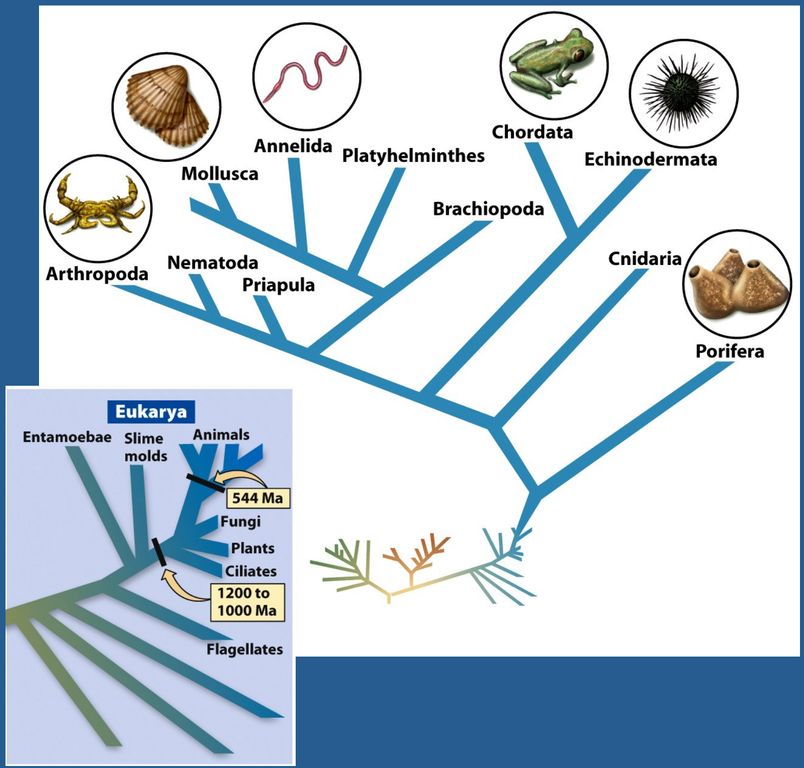
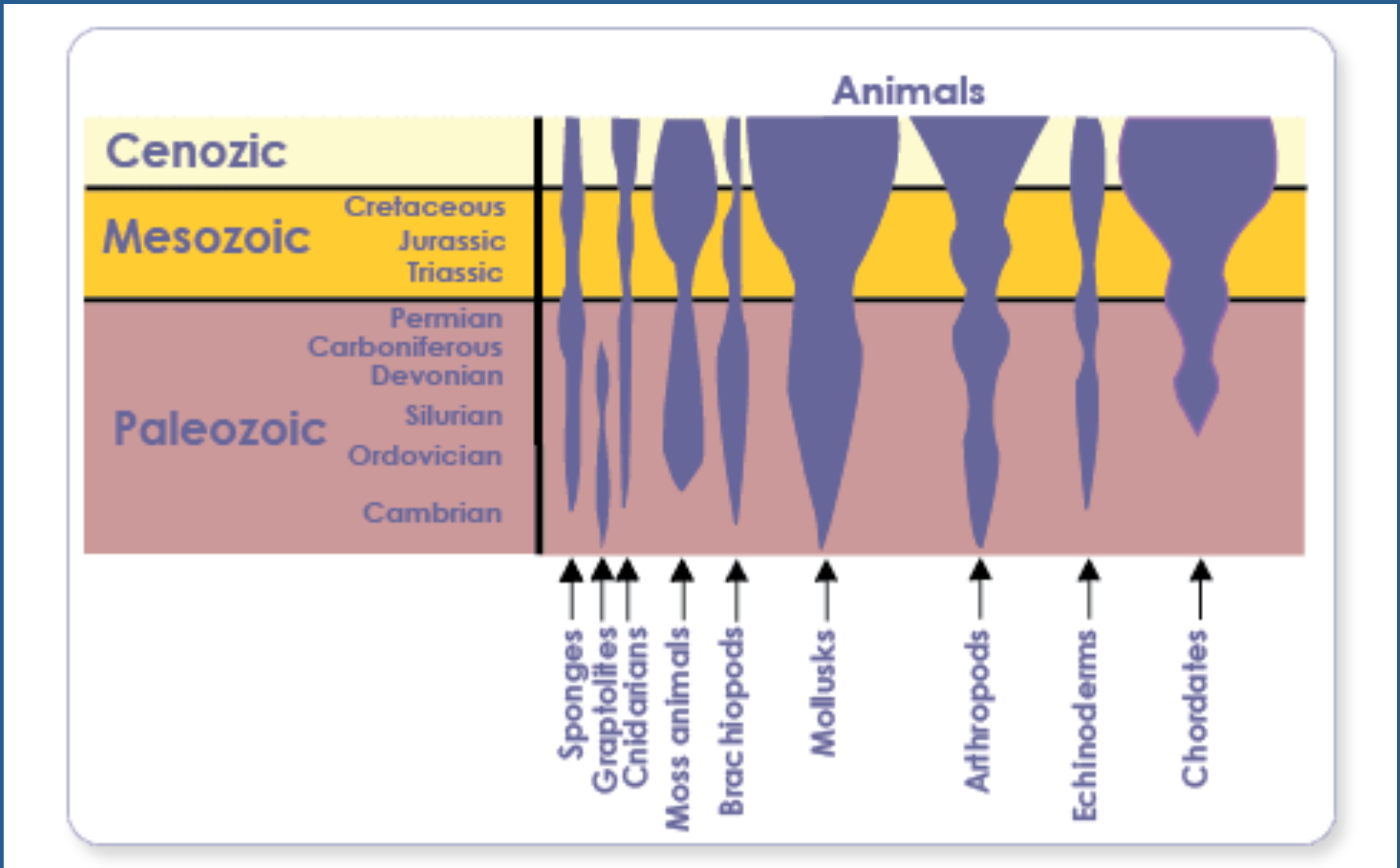
Cambrian Evolutionary Radiation

- 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 Echinodermata

- Phylum Echinodermata is represented by about 7,000 living species of entirely marine, spiny-skinned animals distinguished by their pentaradial symmetry, including sea lilies, sea stars (starfish), sea urchins, sand dollars, and sea cucumbers.

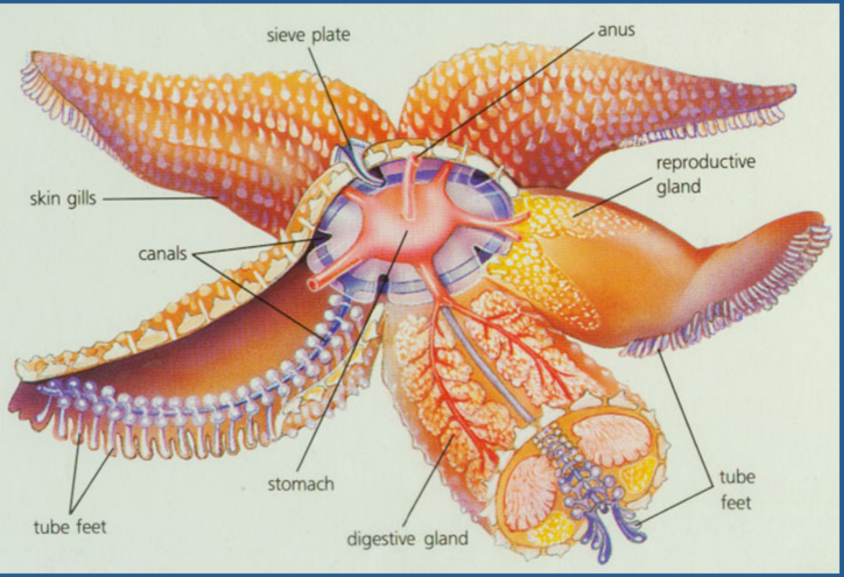
- Echinodermata is the largest phylum that has no freshwater or terrestrial representatives. Echinoderms are found at every depth in the ocean, from the intertidal zone to the abyssal zone.

