# Science B-16: The History of Life

## Lab 1: The Invertebrate Phyla

**Objectives**

The object of this lab is to get you familiar with the sorts of organisms that comprise the fossil record. We'll discuss how fossils form in more detail next week, but first you need to be able to identify the major types of organisms which exist today and which have existed in the past. Towards that end you will spend this week's lab section studying specimens of these major types. Some of these creatures will be familiar to you, but odds are that many will be new. This handout discusses how biologists and paleontologists classify organisms and how to recognize and identify organisms that you will see in the lab. There will be a lot of material to look at in the relatively short time that you have in lab, so it is imperative that you ***read this entire lab handout before coming to section***.

**Classification of Organisms: The Linnean System**

There exist today on Earth probably five to ten million different kinds of organisms, and perhaps as many as one billion have existed throughout all of geologic time. To even begin studying these organisms, paleontologists and neontologists (those that study living organisms) must have a system for organizing this enormous diversity. Both paleo- and neontologists group organisms into a hierarchical system of classification that was first employed by the Swedish botanist Carl von Linne in the 18th Century. In this system the basic unit is the **species**. Two individuals are members of the same species if they are actually or potentially interbreeding and can produce fertile offspring. This definition of species works for neontologists, but there are obvious problems with applying it to ancient organisms! Paleontologists therefore group fossil organisms based solely on morphological similarity -- if they look the same, they are considered to be the same species. This concept of a species is often distinguished from the neontological one by using the word **morphospecies** instead. Species are grouped into **genera** (plural of **genus**). Each species is given two names, a generic name and a trivial name. Modern humans, for example, are classified as *Homo sapiens*. *Homo* is the genus or generic name, and *sapiens* is the trivial name. The pair together refers to a particular species, and thus comprises the species name. Note that both are always written in italics or are underlined; the generic name is always capitalized and the trivial name is always written in the lower case. This system of classification is often referred to as **binomial nomenclature**, since each species is given two names, or as **Linnaean classification**, after its inventor. To facilitate communication between scientists who may speak and write in different languages, generic and trivial names are Latin or Greek words (or Latinized words from other languages), and follow the rules of spelling and gender of these languages.

In the Linnaean system, genera are themselves grouped into larger categories called **families**, families into **orders**, orders into **classes**, classes into **phyla** (plural of **phylum**), and phyla into **kingdoms**. The names of these higher categories are also

Latinized and capitalized. In the past, all life on Earth was grouped into five kingdoms, the most familiar of these being the plants (Kingdom Plantae) and the animals (Kingdom Animalia). Also included were single-celled organisms without a nucleus (bacteria), with a nucleus (protozoans), and the fungi (Kingdoms Monera, Protoctista, and Fungia respectively). As we will discuss later in the semester, more recent work on genetics and biochemistry has demonstrated that the Five Kingdom system woefully under-represents the diversity of single-celled organisms. Modern classifications of life group organisms into three broad **domains**. Under this system, all organisms with cell nuclei (including the plants, animals, and fungi) belong to the same domain (the Eukarya). The other two domains (Archaea and Eubacteria) are made up entirely of organisms without cell nuclei. While strictly speaking it is incorrect, the Five Kingdom system is still used in taxonomic descriptions due to tradition and common usage.

When appropriate in classifying various groups of organisms, the prefixes **super**-, **sub-,** and **infra-** may be used with any category to add additional levels to the classification. As an example, the classification of the domestic cat is:

**Kingdom:** Animalia
- **Phylum:** Chordata
  - **Subphylum:** Vertebrata
    - **Class:** Mammalia
      - **Order:** Carnivora
        - **Family:** Felidae
          - **Genus:** *Felis*
            - **Species:** *catus*

The general science of classifying organisms is called **taxonomy** or **systematics**. You should be aware that taxonomy is more than just putting labels on organisms, sorting out apples from oranges. Modern classifications group organisms that are believed to be evolutionarily related to one another, not just morphologically similar. Hence, taxonomists must develop theories about evolutionary relationships as they are grouping organisms.

## Why Bother to Study Fossils?

A popular misconception is that paleontologists are dusty old professors shuffling around in dark museum halls doing nothing but describing an endless array of insignificant fossils. This is hardly the case, and hopefully this class will dispel this myth for you. The study of fossils provides crucial information about biological and geological events and processes, information which often cannot be obtained from any other source.

### Biostratigraphy: Establishing a Relative Time Scale and the Correlation of Rocks

Because life has evolved continuously for more than three billion years, sedimentary rocks of different ages contain different types of fossils. Hence, fossils are indicators of the **relative ages** of the rocks in which they are found. Relative dating allows you to develop a sequential ordering of events (such as the deposition of particular bodies of rock) in time -- for example, event A is older than event B but younger than event C. It does not allow exact numerical ages to be assigned to those events. This process of assigning relative dates to rocks is called **stratigraphy**, and dating the rocks by the fossils they contain is called **biostratigraphy**. Fossils that are particularly useful for dating rocks because they are restricted to a known time interval are called **index fossils**. Once it has been established at one locality that rocks of a certain age contain a particular group of fossil organisms, recognition of this same group of fossils in rocks elsewhere in the world allows a geologist to conclude that the two rock units are of approximately the same age. This matching up of rock units of the same age from different localities is called **correlation**, and it is perhaps the most fundamental part of the science of geology.

**Economic Importance**

Fossils are a major component of many sedimentary rocks, including economically useful ones. For example, the great majority of limestones, an important building stone, are composed entirely of the remains of organisms that secreted calcium carbonate skeletons when alive (such as calcareous algae, corals, and molluscs). Many cherts (used, among other things, by prehistoric peoples to make stone tools and arrowheads) are made up of the silica skeletons of microscopic animals or sponges. Coal, oil, tar, peat, and natural gas are all ultimately derived from organic material that has been fossilized. In addition, fossils can be used as indicators of nearby petroleum reserves; for example, oil reservoirs are often associated with fossil reefs.

