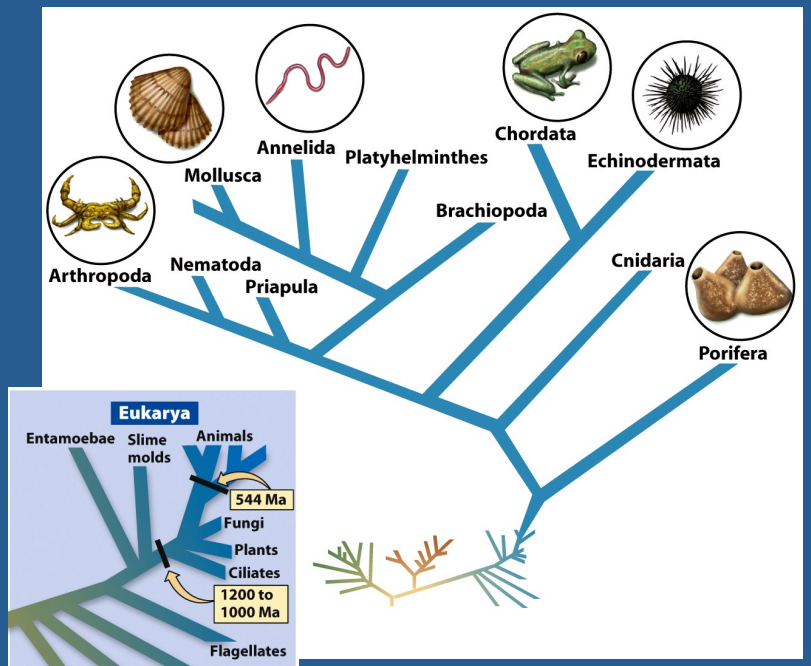
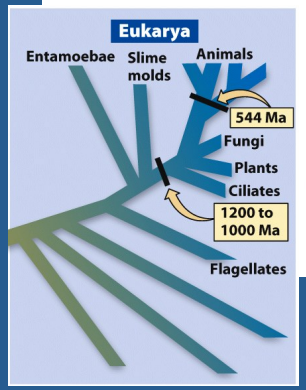
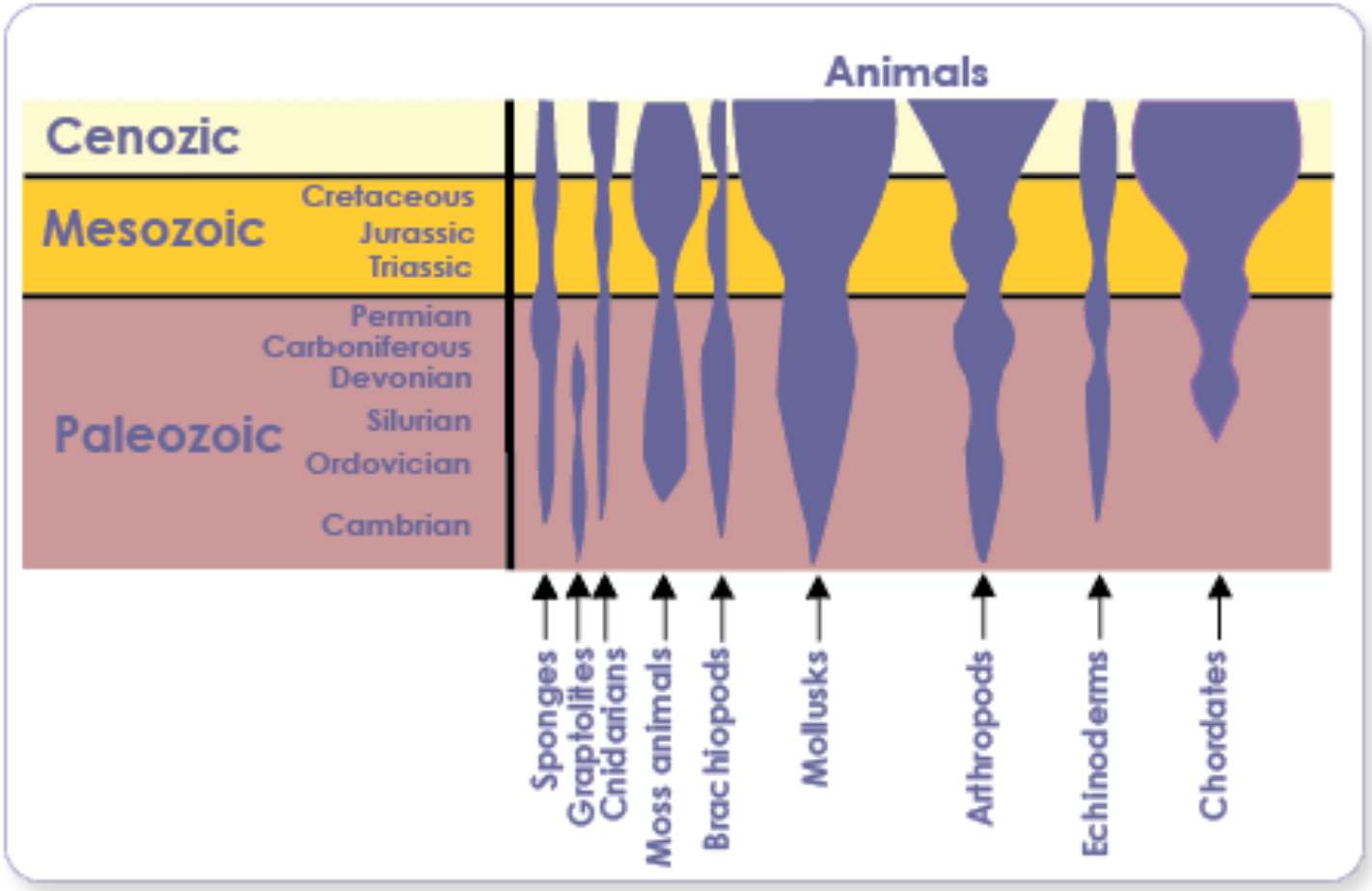
# Cambrian Evolutionary Radiation

- Every major animal phylum that exists on Earth today, as well as a few more that have since become extinct, appeared within less than 10 million years during the early Cambrian evolutionary radiation, also called the Cambrian explosion.



# Cambrian Evolutionary Radiation



# Phylum Annelida

- Phylum Annelida is represented by over 22,000 modern species of marine, freshwater, and terrestrial annelids, or segmented worms, including bristleworms, earthworms, and leeches. These worms are classified separately from the roundworms in Phylum Nematoda and the flatworms in Phylum Platyhelminthes.
- The annelids may be further subdivided into Class Polychaeta, which includes the bristleworms (polychaetes), and Class Clitellata, which includes the earthworms (oligochaetes) and leeches (hirudineans).

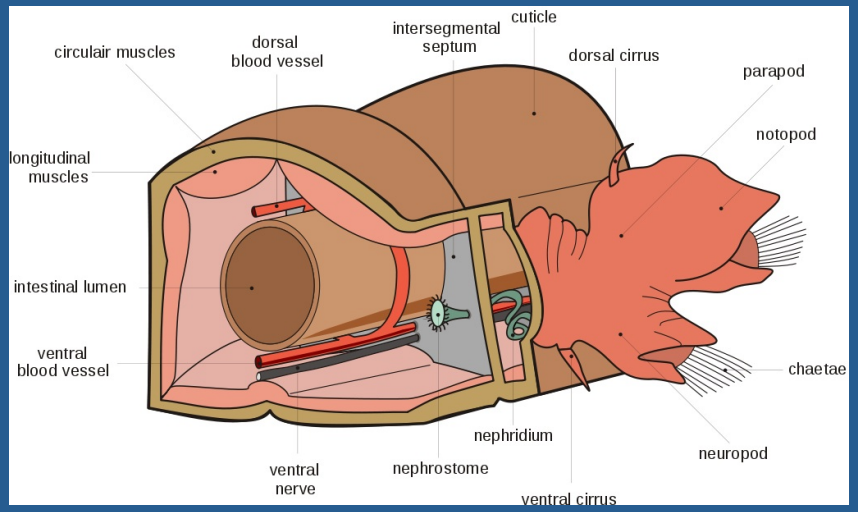


# Polychaetes

- The polychaetes, or bristleworms, are the largest group of annelids and are mostly marine. They include species that live in the coldest ocean temperatures of the abyssal plain, to forms which tolerate the extreme high temperatures near hydrothermal vents. Polychaetes occur throughout the oceans at all depths, from planktonic species such as *Tomopteris* that live near the surface to an unclassified benthonic form living at a depth of nearly 11,000 m at the bottom of the Challenger Deep in the Mariana Trench.

