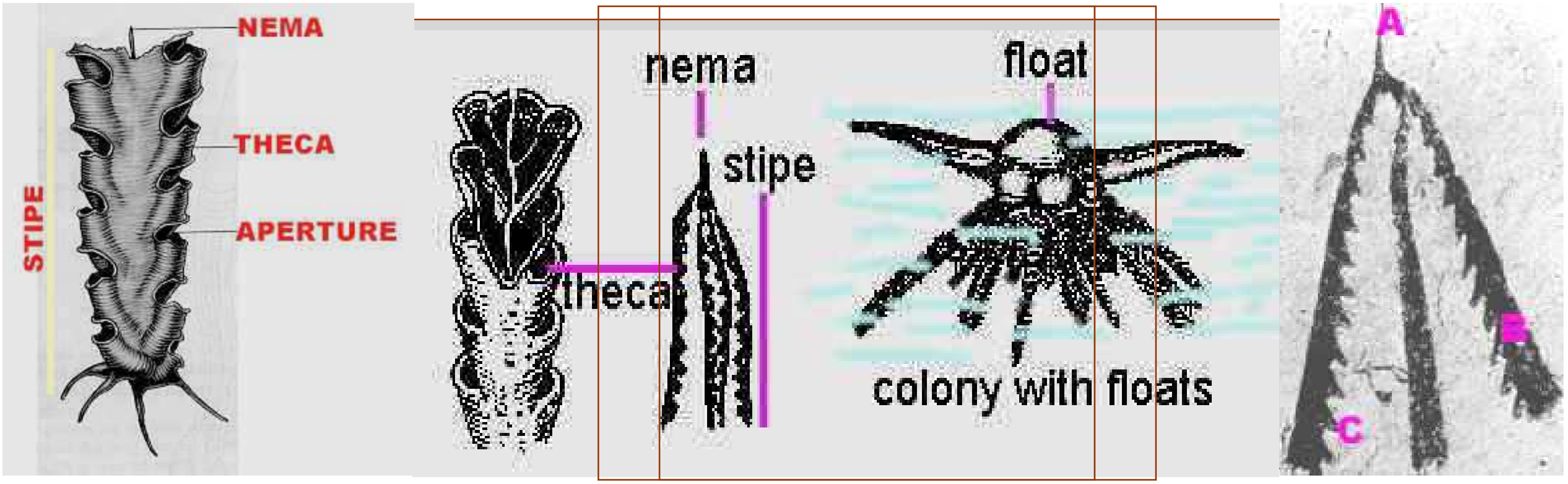
Climacograptus

Didymograptus from Victoria, Australia
(Lower Ordovician)
Graptolites range from the middle Cambrian to the Carboniferous. Dendroidea are found across this entire span while Graptoloida are found from the Ordovician until the early Silurian. Graptolites are most commonly found in deep water, dysoxic facies (black shales), but do extend into shallow facies. Because they did not biomineralize an easily preservable skeleton they are nearly always carbonized.



The dendroid graptolite *Rhabdinopora*, lower Ordovician. Did it float suspended from a "bubble", like a Portuguese Man-o-war, or as epiplankton, attached to seaweed? A colony like this could become at least a foot long.

FIGURE 8–21 **Branches (stipes) of the graptolite *Diplograptus*.** *Diplograptus* is also common in dark shales of Ordovician age in both Europe and North America.



A. *Portions of* ***dendroid*** *graptolite colonies preserved as carbonized films on the surface of black shale of Early Paleozoic age   Dendroid graptolites were probably benthic organisms* (approximately life size).
B. *Fragments of* ***graptoloid*** *graptolite colonies (****stipes****) preserved as carbonized films on the surface of black shale of Early Paleozoic age. Graptoloids were probably planktic organisms and may have attached their colonies to other floating objects as illustrated in morphology figure above* (approximately life size).

KINGDOM: **ANIMALIA**

PHYLUM: **CHORDATA**

SUB-PHYLA: UROCHORDATA (sea squirts)

HEMICHORDATA (pterobranchs, graptolites*) *CAMB.*

CEPHALOCHORDATA (lancets) *CAMB.*

CRANIATA (vertebrates) *CAMB.*

CLASSES: **CONODONTA*** *CAMB.*

AGNATHA (jawless fish) *CAMB.*

ACANTHODI (spiny sharks)* *SIL.*

PLACODERMI (armored fish)* *SIL.*

CHONDRICHTHYES (cartilaginous sharks) *DEV*

OSTEICHTHYES (bony fish) *SIL.*

AMPHIBIA (amphibians) *DEV.*

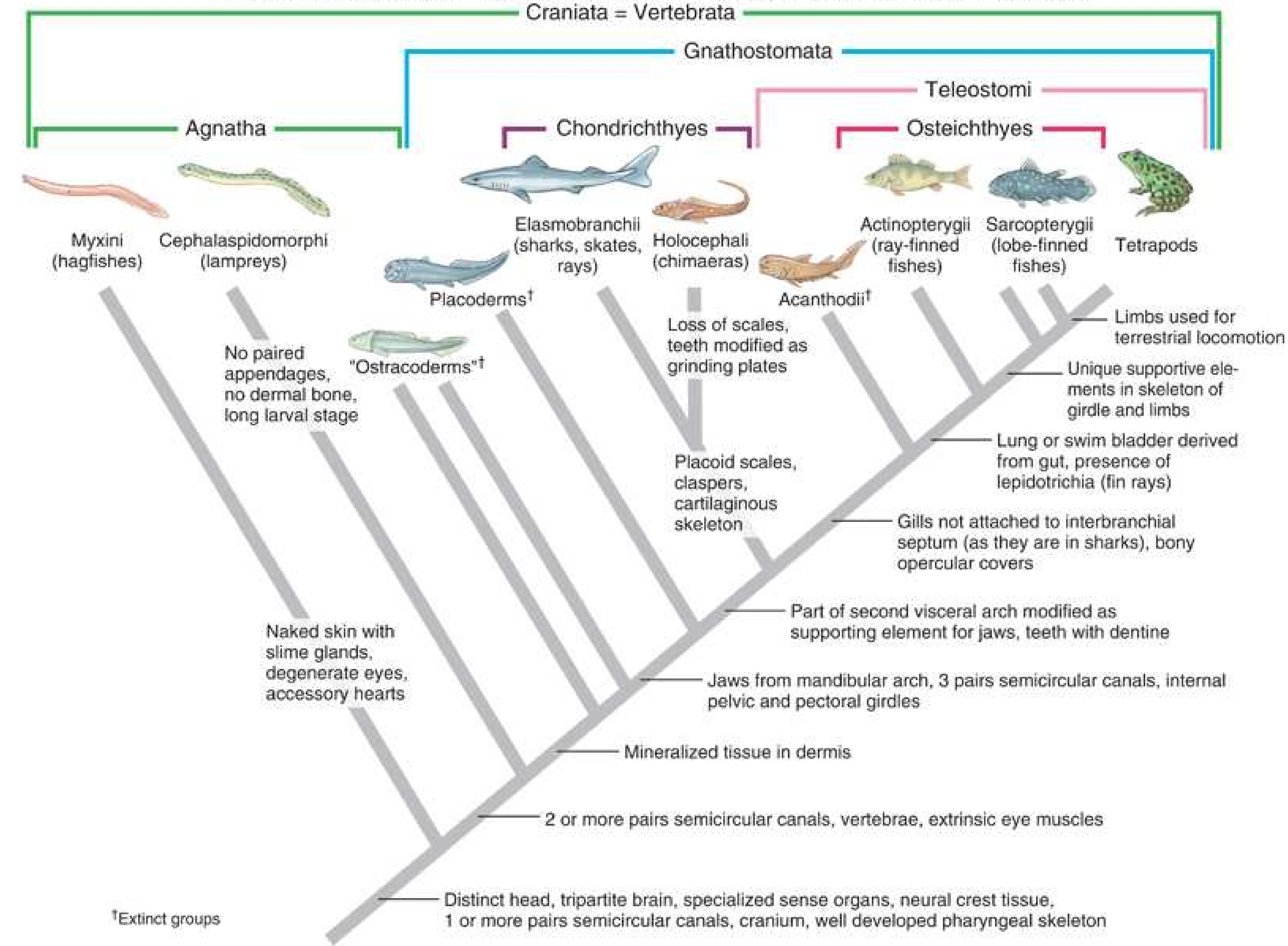
REPTILIA (reptiles) *CARB.*

AVES (birds) *JURASSIC*

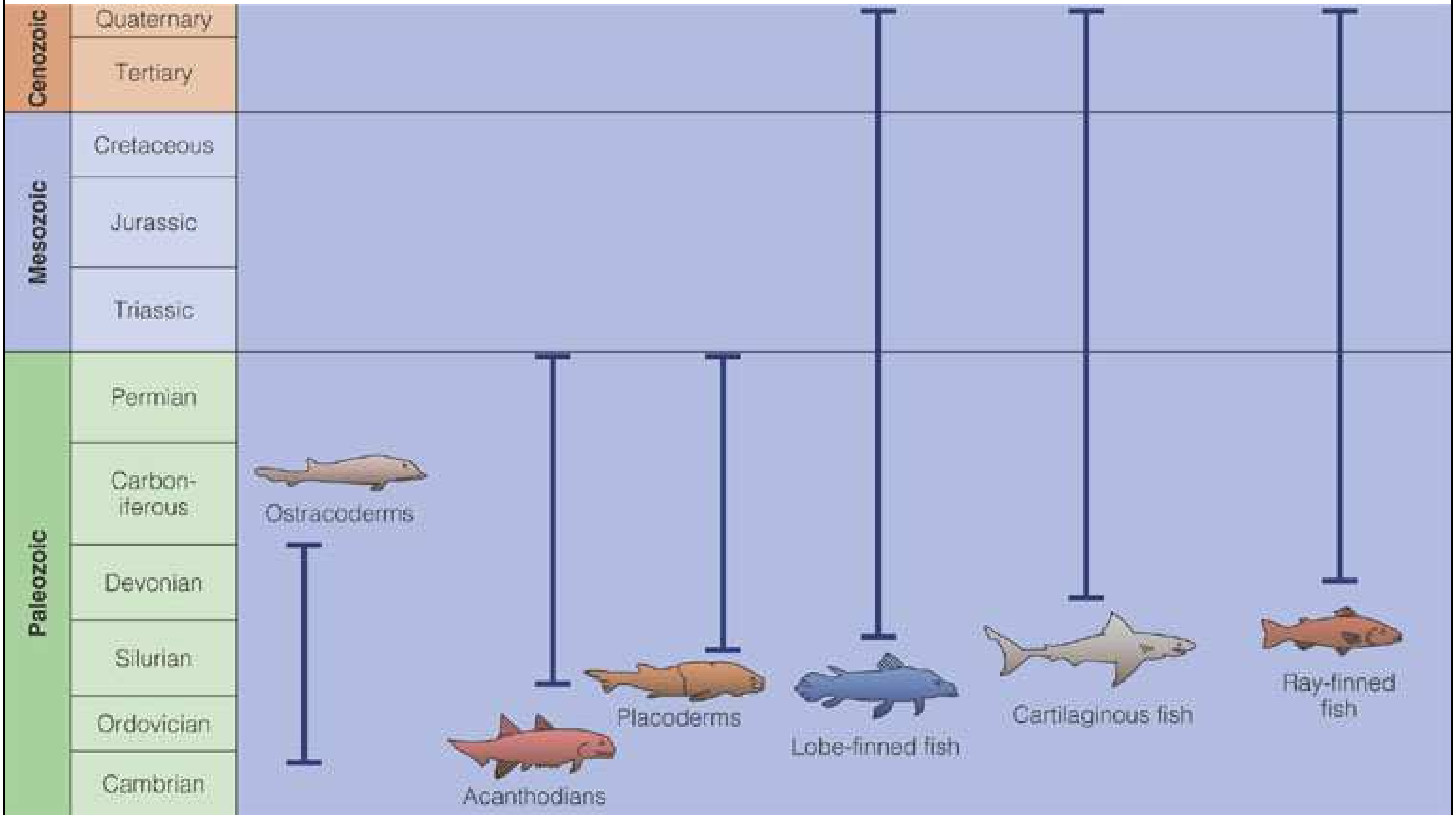
MAMMALIA (mammals) *TRIASSIC*

Subphylum Vertebrata

- Subphylum Vertebrata has several divisions you need to be familiar with:
  - Superclass Agnatha – Jawless Fish; Lampry Eel; Ostracoderm (fossil)
  - Superclass Gnathostomata
    - Class Placodermi – First Jawed Fish (Fossils)
    - Class Chondricthyes – Cartilagenous Fish; Sharks; Rays
    - Class Osteicthyes
      - Subclass Actinopterygii – Ray-finned Fish; Goldfish; Sea Horse
      - Subclass Sarcopterygii – Lobe-finned Fish; Coelocanth


Craniata = Vertebrata
Gnathostomata
Teleostomi
Agnatha
Chondrichthyes
Osteichthyes
Myxini (hagfishes)
Cephalaspidomorphi (lampreys)
Placoderms†
Elasmobranchii (sharks, skates, rays)
Holocephali (chimaeras)
Acanthodii†
Actinopterygii (ray-finned fishes)
Sarcopterygii (lobe-finned fishes)
Tetrapods
"Ostracoderms"†
No paired appendages, no dermal bone, long larval stage
Loss of scales, teeth modified as grinding plates
Limbs used for terrestrial locomotion
Unique supportive elements in skeleton of girdle and limbs
Lung or swim bladder derived from gut, presence of lepidotrichia (fin rays)
Placoid scales, claspers, cartilaginous skeleton
Gills not attached to interbranchial septum (as they are in sharks), bony opercular covers
Part of second visceral arch modified as supporting element for jaws, teeth with dentine
Naked skin with slime glands, degenerate eyes, accessory hearts
Jaws from mandibular arch, 3 pairs semicircular canals, internal pelvic and pectoral girdles
Mineralized tissue in dermis
2 or more pairs semicircular canals, vertebrae, extrinsic eye muscles
Distinct head, tripartite brain, specialized sense organs, neural crest tissue, 1 or more pairs semicircular canals, cranium, well developed pharyngeal skeleton
†Extinct groups

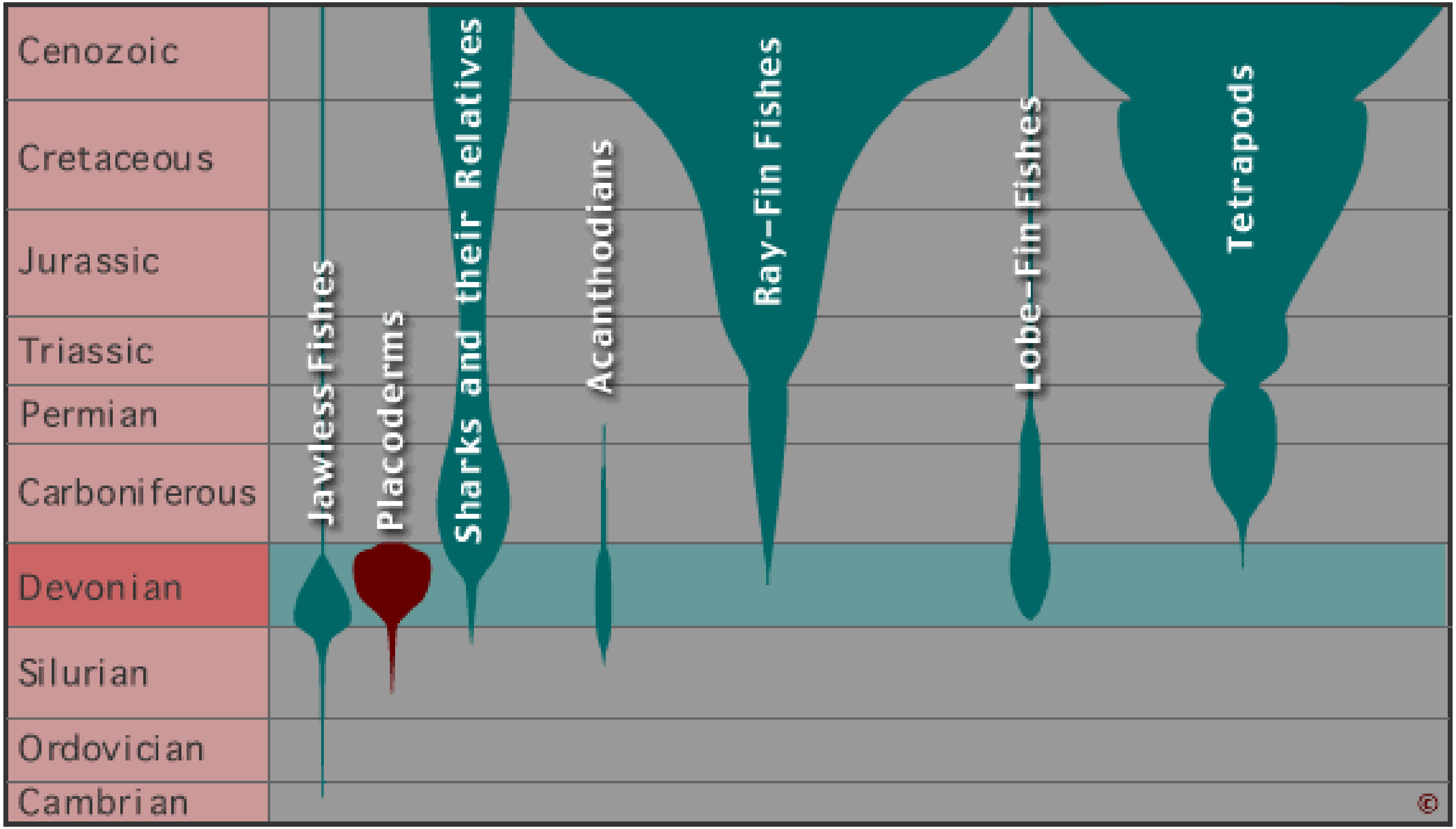
Geologic Ranges of Major Fish Groups



EARLY PALEOZOIC LIFE

Vertebrates

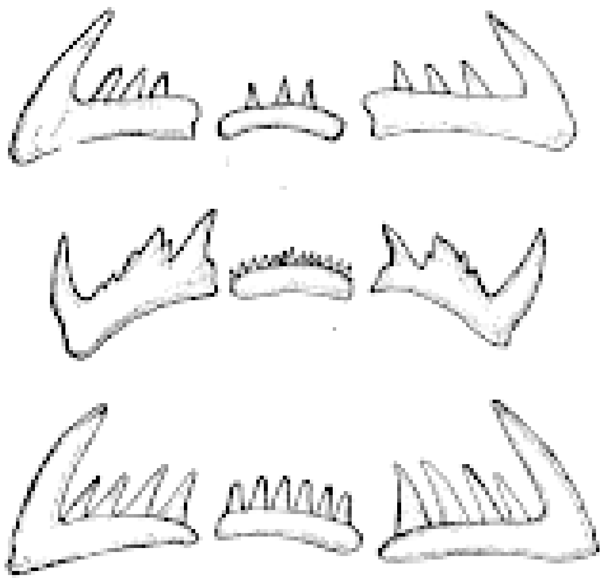
Fish

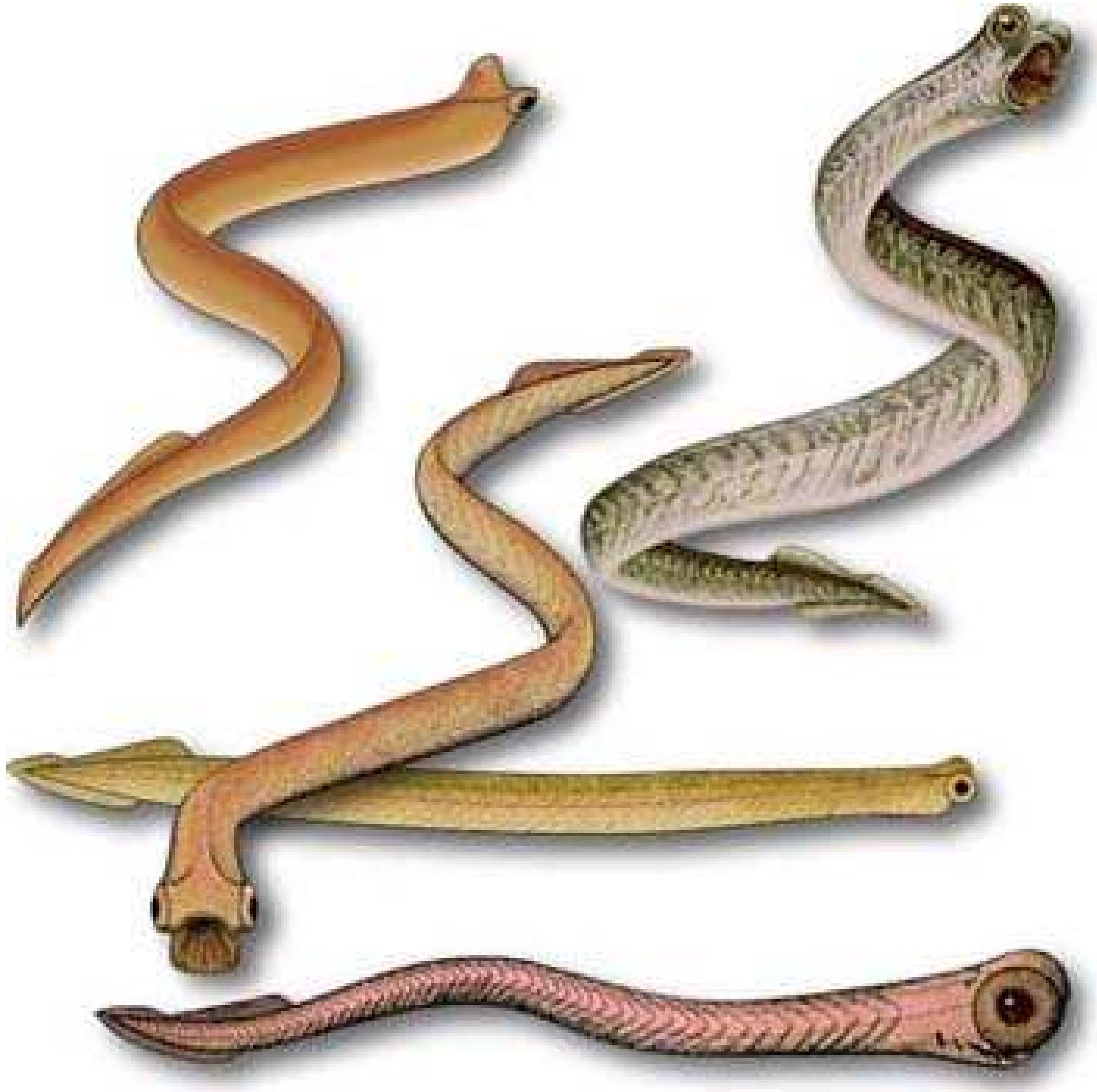


EARLY PALEOZOIC LIFE

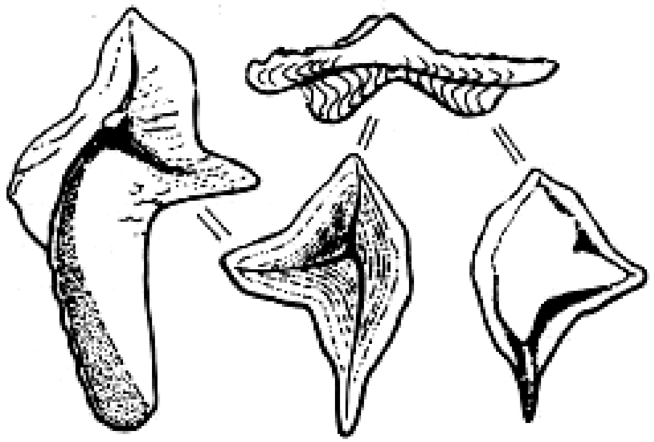
Vertebrates

Conodonts
Chordate
Resemble teeth
Proterozoic to Triassic
Calcium phosphate





CONODONTA



Conodont animals
(Conodontophorida)

- Conodont teeth are very common fossils, known since early 1800s, but animal body only described in 1983
- May or may not be true vertebrates
    - **Vertebrate characters** sense organs with capsules; $CaPO_4$ mineralization
    - **Non-vertebrate characters** V-shaped myomeres; notochord but no trace of vertebrae
- 250+ million-year fossil history (Late Cambrian-Triassic)

A single conodont. . .

A conodont apparatus. . .

EARLY PALEOZOIC LIFE

Vertebrates

Conodonts

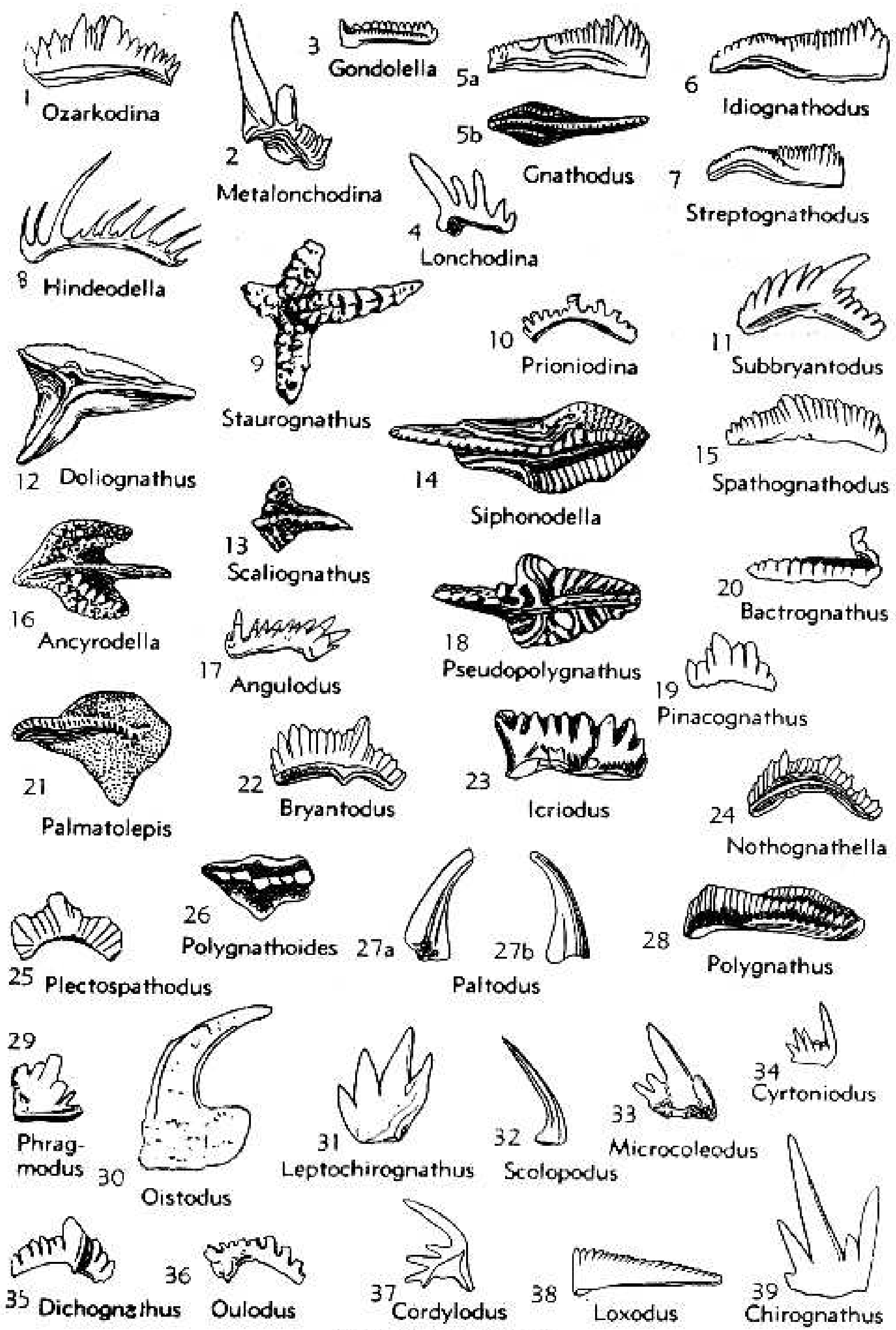


FIG. 23-2. (*See next page.*)

Pre-1964 examples

Ordovician-29-39
Silurian-25-27
Devonian-16,17,21-24,28
Mississippian-4,8-15,18-20
Pennsylvanian-1-3,5-7