**Interpretation of Depositional Environments and Climate**

Fossils are vital to the reconstruction of past environments (**paleoenvironments**). The ancient Greeks recognized that the presence of fossil seashells in the mountains meant that the ocean had once covered the area. Such a deduction is the simplest kind of paleoenvironmental reconstruction, but fossils usually allow much finer resolution. Two methods are possible. If it is assumed that closely related organisms have inhabited similar environments through time, then inferences about the environment of a fossil organism can be based on the environments inhabited by its present-day descendants. For example, corals, echinoderms, and cephalopod molluscs (squid etc.) today live only in the saltwater of seas and oceans, so fossils of these animals are assumed to be indicative of a marine paleoenvironment. The second method makes inferences based not on the habits of modern relatives, but on the morphology (*i.e.,* what they look like) of the fossils themselves. An abundance of fossil leaves with long, tapered "drip tips", for example, suggests that those plants lived in an especially wet climate. More "high-tech" studies of the microstructure and chemical composition of fossils yield information on temperature, moisture levels, and other factors related to the climate conditions when the organism was alive.

**Paleobiology and Evolution**

In this course, our focus will be on fossils as biological objects. There are two major issues in the study of past life. One is reconstructing and understanding the biology and ecology of extinct organisms. This type of study is referred to as **paleobiology**. There are several ways of approaching such a problem. One can directly compare a fossil organism with closely related living organisms. The life habits and locomotion of fossil coiled cephalopod molluscs, for example, are inferred from our knowledge of the living *Nautilus*. In the same way, we believe that all fossil echinoderms inhabited marine environments because all modern echinoderms live in the sea. The paleobiology of organisms can also be inferred by relying not on references to modern descendants, but on generalities based on observations of a wide range of living forms. This method is based on a general concept of historical science, which maintains that while details of pattern and process may change with time, there appear to be generalities about the way organisms have evolved and adapted to their environments that have not changed over time. Abundant spines on an organism, for example, may serve a limited number of functions: they may discourage predation, as was probably the case for some very spiny trilobites, or they may keep an organism from sinking through water or sediment, as was probably the case for some floating microorganisms and spiny brachiopods. Among marine bivalves, common sense tells us that forms with highly ornamented, spiny shells would have a difficult time burrowing in sand or mud, whereas more compact, streamlined shell forms would more likely characterize this lifestyle. The same generalization holds for other, very different types of animals, such as sea urchins.

The second major issue in the study of past life is reconstructing and understanding the evolutionary relationships among organisms, and how the processes of evolution work. In this sort of study, paleontologists have one great advantage over biologists who work only with living organisms -- time. By looking at a series of fossil organisms from different geological ages, a paleontologist can, in a sense, "watch" evolution occur. While it is impossible to know exactly who is related to whom in the evolutionary history of life (we cannot go back in time and follow each group generation by generation), paleontologists can infer relationships on the basis of morphological similarities among organisms. Organisms that are related to one another share morphological characteristics that they inherited from a common ancestor. Such characters are called **homologies**. For example, the front limbs of a human, a dog, a bird, and a whale have a very similar anatomical structure, and it is reasonable to assume that this similarity is due to inheritance of the structure from a common ancestor. Hence, the front limbs are considered to be **homologous structures**. Comparing sets of homologous structures allows paleontologists to sort organisms into evolutionarily-related groups. The nature of these groups, and the patterns and processes of evolution that produced them, can then be studied.

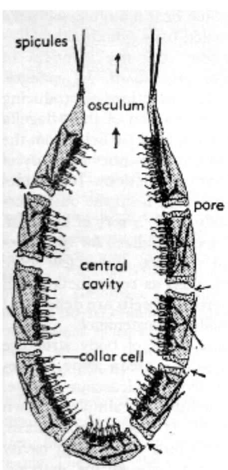
## **Taxonomy of the Major Groups:**

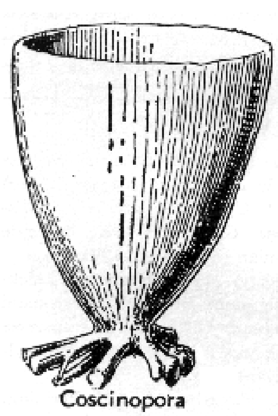
The remainder of this lab will be devoted to an examination of the commonly fossilized members of the animal kingdom. We will deal mostly with **invertebrate** animals -- those without a backbone -- because their record is longer and more complete than that of the vertebrates. Of the approximately thirty invertebrate phyla, we will further restrict our examination to those that form the majority of the fossil record – less than a dozen. The other phyla are too rare, too small, or too soft to become prominent members of the fossil record.

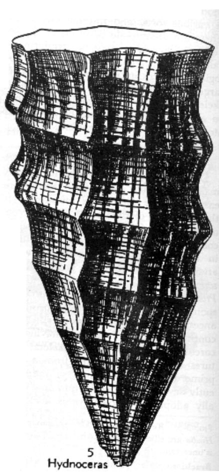
We will now go through the major phyla of animals, providing you with their **stratigraphic range** (the time period in which they lived), a general description of the group, and pictures showing the range of morphology. Compare these descriptions and pictures to the fossils provided during the lab period.

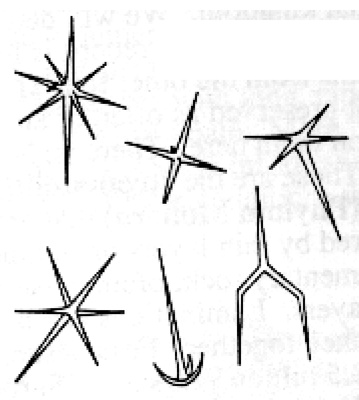
**Phylum Porifera** (Cambrian—Recent)

The phylum Porifera contains the sponges, the simplest many-celled animals. They contain several types of cells, but have no true tissues or organs. Because of this, you can smash an intact, living sponge through a window screen into a bucket of water, and the cells will reorganize into another sponge! If you separate the disaggregated sponge cells into two piles, you will get two new sponges! The simplest sponges are shaped like perforated vases. Cells lining the inside of the vase have whip-like flagella that beat in unison, drawing water through the perforations in the side of the sponge. Food is filtered out, and the water is pumped out the large opening at the top. Sponge skeletons are made of **spicules**—needle-like structures made out of minerals like calcium carbonate or opal—and/or **spongin**, the mesh-like organic material of which natural bath sponges are made. Sometimes the spicules are joined into a rigid skeleton which can be preserved, showing the shape of the entire sponge. In other sponges, the spicules are attached only to the organic spongin; these spicules scatter when the sponge dies and can often be found in sedimentary rocks. Sponges live attached to surfaces in marine settings.

