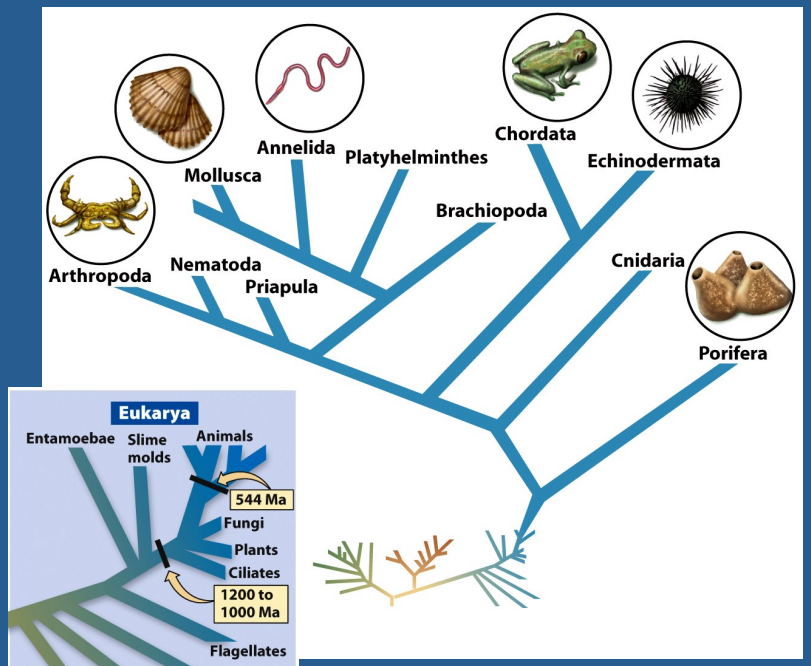
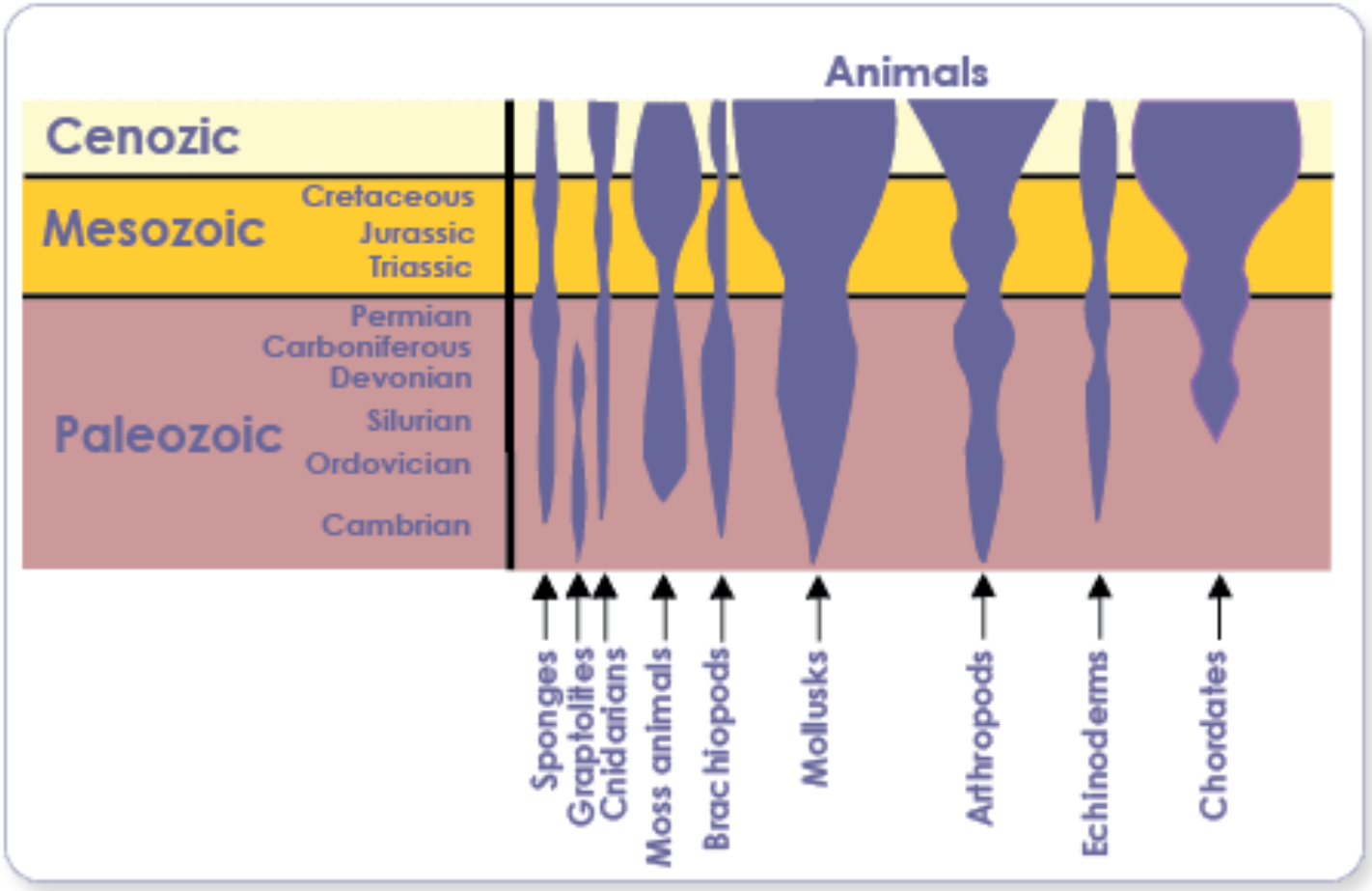
Cambrian Evolutionary Radiation

- 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.

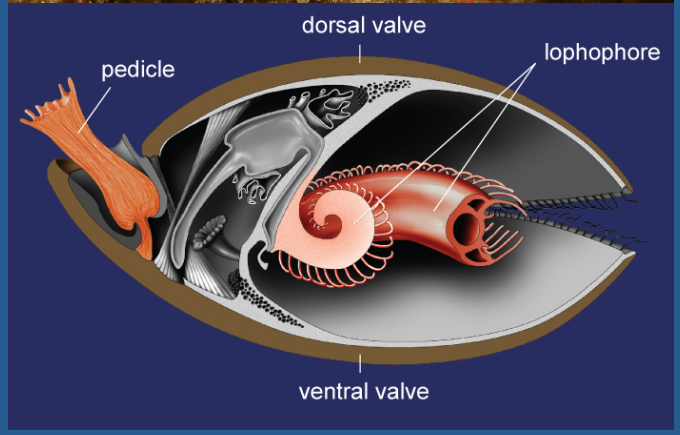


Cambrian Evolutionary Radiation



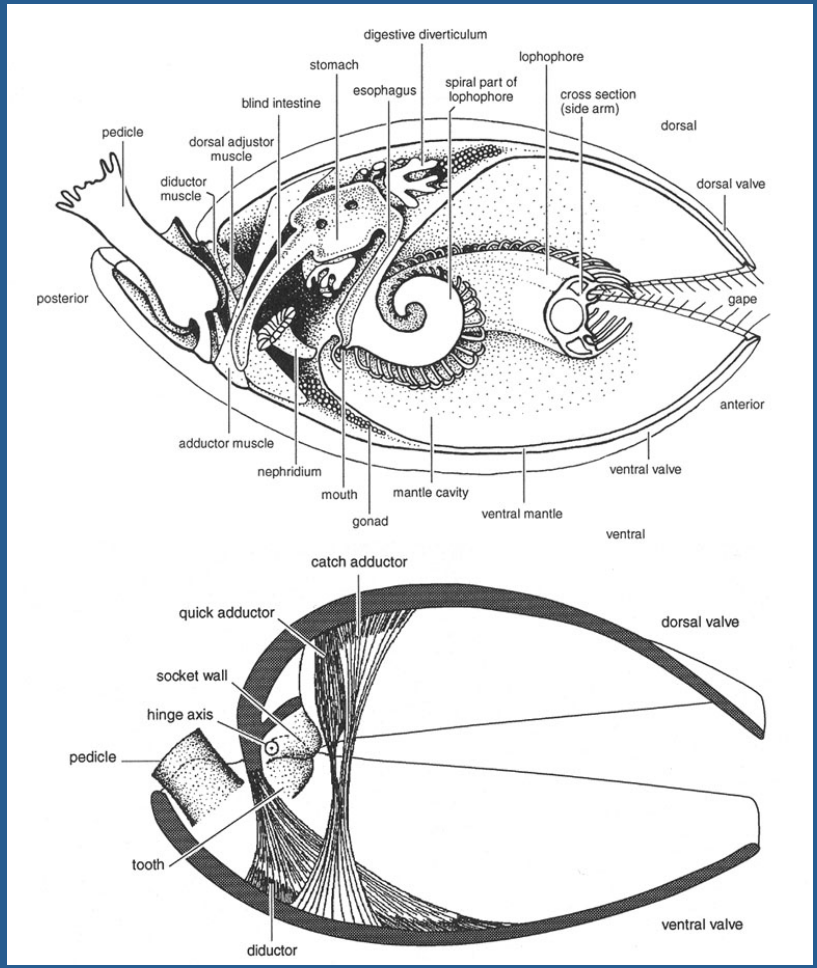
Phylum Brachiopoda

- Phylum Brachiopoda is represented by the brachiopods, marine animals that have calcareous or chitino-phosphatic shells, or valves, that surround a variety of internal organs and muscles. Brachiopod valves are hinged at the rear, while the front can be opened for feeding or closed for protection. In a typical brachiopod a stalk-like pedicle projects from an opening called a foramen in the larger ventral valve, attaching the animal to the seabed but clear of silt that would obstruct the opening.