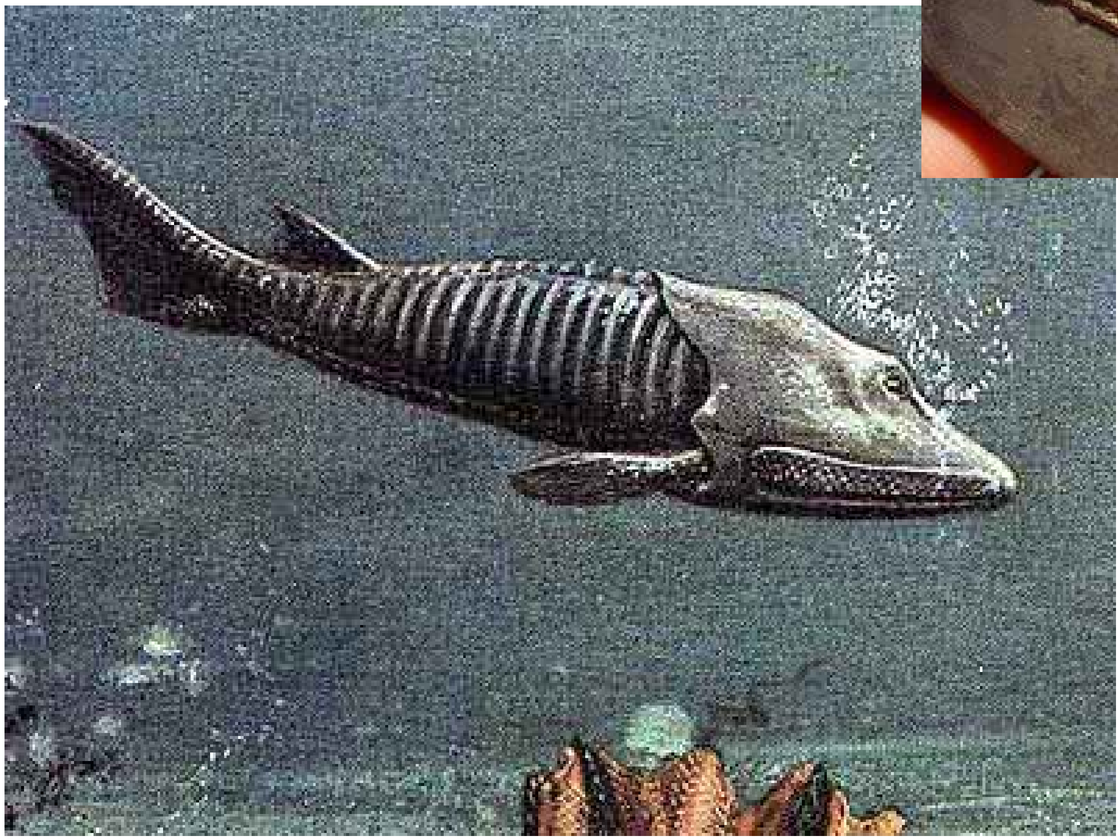
EARLY PALEOZOIC LIFE

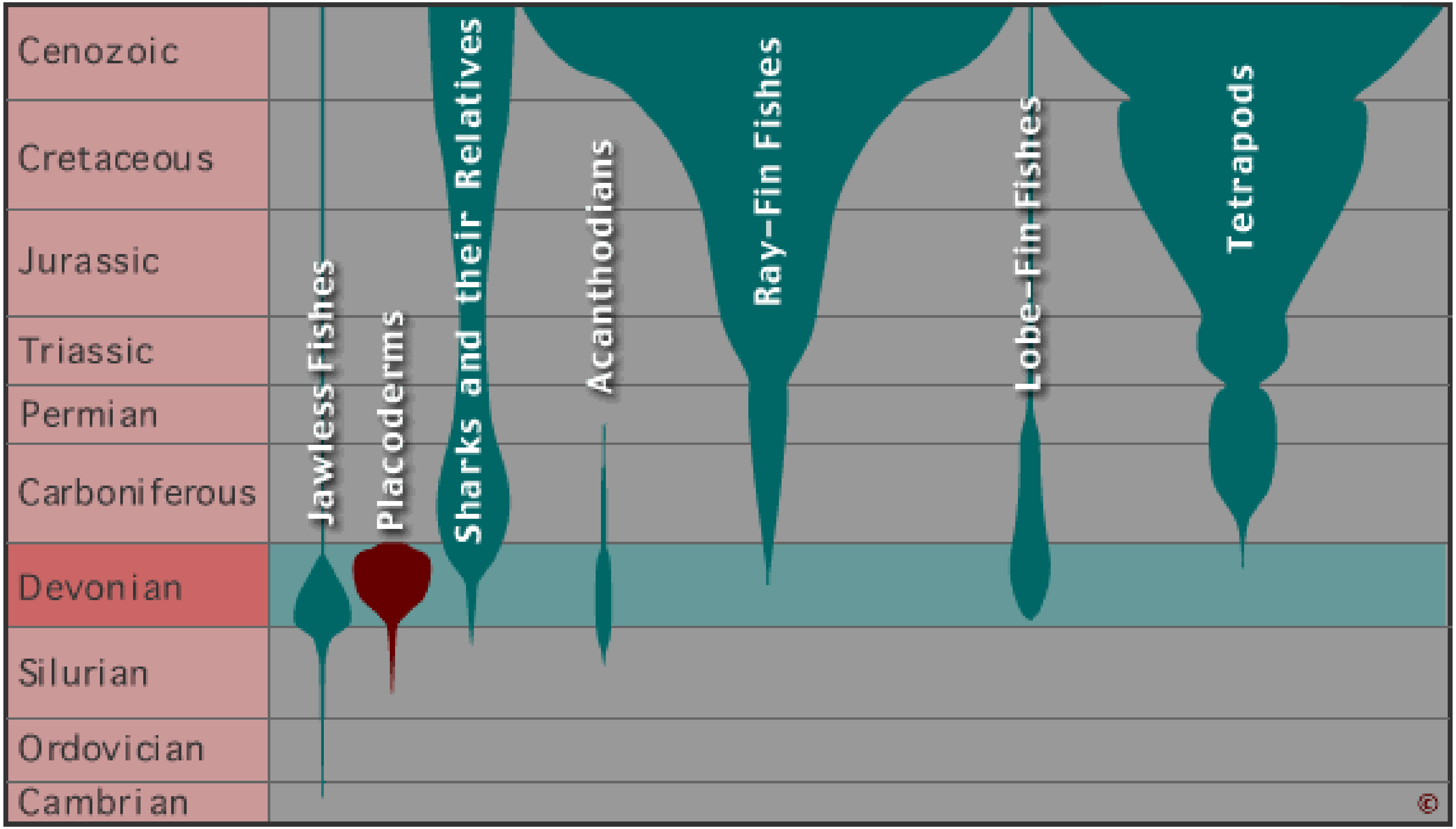
Vertebrates

Fish

Agnatha (Agnathids)

Jawless fish



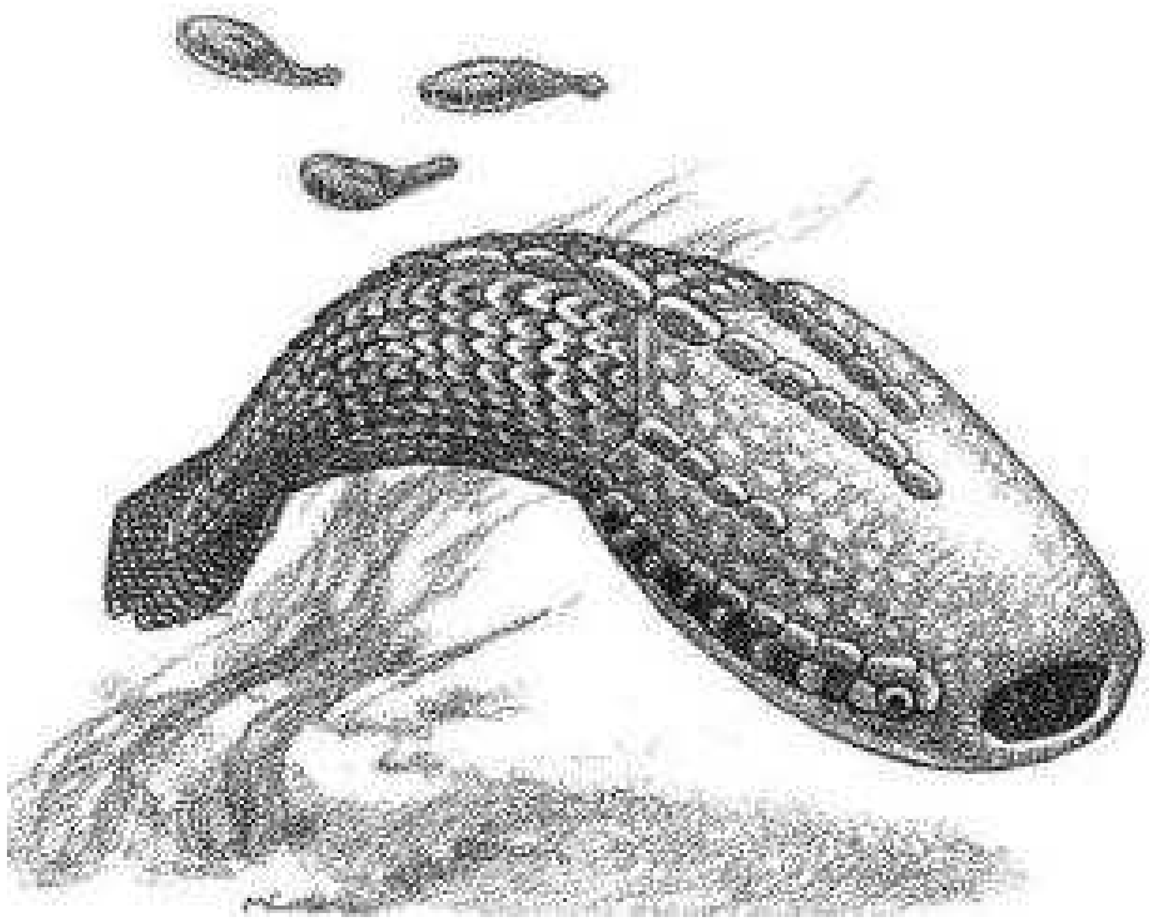

Cenozoic
Cretaceous
Jurassic
Triassic
Permian
Carboniferous
Devonian
Silurian
Ordovician
Cambrian
Jawless Fishes
Placoderms
Sharks and their Relatives
Acanthodians
Ray-Fin Fishes
Lobe-Fin Fishes
Tetrapods
©

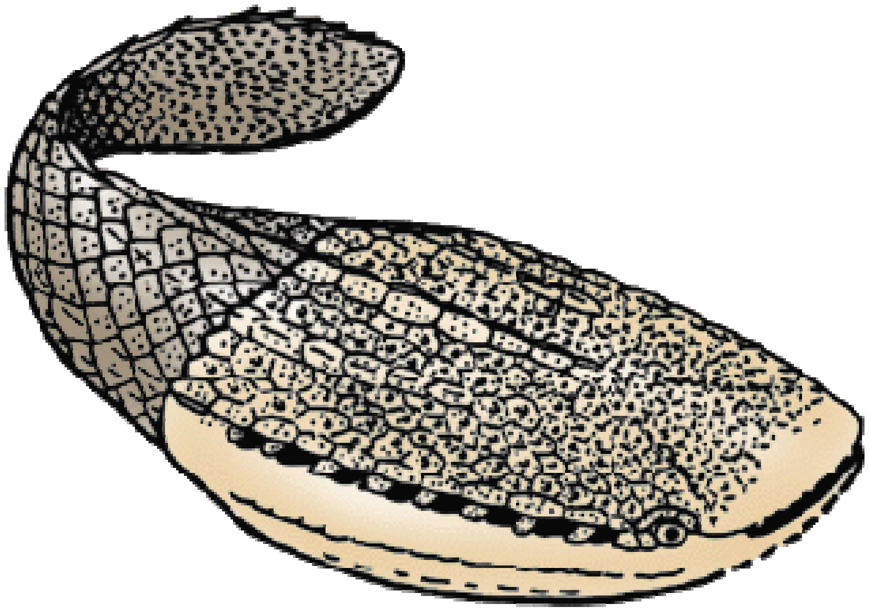
EARLY PALEOZOIC LIFE

Vertebrates

Fish
Agnatha (Agnathids)
Jawless fish

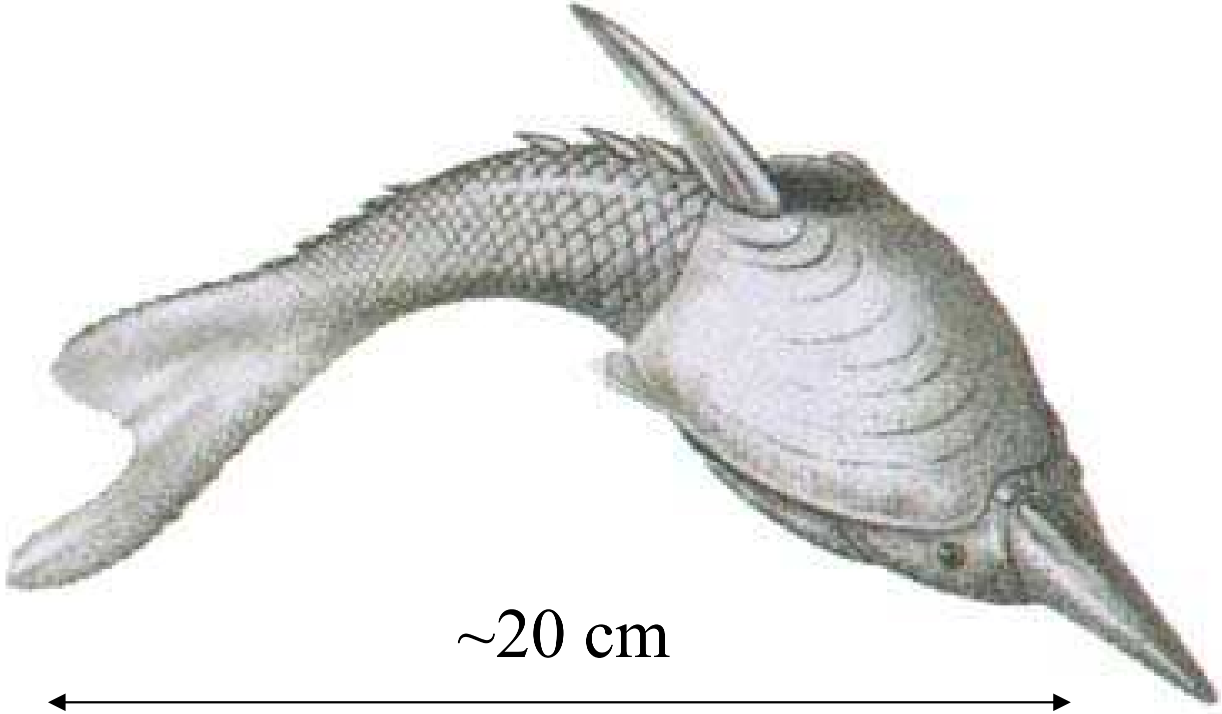
Astrapis



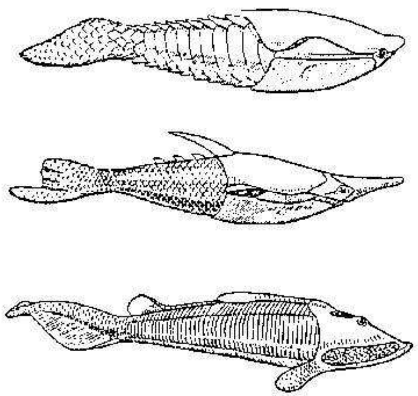


Astraspis

Devonian Jawless Fish

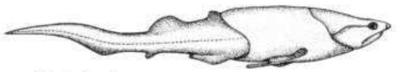


Ostracodermi

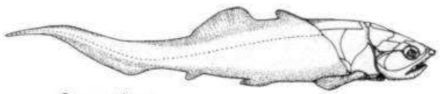


Placodermi (Elasmobranchiomorphi)

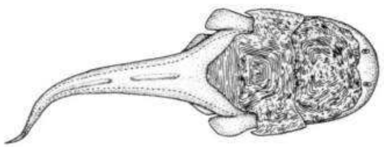
aus Romer & Parsons - Vergleichende Anatomie der Wirbeltiere



Arctolepis

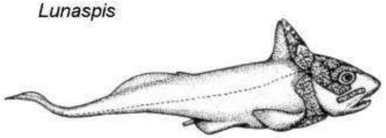


Coccosteus

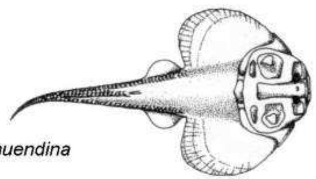


Phyllolepis

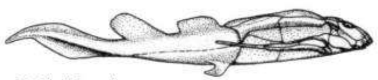
Lunaspis



Ramphodopsis



Gemuendina



Bothriolepsis

Agnatha

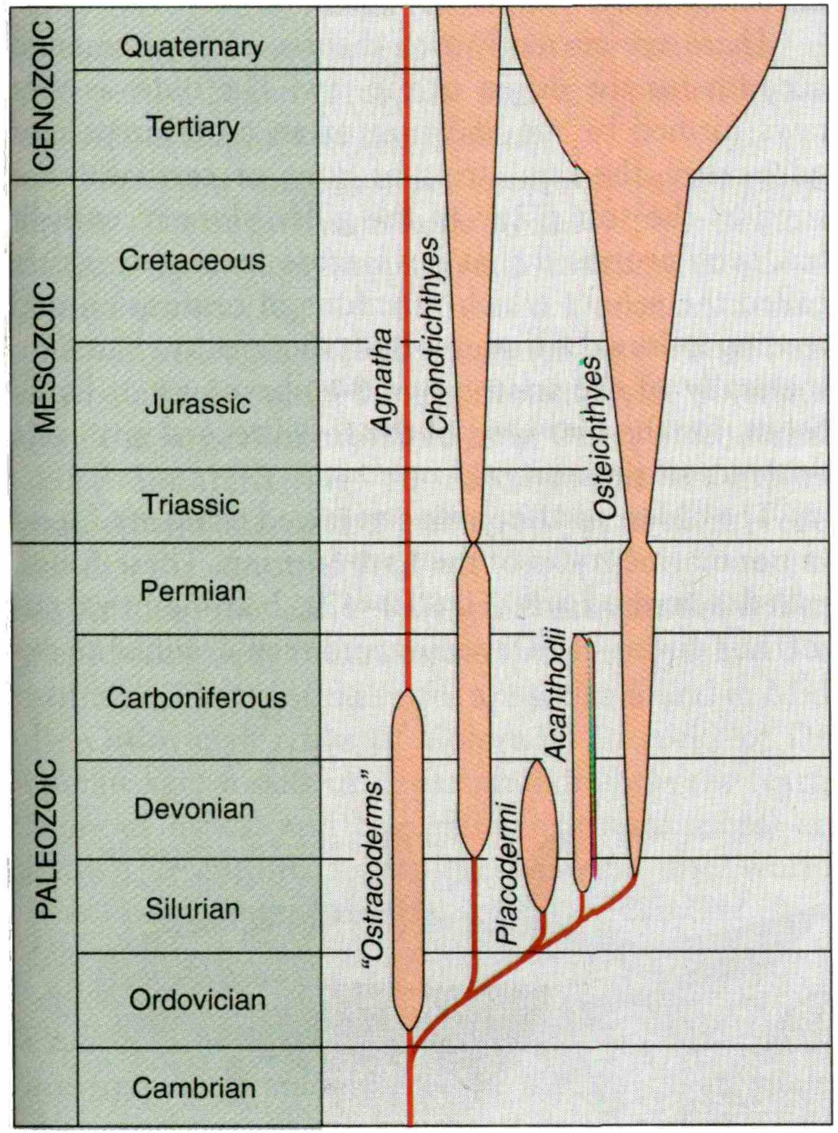


FIGURE 10–64 Evolution of the five major categories of fishes. The width of the vertical red areas indicates the approximate relative abundance of each group. *(From many authors.)*

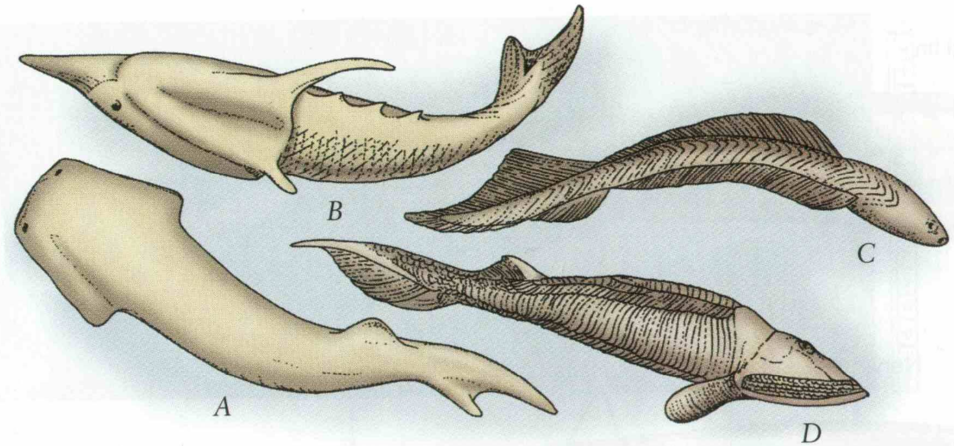
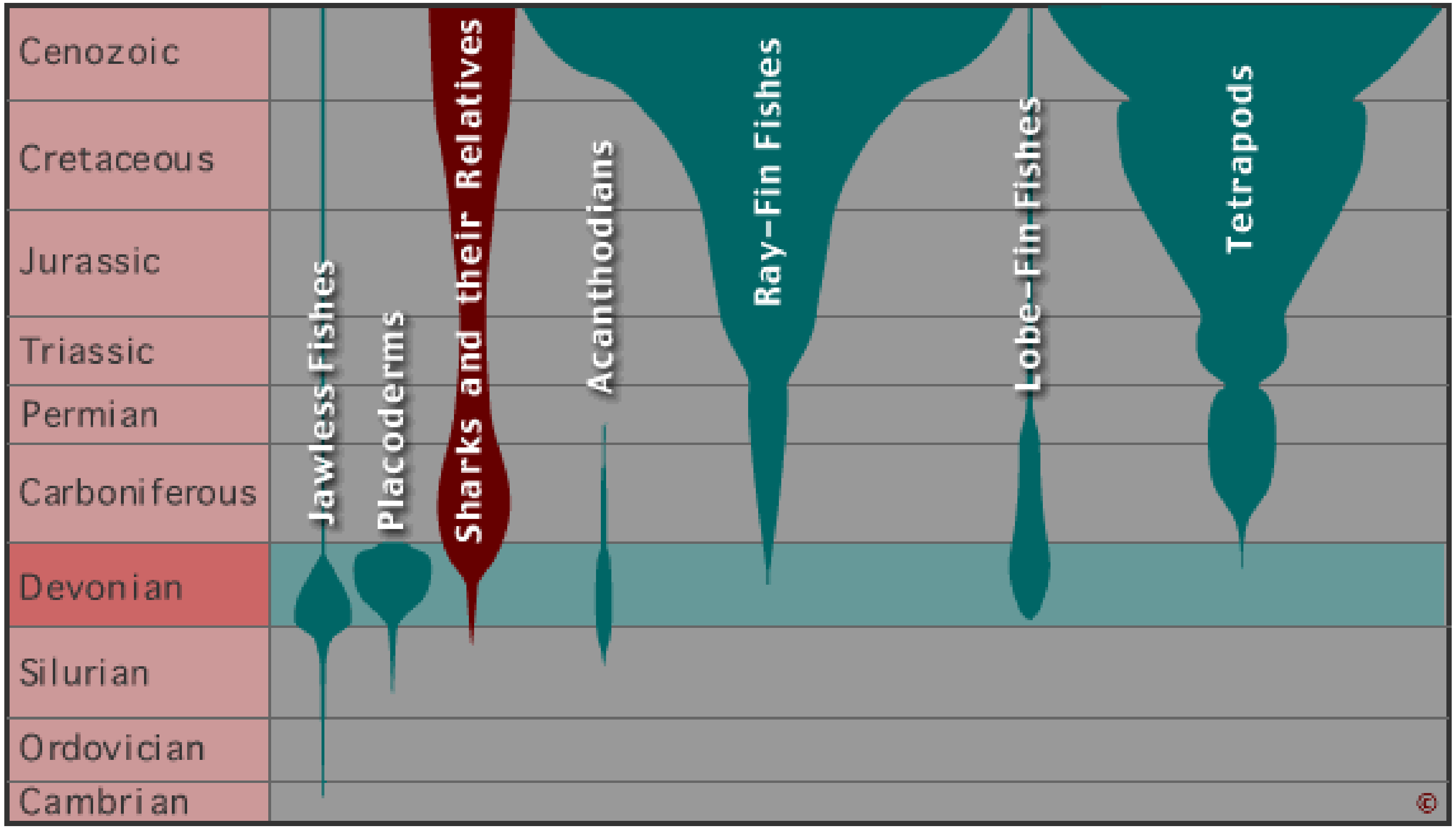
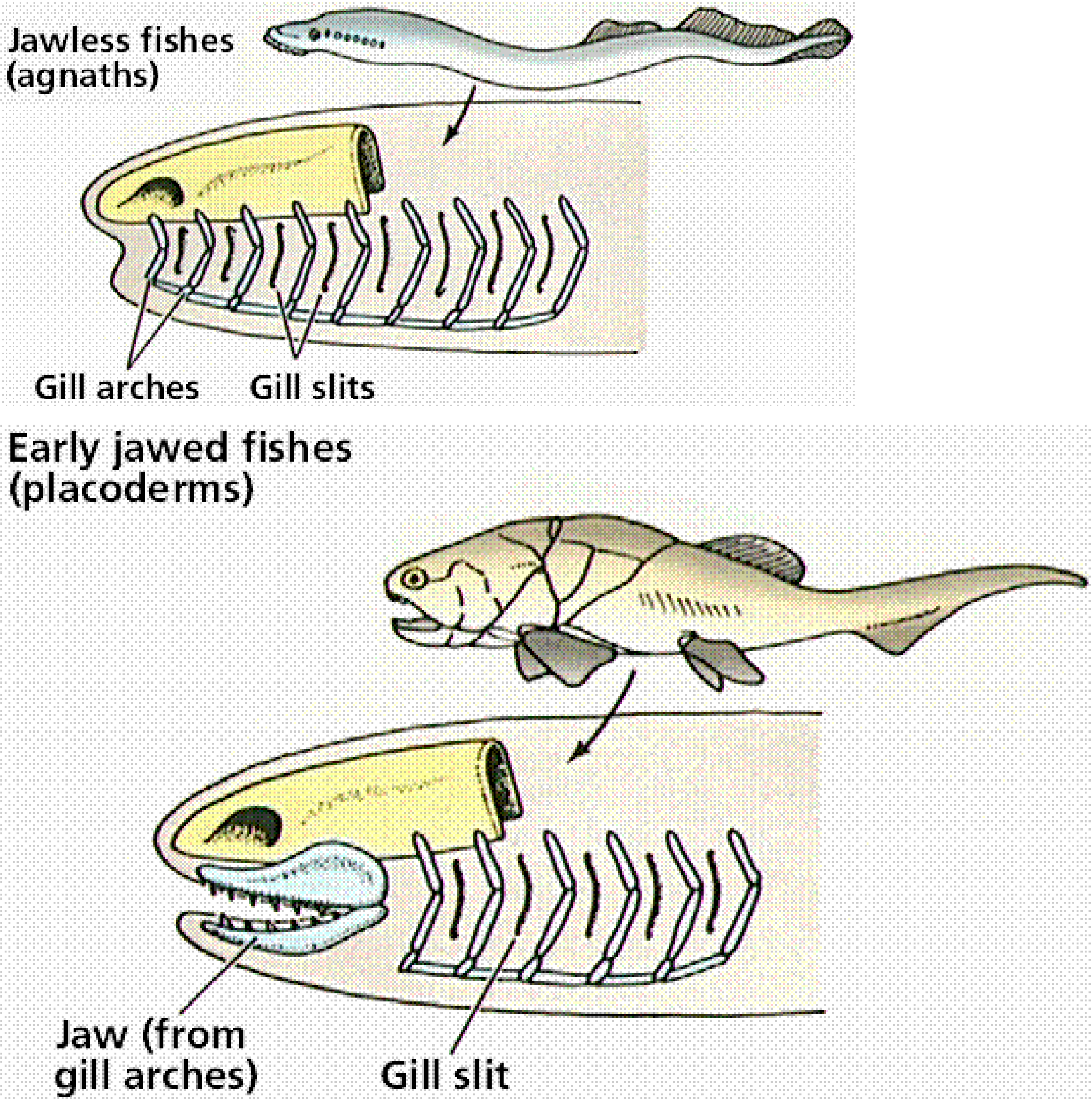


FIGURE 10–66 The early Paleozoic ostracoderms. (A) *Thelodus*, (B) *Pteraspis*, (C) *Jamoytius*, and (D) *Hemicyclaspis* drawn to the same scale.