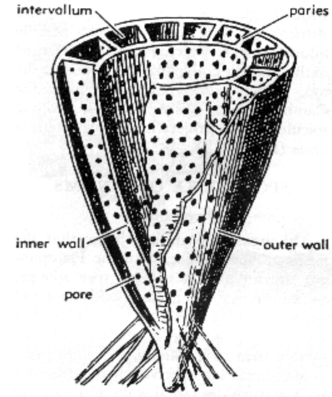


Spicules




**Phylum Archaeocyathida** (Lower—Middle Cambrian)

The archaeocyaths may be related to the sponges, but they have a distinct morphology. Their skeleton consists of two cones, one inside the other, connected by vertical partitions. The cones and partitions have pores.

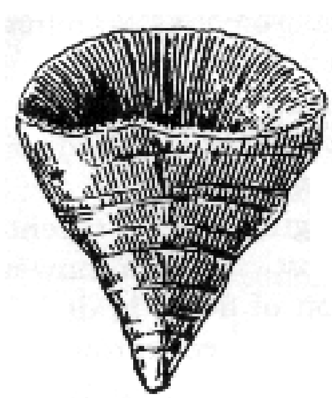
Archaeocyaths are found only in Cambrian marine rocks, but they were important reef builders at that time.

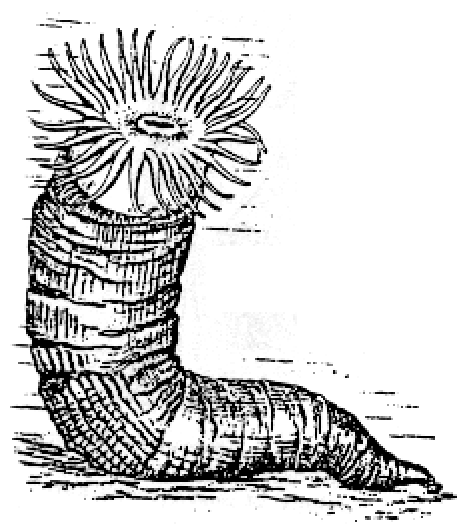
**Phylum Cnidaria** (formerly Coelenterata)

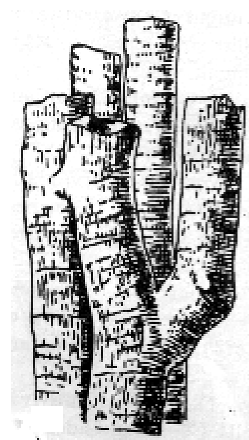
The cnidarians include the jellyfish, sea anemones, and corals. They are defined by the presence of stinging cells called **nematocysts** in their tentacles that are used to capture and subdue prey. Like the sponges, cnidarians are also shaped rather like a bag, but in this case true organs are present, not just different tissue types. The open end of the bag serves as both mouth and anus (everything goes in and out the same opening), and it is surrounded by tentacles that aid in food gathering. Cnidarians show **radial symmetry** in their body plan - you can slice them any way through the middle and both halves will be symmetric.

Members of the **Class Anthozoa**, which includes the corals, are of the most importance to paleontologists because they have easily-preserved, calcified skeletons. Many corals are **colonial** organisms, in which individuals live together in close association...so close that they actually share the same digestive tract and are connected by it. There are three important groups of corals you will need to become familiar with:

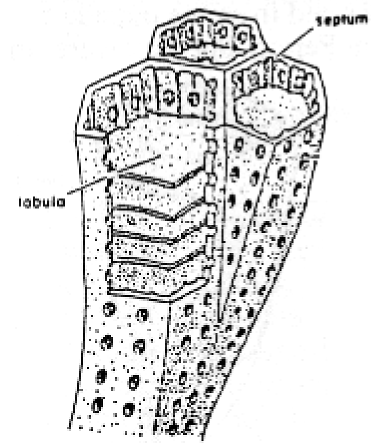
**Order Rugosa** (Cambrian-Lower Triassic) includes the "**horn corals**", so named for their characteristic horn-like shape. Each horn is divided up on the inside by vertical partitions called **septae**. The organism sits in the cup-like end of the horn, folded in and around the septae. These individuals lived on the mud with the wide end pointed up and their mouth and tentacles protruding from it. Most of the members of this group are solitary, but a few types are colonial.





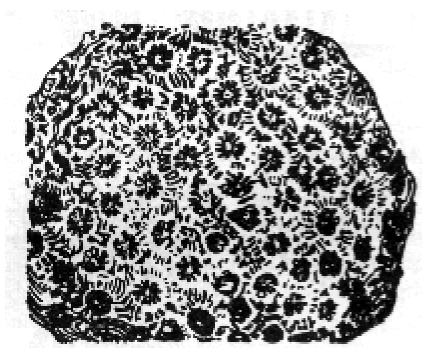


**Order Tabulata** (Ordovician-Permian) contains colonial corals that can be recognized by the pronounced horizontal divisions, called **tabulae**, in their skeletons (in addition to septae). Common skeletal forms look like honeycombs or interconnected chains when viewed from above. There is some controversy over whether or not the tabulates actually are corals or not. If you were to take this course in a few years, you might find them listed as sponges.

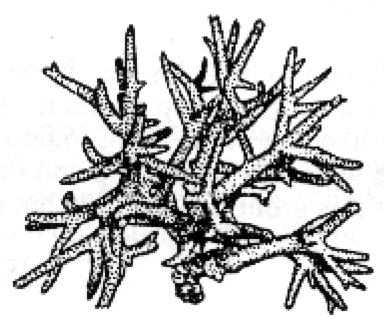



Both the rugose and tabulate corals were common in the Paleozoic Era, but are now extinct.

**Order Scleractinia** (Upper Triassic-Recent) includes all of the modern, shallow-water, reef-building corals that you see if you go SCUBA diving in the tropics. These colonies are massively calcified and can grow to huge dimensions. An interesting feature of this group is that many types house photosynthetic algal cells inside their tissues. These symbionts seem to enable the corals to grow faster and larger than others of the group that do not contain algae.