Brachiopods

- Brachiopods have an epithelial mantle that secretes and lines the shell, and encloses the internal organs. The brachiopod body occupies only about one-third of the internal space inside the shell, nearest the hinge. Like bryozoans, brachiopods have a lophophore, a coil of tentacles whose cilia create currents that enables them to filter food particles out of the water. Unlike bryozoans, brachiopod lophophores are non-retractable and occupy up to two-thirds of the internal space, near the front where the valves gape when opened.

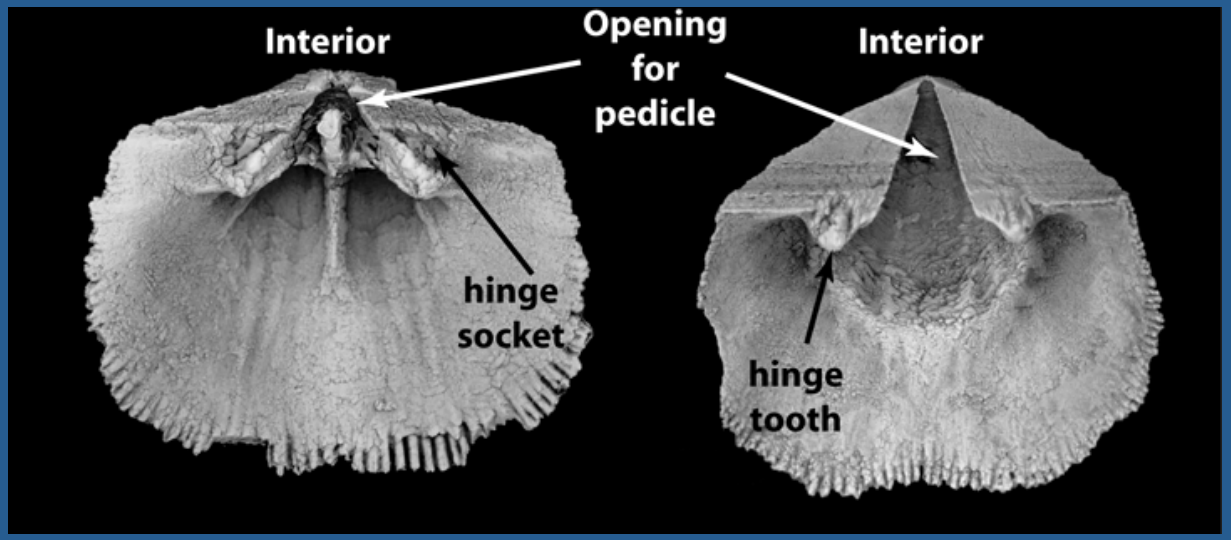


Brachiopods

- Some brachiopods have a calcareous brachidium that supports the lophophore.

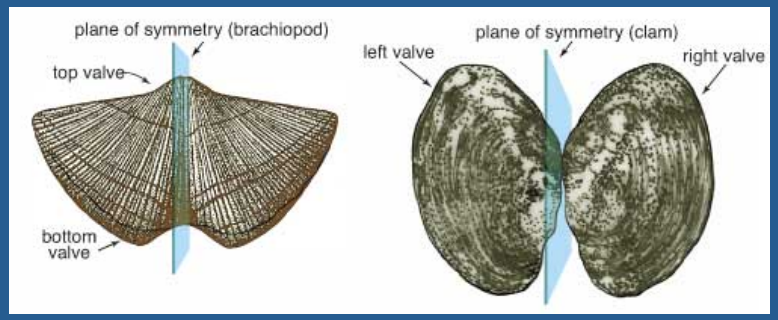
Brachiopods

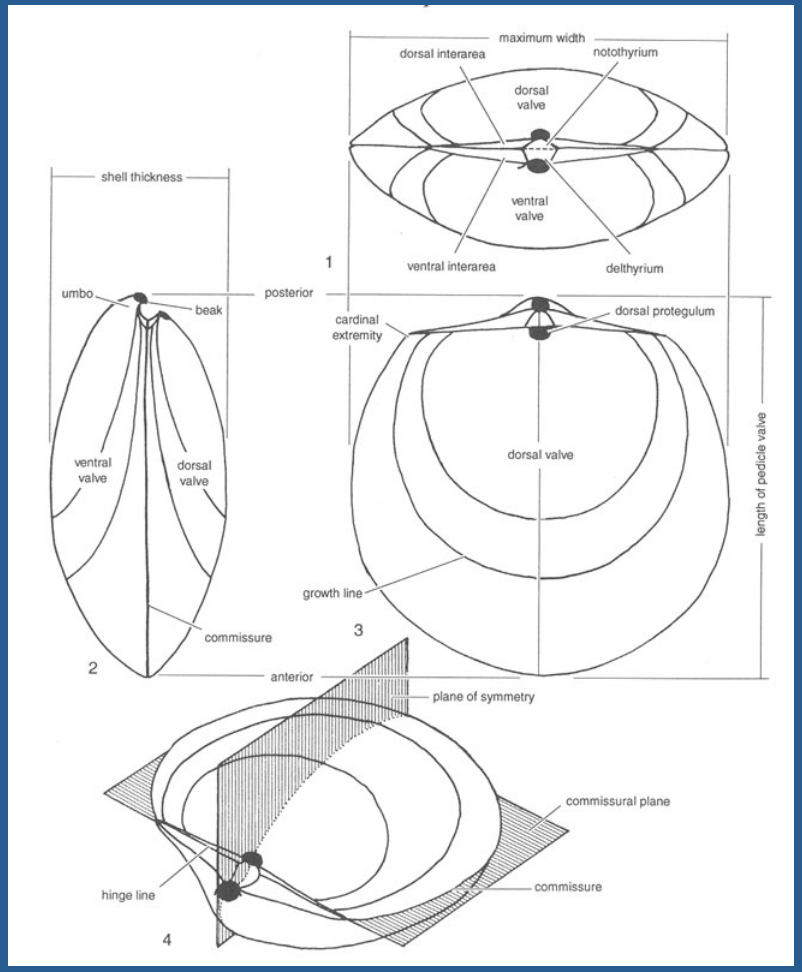
- Two major groups of brachiopods are recognized, articulate and inarticulate. Articulate brachiopods have toothed hinges and simple muscles for opening and closing the two valves, while inarticulate brachiopods have untoothed hinges and a more complex system of muscles used to keep the valves aligned.



Brachiopods

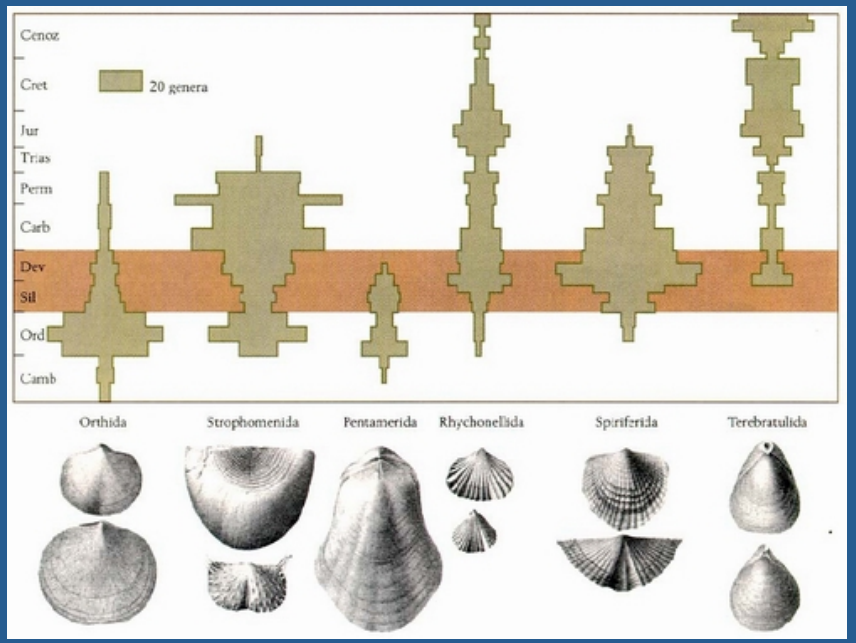
- Brachiopods possess a bilateral symmetry across their dorsal and ventral valves, unlike the pelecypods which have bilateral symmetry between their two valves.