Cenozoic
Cretaceous
Jurassic
Triassic
Permian
Carboniferous
Devonian
Silurian
Ordovician
Cambrian
Jawless Fishes
Placoderms
Sharks and their Relatives
Acanthodians
Ray–Fin Fishes
Lobe–Fin Fishes
Tetrapods
©


Jawless fishes
(agnaths)
Gill arches
Gill slits
Early jawed fishes
(placoderms)
Jaw (from
gill arches)
Gill slit

EARLY PALEOZOIC LIFE

Vertebrates

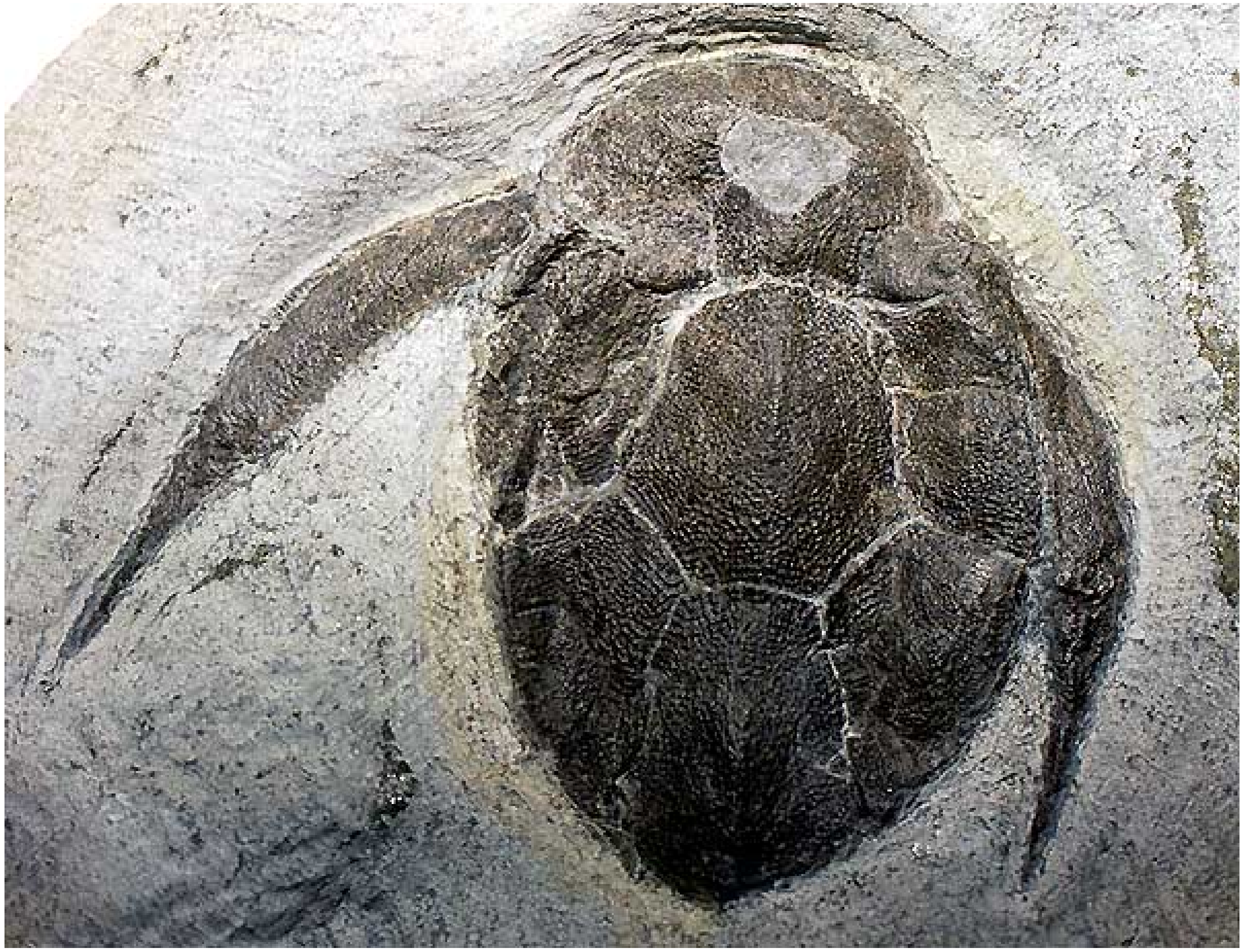
Fish

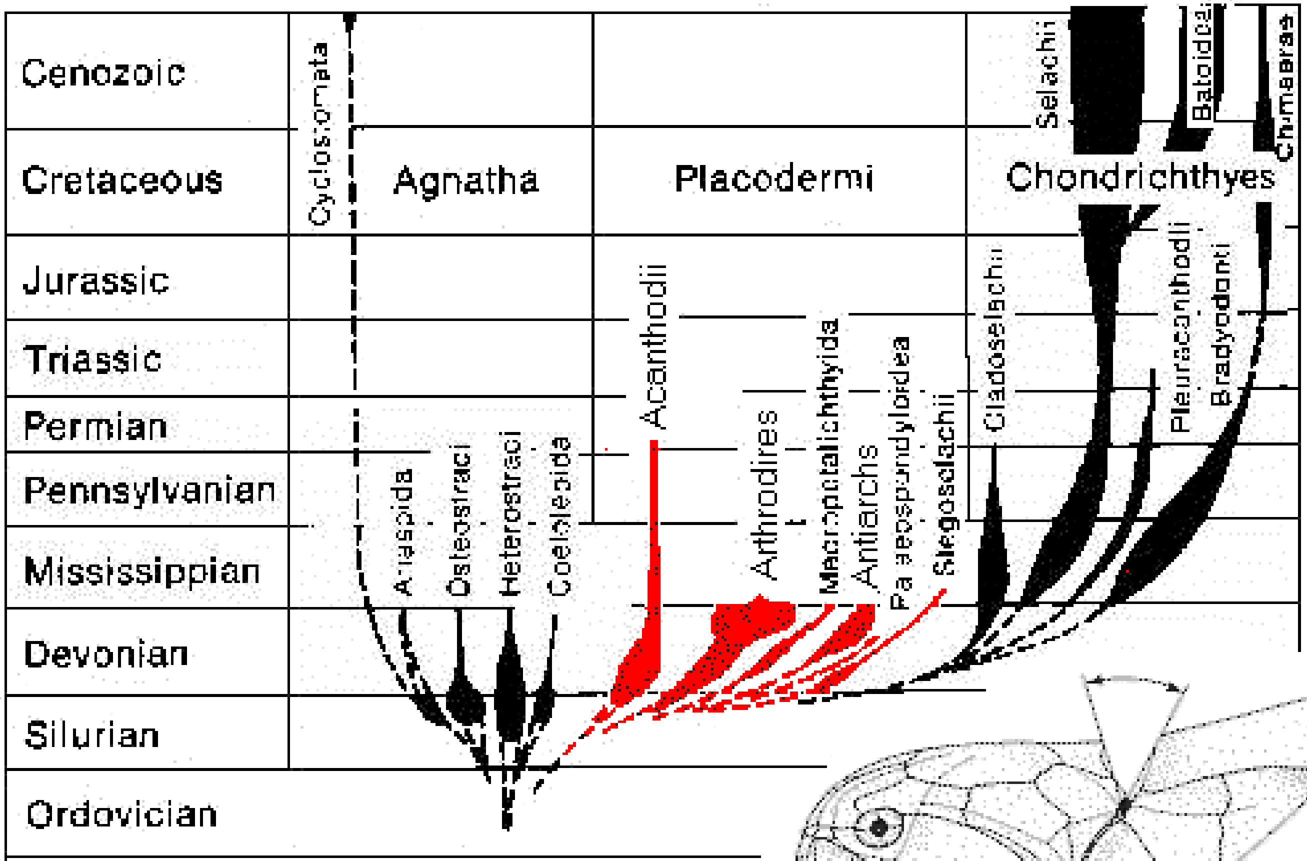
Placodermi (Placoderms)

Plate-skinned fishes

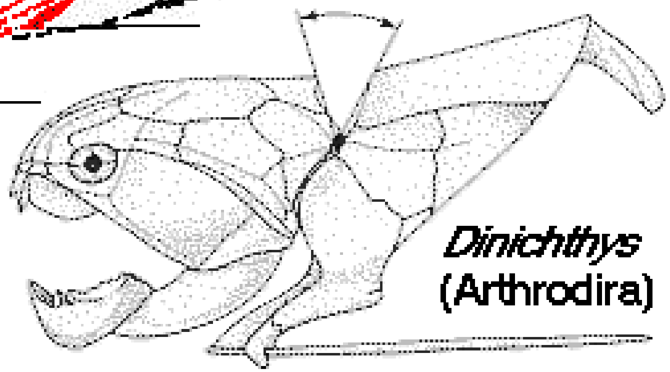
Late Silurian to Permian

Bothryolepis



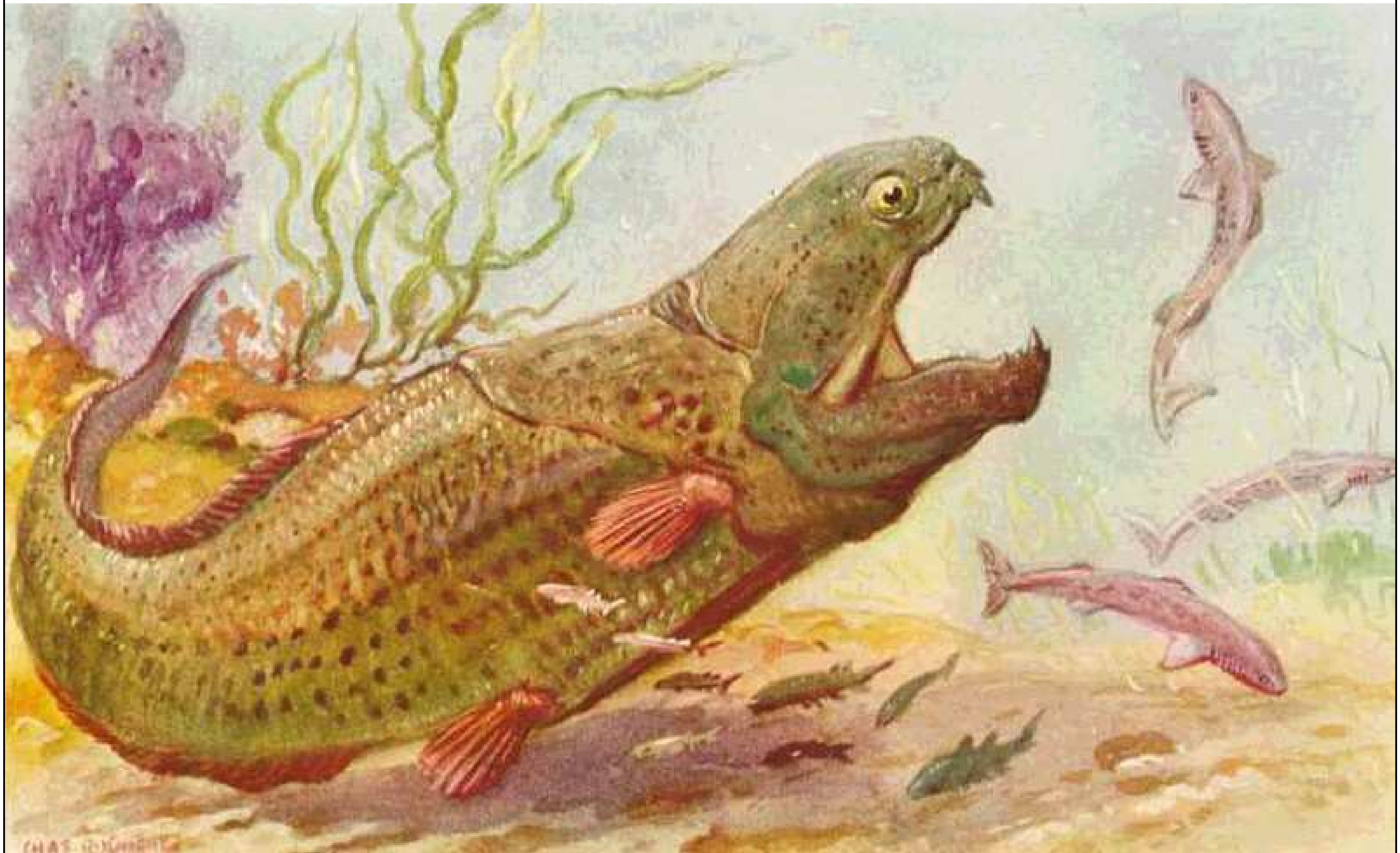


Adaptive Radiation of six Placoderm orders in the Devonian

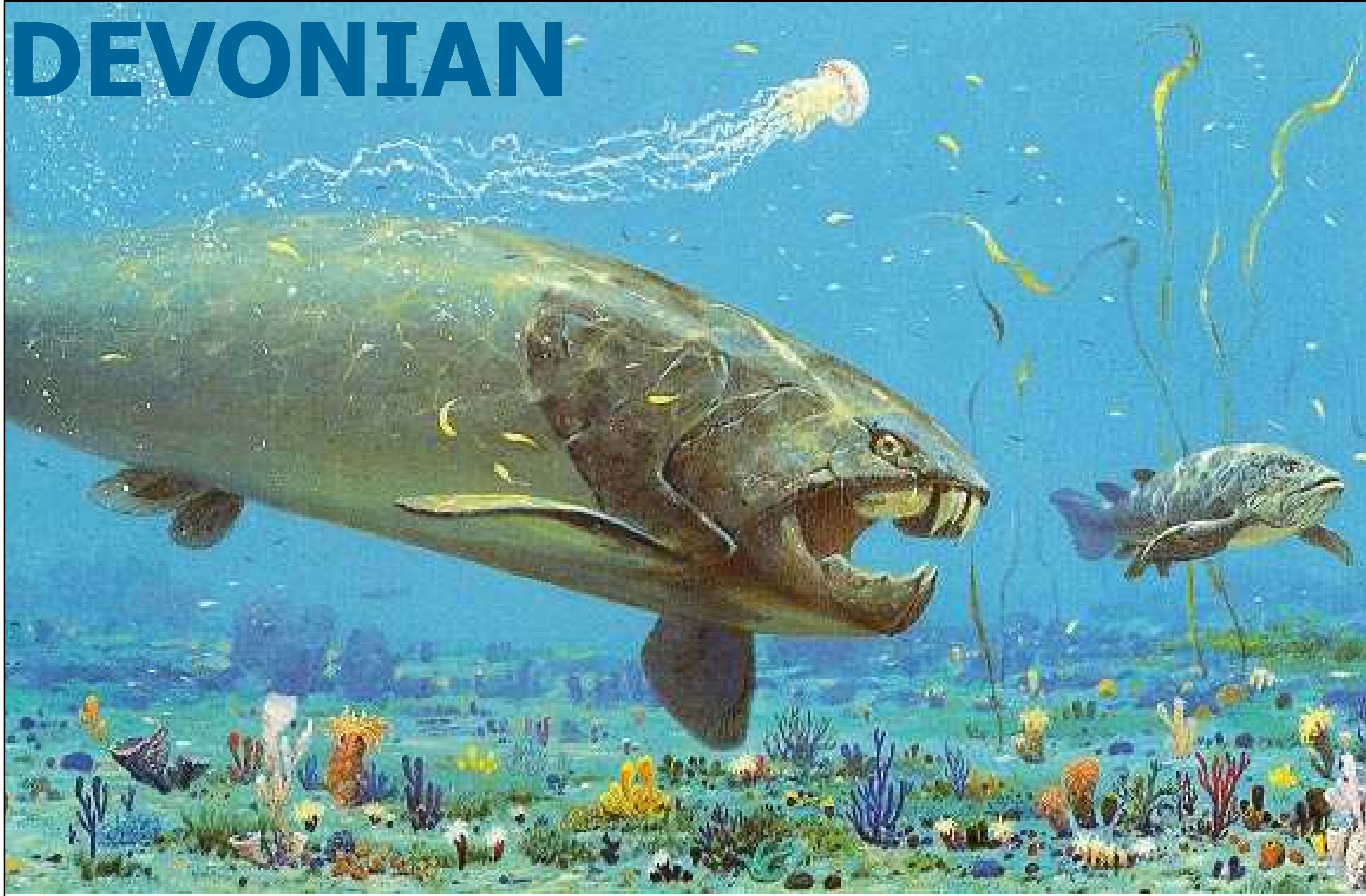


Dinichthys (Arthrodira)

FIGURE 10–68 **The gigantic armored skull and thoracic shield of the formidable late Devonian placoderm fish known as *Dunkleosteus*.** *Dunkleosteus* was over 10 meters (about 30 feet) long. The skull shown here is about 1 meter tall. It is equipped with large bony cutting plates that functioned as teeth. Each eye socket was protected by a ring of four plates, and a special joint at the rear of the skull permitted the head to be raised and thereby provided for an extra large bite. *Dunkleosteus* ruled the seas 350 million years ago. *(Courtesy of the U. S. National Museum of Natural History, Smithsonian Institution; photograph by Chip Clark.)*



DEVONIAN

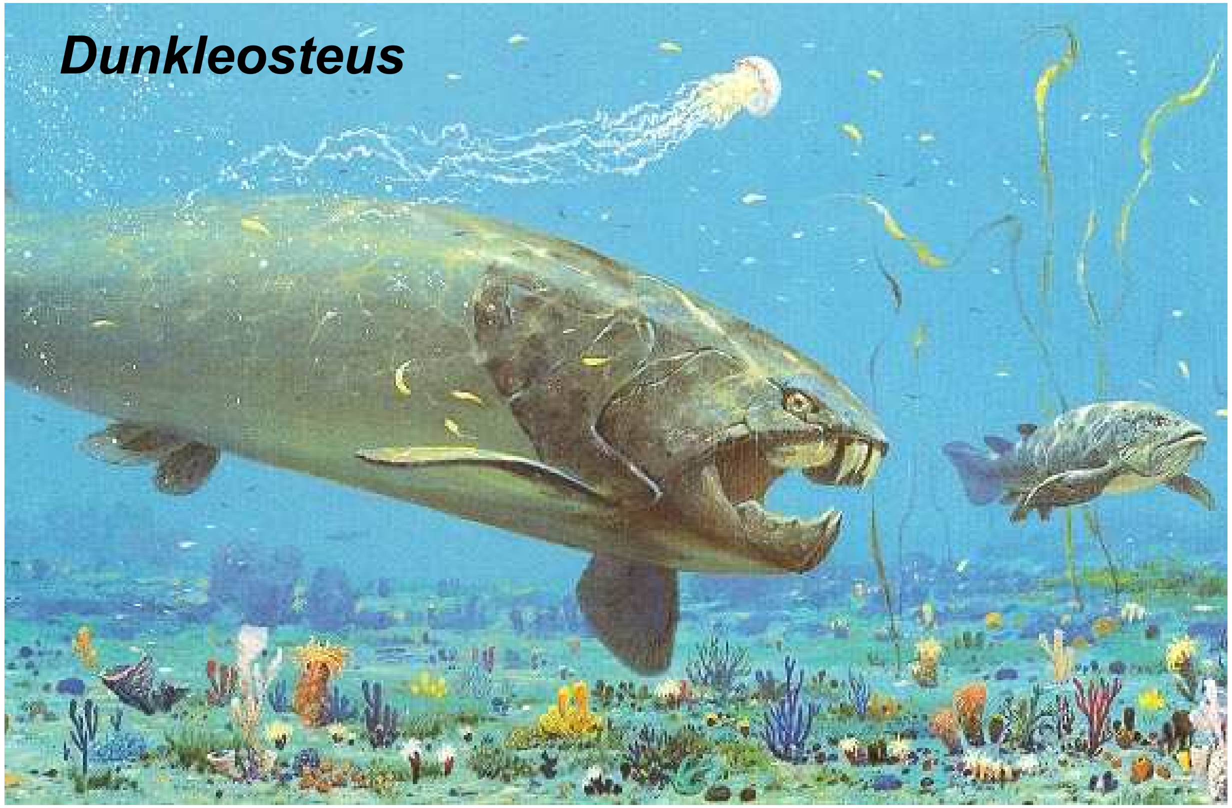


EARLY PALEOZOIC LIFE

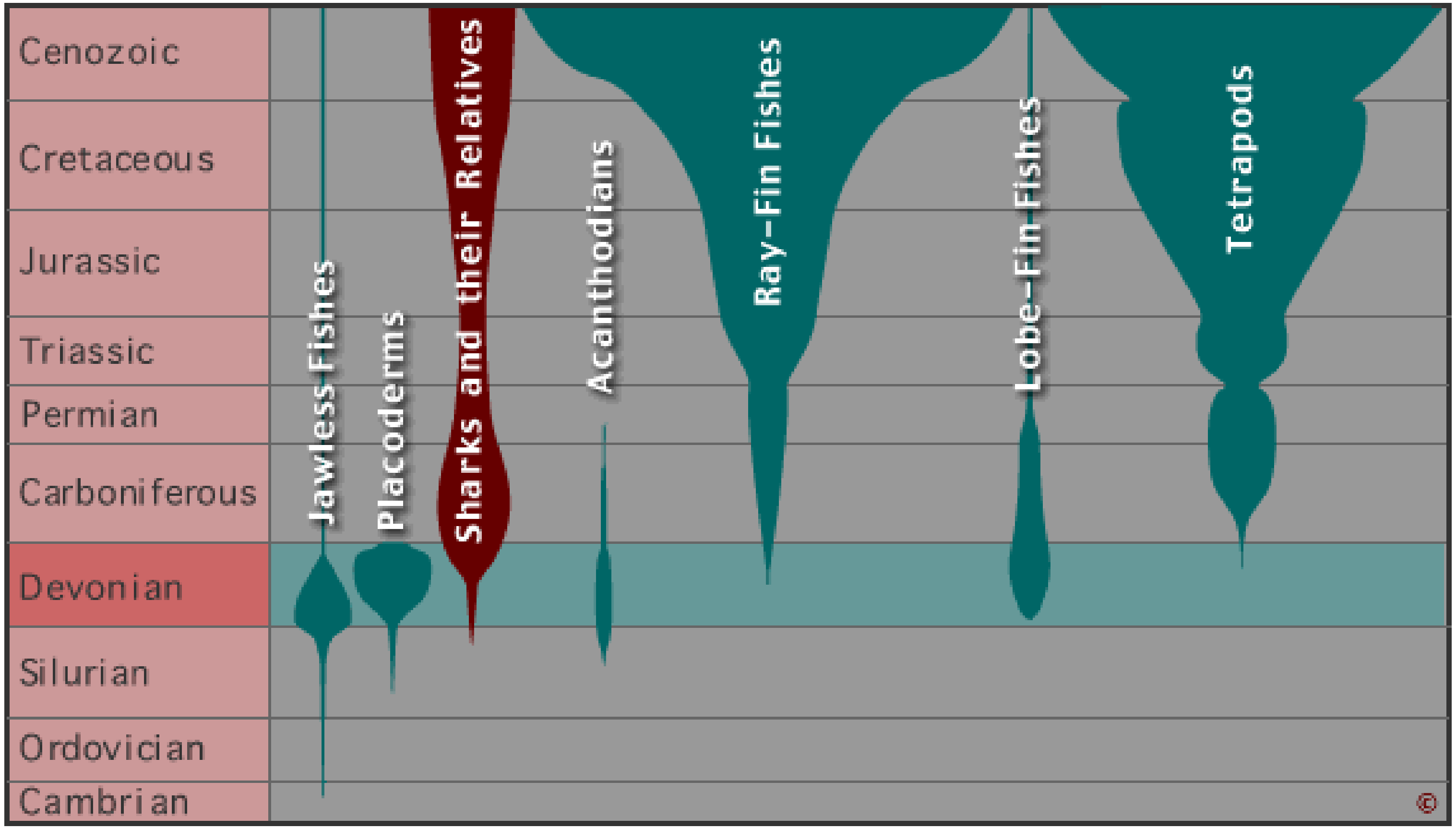
Vertebrates

Fish

Placodermi (Placoderms)



ACANTHODI



Cenozoic
Cretaceous
Jurassic
Triassic
Permian
Carboniferous
Devonian
Silurian
Ordovician
Cambrian
Jawless Fishes
Placoderms
Sharks and their Relatives
Acanthodians
Ray-Fin Fishes
Lobe-Fin Fishes
Tetrapods
©

EARLY PALEOZOIC LIFE

Vertebrates

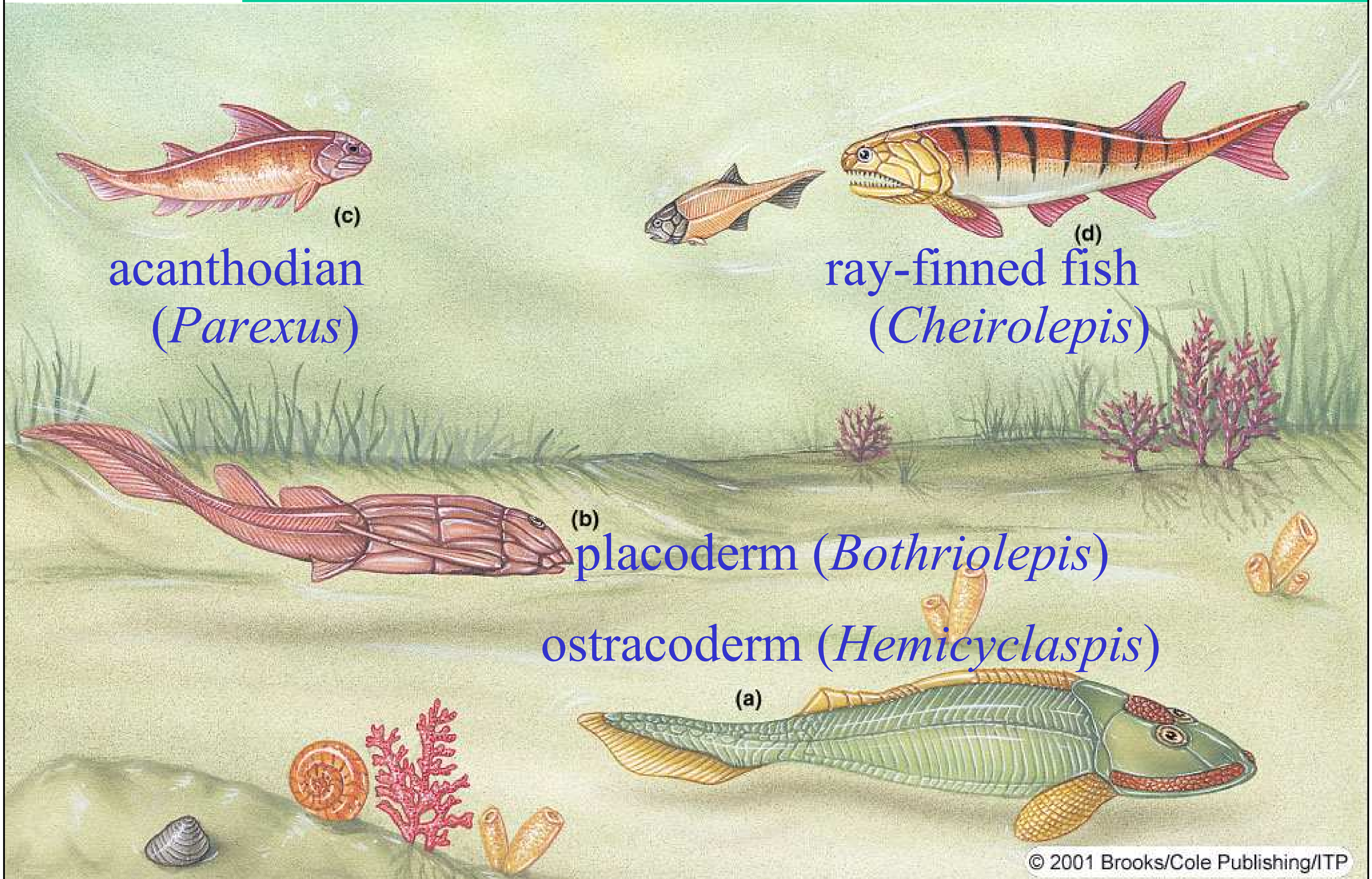
Fish

Acanthodii (Acanthodians)

Early jawed fish

Late Silurian to Permian

Devonian Seafloor



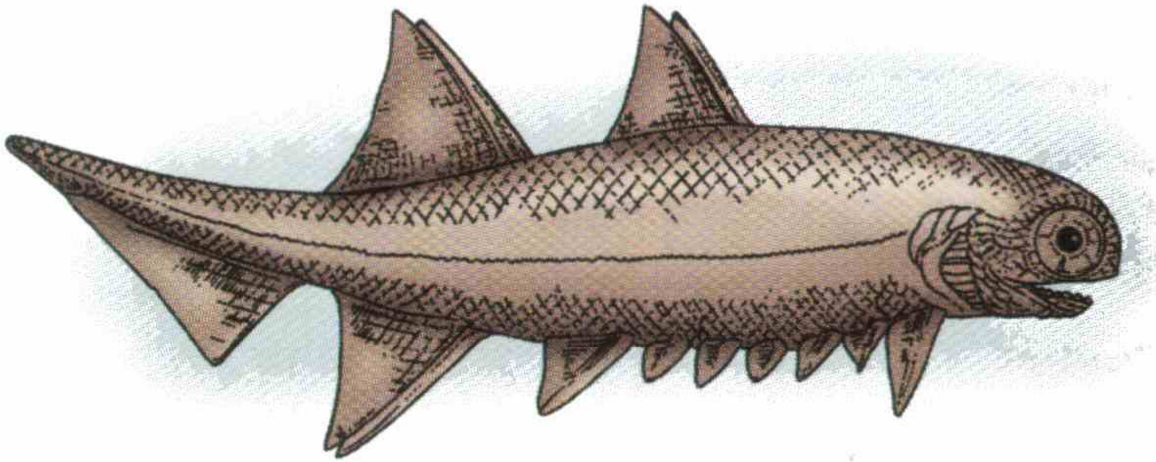
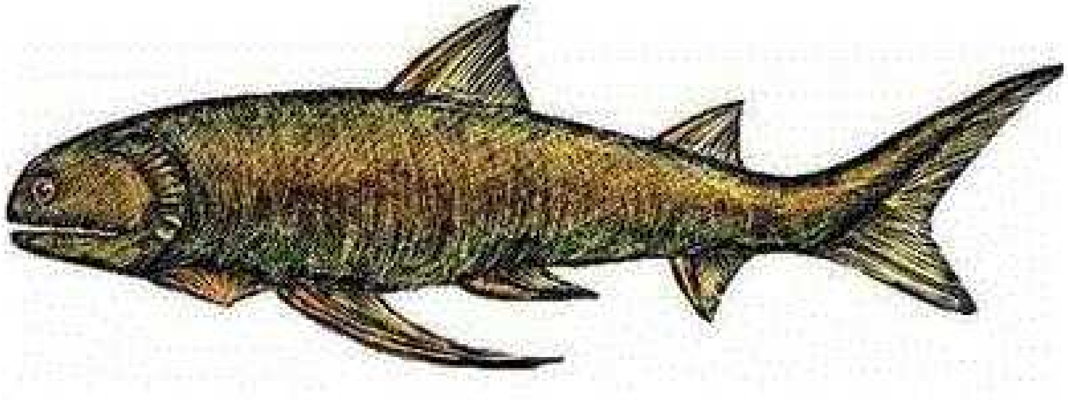
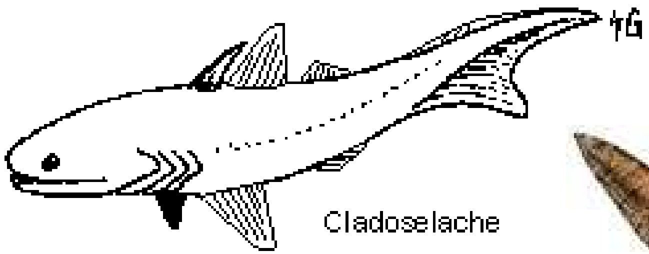


FIGURE 10–67 **The Early Devonian acanthodian fish *Climatius*.** *(After Romer, A. S. 1945.* Vertebrate Paleontology. *Chicago: University of Chicago Press.)*

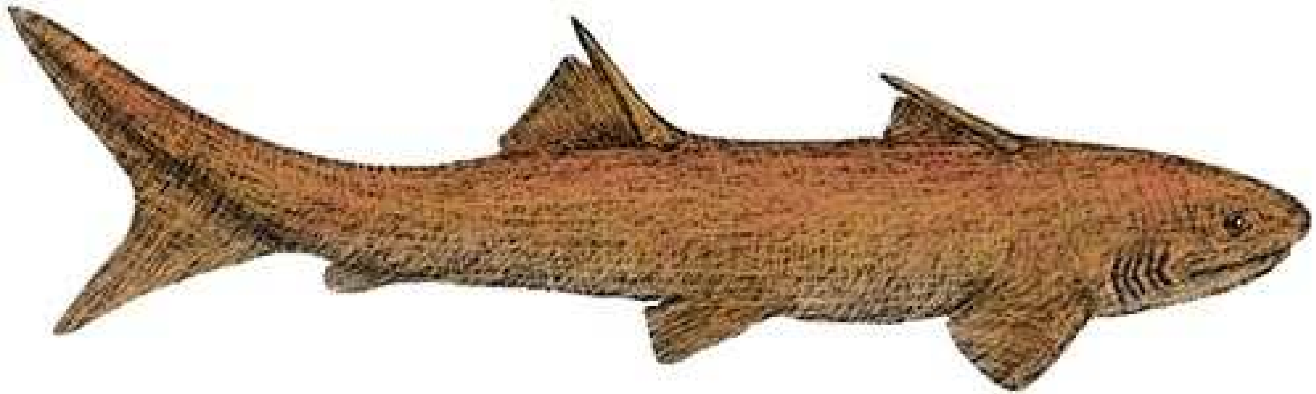


Acanthodii

Chondrichtyes



First sharks



Ctenacanthus sp, a Late Devonian and Carboniferous shark

The very earliest signs of sharks are minute fossil **scales** and teeth which are found in rocks from the late **Silurian to early Devonian** period {around 400 million years ago). It becomes more and more difficult, however, to identify shark scales in older rocks because they closely resemble those from jawless fishes called the lodonts, which lived at the same time. Only microscopic differences separate shark and the lodont scales, and the two kinds seem to become more and more alike the further one goes back.