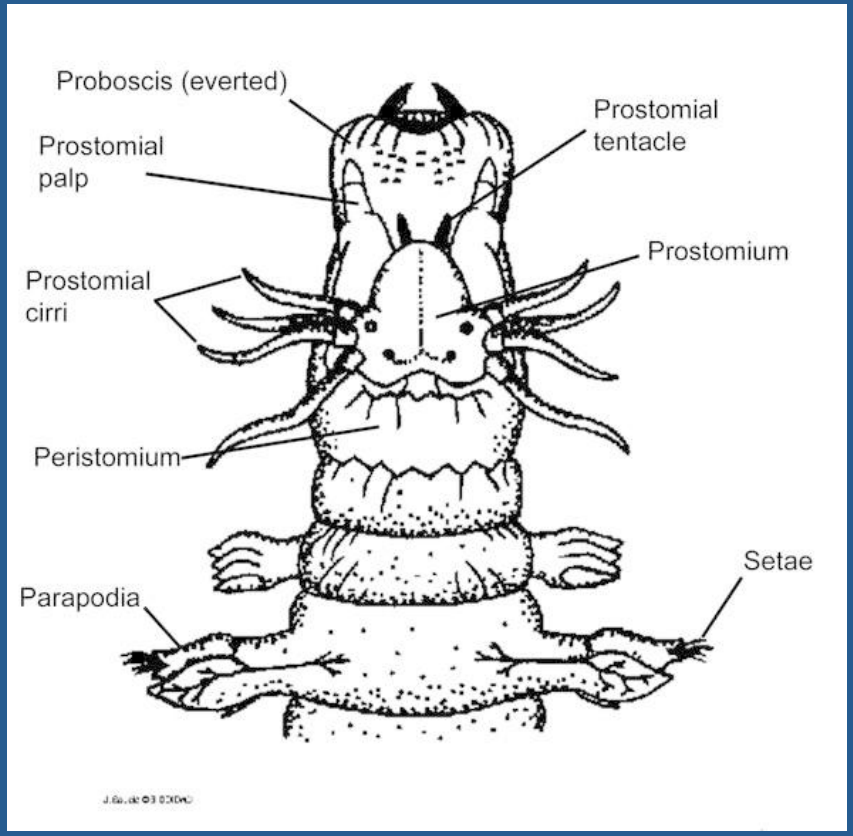
# Polychaetes

- Although many polychaetes are pelagic or benthic, others have adapted to burrowing, boring or tube-dwelling, and parasitism.
- Each segment of a polychaete bears a pair of paddle-like and highly vascularized parapodia, which are used for locomotion and, in many species, act as the worm's primary respiratory surfaces. Bundles of chitinous bristles, called chaetae, project from the parapodia.



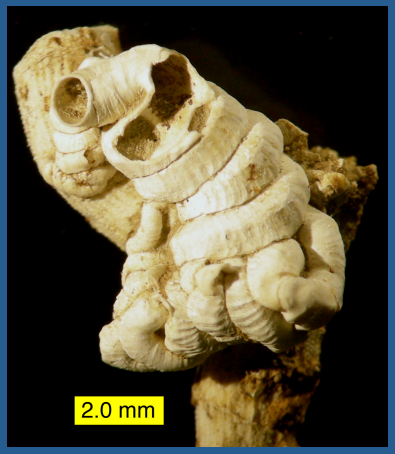
# Polychaetes

- The head of polychaete, or prostomium, is relatively well developed, compared with other annelids. It projects forward over the mouth, which therefore lies on the animal's underside. It normally includes two to four pair of eyes.
- The mouth normally possesses a pair of jaws made of hardened collagen and a pharynx that can be rapidly everted, allowing the worm to grab food and pull it into the mouth. In some species, the pharynx is modified into a lengthy proboscis.



# Polychaetes

- The polychaetes are by far the best represented annelids in the fossil record. Because they are soft-bodied, however, their record is generally sparse and dominated by their fossilized jaws, known as scolecodonts, and the mineralized tubes that some of them secrete. More rarely, their chitinous chaetae may be preserved as films of organic matter in black shales, such as in the Burgess Shale fauna.



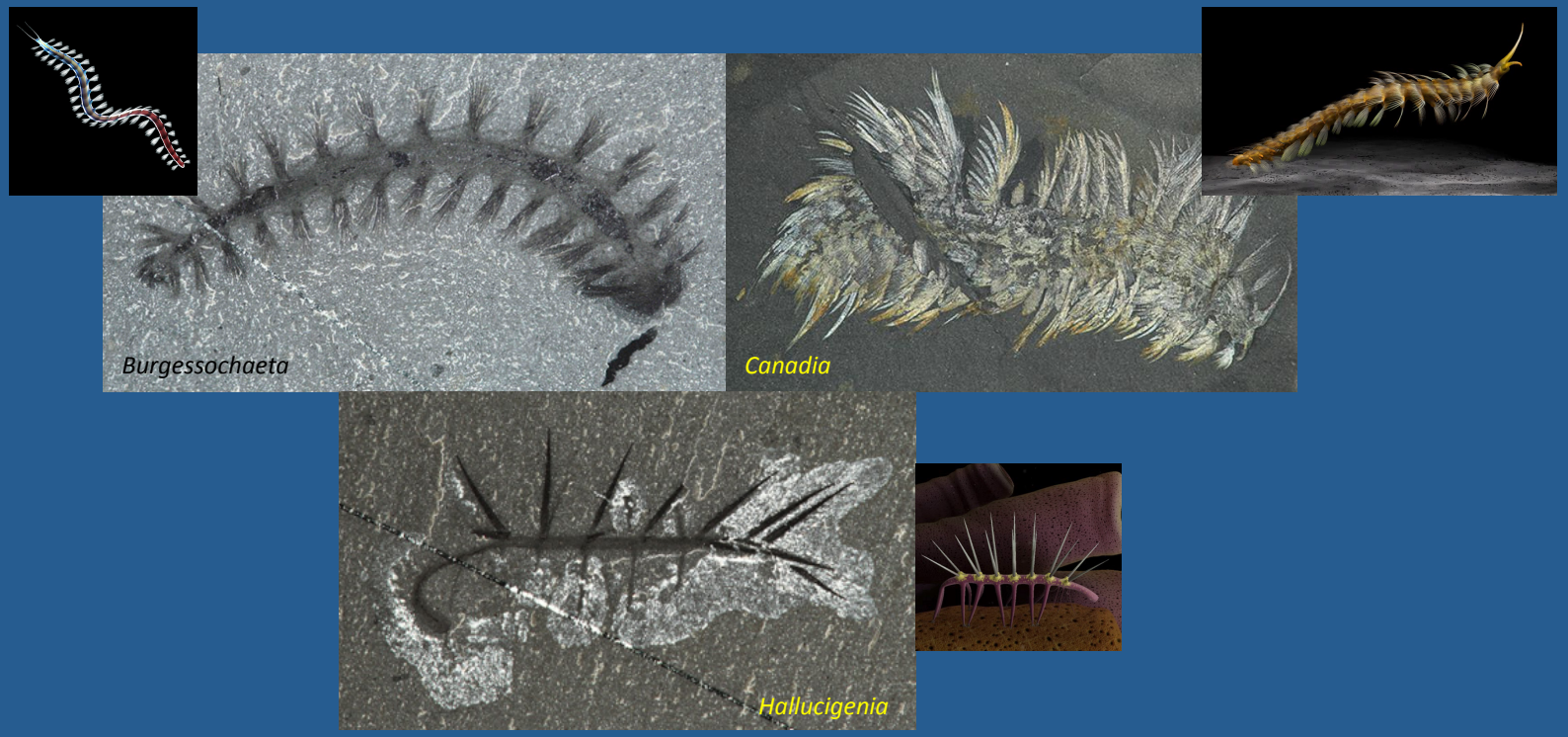
# Burgess Shale

- The Burgess Shale Formation is a Middle Cambrian (505 Ma) black shale that crops out near the town of Field in Yoho National Park, southeastern British Columbia.


