ered constantly by paleontologists, fossil animal species now outnumber living forms. Consequently, the classification of these animals and the interpretation of their relationships to the general evolutionary development of life forms have changed in the last couple of decades. The following classification scheme is merely a capsule summary of more detailed animal and plant classifications. There is no single taxonomic scheme that is agreed upon by all biologists and paleontologists.

PALEONTOLOGY

CLASSIFICATION AND DESCRIPTIONS OF SELECTED KINGDOMS, PHYLA, AND CLASSES

KINGDOMS: Monera, Protista, Animalia, Plantae

I. KINGDOM MONERA

Kingdom Monera consists of modern species of bacteria and cyanobacteria (photosynthetic bacteria also known as blue-green algae). All living members of Kingdom Monera consist of single, prokaryotic cells (very small cells having no nuclear wall or organelles). Ancient members of Kingdom Monera were the earliest fossil life forms and have been found in Archean rocks as old as 3.5 billion years. Mats of cyanobacteria form structures called stromatolites in modern intertidal tropical waters [see Fig. 4.14 (a)] and cyanobacteria also have been discovered in ancient stromatolite structures found in Archean and Proterozoic rocks.

In Figure 4.14 (a), a modern group of stromatolites grows in the shallow tidal waters of Shark Bay on the northwest coast of Australia. In this figure, the individual 2–3 foot wide stromatolites undergo a growth sequence, as shown in Figures 4.14 (b)–(d). At night the mat of algae is dormant [Fig. 4.14 (b)]. As sunlight increases, the algae begin to grow. As the wind and surf energy in the environment increase during the day, sediment is moved in the shallow water, with some being trapped in

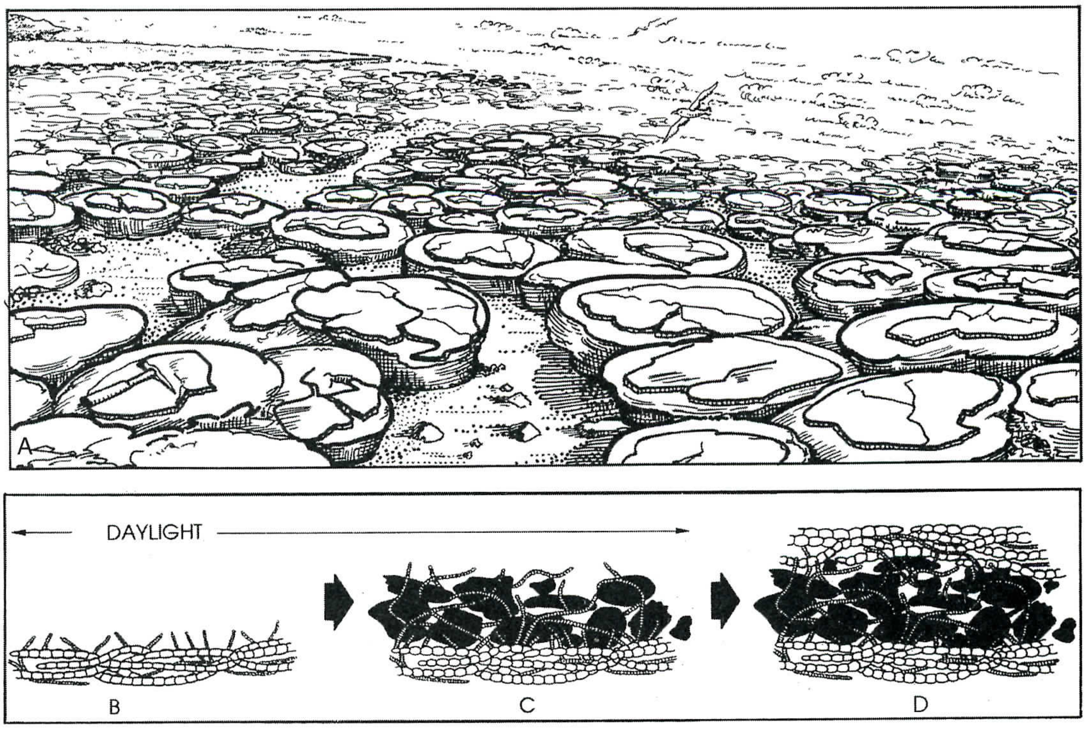


Figure 4.14 **(a)** Modern stromatolites, Shark Bay, eastern Australia (notice geologist's pick at lower left for scale). **(b), (c), (d)** Stromatolite growth sequence

the growing filaments of algae [Fig. 4.14 (c)]. During the late afternoon, the wind, surf, and sediment movement decrease, but the algae continue to grow until darkness. In this phase the algae growth binds the trapped sediment [Fig. 4.14 (d)].

II. KINGDOM PROTISTA

Members of Kingdom Protista consist of single eukaryotic cells (cells having a nuclear wall and organelles). Some members are photosynthetic and others (protozoa) must consume other protists. Four major types are discussed here: foraminifera, radiolaria, diatoms, and coccoliths (see Fig. 4.15).

A. Foraminifera

Foraminifera are a marine protista group in which some members are planktonic (zooplankton) and others are benthic. Foraminifera are protozoans that secrete tests of calcite or create tests of cemented silt grains (called agglutinated). The structure of the *test* is a single chamber or a series of chambers, and the size is about that of a grain of sand. Some fossil forms, such as *Nummulites*, were considerably larger. The protoplasm of the living cell extends out from the main opening, or aperture, and also from pores in the test (see Fig. 4.15). This external net of pseudopodia traps food particles for digestion inside the cell. Foraminifera reproduce by alternation of sexual and asexual phases.

In the Paleozoic era agglutinated foraminifera were most common. Wheat grain-sized calcareous forms with complex chamber structure, the fusulinids, are good index fossils for the late Paleozoic. Foraminifera with calcite tests were more common in the Mesozoic and Cenozoic. Foraminifera are extremely useful in biostratigraphy and can be used to subdivide geologic time into finer intervals called zones.

B. Radiolaria

Radiolaria are marine zooplankton that secrete a test of opaline silica in spherical, helmet-shaped, and spiny forms commonly with open pores. Radiolaria became abundant in the Mesozoic era. As in the foraminifera, the cell is protozoan, and pseudopodia extend from openings in the lattice of the test to trap food particles. Some radiolaria contain algae within their tissue, which supply them with oxygen. Radiolaria are smaller than foraminifera, closer to silt size, and are abundant in modern seas.