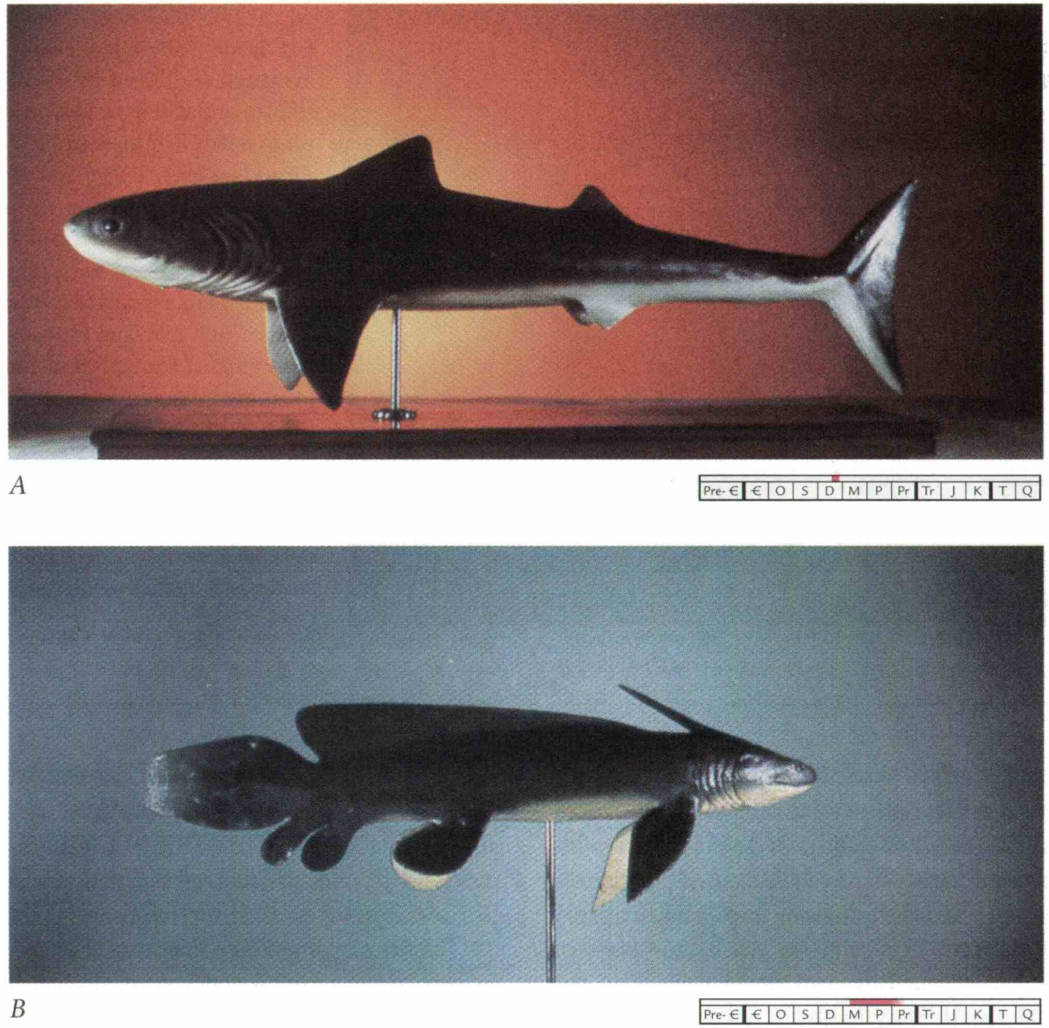
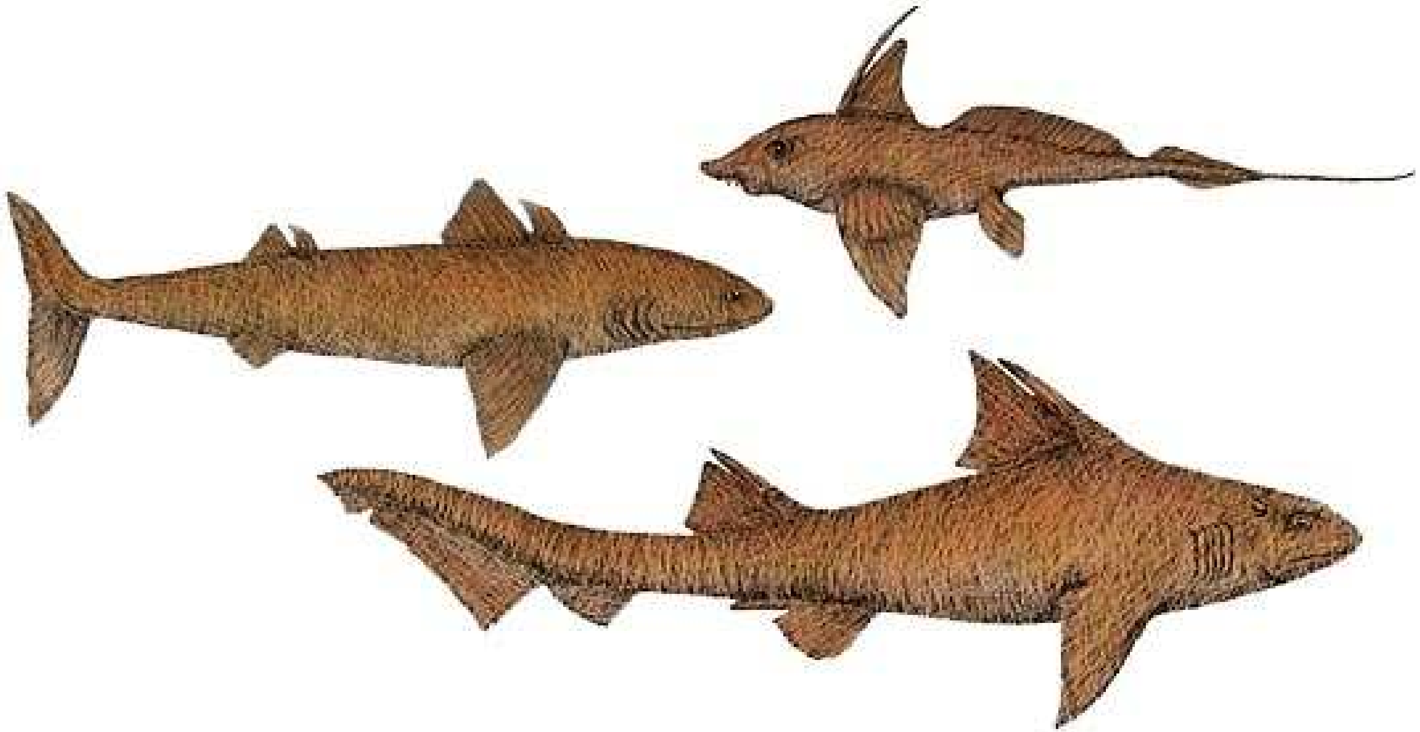


FIGURE 10–70 Models of (A) the Devonian marine shark *Cladoselache* and (B) the Pennsylvanian freshwater shark *Xenacanthus*.



Cladoselache (top left, Middle Devonian), *Ischyodus* (top right, Upper Jurassic) and *Hybodus* (bottom, Lower Jurassic) ©

•Bony fish (Osteichtyes)

•There are two groups of bony fish

1.Ray-finned fish (Actinopterygii)

began their evolution in Devonian lakes and streams (freshwater) and then spread to the sea. They are the **dominant fishes of the modern world**.

2.Lobe-finned fish

Lobe-finned fish have muscular fins with articulating bones. There are two groups of lobe finned fish.

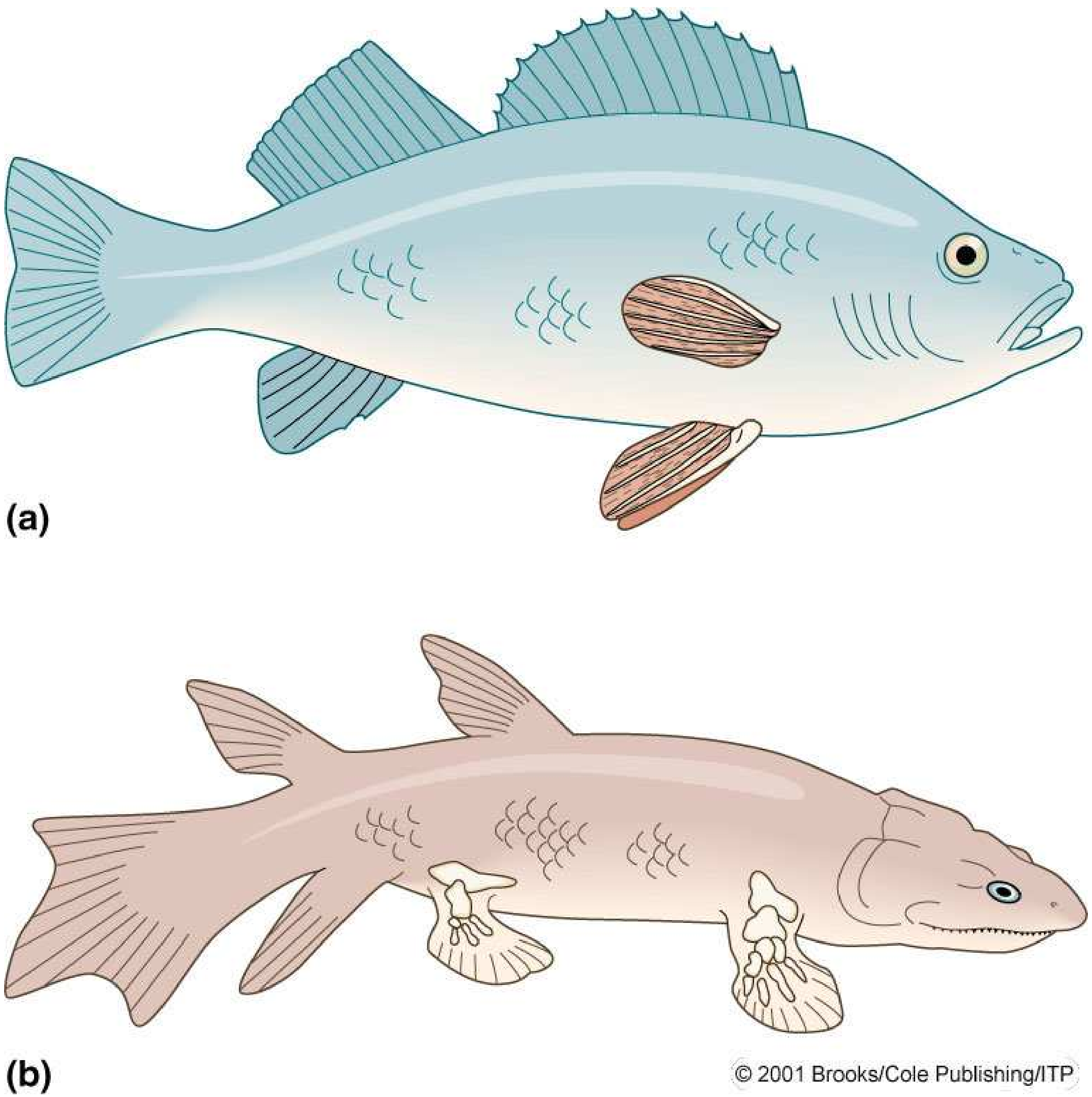
a.The **lungfish**

Lungfish live today in freshwater.

b.The **crossopterygians**

This is an important group of lobe-finned fish because it **gave rise to the amphibians** during the Devonian.

Ray-Finned and Lobe-Finned Fish



- Arrangement of fin bones for

  (a) a ray-finned fish

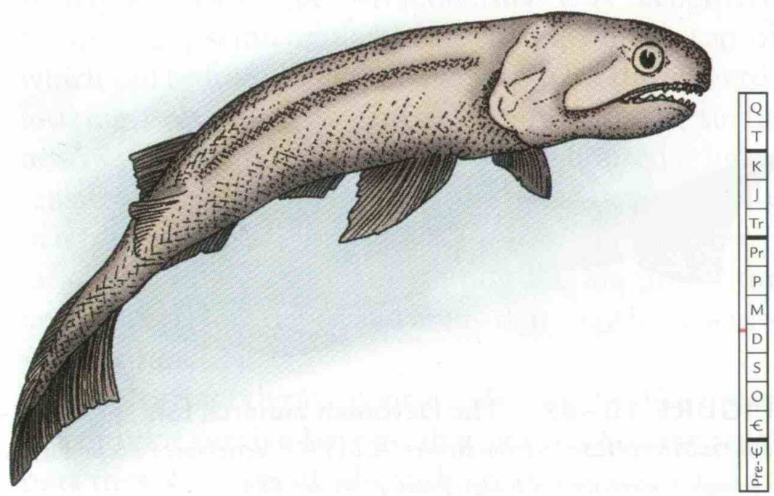
  (b) a lobe-finned fish
  - muscles extend into the fin allowing greater flexibility

Actinopterygii

Chondrostei

well represented by the genus *Cheirolepis* (Fig. 10–71). From such fishes as these evolved the more advanced bony fishes during the Mesozoic and Cenozoic.

The second category of bony fishes, the Sarcopterygii, is characterized by fishes with sturdy, fleshy lobe-fins and a pair of openings in the roof of the mouth that led to clearly visible external nostrils.



Dipnoi

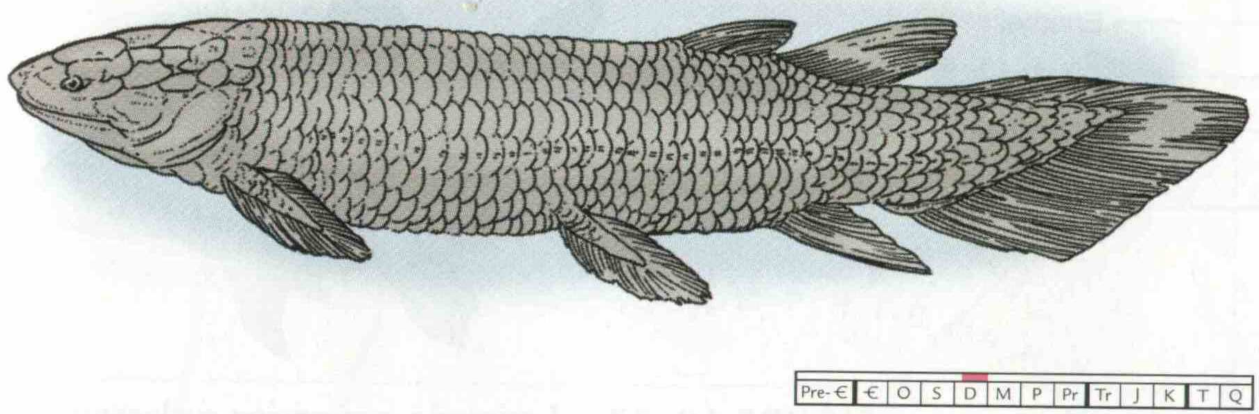
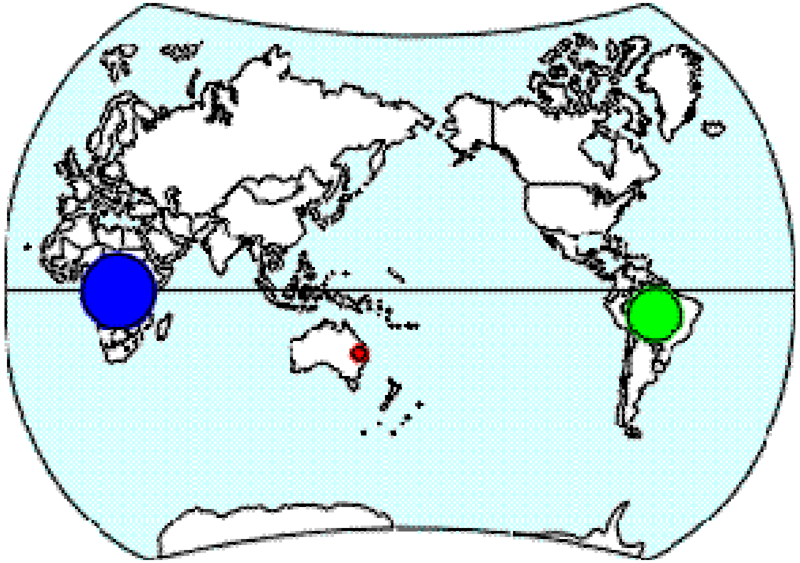
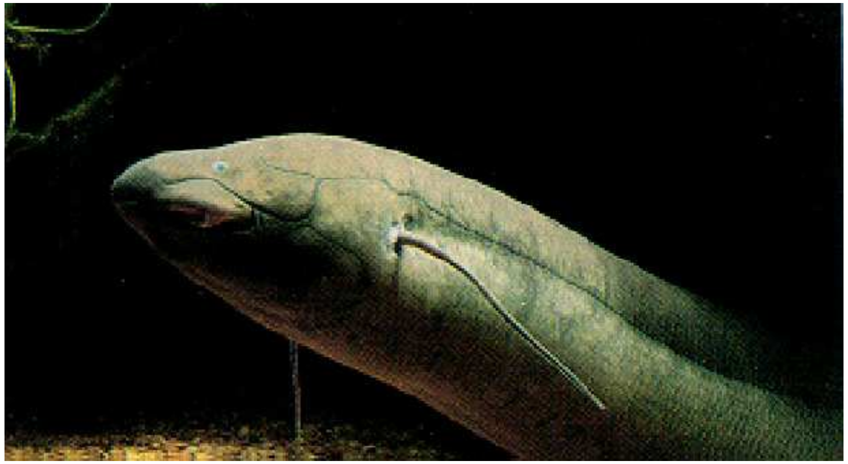


FIGURE 10–72 *Dipterus,* a Devonian lungfish.