- The formation contains an amazing variety of exquisitely preserved soft-bodied animals, including many annelids and arthropods. It was discovered in 1909 by American paleontologist Charles Walcott, shown here in the center of the photograph with his family which he often took on collecting trips.

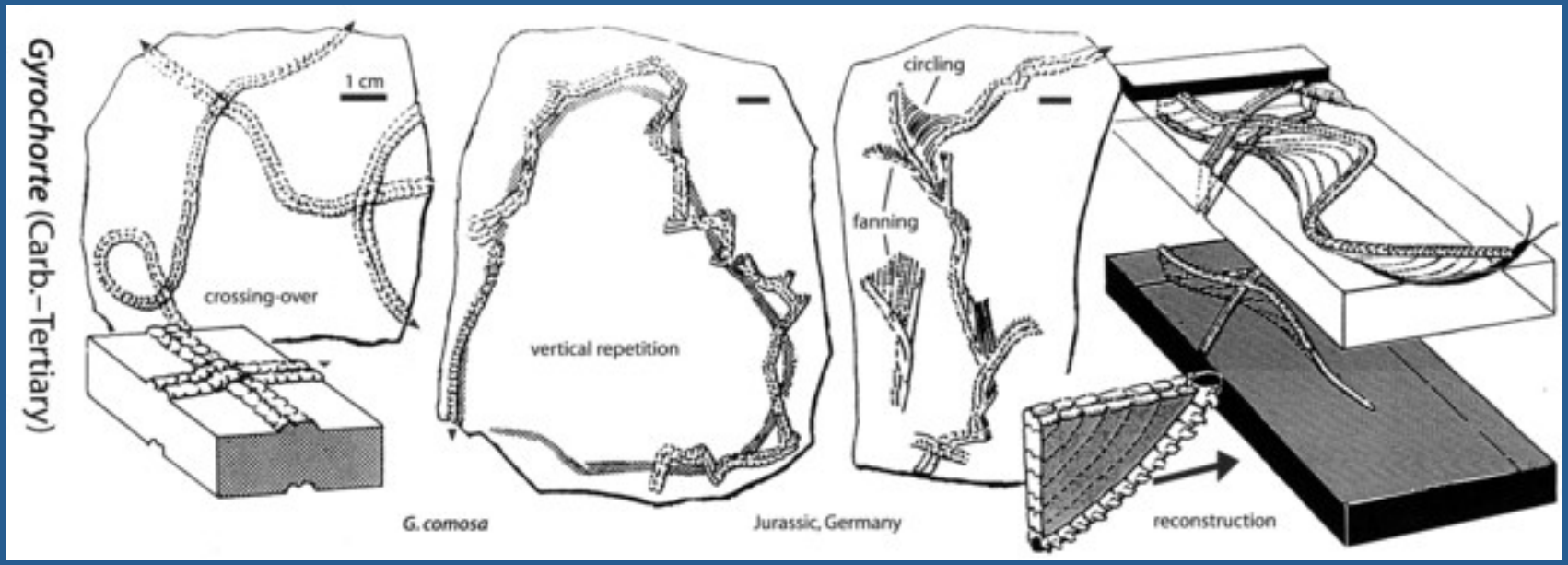
# Burgess Shale Polychaetes

- Examples of the remarkable polychaete fauna of the Burgess Shale includes *Burgessochaeta setigera*, *Canadia spinosa*, and *Hallucigenia sparsa*.



# Annelid Trace Fossils

- Annelids may occasionally leave feeding trails and shallow burrows on the sediment surface which may be preserved as trace fossils.



# Phylum Arthropoda

- Phylum Arthropoda is represented by the arthropods, animals which have an exoskeleton, an elongate transversely segmented body, and jointed appendages. Their bodies display more or less perfect bilateral symmetry.

- Living arthropods number more than 1,000,000 species and include the crustaceans, spiders, centipedes and millipedes, and insects.


Crab


Spider


Beetle

# Arthropods

- Phylum Arthropoda may be divided into the five main subphyla shown here, including one, Trilobitomorpha, which contains the extinct animals known as trilobites, the only arthropods with an extensive fossil record.

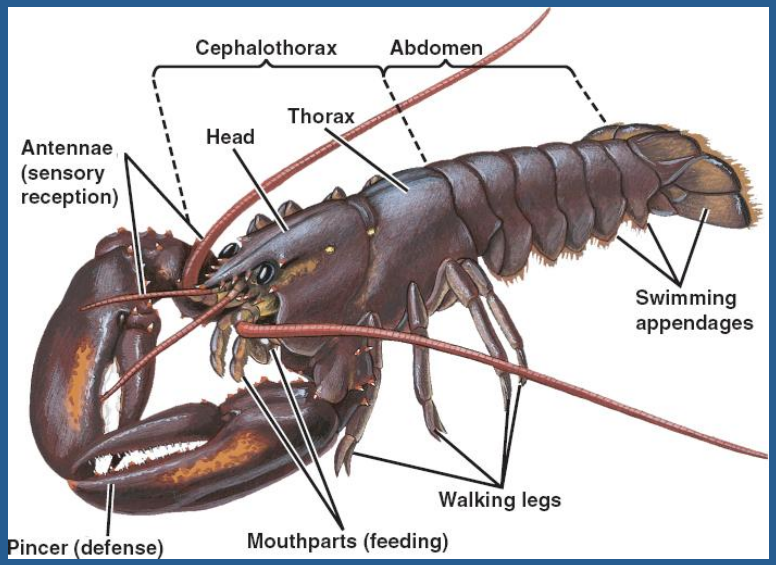
- Classification is generally based on the number of body segments which have been incorporated into the head — those with mandibles, the Crustacea, Myriapoda, and the Hexapoda, being separated from those with grasping organs, or chelicerae, the Trilobitomorpha and Chelicerata.