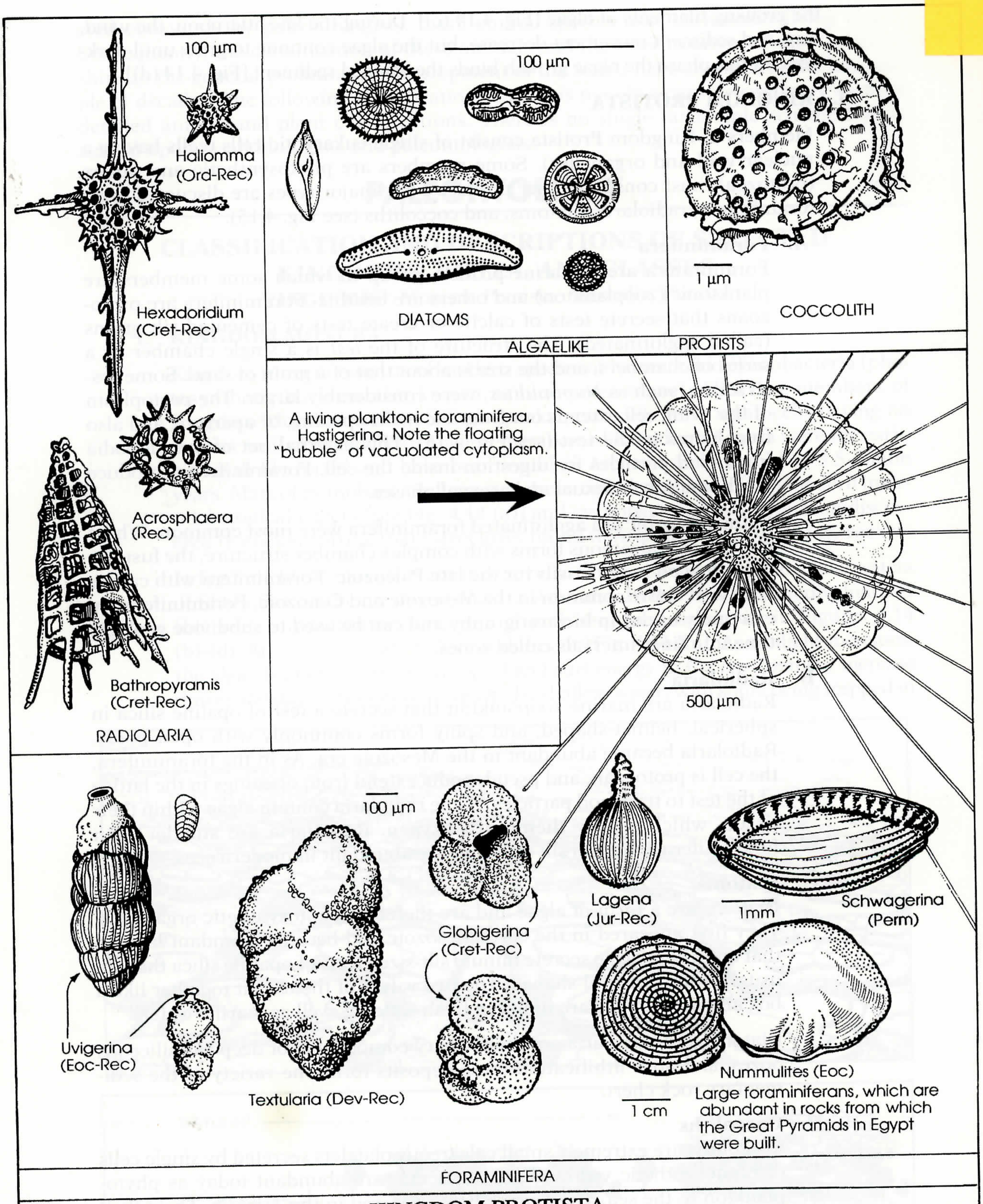
C. Diatoms

Diatoms are a form of algae and are therefore photosynthetic organisms. They first appeared in the early Mesozoic and became abundant later in that era. These algae secrete minute silt-sized tests of opaline silica that are usually round or oval-shaped. The two valves of the test fit together like a box and its lid. They are found in fresh water as well as marine waters.

Diatoms and radiolaria are the primary components of deep-sea siliceous oozes, and after lithification these deposits form one variety of the sedimentary rock chert.

D. Coccoliths

Coccoliths are extremely small calcareous platelets secreted by single cells of photosynthetic yellow-green algae that are abundant today as phytoplankton in the sea. These algae first appeared in the Triassic. Their shell fragments, along with foraminifera, are an abundant component of pelagic calcareous oozes. Coccolith platelets are the primary constituent of the sedimentary rock chalk. The chalk cliffs of Dover along the English Channel are composed mostly of coccoliths.



KINGDOM PROTISTA

III. KINGDOM ANIMALIA

Phylum Porifera

The phylum Porifera (see Fig. 4.16) consists of sponges, stromatoporoids, and possibly archaeocyathids. Members of this phylum are multicelled but have no true organs or tissues. They are mostly marine and range from Cambrian to Recent.

Sponges consist of two layers of cells separated by jellylike material containing amoeboid cells that carry on bodily functions and secrete skeletal components. The skeletons of sponges can be composed of collagen (organic fibers) or spicules of silica or calcite. Some sponges secrete a solid continuous skeleton of calcite or aragonite. The living tissue of the sponge surrounds a central cavity. The sponge draws in water through the pores in the outer layer. Food is trapped by collar cells that possess a flagellum and cilia, the food is digested and passed to the amoeboid cells, which distribute it to other body cells.

Archaeocyathids are an extinct group of early Paleozoic organisms that sometimes are classified with sponges and sometimes as a separate phylum. Their skeleton is composed of two cones, one inside the other, separated by vertical partitions called septae. The central cavity is open, like modern sponges. Archaeocyathids make excellent index fossils because they were very abundant in the early Cambrian period and became extinct by middle Cambrian [see Fig. 4.16 (c)].

Stromatoporoids are an extinct group of reef-building sponges from the Paleozoic. They are characterized by star-shaped grooves on their growth surface (astrorhizal canals). Their skeletons are preserved as calcite, but they may have originally been composed of aragonite [see Fig. 4.16 (d)].

Phylum Cnidaria (formerly Coelenterata)

Members of this phylum include the corals, sea anemones, and jellyfish and exist as polyps or medusae, or they alternate stages. The polyp stands on a base with mouth and tentacles extended upward. The medusa floats with mouth and tentacles extending downward. The phylum ranges in geologic time from late Precambrian to Recent (Fig 4.17).