Neoceratudos forsteri



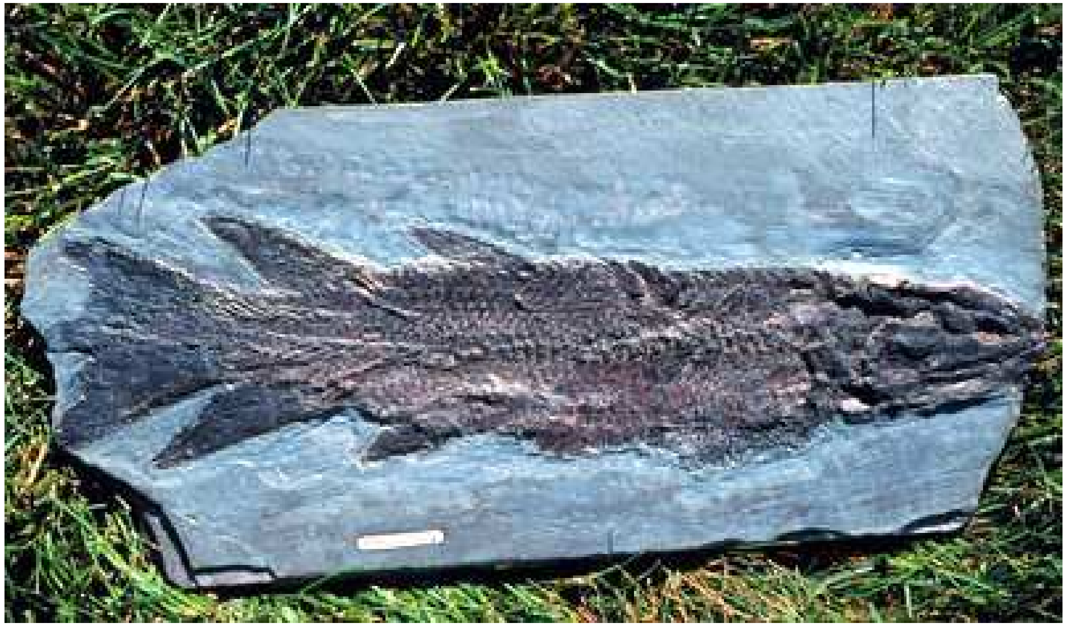
Protopterus ssp

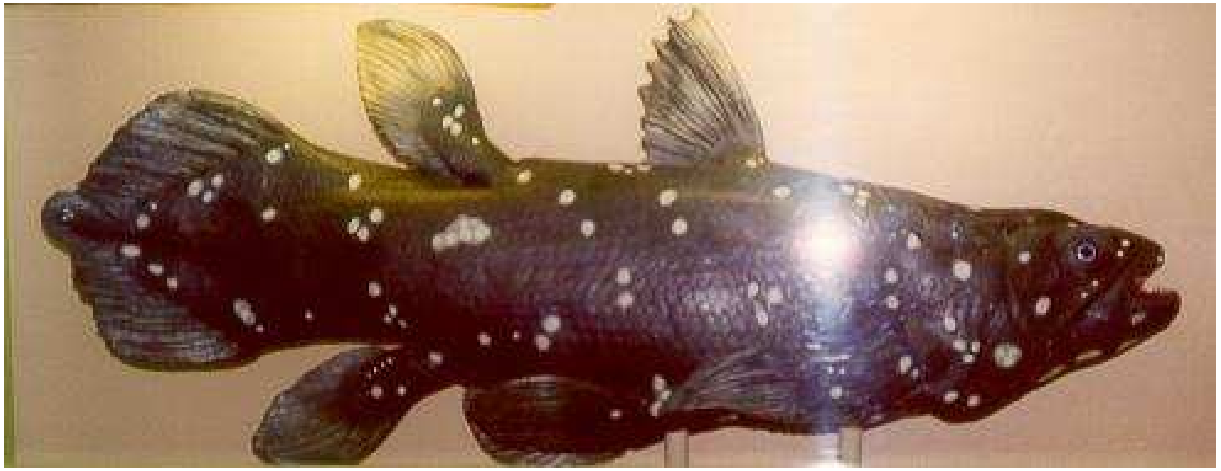


Lepidosiren paradoxa

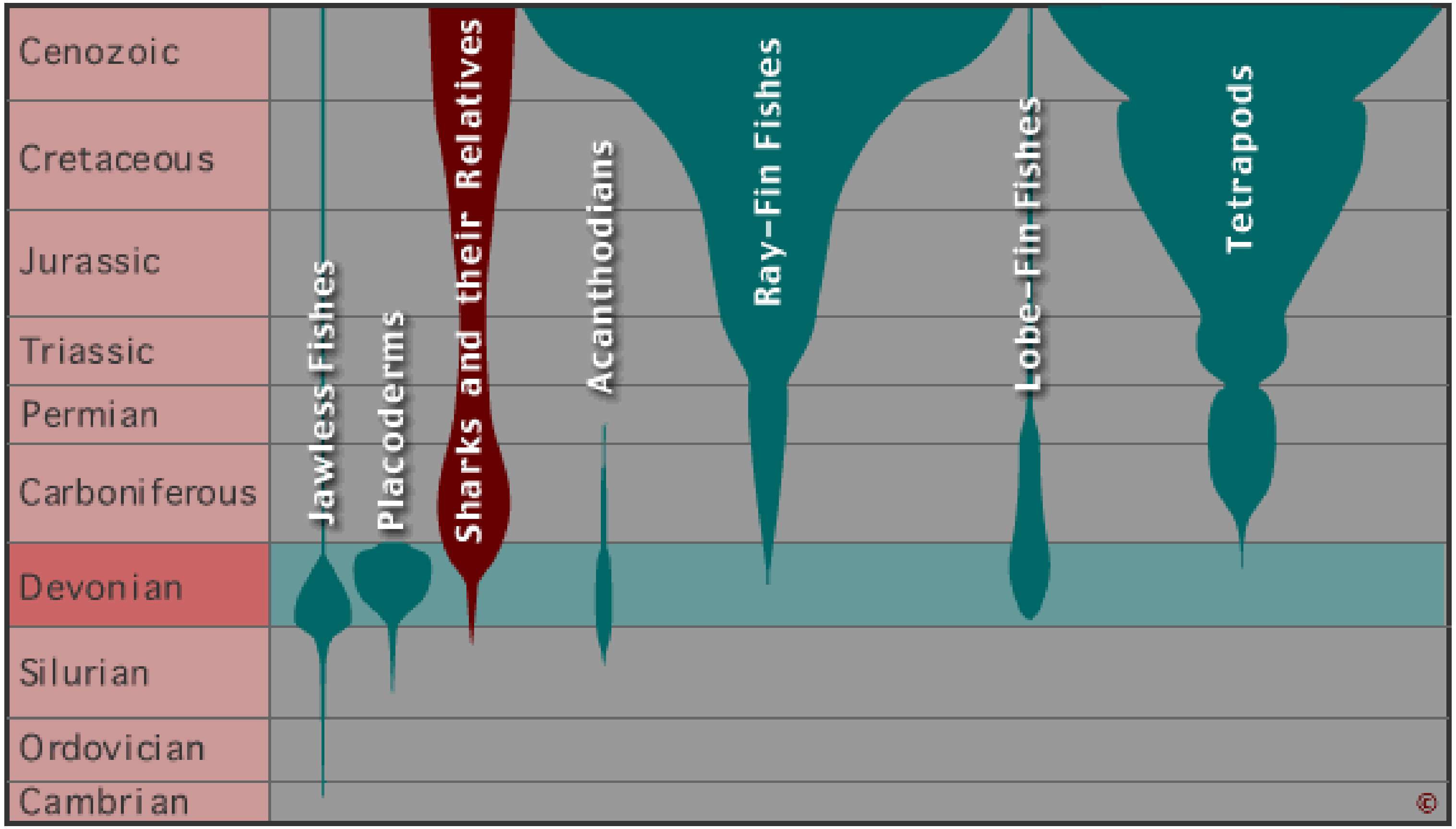
Crossopterygii

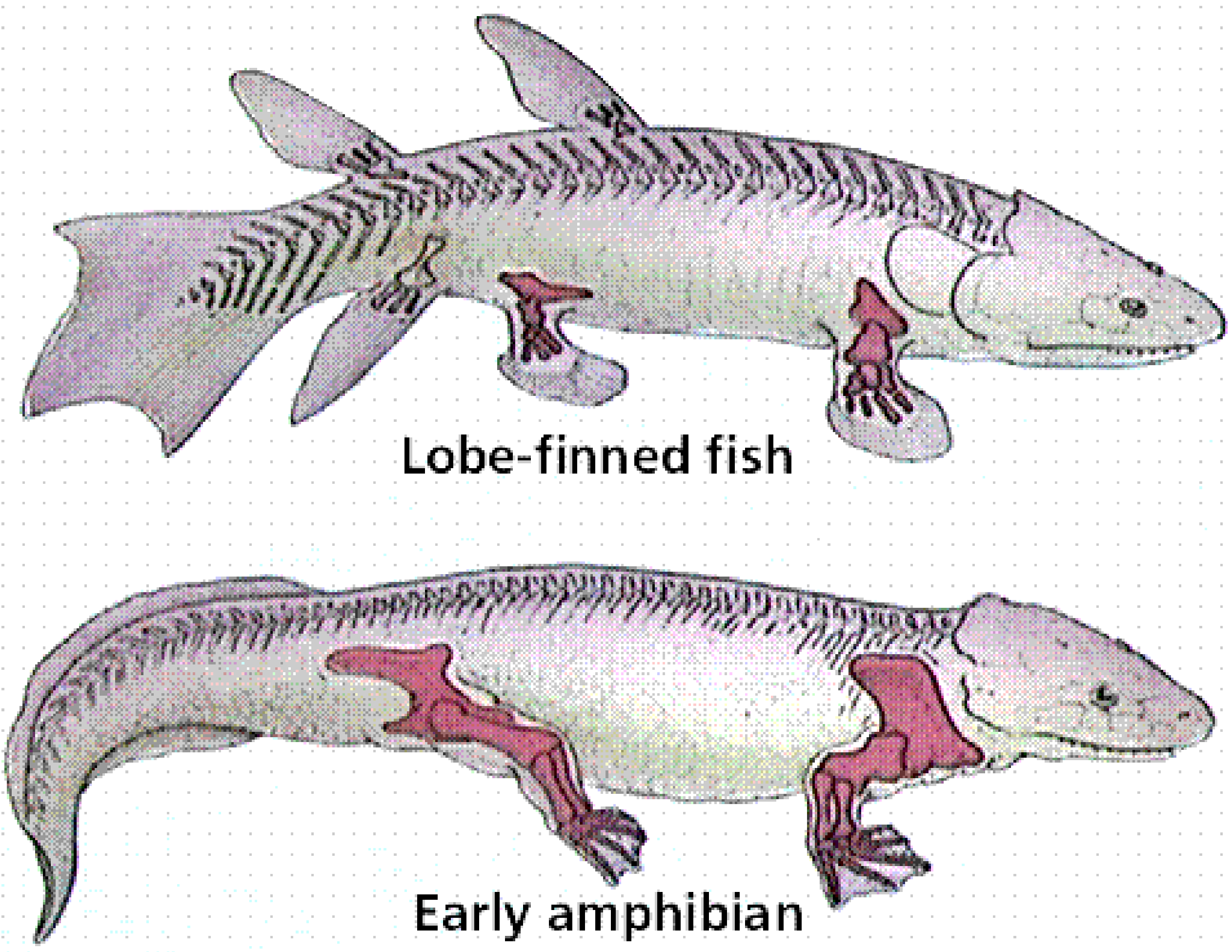
Eusthenopteron





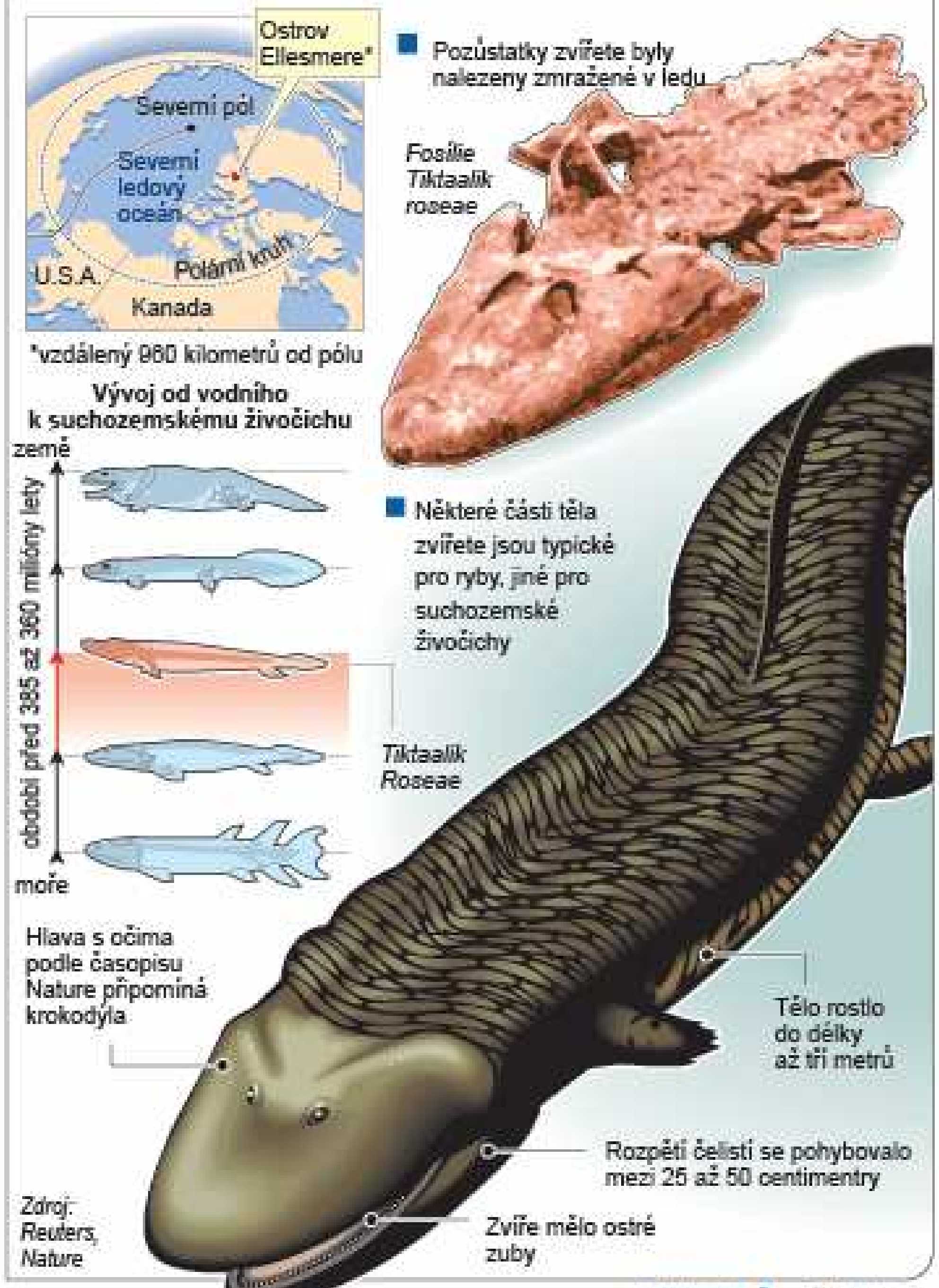
Latimeria chalumnae




Lobe-finned fish
Early amphibian

Objev Tiktaalik roseae

Fosílii starou 375 miliónů let našli vědci na ostrově Ellesmere poblíž Severního pólu. Jde o živočicha, který má být „evoluční spojnicí“ mezi vodními a suchozemskými tvory.



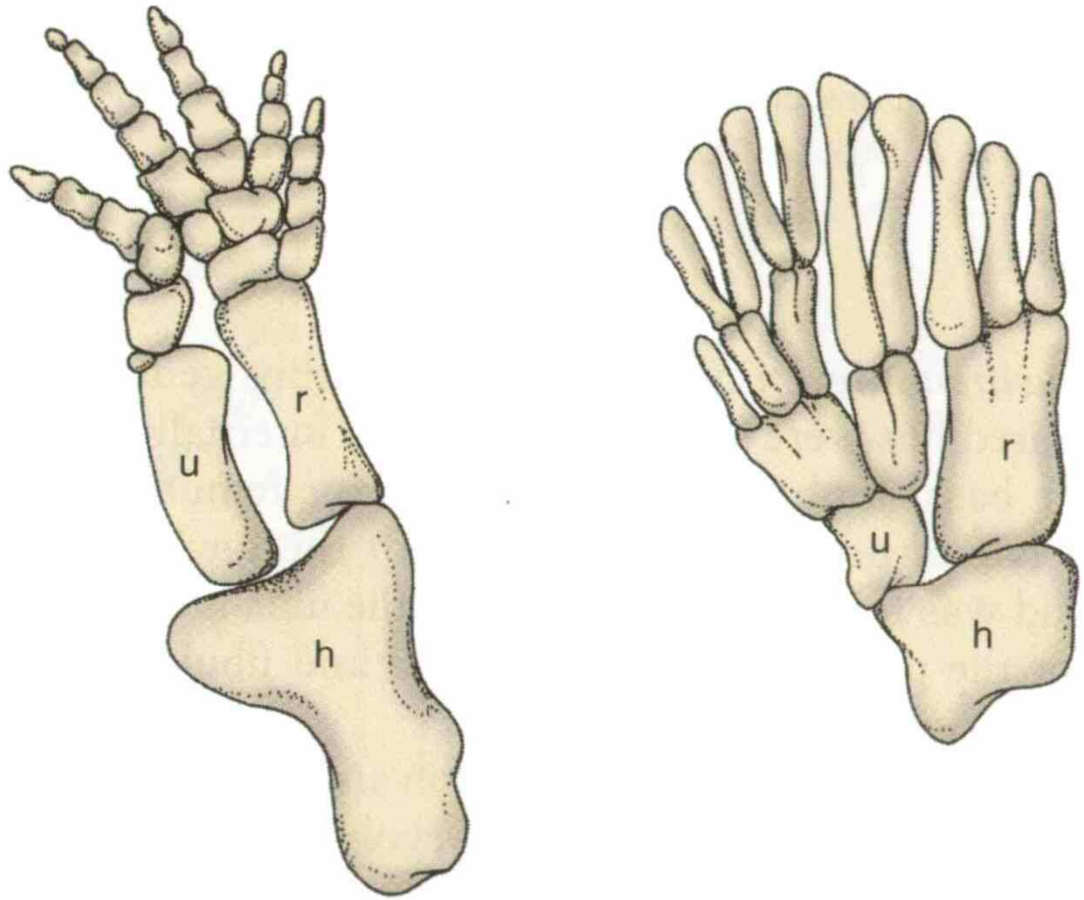


FIGURE 10–73 **Comparison of the limb bones of a crossopterygian fish (upper right) and an early amphibian.** (Some early amphibians may have had more than five digits.) *(From Levin, H. L. 1975.* Life Through Time. *Dubuque, IA: William C. Brown Co.)*

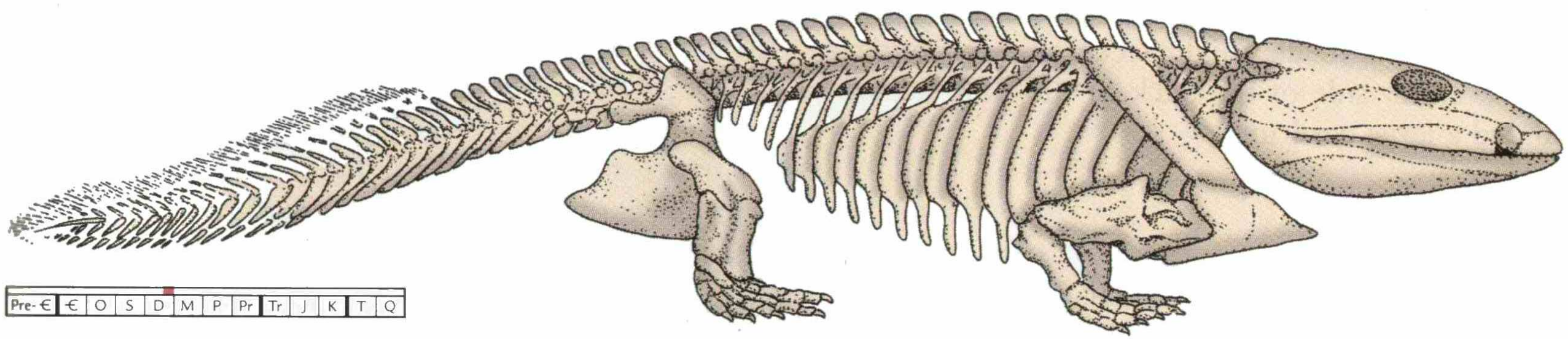
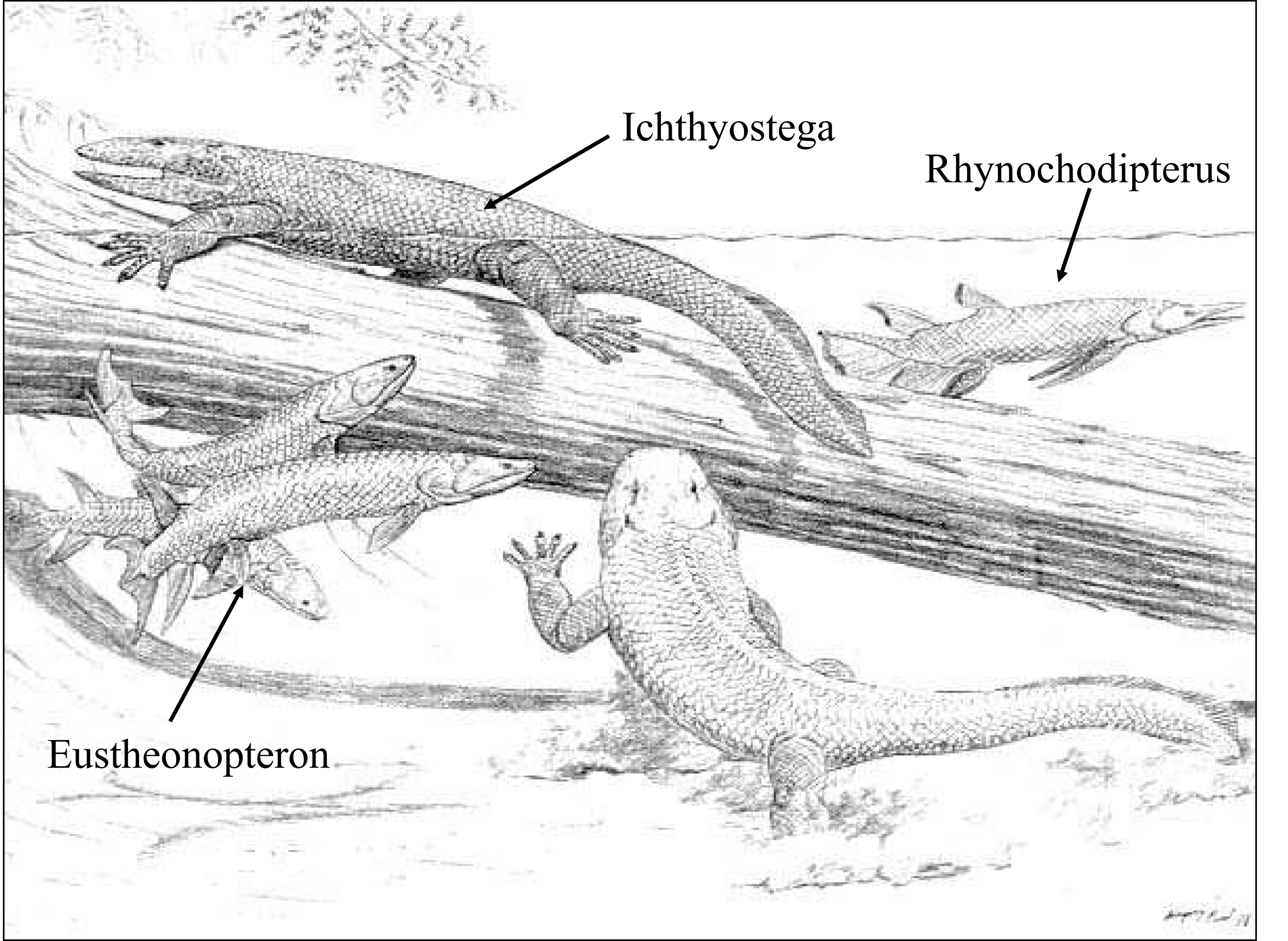


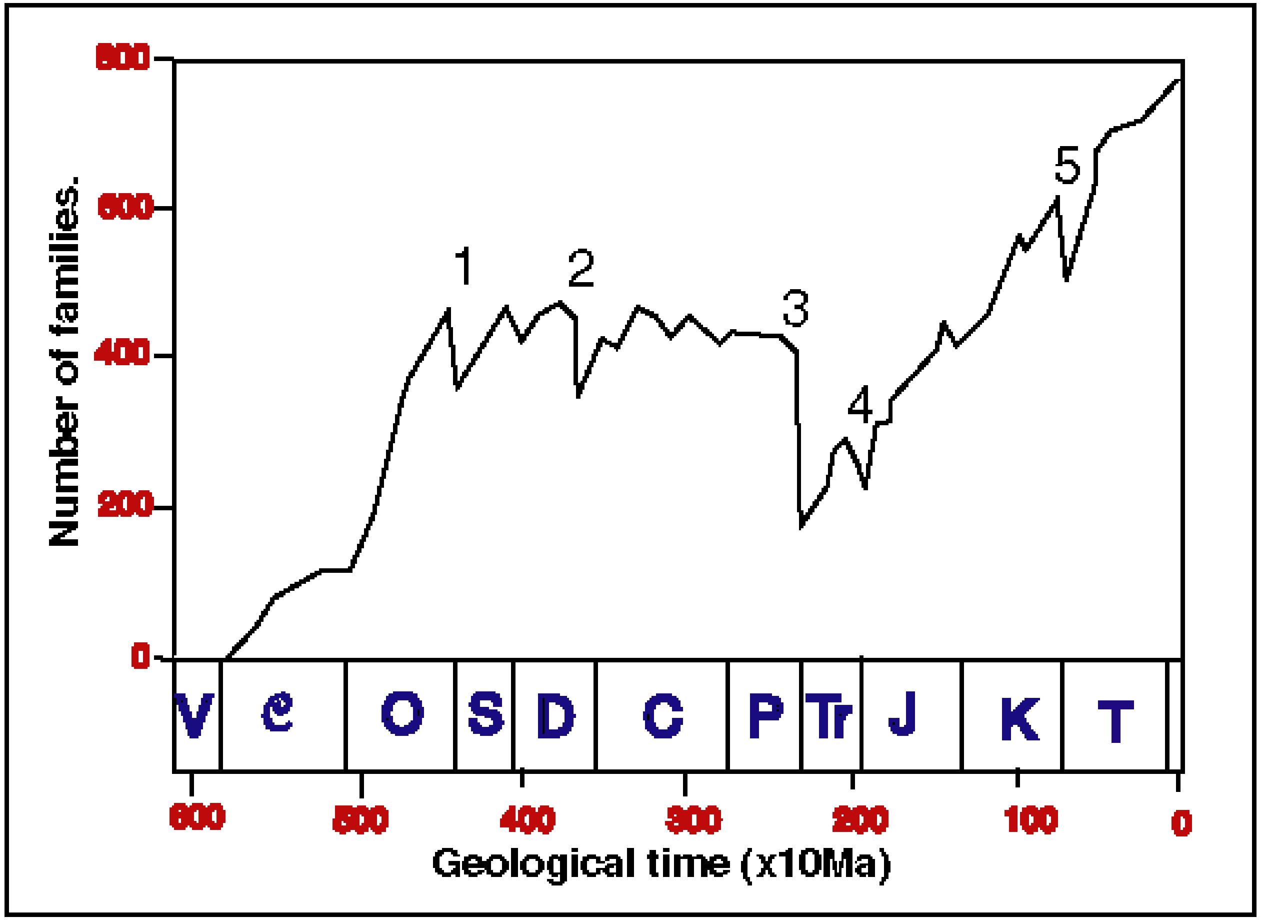
FIGURE 10–79 **The skeleton of *Ichthyostega* still retains the fishlike form of its crossopterygian ancestors.** *(From Levin, H. L. 1975.* Life Through Time. *Dubuque, IA: William C. Brown Co.)*


Ichthyostega
Rhynochodipterus
Eustheonopteron

What is a mass extinction?

- A **mass extinction** occurs when a large fraction of all living species becomes rapidly extinct.
- The fossil record shows that at least five major mass extinctions have occurred in the past 500 million years.
- Impacts of asteroids on Earth are suspected as a primary cause of mass extinction.

- Three of the five major mass extinctions occurred during the Paleozoic era:
  - At the end of the **Ordovician** period,
  - during the late **Devonian** period, and
  - at the end of the **Permian** period.



- **The graph shows when the five extinctions occurred. As you can see, the Permian extinction was the most severe.**

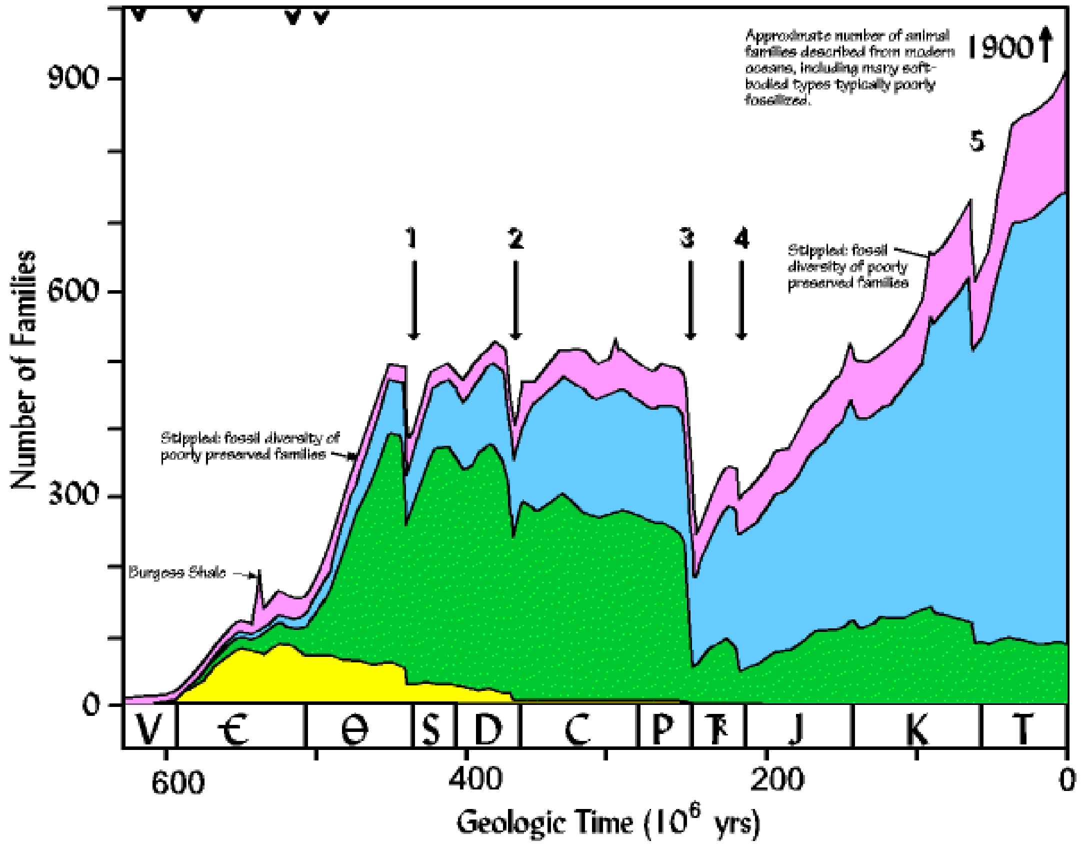
EARLY PALEOZOIC LIFE

Mass Extinctions

Ordovician Mass Extinction

Second most devastating in earth history

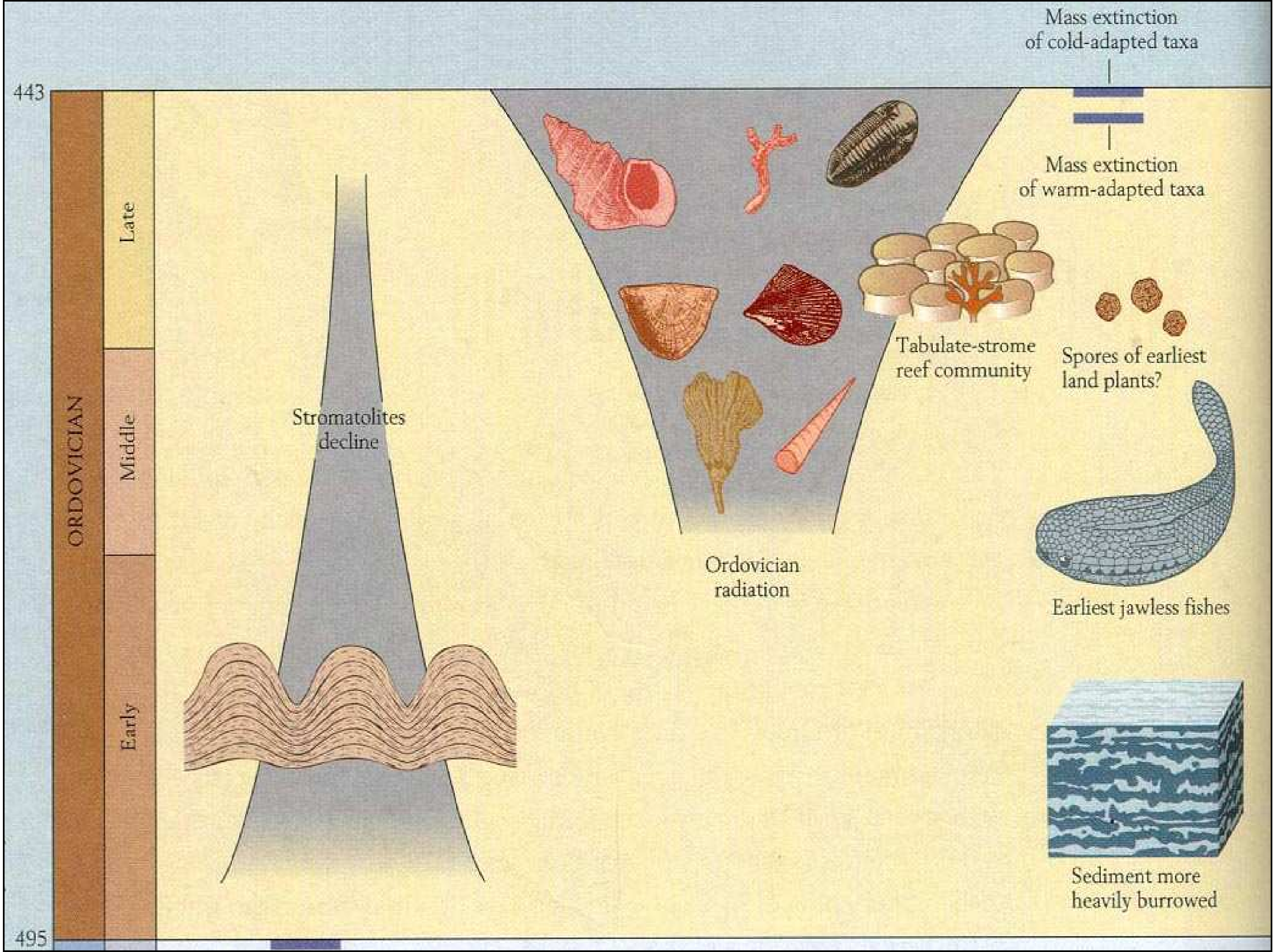
Caused by glaciation and associated lowering of sea level



The Ordovician Extinction

- This extinction occurred at end of the period, about 440-450 mya.
- It is thought to be caused by a global cooling, which caused the continent Gondwana to glaciate. Geologists have found glacial deposits in the Saharan desert, which provided the evidence for this theory.

- Since more water was in ice form, the sea level lowered all over the world, causing a reduction of space for life on continental shelves.
- The most affected animal group was the *marine invertebrates*, in which more than 100 families were wiped out.


Mass extinction
of cold-adapted taxa
443
Mass extinction
of warm-adapted taxa
ORDOVICIAN
Late
Middle
Early
Stromatolites
decline
Tabulate-strome
reef community
Spores of earliest
land plants?
Ordovician
radiation
Earliest jawless fishes
Sediment more
heavily burrowed
495

Next, in terms of severity, was probably the Ashgillian (latest Ordovician) event when perhaps **50% of marine species** went extinct.