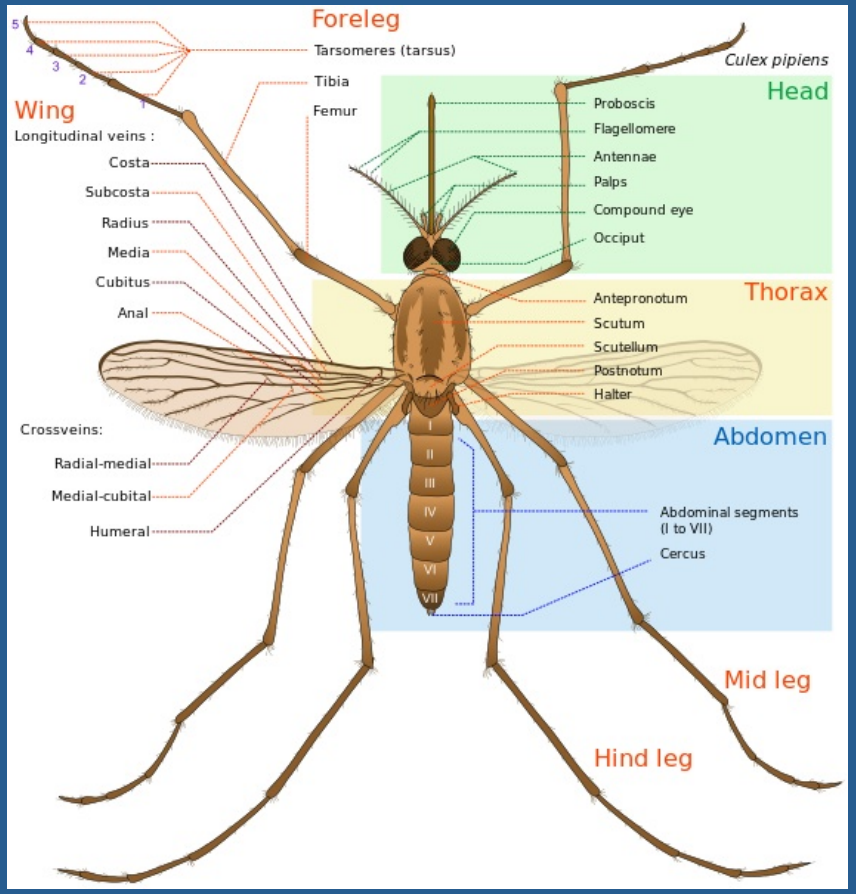
**Subphyla and Classes**

- **Subphylum Trilobitomorpha**
  - Trilobita – trilobites (extinct)
- **Subphylum Chelicerata**
  - Arachnida – spiders, scorpions, etc.
  - Merostomata – horseshoe crabs, sea scorpions (extinct), etc.
  - Pycnogonida – sea spiders
- **Subphylum Myriapoda**
  - Chilopoda – centipedes
  - Diplopoda – millipedes
  - Pauropoda – sister group to millipedes
  - Symphyla – resemble centipedes
- **Subphylum Crustacea**
  - Branchiopoda – brine shrimp etc.
  - Remipedia – blind crustaceans
  - Cephalocarida – horseshoe shrimp
  - Maxillopoda – barnacles, fish lice, etc.
  - Ostracoda – seed shrimp
  - Malacostraca – lobsters, crabs, shrimp, etc.
- **Subphylum Hexapoda**
  - Insecta – insects
  - Entognatha – wingless

# Arthropods

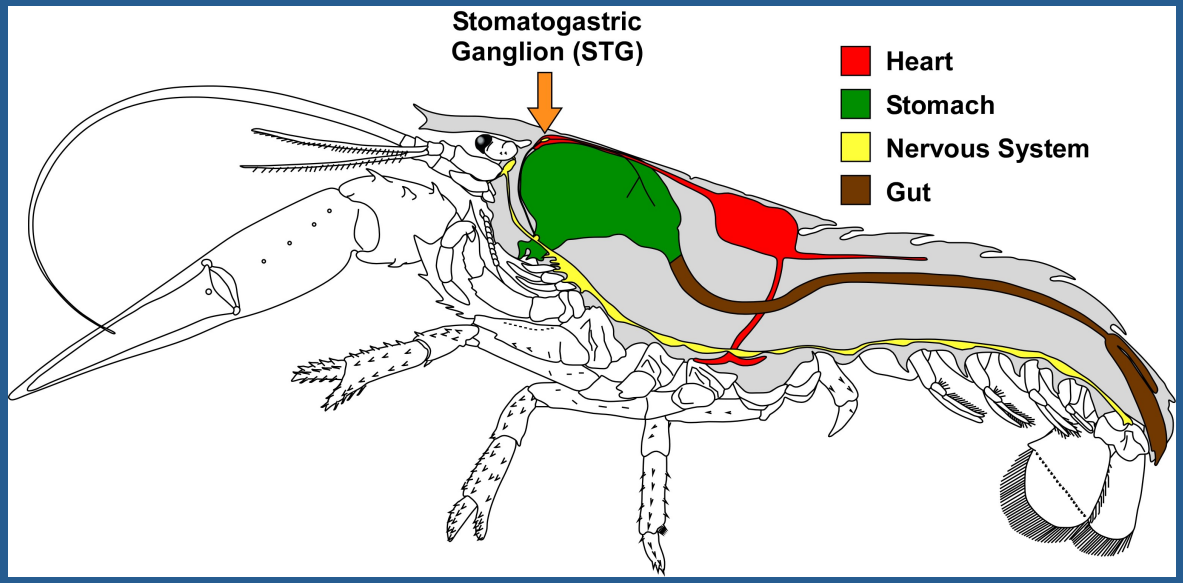
- Arthropod anatomy is extremely varied, but in general, these animals have a body divided into a head, a thorax, and an abdomen.



# Arthropods

- Attached to a few or most of the segments of the arthropod body are pairs of jointed appendages. The head contains a dorsal brain above the esophagus. Eyes are either simple or compound. The mouth and anus are at opposite ends of the body. Growth takes place by shedding, or molting, the rigid exoskeleton.



# Subphylum Trilobitomorpha

- Class Trilobita in Subphylum Trilobitomorpha includes the trilobites, an extinct group of marine arthropods that first appeared in the Early Cambrian and flourished during the early Paleozoic Era. Trilobite diversity began to decline during the Late Ordovician and only one trilobite order remained at the end of the Devonian. Trilobites finally went extinct at the end of the Permian, leaving behind some 17,000 known species.

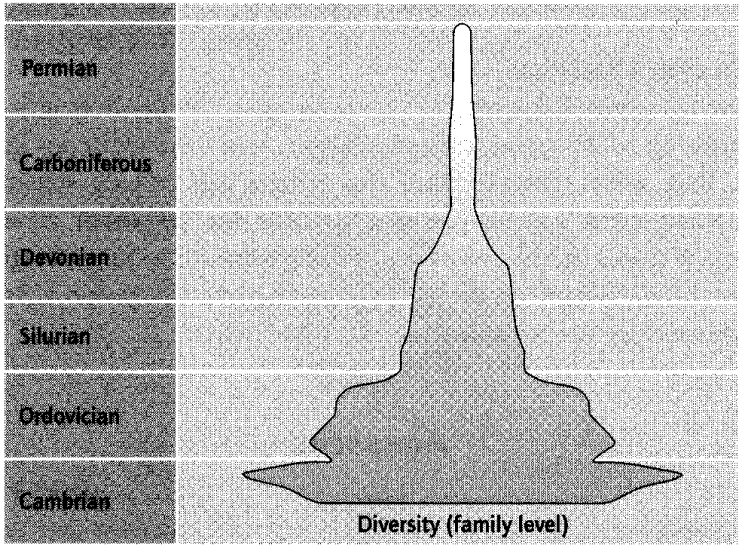
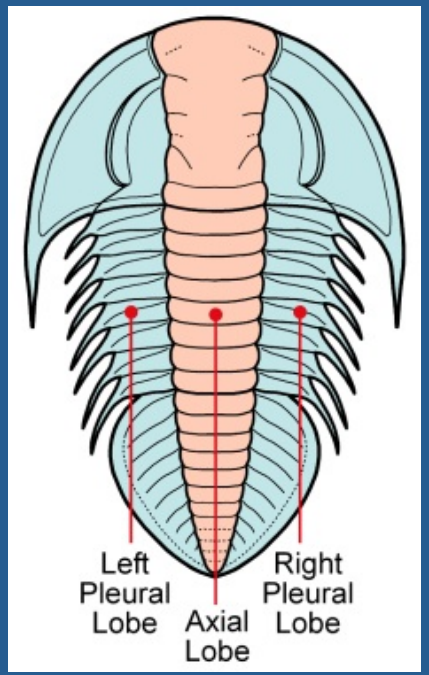
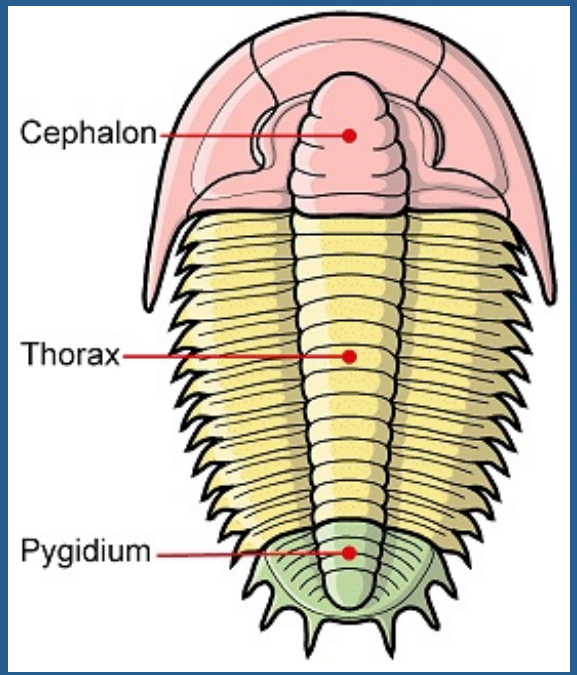