Classes: Hydrozoa, Scyphozoa (hydra and jellyfish)

These classes are rare in fossil form and are not discussed here.

Class Anthozoa

This class includes the corals. Corals have a polyp stage only, with no medusa stage in the life cycle. Though some corals are soft and have no calcareous skeletons, hard corals secrete aragonite skeletons. The skeleton is tube-shaped, and has walls that extend upward as the polyp grows; the tube is called a corallite. As the polyp grows, it lifts its base and secretes a support plate beneath it. A flat plate is called a tabula, and small plates along the edge of the corallite are called dissepiments. In addition to the tabula and dissepiments, corals secrete radial plates that stand vertically between the folds of tissue at the base of the polyp. These vertical walls, or septae, look a little like the section dividers in a grapefruit. Hard corals are either solitary or colonial. Solitary corals have corallites that are not attached to any other corallite. In colonial corals, the corallites are attached to one another, forming colonies of various sizes and shapes.

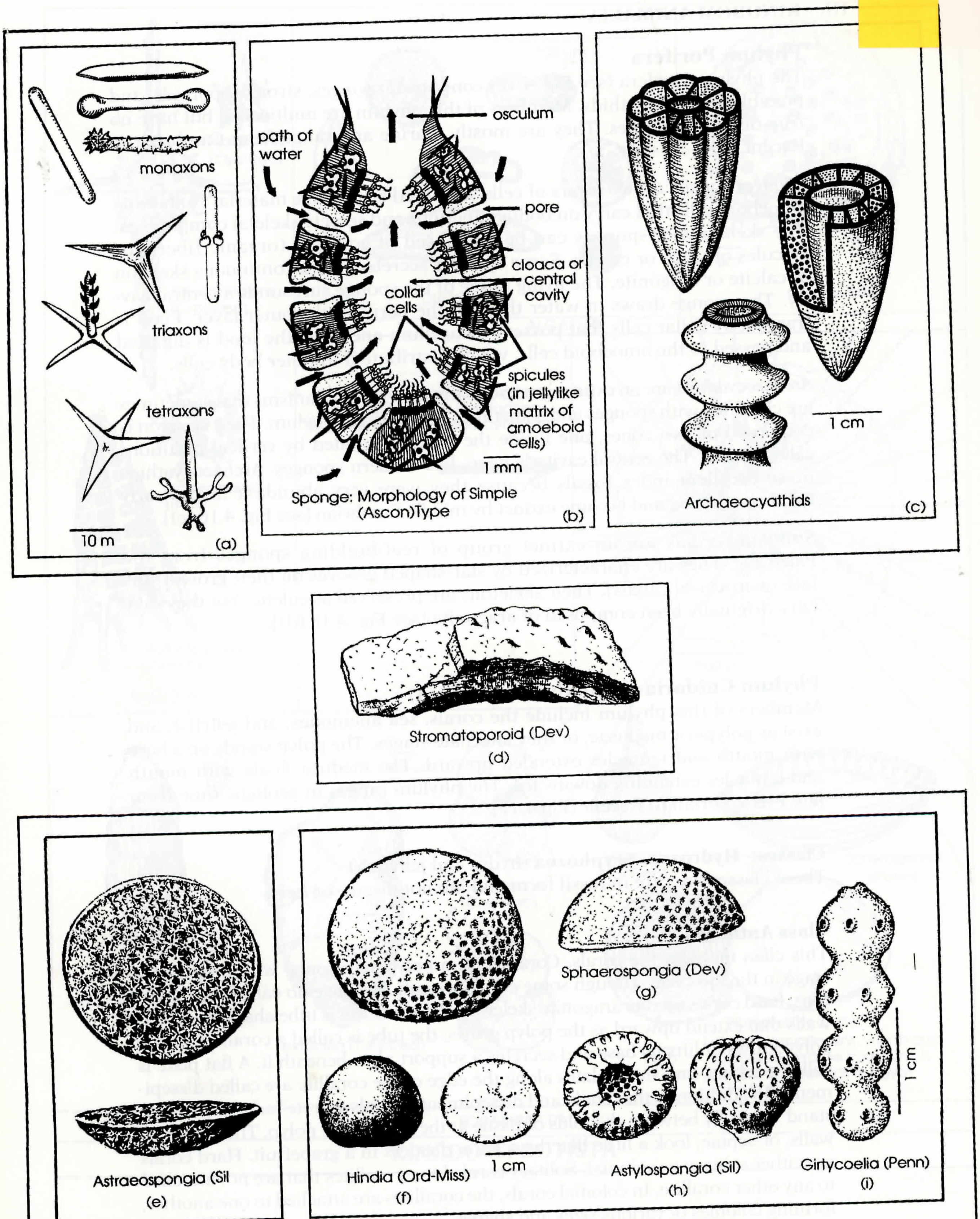


Figure 4.16 Phylum Porifera

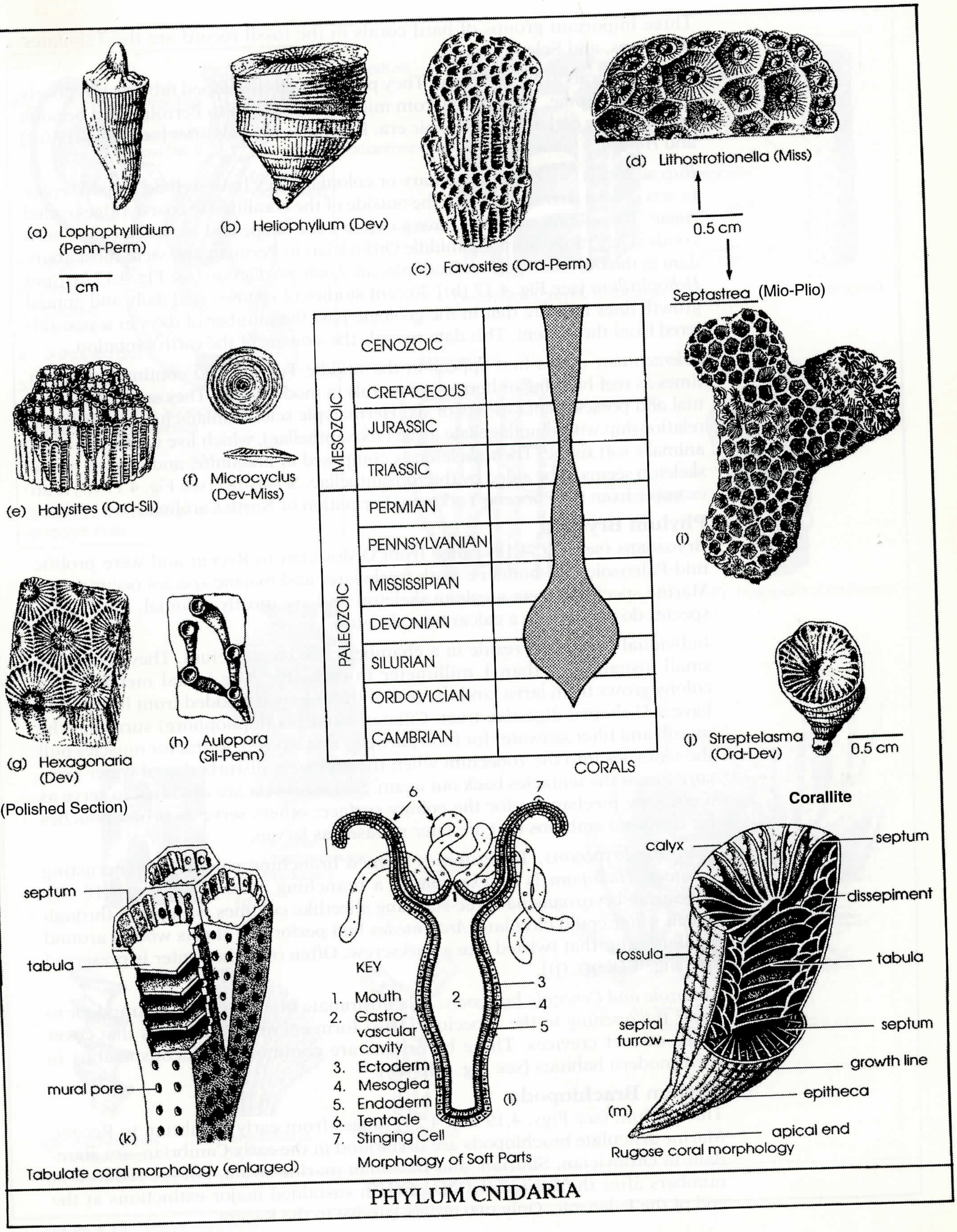


Figure 4.17 Phylum Cnidaria

Three important groups of hard corals in the fossil record are the Tabulates, Rugosans, and Scleractinians.

Tabulate corals are all colonial. They possess well-developed tabulae but poorly developed septae. They range from middle Ordovician to Permian and became extinct at the end of the Paleozoic era. Examples are *Favosites* [see Fig. 4.17 (c)] and *Halysites* [see Fig. 4.17 (e)].

Rugose corals can be either solitary or colonial. They have well-developed septae in sets of four (tetracorals). On the outside of the corallite are coarse ridges called rugae. The solitary rugosans have a cup or cone shape and are often called horn corals. They range from the middle Ordovician to Permian and were most abundant in the Devonian period. Examples are *Lophophyllidium* [see Fig. 4.17 (a)] and *Heliophyllum* [see Fig. 4.17 (b)]. Recent studies of rugose coral daily and annual growth lines indicate that in the geologic past the number of days in a year differed from the present. This data records the slowing of the earth's rotation.