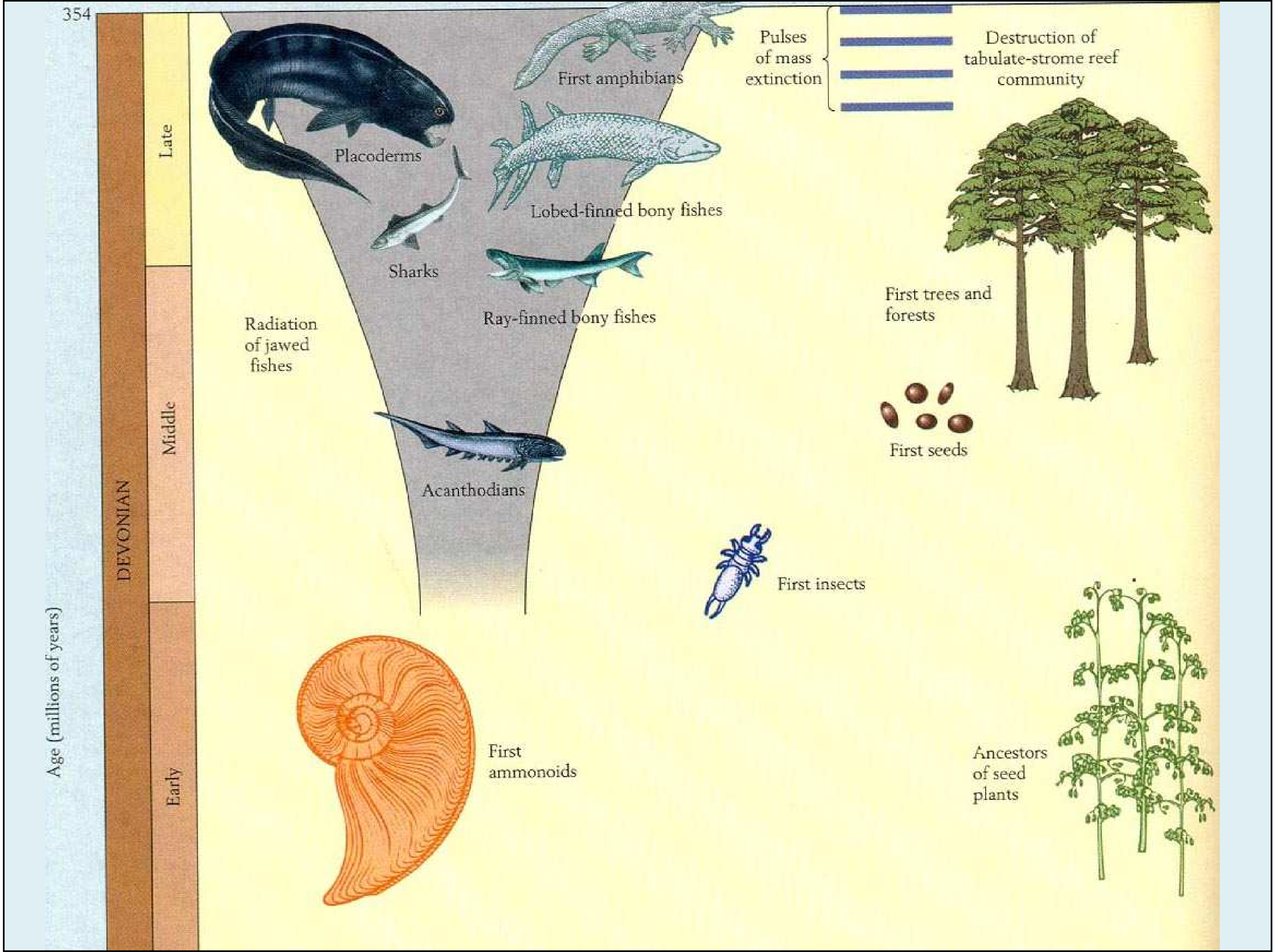
The Ordovician extinction occurred at the end of the Ordovician period, about 440-450 million years ago. This extinction, cited as the second most devastating extinction to marine communities in earth history, caused the disappearance of **one third of all brachiopod** and **bryozoan** families, as well as numerous groups of **conodonts**, **trilobites**, and **graptolites**. Much of the reef-building fauna was also decimated. In total, more than **one hundred families** of marine invertebrates perished in this extinction.
Echinoderms, trilobites, nautiloids and many other groups suffered significant losses,.

The Devonian Extinction

- This event is theorized to be caused by an episode of **global cooling** similar to that of the Ordovician extinction.
- This time, the **glacial deposits** have been found in northern Brazil.
- However, **meteorite impacts** have also been thought a possible cause of this mass extinction, although the evidence remains inconclusive.
- This extinction had little effect on land animals, mostly affecting (again) the **marine life**, in particular, the **reef-builders**.

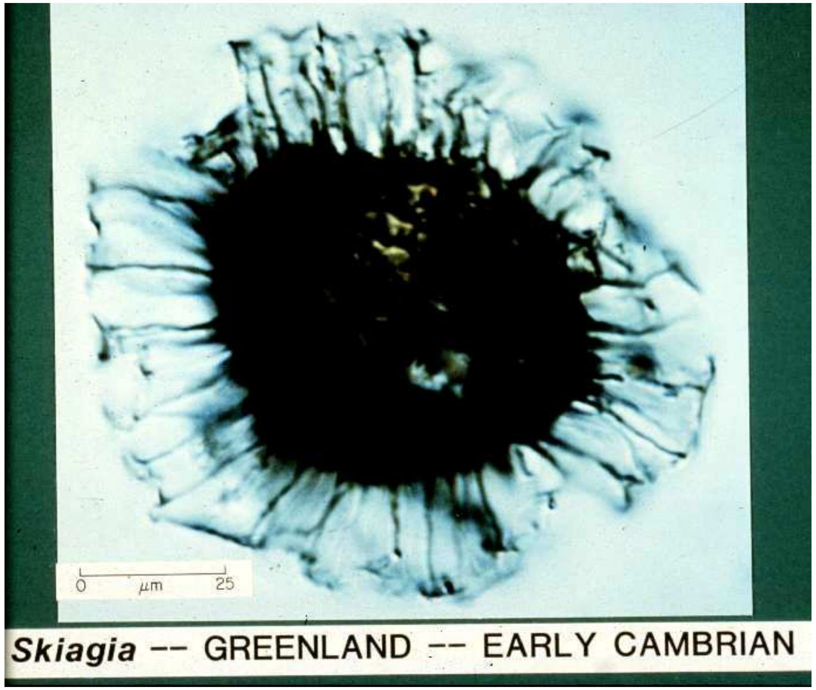
In Famennian strata only about 15 percent of Frasnian brachiopod genera are found. **Ammonoids trilobites,** and **conodonts** experienced a similar decline, and many types of **gastropods** and **trilobites** disappeared as well. The **reef community** became forever changed. After the Famennian, **tabulate corals, stromatoporoids**, and **rugose** corals are rare. These had achieved their greatest faunal diversity during Middle Devonian time and had been important reef contributors for 120 million years. The time of extinctions was also when **acritarchs** (the only phytoplankton with an extensive Devonian fossil record), became rare. **Placoderms** almost disappear at this time. Until then, during the Devonian, they had been the dominant pelagic carnivores. On the land, life appears to have been little affected, although the marine record is that world **climate may have cooled significantly at this time**. The evidence for this (in New York State) is that glass sponges, which today are restricted to cool waters, began to thrive where formerly successful tropical marine fauna had become extinct.

Evidence supporting the Devonian mass extinction suggests that **warm water marine species** were the most severely affected in this extinction event. This evidence has lead many paleontologists to attribute the Devonian extinction to an episode of global cooling, similar to the event which is thought to have cause the late Ordovician mass extinction.

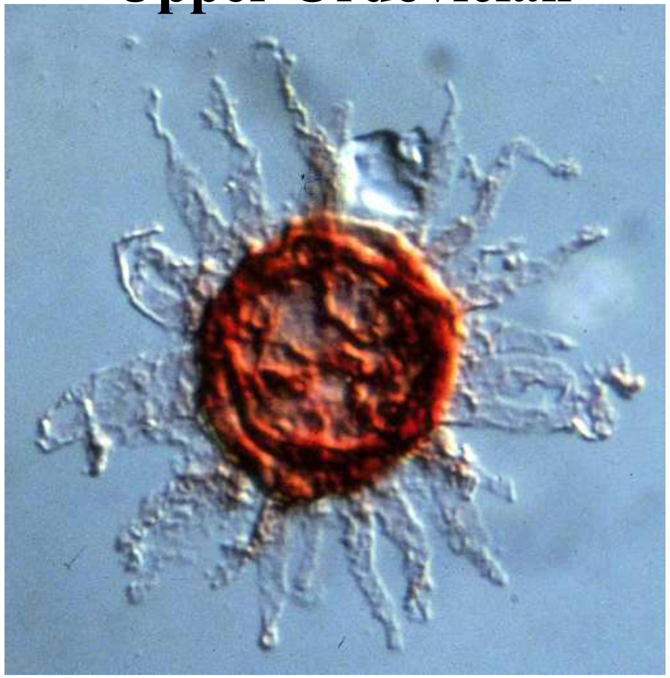


354
Age (millions of years)
DEVONIAN
Late
Middle
Early
Placoderms
First amphibians
Pulses of mass extinction
Destruction of tabulate-strome reef community
Lobed-finned bony fishes
Sharks
Ray-finned bony fishes
Radiation of jawed fishes
First trees and forests
First seeds
Acanthodians
First insects
First ammonoids
Ancestors of seed plants

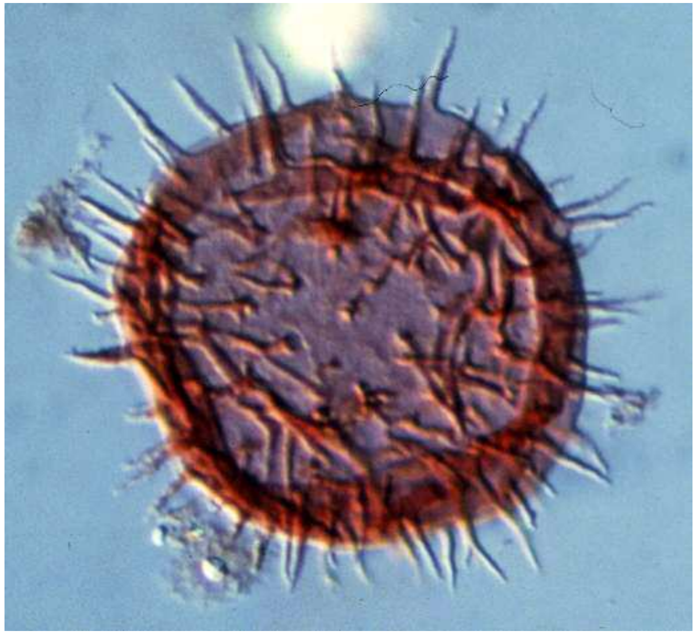
Acritarchs from the lower Paleozoic



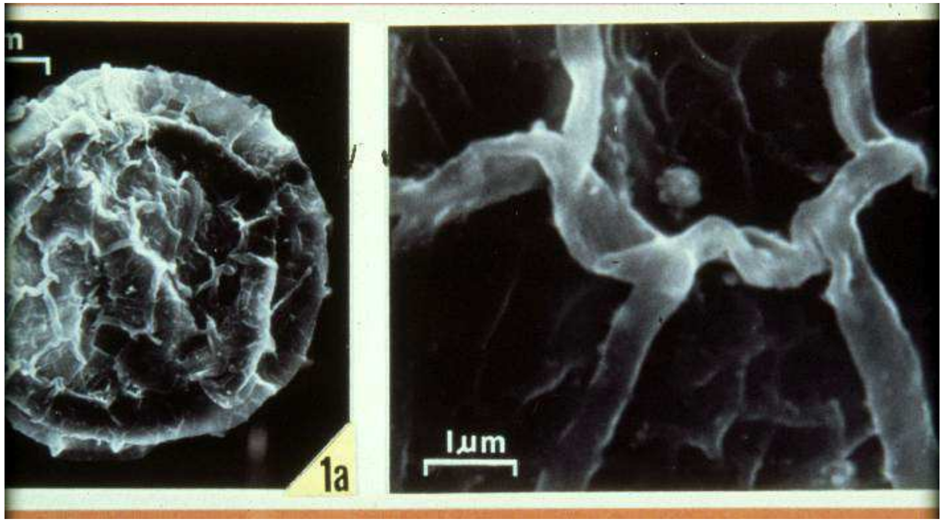
Upper Ordovician



Upper Ordovician



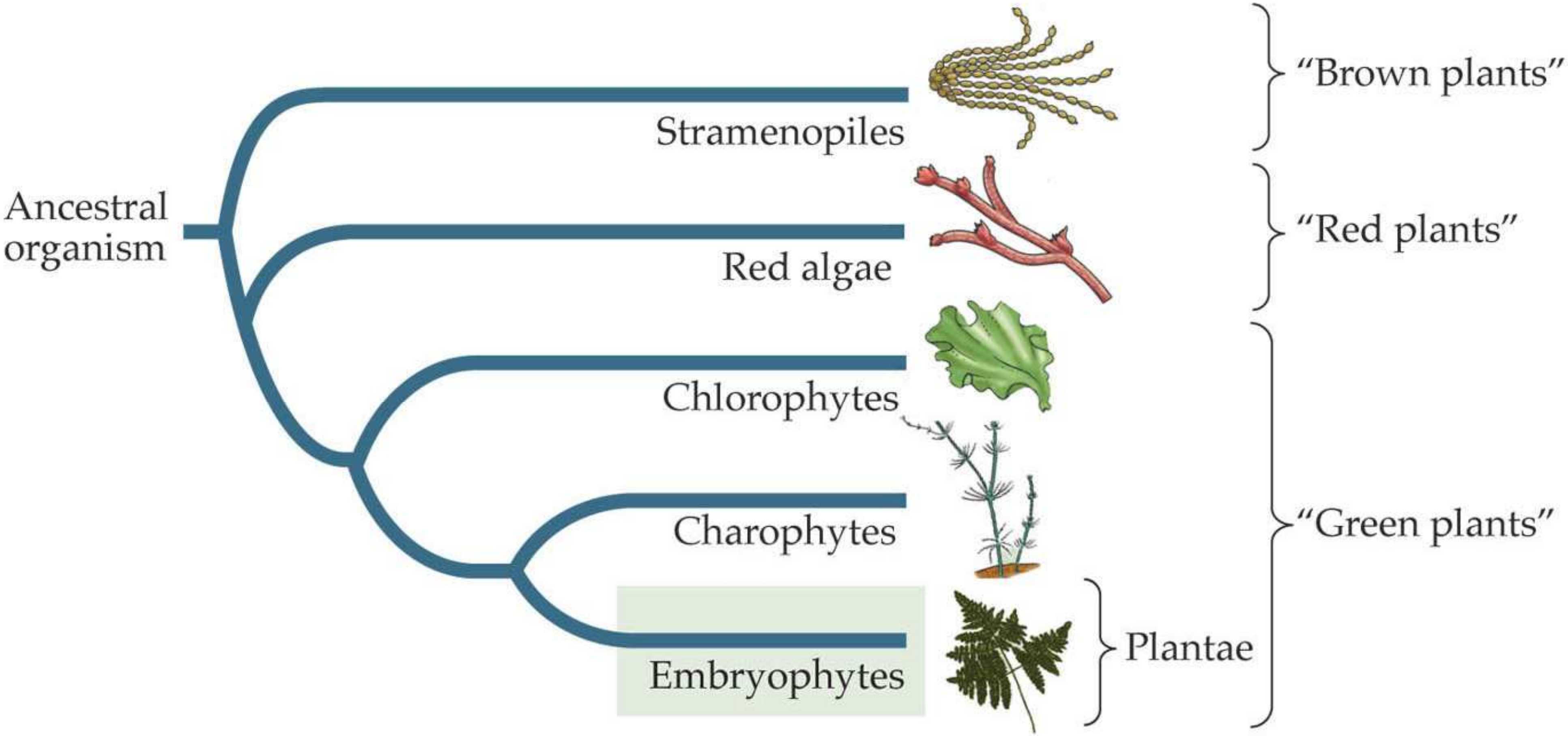
Upper Ordovician-SEM photo



PLANT ANCESTRY

- **Plants represent a monophyletic group**
  - **Evolved from a common ancestor**
  - **Who was this common ancestor?**
- **Multiple lines of evidence indicate that plants evolved from a group of green algae termed *Charophytes***
  - **What is this evidence?**

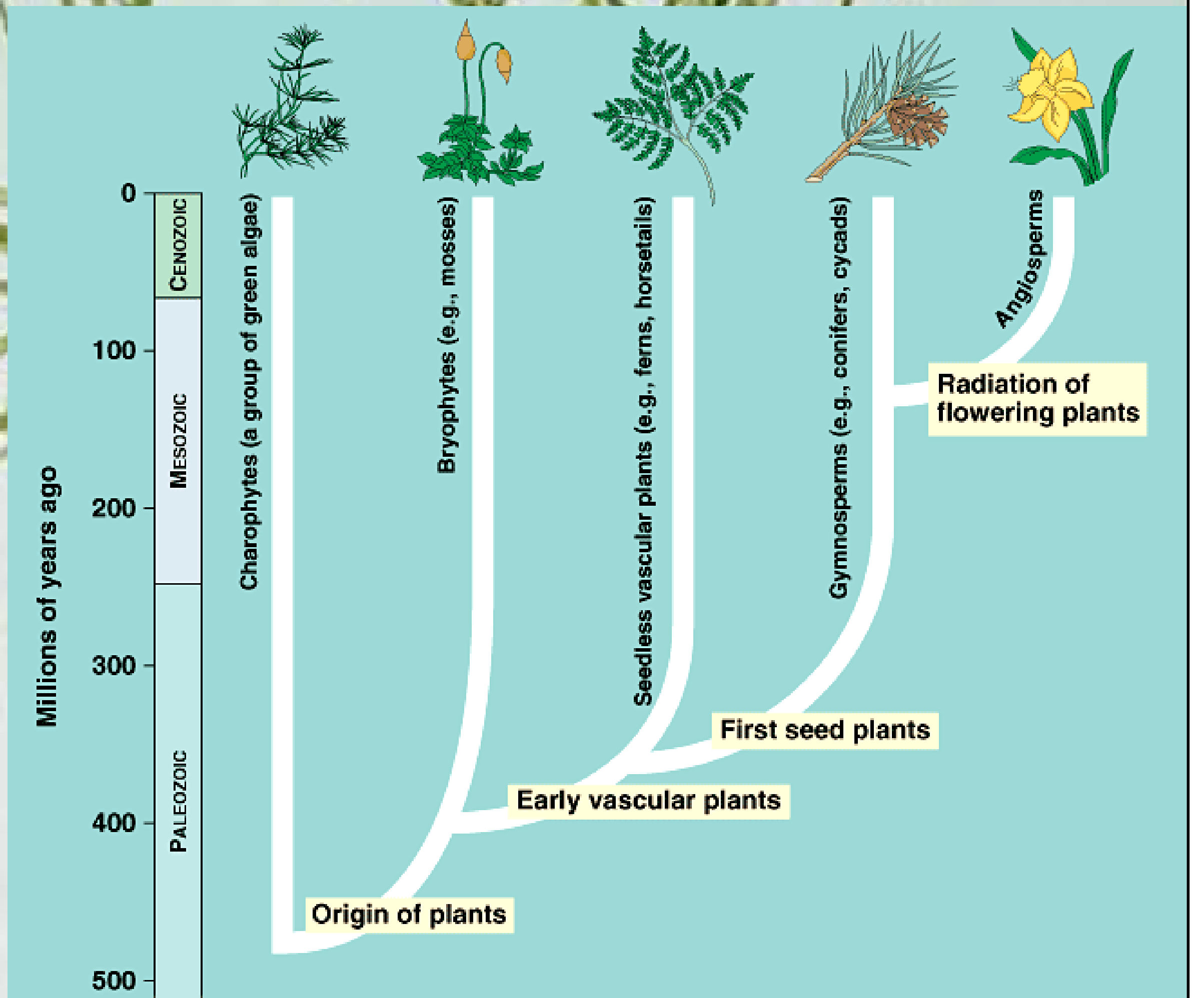
Figure 29.1 *What Is a Plant?*



LIFE: THE SCIENCE OF BIOLOGY, Seventh Edition, Figure 29.1 What Is a Plant?

MAJOR PLANT GROUPS

- Four major periods of plant evolution
  - New structures evolved, adaptive radiations followed
- Origin of plants from aquatic ancestors
- Diversification of vascular plants
- Origin of seeds
- Emergence of flowering plants



D. Evolution of land plants

1. Latest Ordovician

2. Early and Middle Silurian

3. Late Silurian

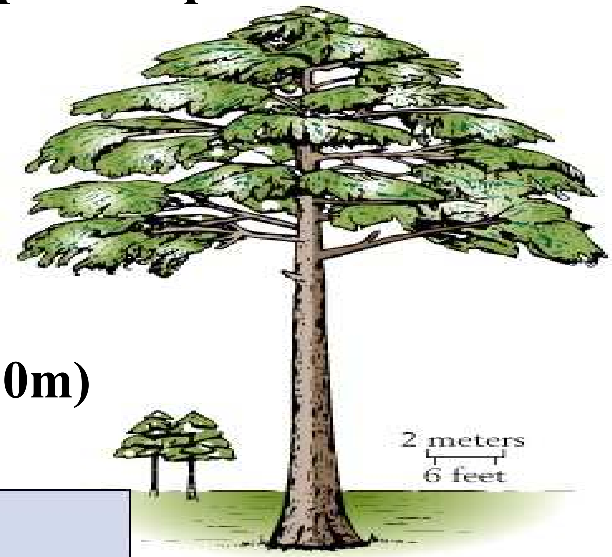
   i. Vascular tissue (e.g. rhyniophytes)