Brachiopods

- Brachiopods are arguably the most important group of fossil animals. They arose in the Early Cambrian and flourished during the Paleozoic Era. Their diversity was remarkable — over 12,000 fossil species are known — yet there are only about 350 species alive today.



Brachiopods

- Class Inarticulata
  - Order Lingulida
  - Order Acrotretida
- Class Articulata
  - Order Orthida
  - Order Strphomenida
  - Order Pentamerida
  - Order Rhynchonellida
  - Order Spiriferida
  - Order Terebratulida

Inarticulate Brachiopods

- Order Lingulida (E. Cam.-Rec.): The lingulids have biconvex shells that are nearly all chitino-phosphatic. The pedicle emerges posteriorly between the valves without a special foramen. Example is *Lingula*.

- Order Acrotretida (E. Cam-Rec.): The acrotretids have mostly circular shells that are chitino-phosphatic or calcareous. The pedicle emerges through a foramen in the ventral valve. Example is *Orbiculoidea*.

Brachiopods

- Class Inarticulata
  - Order Lingulida
  - Order Acrotretida
- Class Articulata
  - Order Orthida
  - Order Strphomenida
  - Order Pentamerida
  - Order Rhynchonellida
  - Order Spiriferida
  - Order Terebratulida

Articulate Brachiopods

- Order Orthida (E. Cam.-L. Perm.): The orthids have subcircular to semielliptical, generally biconvex shells with straight hinge lines and radial ribs. The foramen notches the edge of both valves. Examples include *Dinorthis* (Ord.), *Rhapidomella* (Dev.), and *Tropidoleptus* (Dev.).

Dinorthis

Rhapidomella

Tropidoleptus

Articulate Brachiopods

- Order Strophomenida (E. Ord.-E. Jur.): The strophomenids have shells with one valve convex and the other flat or concave. The hinge lines are straight. Foramen are very minute or lacking. Examples include *Rafinesquina* (Ord.), *Leptaena* (Sil.), and *Chonetes* (Dev.).

Rafinesquina *Leptaena* *Chonetes*

Articulate Brachiopods

- Order Pentamerida (M. Cam.-L. Dev.): The pentamerids have heavy, generally smooth, strongly biconvex shells with short hinge lines. An internal spondylium, a spoon-shaped calcareous muscle support, is variably developed. Examples include *Kirkidium* (Sil.), *Pentamerus* (Sil.), and *Stringocephalus* (Dev.).

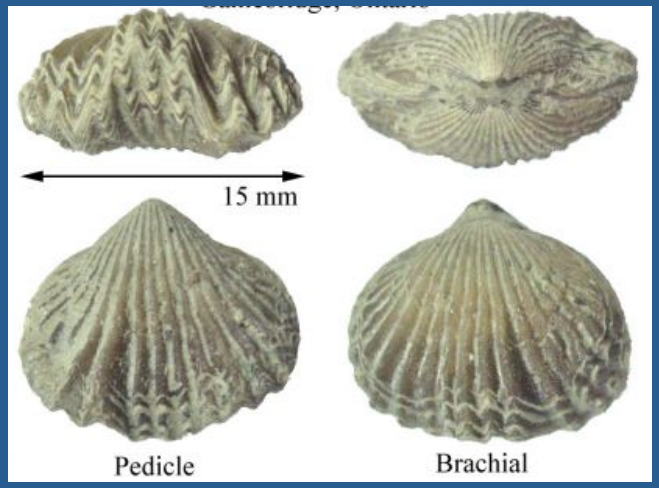
Kirkidium

Pentamerus

Stringocephalus

Articulate Brachiopods

- Order Rhynchonellida (M. Ord.-Rec.): The rhynchonellids have biconvex shells that usually have strong radial ribs and very short hinge lines. They have well-developed foramen. Examples include *Rhynchotrema* (Ord.), *Rhynchotreta* (Sil.), and *Camarotoechia* (Miss.).



Rhynchotrema

Rhynchotreta

Camarotoechia

Articulate Brachiopods

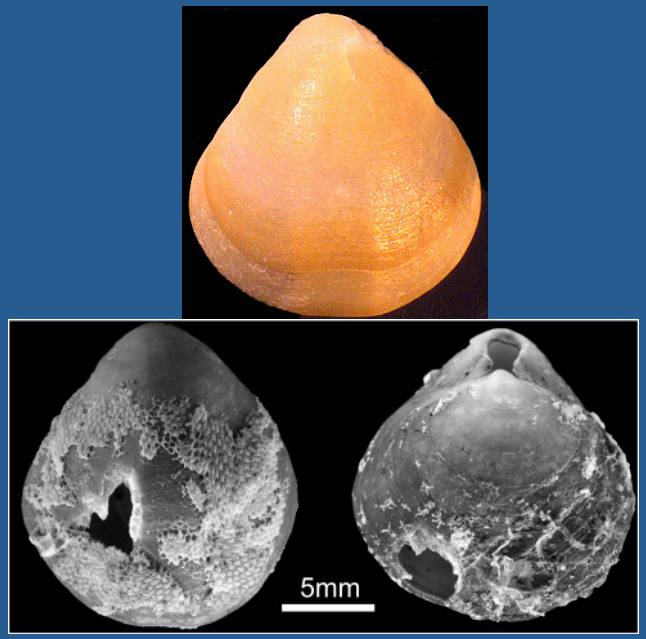
- Order Spiriferida (M. Ord.-L. Jur.): The spiriferids have shells that have either rounded, very short hinge lines or extended hinge lines. Foramen are always present and a spiral brachidium is usually well-developed. Examples include *Atrypa* (Dev.), *Athyris* (Dev.), and *Mucrospirifer* (Dev.).

Articulate Brachiopods

- Order Terebratulida (E. Dev.-Rec.): The terebratulids have shells with very short, rounded hinge lines. Foramen are present as are looped brachidia. Examples include *Terebratula* (Jur.), *Oleneothyris* (Pal.), and *Calloria* (Rec.).

Terebratula

Oleneothyris



Calloria

Phylum Mollusca

- Phylum Mollusca includes seven classes of animals:
  - Amphineura
  - Pelecypoda
  - Gastropoda
  - Conularida
  - Pteropoda
  - Scaphopoda
  - Cephalopoda

Mollusca

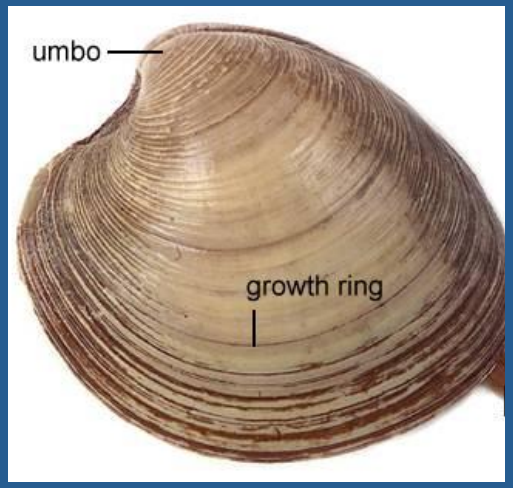
- Mollusca include marine, freshwater, and terrestrial animals. Most of them have an exoskeleton or a shell of some kind secreted by the mantle. They are all free-moving and swim, crawl, or burrow. The body consists of a head (except in the pelecypods), a foot, and a dorsal portion which includes the internal organs and is covered by the mantle. They have well-developed circulatory, digestive, excretory, and nervous systems. Respiration is carried out by gills.

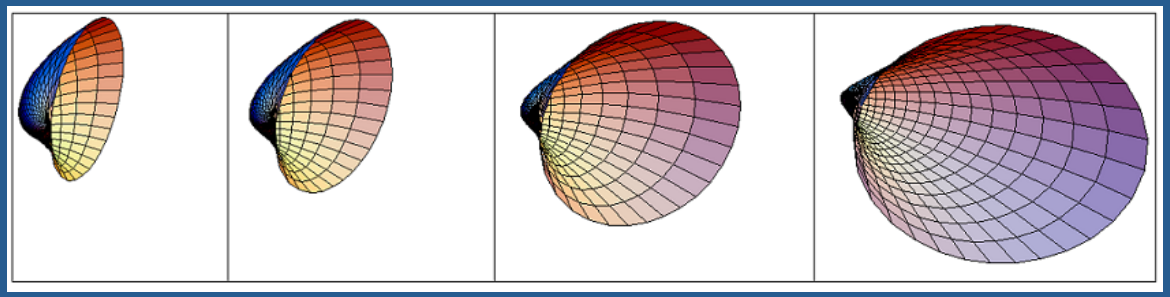
Mollusca

- The phylum is represented by over 60,000 living species and many thousands of fossil ones, but only the pelecypods (bivalves), gastropods (snails), and the cephalopods (squids, nautiloids, and ammonoids) have an abundant fossil record.

