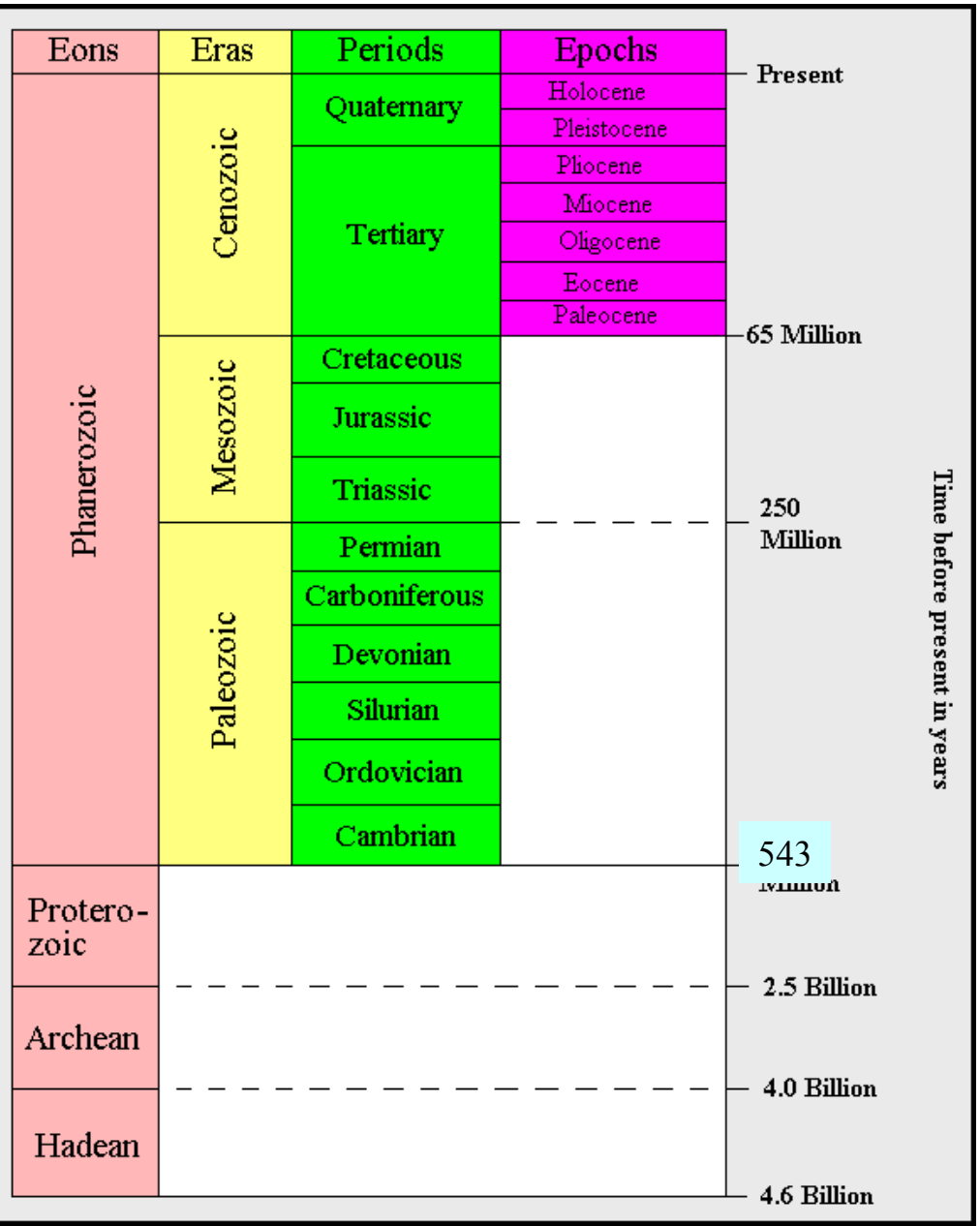
# THE PHANEROZOIC TIME SCALE




| Príklad: | Chronostratigrafické jednotky | Geochronologické jednotky | Oblastné litostratigrafické jednotky | Rýdzo biostratigrafické jednotky |
|---|---|---|---|---|
| fanerozoikum | eonotem | eón | | |
| mezozoikum | eratem | éra | | |
| jura | útvar | perióda | skupina | |
| lias | oddelenie | epocha | súvrstvie | rôzne druhy biostratigrafických zón (subzóna) |
| toark | stupeň | vek | člen | |
| Hildoceras bifrons | chronozóna | chron | vrstva (horizont) | (biohorizont) |

Obr. 23a. Prehľad hlavných stratigrafických jednotiek. Chronostratigrafické a geochronologické jednotky si vz
jomne zodpovedajú a ich obsah je presne stanovený. Oblastné litostratigrafické a biostratigrafické jednotky
nezávislé od iných stupníc a hierarchické usporiadanie je relatívne

# Phanerozoic period

- Fossils with recognisable affinities with forms of present.
- Evolution of animal shell
- Increases Paleobiological record
- Secreted calcium carbonate, calcium phosphate and silica
- Remains deposited as sediment
- Geologically known period
- All major animal phyla and vascular plants quickly established
- Evolution of atmosphere at near its present levels of oxygen

# Paleozoic eratem

**Lasted nearly 300 milion years**
**Lower Paleozoic – Cambrian – Devonian, Upper Paleozoic – Carboniferous-Permina**
**Some authors Lower, Middle, Upper Paleozoic**

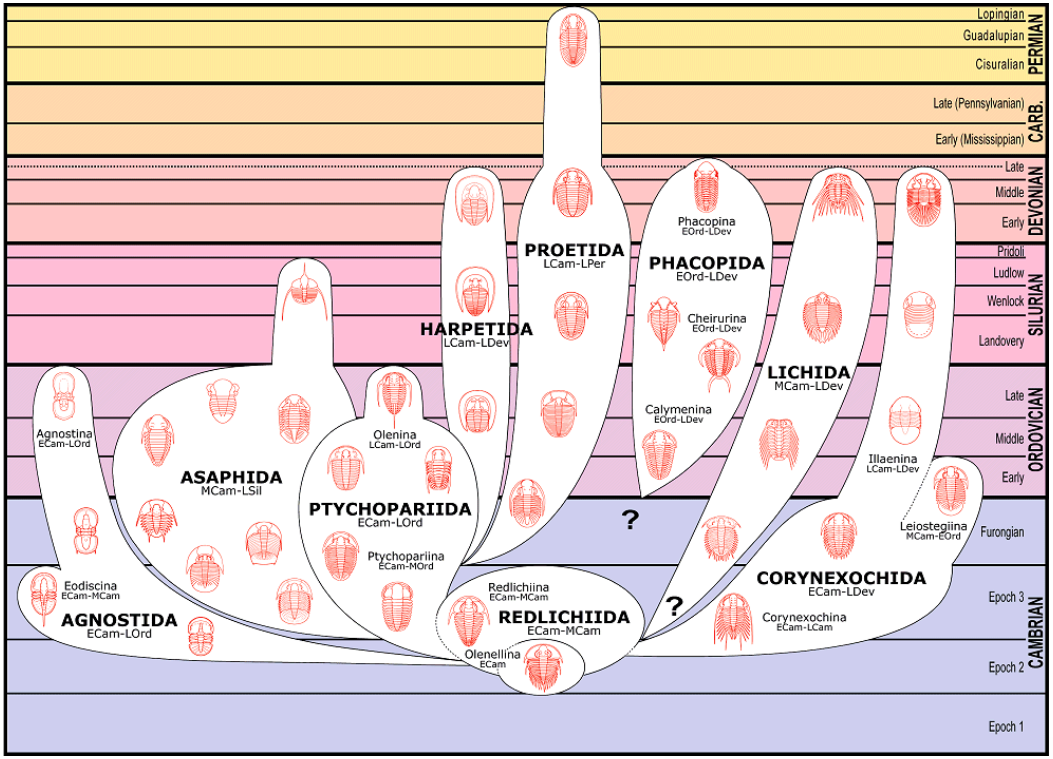
**Paleozoický eratem** je součást **fanerozoika** tvořeného ještě mesozoickým a kenozoickým eratemem. Má rozpětí zhruba **300 milionů let** a je nejdelším ve fanerozoiku. Dělí se na 6 útvarů, z nichž první čtyři jsou někdy označovány jako starší (spodní) paleozoikum a poslední dva jako mladší (svrchní) paleozoikum.

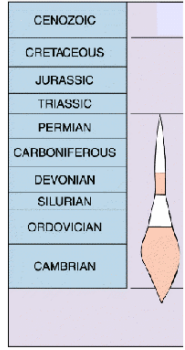
Původně jednotný superkontinent **Rodinia** se začal rozpadat již během nejvyššího proterozoika a jeho rozpadání pokračovalo i v nejspodnějším paleozoiku. Na počátku paleozoika můžeme ještě sledovat doznívání **kadomské** (assyntské) orogeneze. Kolize kontinentů v paleozoiku měla za následek **kaledonskou** (spodní paleozoikum - uzavírání Japetu) a **variskou** (především svrchní paleozoikum - uzavírání Paleotethydy) orogenezi, která byla ukončena opětovným vznikem nového superkontinentu **Pangei**.

**Paleozoikum** se na rozdíl od prekambria vyznačuje bohatým rozvojem fauny a flóry. V **kambriu** se explozívně objevují zástupci všech dnes známých živočišných **kmenů.** Ve vývoji živočichů patří k charakteristickým znakům paleozoika zejména vývoj **trilobitů** (maximum v kambriu a ordoviku), velké rozšíření **brachiopodů**, bohatý rozvoj tabulátních a rugózních **korálů** a **stromatoporoideí** (hlavně silur a devon), bohatý rozvoj nautiloidních **hlavonožců** (od ordoviku) a ammonoidních hlavonožců) od devonu, radiace **ryb** (od siluru), celosvětové rozšíření **obojživelníků** (karbon) a plazů (perm). Vývoj paleozoické fauny byl ukončen zatím největším známým **vymíráním** na hranici paleozoika a mesozoika.

Osídlení pevnin vyššími cevnatými **rostlinami** můžeme sledovat až od siluru. V devonu se již objevuje v klimaticky příznivých podmínkách relativně souvislý **rostlinný pokryv**. Explozivní rozvoj a velké rozšíření **výtrusných rostlin** ve svrchním paleozoiku umožnilo vznik ložisek černého uhlí. V nejvyšším paleozoiku (svrchní perm) můžeme sledovat výraznou změnu ve složení flóry - výtrusné rostliny ustupují rychle se rozvíjejícím nahosemenným (hranice **paleofytikum-mesofytikum**).

# The Cambrian Fauna
## Trilobites



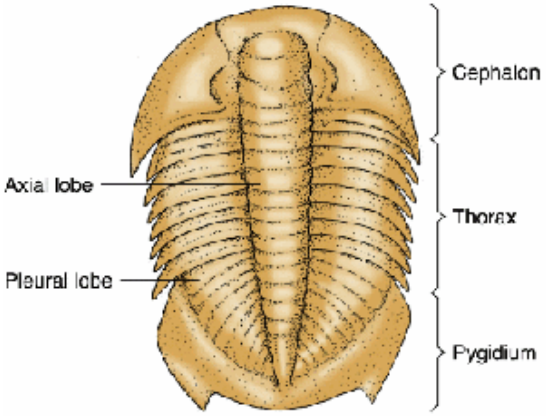





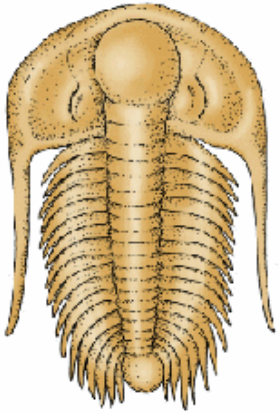

*Paradoxides harlani*

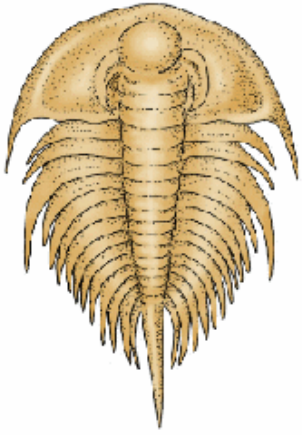
*Olenellus thompsoni*

- Phylum: Arthropoda
- Class: Trilobita
- Species: >600




*Dikelocephalus minnesotensis*





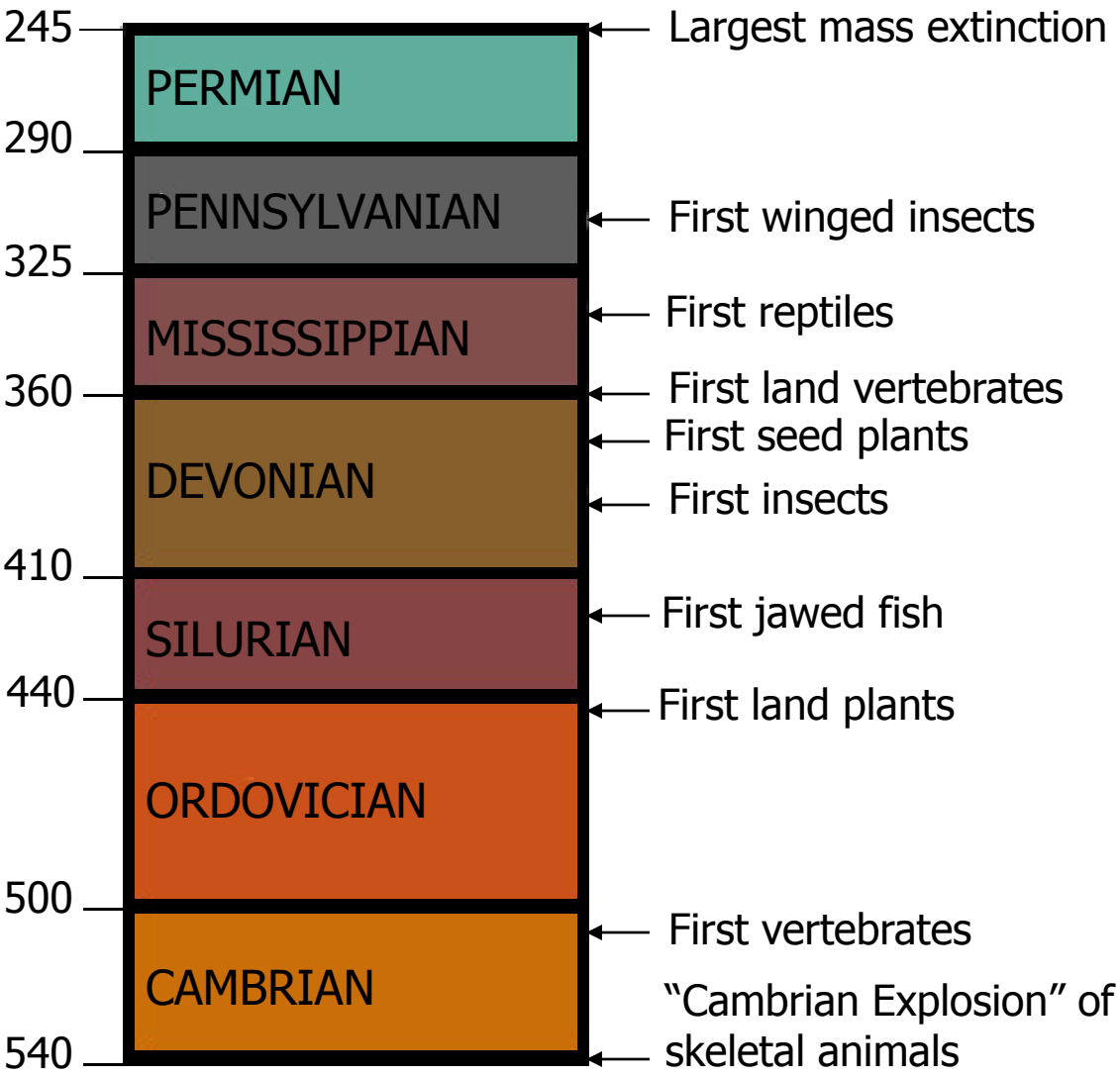
# Paleozoic fauna

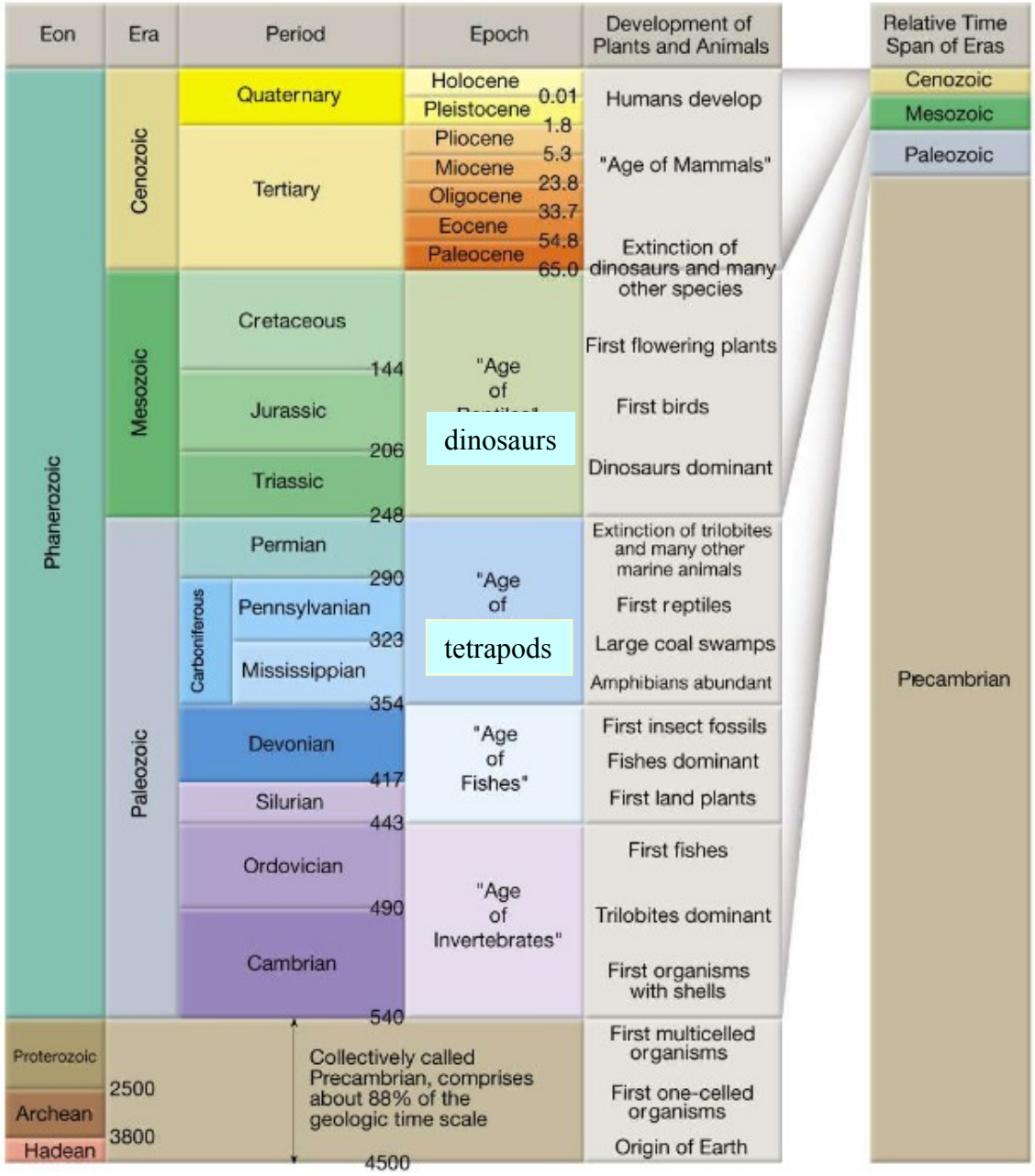
**In Cambrian representatives of all animal phyla**
**Great development of trilobites (Cambrian-Ordovician), high representtaion of brachiopods, nautiloid and ammonoid cephalopods. Rugose and tabulate corals (Silurian, Devonian), radiation of fishes (since Devonian), Amphibians (Carboniferous), reptiles (Permian). Biggest mass extinction at the end, smaller at the end of Ordovician and Devonian.**

# Paleozoic flora

**LAND FLORA SINCE ordovician, Silurian – vascular plants, larger representation and continuous cover in Devonian. Explosive development of spore plants in Carboniferous – coal. Boundary between Paleophyticum and Mesophyticum In middle Permian**

# PALEOZOIC


245
290
325
360
410
440
500
540
PERMIAN
PENNSYLVANIAN
MISSISSIPPIAN
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN
Largest mass extinction
First winged insects
First reptiles
First land vertebrates
First seed plants
First insects
First jawed fish
First land plants
First vertebrates
"Cambrian Explosion" of skeletal animals



# The Age of Ancient Life - Paleozoic

Of the three main eras that make up the Phanerozoic, the Paleozoic is the longest and most diverse, spanning the period from very early multicellular life that only inhabited the oceans to quite advanced tetrapods* and reptiles and extensive forests on land.

**Early Paleozoic: Age of Invertebrates**

Coelomate radiation (Cambrian explosion) - origin of major groups of organisms; nervous system, behavior patterns and simple consciousness (the nascent Noosphere); continents drift apart.