Echinoderms

- The echinoderms may be divided into two subphyla, the sessile Pelmatozoa and the mobile Eleutherozoa. The two subphyla may be subdivided into several classes:
  - Pelmatozoa
    - Cystoidea (cystoids; extinct)
    - Blastoidea (blastoids; extinct)
    - Crinoidea (sea lilies)
  - Eleutherozoa
    - Asteroidea (sea stars)
    - Ophiuroidea (brittle stars)
    - Echinoidea (sea urchins and sand dollars)
    - Holothuroidea (sea cucumbers)

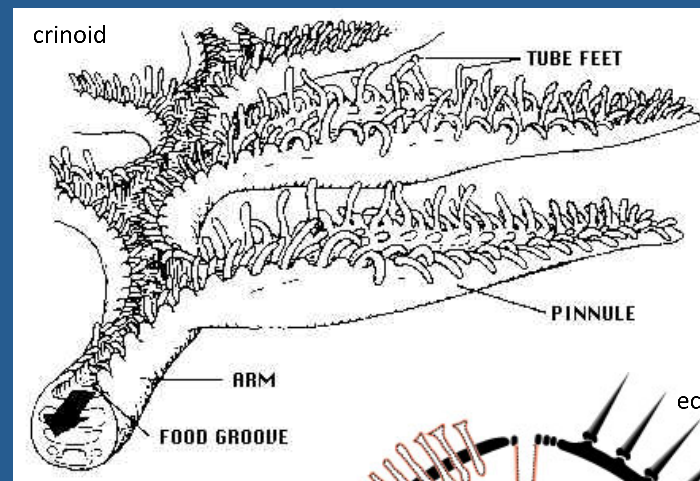
Echinoderms

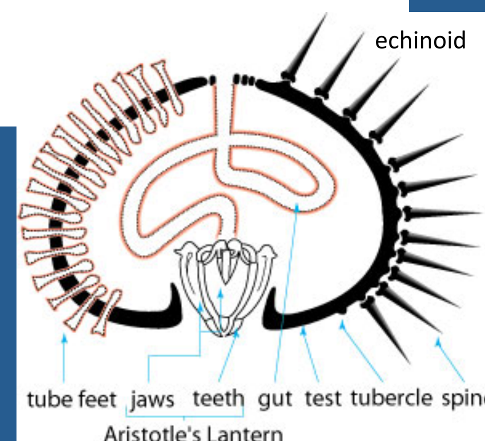
- Echinoderms possess a unique water vascular system for locomotion, food and waste transportation, and respiration. The system is composed of canals, or ambulacral grooves, connecting numerous tube feet which extend through holes in the skeleton. Echinoderms move by alternately contracting muscles that force water into the tube feet, causing them to extend and push against the ground, then relaxing to allow the feet to retract.



Echinoderms

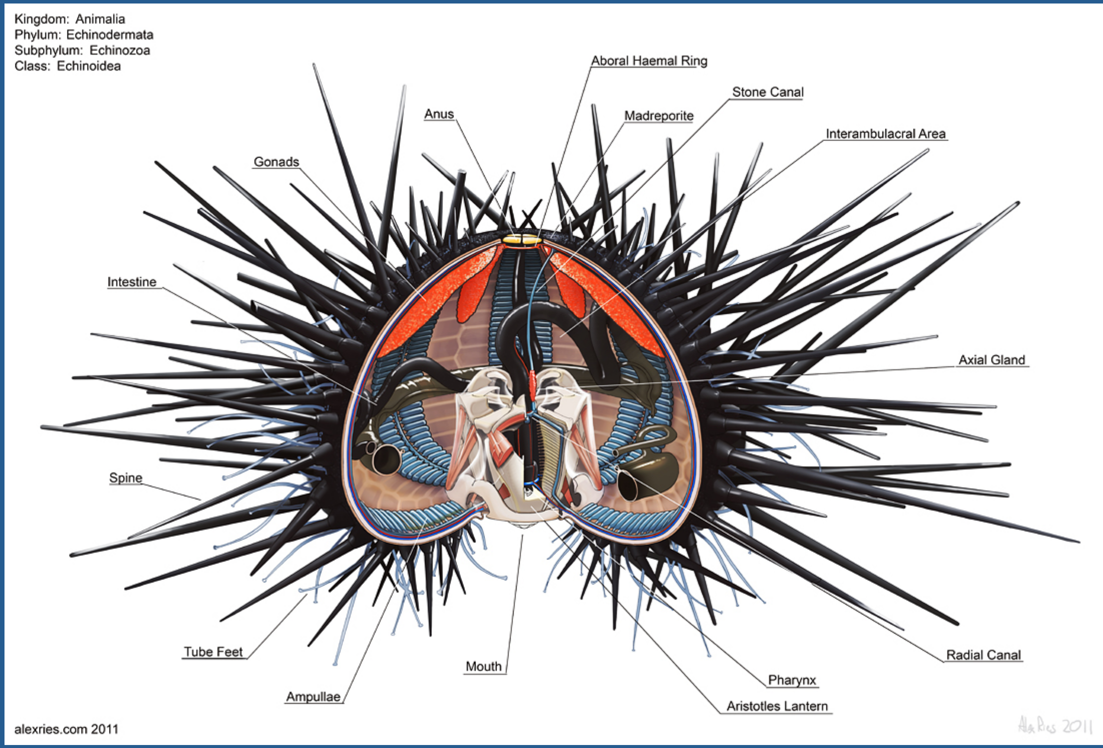
- In the crinoids, the tube feet waft food particles captured on the radial limbs towards the central mouth; in the asteroids, the same wafting motion is employed to move the animal across the ground. Echinoids use their feet to prevent the larvae of encrusting organisms from settling on their surfaces.





Echinoderms

- The circulatory, digestive, excretory, and nervous systems of echinoderms are all relatively simple, though they are more advanced than those of cnidarians.