Pelecypods

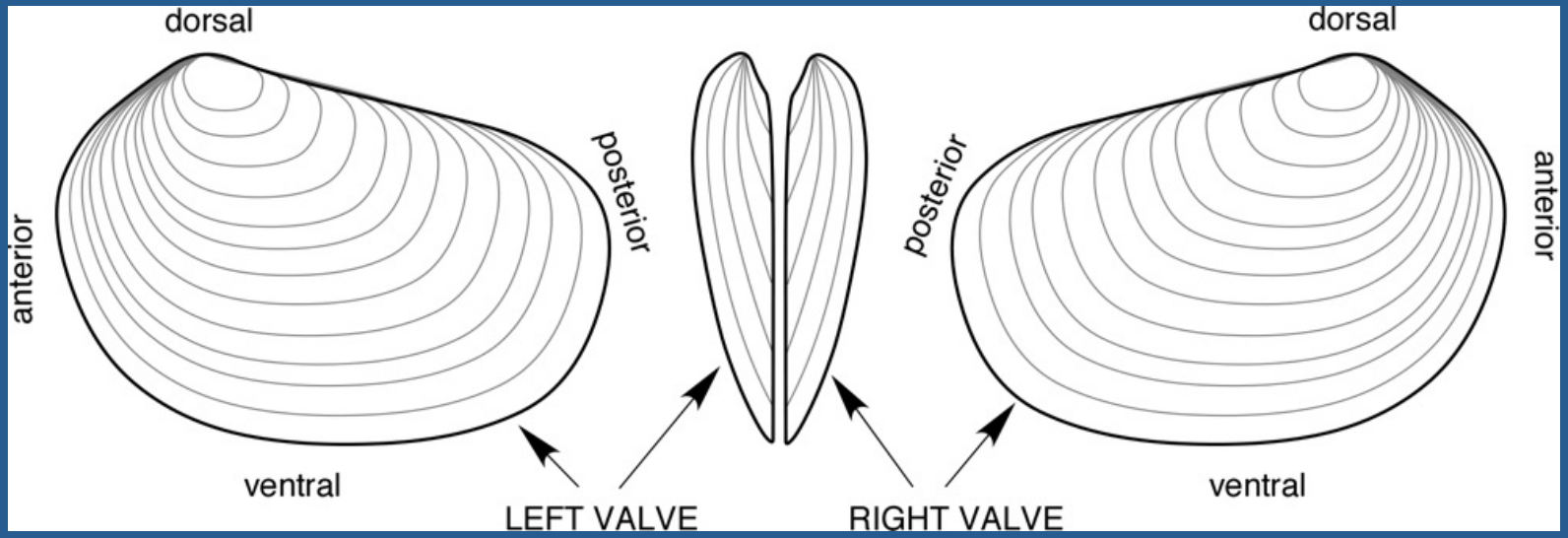
- The pelecypods, also known as bivalves, are represented by clams, muscles, and oysters, among others. They are nearly all marine. They have a calcareous shell of two valves with bilateral symmetry between the valves. Valve growth begins at an initial point, a beak or umbo, and proceeds outward concentrically.





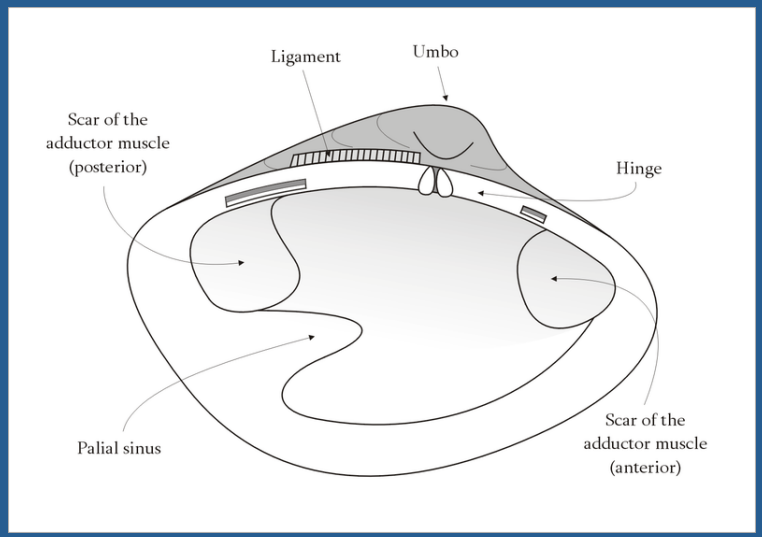
Pelecypods

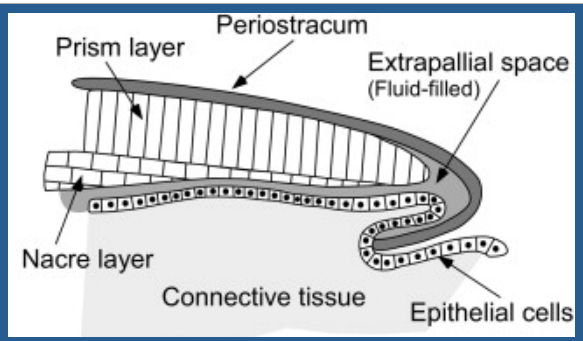
- Pelecypod valves are lateral, or left and right. They are mirror images of each other, with the plane of symmetry between the valves.



Pelecypods

- Pelecypod valves are closed by muscles and opened by hinge ligaments when the muscles relax. Teeth along the hinge aid in articulation. The shell is made up of several layers. The external layer is the periostracum, a thin, flexible, dark-colored layer composed of a protein called concholin. The periostracum protects an underlying calcareous layer which is composed of an outer prismatic calcitic layer and an inner porcellaneous or pearly aragonitic layer made up of thin subparallel lamellae.

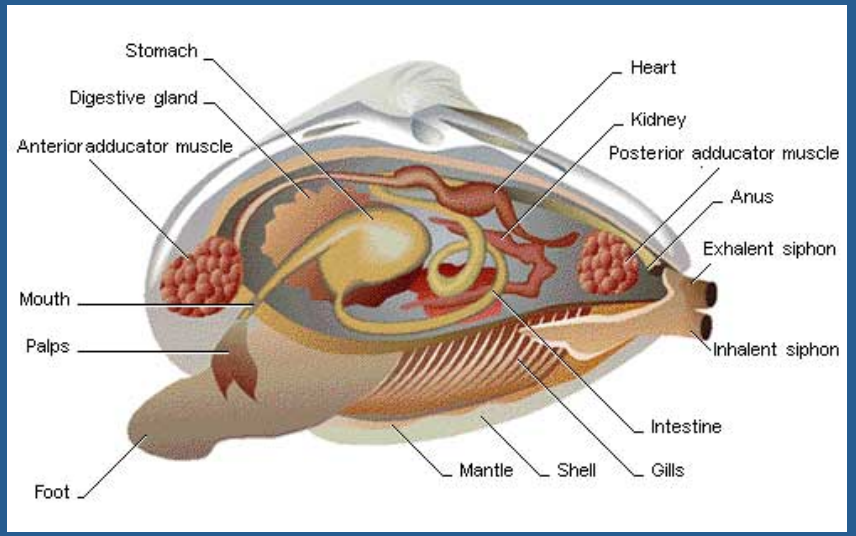




Jacobs et al. (2008)