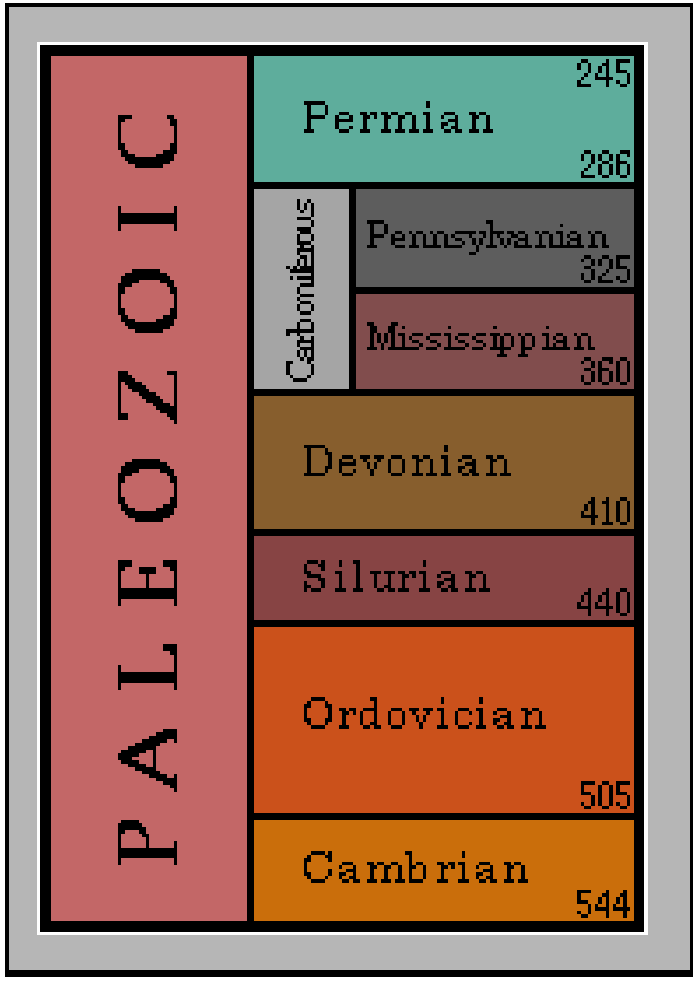
**Middle Paleozoic: Age of Fish**

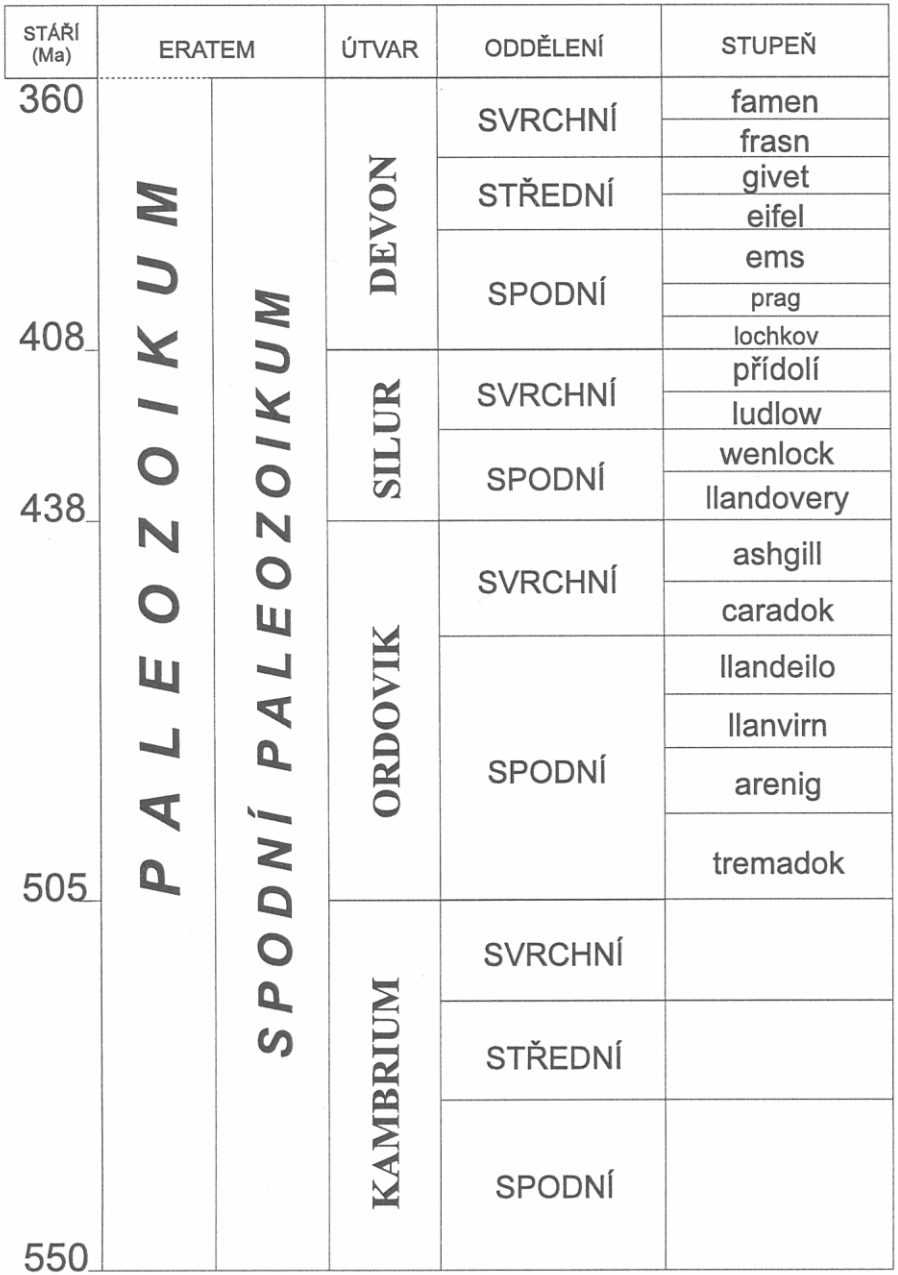
Tropical conditions. Extinction of many "experimental" animal groups; diversification of surviving invertebrate groups, rise of vertebrates (fish). Life moves on land (rhyniophytes, lycopods, uniramious arthropods, proto-amphibians)

**Late Paleozoic: Age of Tetrapods* and Reptiles**

Ice age. Coal forests of giant lycopods, calamites, pteridophytes and ferns cover the tropical landmasses. Southern landmass of Gondwanaland buried under glaciers; continents drift together. Reptiles conquer the land.

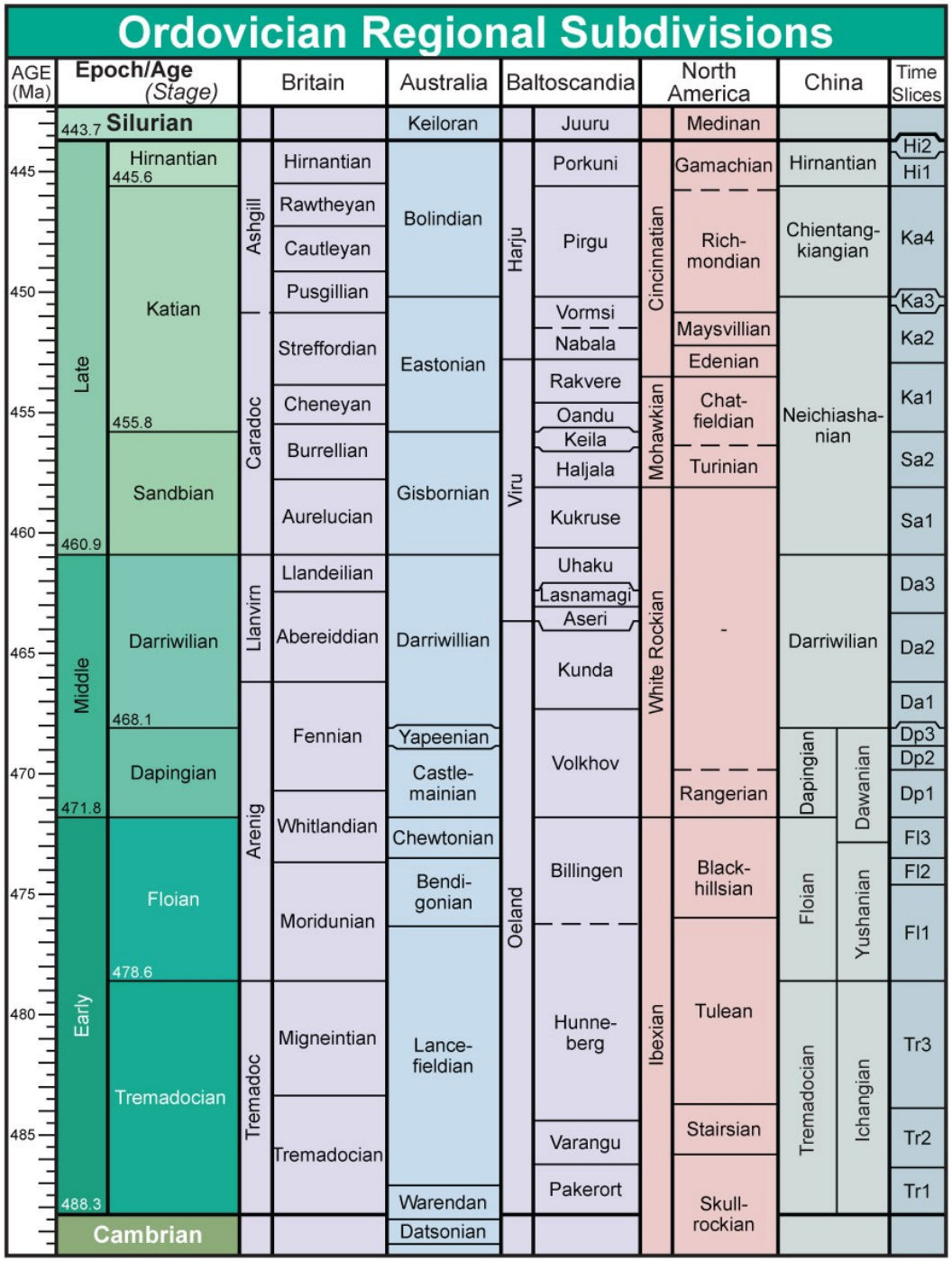
# Paleozoic


PALEOZOIC
Permian
245
286
Carboniferous
Pennsylvanian
325
Mississippian
360
Devonian
410
Silurian
440
Ordovician
505
Cambrian
544




**Obr. 30.** Základní členění spodního paleozoika.

**Early Paleozoic**


Ordovician Regional Subdivisions
AGE (Ma)
Epoch/Age (Stage)
Britain
Australia
Baltoscandia
North America
China
Time Slices
443.7
Silurian
Keiloran
Juuru
Medinan
Hirnantian
445.6
Katian
455.8
Sandbian
460.9
Late
Darriwilian
468.1
Dapingian
471.8
Middle
Floian
478.6
Tremadocian
488.3
Early
Cambrian
Datsonian
Ashgill
Caradoc
Llanvirn
Arenig
Tremadoc
Hirnantian
Rawtheyan
Cautleyan
Pusgillian
Streffordian
Cheneyan
Burrellian
Aurelucian
Llandeilian
Abereiddian
Fennian
Whitlandian
Moridunian
Migneintian
Tremadocian
Bolindian
Eastonian
Gisbornian
Darriwillian
Yapeenian
Castle-mainian
Chewtonian
Bendi-gonian
Lance-fieldian
Warendan
Harju
Viru
Oeland
Porkuni
Pirgu
Vormsi
Nabala
Rakvere
Oandu
Keila
Haljala
Kukruse
Uhaku
Lasnamagi
Aseri
Kunda
Volkhov
Billingen
Hunne-berg
Varangu
Pakerort
Cincinnatian
Mohawkian
White Rockian
Ibexian
Gamachian
Rich-mondian
Maysvillian
Edenian
Chat-fieldian
Turinian
-
Rangerian
Black-hillsian
Tulean
Stairsian
Skull-rockian
Hirnantian
Chientang-kiangian
Neichiasha-nian
Darriwilian
Dapingian
Floian
Tremadocian
Dawanian
Yushanian
Ichangian
Hi2
Hi1
Ka4
Ka3
Ka2
Ka1
Sa2
Sa1
Da3
Da2
Da1
Dp3
Dp2
Dp1
Fl3
Fl2
Fl1
Tr3
Tr2
Tr1
445
450
455
460
465
470
475
480
485

# Early Paleozoic

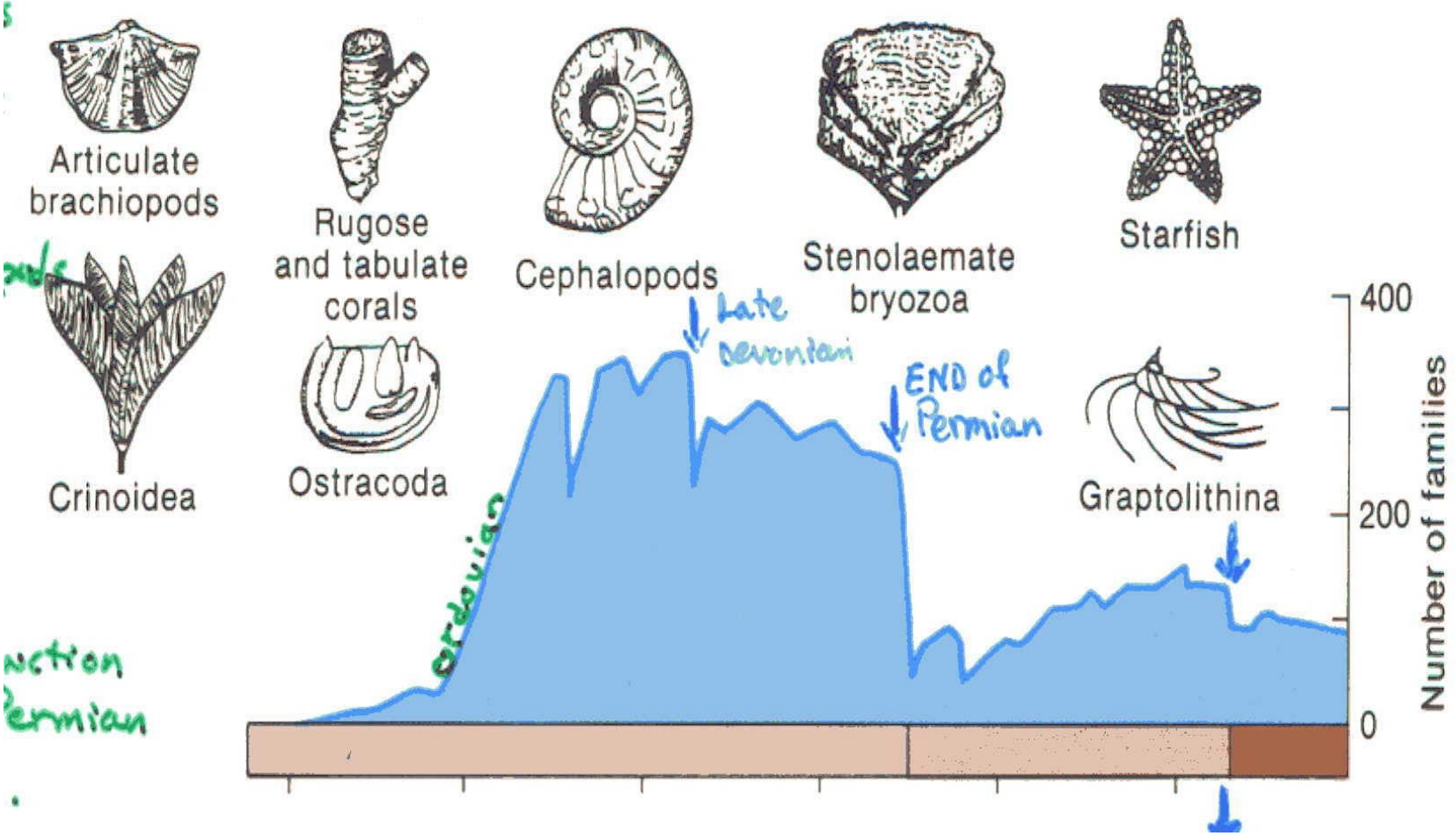
**Two types of distinct evolutionary fauna – Cambrian and Ordovician to Devonian**

**Z hlediska vývoje fauny můžeme ve spodním paleozoiku roslišit kambrickou faunu, kde dominovali členovci a více diversifikovanou faunu ordoviku-devonu, kdy došlo k většímu zastoupení a rozrůznění dalších živočišných kmenů jako jsou mechovky, brachiopodi, měkkýši (hlavně hlavonožci), ostnokožci, strunatci, láčkovci (korály) a houby(zejména stromatoporoidea).**

# INVERTEBRATES

- In Cambrian
  - trilobites - now gone - 60% of Cambrian fossils
  - brachiopods - rare now - 30% of Cambrian

# PALEOZOIC FAUNA



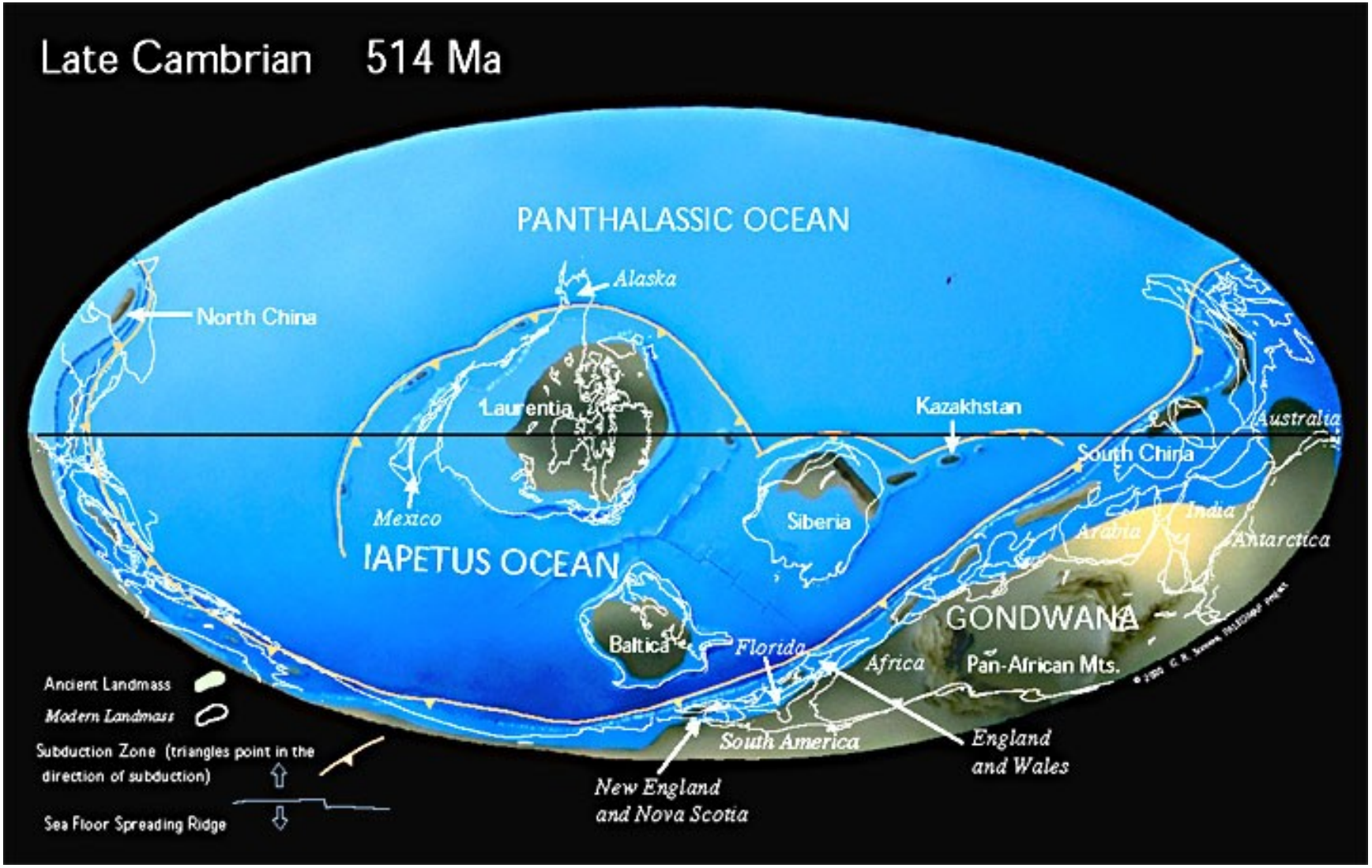
# Cambrian

| | |
|---|---|
| **Upper** | ***Olenus*** |
| **Middle** | ***Paradoxides*** |
| **Lower** | ***Olenellus*** |

# Paleogeography

V kambriu byla největším kontinentem **Gondwana** protínaná rovníkem a tvořená prekambricky konsolidovaným jihoamerickým, africkým, indickým, arabským, australským a antarktickým kratonem, Arábií a jižní Evropou a čínskými kontinenty, které zasahovaly do nižších zeměpisných šířek. V nízkých zeměpisných šířkách se nacházely kontinent **laurentský**, **sibiřský** a **kazašský**. **Baltika** ve vyšších zeměpisných šířkách jižní polokoule. Rozsah kambrické teplé klimatické zóny dokumentují **archeocyátové** vápence, ložiska evaporitů a facie červených pískovců zjištěné na území Kanady, Indie a Austrálie. Zatímco na počátku kambria ležely kontinenty ještě blízko sebe, během kambria docházelo k jejich **rychlému vzdalování**.

**Paleogeography – disintegration of Rodinia. Biggest continent - Gondwana**



The Cambrian Period is the first period of the Paleozoic Era. It was named in 1835 by the geologist Adam Sedqwick, after the region of Cambria in North Wales, where rocks of this age were first found. The name "Cambria" is a version of *Cumbria*, a latinisation the Welsh *Cymry* (= countryman, compatriot against the (invading) Anglo-Saxons).

Accordingly, the International Subcommission on Cambrian Stratigraphy (through its Working Group on the Precambrian-Cambrian Boundary) made the official decision in 1991 to draw the base on the Cambrian at the first appearence date (FAD) of ***Trichophycus pedum*** (formerly known as "*Phycodes pedum*"). in the reference section at Fortune Head. southeastern Newfoundland, which belonged to the Cambrian continent Avalonia

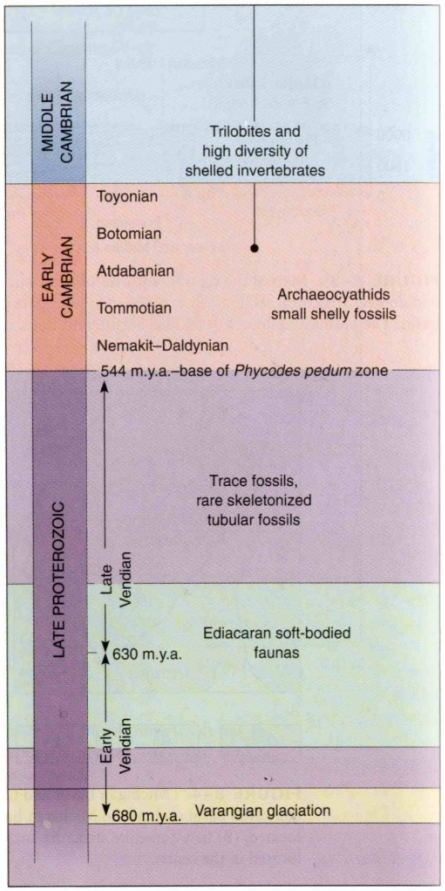



**FIGURE 8–6** The Cambrian–Precambrian boundary is placed at the base of the *Phycodes pedum* zone, corresponding to a uranium–lead age determination of 544 million years.