Scleractinian corals first appear in the middle Triassic and continue to recent times as reef-building or hermatypic corals in modern seas. They are mostly colonial and possess septa in sets of six. Hermatypic scleractinians have a symbiotic relationship with dinoflagellate algae (zooxanthellae), which live within the coral animal's soft tissue. Their skeleton is composed of aragonite, and growth of the skeleton seems to be aided by the zooxanthellae. *Septastrea* [see Fig. 4.17 (i)] is an example from the Pliocene Yorktown Formation of North Carolina.

Phylum Bryozoa

Bryozoans (see Fig. 4.18) range from Ordovician to Recent and were prolific mid-Paleozoic reef-builders. Both freshwater and marine species occur today. Marine species secrete a calcite skeleton and are mostly colonial. Freshwater species do not secrete a calcareous skeleton.

Individual bryozoans reside in a chamber called a zooecium. They are rather small, usually less than 1 millimeter in diameter. The initial member of a colony grows from larva, and the rest of the colony is budded from it. Bryozoa have a U-shaped digestive tract. Ciliated tentacles (lophophore) surround the mouth and filter seawater for food particles and oxygen. Retractor muscles pull the tentacles into the zooecium when the animal is disturbed, and water pressure forces the tentacles back out again. Some zooecia are modified to serve as a cleaning mechanism for the colony surface; others serve as brood pouches for fertilized embryos that are later released as larvae.

Paleozoic bryozoans. Trepostomes formed branching colonies or encrusting colonies. *Hallopora* is an example of a branching colony [see Fig. 4.18 (f)]. Fenestrate bryozoans had free-standing sheetlike colonies with pores through which water could circulate. *Archimedes* had perforated sheets wound around a solid center that twisted like a corkscrew. Often only the center is preserved [see Fig. 4.18 (g), (j)].

Mesozoic and Cenozoic bryozoans. Cheilostomate bryozoans have a trapdoor to cover the opening to the zooecium. Most form encrusting colonies that cover shells or reef crevices. These bryozoans are common but inconspicuous in their modern habitats [see Fig. 4.18 (d)].

Phylum Brachiopoda

This phylum (see Figs. 4.19 and 4.20) ranges from early Cambrian to Recent. Marine articulate brachiopods are first found in the early Cambrian, are abundant in Ordovician, Silurian, and Devonian marine strata, but are reduced in numbers after the Devonian. The phylum sustained major extinctions at the end of the Paleozoic. Only two orders survive to the Recent.