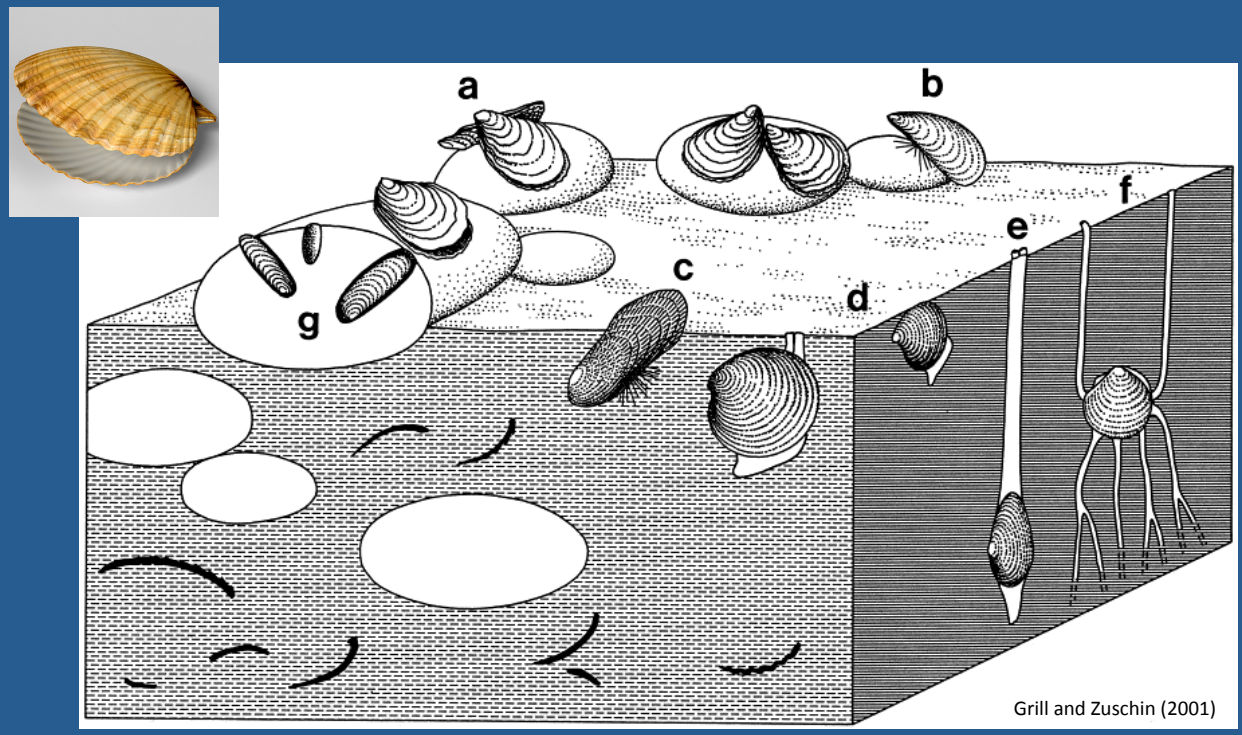
Pelecypods

- Locomotion in pelecypods is accomplished by a hatchet-shaped foot capable of burrowing. An incurrent or branchial siphon draws in water bringing food to the mouth and oxygen to the gills; an excurrent or anal siphon carries off the waste products and water that has passed over the gills. Eyes are present in some pelecypods such as the scallop *Pecten*.



Pelecypods

- Pelecypods occupy a wide range of habitats and are found in tidal zones to water as deep as 17,000 feet. Some are free-swimming, like the scallop *Pecten*.



Grill and Zuschin (2001)

Pelecypods

- Pelecypods are found in the fossil record in the Cambrian, but they are quite rare until the Late Cambrian. They rapidly diversified during the Ordovician and Silurian. Examples include *Orthonota* (Dev.), *Pecten* (Carb.), *Ostrea* (Tri.), and *Mercenaria* (Jur.), among many others. Representatives of many of these genera are alive today.

Orthonota

Pecten

Ostrea

Mercenaria

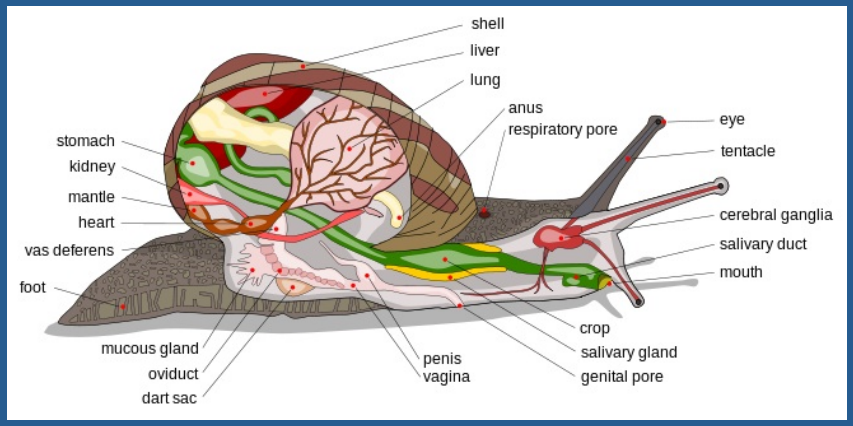
Pelecypods

- The rudists were among many bizarre pelecypods that evolved during the Mesozoic Era. They arose during the Jurassic and became so diverse during the Cretaceous that they were major reef-building organisms. The rudists went extinct at the end of the Cretaceous.

Figure 5.23
Understanding Earth, Sixth Edition

Gastropods

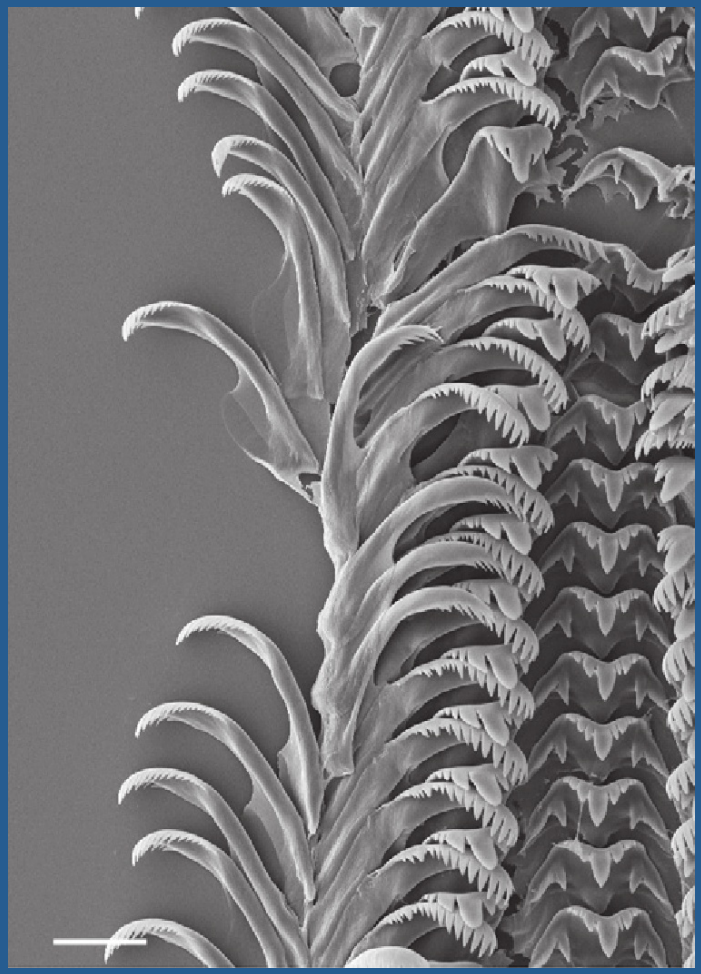
- The gastropods are represented by the snails, single-valved mollusks, and include marine, freshwater, and terrestrial forms.
- The general anatomy of gastropods is similar to that of pelecypods, but they differ from pelecypods in having a more or less distinctly marked head which usually bears tentacles, eyes, and ears and usually contains a large cerebral ganglion. Marine gastropods would have a gill in place of a lung.



Terrestrial gastropod

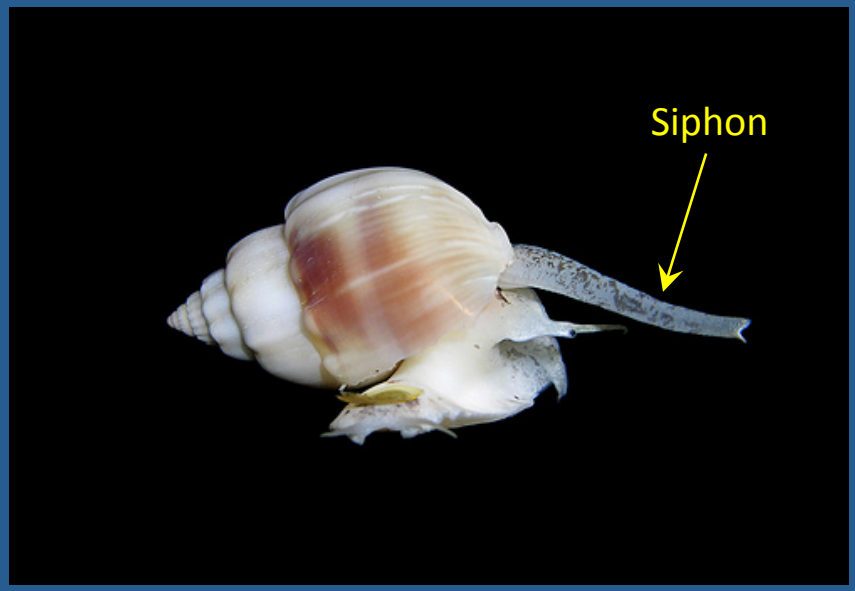
Gastropods

- Gastropods are both herbivorous and carnivorous. Their mouth contains a radula, a minutely toothed, filelike, chitinous ribbon, which is typically used for scraping or cutting food before the food enters the esophagus. Some gastropods use their radula to bore into other shelled animals, while others, such as cone snails, secrete toxins and use them as poisoned harpoons.