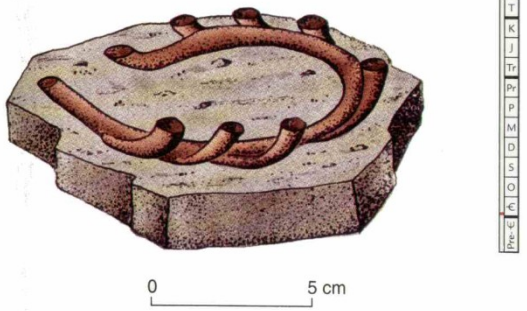


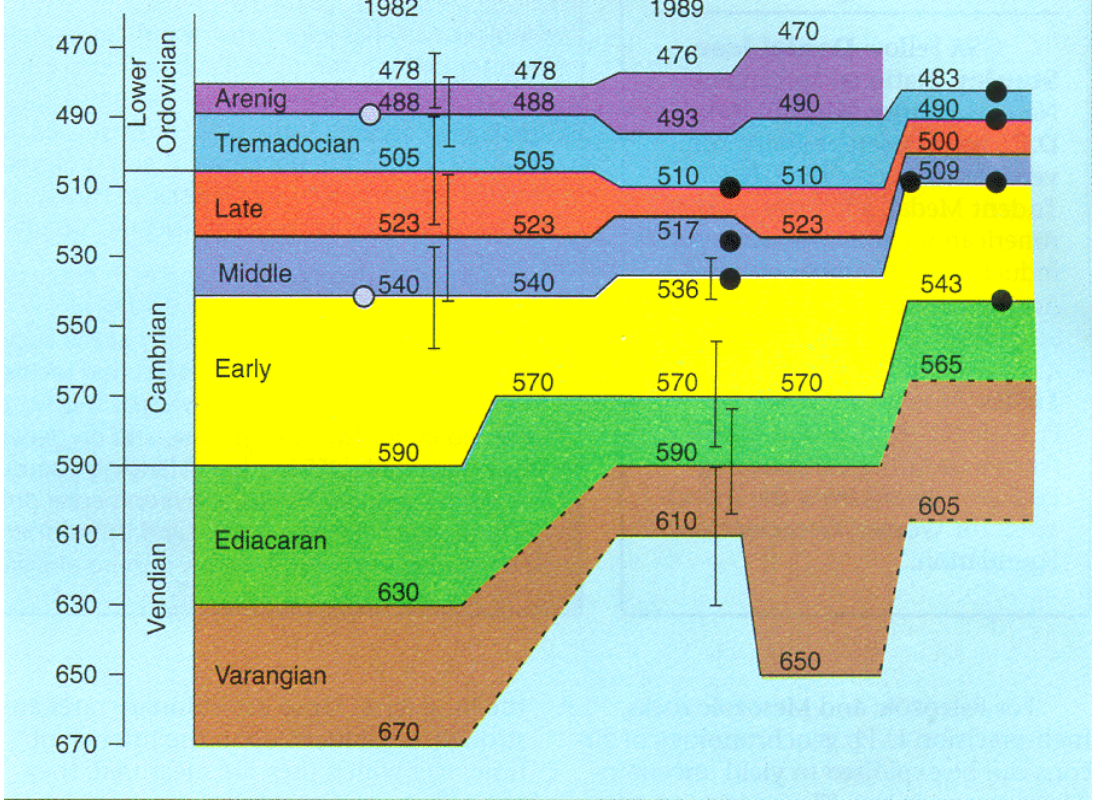

**FIGURE 8–7** **The trace fossil *Phycodes*.** The fossil represents the feeding behavior of a benthic organism that produced horizontal cylindrical burrows with sequential upward shafts as it explored for food. The base of the *Phycodes pedum* biozone is a marker for the base of the Cambrian system. *(After Crimes, T. P. 1989. Trace Fossils, in* The Cambrian–Precambrian Boundary. *Oxford Monographs on Geology and Geophysics 12. Oxford, England: Clarendon Press.)*

The horizontal burrow trace fossil, *Trichophycus* (formerly *Phycodes*) *pedum* defines the lower boundary of the Cambrian in the reference section at Fortune Head, southeastern Newfoundland. It has been suggested that newly evolved, burrowing organisms like this may have closed the taphonomic door on the peculiar 'Ediacaran preservation'. [Image courtesy of Dr. Gerd Geyer

# The top of the Cambrian

The Cambrian-Ordovician Boundary Working Group finally decided in 1998 by majority that the base of the Ordovician should be placed at the base of the conodont zone with ***Iapetognathus fluctivagus*****,** The GSSP for this boundary was chosen at the Green Point section, Newfoundland.

**Geochronological framework**




**Latest Proterozoic and base of the Cambrian**

595 15 m.y. mid-Dahai Mb., Meishucun, South China (Rb-Sr whole rock age; Zhang et al., 1984)

575 7.6 m.y. volcanics, Carolina Slate Belt, eastern United States (U-Pb age, Kozuch et al., 198)

550 26 m.y. volcanics, Puncoviscana Foldbelt, northwestern Argentina (K-Ar age, Omarini et al., 1996)

551.4 5.8 m.y. rhyolite flow, Mooring Cove Fm., Fortune Bay, Nfld. (isotope dilution U-Pb age; Tucker and McKerrow, 1995)

543.6 0.24 m.y. volcanic breccias, Lessyusa Fm., Nemakit-Dal'dyn Stage, Khorbusuonka, Olenek uplift, Siberia (U-Pb zircon age; Bowring et al., 1993)

535 7 m.y. granitoids, Puncoviscana Foldbelt, northwestern Argentina (U-Pb age, Bachmann et al., 1987)

534.6 0.4 fluvial conglomerates, between Nemakit-Dal'dyn and Tommotian stages, Kharaulakh Mountains, Siberia (U-Pb zircon age; Bowring et al., 1993)

525 7 m.y., max. 539 34 m.y. K-bentonite, Zhongyicun Mb., Dengying Fm., Meishucun, South China (SHRIMP zircon ages; Compston et al., 1992)

# Cambrian Life

- Base of the Cambrian is easy to spot in most places - set at the place where you first get shelled fossils
- There were a few Precambrian shelled species, but the “Cambrian Explosion” produced many more
- All phyla with hard parts (except Bryozoa) began in Cambrian, and many without hard parts too.

# EARLY PALEOZOIC LIFE

## The Cambrian Explosion

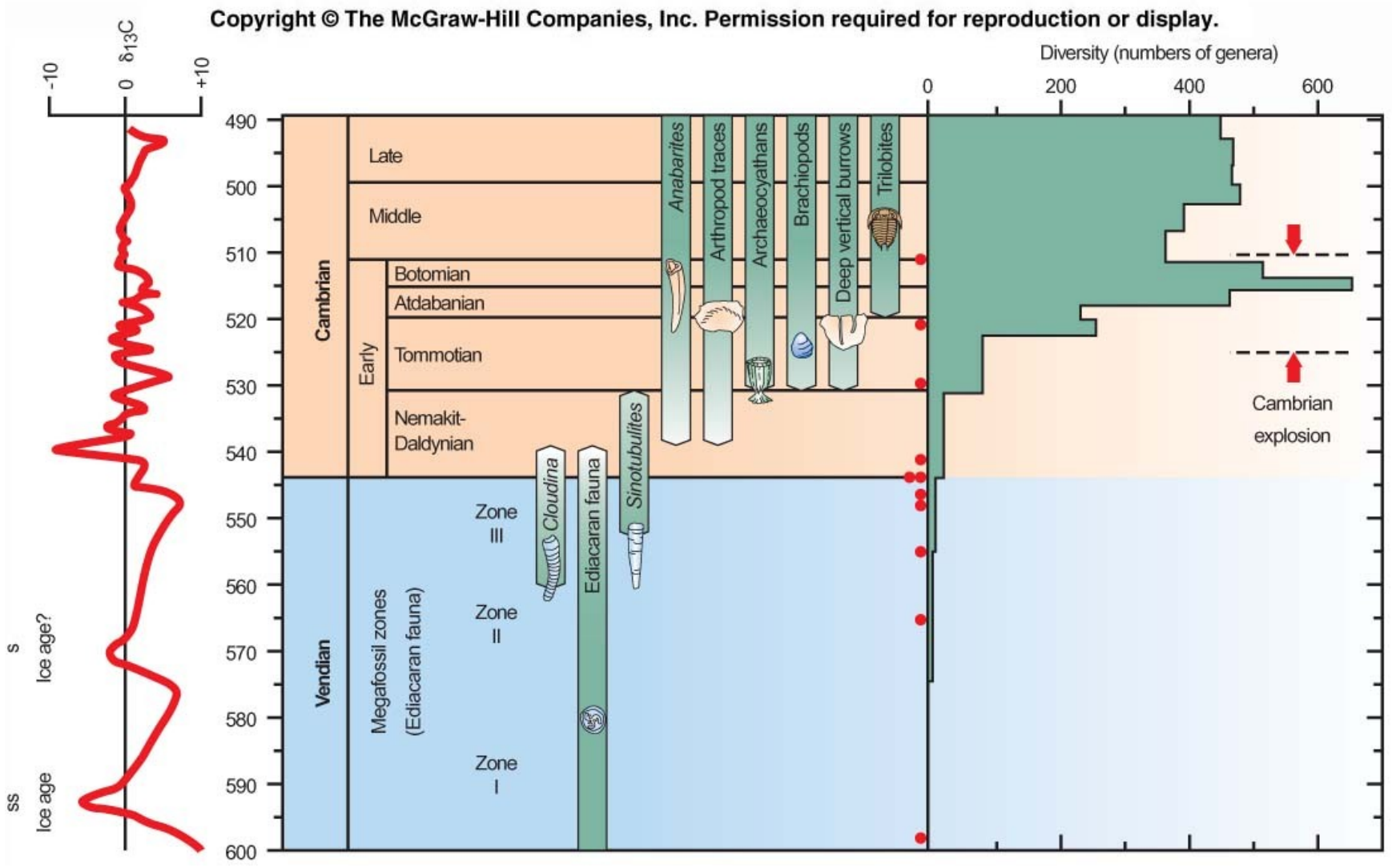
**Cambrian Explosion**

**Evolution's "big bang"**

**lasted about 10 million years**

**All principal animal phyla except Bryozoa appeared between 535 to 520 myBP**

# Cambrian Life
## The Cambrian Explosion



## Origin of skeletons (shells)

Function:

1. Support for muscles, etc.
2. Protection against environment & other organisms, predators
3. Aid in locomotion

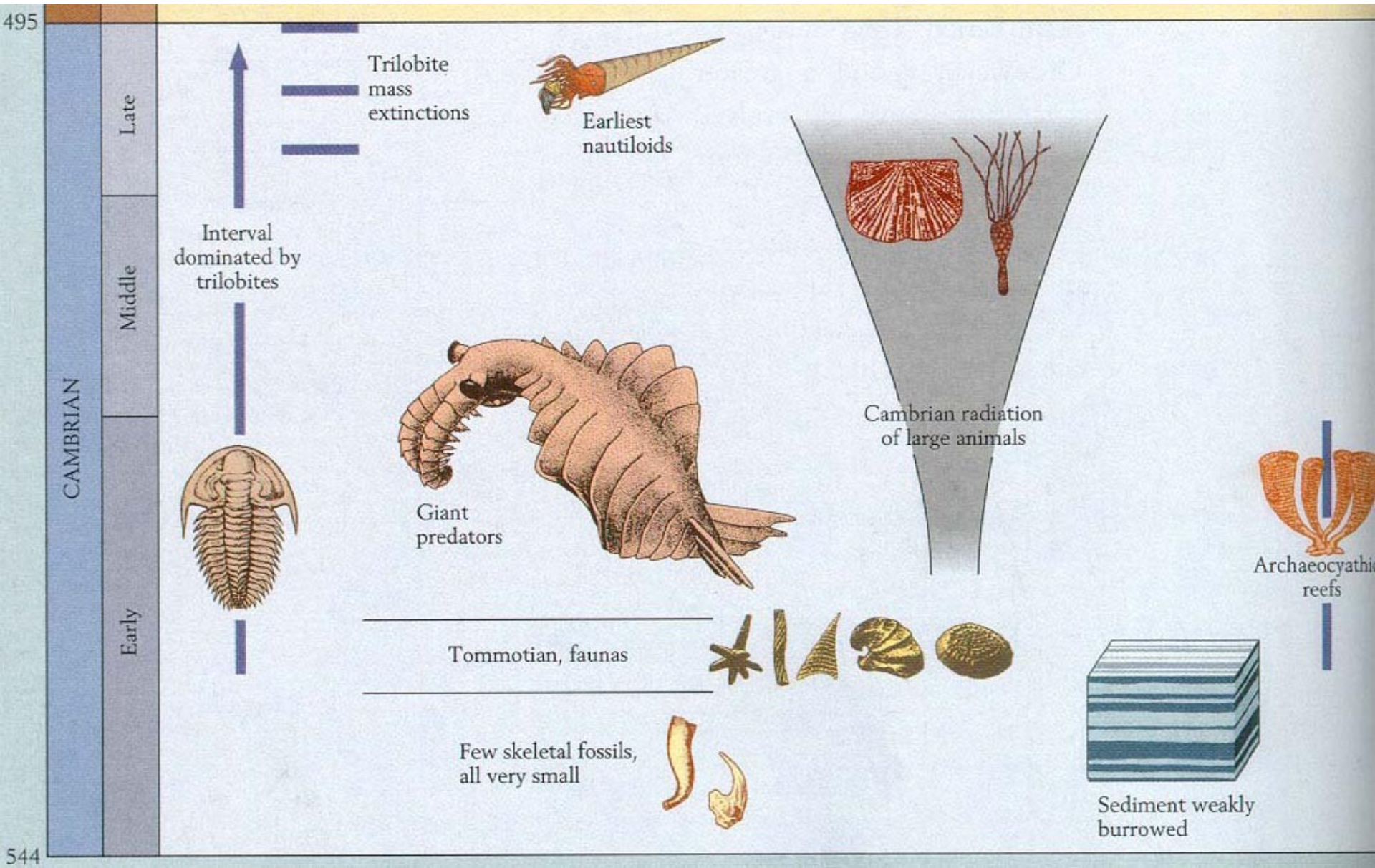
**Possible reasons for the advent of skeletonization:**

Increasing oxygen levels

**Evidence**: modern low $O_2$ environments have only small, soft-bodied forms.

# The abundant shelly fauna – beginning of the Cambrian

# Cambrian Timeline



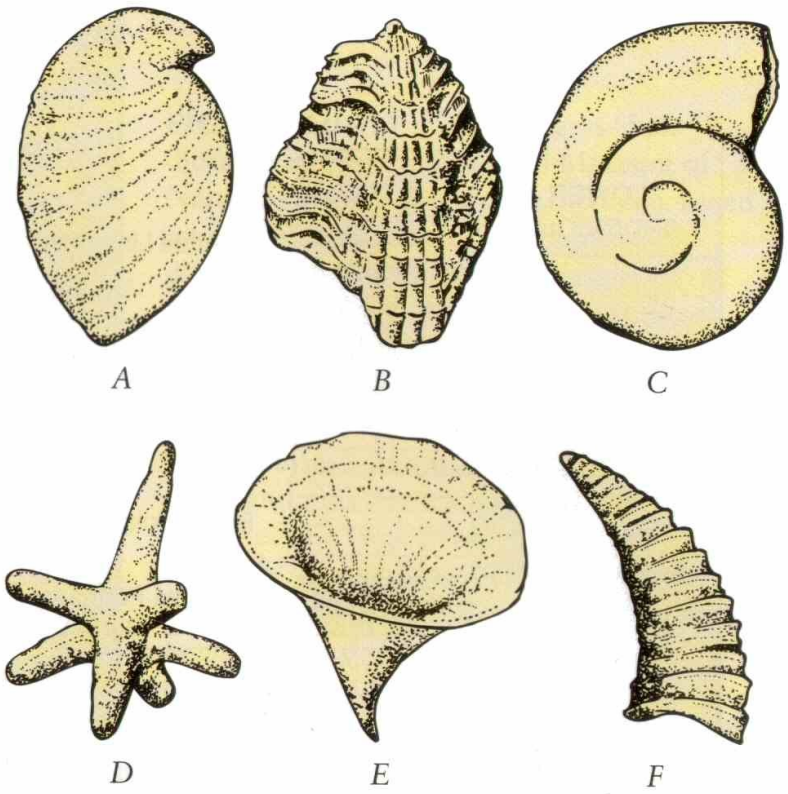



**FIGURE 10–13** Late Precambrian and Early Cambrian shell-bearing fossils from Siberia. (A) *Anabarella*, ×20, a gastropod; (B) *Camenella*, ×18, affinity uncertain; (C) *Aldanella*, ×20, a gastropod; (D) sponge spicule, ×30; (E) *Fomitchella*, ×45, affinity uncertain; and (F) *Lapworthella*, ×20. *(After Matthews, S. J. and Missarzhevsky, V. V. J. 1975.* Geol. Soc. London *131:289–304.)*

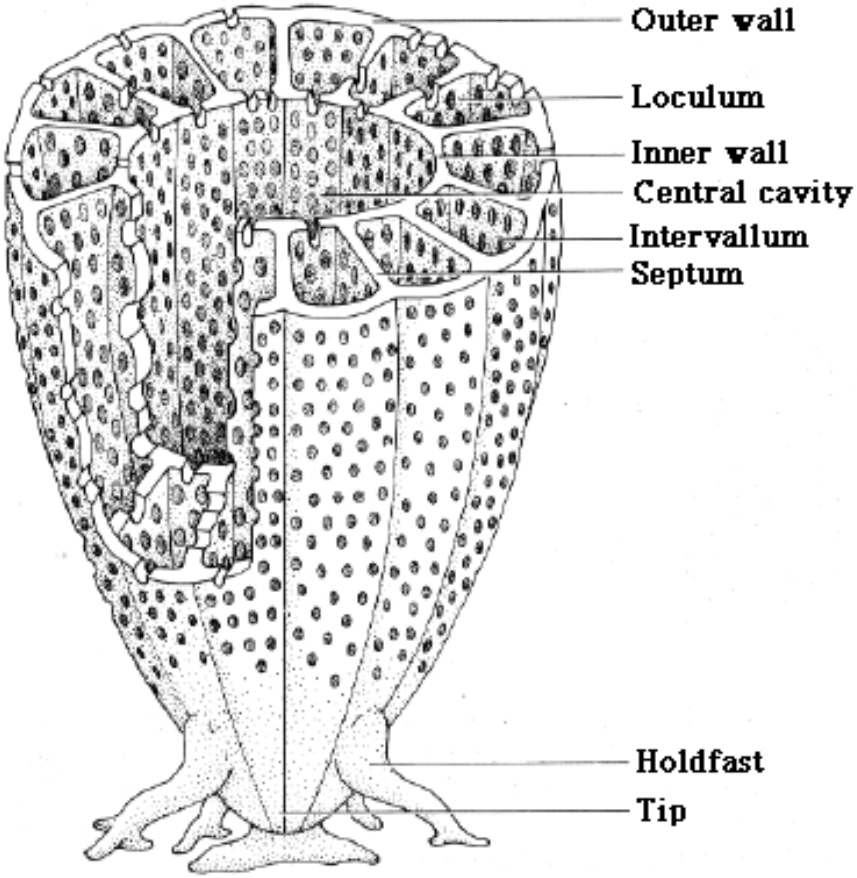
The typical *small shelly fossils* (SSFs, or early shelly fossils, ESFs) are tiny (generally 1 to 5 mm) tubes, spines, cones and plates that are **not clearly allied with modern groups.** Many of these organisms were recognized either as of unknown affinity or as representatives or groups that became extinct before the end of the Cambrian. Frequent **phosphatic skeletons.** Known as the "**Tommotian** fauna."