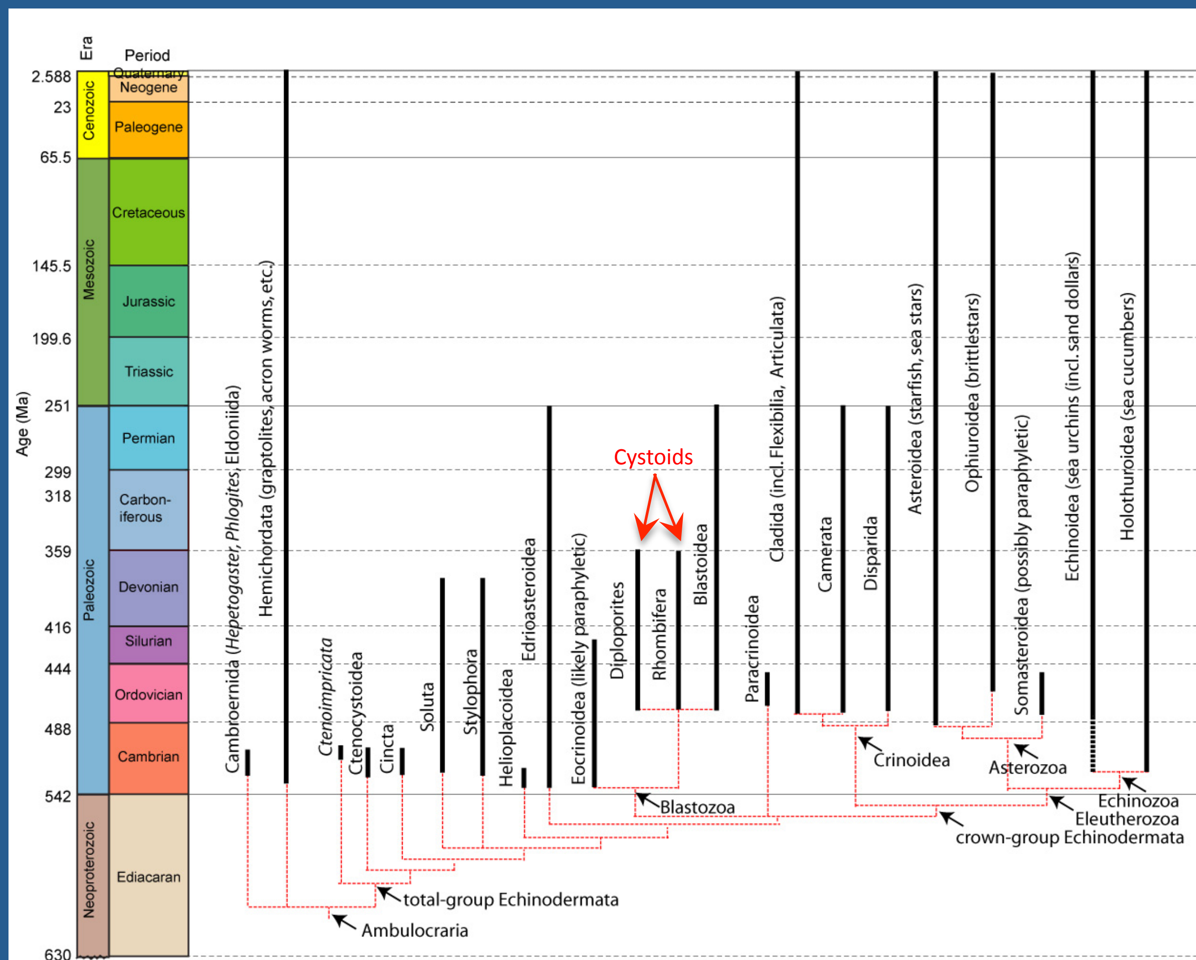
Echinoderms

- Echinoderms have an internal skeleton composed of high-Mg calcite plates, or ossicles, formed from the mesoderm. Despite the robustness of the individual skeletal elements, complete echinoderm skeletons are rare in the fossil record because they quickly disarticulate once the encompassing skin disintegrates.

- Skeletal elements are also deployed in some specialized ways, such as the "Aristotle's lantern" of sea urchins, the stalks of crinoids, and the supportive "lime ring" of sea cucumbers.

- Only the cystoids, blastoids, crinoids, and echinoids have an extensive fossil record. Most of these animals made their first appearance in the Early Ordovician, although some sources have the cystoids evolving in the latest Cambrian.

Echinoderms



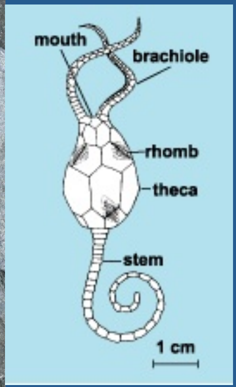
Cystoids

- The cystoids are the least specialized of the sessile filter-feeding echinoderms. They appeared in the Early Ordovician, may have given rise to the blastoids, and went extinct in the Late Devonian. They have a somewhat flattened ovoid body, or theca, covered with many plates that have distinctive pores that likely served in respiration. A variable number of food-gathering arms, or brachioles, extend from the body. The body is usually attached to a stalk which anchored the body to the sea floor by a holdfast at the base of the stem.

- The pattern of distribution of the pores over the plates of the theca distinguish the two major orders of cystoids: the rhombiferans, in which thecal pores are shared between adjacent plates, and the diploporitids, in which the pores are confined to each plate.

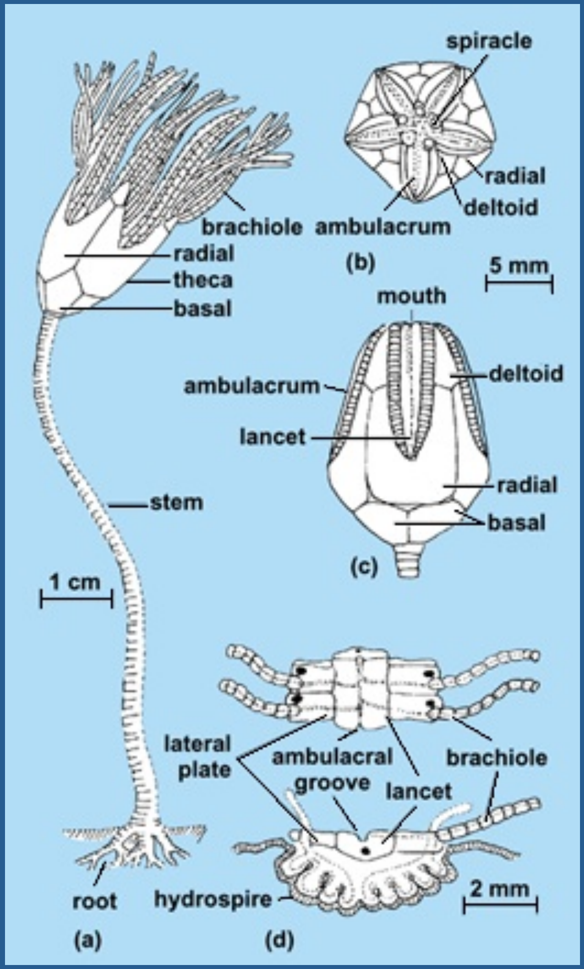
Cystoids

- Examples of cystoids include *Pleurocystites* (M. Ord.) and *Caryocrinites* (M. Sil.).



Blastoids

- The blastoids are more advanced than the cystoids. They appeared in the Early Ordovician, reached their maximum diversity in the Mississippian, and went extinct at the end of the Permian. Their theca is more bud- or cup-like than that of cystoids and is called a calyx. Numerous delicate pinnules extend from the calyx in the place of thicker arms. The stem is made up of thin disk-shaped columnals with a central hole, or axial canal, for the passage of nerves and muscles.