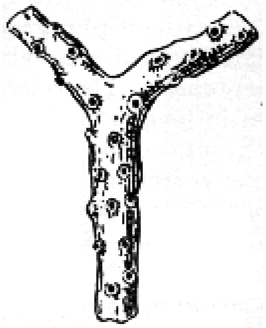
Montastrea

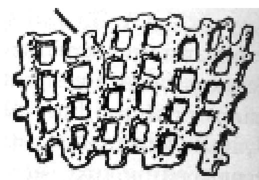


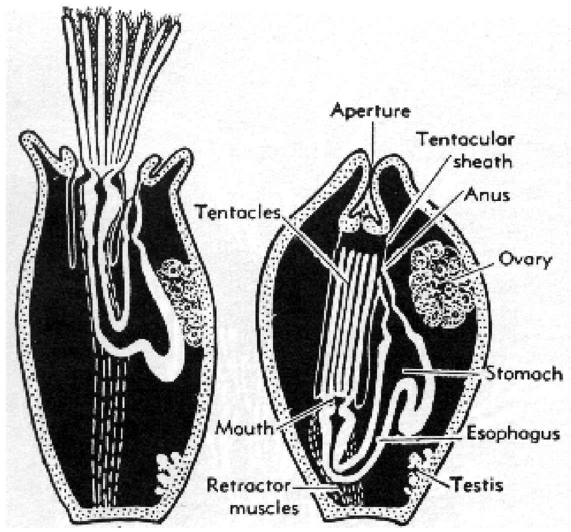
Acropora

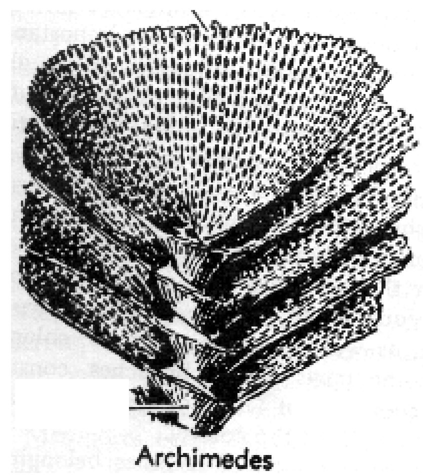
**Phylum Bryozoa** (Ordovician-Recent)

The bryozoans are the only phylum to originate after the Cambrian. They are exclusively colonial. Bryozoans feed using a tentacular organ called a **lophophore** that sweeps food particles out of the water into the mouth. The form of their colony is highly variable depending on the environment they live in: it can look like a corkscrew, a dome, an erect branch, a fan, or a screen encrusting the surface of something else.  Because they are small, slow evolving, and difficult to identify at the species level, bryozoans are not used extensively in stratigraphic determinations.



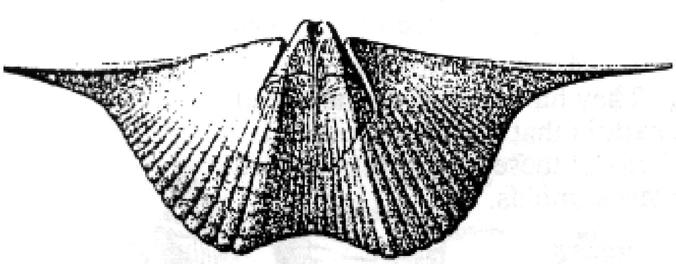


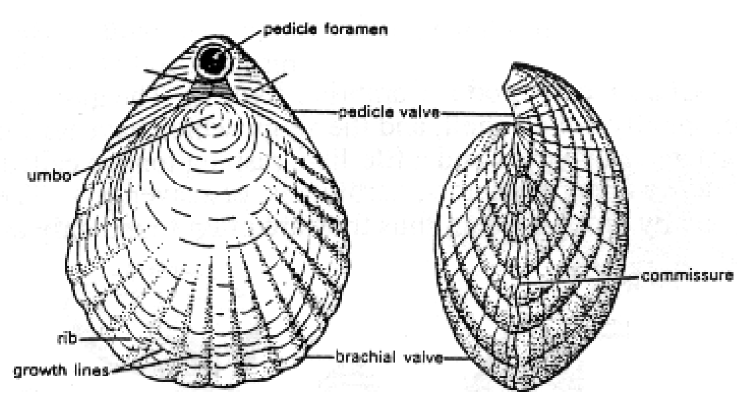


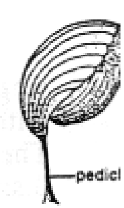




**Phylum Brachiopoda** (Cambrian-Recent)

Like the bryozoans, the brachiopods have a lophophore, but they are solitary organisms with a two-part, calcareous shell attached by a hinge.  Brachiopods look very much like the bivalved molluscs (e.g. clams), but their shells can be distinguished by the plane of symmetry:  *brachiopod shells are symmetric across the valves (not between them)*, so that each half of a valve is a mirror image of the other.  The lophophores of brachiopods are like a pair of coiled, feathery arms inside the shell that sweep the water for food particles.  Most brachiopods have a tough, muscular stalk called a **pedicle** that anchors them to the substrate.  The opening through which the pedicle protruded is often still visible near the "beak" along the hingeline.  There is a wide range of shell shapes, with the most unusual forms occuring during the Permian.  Most brachiopods are found articulated, as they have a tooth-and-socket hinge structure that has to break before the valves will separate.  Brachiopods are a very common and extremely useful fossil in Paleozoic rocks.  They are still extant, but their decline in diversity and abundance since the Paleozoic has decreased their utility.