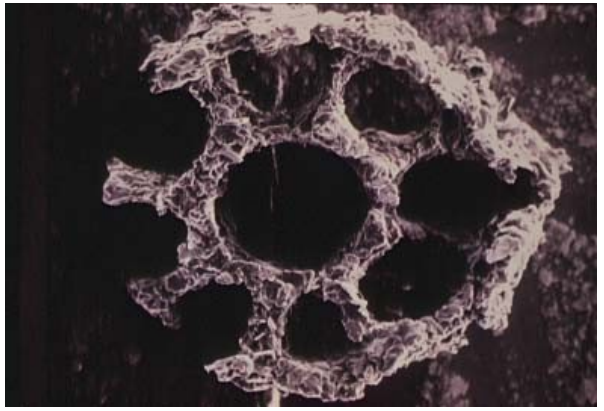
# Cambrian Marine Community

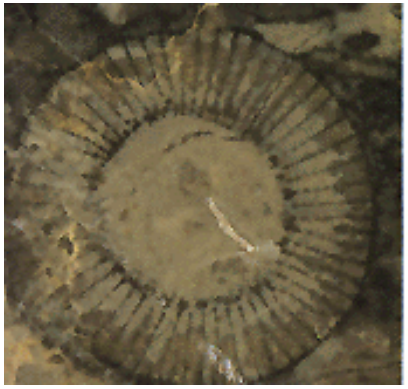
- Many body plans and experiments are observed in Cambrian fossils, more than in any other period
  - **trilobites** - benthonic mobile sediment-deposit feeders that crawled or swam across the sea floor
  - **brachiopods** - primitive benthonic sessile suspension feeders
  - **archaeocyathids** - benthonic sessile suspension feeders and reef builders

# Archeocyathids (“ancient cup”)

**Archaeocyathids,** an extinct group of sponges
benthonic sessile suspension feeders
constructed reeflike structures





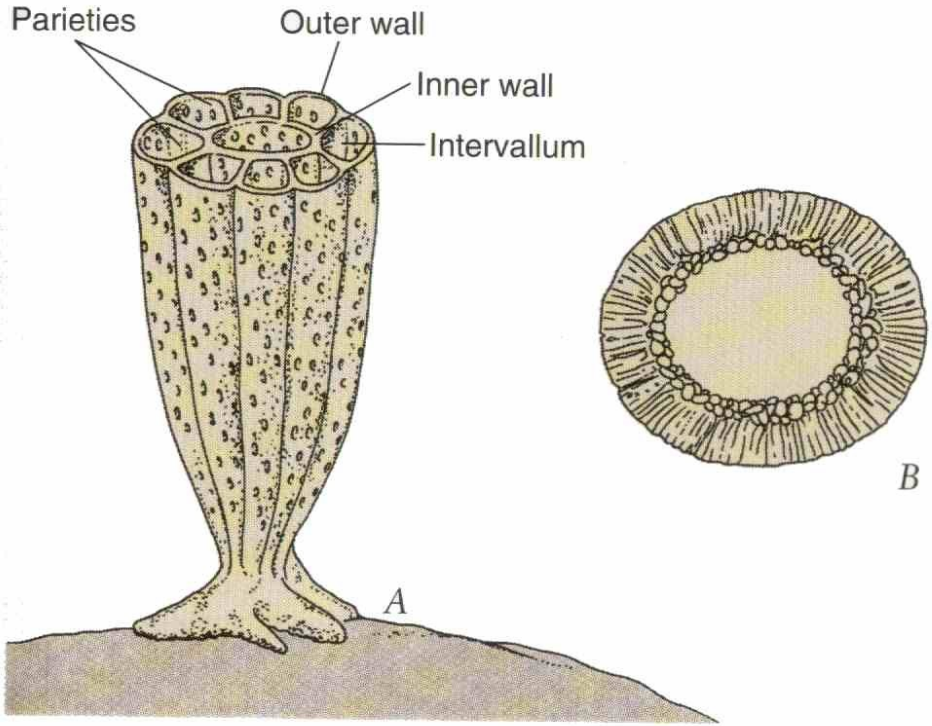
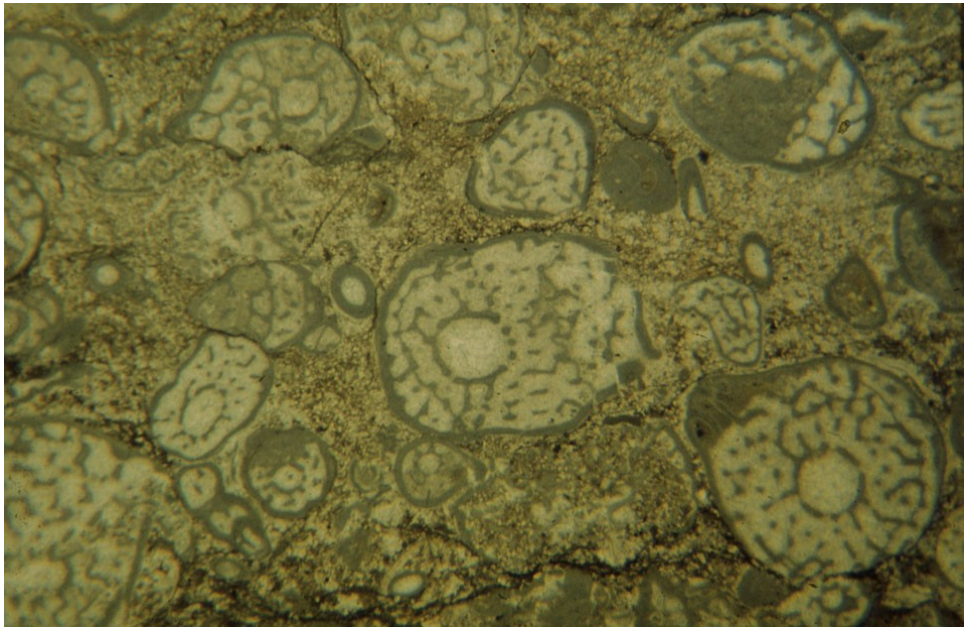
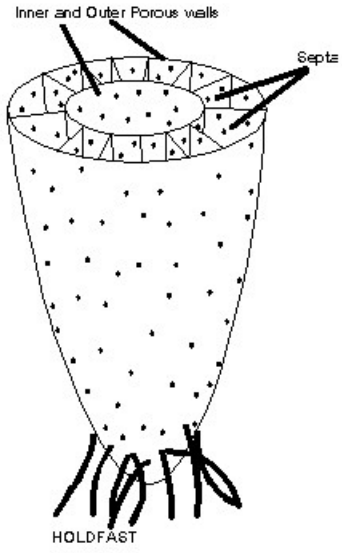



**FIGURE 10–25 The archaeocyathan skeleton.** (A) Longitudinally fluted cup of an archaeocyathan, about 6 cm in height. (B) Transverse section of a nonfluted archaeocyathan having closely spaced parieties and a vesicular inner wall. (Maximum diameter is 4 cm.)

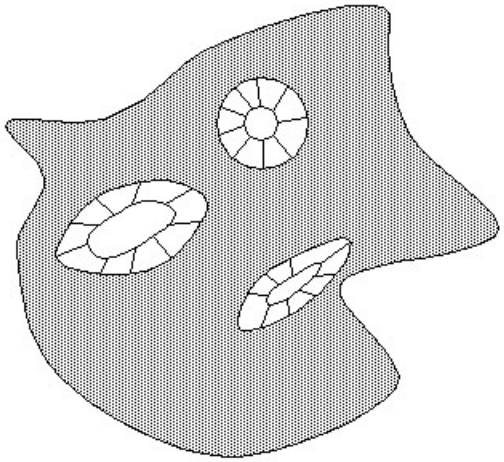
**•Reef builders: archaeocyathid sponges (in Early Cambrian only: almost no Middle or Late Cambrian reefs)**

Thin section of archaeocyath "bioherm" showing cross-sections
of archaeocyaths and intergrowing calcimicrobes.
Lower Cambrian Lemdad Formation,
Lemdad syncline, High Atlas, Morocco





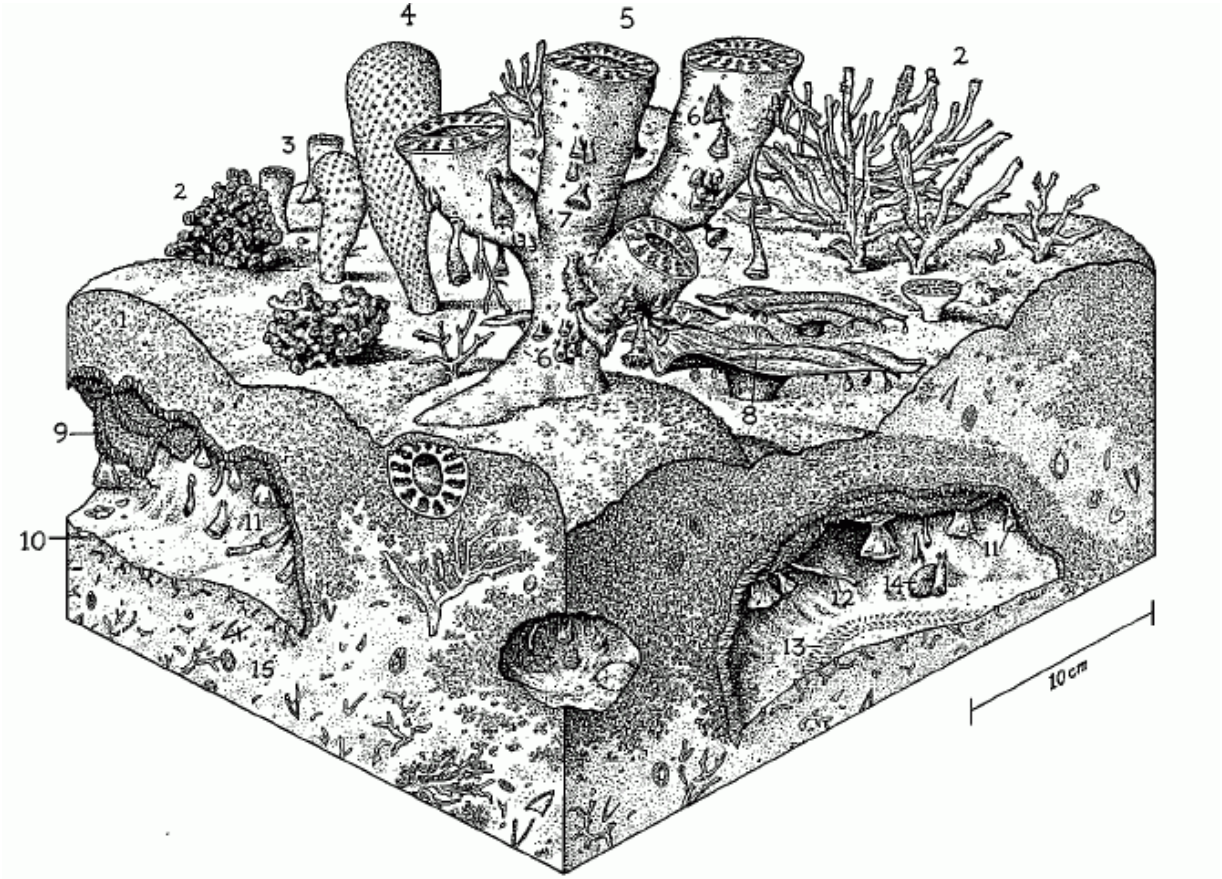

COMPLETE ARCHAEOCYATHID



ROCK FRAGMENT WITH
CROSS-SECTIONS

**Archaeocyaths are an extinct group of sponges that had a very brief (geologically speaking) and spectacular history. The first archaeocyaths appear roughly 530 million years ago, during the Lower Cambrian. Archaeocyath species were very important members of Lower Cambrian communities. They diversified into hundreds of species during this time period and some of these species contributed greatly to the creation of the first reefs. Reef ecosystems tend to support a wide variety of organisms both in the present and in the past. Despite their great success in terms of numbers, the archaeocyaths were a short-lived group. They were almost completely non-existent by the middle Cambrian, some 10 to 15 million years after their first appearance.**

Reconstruction of an Early Cambrian reef community (from 97). 1. *Renalcis* (calcified cyanobacterium); 2: branching archaeocyath sponges; 3: solitary cup-shaped archaeocyath sponges; 4: chancellorid (?sponge); 5: radiocyath (?sponge); 6: small, solitary archaeocyath sponges; 7: cryptic "coralomorphs"; 8: *Okulitchicyathus* (archaeocyath sponge); 9; early fibrous cement forming within crypts; 10: microburrows (traces of a deposit-feeder) within geopetal sediment; 11: cryptic archaeocyaths and coralomorphs; 12: cryptic cribricyaths (problematic, attached skeletal tubes); 13: trilobite trackway; 14: cement botryoid; 15: sediment with skeletal debris.

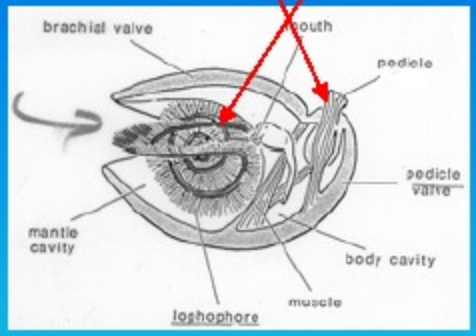


# PHYLUM BRACHIOPODA

Name derived from Latin *Bracchium* (arm) and Greek *pod* (foot).

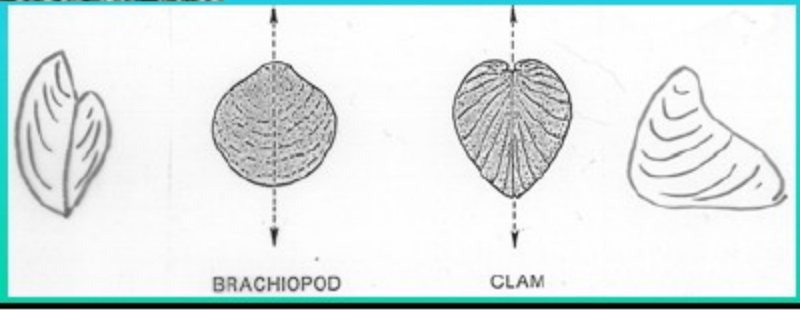
Class Lingulata (Inarticulata); lack tooth and socket and have chitinophosphatic shell

Class Articulata; tooth and socket and calcareous shell, 95% of genera




-but the lophophore support and pedicle are neither arm nor foot

Have two valves like clams (Phylum Mollusca), but very different planes of symmetry (across valve rather than between).



- Brachiopods:
- Two-shelled filter feeders
- Dominant groups in Cambrian are "**inarticulates**": linguates (infaunal forms with calcium phosphate shells) and **craniids** epifaunal forms with calcite shells)
- Articulate brachiopods (epifaunal with calcite shells) are present but rare

Lingulella ampla
**Período:** Cámbrico superior
**Localización:** Eau Claire Form. Colfax. Wisconsin. USA.


Bohemiella roemingeri

# Trilobites

- Most conspicuous element of the Cambrian marine invertebrate community
  - about half of the total fauna
  - nectobenthonic
  - mobile
  - sediment-deposit feeders
- Appeared in the Early Cambrian and rapidly diversified
  - reached their maximum diversity in the Late Cambrian
  - mass extinctions near the end of the Cambrian, never fully recovered

Anterior

Cephalon or head

Glabella, fixed cheeks (fixigena), free cheeks (librigena)

Facial suture

Genal spine

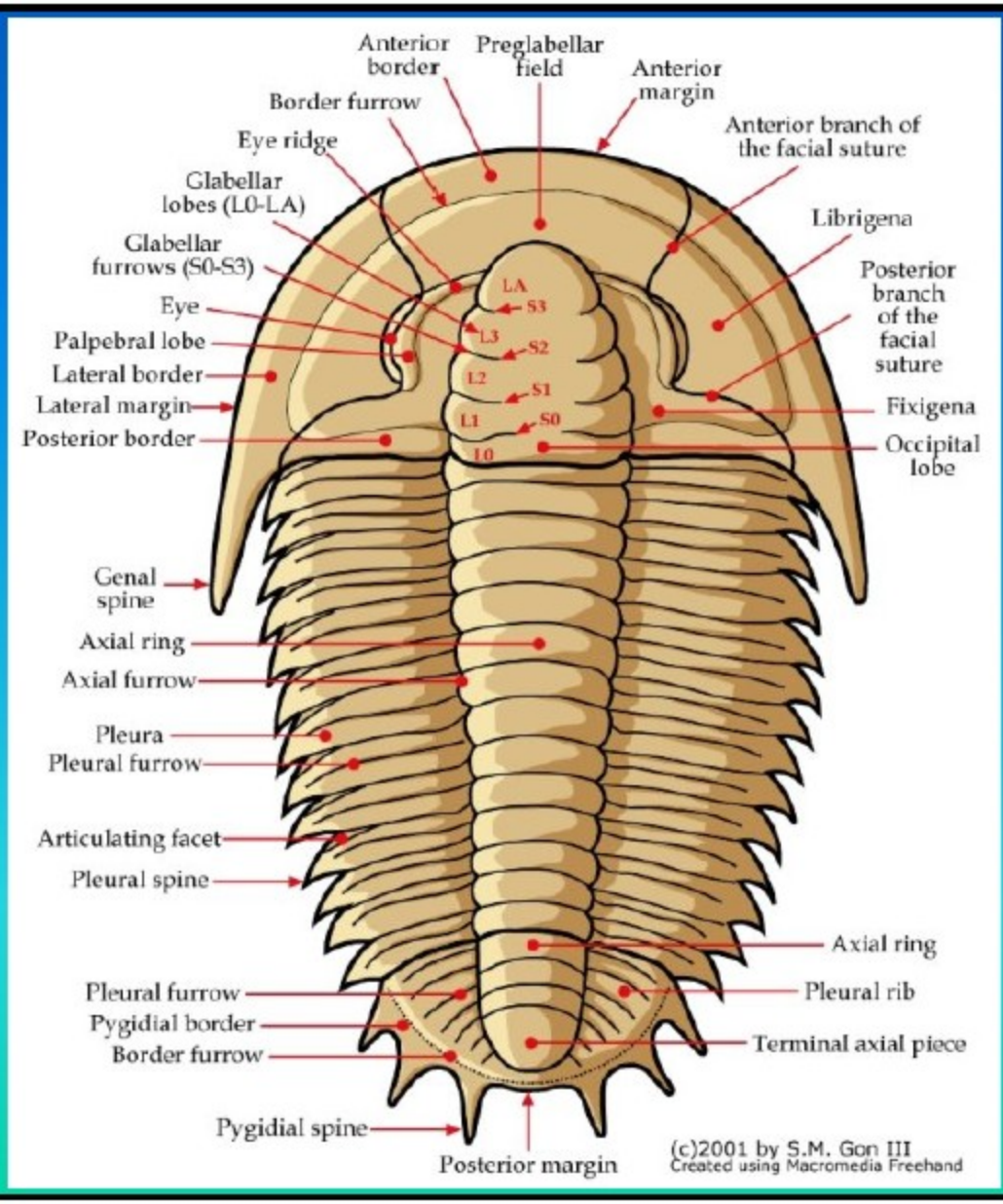
Thorax or main body

3 Pleura or lobes

Pygidium or tail

Pygidial spines

Posterior



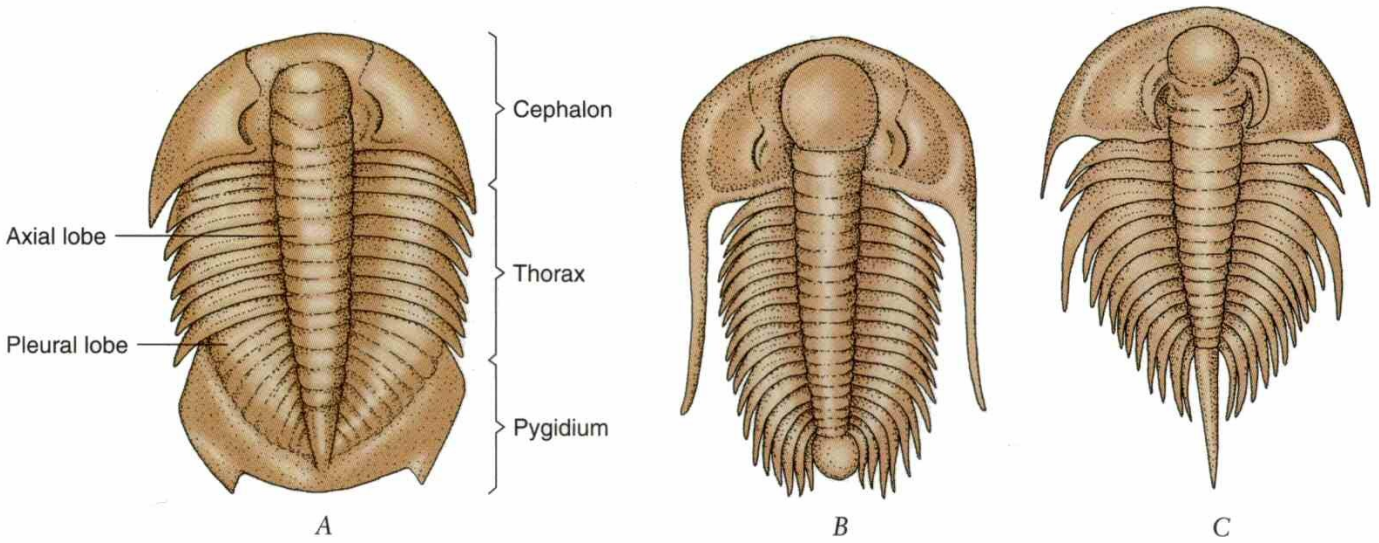
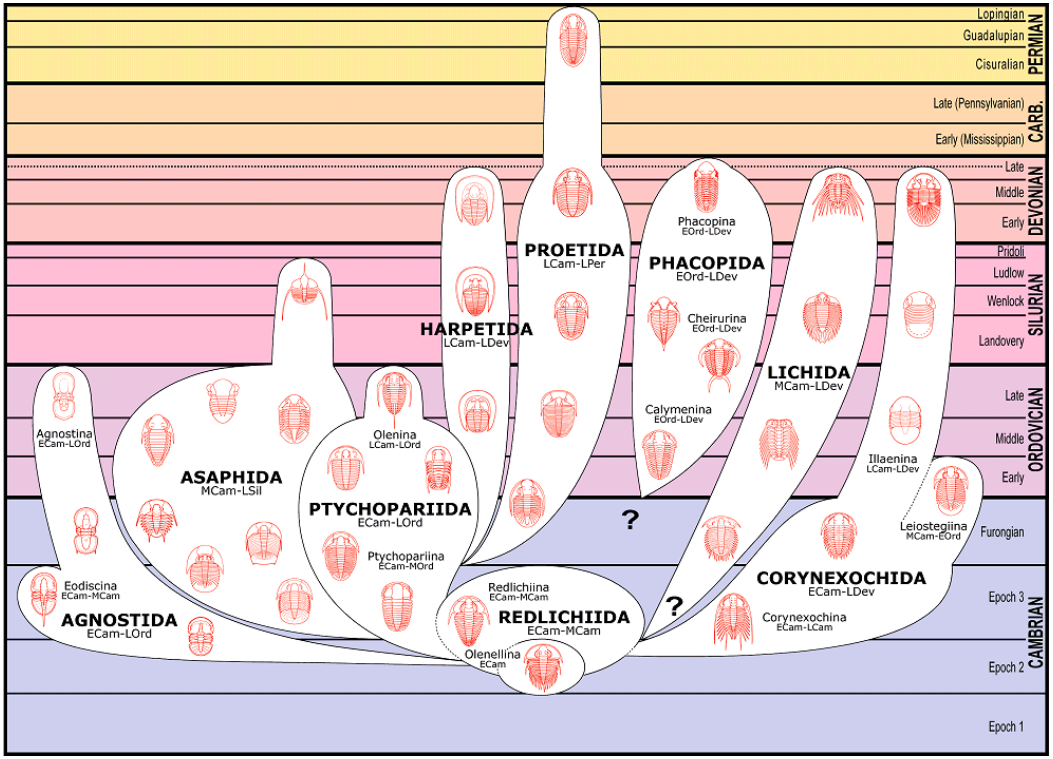
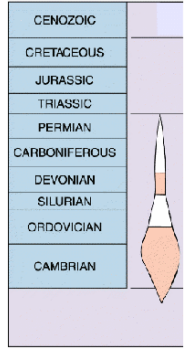



**FIGURE 10–49** **Three well-known Cambrian trilobites.** (A) *Dikelocephalus minnesotensis* (Upper Cambrian), (B) *Paradoxides harlani* (Middle Cambrian), and (C) *Olenellus thompsoni* (Lower Cambrian).