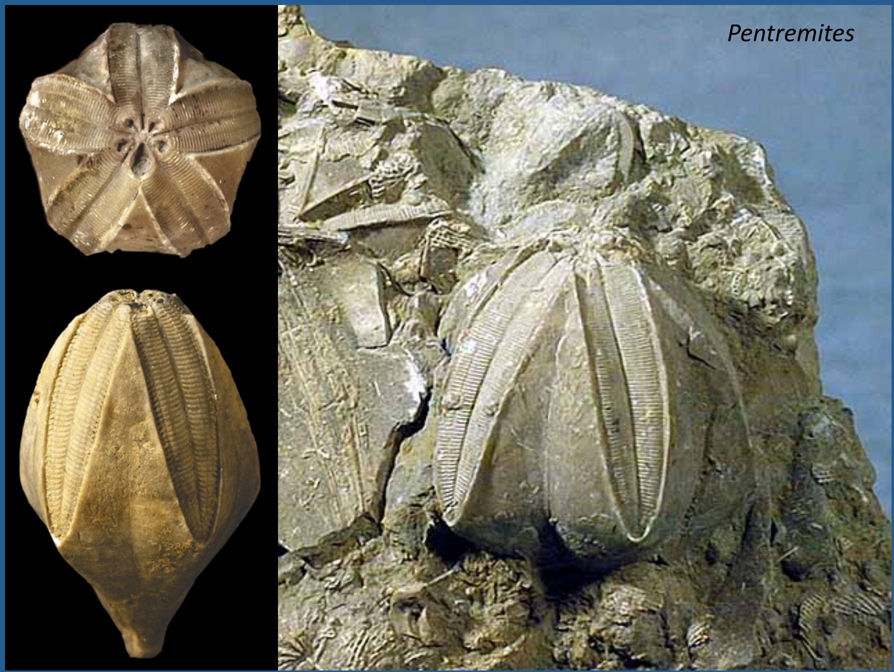


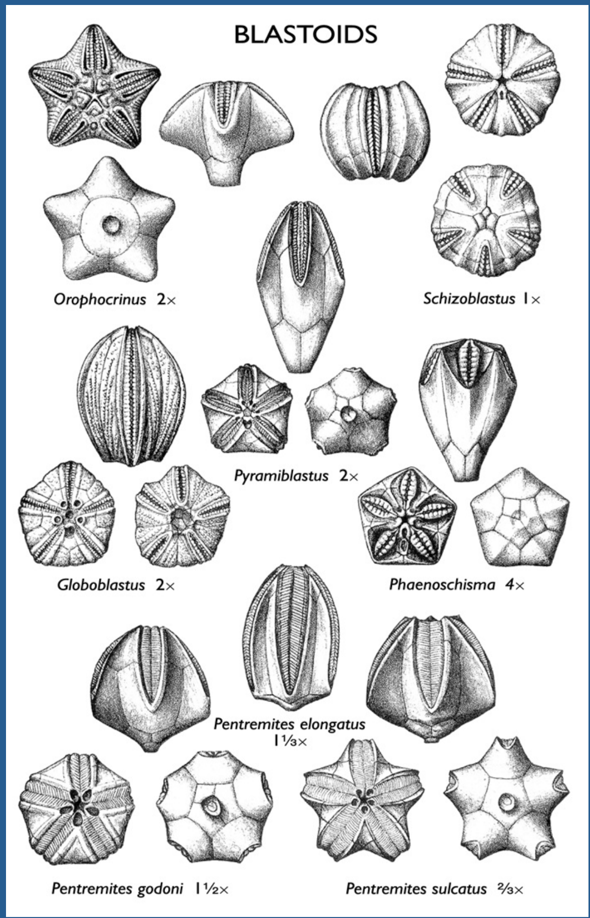
Blastoids

- Examples of blastoids include *Nucleocrinus* (M. Dev.) and *Pentremitidea* (M. Dev.).

Blastoids

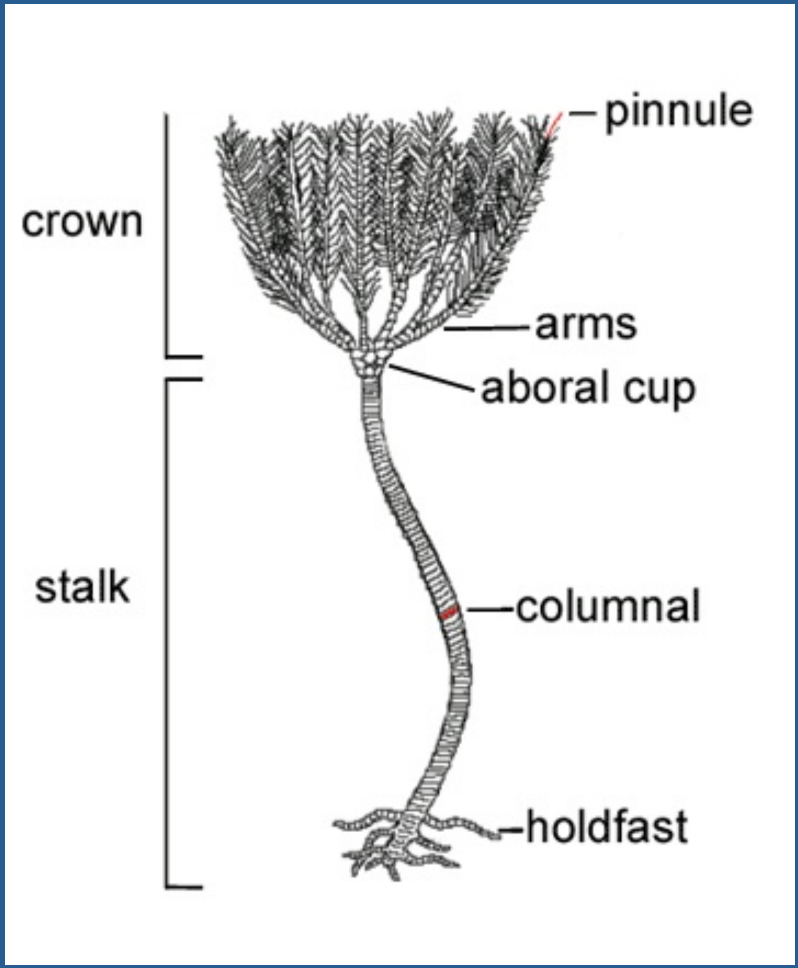
- *Pentremites* and other Mississippian blastoids from Illinois.





Crinoids

- The crinoids are more advanced than the blastoids. They appeared in the Early Ordovician, suffered a significant reduction in diversity at the end of the Permian, and had a second radiation in the Triassic. Only about 600 species remain today, many living at considerable depths in the ocean. Their morphology is very similar to that of the blastoids, although they possess both arms and pinnules. Many of the crinoids that evolved after the Permian extinction did not have a stem and were free-swimming.



Crinoids

- Examples of crinoids include *Glyptocrinus* (Ord.), *Pycnocrinus* (Ord.)., and *Ctenocrinus* (Dev.).

Crinoids

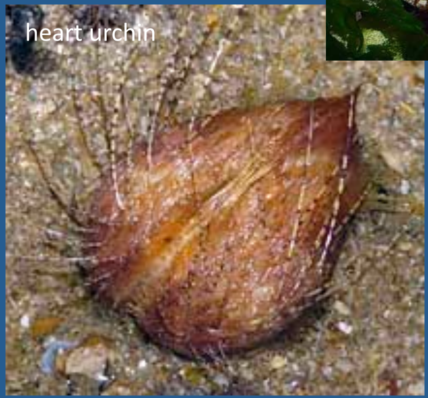
- Examples of crinoids include *Platycrinites* (Miss.) and *Uintacrinus* (Cret.).

Platycrinites

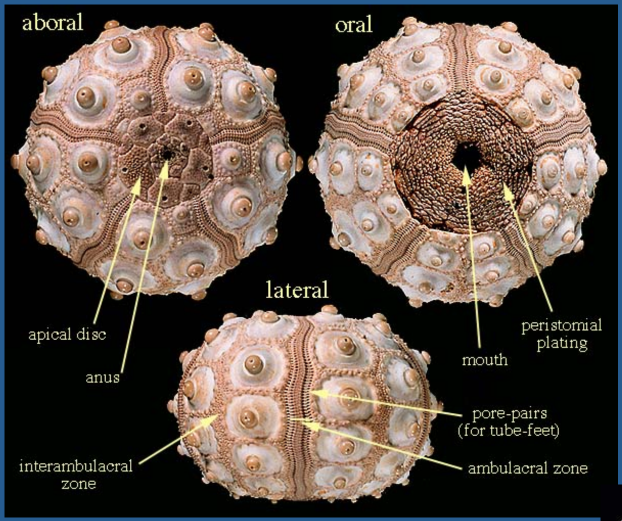

Uintacrinus

Echinoids

- The echinoids are free-moving echinoderms with globular or disk-like skeletons. They are represented by the sea urchins, sand dollars, and heart urchins. Nearly 1,000 species remain today, living in shallow to abyssal marine environments.