**Fig. 8.3** Trilobite diversity through time. Note the high diversity in the late Cambrian and early Ordovician.

# Trilobites

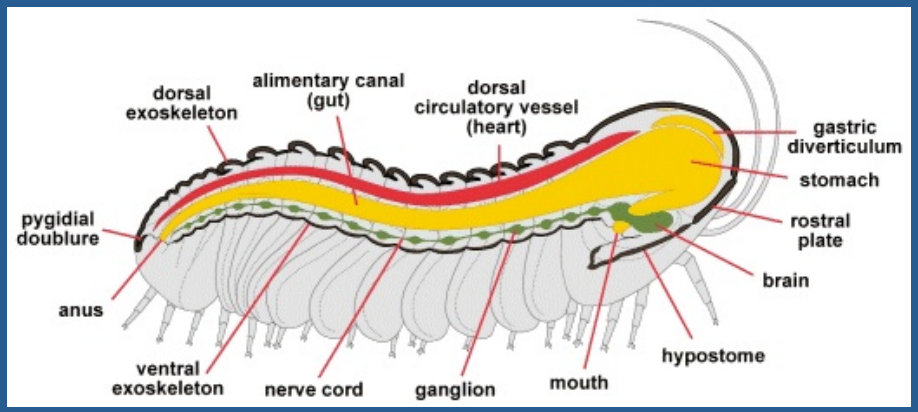
- Trilobites have a dorsal exoskeleton that is longitudinally divisible into three regions, an axial lobe flanked by left and right pleural lobes. The exoskeleton is also transversely divisible into three regions, an anterior cephalon, a middle thorax, and a posterior pygidium.

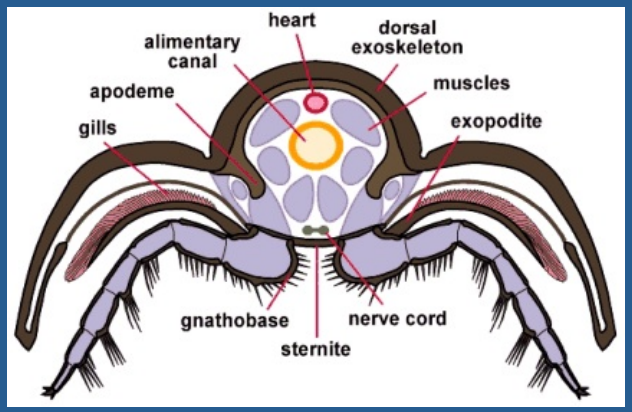


# Trilobites

- The internal anatomy of trilobites is generally similar to other arthropods, as shown in the longitudinal and cross sections below.




- When trilobites first appeared in the fossil record they were already highly diverse and geographically dispersed.

# Trilobites

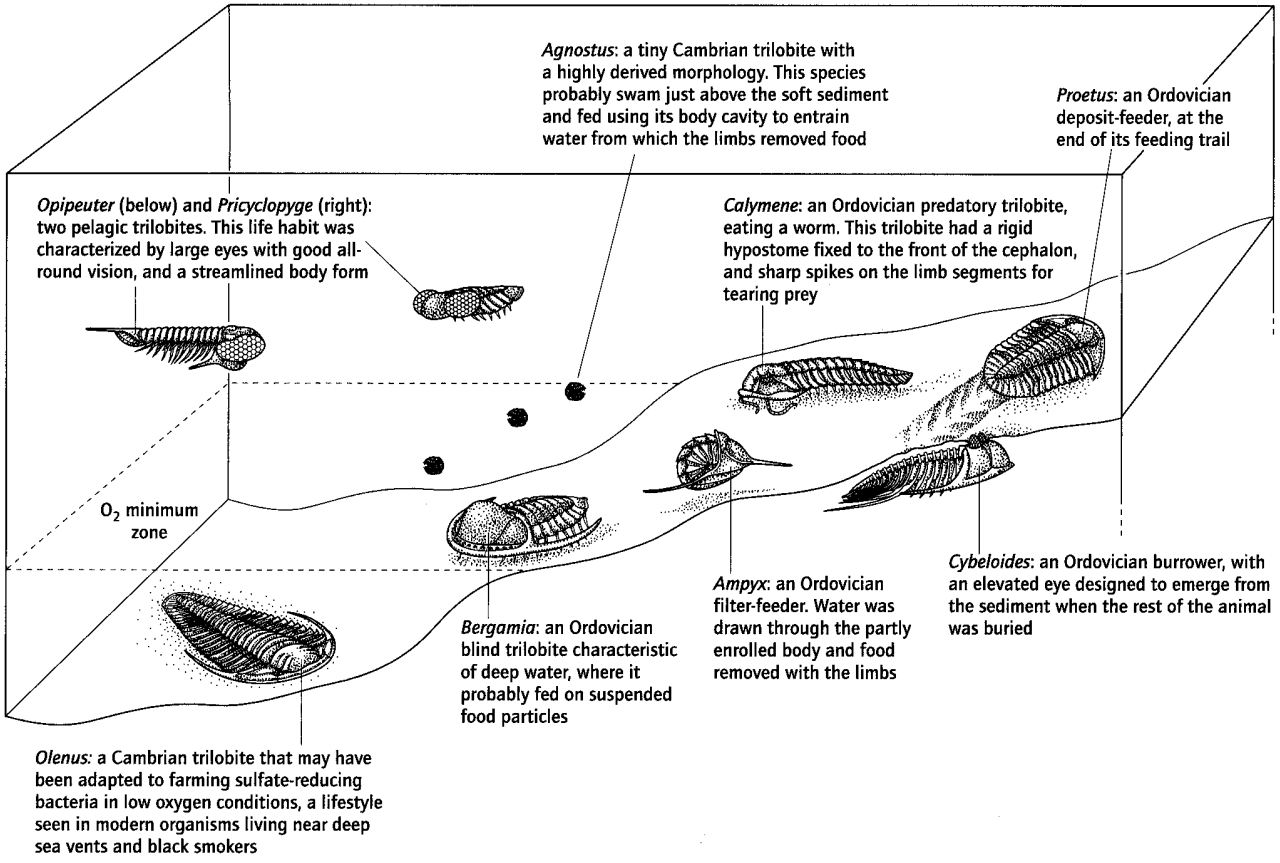


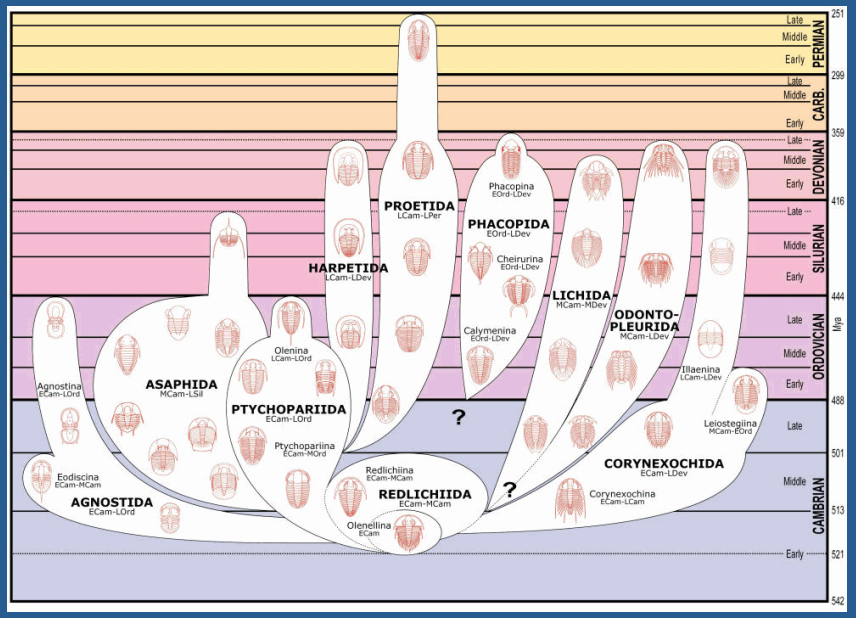

**Fig. 8.2** A reconstruction of a range of late Cambrian to Silurian trilobites showing their probable life habits and positions. The reconstruction deepens from right to left, and there is an oxygen minimum zone above the sea bed in the extreme left of the image. All trilobites were marine.