- Trilobites:
- Group of arthropod found only in Paleozoic
- EXTREMELY common in Cambrian and Ordovician; still common but lower diversity in rest of Paleozoic
- Benthic epifaunal detritovores (backwards facing mouth).
- Known from many growth stages, thousands of species, trace fossils, etc.
- **The main index fossils of the Cambrian.**

# The Cambrian Fauna
## Trilobites



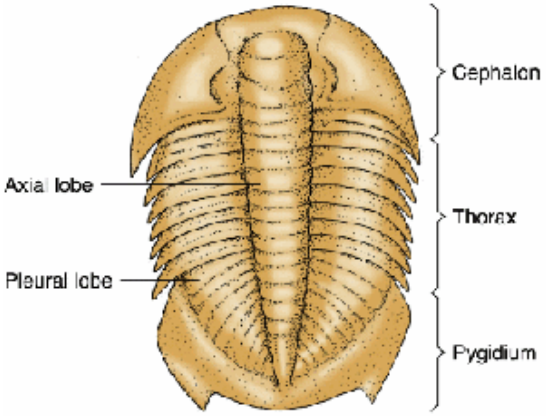





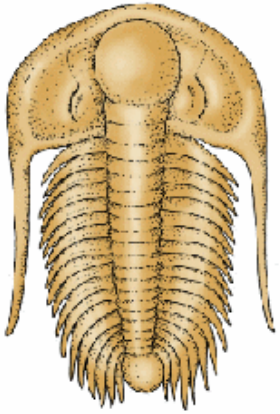

*Paradoxides harlani*

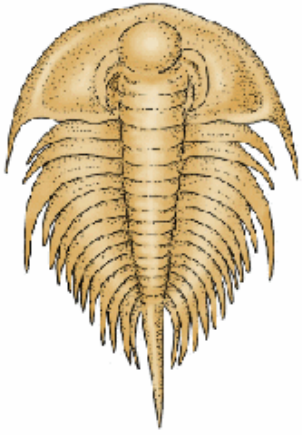
*Olenellus thompsoni*

- Phylum: Arthropoda
- Class: Trilobita
- Species: >600




*Dikelocephalus minnesotensis*

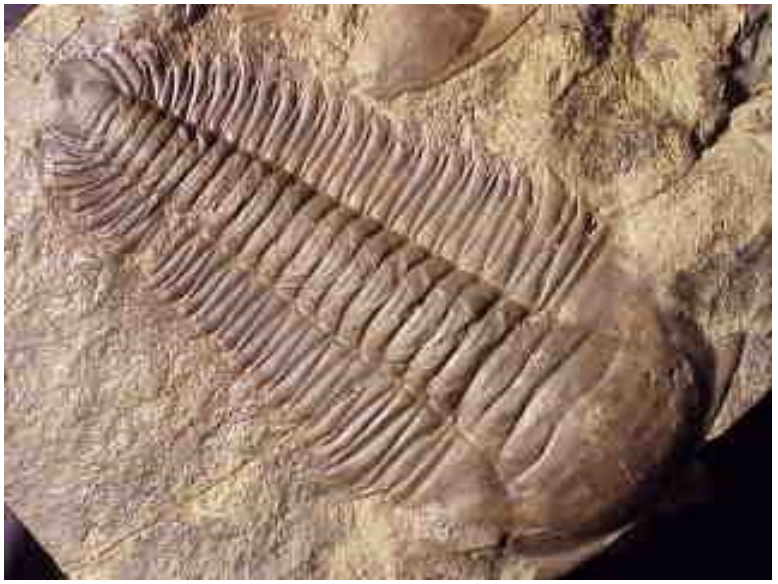




*Olenellus fowleri*, Lower Cambrian,
Pioche Formation, Lincoln County, Nevada

Ptychoparia striata #252
Middle Cambrian, 530 million years old
Jince, Czech Republic

Hydrocephalus minor
Middle Cambrian, 530 million years old
Jince, Czech Republic



Paradoxides gracilis
Middle Cambrian, 530 million years old
Jince, Czech Republic

Ellipsocephalus hoffi

Eccaparadoxides
M. Cambrian
Location: France

Conocoryphe sulzeri #253
Middle Cambrian, 530 million years old
Jince, Czech Republic

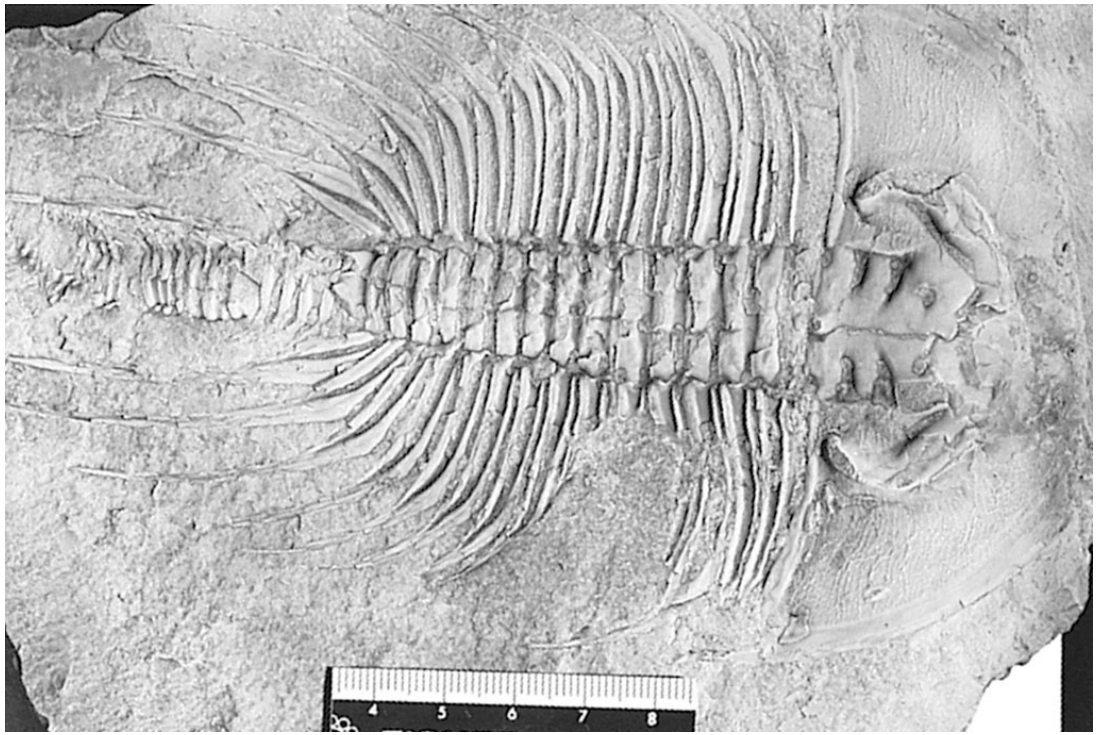
Sao hirsuta, Middle Cambrian, Skryje

Sao hirsuta

Conocoryphe sulzeri


**Olenus**

# Wounded Trilobite



- Wounds to the body of the trilobite *Olenellus robsonensis*
  - wounds have healed, demonstrating that they occurred when the animal was alive and were not inflicted on an empty shell

# Molluscs

**Hyoliths** (extinct forms thought to be related to mollusks),
**Bivalves** – mainly Polyplacophors, monoplacophors

Mopalia lignosa
Lives between the high and low tides and can be found on the undersides of rocks. Occasionally found on pilings and floating docks.

# EARLY PALEOZOIC LIFE

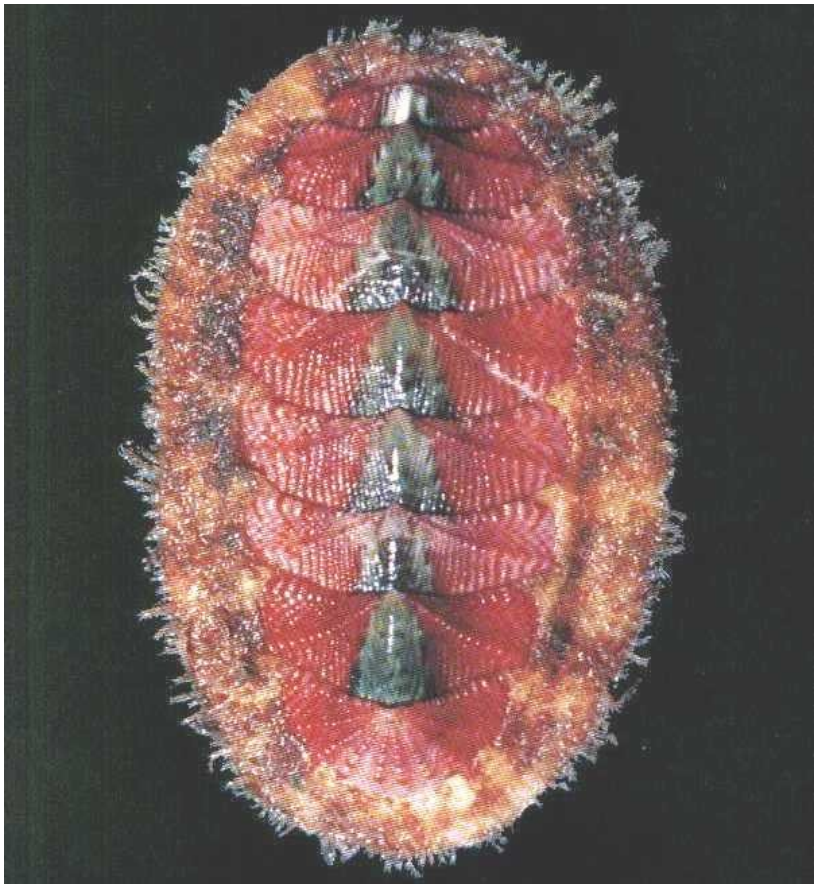
## Metazoan Invertebrates

### Mollusca

### Chitons

- Ancestor is flattened, elongated
- Mantle and shell dominate head, foot
- Mantle produces shell in 8 plates
- Radula scrapes encrusting vegetation

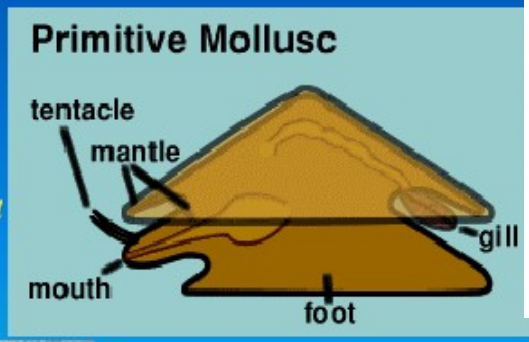
**Late Cambrian to Recent**

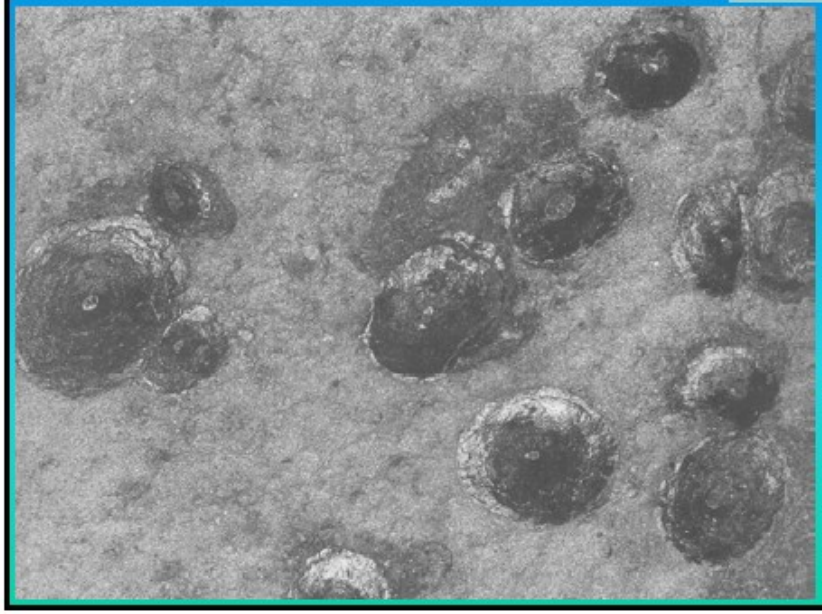


Phylum Mollusca

Class **Monoplacophora**

See M. Cambrian Burgess Shale *Scenella*
-limpet like shell with
segmented body parts



-partially segmented primitive mollusc thought to be extinct since the Triassic (230 million years ago), but a living form (*Neopilina*) was dredged up from 3000m in the Pacific in 1957. A living fossil!

**Phylum Echinodermata**

**Subphylum Blastozoa**

.....Class Eocrinoidea (Cambrian - Silurian, 30-32 genera)

**Subphylum Crinozoa**

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

**Subphylum Echinozoa**

.....Class Echinoidea (Sea Urchins) (Ordovician - Recent, 765 genera)

.....Class **Edrioasteroidea** (terčovci) (Early Cambrian**)** - Carboniferous, 35 genera)

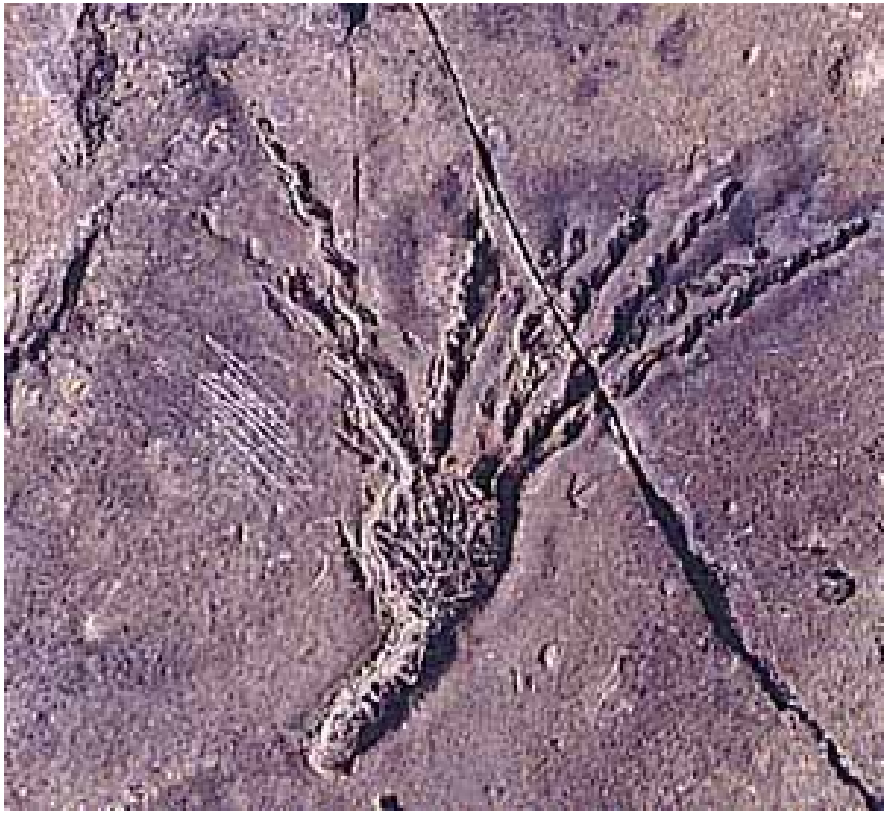
.....Class **Helicoplacoidea (**Cambrian, 3 genera)

# Echinoderms

## Eocrinoidea

Eocrinoids are among the earliest groups of echinoderms to appear, ranging from the Early Cambrian to the Silurian.

Most eocrinoids were sessile and fed with their long **brachioles** (the arm-like structures, which in this specimen are spirally twisted).



• The body was covered by plates; in early eocrinoids the holdfast was also covered by plates, but later eocrinoids evolved a stalk with columnals, like crinoids and blastoids.

# Helicoplacoids

Helicoplacoidea is a small group of fossil echinoderms known only from the Lower Cambrian.

- In life, they were shaped somwhat like a slender football or a fat cigar, and were able to extend or contract the length of their bodies.
- Their "skin" was covered in spirals of overlapping **ossicles** that functioned like armor; their "mouth" was a long groove that also spiralled around their body.
- It is thought that helicoplacoids lived in burrows, extending their bodies outward to feed.
- The helicoplacoids are among the oldest groups of echinoderms to appear in the fossil record, along with eocrinoids

Fossil of *Helicoplacus* from the Lower Cambrian strata of the White Mountains in California

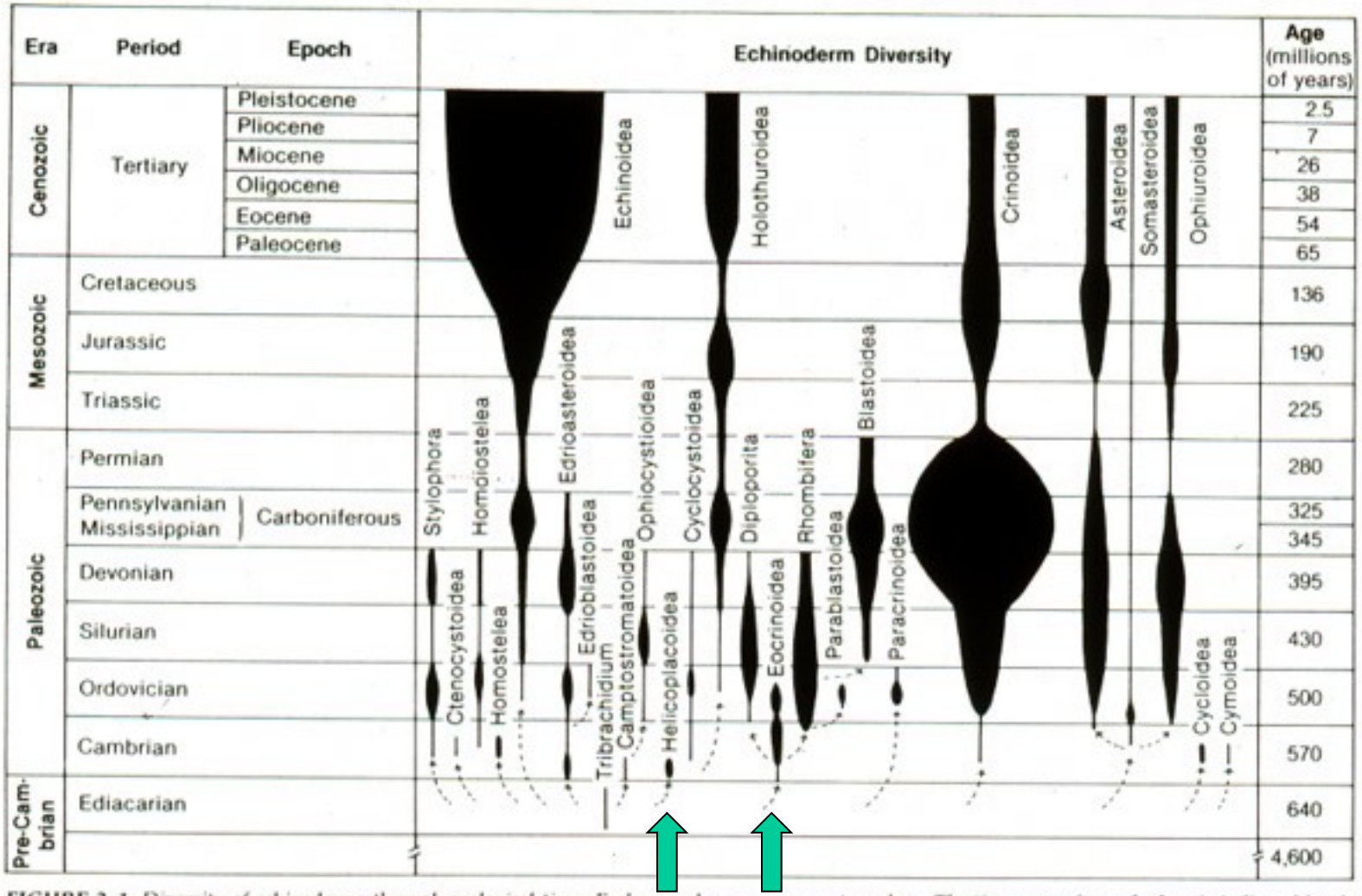



*FIGURE 2–1. Diversity of echinoderms through geological time. Each named group represents a class. The time range for each class is indicated by the length of the line representing it. Five major groups, Echinoidea (sea urchins), Holothuroidea (sea cucumbers), Crinoidea (sea lilies), Asteroidea (starfish), Somasteroidea (primitive starfish), and Ophiuroidea (brittle stars), survive to the present. Diversity in any period is indicated by the width of the group's line. Hypothetical relationships between classes are shown by dashed lines.* [Modified from C. R. C. Paul, Evolution of primitive echinoderms, in *Patterns of Evolution as Illustrated by the Fossil Record*, A. Hallan, ed., Elsevier Scientific Publishing Co., Amsterdam, 1977, p. 125.]