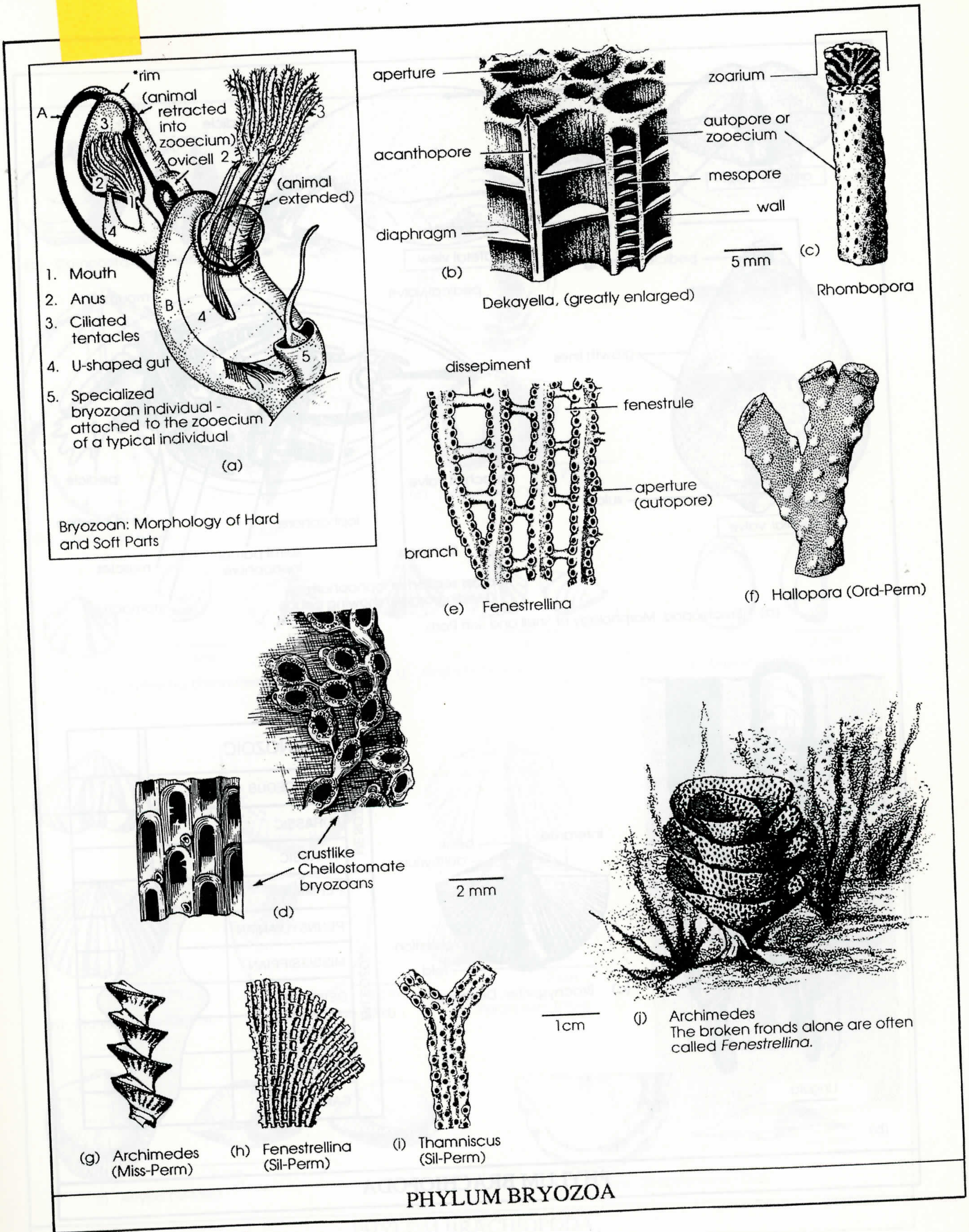
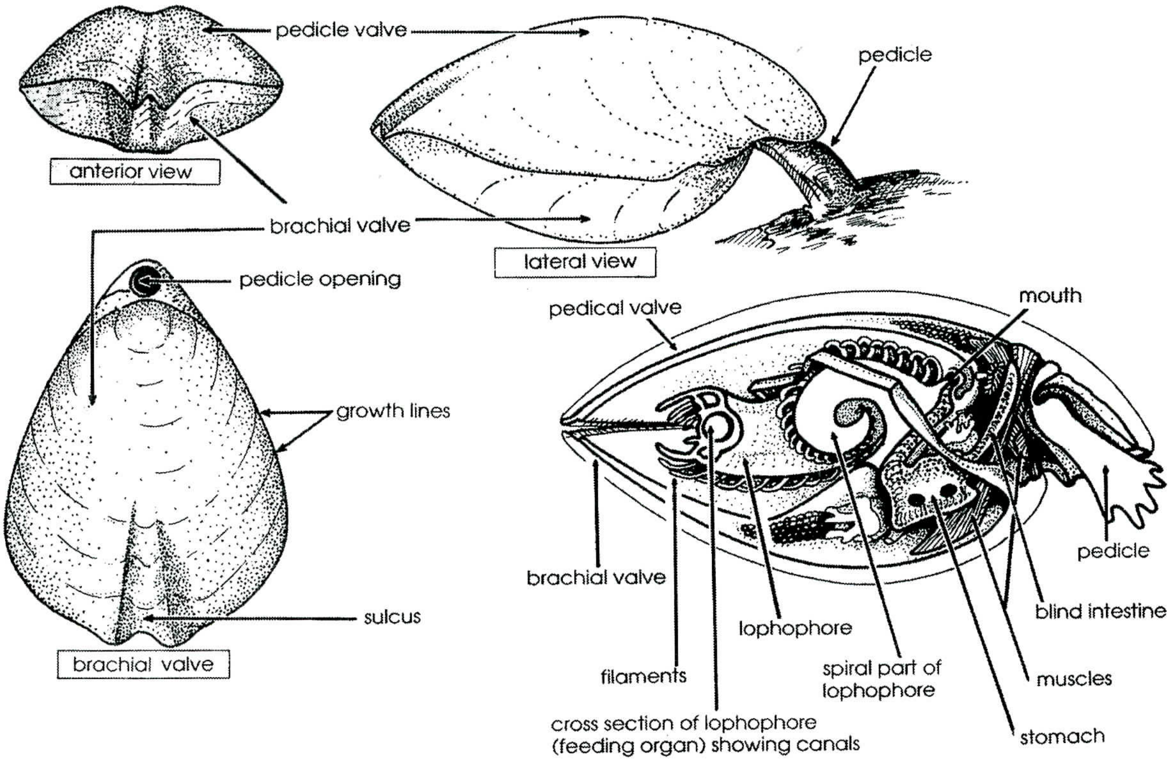
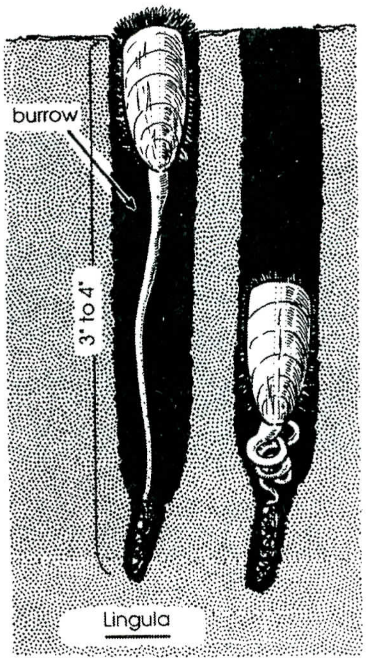