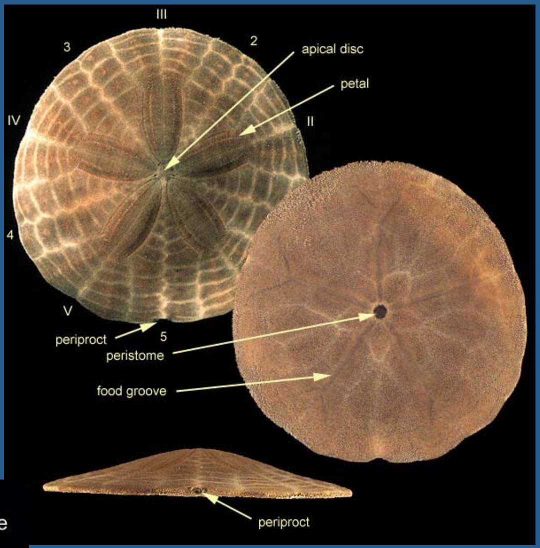


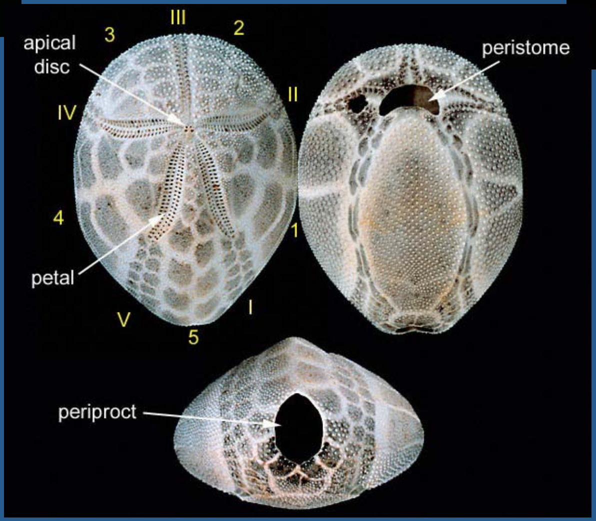
Echinoid Skeletal Morphology



sea urchin

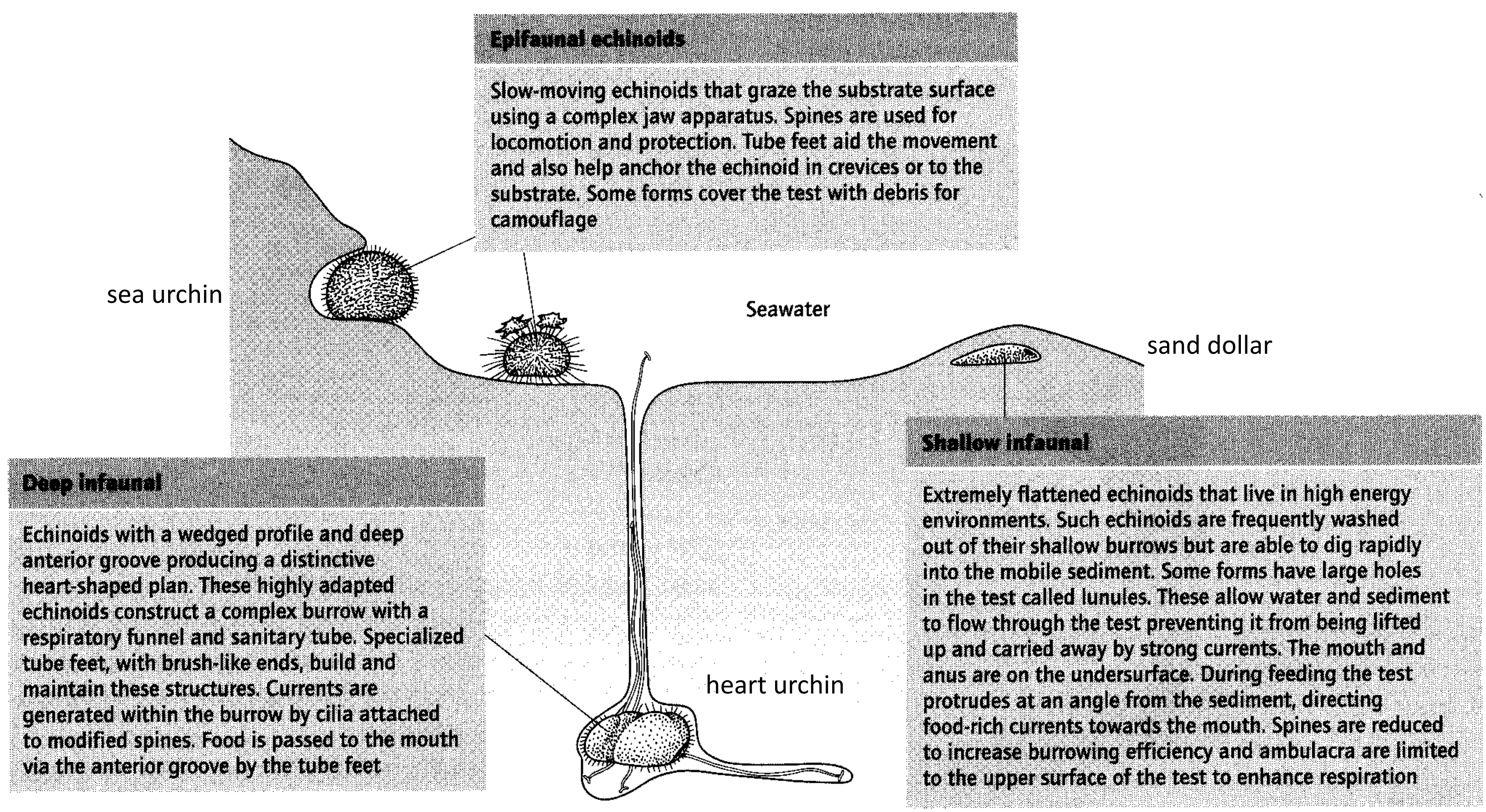
sand dollar





heart urchin

Echinoid Habitats



Fossil Echinoids

- Of the echinoids, the sea urchins first appeared in the fossil record in the Early Ordovician, suffered a significant reduction in diversity at the end of the Permian, and had a second radiation in the Triassic and became much more abundant by the Early Jurassic. Sand dollars first appeared in the fossil record during the Middle Eocene, but they rapidly dispersed globally by the end of the Eocene. Examples include *Psephechinus* (Cret.), *Micraster* (Cret.), and sand dollars from the Oligocene.

Phylum Hemichordata

- Within the Phylum Hemichordata, the Class Graptolithina includes the graptolites, colonial marine animals thought to be closely related to modern pterobranchs, worm-shaped animals that live on the ocean floor in tubes they secrete, that are also in the Phylum Hemichordata.