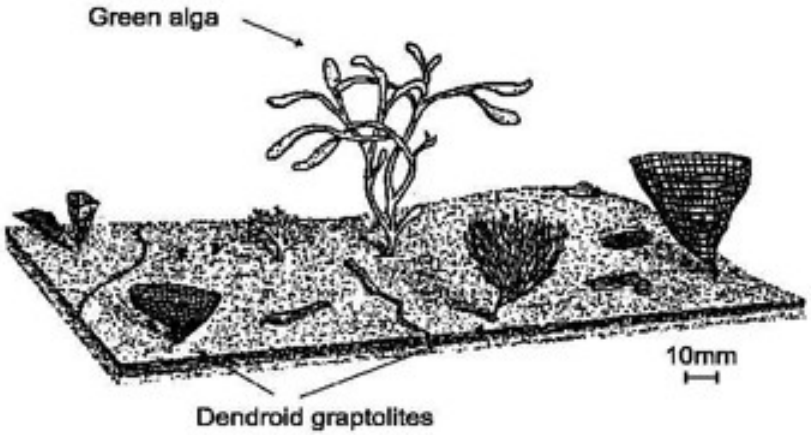
# Cambrian Echinoderms

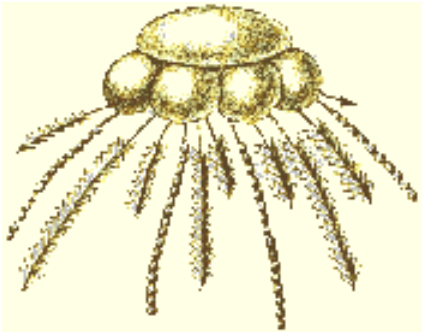
Helioplacus

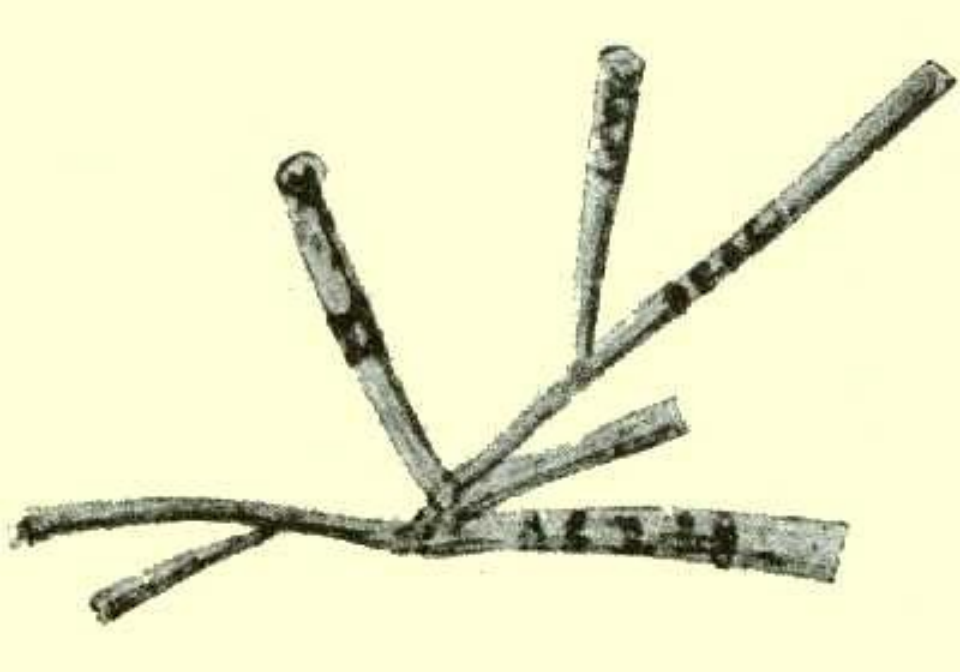
Helicoplacoidea are known only from the early Cambrian of western North America,

# 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.**





***Haplograptus wisconsinensis***
**Cambrian, Wisconsin, U.S.A. Holotype.**

# Burgess Shale type fauna

**Burgess Pass – middle Cambrian**

**Chengjiang fauna – early Cambrian**

**The fauna is composed of a range of soft bodied organisms; creatures with hard, mineralised skeletons are rare, although trilobites are quite commonly found. The major soft-bodied groups are arthropods, sponges, worms**

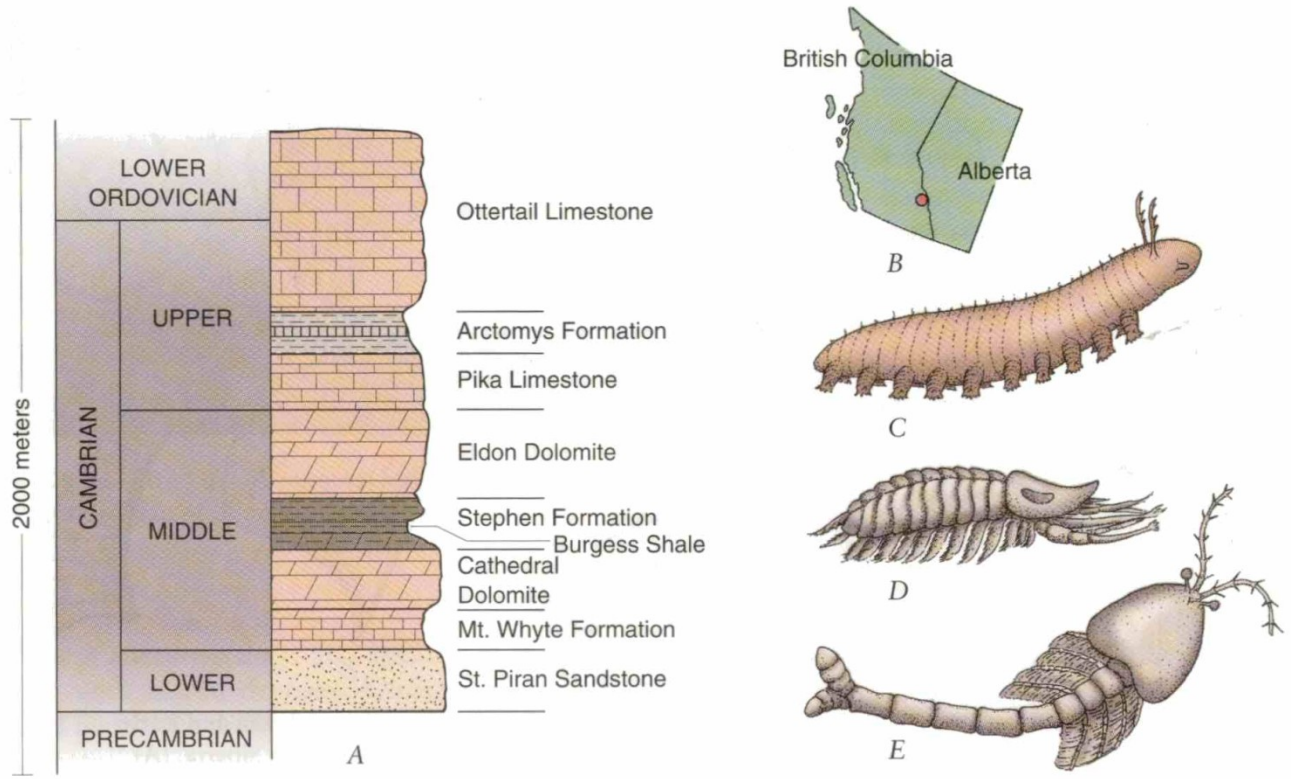



**FIGURE 10–15 The Cambrian geologic column (A) at Kicking Horse Pass, British Columbia (B) where Walcott discovered the Burgess Shale Fauna.** *Aysheaia* (C) is an invertebrate called an onycophoran or velvet worm. They are of particular interest because they appear to be intermediate in evolution between segmented worms and arthropods. *Leanchoila* (D) and *Waptia* (E) are among the many kinds of arthropods found at this locality.

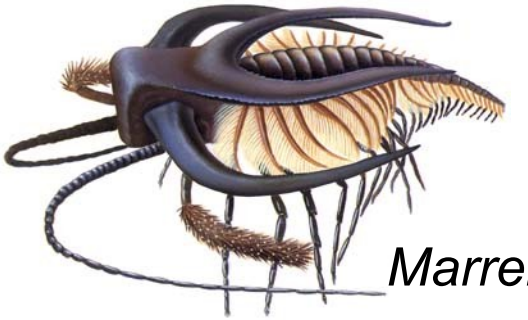
# Burgess Animals Arthropoda

*Canadaspis*

*Anomolacaris*

*Sanctacaris*

*Yohoia*



*Marrella*

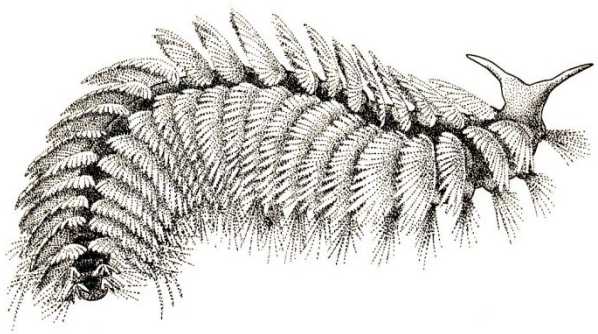
*Opabinia*

# Burgess Animals

Chordata

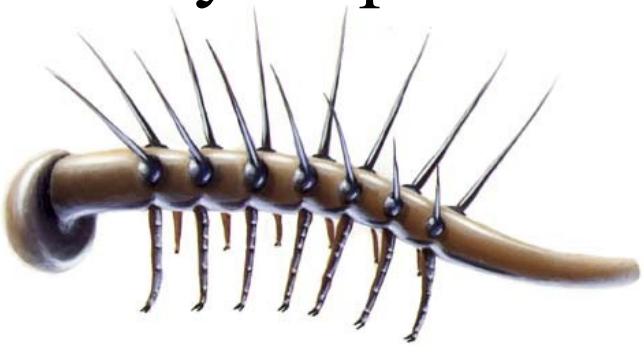
*Pikaia*

Annelida



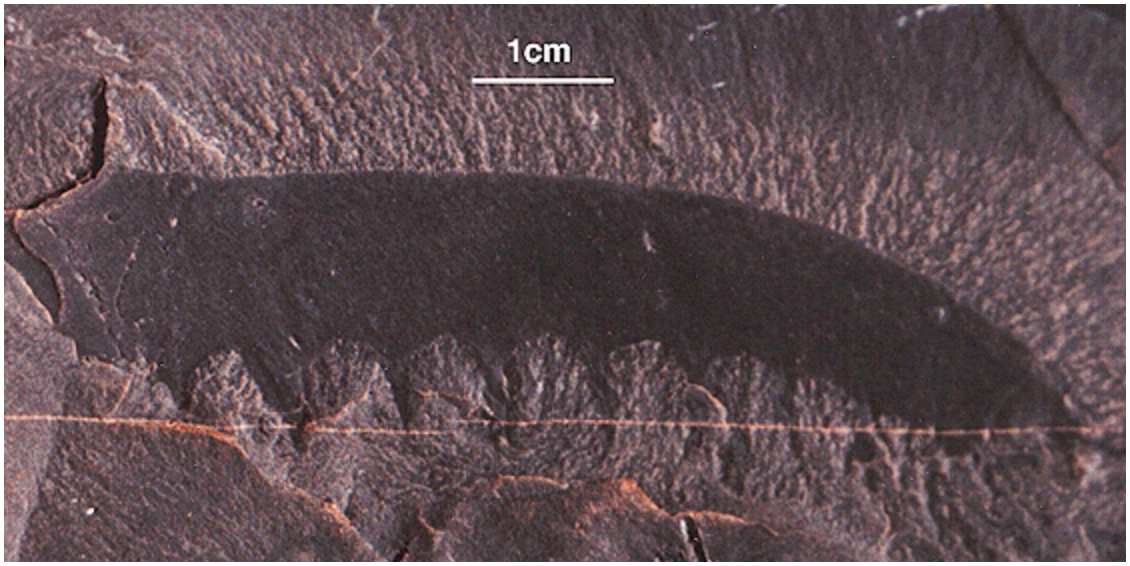
*Canadia*

Onychophora



*Hallucigenia*

*Aysheaia*





Marella

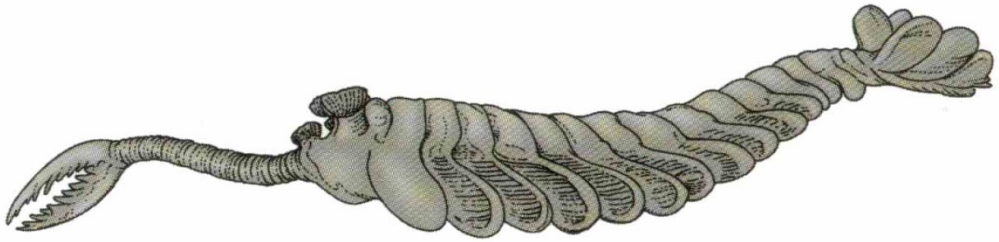


**FIGURE 10–20** *Opabinia.* This strange Burgess Shale animal had a frontal "nozzle" with a jawlike structure at its end used for gathering food. There were five eyes on its head. Each side was covered with overlapping lobes bearing narrow stripes interpreted as gills. This specimen was 7 cm long. *(Adapted from Whittington, H. B. 1975.* Philosophical Transactions of the Royal Society of London, vol. B.)

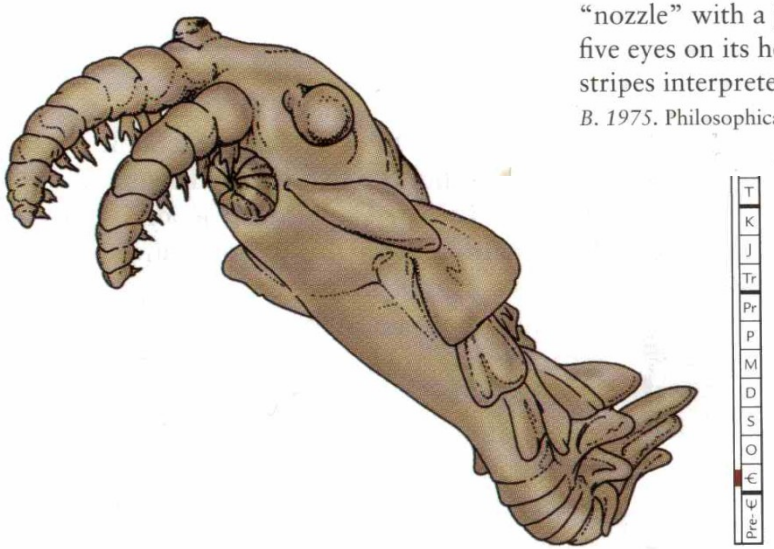



**FIGURE 10–19** *Anomalocaris.* This giant predator (often 60 cm in length) captured its prey with its huge frontal appendages and passed the victims back to the circular mouth with its outer and inner circles of teeth. The side flaps were used in swimming, like underwater wings.

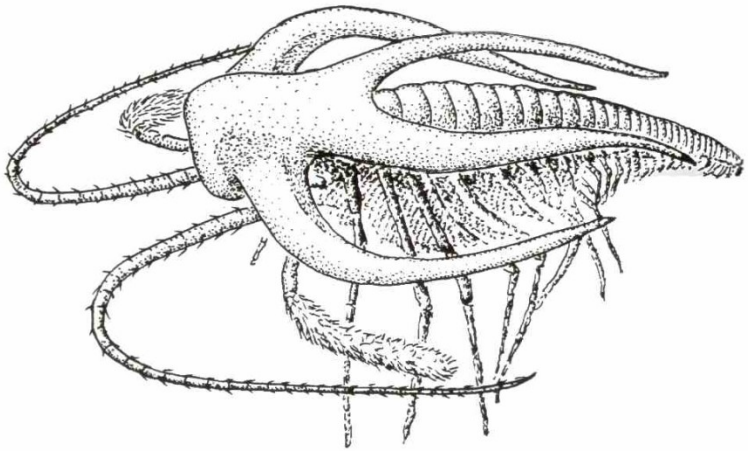
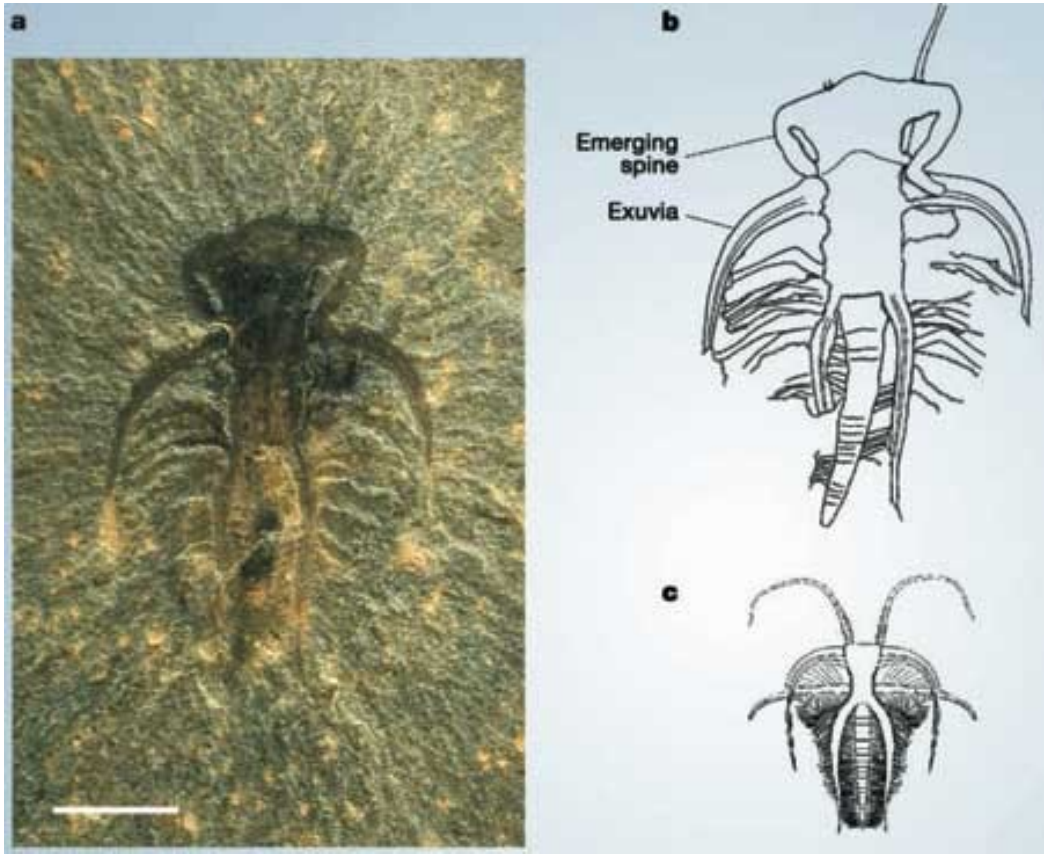


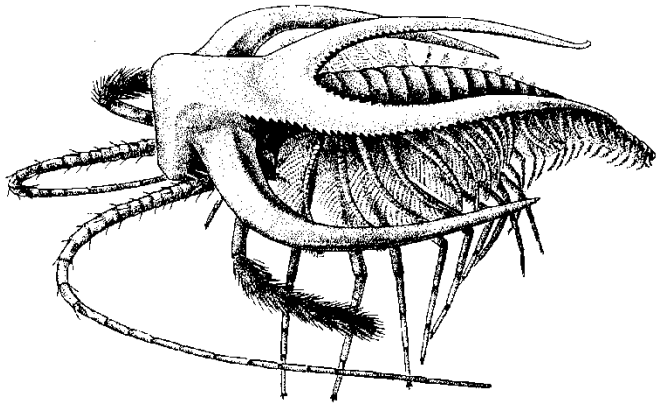
**FIGURE 10–21** *Marrella,* **the most common arthropod in the Burgess Shale fauna.** The animal was about 2 cm in length.

# EARLY PALEOZOIC LIFE

## Animals With Shells

## THE BURGESS SHALE



***Marrella*** **(crustacean) most common Burgess Shale fossil**

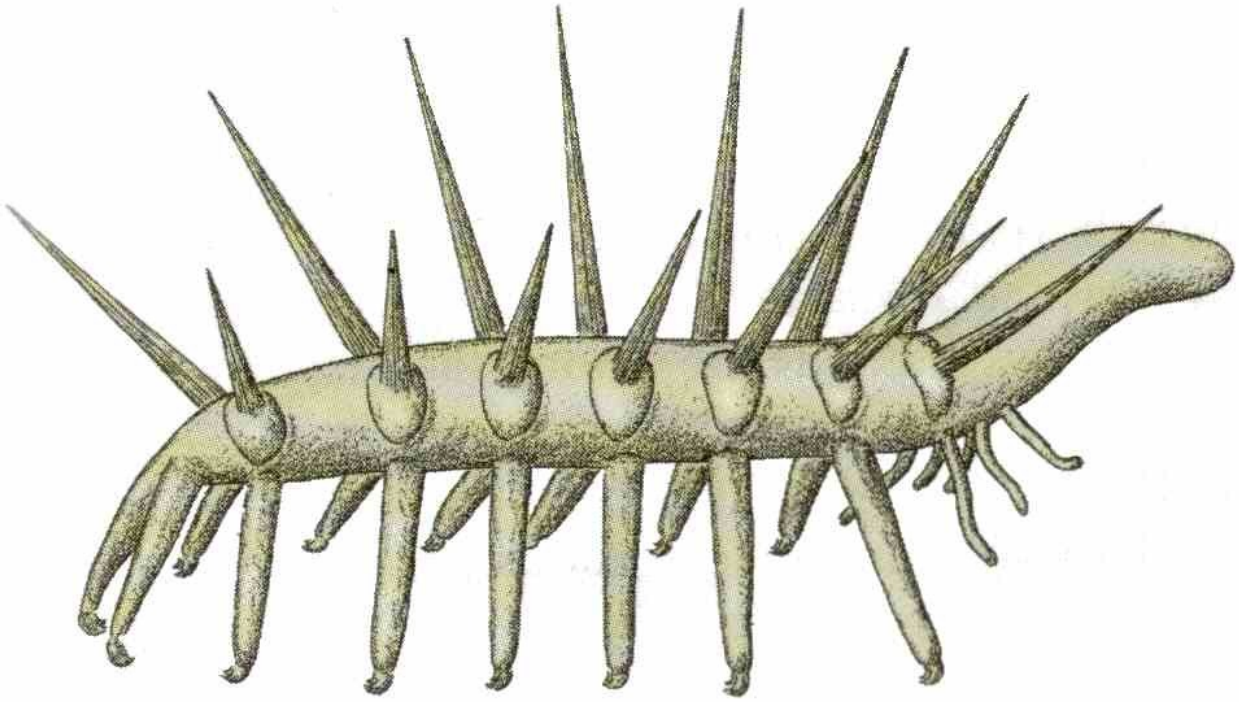


**FIGURE 10–22** The early Cambrian Burgess Shale fossil *Hallucigenia*.

**Mid Cambrian scene,** a reconstruction of the famous Burgess Shale lagerstätten of what is now British Columbia. In the foreground a swimming *Laggania cambria* has captured a hapless trilobite. On the sea floor from left to centre respectively are a solitary specimen of the proto-annelid *Wiwaxia* and three specimens of the lobopod *Hallucigenia*. Note in both animals the defensive array of spines. Further to the right is the lobopodian *Aysheaia* with its anterior prongs around the mouth, as well as the protoarthropod *Opabina*, a close relative of *Laggania* Descending to the sea floor are two individuals of the basal arachnomorph *Marrella*. Also visible in this scene are sessile epifauna in the form of the deuterostome lophophorate *Dinomischus* (yellow) and the Hexactinellid sponge *Vauxia* (blue).