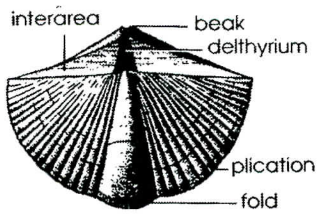
Figure 4.18 Phylum Bryozoa



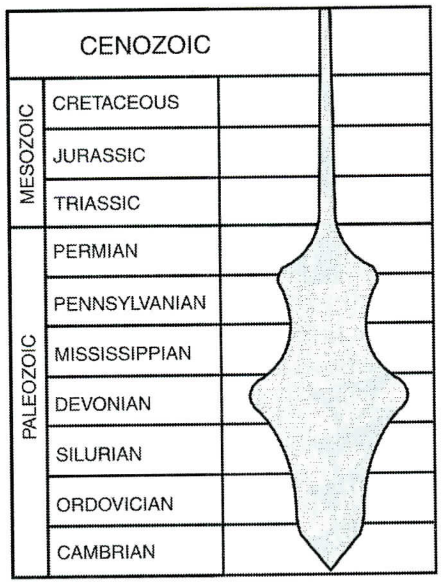
(a) Brachiopod: Morphology of Shell and Soft Parts



(b)



(c) Brachyspirifer, Devonian



PHYLUM BRACHIOPODA

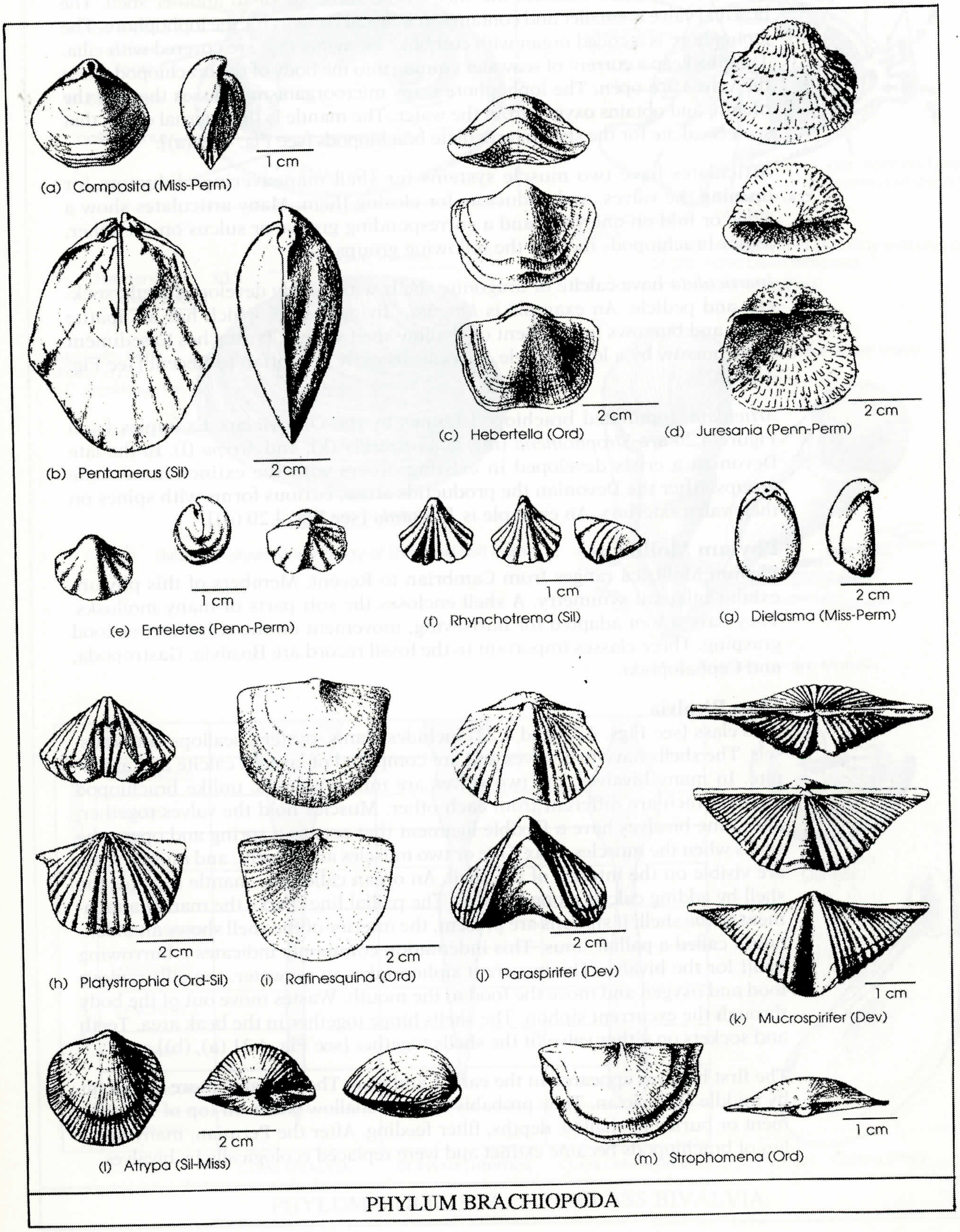


Figure 4.20 Phylum Brachiopoda

Brachiopods are bivalved, with the plane of symmetry running through the center of each valve. The pedicle valve is the larger and often has an opening for the pedicle, or stalk, which attaches the shell to the substrate or to another shell. The brachial valve is smaller and contains an internal support for the lophophore. The lophophore is a coiled organ with comblike filaments that are covered with cilia. The cilia keep a current of seawater coming into the body of the brachiopod when the valves are open. The lophophore traps microorganisms, passes them to the mouth, and obtains oxygen from the water. The mantle is the internal organ that secrets calcite for the shell in articulate brachiopods [see Fig. 4.19 (a)].

Articulates have two muscle systems for shell maneuvering, diductors for opening the valves, and adductors for closing them. Many articulates show a ridge or fold on one valve and a corresponding groove or sulcus on the other. Major brachiopods include the following groups.