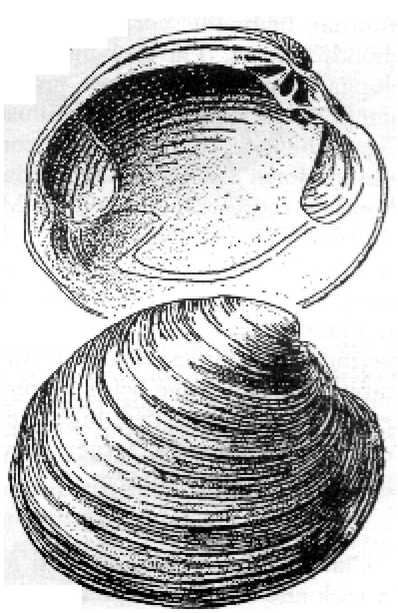


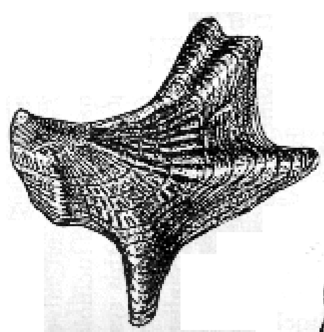



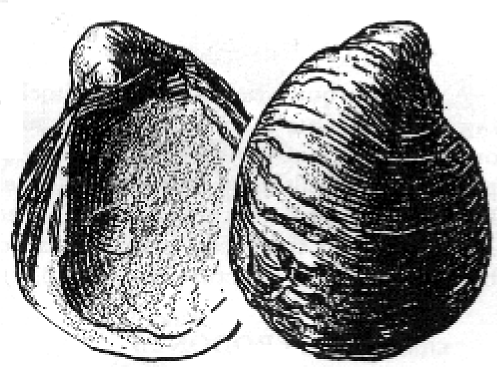
**Phylum Mollusca** (Cambrian—Recent)

The Ediacaran (Late Precambrian) fossil *Kimberella* may belong to this phylum, but the first definite molluscs are Cambrian. This diverse group is united by several "soft-part" organs, including a muscular **foot** used for locomotion and an envelope of tissue called the **mantle** that secretes the animal's shell (if it has one). Mollusk (or mollusc) bodies are often muscular and fleshy, making them a popular food among invertebrate predators, fish, or humans. The mollusk shell grows by **accretionary growth**, with new layers of calcium carbonate added to the edge of the existing shell. Growth lines, which mark the edge of the shell at an earlier life stage, are easily observed on many mollusks. Growth lines often follow seasonal patterns, so they can be used to study growth patterns and to tell the age of a mollusk. Mollusks live in marine, freshwater, and terrestrial habitats, and their diet and life habit vary enormously. The soft parts are rarely preserved, so the classification of fossil mollusks is based entirely on the animals' shells. Luckily, a mollusk's shell is a rich source of information about the biology and behavior of the living creature. The three main classes of mollusks are the bivalves, gastropods, and cephalopods.

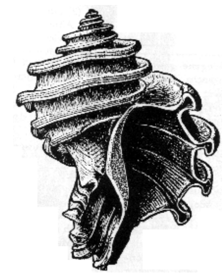
**Class Bivalvia** (Lower Cambrian—Recent) Clams, oysters, mussels, scallops, and their relatives are bivalves. The bivalve's calcium carbonate shell is divided into two halves, or **valves** (hence the name *bivalve*). *Contrary to brachiopods, bivalve shells are symmetric **between** the valves (with a few exceptions), so that each entire valve is a mirror image of the other*. A bivalve closes its shell using muscles that stretch between the valves, but an elastic hinge ligament automatically pops the shell open when the animal relaxes or dies. Many bivalves use their shell and muscular foot to burrow into soft sediments; others (oysters, mussels) live attached to rocks or other hard surfaces, and some even bore into solid rock or wood. Many bivalves filter small particles of food directly out of the water (**suspension or filter feeders**), but others ingest sediment and digest the enclosed organic material (**deposit feeders**). They live in marine or freshwater settings.

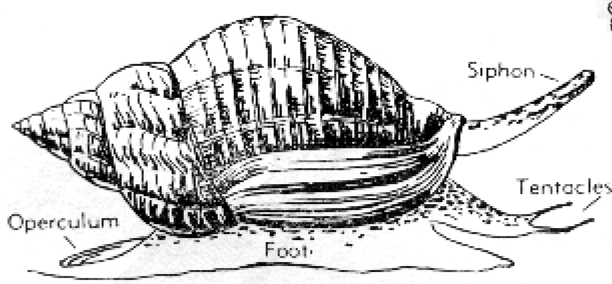


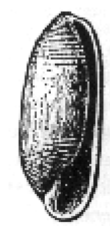




**Class Gastropoda** (Cambrian—Recent) The gastropods include the snails, which have a single, spirally-coiled shell, and the shell-less slugs and sea slugs. They have a well-defined head with eyes and other sense organs, and they move by muscular contractions of their pad-like foot. *Unlike the cephalopod shell, the shell of a gastropod has no internal partitions dividing it into chambers*. Most gastropods are active predators, herbivores, or scavengers, but a few are deposit feeders or suspension feeders. Gastropods live in marine, freshwater, and terrestrial habitats.