   ii. Advantages

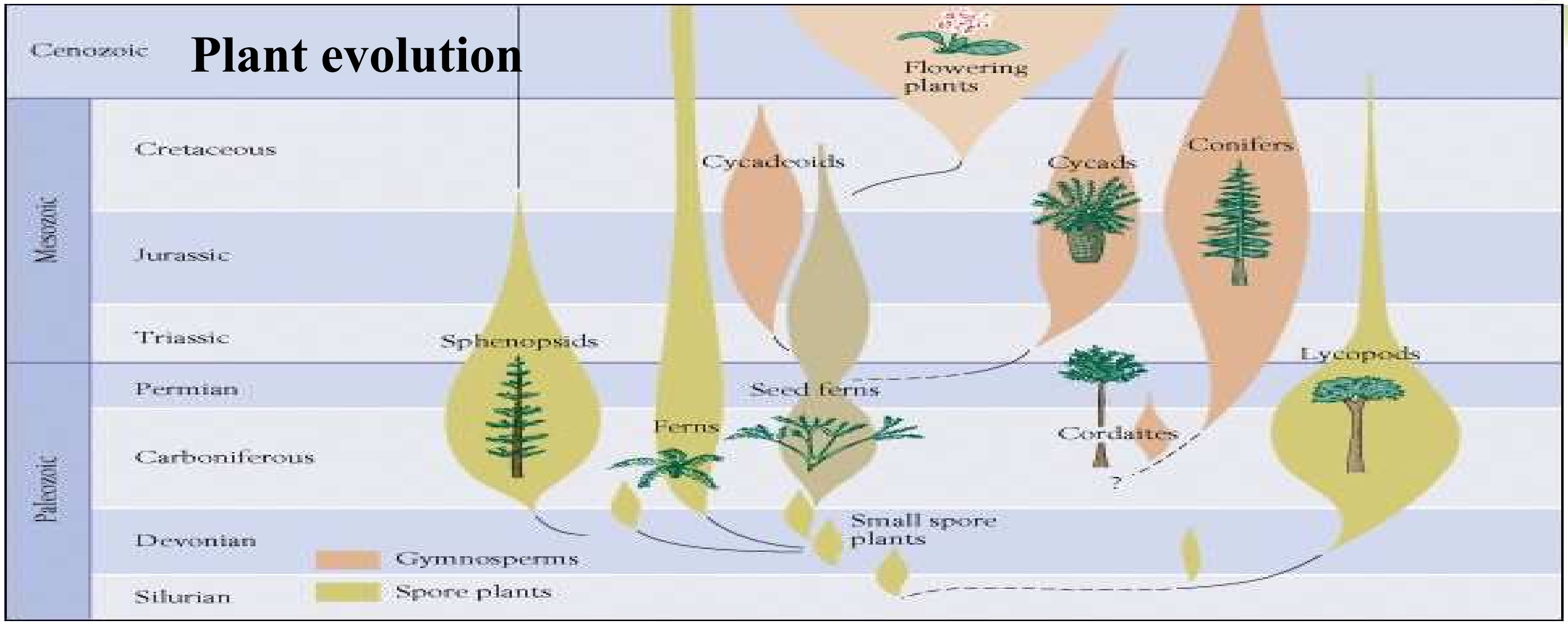
4. Early Devonian

Adaptive radiation

E. Devonian plantscape



E. Devonian tree (Archaeopteris, 30m)

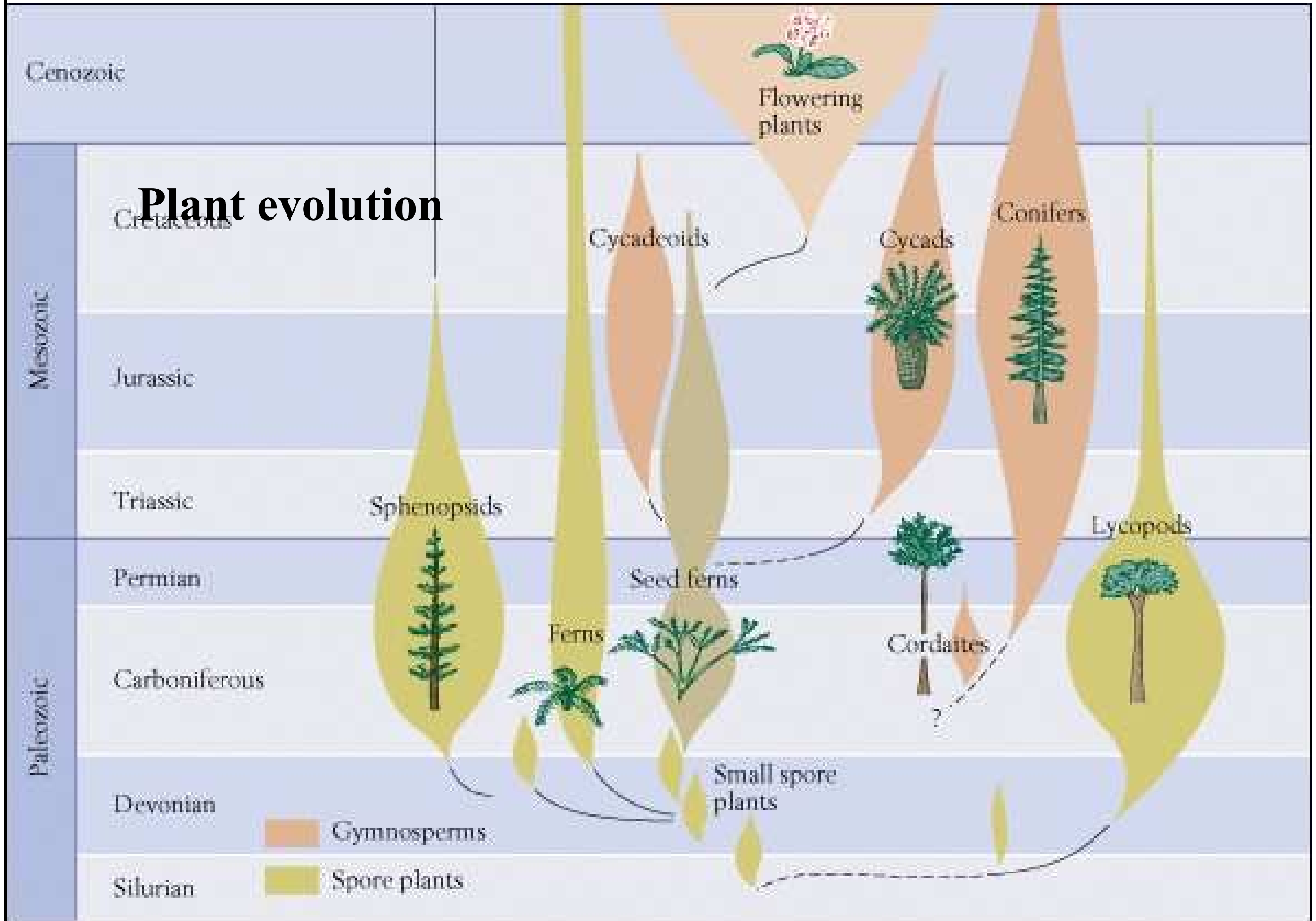


5. Late Devonian

i. Seeds

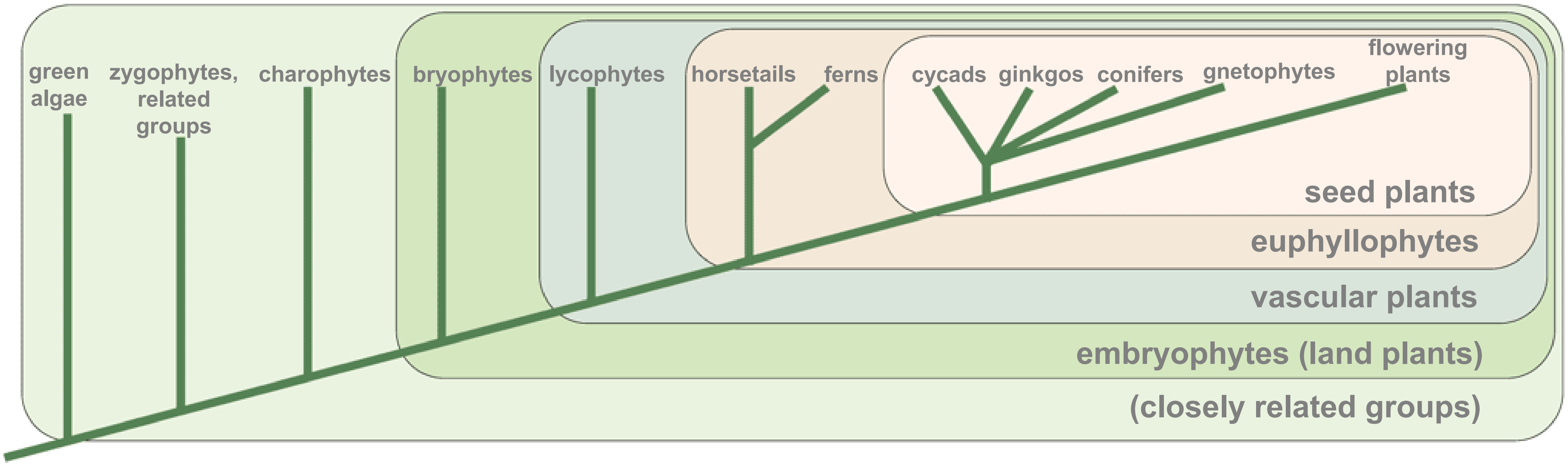
a. Advantages

ii. Adaptive radiation



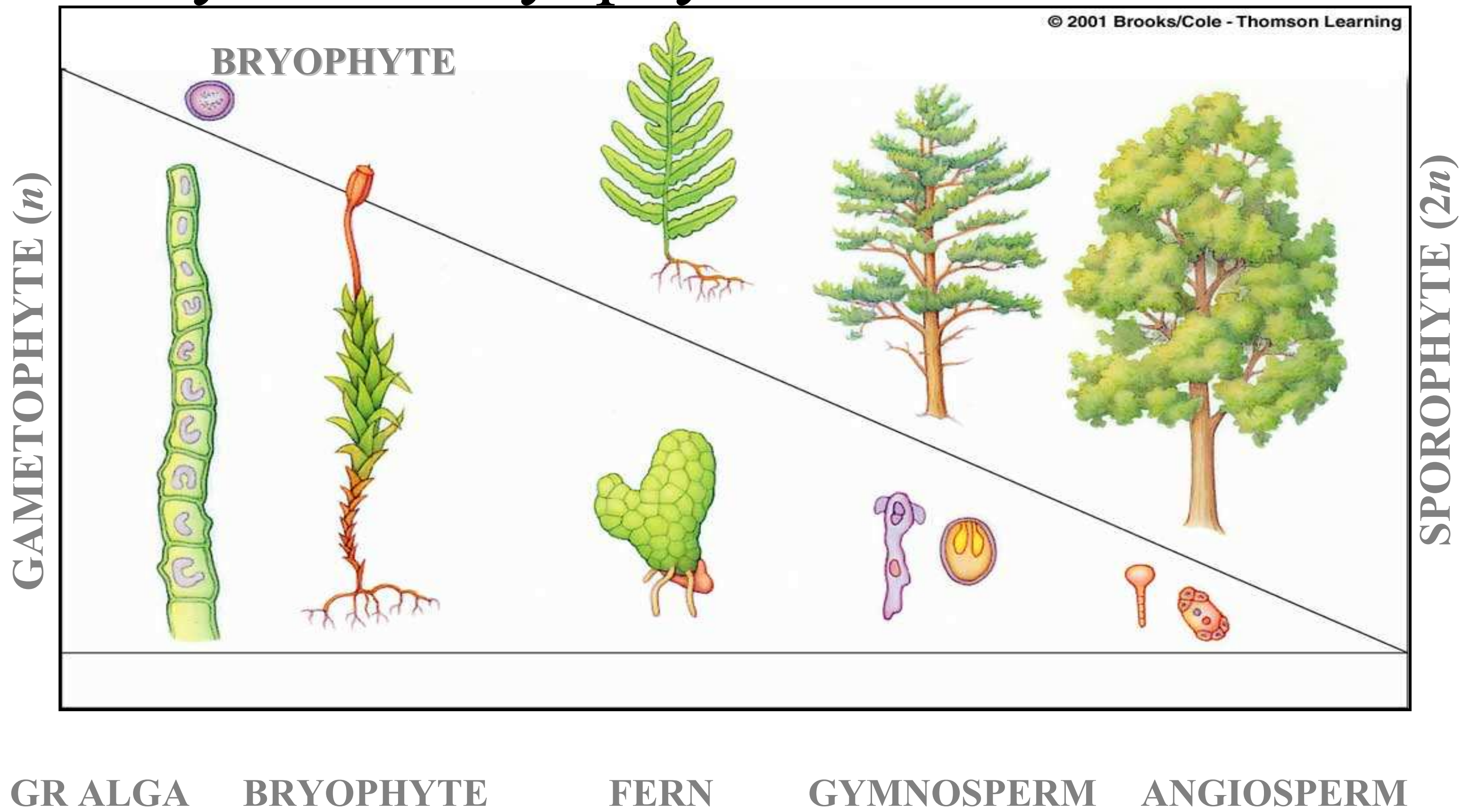
PLANT EVOLUTION

- Plant ancestry can be viewed in terms of a



BRYOPHYTES – first in Ordovician

- The gametophyte is the dominant generation in the life cycles of bryophytes



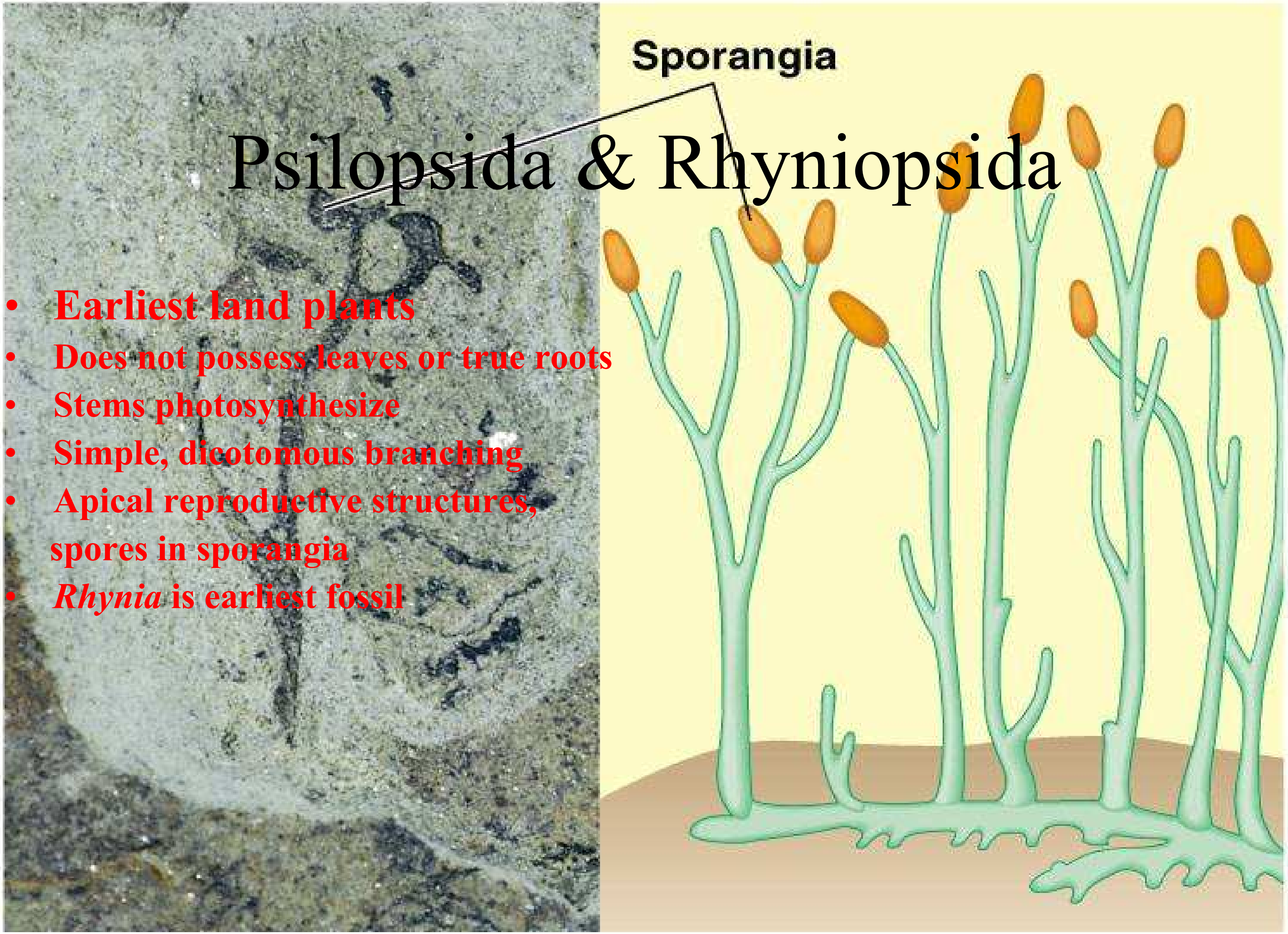
VASCULAR PLANTS

<u>Adaptations of vascular plants</u>

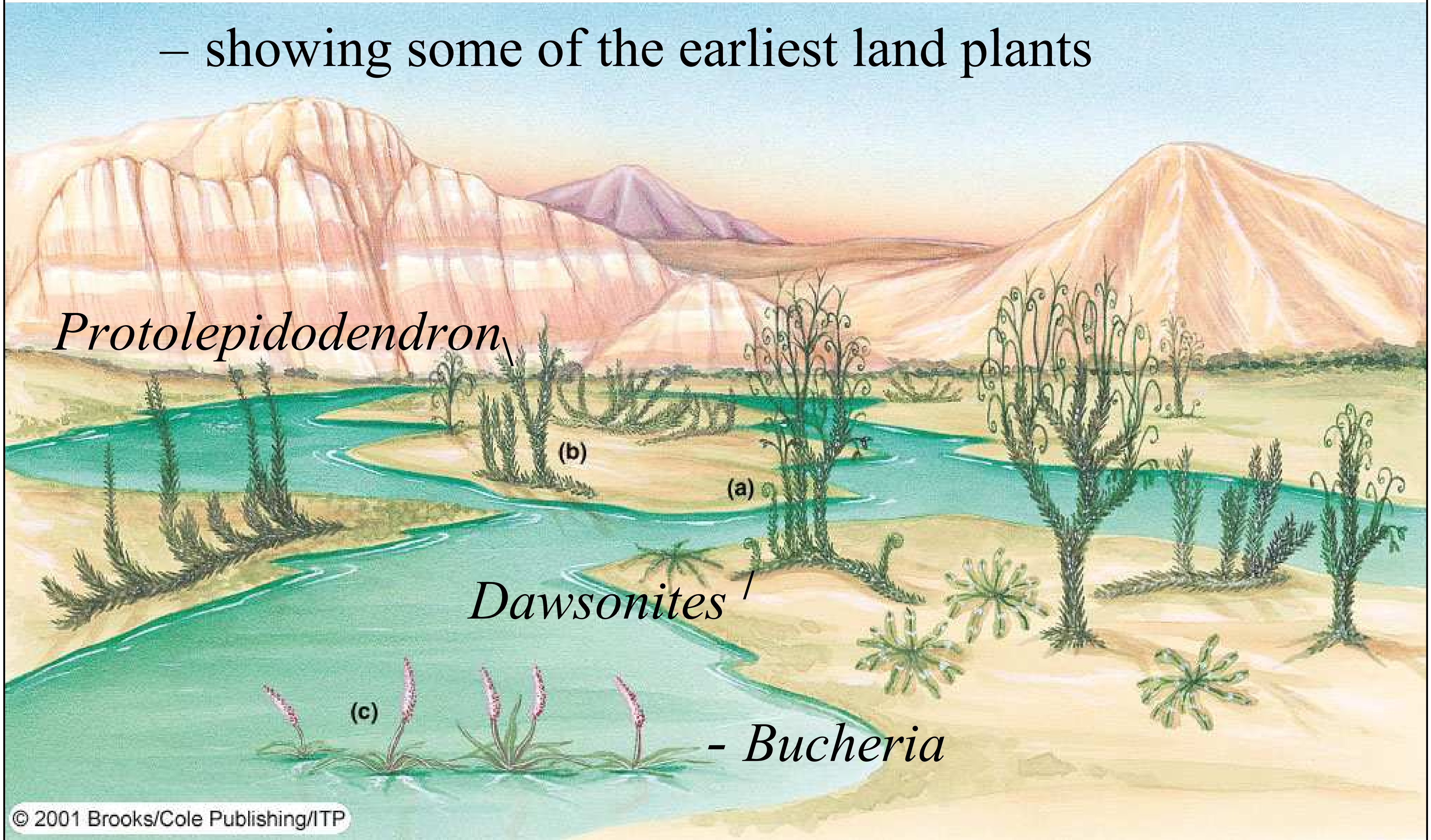
- Differentiated bodies
  - Subterranean root systems (water & minerals)
  - Aerial stems and leaves (photosynthesis)
- Vascular tissue
  - Xylem (water & minerals)
  - Phloem (organic nutrients)
- Lignin
  - Cell wall component providing mechanical support

Psilopsida & Rhyniopsida

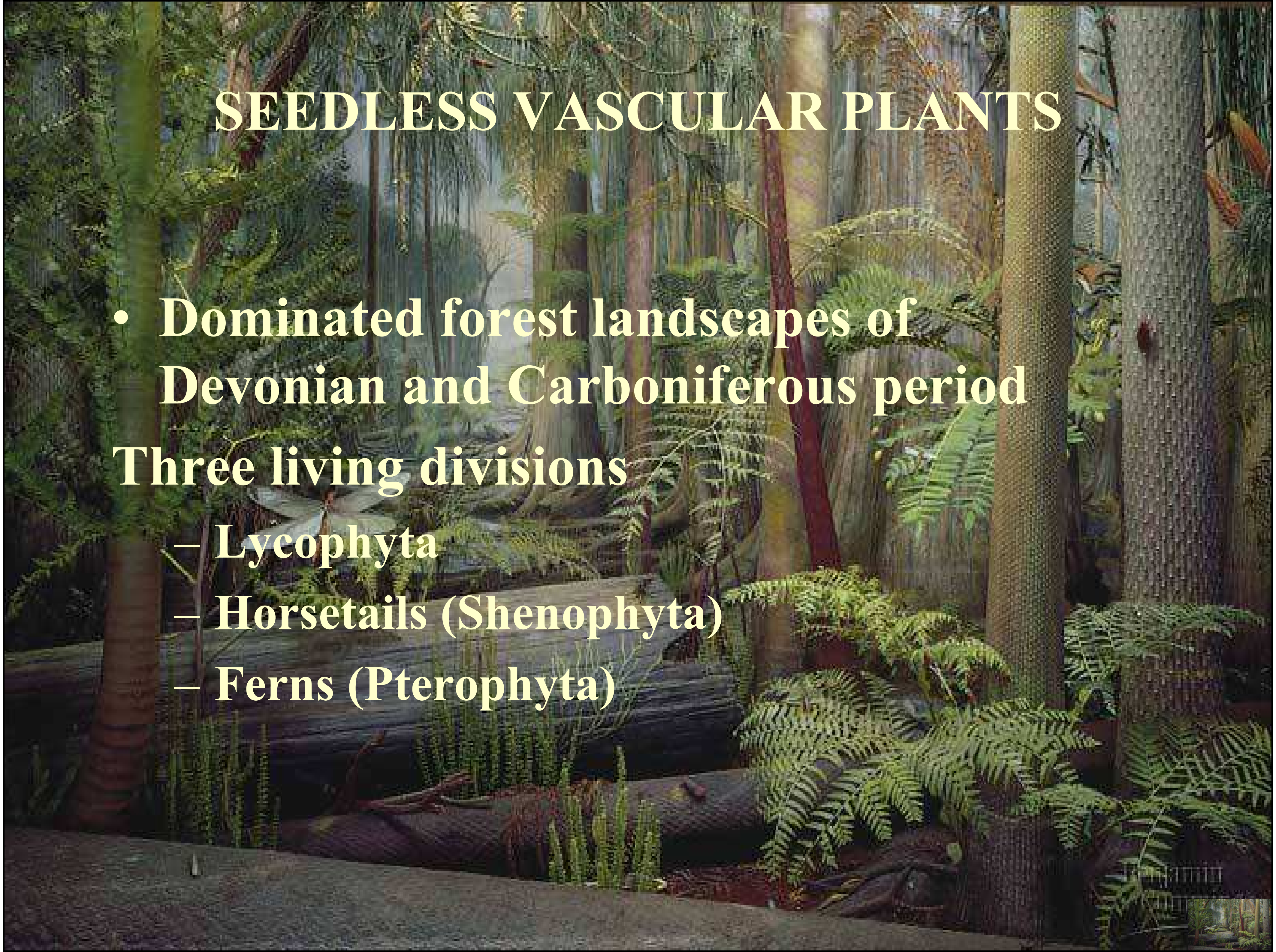
- **Earliest land plants**
- **Does not possess leaves or true roots**
- **Stems photosynthesize**
- **Simple, dicotomous branching**
- **Apical reproductive structures, spores in sporangia**
- ***Rhynia* is earliest fossil**



- **Reconstruction of Early Devonian landscape.**
  - showing some of the earliest land plants




Lower Devonian landscape



SEEDLESS VASCULAR PLANTS

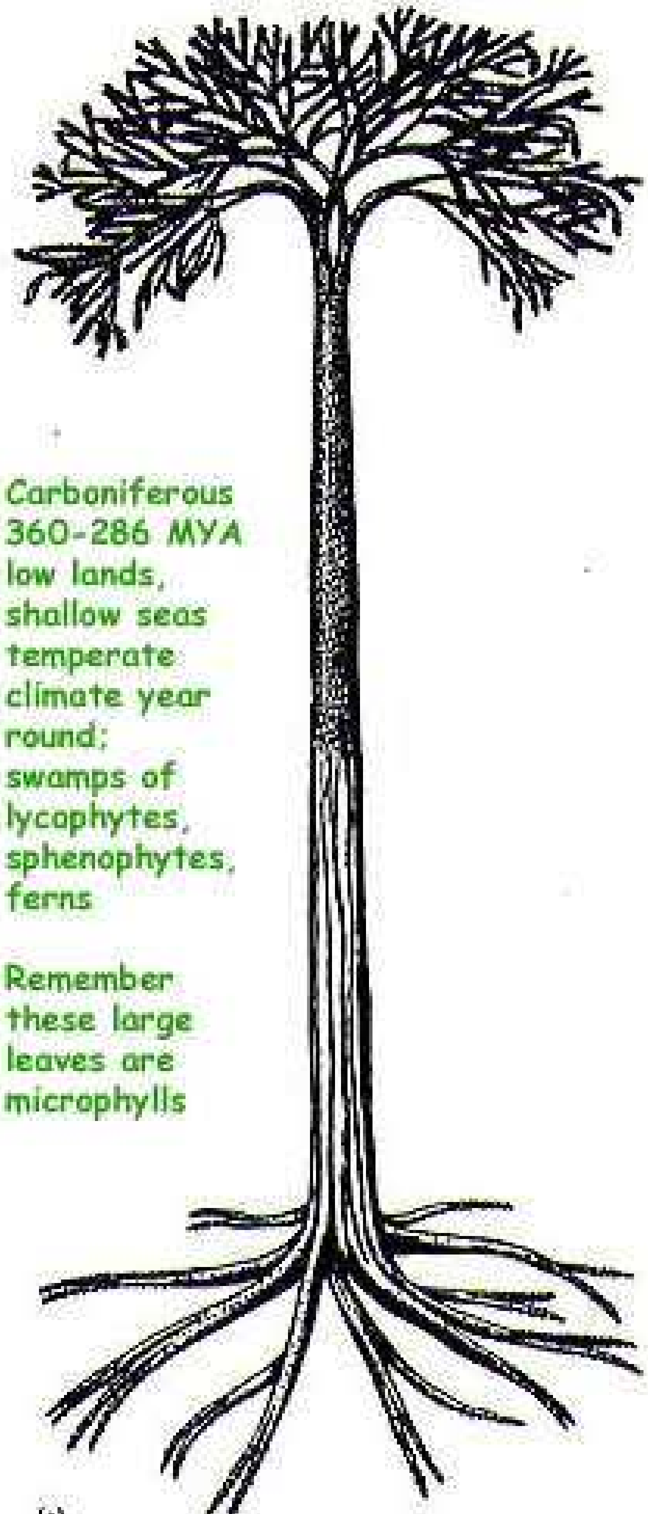
- Dominated forest landscapes of Devonian and Carboniferous period

Three living divisions

- Lycophyta
- Horsetails (Shenophyta)
- Ferns (Pterophyta)

LYCOPHYTES

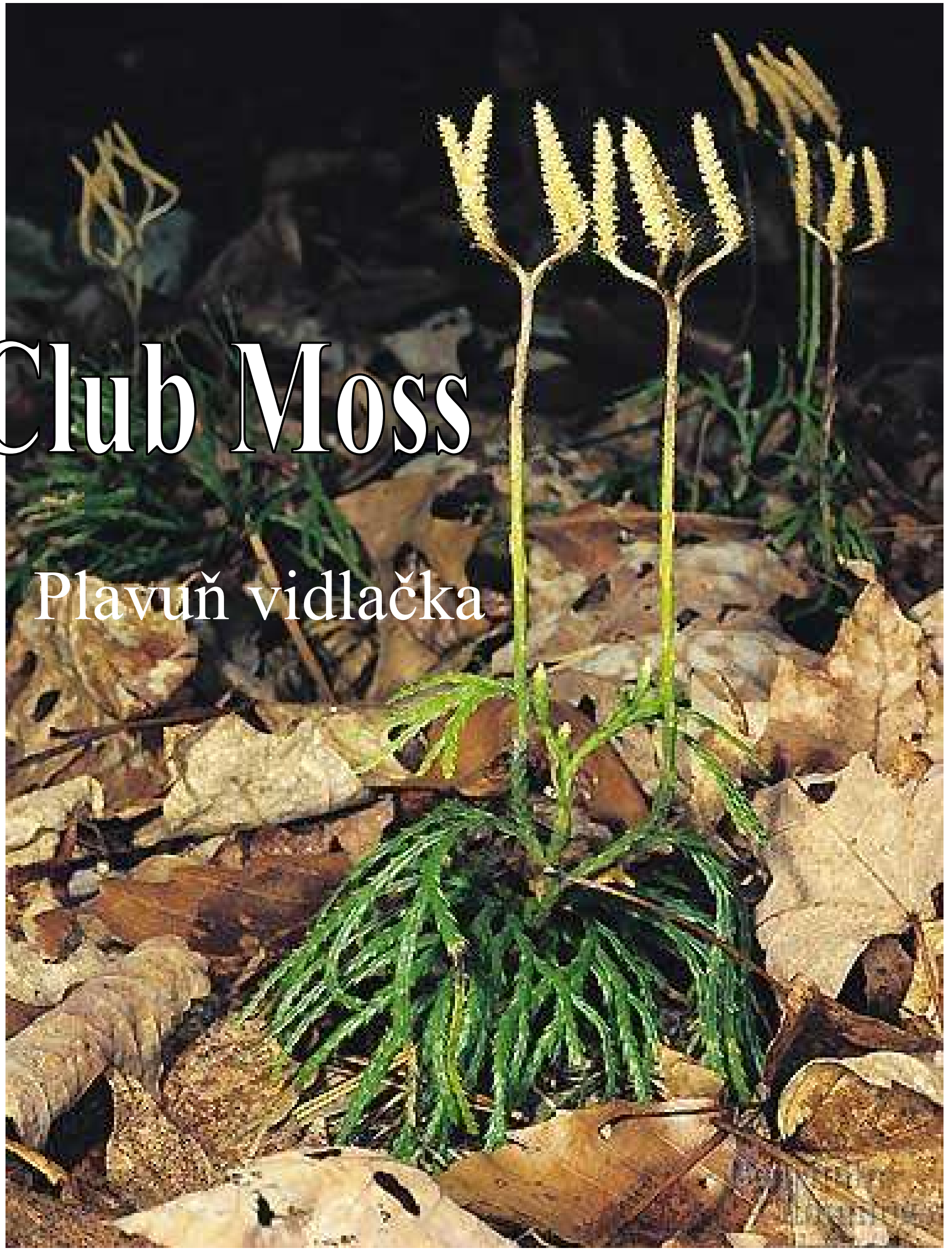
- Division *Lycophata*
- Evolved in Devonian period
  - Prevalent in Carboniferous period
  - Woody tree lineage
    - Became extinct near end of Carboniferous period
  - Herbaceous lineage
    - Represented today by ~1,000 species

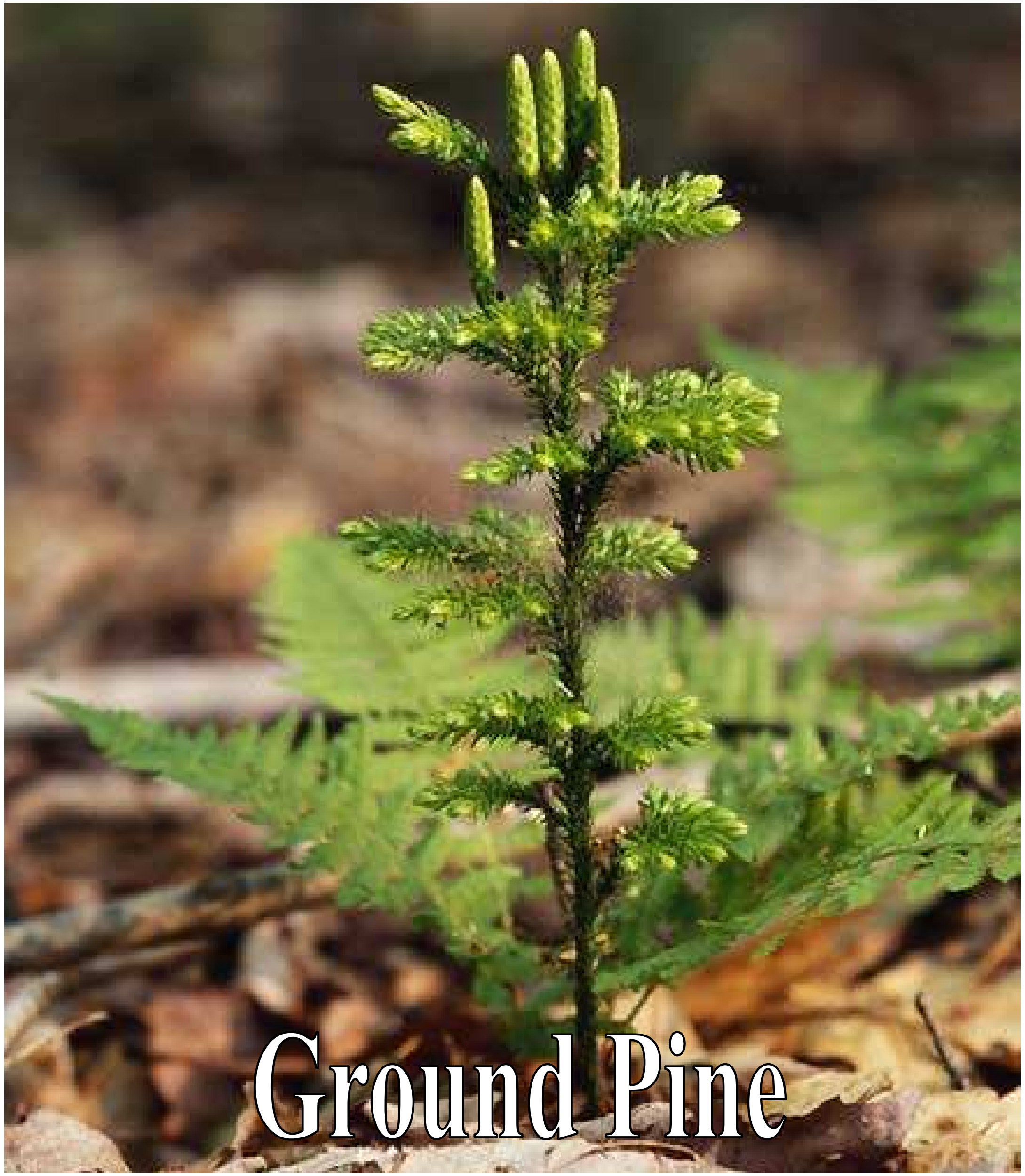


Carboniferous
360-286 MYA
low lands,
shallow seas
temperate
climate year
round;
swamps of
lycophytes,
sphenophytes,
ferns