Inarticulata have calcite or aragonite shells with poorly developed teeth, sockets, and pedicle. An example is *Lingula*, "living fossil," which has an apatite shell, and burrows in sediment of shallow shelf waters. It attaches to sediment in its burrow by a long pedicle. Its range is early Cambrian to Recent [see Fig. 4.19 (b)].

Articulata dominated brachiopod faunas by the Ordovician. Examples from Figure 4.20 are *Strophomena* (m), *Mucrospirifer* (k), and *Atrypa* (l). In the late Devonian a crisis developed in existing orders with the extinction of some groups. After the Devonian the productids arose, curious forms with spines on their valve exteriors. An example is *Juresania* [see Fig. 4.20 (d)].

Phylum Mollusca

Phylum Mollusca ranges from Cambrian to Recent. Members of this phylum exhibit bilateral symmetry. A shell encloses the soft parts of many mollusks. They have a foot adapted for burrowing, movement on the substrate, or food grasping. Three classes important in the fossil record are Bivalvia, Gastropoda, and Cephalopoda.

Class Bivalvia

This class (see Figs. 4.21 and 4.22) includes clams, oysters, scallops, and mussels. The shells have two valves and are composed of layered calcite and aragonite. In many bivalves, the two valves are mirror images, unlike brachiopod valves, which are different from each other. Muscles hold the valves together, and some bivalves have a flexible ligament that acts as a spring and opens the shells when the muscles relax. One or two muscles are present, and muscle scars are visible on the interior of the shell. An organ called the mantle secretes the shell by adding calcite along its edge. The pallial line marks the mantle attachment to the shell. If siphons are present, the interior of the shell shows an indentation called a pallial sinus. This indentation commonly indicates a burrowing habit for the bivalve. The incurrent siphon takes in seawater, the gills remove food and oxygen and move the food to the mouth. Wastes move out of the body through the excurrent siphon. The shells hinge together in the beak area. Teeth and sockets on either valve fit the shells together [see Fig. 4.21 (a), (b)].

The first bivalves appeared in the early Cambrian. They became more abundant by middle Ordovician. They probably lived in shallow water on top of the sediment or buried at shallow depths, filter feeding. After the Permian, many families of brachiopods became extinct and were replaced ecologically by bivalves.