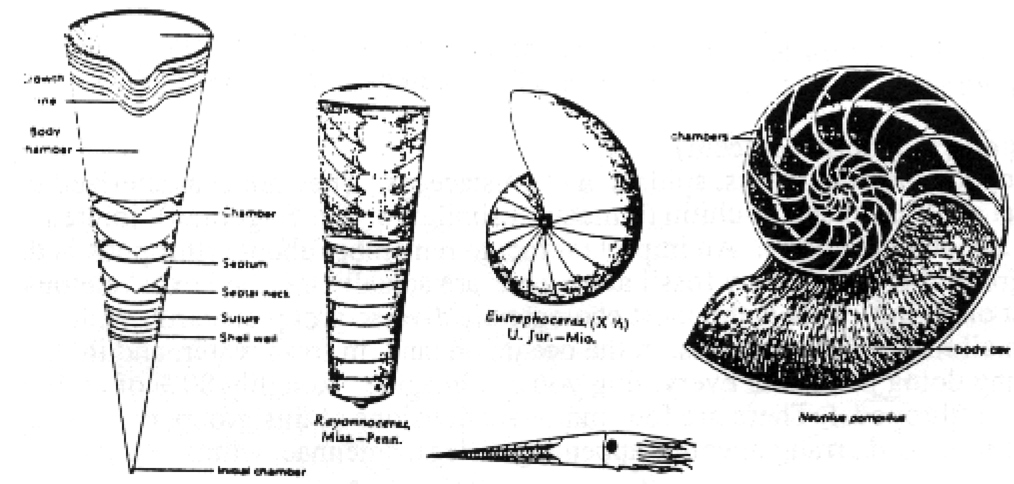




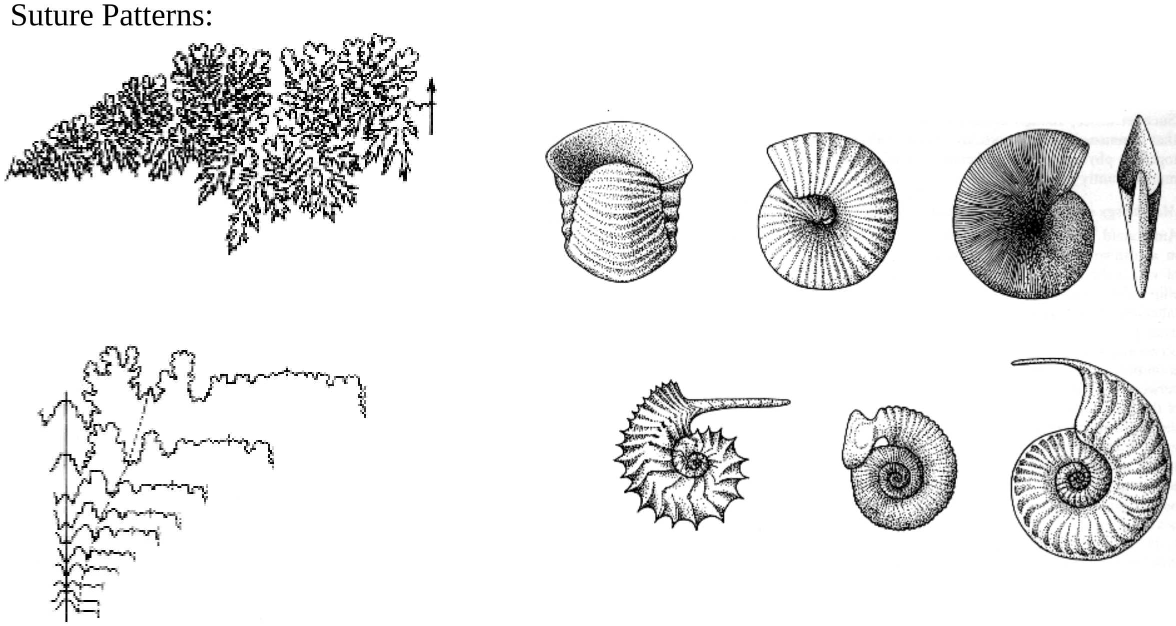
**Class Cephalopoda** (Upper Cambrian—Recent) Modern cephalopods include the squid, octopus, chambered *Nautilus*, and cuttlefish. They are the most intelligent of the invertebrates, with large brains and sophisticated eyes. They can change skin color and pattern to communicate with each other. Modern (and presumably fossil) cephalopods are active predators or scavengers, swimming in the open water or hovering and crawling along the seafloor. **Arms** and **tentacles** surround the animal's mouth, and the suction cups or hooks they bear are used to capture prey and draw it into the powerful, beak-like jaws. Cephalopods swim by jet propulsion, and some have fins as well. They are exclusively marine. The three subclasses of cephalopods all have important fossil representatives.

**Subclass Nautiloidea** (Upper Cambrian—Recent) Only a handful of nautiloid species are alive today, but the subclass was important and diverse during the Paleozoic. Nautiloid shells can be coiled or straight and cone-shaped. *Unlike the gastropod shell, the nautiloid shell is divided into chambers by a series of walls, or* ***septa***. Each septum joins the shell's outer wall at a **suture**. The nautiloid inhabits the last (outermost) chamber; the other chambers are filled with liquid and gas and control the animal's buoyancy. Unlike the ammonoids, the septa are straight or gently curved.

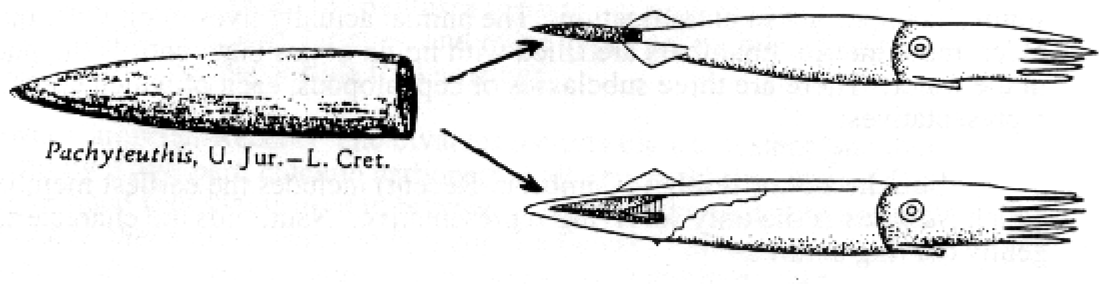



**Subclass Ammonoidea** (Upper Silurian—Cretaceous) The ammonoids are similar to the nautiloids in general shell form, but *the sutures are folded*. In some ammonoids, the sutures are folded quite elaborately, and these shells are among the most beautiful fossils. The shell can be straight, coiled, or irregularly folded. Ammonoids are common in the Mesozoic and are used in biostratigraphy.

Suture Patterns:

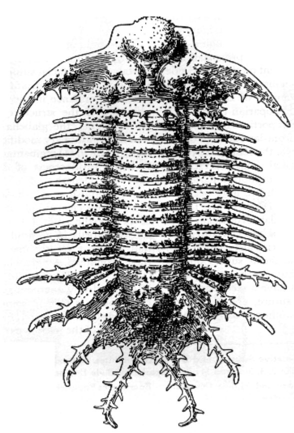


**Subclass Coleoidea** (Lower Devonian—Recent) Modern representatives include the squid, octopus, and cuttlefish. Most coleoids have no shell or an internal shell (the cuttlefish “bones” that are sold at pet stores are the internal shells of cuttlefish). The extinct Mesozoic **belemnites** are the most important fossil group. The squid-like animals had internal, bullet-shaped skeletons.