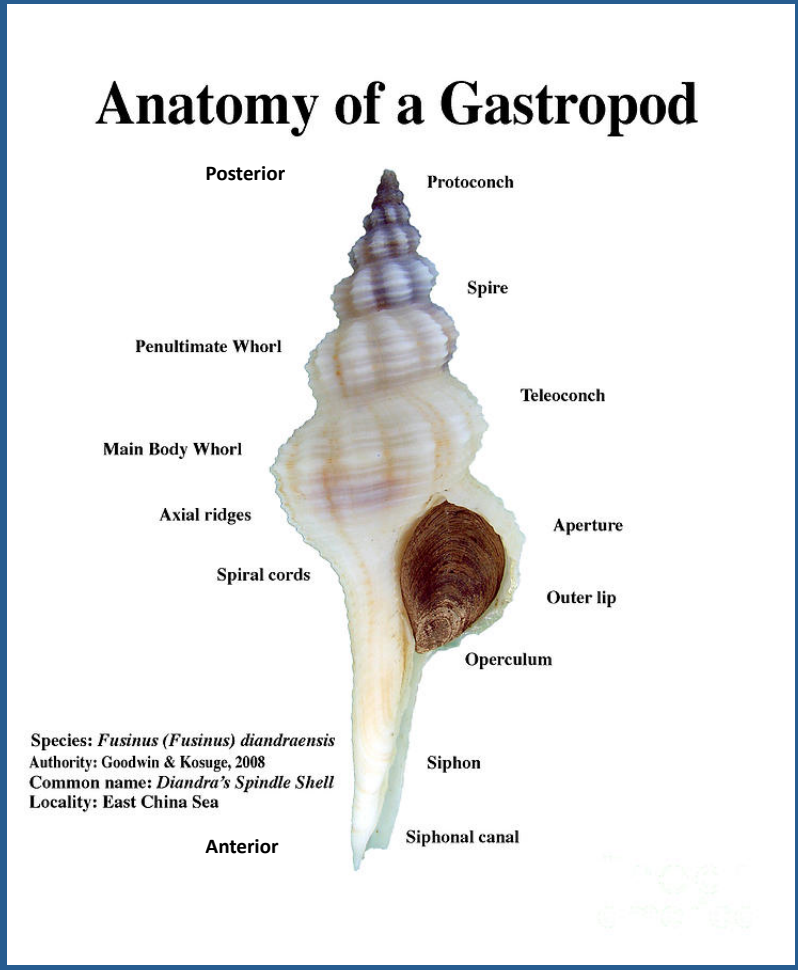
Gastropods

- Many marine gastropods are burrowers and have a siphon that extends out from the mantle edge through a siphonal canal. A siphon enables the animal to draw water into their mantle cavity and over the gill. They use the siphon primarily to "taste" the water to detect prey from a distance. Gastropods with siphons tend to be either predators or scavengers.



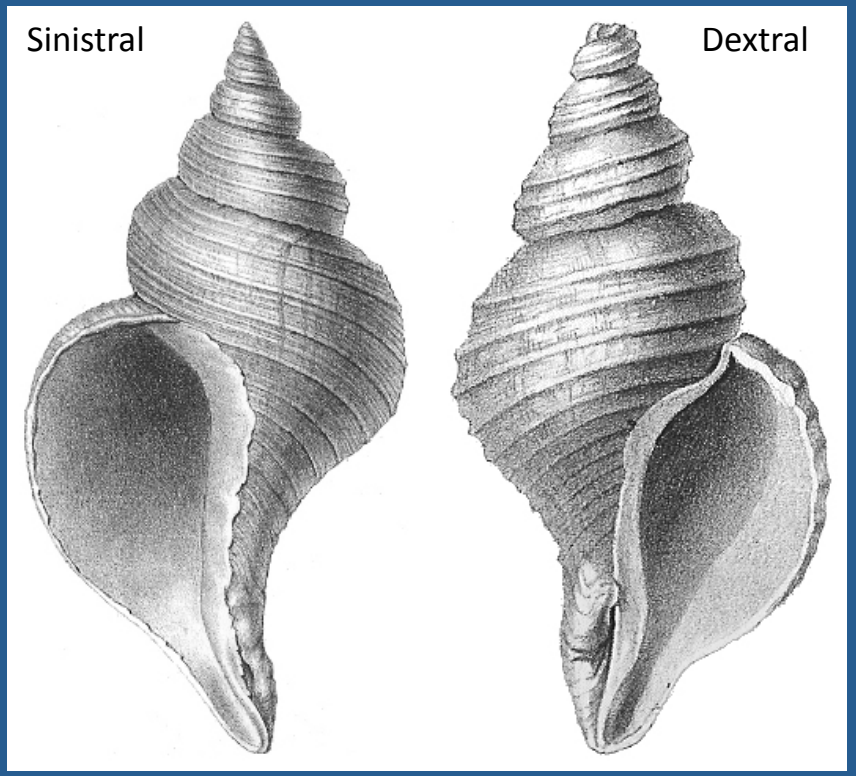
Gastropods

- The embryonic shell is called the protoconch. The shell grows as a gradually widening cone which is wound around an axial pillar, the columella, or around a central tubular cavity. Each coil is known as a whorl. The last whorl, in which the animal lives, is known as the body whorl; all of the other whorls together form the spire. The aperture varies in form and it may be closed by a calcareous or chitinous plate, the operculum, attached to the posterior part of the foot.



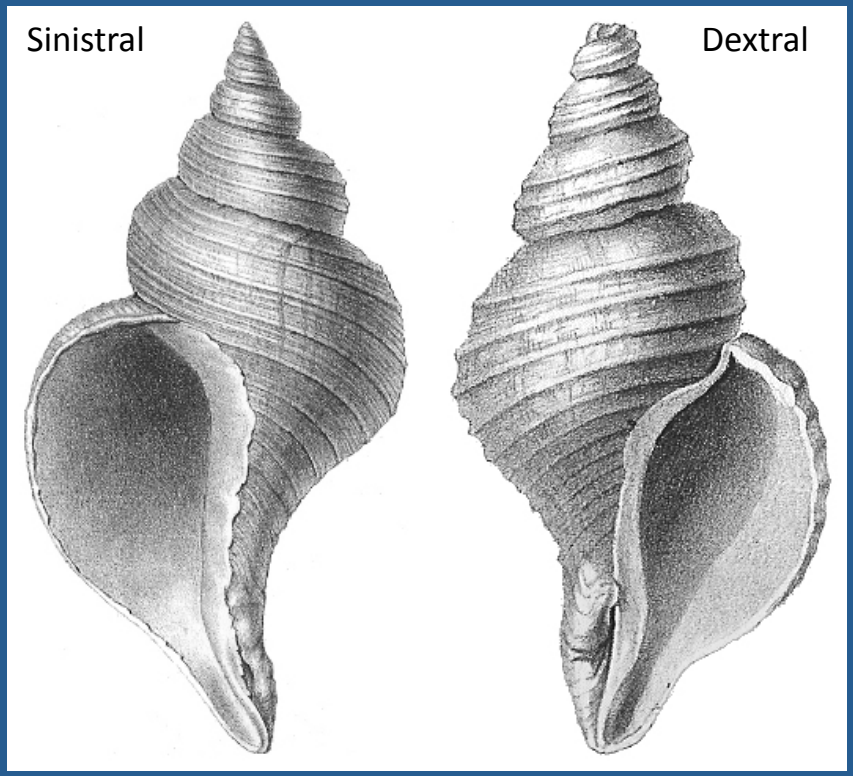
Gastropods

- Whether conical or saucer-shaped, gastropod shells are usually coiled into a spiral which is either right-handed (dextral) or left-handed (sinistral). The coiling is the result of the more rapid growth of one side of the gastropod's body, and as it is usually the left side which grows more rapidly than the right, the dextral coil is the more common type.



Gastropods

- The shell is oriented by holding it so that the apex (posterior end) is above and the aperture (anterior end) is below facing the observer.
- In a dextral shell, the aperture is on the right side; in a sinistral shell, the aperture is on the left side. These are two species in the genus *Neptunea*.