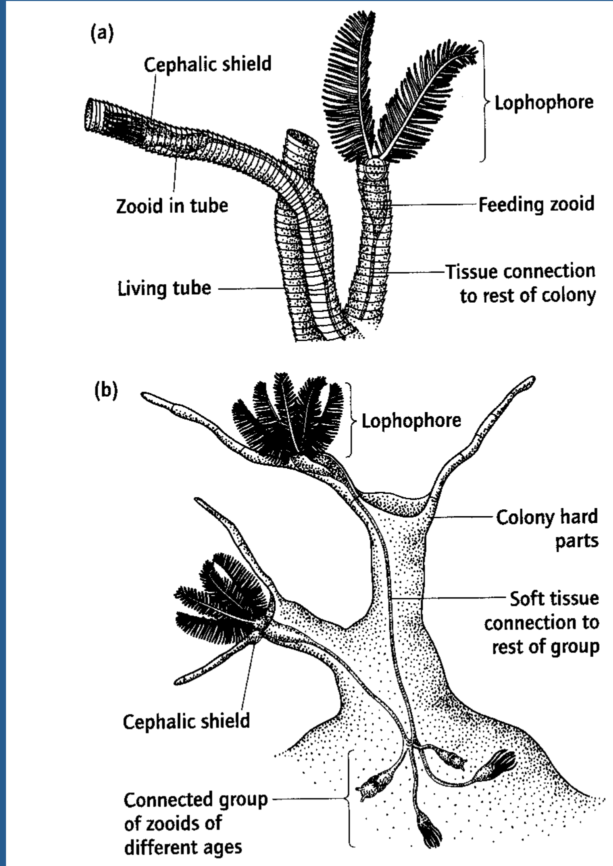
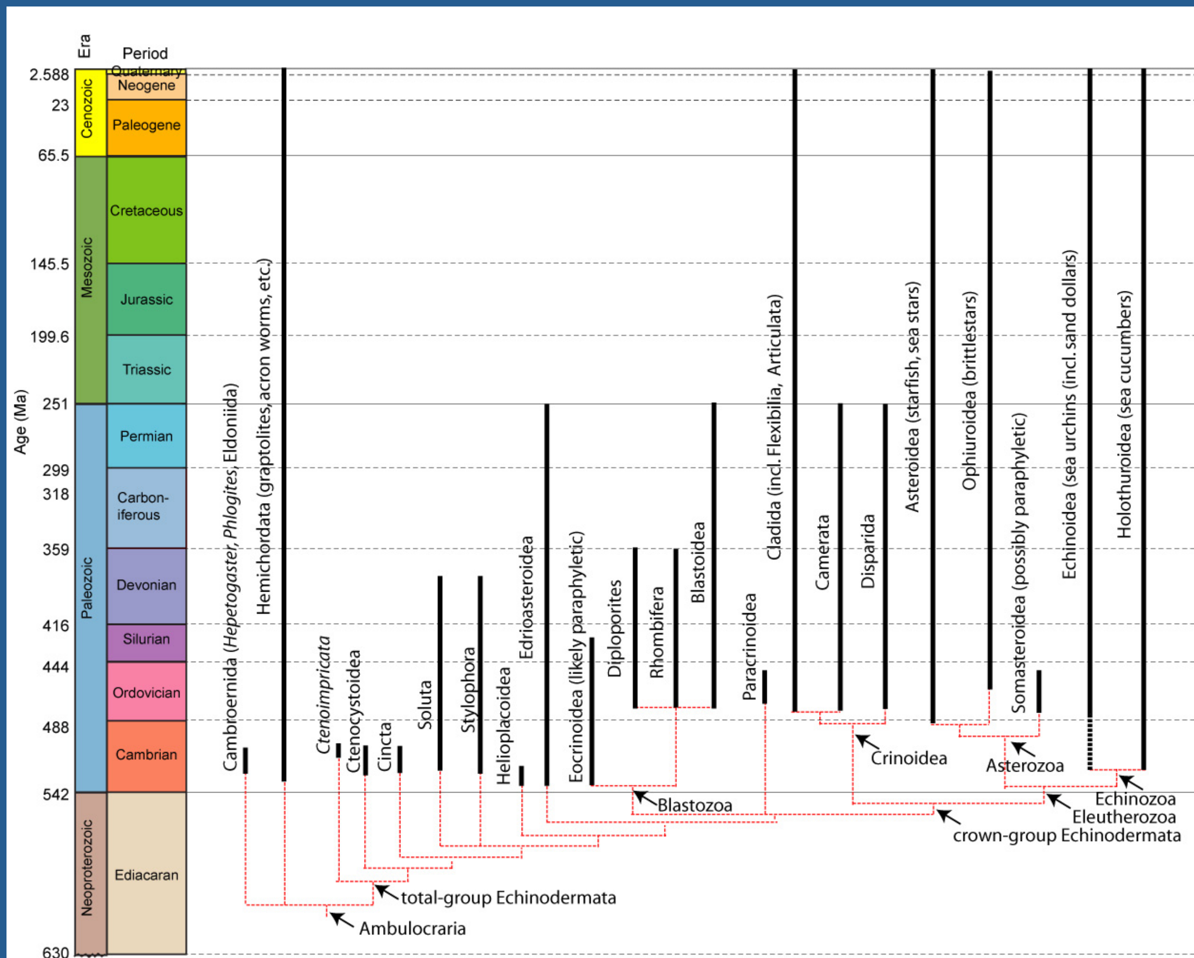


Fig. 10.2 Drawings of living pterobranchs: (a) *Rhabdopleura*, and (b) *Cephalodiscus*. The zooids are approximately 1 mm long.

Graptolites



Graptolites

- Graptolites are preserved as carbonized films in rocks beginning in the Middle to Late Cambrian. Previously they were thought to have become extinct at the end of the Mississippian, but one very recent phylogenetic analysis (Mitchell et al., 2012 suggests that the pterobranch *Rhabdopleura* is a living graptolite.

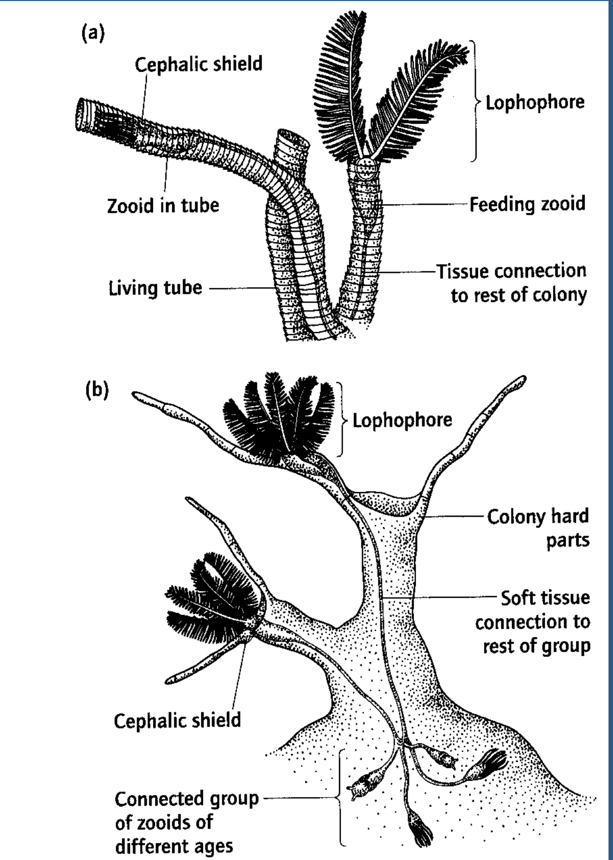
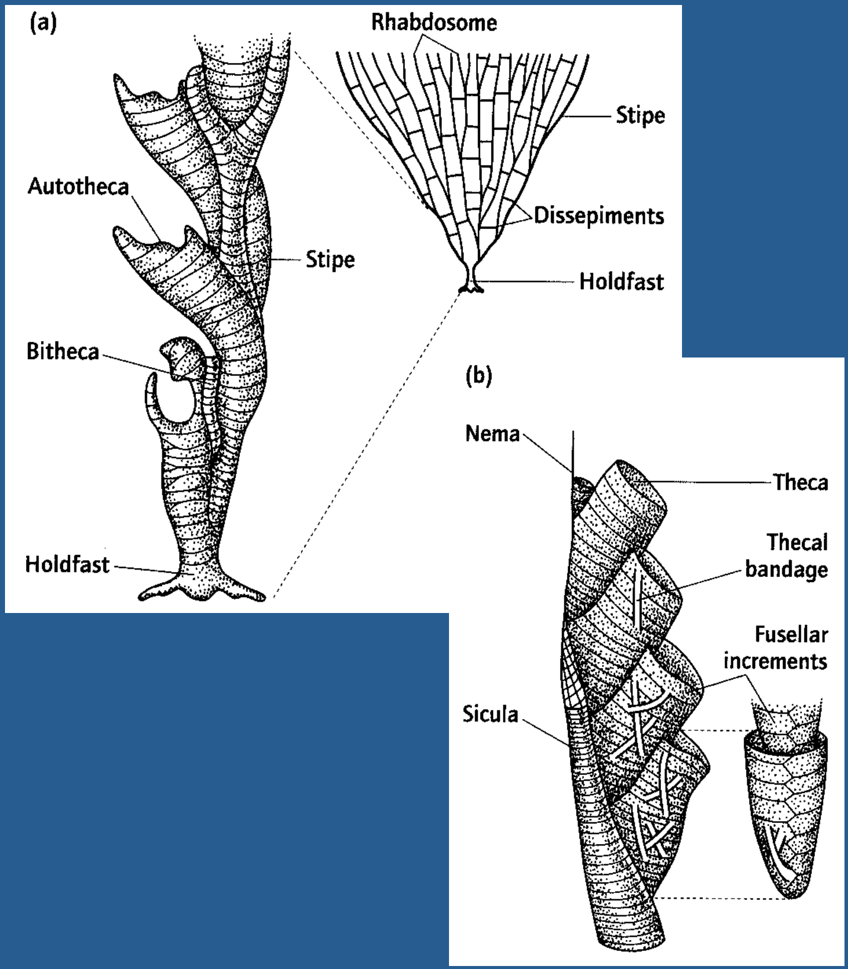


Fig. 10.2 Drawings of living pterobranchs: (a) *Rhabdopleura*, and (b) *Cephalodiscus*. The zooids are approximately 1 mm long.