Remember
these large
leaves are
microphylls

LYCOPHYTES





Sphenophyta

- Division horsetail
- Ancient lineage of seedless vascular plants
  - Dates back to **Devonian** Prevalent during **Carboniferous**
- Modern survivors include ~15 species in the genus *Equisetum*
  - Most common in Northern hemisphere
  - Generally found in damp locations, streambanks

FERNS

- **Division *Pterophyta***
- **Ancient ancestry**
  - **Origins in Devonian period**
  - **Prevalent in Carboniferous period**
- **Currently most prevalent seedless vascular plant**
  - **>12,000 species exist today**
  - **Most diverse in tropics**

SEED PLANTS

Key adaptations of seed plants

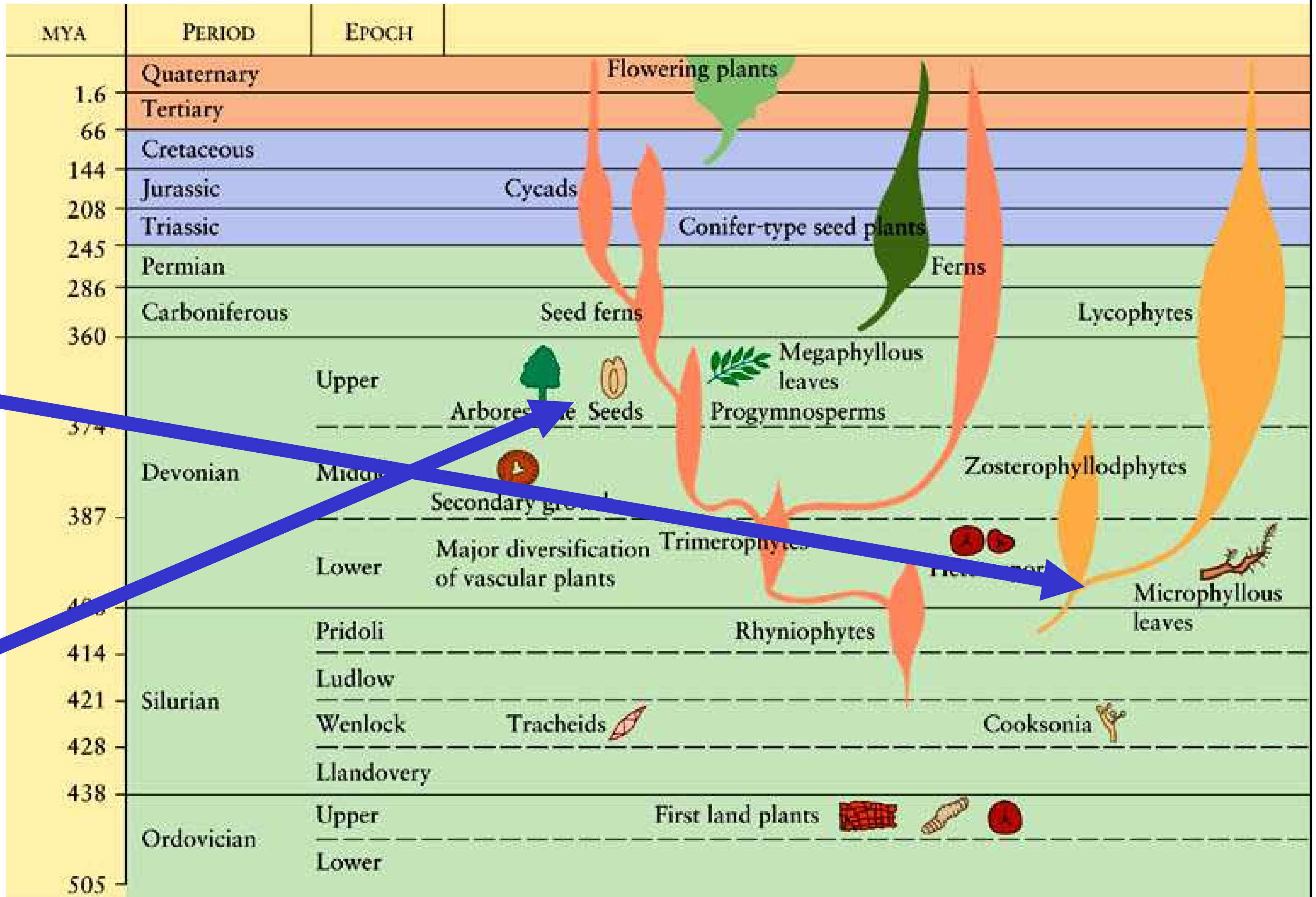
- Reduction of the gametophyte
  - Minute gametophytes retained within and protected by the sporophyte
- Advent of the seed
  - Seeds replaced spores as a means of dispersing offspring
- Evolution of pollen
  - **Eliminated the liquid H_2O fertilization requirement**

Plant Evolution

- Major events in the evolution of land plants
  - The Devonian Period was a time of rapid evolution for the land plants

– the appearance of leaves

– and emergence of seeds

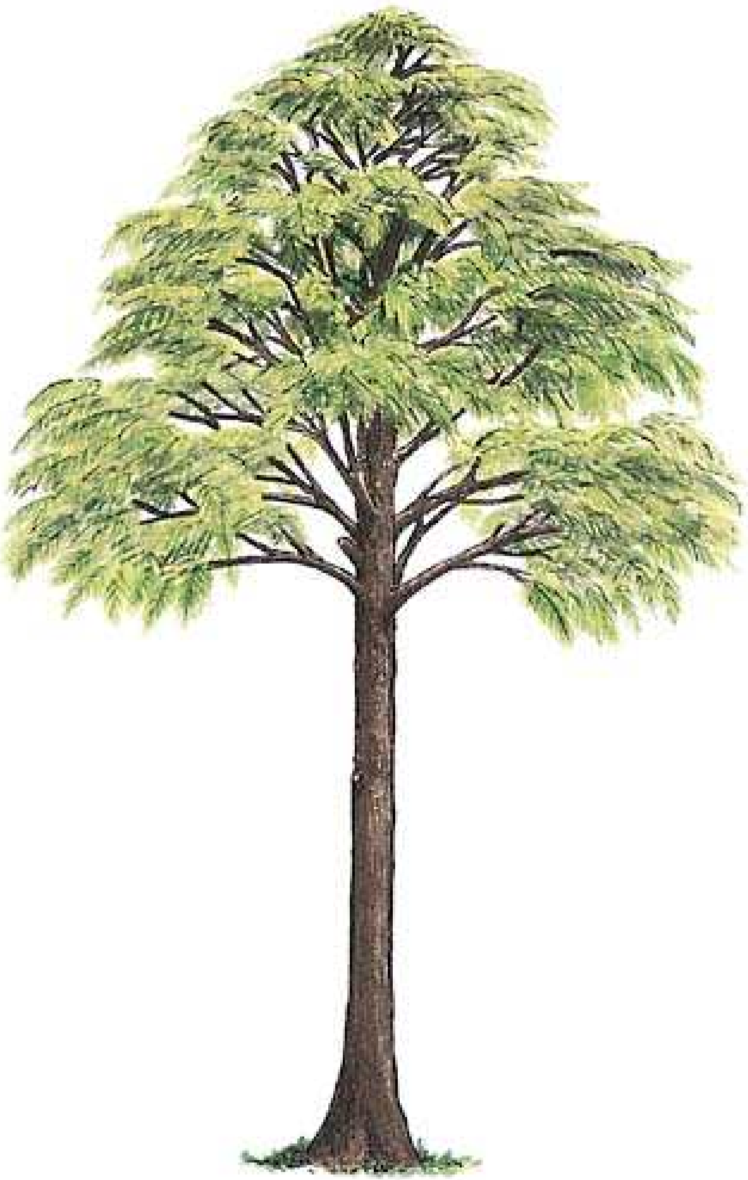


Evolution of Seeds

- The evolution of the seed during the Late Devonian
  - liberated land plants from their dependence on moist conditions
  - and allowed them to spread over all parts of the land
- In the seed method of reproduction
  - the spores are not released to the environment
  - but are retained on the spore-bearing plant
  - where they grow into the male and female forms

Progymnosperms

- Seedless vascular plants – but likely progenitors of seed plants
- Unlike other seedless vascular plants, progymnosperms had secondary vascular tissue (both xylem and phloem) and its structure is very like that of modern conifers
- Some had a eustele and were heterosporous



Reconstruction of progymnosperm
Archaeopteris

Evolution of Conifer Seed Plants

- The appearance of heterospory
  - was followed several million years later
  - by the emergence of progymnosperms
    - Middle and Late Devonian plants
    - with fernlike reproductive habit
    - and a gymnosperm anatomy
  - which gave rise in the Late Devonian
  - to such other gymnosperm groups as
    - the **seed ferns**
    - and conifer-type **seed plants**

Gymnosperms

- Paraphyletic grouping of unrelated woody seed plants that are just not Angiosperms
- Flowerless, seed-bearing plants
- Possess cones, pollen carried by wind
- Seeds dispersed by gravity or some animals
- Important groups:
  - **Pteridosperms** - “seed ferns”
  - **Cordaitales** - strap-like leaves with parallel venation
  - Cycads
  - Ginkgos
  - **Conifers** (pines & firs) - next lab

Evolution of Seeds

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Pteridosperms

- Seed ferns
- Have similar phenotypic characters as the true ferns, but with seeds & cones instead of spores

Fossils

- Oldest seeds from Devonian (365 mya)
- *Elkinsia*
- *Archaeosperma*

Gymnosperm phylogeny is a mess.

MYA--Epoch

50 Tertiary

100

150 Cretaceous

200 Jurassic

250 Triassic

286 Permian

360 Carboniferous

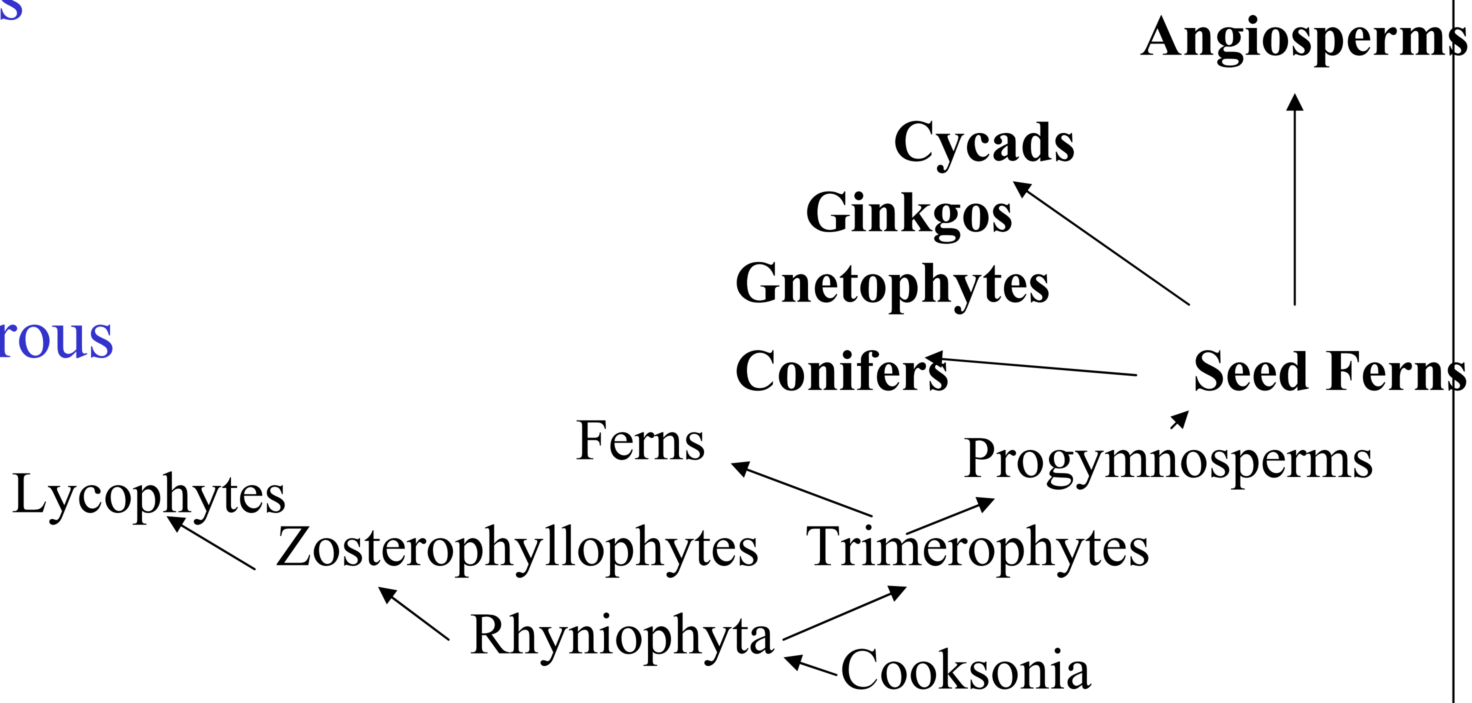
400 Devonian

425

450

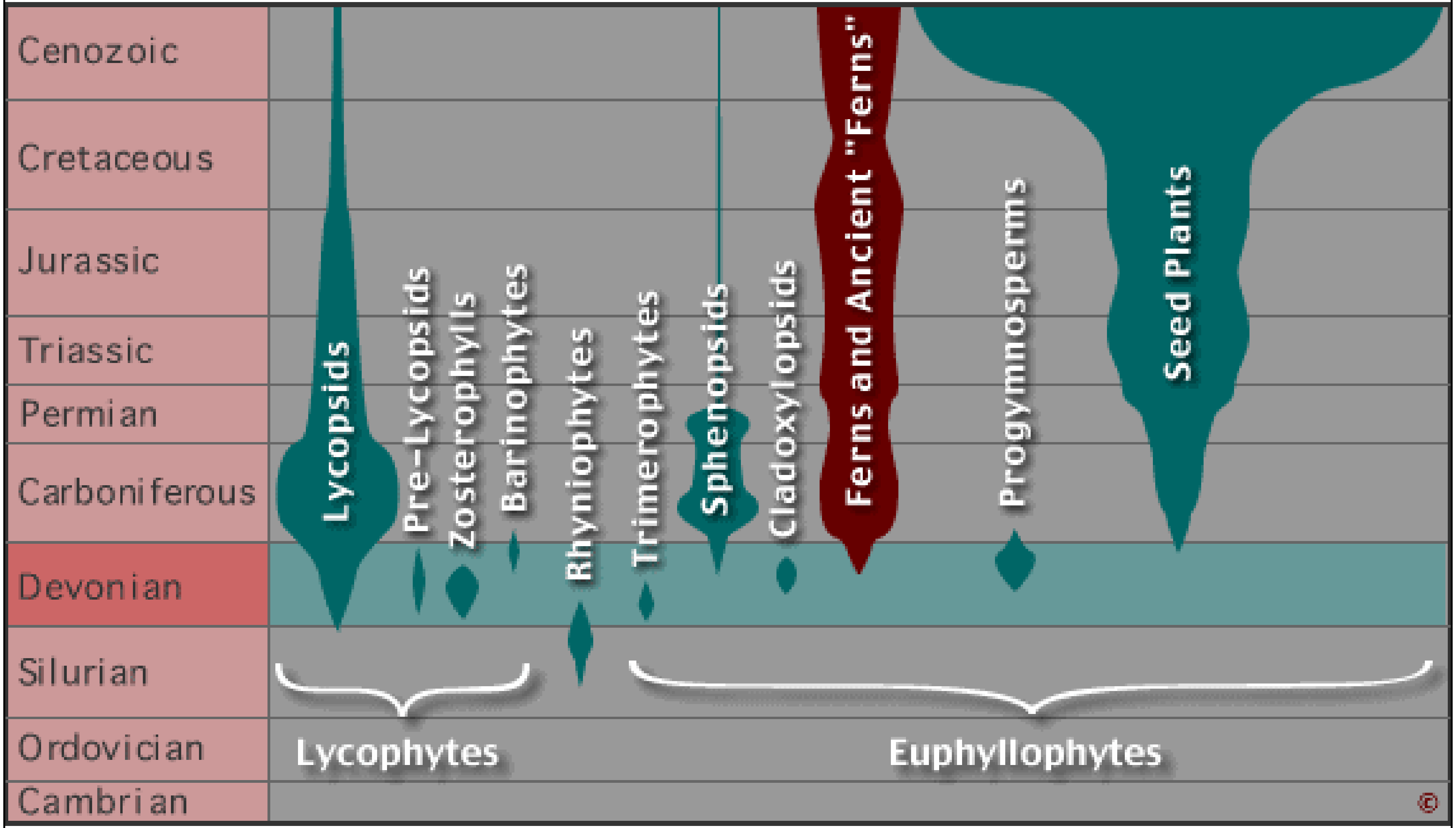
500 Silurian

600 Cambrian--Ordovician



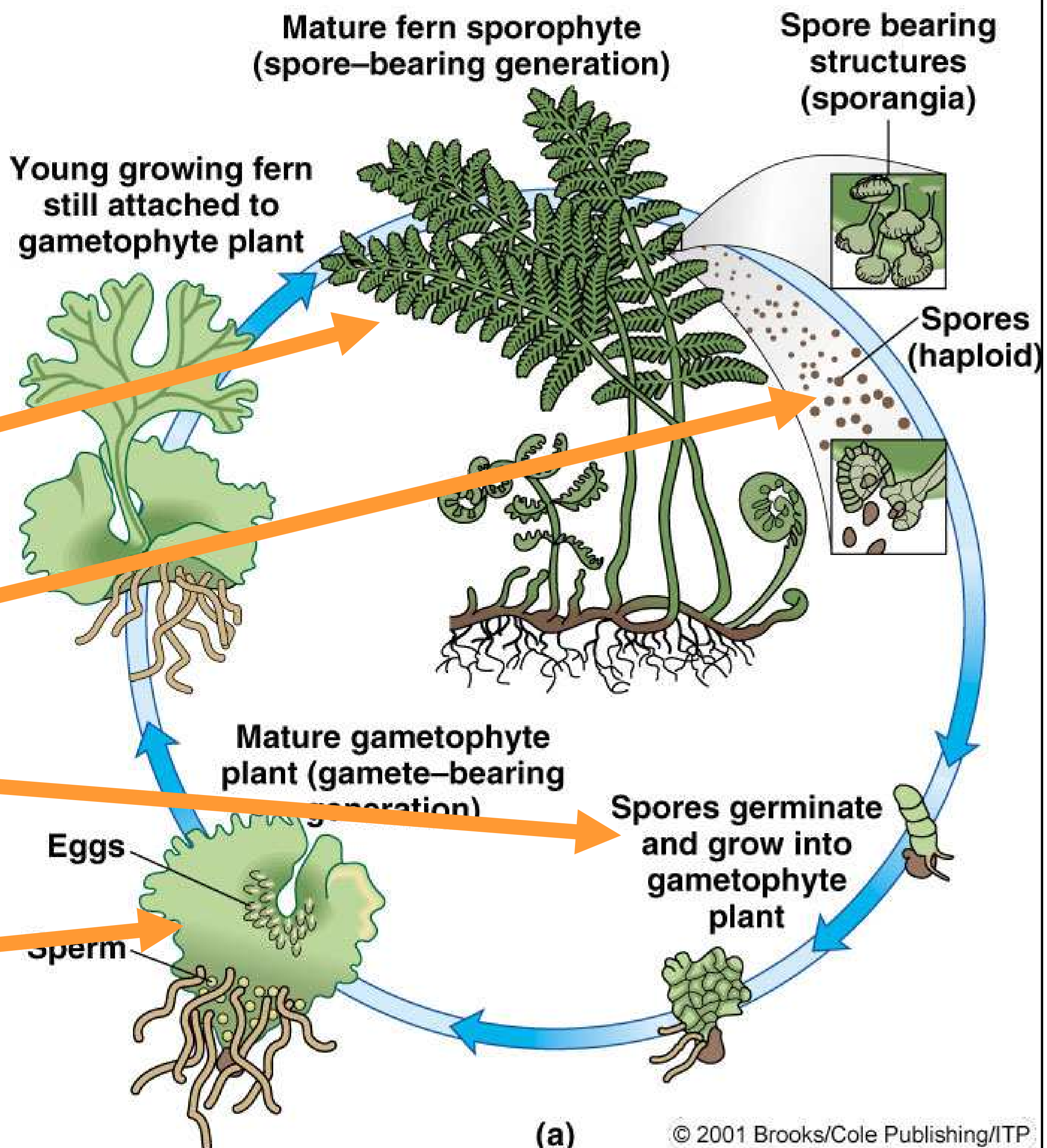
Ordovician Marine Community

- Uniformly warm, vast epeiric seas opened new marine habitats that were quickly filled
  - bryozoans, stromatoporoids, tabulate and rugose corals were important reef builders
  - built patch and massive reefs with high diversity dominated by suspension feeders
  - massive extinctions in the marine ecosystem mark the end of the Ordovician, likely related to glaciation in Gondwana and falling sea level

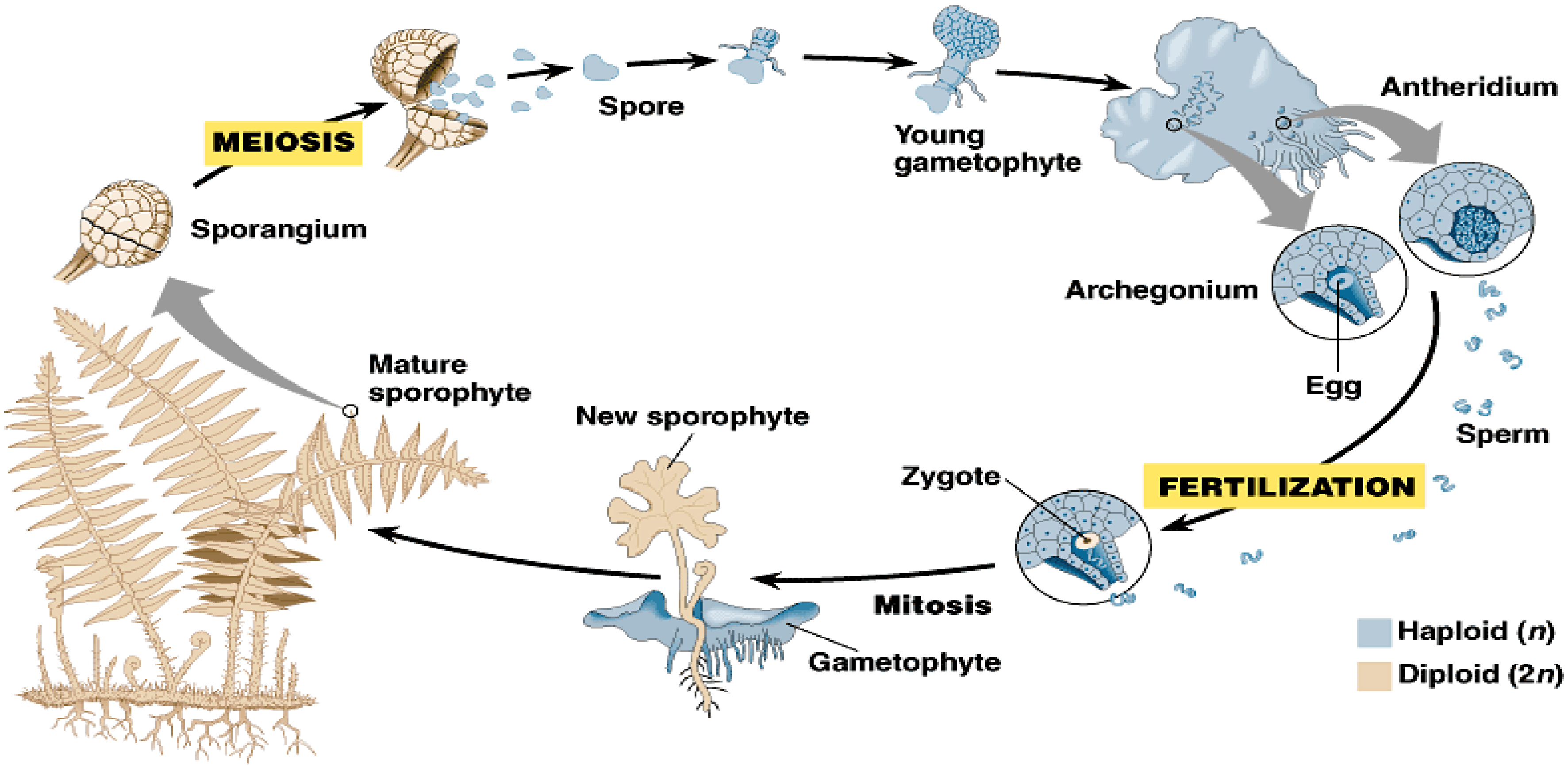

Cenozoic
Cretaceous
Jurassic
Triassic
Permian
Carboniferous
Devonian
Silurian
Ordovician
Cambrian
Lycopsids
Pre-Lycopsids
Zosterophylls
Barinophytes
Rhyniophytes
Trimerophytes
Sphenopsids
Cladoxylopsids
Ferns and Ancient "Ferns"
Progymnosperms
Seed Plants
Lycophytes
Euphyllophytes
©

Seedless Vascular Plant

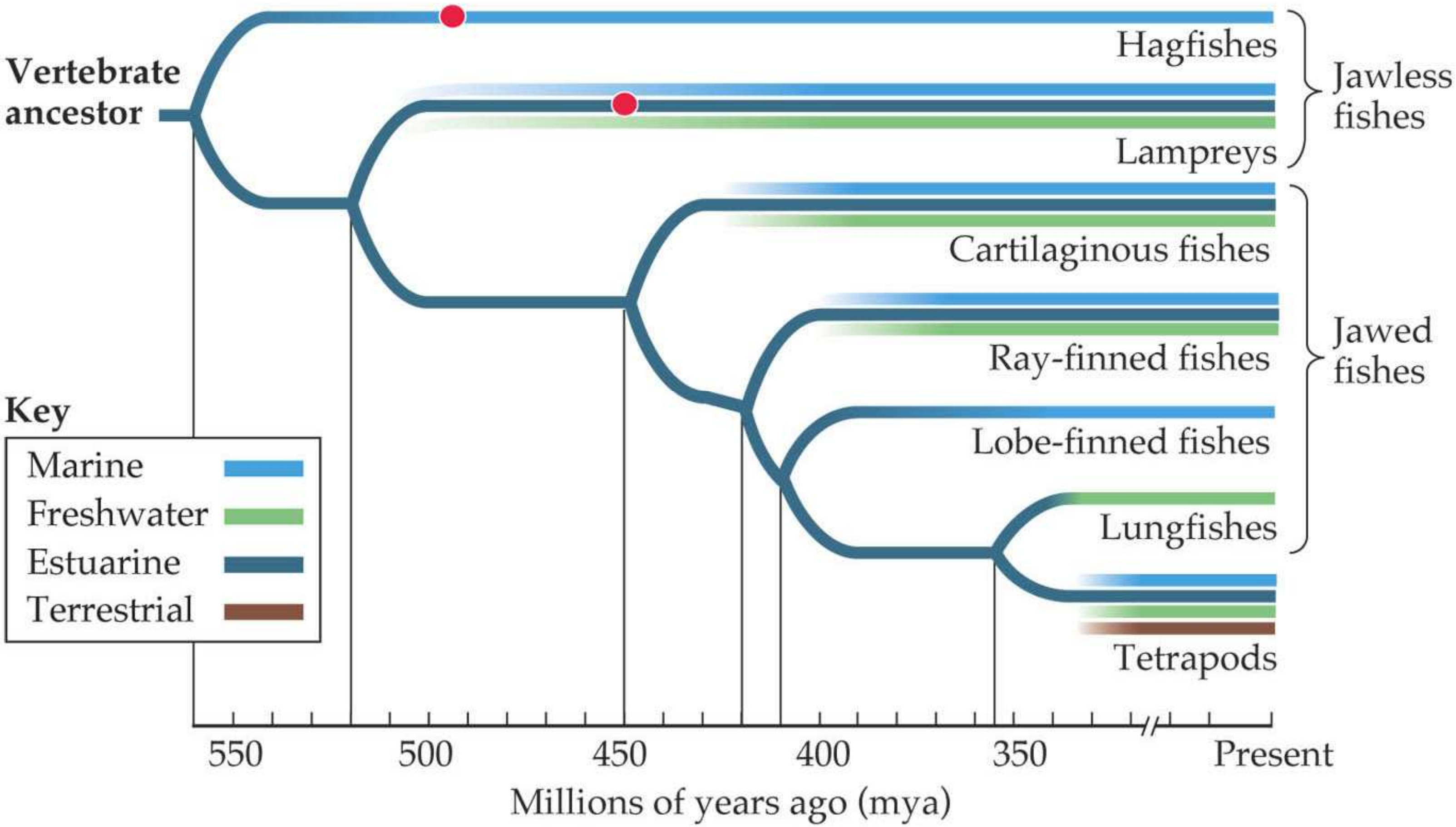
- Generalized life history of a seedless vascular plant
- The mature sporophyte plant produces spores
  – which upon germination grow into small gametophyte plants



SEEDLESS VASCULAR PLANTS



Vertebrate Phylogeny



LIFE: THE SCIENCE OF BIOLOGY, Seventh Edition, Figure 34.8 A Current Phylogeny of the Vertebrates