Gastropods

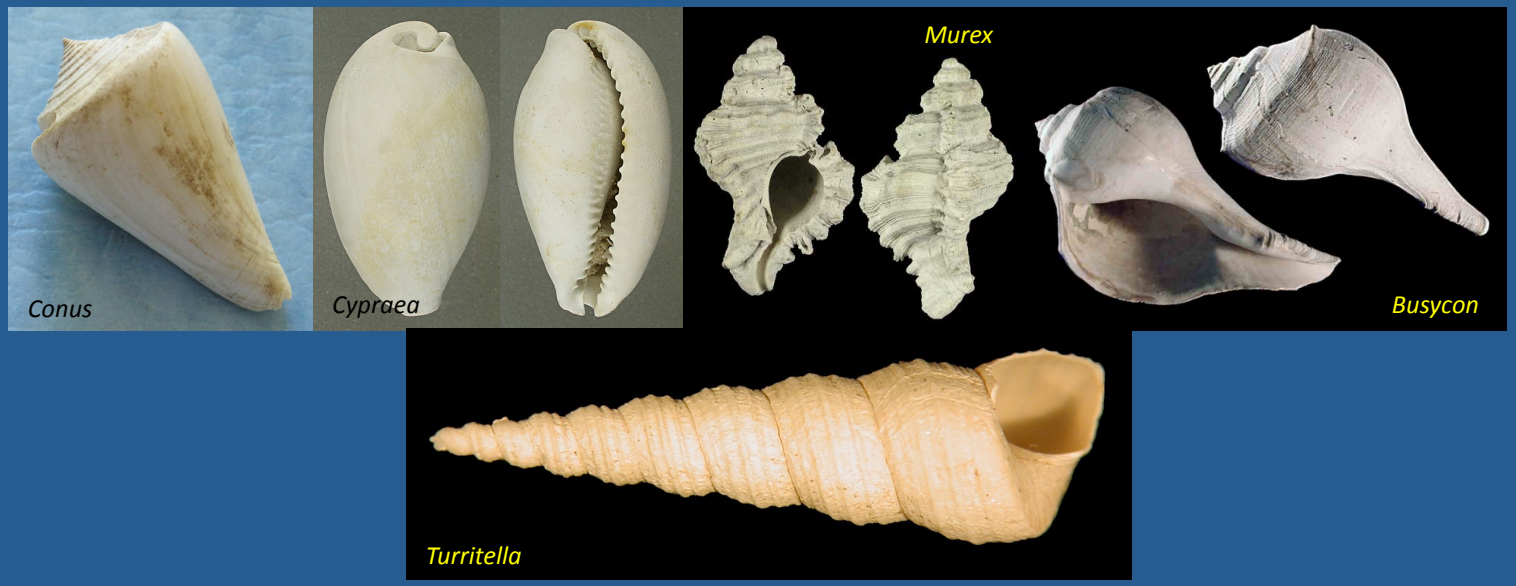
- Gastropods exceed all classes of mollusks in variety and importance. There are more than 30,000 known species, of which more than 20,000 are recent.

Gastropods

- The first gastropods were exclusively marine and have been found in rocks as old as Late Cambrian. Most of the gastropods of the Paleozoic Era belong to primitive groups. Examples include *Maclurites* (Ord.), *Bellerophon* (Ord.-Tri.), *Lophospira* (Ord.-Carb.), and *Loxonema* (Ord.-Carb.).

Gastropods

- The number of marine gastropod families increased steadily from the Ordovician. The first terrestrial and freshwater snails are found in the Carboniferous and in the Jurassic, respectively. The ancestors of many modern gastropods are found in Cenozoic rocks. Examples include *Conus* (Mio.), *Cypraea* (Plio.), *Murex* (Plio.), *Busycon* (Pleis.), and *Turritella* (Pleis.).

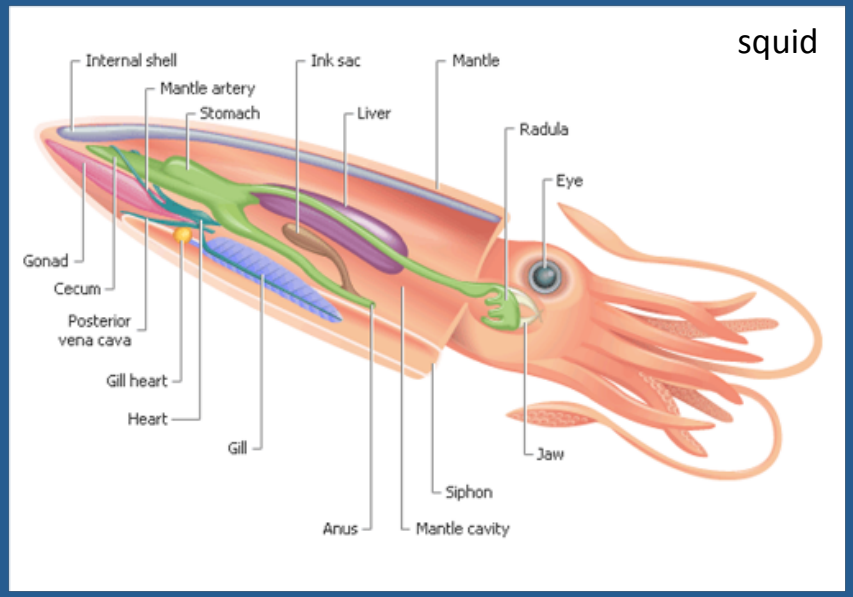


Cephalopods

- The living cephalopods are represented by Subclass Belemnoidea, which includes the cuttlefishes, squids, and octopi, and Subclass Nautiloidea, which includes two modern species of nautiloids, *Nautilus* and *Allonautilus*.
- Cephalopods are bilaterally symmetric carnivorous marine animals that are nearly all free-swimming.

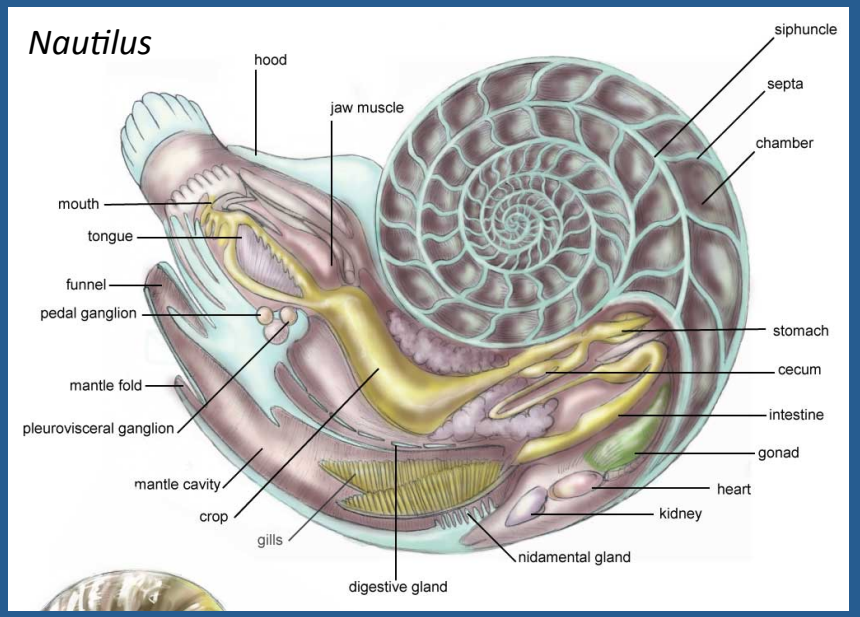
Cephalopods

- The circulatory, digestive, nervous, and respiratory systems of cephalopods are all very highly developed compared to those of the other Mollusca. They have a defined head with a pair of highly developed eyes. The anterior portion of the foot is modified into arms or tentacles which surround the mouth. The mouth has beaklike jaws with calcified tips, and a radula. Internal or external, straight or coiled, aragonitic shells are secreted by the mantle.



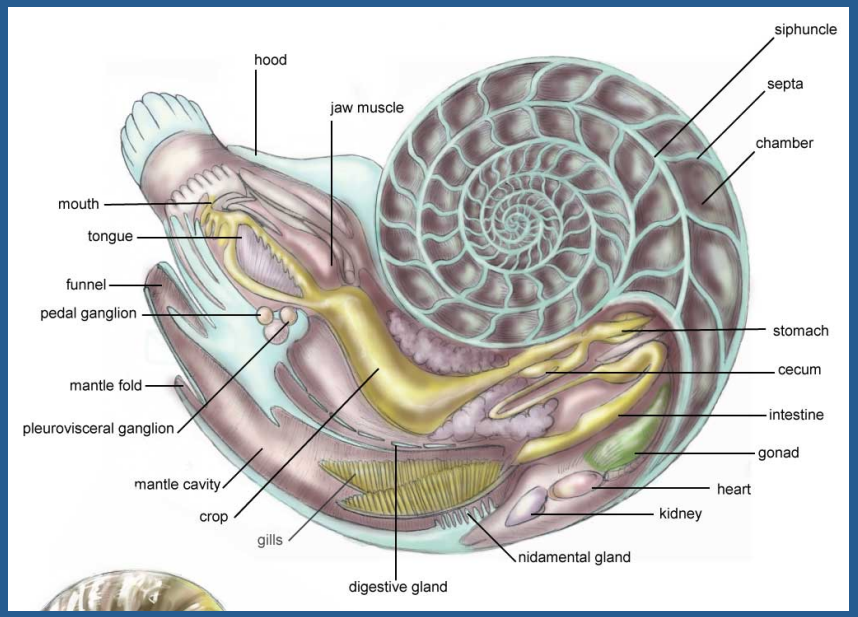
Cephalopods

- The soft parts of *Nautilus* are contained in the outermost compartment, or living chamber, of a coiled shell. A tubular extension of the mantle, the siphon, connects this chamber with the earlier-formed unoccupied chambers through perforations in the septa, which separate the chambers.