# Chordates

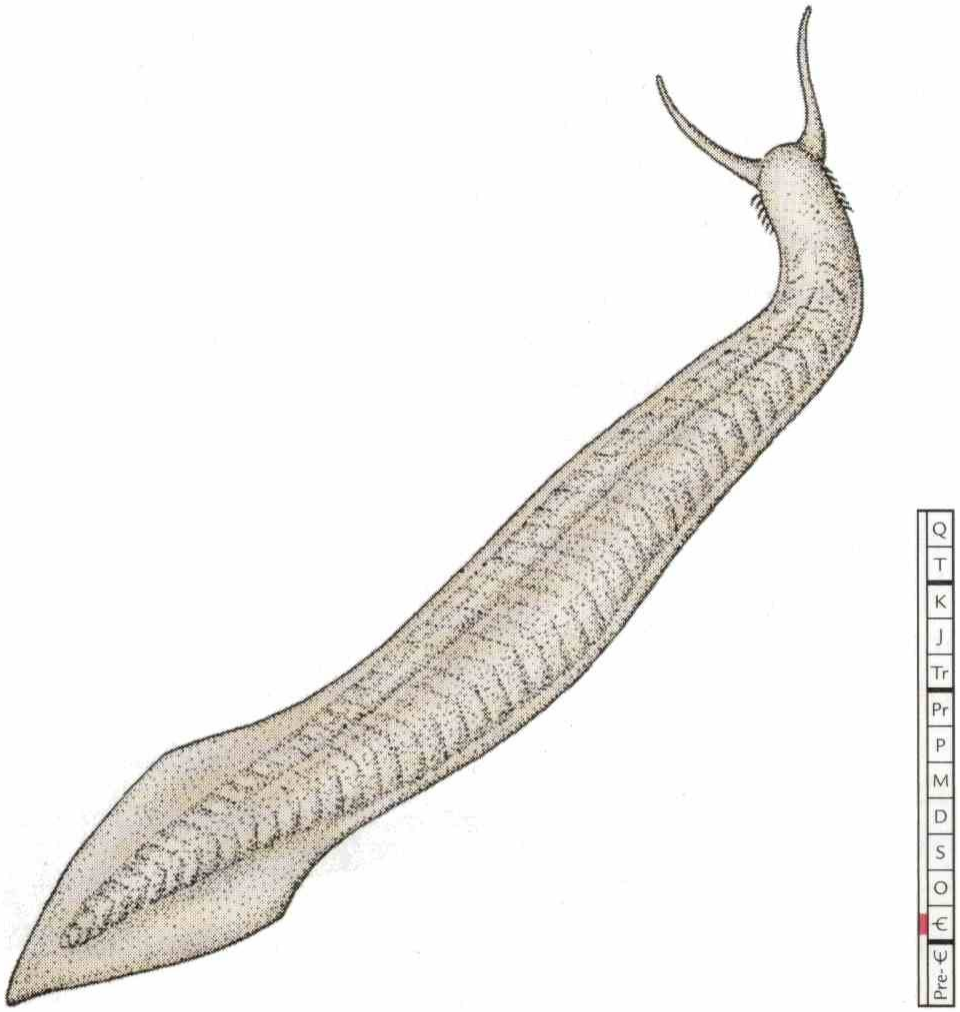
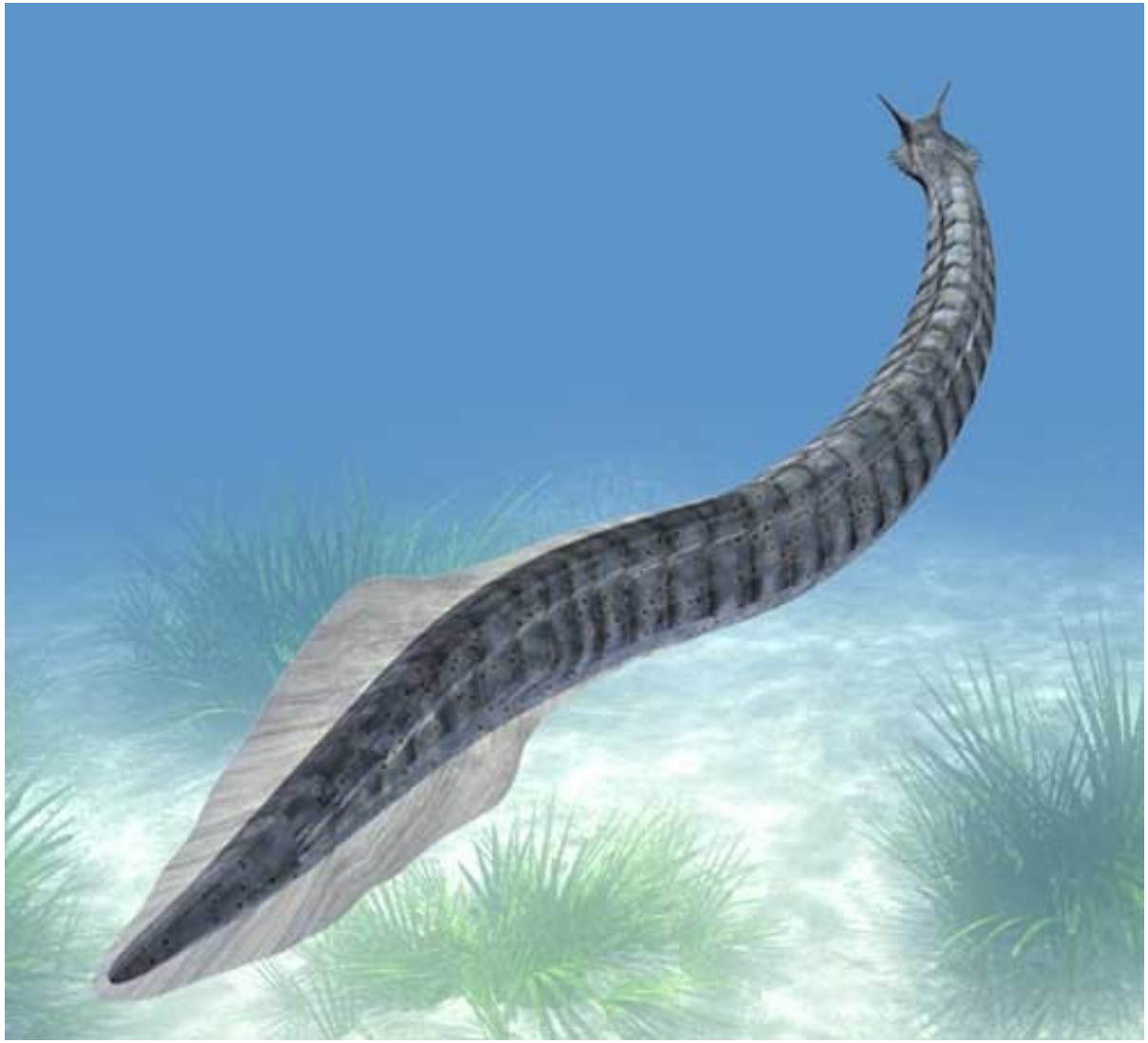



**FIGURE 10–18 Reconstruction of *Pikaia*, the earliest known member of our own phylum, the Chordata.** Note the rod along the animal's back that appears to be a notochord (Length is about 4 cm.) Name another chordate feature seen in *Pikaia* fossils.



Pikaia


Early Cambrian (about 530 million years ago)

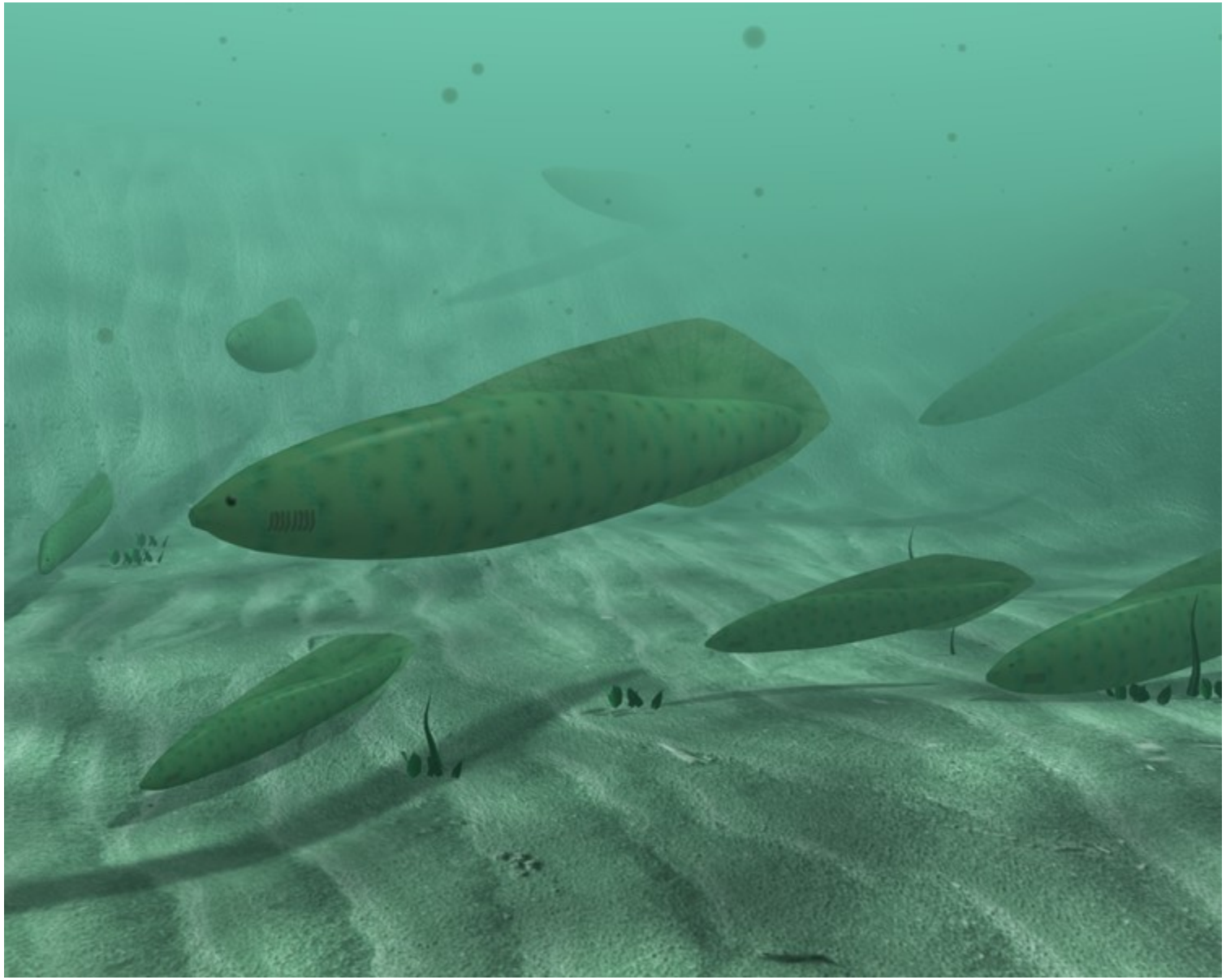
This is oldest known example of a cephalochordate. The form of *Cathaymyrus* resembles that of *Pikaia* from the Middle Cambrian Burgess Shale of Canada, but this animal is about 10 million years older. Some palaeontologists have suggested that the vertebrates, which include humans, evolved from cephalochordates like *Cathaymyrus*


*Cathaymyrus diadexus*
Early Cambrian (about 530 million years ago)

# Vertebrata

Vertebrates originated about **525 million years ago** during the **Cambrian explosion**, which saw the rise in organism diversity. The earliest known vertebrate is believed to be the ***Myllokunmingia***.[1] Another early vertebrate is ***Haikouichthys ercaicunensis***. Unlike the other fauna that dominated the Cambrian, these groups had the basic vertebrate body plan: a notochord, rudimentary vertebrae, and a well-defined head and tail.[17] All of these early vertebrates lacked jaws in the common sense and relied on filter feeding close to the seabed.[18] A vertebrate group of uncertain phylogeny, small-eel-like conodonts, are known from microfossils of their paired tooth segments from the late Cambrian to the end of the Triassic

# *Haikouichthys ercaicunensis*



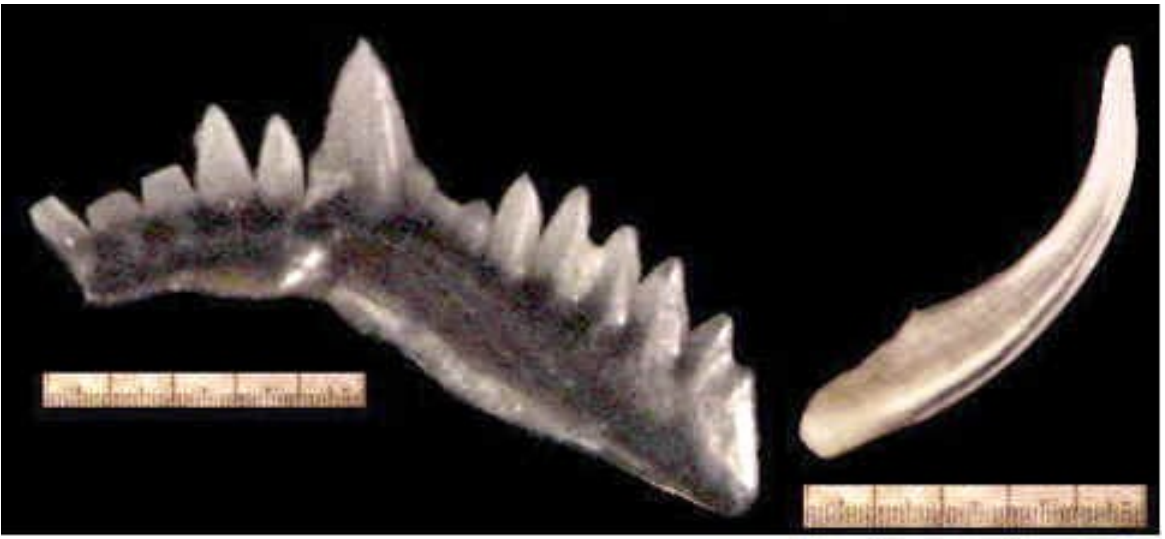
**AGNATHA** (jawless “fish”):

- Cambrian **vertebrates** known from bony plates and impressions of lamprey-like forms from Chengjiang.

AGNATHA (Ostracoderms) - Upper Cambrian of Wyoming

# CONODONTS

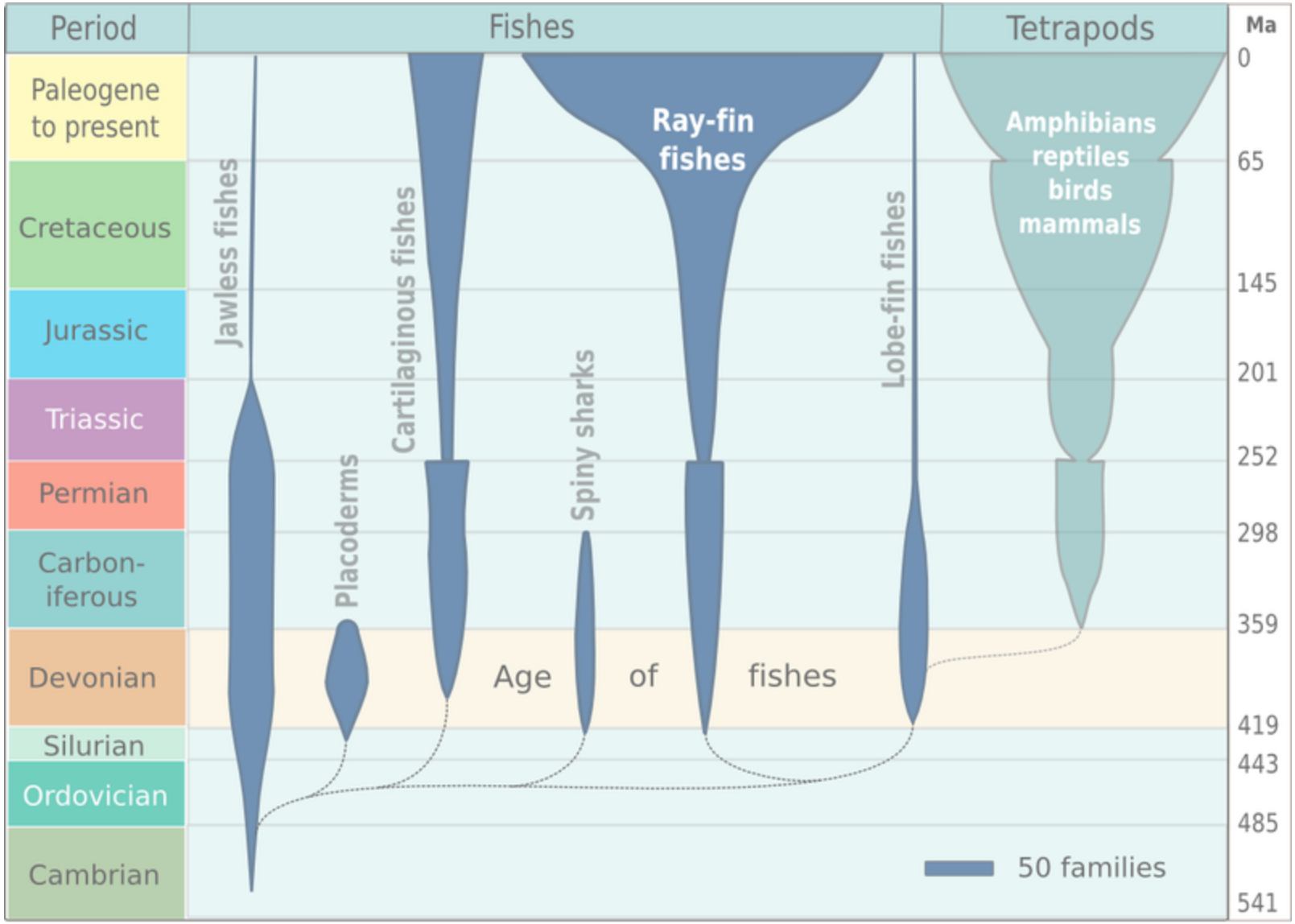
- conodonts are small tooth shaped structures
  - have been found in fossil record for many years
  - important biostratigraphically
  - made of phosphate (like most vertebrate bones)
  - Ordovician conodont over 1 foot long (1995)
  - probably a predator in Chordata

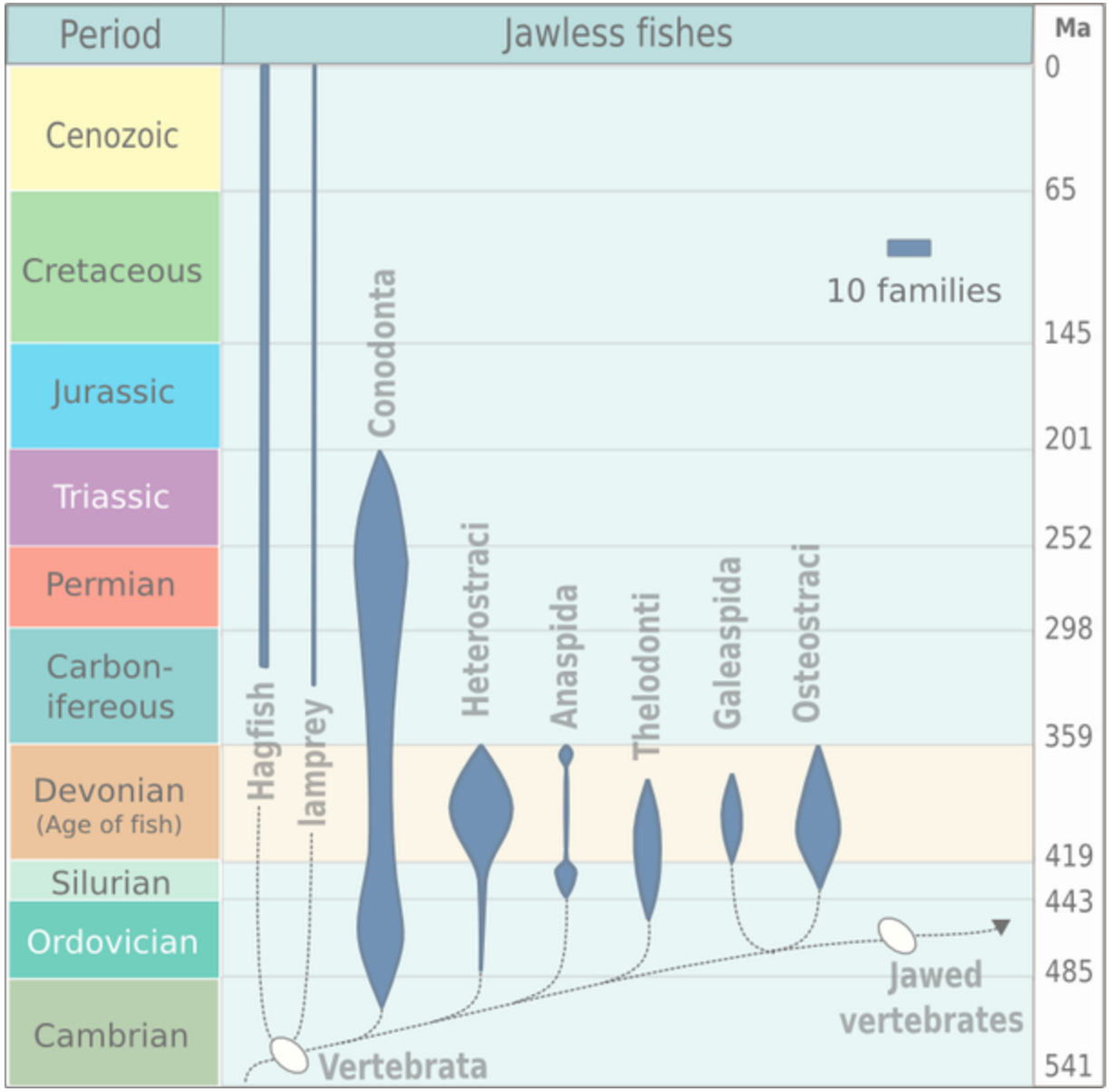


Examples of compound (left) and coniform (right) conodont elements. Scale bar is 0.5 mm