# Trilobites

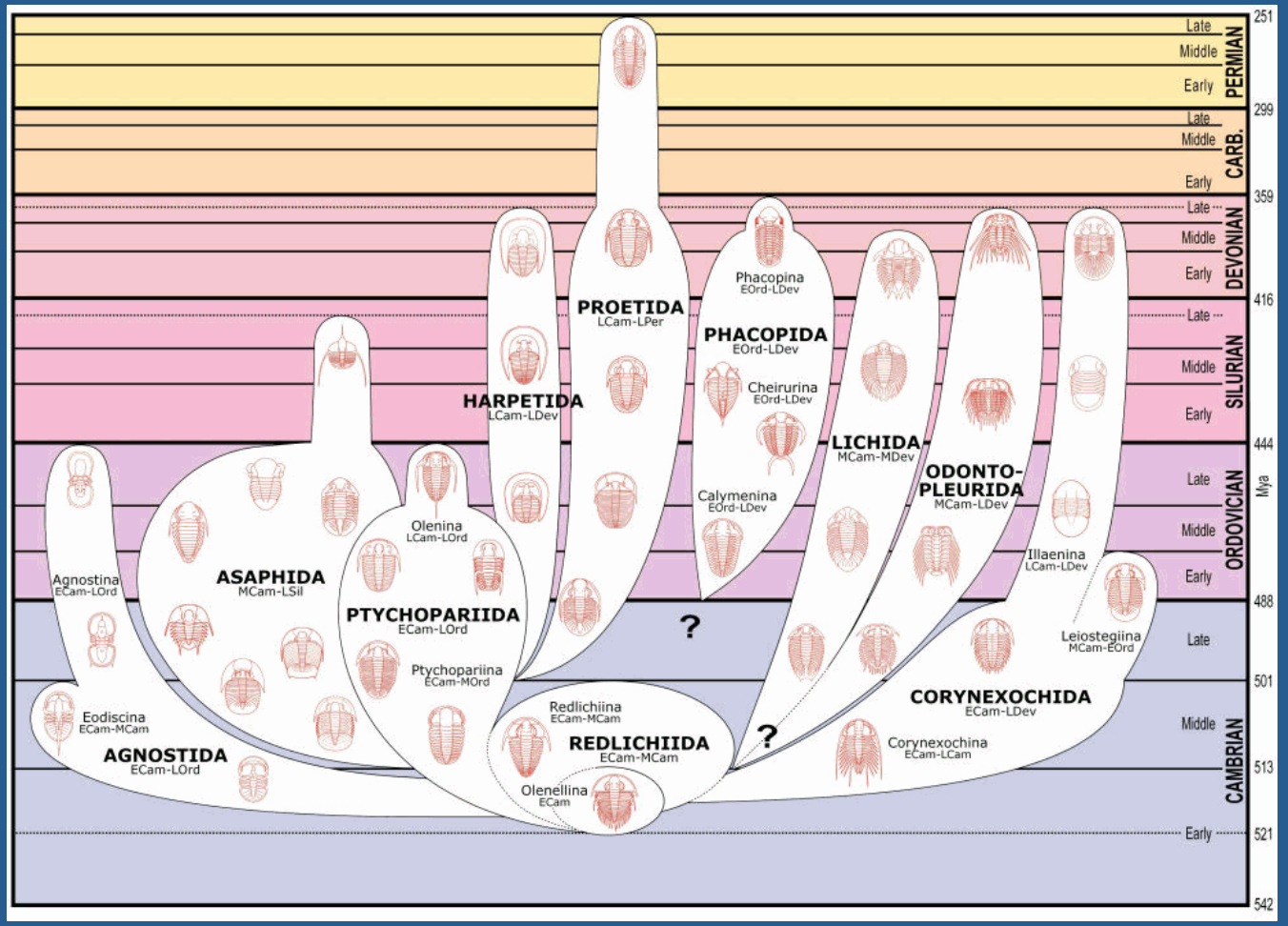
- Trilobites had the ability to protect themselves by enrolling, a behavior similar to that of an armadillo. These examples of the trilobite *Flexicalymene* show how the animals reacted to an influx of sediment that ultimately buried them.


# Trilobites

- There are at least nine orders in Class Trilobita:
  - Redlichiida
  - Ptychopariida
  - Agnostida
  - Corynexochida
  - Asaphida
  - Lichida
  - Harpetida
  - Proetida
  - Phacopida

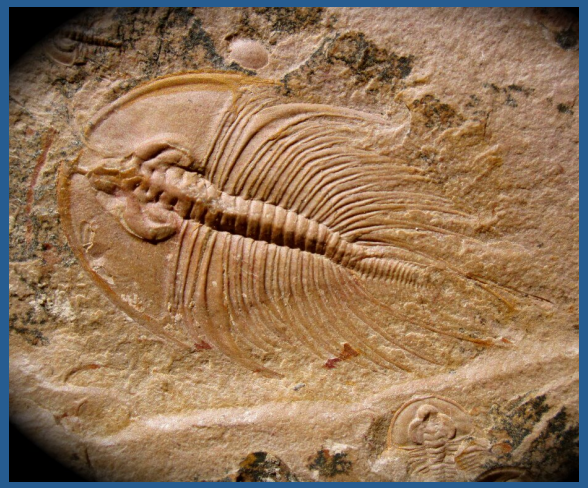


# Trilobites


Late
Middle
Early
PERMIAN
Late
Middle
Early
CARB.
Late
Middle
Early
DEVONIAN
Late
Middle
Early
SILURIAN
Late
Middle
Early
ORDOVICIAN
Late
Middle
CAMBRIAN
Early
251
299
359
416
444
488
501
513
521
542
Mya
PROETIDA
LCam-LPer
HARPETIDA
LCam-LDev
PHACOPIDA
EOrd-LDev
Phacopina
EOrd-LDev
Cheirurina
EOrd-LDev
Calymenina
EOrd-LDev
LICHIDA
MCam-MDev
ODONTO-
PLEURIDA
MCam-LDev
Illaenina
LCam-LDev
Leiostegiina
MCam-EOrd
CORYNEXOCHIDA
ECam-LDev
Corynexochina
ECam-LCam
ASAPHIDA
MCam-LSil
Agnostina
ECam-LOrd
Olenina
LCam-LOrd
PTYCHOPARIIDA
ECam-LOrd
Ptychopariina
ECam-MOrd
Redlichiina
ECam-MCam
REDLICHIIDA
ECam-MCam
Olenellina
ECam
Eodiscina
ECam-MCam
AGNOSTIDA
ECam-LOrd
?
?

# Trilobites

- Order Redlichiida (E. Cam.-M. Cam.): The redlichiids are primitive trilobites with numerous thoracic segments that are usually spiny, large eyes, and a small pygidium. An example is *Olenellus*.



- Order Ptychopariida (E. Cam.-L. Ord.): The ptychopariids are a highly varied, generalized group of trilobites. An example is *Elrathia*.