Graptolites

- Each graptolite colony is known as a rhabdosome and has a variable number of branches, called stipes, originating from an initial individual, called a sicula. Each subsequent individual, or zooid, is housed within a tubular or cup-like structure called a theca. The number of branches and the arrangement of the thecae are used to identify graptolites.



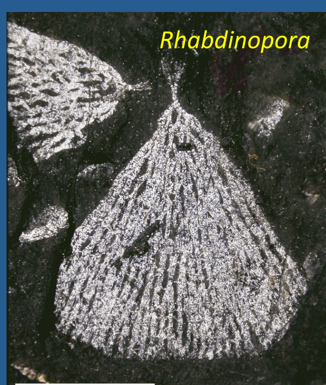
Graptolites

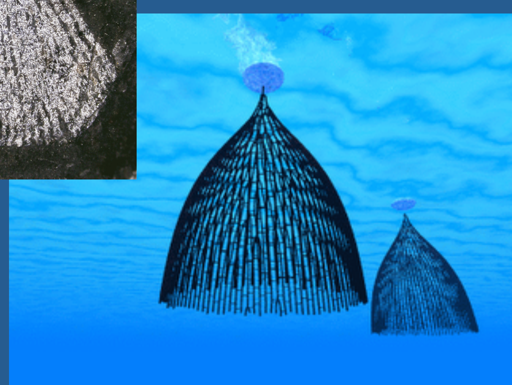
- Most of the dendritic or many-branched types are classified as dendroid graptolites in the Order Dendroidea. They appear earlier in the fossil record and were generally benthic animals, although the first planktonic graptolites were dendroids.

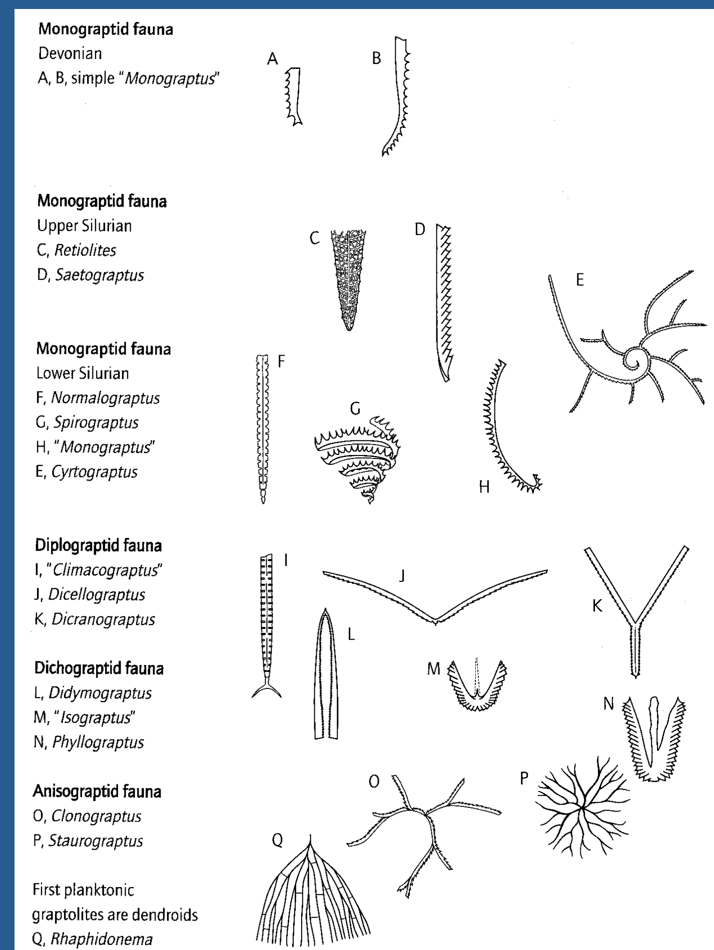
- Graptolites with relatively few branches are classified as graptoloid graptolites in the Order Graptoloidea. They were derived from the dendroid graptolites at the beginning of the Ordovician and were pelagic animals, drifting freely or attached to floating seaweed, making them useful for biostratigraphic correlation. They were prolific during the Ordovician and Silurian but went extinct in the Early Devonian.

Graptolites

- Examples of graptolites include the planktonic graptoloid *Rhabdinopora* (Ord.), with reconstruction.