- **Conodonta** (appear in Late Cambrian):
- A group of **chordates**, very likely craniates, and possibly even vertebrates
- Known almost exclusively from their hard (calcium phosphate) tooth-like elements
- Soft tissue preservation allows us to see that they had flattened elongate "eel-like" bodies
- Were probably fast swimming micropredators

Cambrian - Triassic


Period
Fishes
Tetrapods
Ma
Paleogene to present
Cretaceous
Jurassic
Triassic
Permian
Carbon-iferous
Devonian
Silurian
Ordovician
Cambrian
0
65
145
201
252
298
359
419
443
485
541
Jawless fishes
Placoderms
Cartilaginous fishes
Spiny sharks
Ray-fin fishes
Lobe-fin fishes
Amphibians
reptiles
birds
mammals
Age of fishes
50 families


Period
Jawless fishes
Ma
Cenozoic
Cretaceous
Jurassic
Triassic
Permian
Carbon-
iferous
Devonian
(Age of fish)
Silurian
Ordovician
Cambrian
0
65
145
201
252
298
359
419
443
485
541
10 families
Hagfish
lamprey
Conodonta
Heterostraci
Anaspida
Thelodonti
Galeaspida
Osteostraci
Vertebrata
Jawed
vertebrates

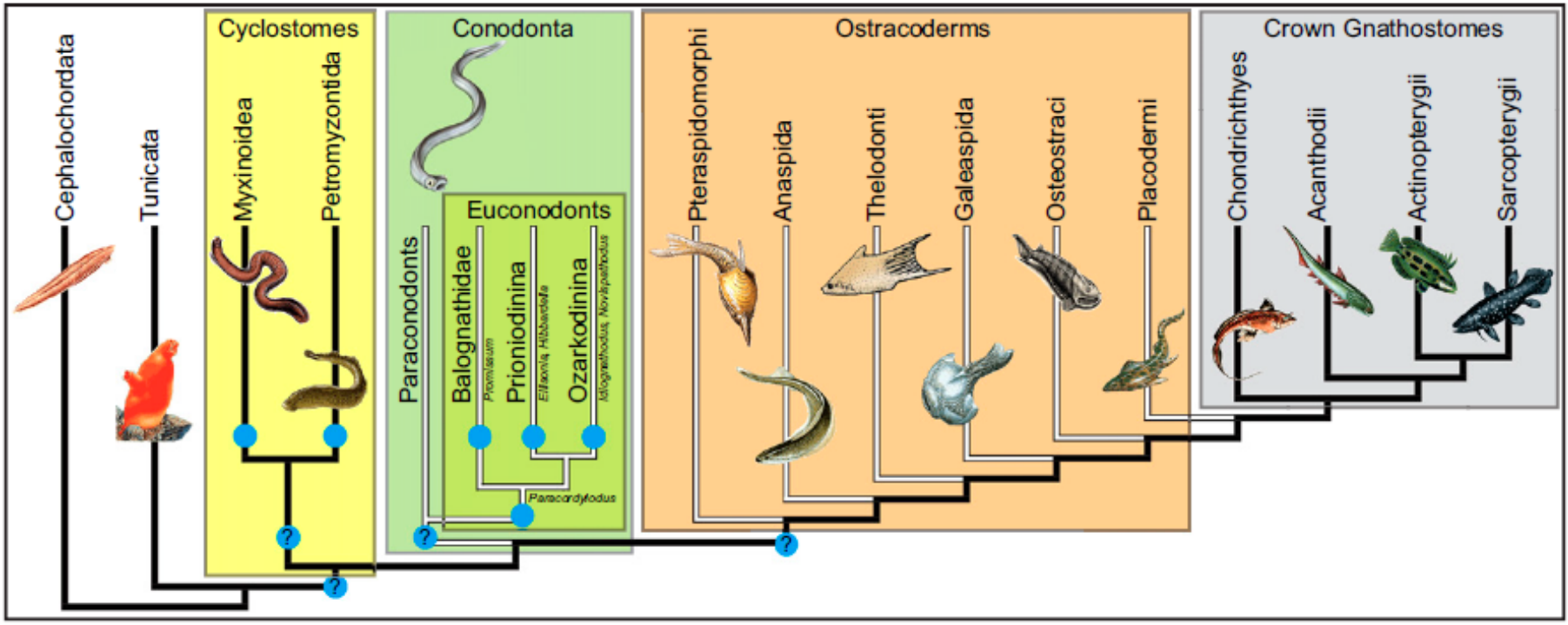
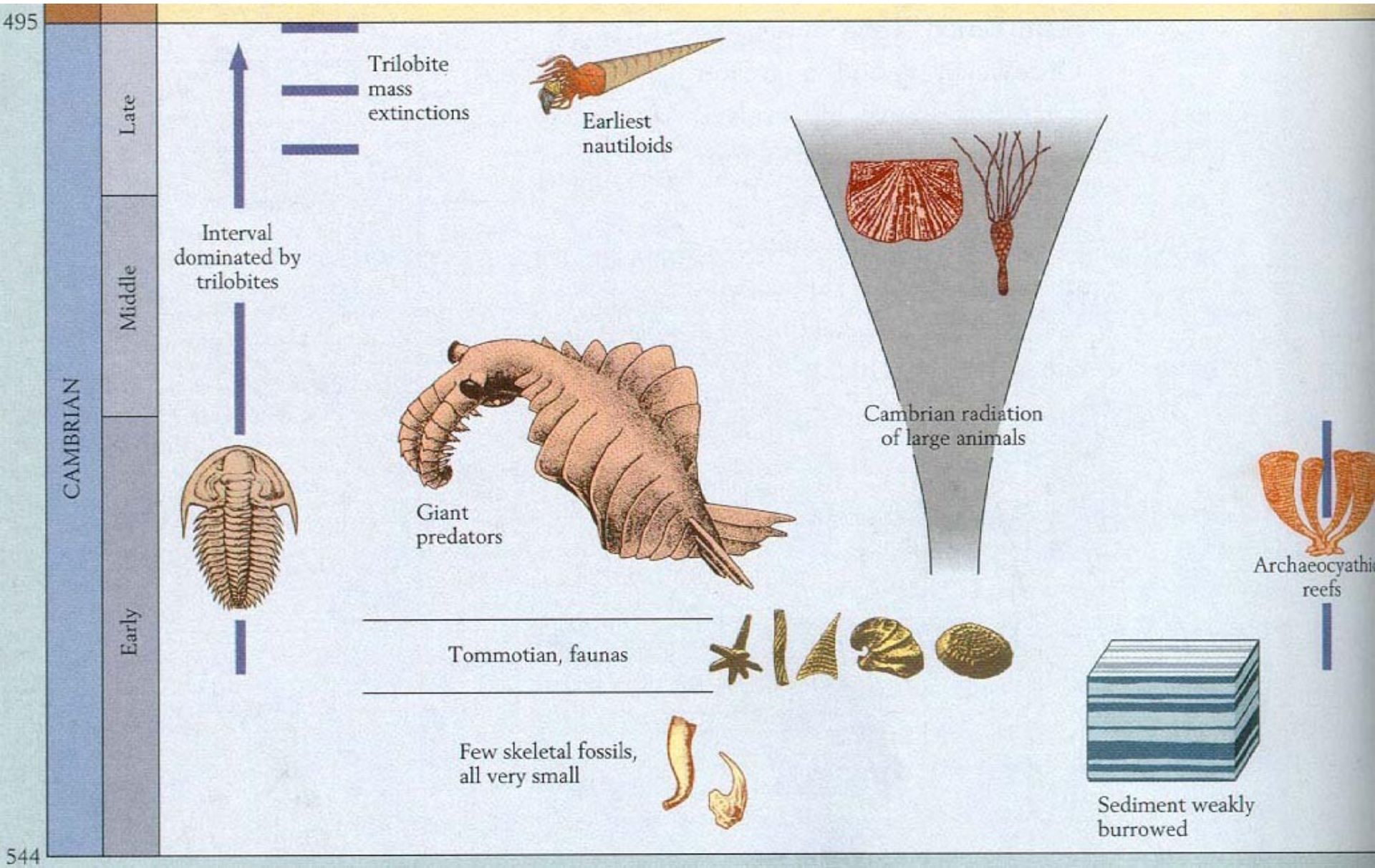


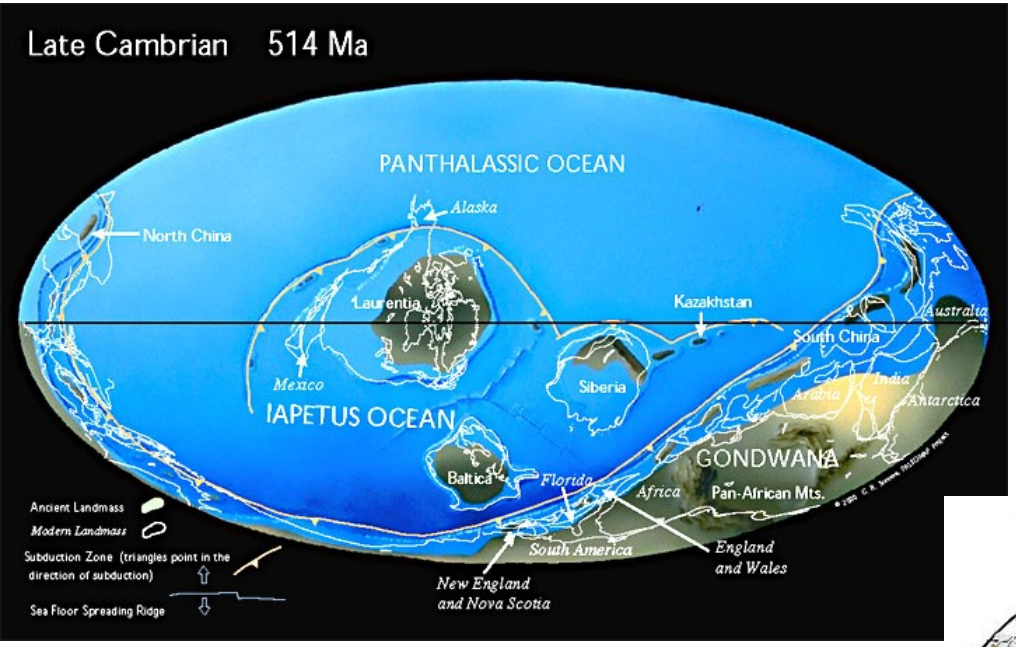

Fig. 6. Hypothesis of relationships among chordates that is primarily based on refs. 27 and 30. Evidence from molecular data supports monophyly of cyclostomes and shows that the closest relatives of vertebrates are the tunicates, not the cephalochordates (31). The relationships among euconodonts are derived from ref. 32. Blue circles indicate the presence of a lingual cartilage.

# Cambrian Timeline

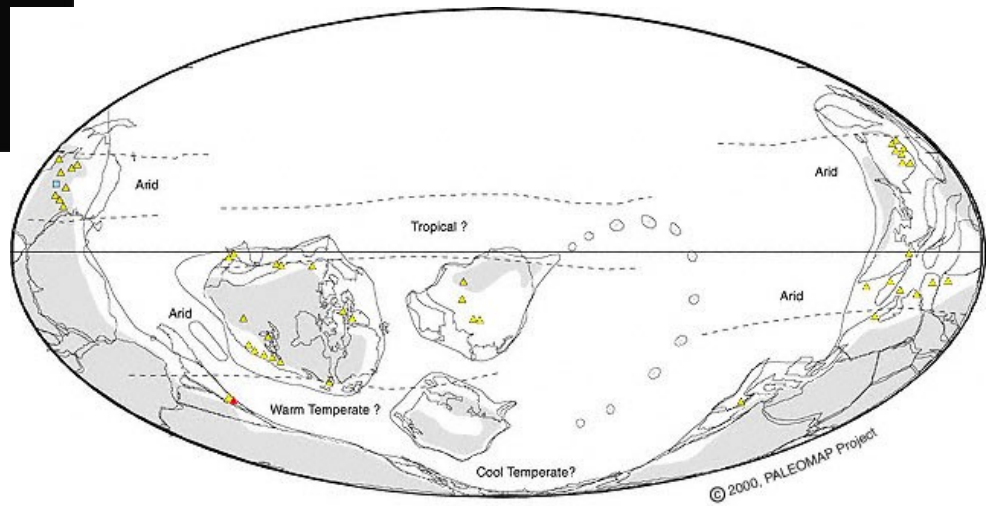


# Cambrian Tectonics (NA) and Climate

- Break-up of Rodinia and Pannotia
- Passive-margin seds from Newfoundland to AL—Iapetus Ocean (Cambrian to Middle Ordovician)

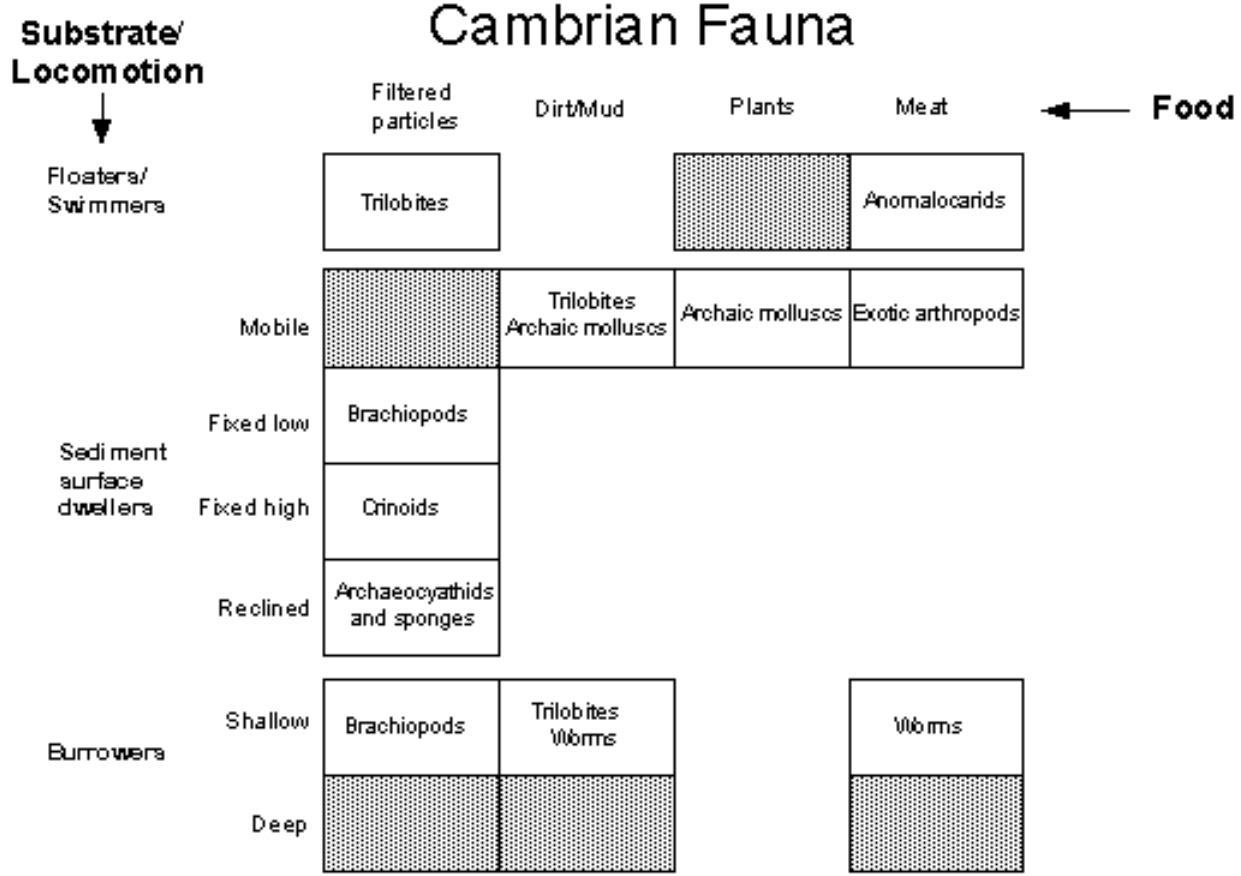



Generally temperate climate; no evidence of large glaciers




Middle & Upper Cambrian

# Cambrian Fauna



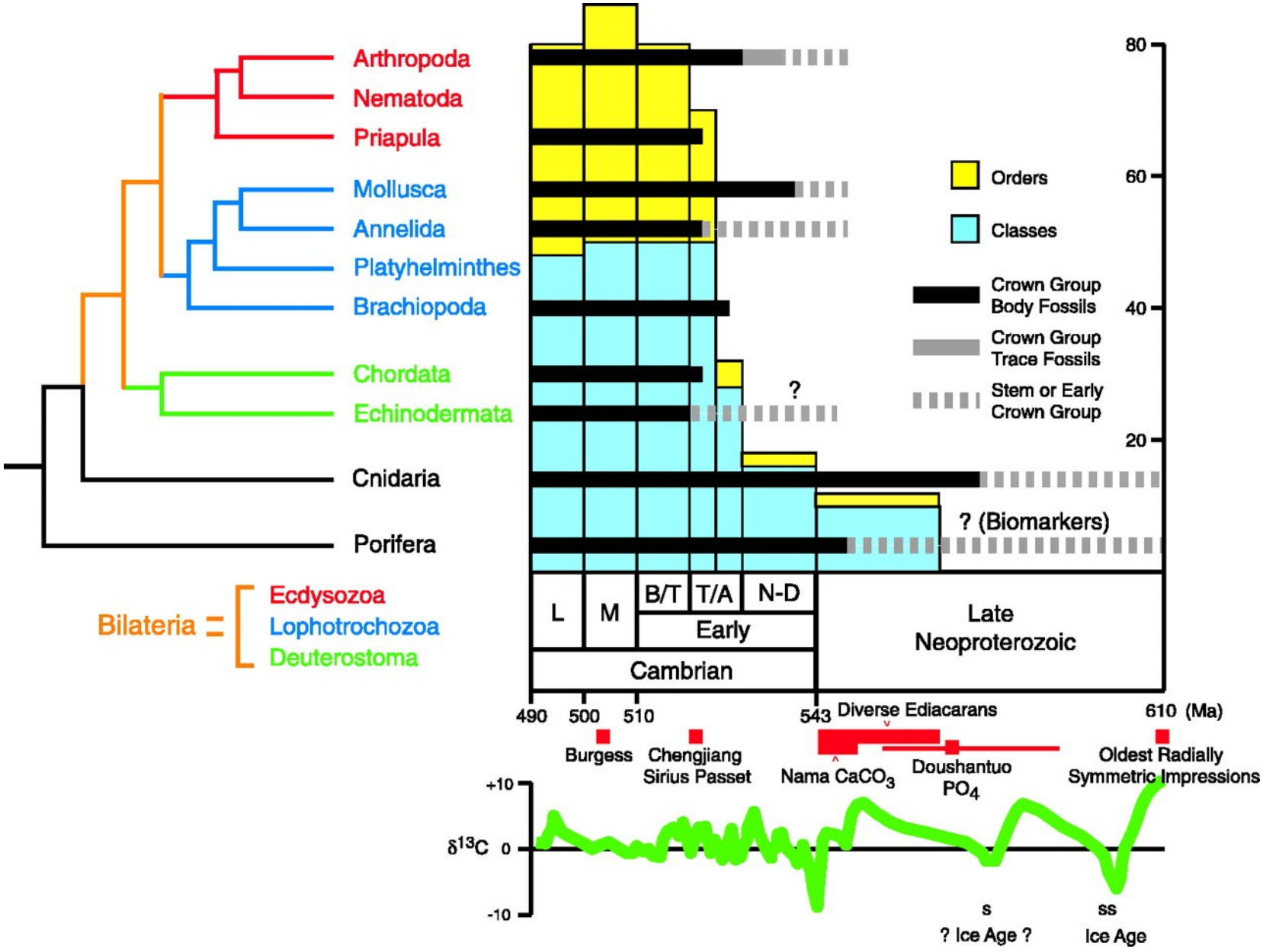

**Dominant animals**: Trilobites, Worms, Inarticulate brachiopods

**Dominant life modes**:

Slow, surface-dwelling detritus feeding
Few filter feeders, herbivores or carnivores
Few burrowers or swimmers

**Local Diversity:**

~ 7 species in stressed zones
~13 species in near shore regions
~20 species in open marine


Arthropoda
Nematoda
Priapula
Mollusca
Annelida
Platyhelminthes
Brachiopoda
Chordata
Echinodermata
Cnidaria
Porifera
Bilateria
Ecdysozoa
Lophotrochozoa
Deuterostoma
80
60
40
20
Orders
Classes
Crown Group Body Fossils
Crown Group Trace Fossils
Stem or Early Crown Group
?
? (Biomarkers)
L
M
B/T
T/A
N-D
Early
Cambrian
Late Neoproterozoic
490
500
510
543
610 (Ma)
Diverse Ediacarans
Burgess
Chengjiang
Sirius Passet
Nama CaCO3
Doushantuo
PO4
Oldest Radially Symmetric Impressions
+10
δ13C 0
-10
s
? Ice Age ?
ss
Ice Age

**The Cambrian plankton was more abundant and diverse than that of the Precambrian oceans. The acritarchs radiated during the Cambrian, radiolarians occupied tropical latitudes, whereas chitinozoans were present in Cambrian plankton but not abundant. Larval phases of benthic organisms together with the agnostic trilobites (illustration above) dominated a zooplankton still apparently free of macrophagous predators.**