# Trilobites

- Order Agnostida (E. Cam.-L. Ord.): The agnostids are tiny trilobites with only two or three thoracic segments. An example is *Eodiscus*.

- Order Corynexochida (E. Cam.-L. Dev.): The corynexochids are typically spiny trilobites with ten or fewer thoracic segments. An example is *Bumastus*.

# Trilobites

- Order Asaphida (M. Cam.-L. Sil.): The asaphids are large, smooth trilobites with six to nine thoracic segments. An example is *Asaphus*.

- Order Lichida (M. Cam.-L. Dev.): The lichids are trilobites with a broad glabella, large pygidium, and an exoskeleton that is ornamented with tubercles. An example is *Kettneraspis*.

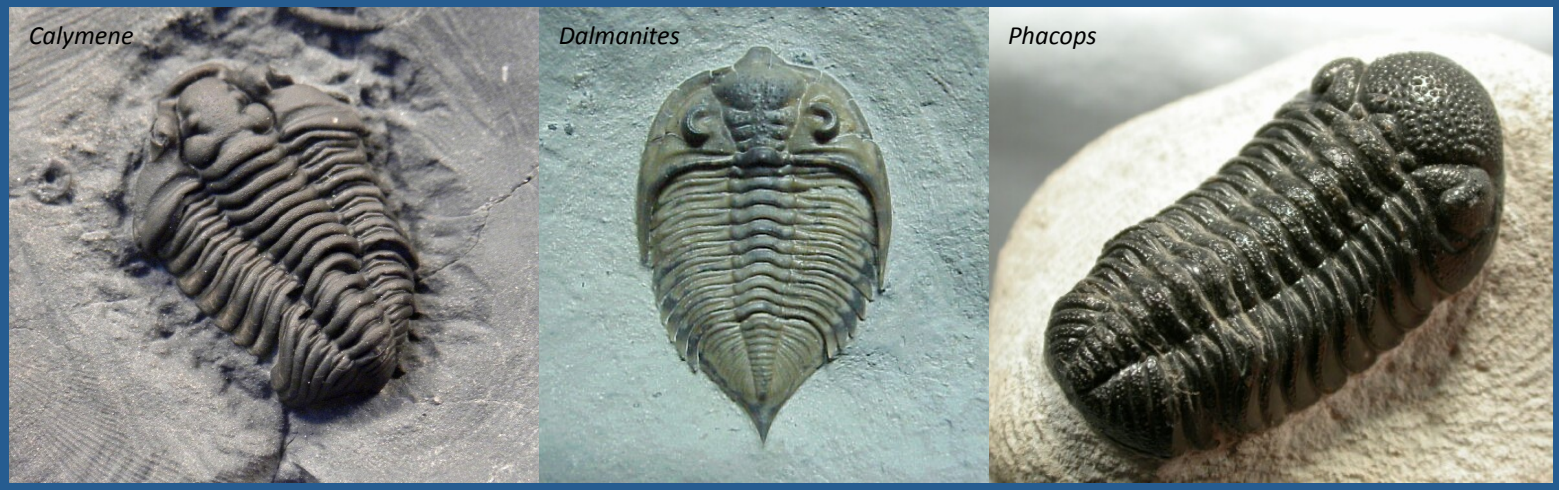
# Trilobites

- Order Harpetida (L. Cam.-L. Dev.): The harpetids are trilobites with large cephalons, very small eyes, numerous thoracic segments, and a short pygidium. An example is *Eoharpes*.

- Order Proetida (L. Cam.-L. Perm.): The proetids are trilobites with a large, domed glabella and eight to ten thoracic segments. An example is *Phillipsia*.

# Trilobites

- Order Phacopida (E. Ord.-L. Dev.): The phacopids are a varied group of trilobites. Examples include *Calymene*, *Dalmanites*, and *Phacops*.



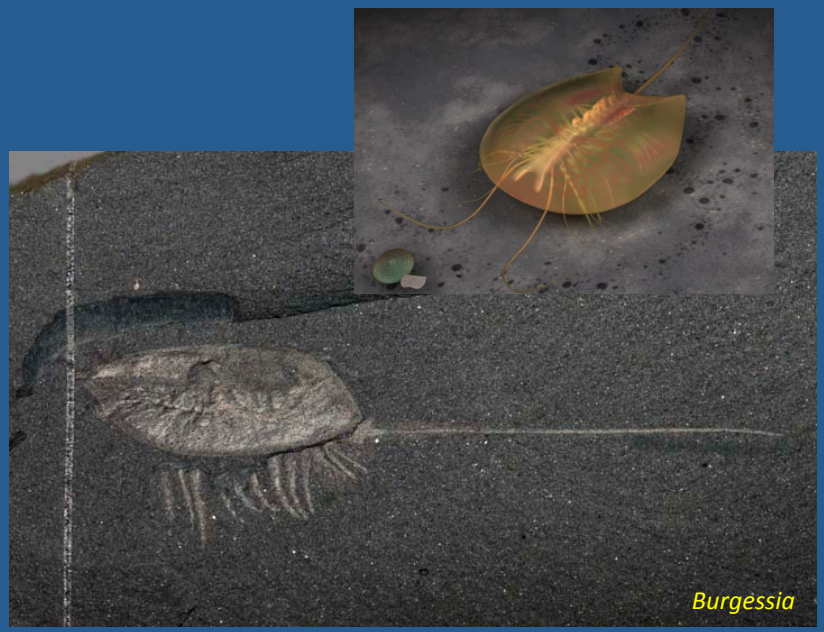
# Trilobites

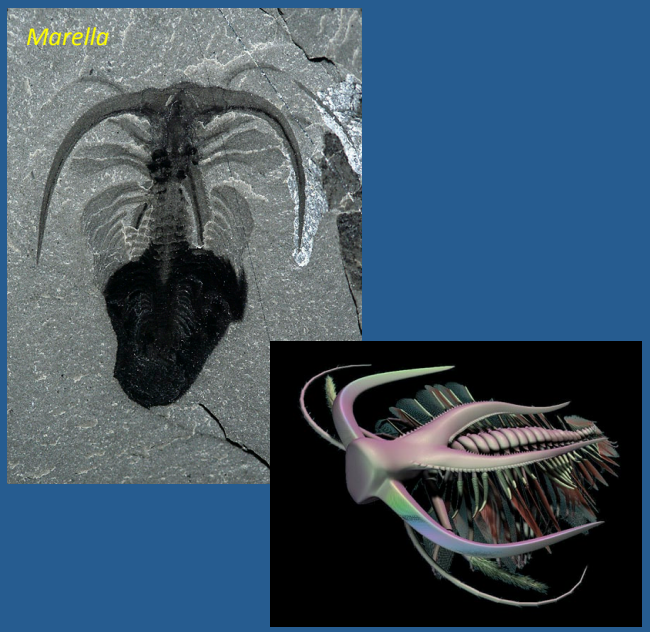
- Beecher's Trilobite Bed is located within the Late Ordovician Frankfort Shale in Cleveland's Glen, near Rome, New York. The bed has yielded numerous exceptionally preserved trilobites, especially *Triarthrus eatoni*, with the ventral anatomy and soft tissue intact, the soft tissue preserved by pyrite replacement. Pyritization allows the use of x-rays to study fine detail of preserved soft body parts still within the host rock.

*Triarthrus eatoni*

# Burgess Shale Arthropods

- Like the polychaete annelids, soft-bodied arthropods of Middle Cambrian age are exquisitely preserved in the Burgess Shale. Examples include *Burgessia bella*, *Marella splendens*, and *Anamolocaris canadensis*.