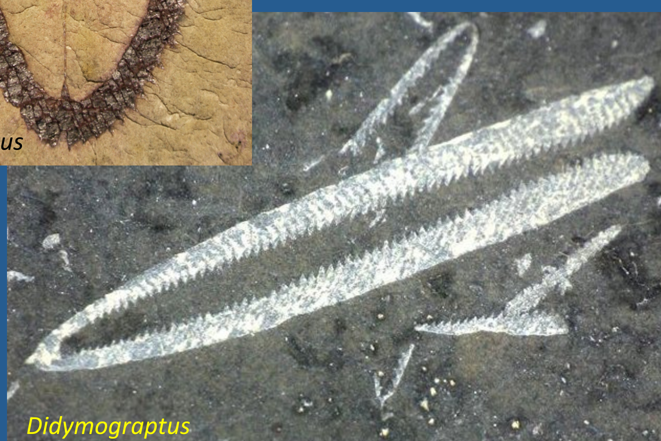


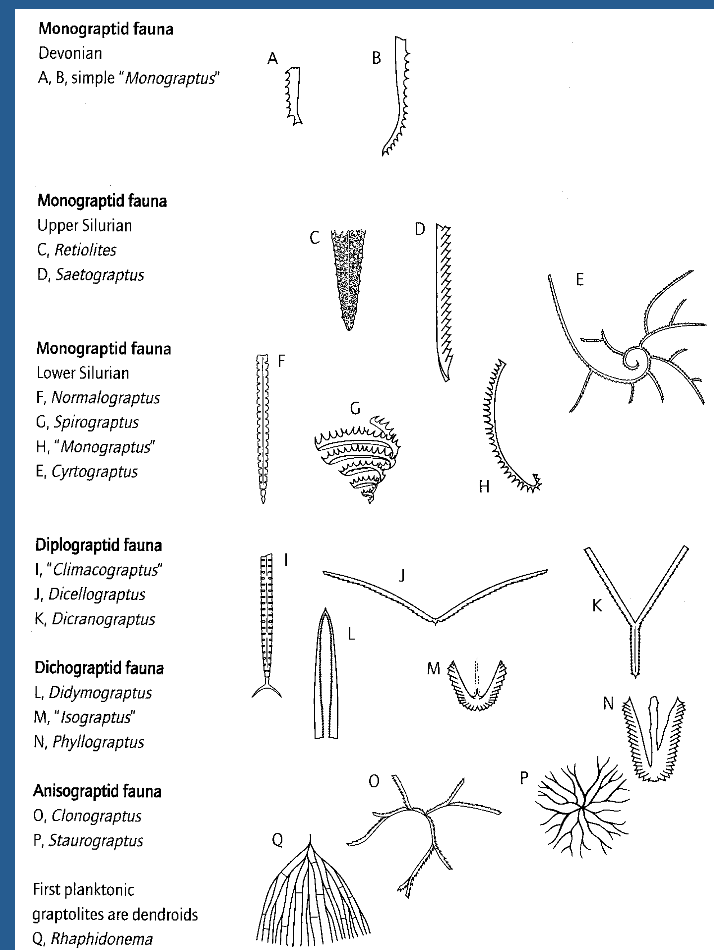




Graptolites

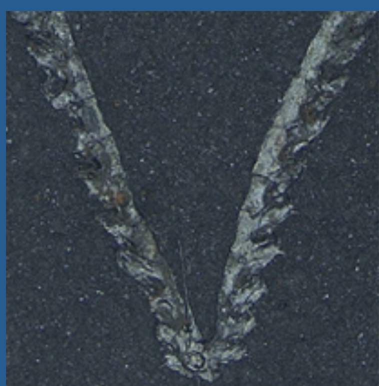
- Examples of graptolites include *Isograptus* (E. Ord.) and *Didymograptus* (Ord.).





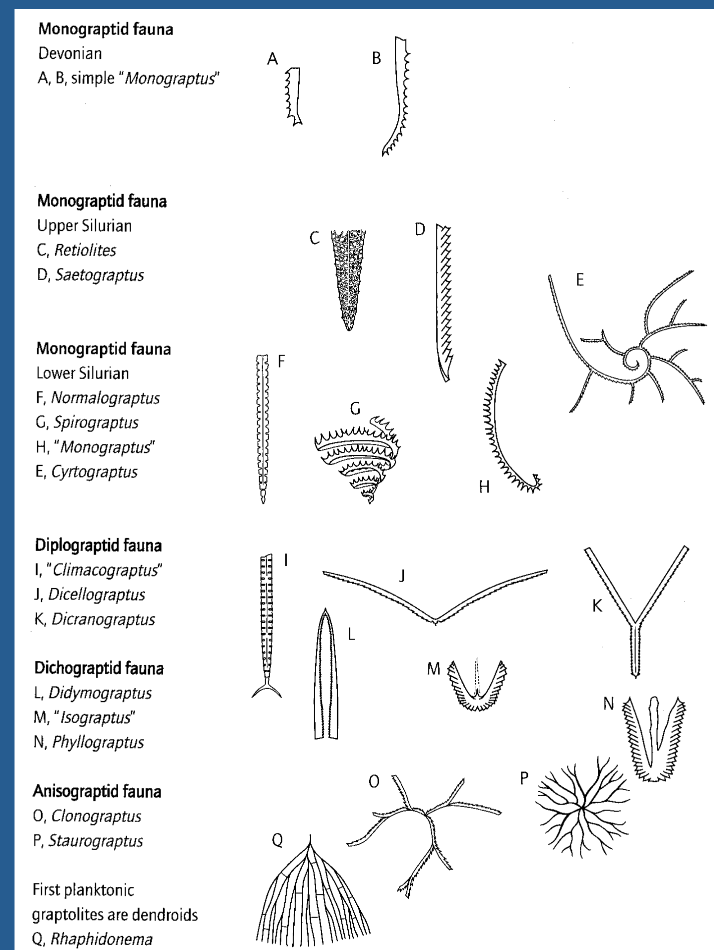
Graptolites

- Examples of graptolites include *Dicellograptus* (Ord.) and *Dichranograptus* (L. Ord.).



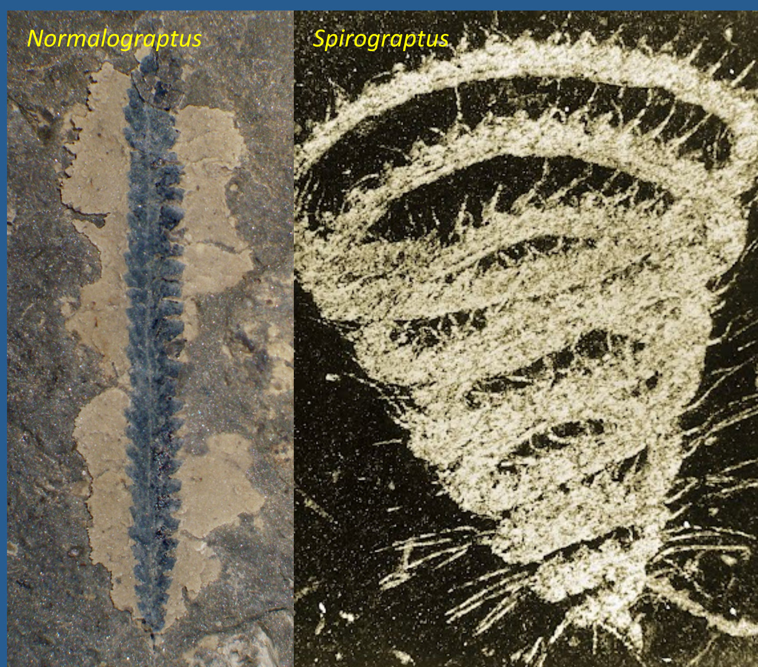
Dicellograptus

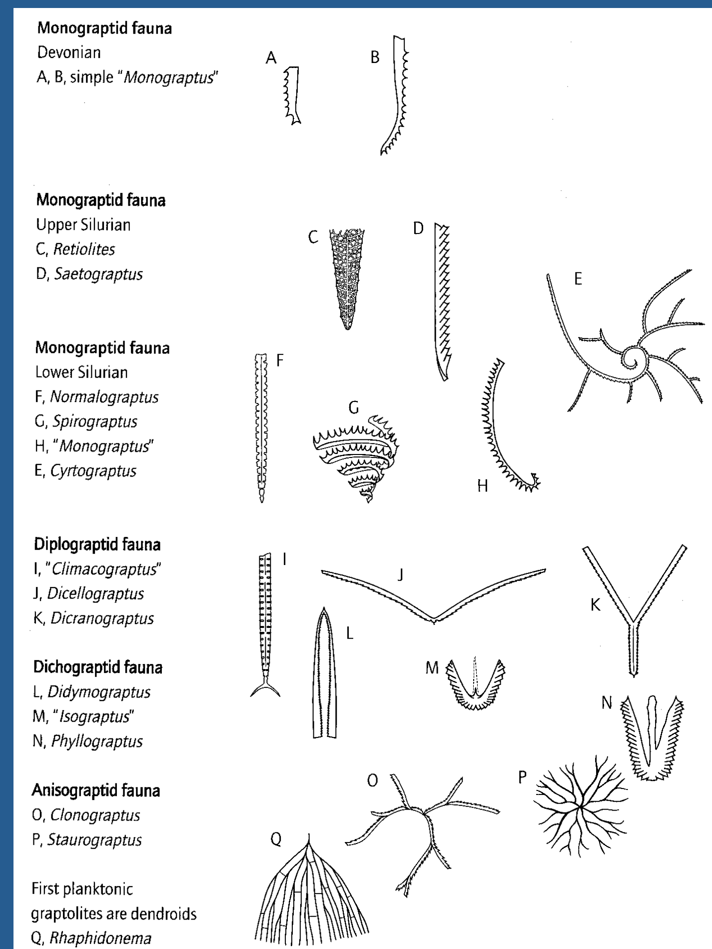
Dichranograptus



Graptolites

- Examples of graptolites include *Normalograptus* (L. Ord.) and *Spirograptus* (Sil.).





Graptolites

- Examples of graptolites include *Cyrtograptus* (Sil.) and *Retiolites* (Sil.).