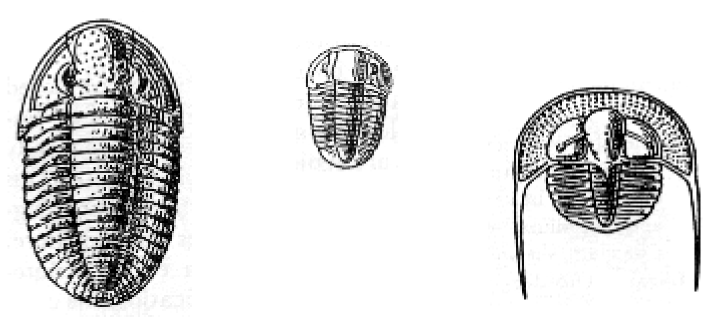



**Phylum Arthropoda** (Cambrian - Recent)

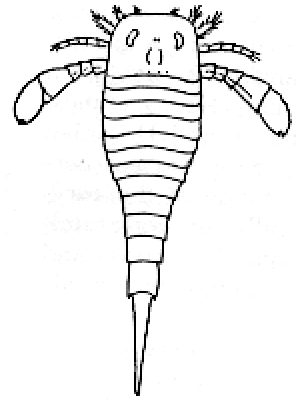
The arthropods include insects, spiders, crustaceans, and the now-extinct trilobites. They are characterized by jointed appendages, a segmented body divided up into two or more major parts or **tagmata**, and an external skeleton made of **chitin**, a material similar to your fingernail. Since arthropods have to molt (shed their exoskeleton) to grow, many fossil arthropods are actually the discarded exoskeletons of animals that went on living. The arthropods are the most ecologically diverse group on earth, with representatives in all major environments: marine, terrestrial, fresh water, and in the air, and making a living doing just about anything you can imagine. About 80% of all living animal species are arthropods, and of those, over 85% are species of insects. There are four major subdivisions of this group, divided up on the basis of the shape, number, and arrangement of appendages, as well as the **tagmatization** of body segments (fusion into major parts).



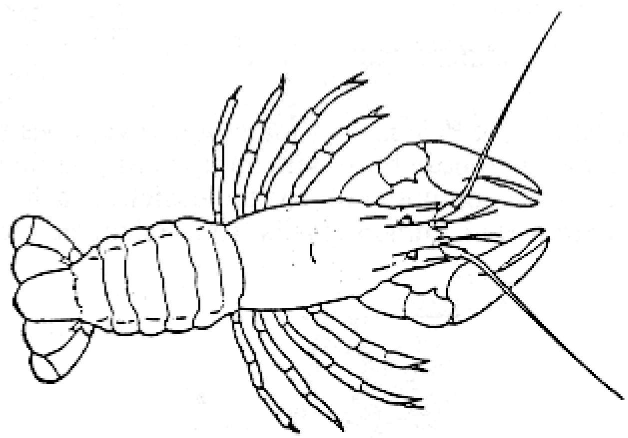
**Trilobites** (Cambrian-Permian) are now extinct, but they are an important Paleozoic index fossil, diagnostic of that time period. They had a single head shield, followed by several short body segments of a "tri-lobed" appearance, each with a pair of jointed legs on the underside. Many species had antennae and insect-like compound eyes -- well-preserved trilobites still show remarkable detail in the **ommatidia** (compound eye subunits.) Trilobites were probably bottom feeders, scavenging for organic material on the surface of the mud.

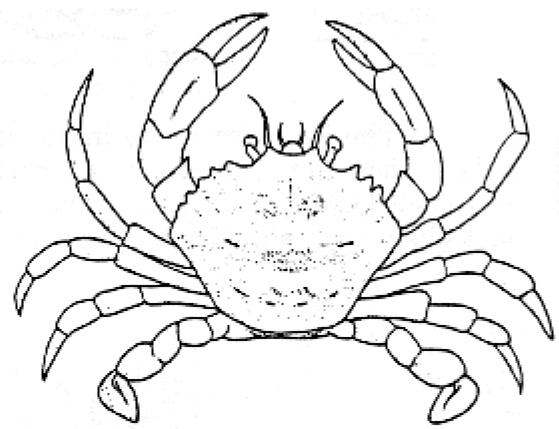


**Chelicerates** (Cambrian-Recent) include spiders, ticks, scorpions, and horseshoe crabs. They are characterized by the presence of a pair of pincer-like appendages in front of the mouth, called **chelicerae**, and by their tagmatization into two main body regions: the **cephalothorax**, and the **abdomen**. Important fossil members are the predatory **eurypterids**, or "sea scorpions" -- the terror of the deep during the Paleozoic. Some got to be nearly 2 meters in length!

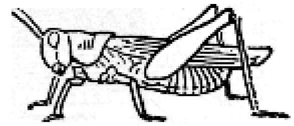


**Crustaceans** (Cambrian-Recent) include the crabs, lobsters, barnacles, ostracods, and shrimp (including Sea-Monkeys[a]). The vast majority of species are marine but some have spread into fresh water and onto the land. Their exoskeletons are calcified and greatly hardened, and unlike the insects, many of their appendages are biramous, or branched into two parts. Crustaceans are the arthropods you are most likely to have eaten (knowingly, anyway). A curious subdivision of the Crustaceans are the Cirripedia (barnaces) which are free-swimming as larvae, but cement themselves to rocks, ships, or whales in the adult stage, surrounded by a volcano-shaped shell -- hardly resembling arthropods at all!





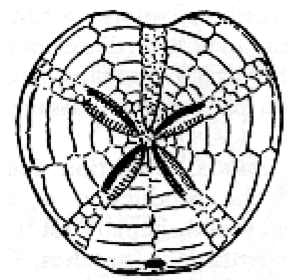
**Uniramians** include the centipedes, millipedes, and the insects. This is the most diverse group of animals on Earth, containing over 700,000 described species and perhaps up to ten times more that have not been described. The Uniramians are generally recognized by their **uniramous** (unbranched) appendages, as well as aspects of their jaw morphology. The **myriapods** (centipedes and millipedes) have several virtually identical body segments, each of which contains a single pair of legs. The **hexapods** (insects) have bodies which are divided up into three tagmata: the head, thorax, and abdomen. The thorax contains three pairs of legs, and in many cases, wings. The evolution of flight in insects probably facilitated their extensive radiation into habitats and microhabitats of all kinds.