# Burgess Shale Arthropods

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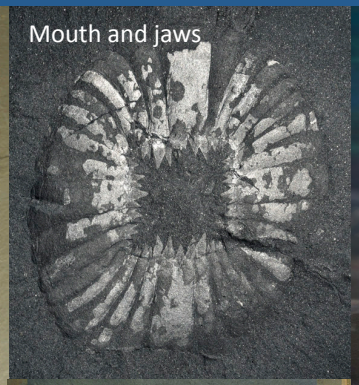
*Anomalocaris* was a top Mid-Cambrian predator



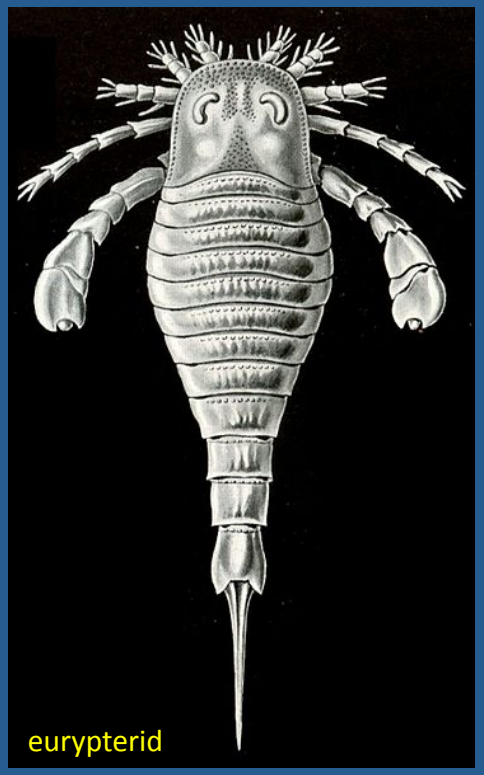


*Anomalocaris* was about 20 cm long

# Subphylum Chelicerata

- Subphylum Chelicerata may be divided into three classes: Arachnida, which includes spiders and scorpions, Merostomata, which includes horseshoe crabs and an extinct group of sea scorpions called the eurypterids, and Pycnogonida, which includes the sea spiders.

- Order Eurypterida in Class Merostomata includes the largest known arthropods that ever lived, some as long as 6 m.



eurypterid

# Eurypterids

- *Eurypterus remipes* is the official state fossil of New York State. Examples of eurypterids include *Eurypterus remipes* and *Acutiramus macrophthalmus*.

*Eurypterus*

*Acutiramus*

*Acutiramus* was about 6 m long

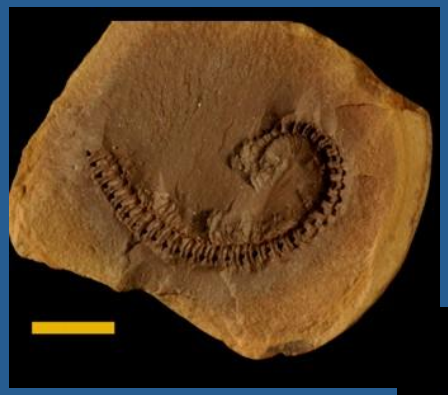
# Arachnids

- *Eoplectreurys gertschi*, a Middle Jurassic spider from China.


- *Araripescorpius laibuuei*, an Early Cretaceous scorpion from Brazil.

# Subphylum Myriapoda

- Subphylum Myriapoda includes Class Chilopoda, the centipedes, and Class Diplopoda, the millipedes. Examples include two Middle Pennsylvanian millipedes from Illinois.



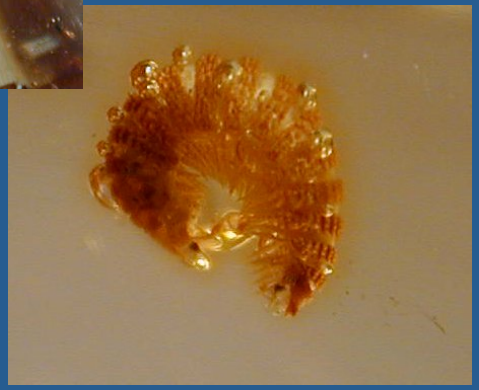
*Hexecontasoma carinatum*

*Pleurojulus* sp.

# Subphylum Myriapoda

- Subphylum Myriapoda includes Class Chilopoda, the centipedes, and Class Diplopoda, the millipedes. Examples include centipedes and millipedes from Pliocene to Pleistocene amber from Colombia.

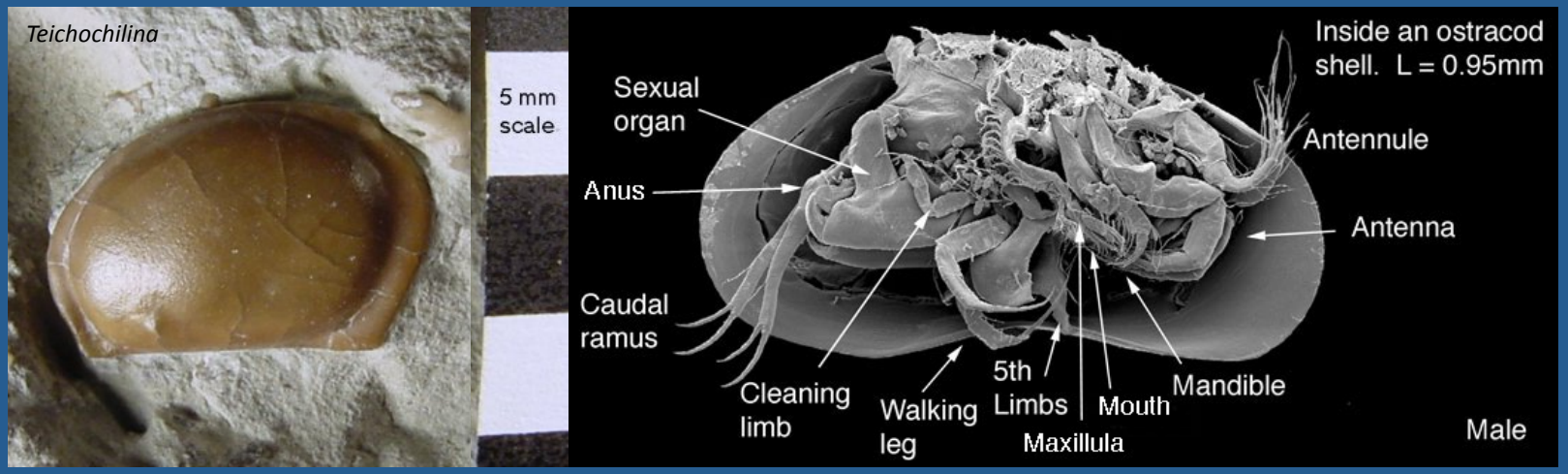
centipede



millipede

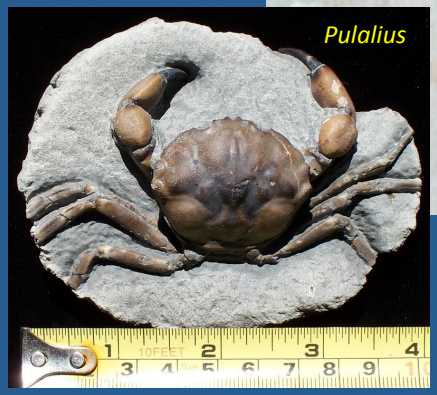
# Subphylum Crustacea

- Subphylum Crustacea includes Class Ostracoda, the ostracods or "seed shrimp," and Class Malacostraca, the crabs, lobsters, and shrimp. Here, the ostracod *Teichochilina jonesi* (M. Ord.) is shown with the internal anatomy of a modern male ostracod.



# Subphylum Crustacea

- Subphylum Crustacea includes Class Ostracoda, the ostracods or "seed shrimp," and Class Malacostraca, the crabs, lobsters, and shrimp. Examples include the crab *Pulalius* (Eoc.), the lobster *Palinurus* (M. Cret.), and the shrimp *Carpopenaeus* (L. Cret.).


# Subphylum Hexapoda

- Subphylum Hexapoda includes Class Insecta, the insects. Examples include a cockroach (L. Cret.), the dragonfly *Cordulagomphus* (L. Cret.), the cricket *Pronemobius* and the cranefly *Pronophlebia* (M. Eoc.), a weevil (M. Eoc.), and a fly (Eoc.).