Cephalopods

- A hood, formed from the inner pair of tentacles, serves the same function as the operculum in gastropods when the animal withdraws into its shell. Chambers are filled with gas and are connected by the siphuncle, a calcareous wall surrounding the siphon. The lines formed by the intersection of the septa with the shell are called sutures.



Cephalopods

- Representatives of three subclasses of cephalopods, Belemnoidea (also known as Coleoidea), Nautiloidea, and Ammonoidea, are found in the fossil record from the Late Cambrian to the present day.

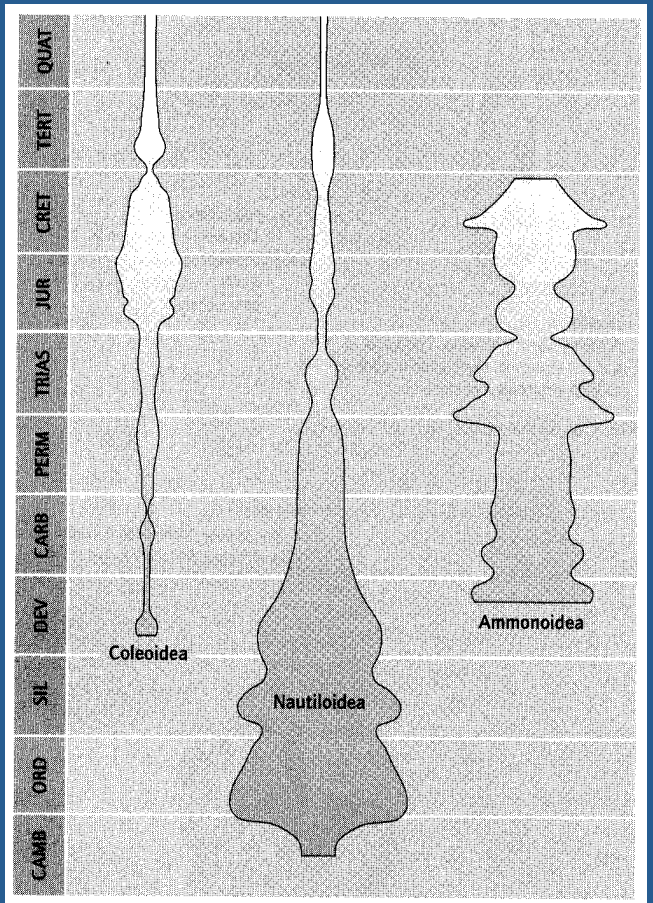


Fig. 9.9 Diversity of cephalopod subclasses through geological time.

Belemnoidea

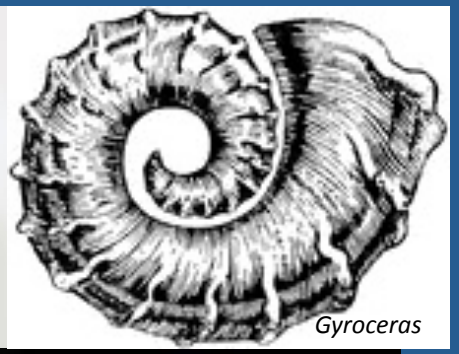
- Belemnoids were abundant during the Jurassic and Cretaceous. An example of a fossil belemnoid is *Belemnitella* (Cret.).

Nautiloidea

- Some 2,500 species of fossil nautiloids are known from the Late Cambrian to the Recent. They reached their maximum diversity during the Silurian, declined after the Devonian, and nearly went extinct after the Permian, the Triassic, and the Miocene.
- Nautiloids may be distinguished from ammonoids by the position of the siphuncle near the center of the septa.
- The nautiloids have the simplest suture patterns of the chambered cephalopods.

Nautiloidea

- Fossil nautiloids may have straight, slightly curved, loosely coiled, or tightly coiled shells. Examples include *Orthoceras* (M. Ord.), *Cyrtoceras* (Mid. Ord-M. Dev.), *Gyroceras* (Sil.-Dev.), *Cenoceras* (E. Jur.), and *Nautilus* (E. Jur.-Rec.).



Ammonoidea

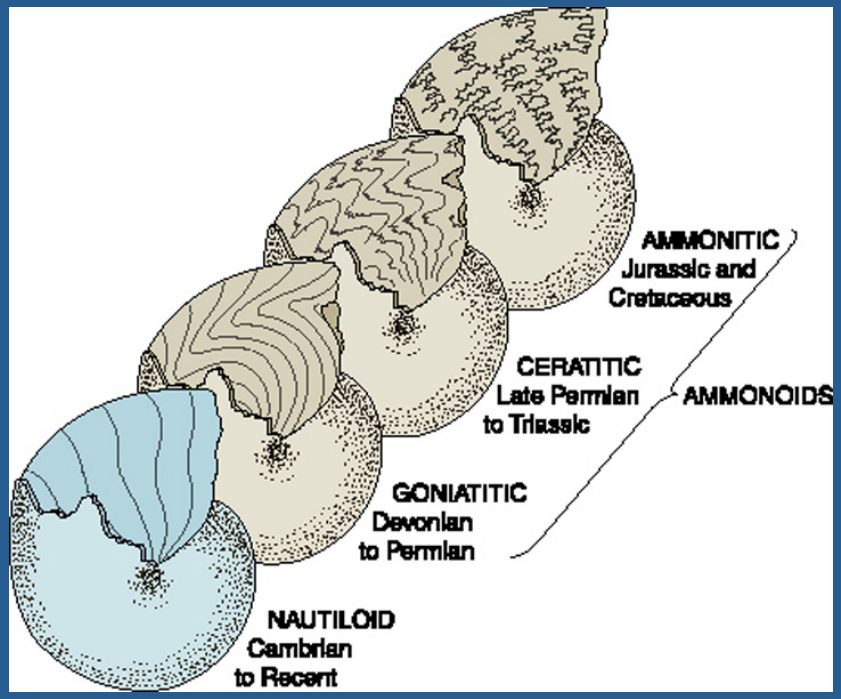
- Some 7,500 species of fossil ammonoids are known from the Late Silurian to the end of the Cretaceous, when they went extinct.
- Ammonoids may be distinguished from nautiloids by the position of the siphuncle near the extreme ventral edge of the septa.
- Ammonoids may be classified into three orders, Goniatitida, Ceratitida, and Ammonitida, based on how complex their suture patterns are.

Ammonoidea

- Ammonoids may have straight, loosely coiled, or tightly coiled shells. Examples include *Bactrites* (E. Dev.-L. Perm.), *Mimoceras* (E. Dev.), and *Agoniatites* (M. Dev.).

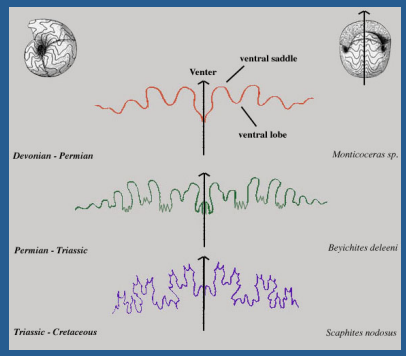
Ammonoids

- Ammonoids may be classified into three orders, Goniatitida, Ceratitida, and Ammonitida, based on how complex their suture patterns are.



Ammonoid Suture Patterns

- Three major types of suture patterns are found in the Ammonoidea:
  - Goniatitic: numerous undivided lobes and saddles; typically 8 lobes around the conch. This pattern is characteristic of the Paleozoic ammonoids.
  - Ceratitic: lobes have subdivided tips, giving them a saw-toothed appearance, and rounded undivided saddles. This suture pattern is characteristic of Triassic ammonoids and appears again in the Cretaceous "pseudoceratites."



  - Ammonitic: lobes and saddles are much subdivided (fluted); subdivisions are usually rounded instead of saw-toothed. Ammonoids of this type are the most important species from a biostratigraphical point of view. This suture type is characteristic of Jurassic and Cretaceous ammonoids, but extends back all the way to the Permian.

Goniatites

- Goniatites have the simplest suture pattern of the ammonoids. They are found in the fossil record from the Middle Devonian to the Late Permian. Examples include *Tornoceras* (M. Dev.), *Monticoceras* (L. Dev.), and *Gastrioceras* (Penn.).

Ceratites

- Ceratites have a more complicated suture pattern than the goniatites. They are found in the fossil record from the Permian to the Triassic. An example is *Ceratites* (M. Tri.).

Ceratites

Ammonites

- Ammonites have the most complicated suture pattern of the ammonoids. They are found in the fossil record from the Early Jurassic to the Late Cretaceous. Examples include *Phylloceras* (E. Cret.), *Cletoniceras* (Cret.), and *Sphenodiscus* (L. Cret.).