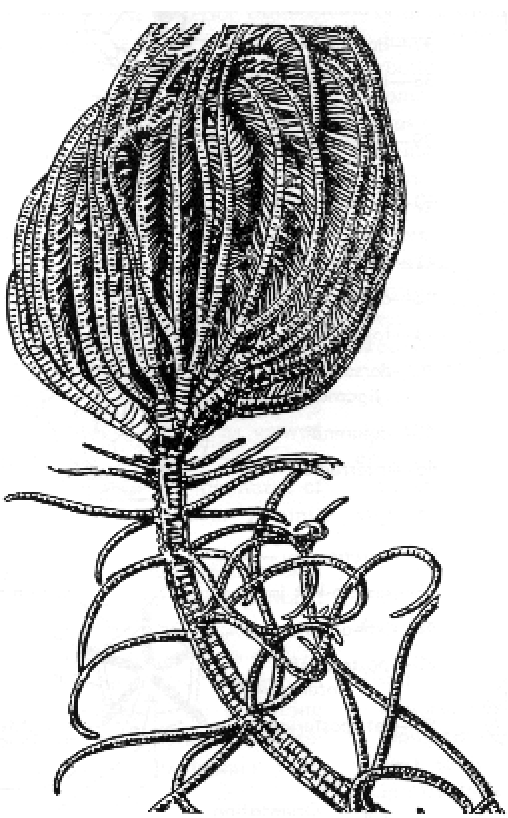


**Phylum Echinodermata** (Cambrian-Recent)

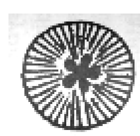
The echinoderms are a strictly marine group that is characterized by "**spiny skin**" (hence the name), and include the starfish, sea urchins, and sand dollars. They have skeletons made of interlocking calcium carbonate plates and can be recognized by their **pentameral**, or five-fold, symmetry. An interesting property of these animals is that they are capable of **regeneration** if part of their body is eaten or broken off. There are many groups of echinoderms described, but you will only be responsible for the following:

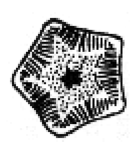
**Echinoids** include forms such as sea urchins, sand dollars, heart urchins, and sea biscuits. Echinoids that live on the surface have long, pronounced spines covering their bodies that are used for defense. Other types burrow in the sand and have only short spines.

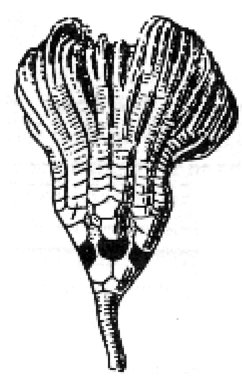




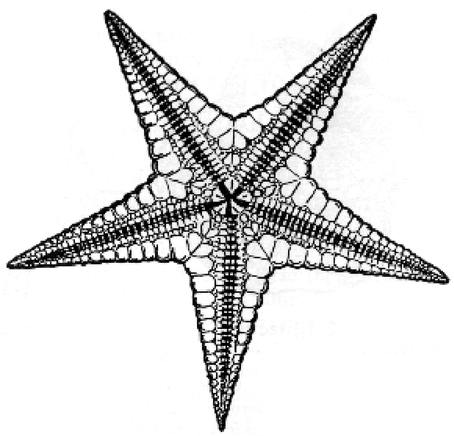
**Crinoids** were a very important group in the Paleozoic, though few varieties survive today. These are stalked echinoderms that had a globose head with an upward-pointing mouth surrounded by long arms. The head sat on a stem composed of stacked **ossicles**, each of which looks like a washer. Crinoid ossicles are extremely common fossils from Paleozoic rocks.

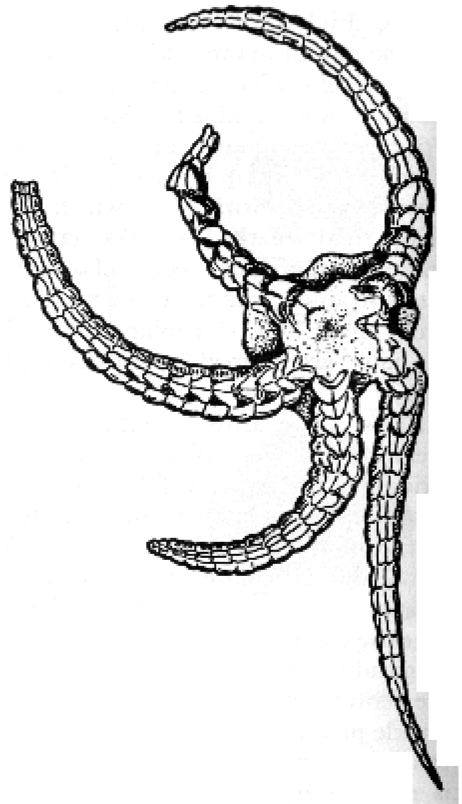






**Asteroids** are the starfish, characterized by thick arms that radiate out from a central disc. These arms are very strong and have tiny suction cups on the underside that are often used during feeding to pull apart the shell of a bivalve. The brittle stars are a related group that have very slender arms and a large central disc.





**Phylum Chordata and Related Groups**

The chordates are animals with a **notochord**, a stiff, flexible, organic rod that is the predecessor of our backbone. Chordates include our own subphylum, **Vertebrata** (mammals, birds, amphibians, fish, and reptiles), and a few other less obvious members like "sea squirts" and "acorn worms". A rare soft-bodied fossil called *Pikaia* from the Cambrian Burgess Shale (to be discussed in lecture) is thought by some to be the first known chordate.

An important fossil group called the **graptolites** are thought perhaps to be ancient relatives of the chordates. They are small, colonial organisms found in Paleozoic rocks, and look a bit like serrated sticks. They are typically preserved as thin films of carbon, so tilt the samples in the light to see them on the surface.