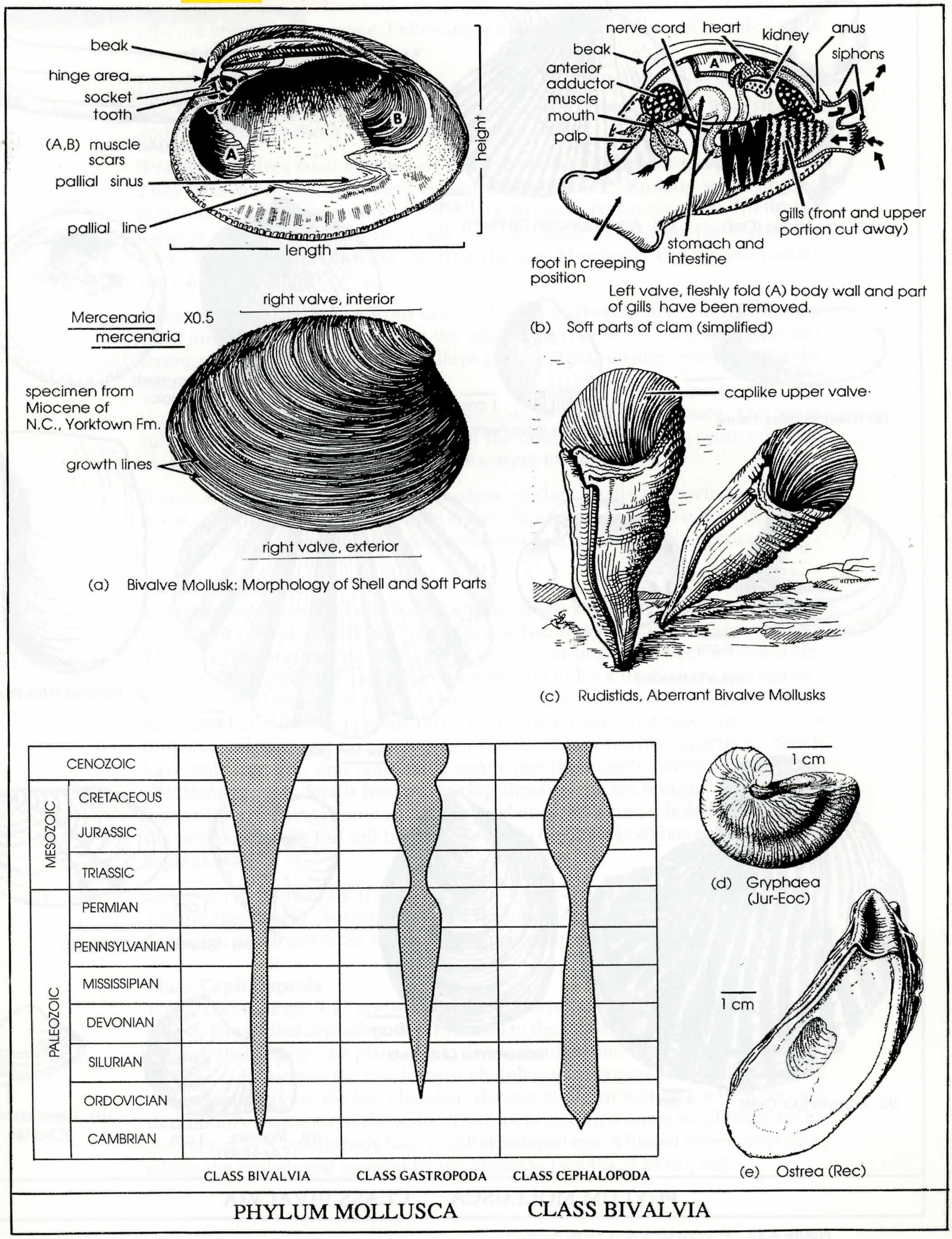


Figure 4.21 Phylum Mollusca, class Bivalvia

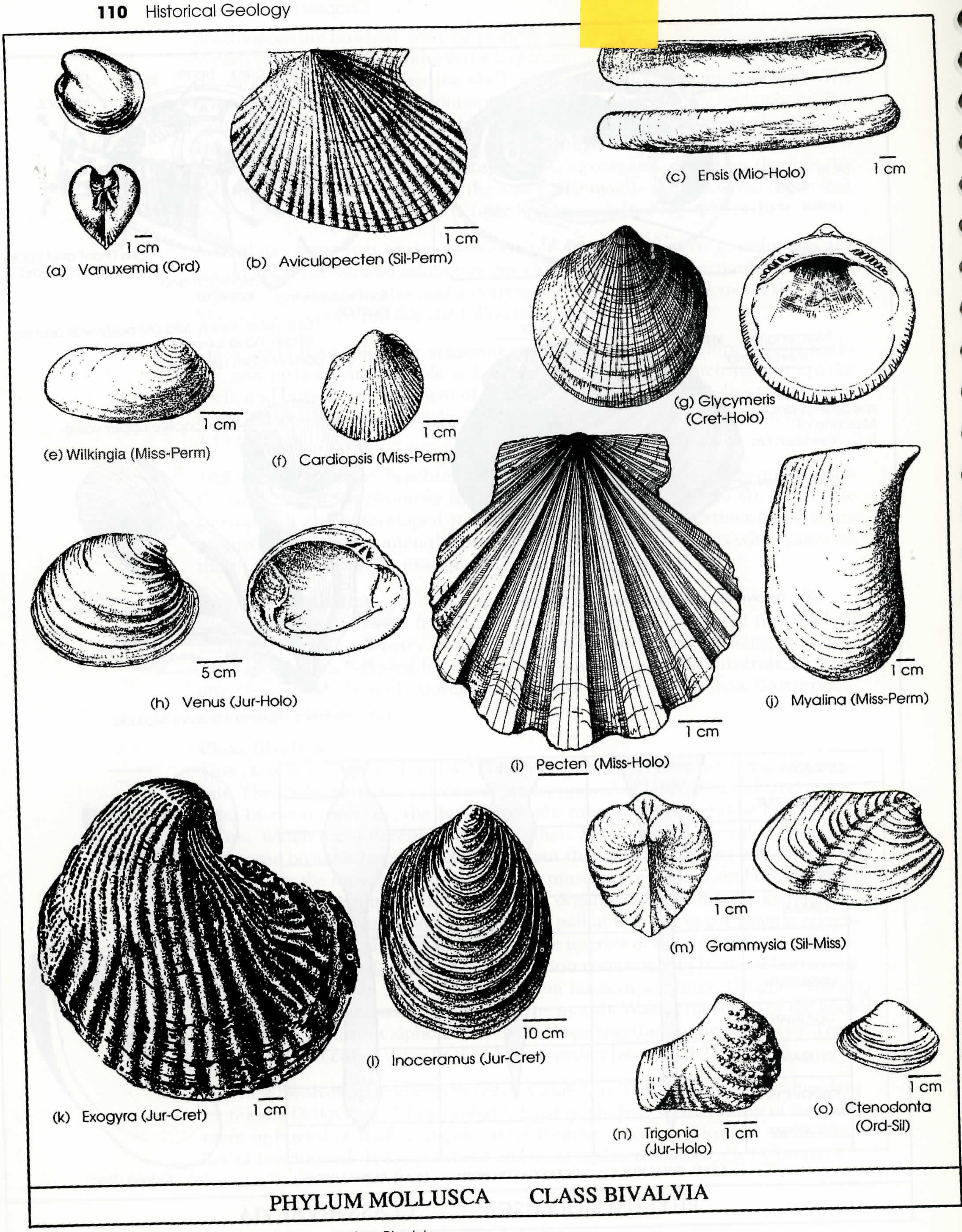


Figure 4.22 Phylum Mollusca, class Bivalvia

During the Mesozoic and Cenozoic, burrowers were more abundant, and scallops made their appearance. Following is a discussion of some of the life habits of members of the class Bivalvia.

Deep burrowers are clams with long siphons to reach the sediment-water interface from the deep burrow. The valves gape to accommodate the long siphons and the siphons cannot be retracted into the shell.

Attached bivalves such as mussels range from late Paleozoic to recent times. They attach by byssus fibers to sediment or rock. Rudists were unique attached bivalves that ranged from late Jurassic to Cretaceous. The lower valve is conical (like a horn coral) and the upper valve caps the top of the cone. They were reef-builders during the late Mesozoic. The largest rudists were 6 feet in length.

Swimming scallops range from Carboniferous to Quaternary. They lie on one valve and can move by snapping the valves together with a single muscle and jetting water from the mantle. Scallops possess light-sensing "eyes" around the outer edge of the mantle.

Cemented oysters range from late Paleozoic to recent Quaternary. The lower valve grows to conform to the shape of the object to which it is cemented, and oysters can form banks or reefs by cementing to each other.

Borers are clams with rough front edges on their shells for boring into rock, wood, or other shells. An example is the shipworm, *Teredo*. To help in boring into hard substances, some of these bivalves secrete corrosive chemicals.

Class Gastropoda

This class (see Figs. 4.23 and 4.24) includes snails and slugs. Snails have left the best fossil record. Snails are found in marine and fresh waters and on land. They are the most diverse and abundant class of mollusks. They secrete a single, spirally coiled shell, and their anatomy includes a head, eyes, and sensory tentacles. Snails move along on a foot and feed with a toothlike organ called a radula. When disturbed, snails retract into their shells, and many have a cover (operculum) that can be positioned over the shell opening (aperture). Snails have only one gill, and land-living snails use the mantle cavity as a lung for obtaining oxygen. Snails feed by grazing algae off the sea bottom, deposit feeding, or filter feeding. Some snails are predatory, scraping a hole in the shell of the prey and eating the soft tissue. One snail (the pteropod) has a thin shell and is planktonic.

Snails first appear in the fossil record in earliest Cambrian strata (the Tommotian stage), but they did not become abundant until the Ordovician. Terrestial and freshwater snails first appeared in the Devonian.

Class Cephalopoda

This class (see Figs. 4.25 and 4.26) includes the nautilus, octopus, squid, and cuttlefish. The shelled cephalopods are related to the modern nautilus and have a single shell that coils in one plane. Septa divide the shell into chambers. A tube called a siphuncle connects the last-formed chamber with previous ones. The body of the animal occupies the last chamber; the rest are filled with gas, which controls the animal's buoyancy in the water. The foot is modified into a set of tentacles for grasping prey. Cephalopods have a well-developed eye. A funnel for jet propulsion allows the cephalopod to swim in any direction [see Fig. 4.25 (a), (c)].

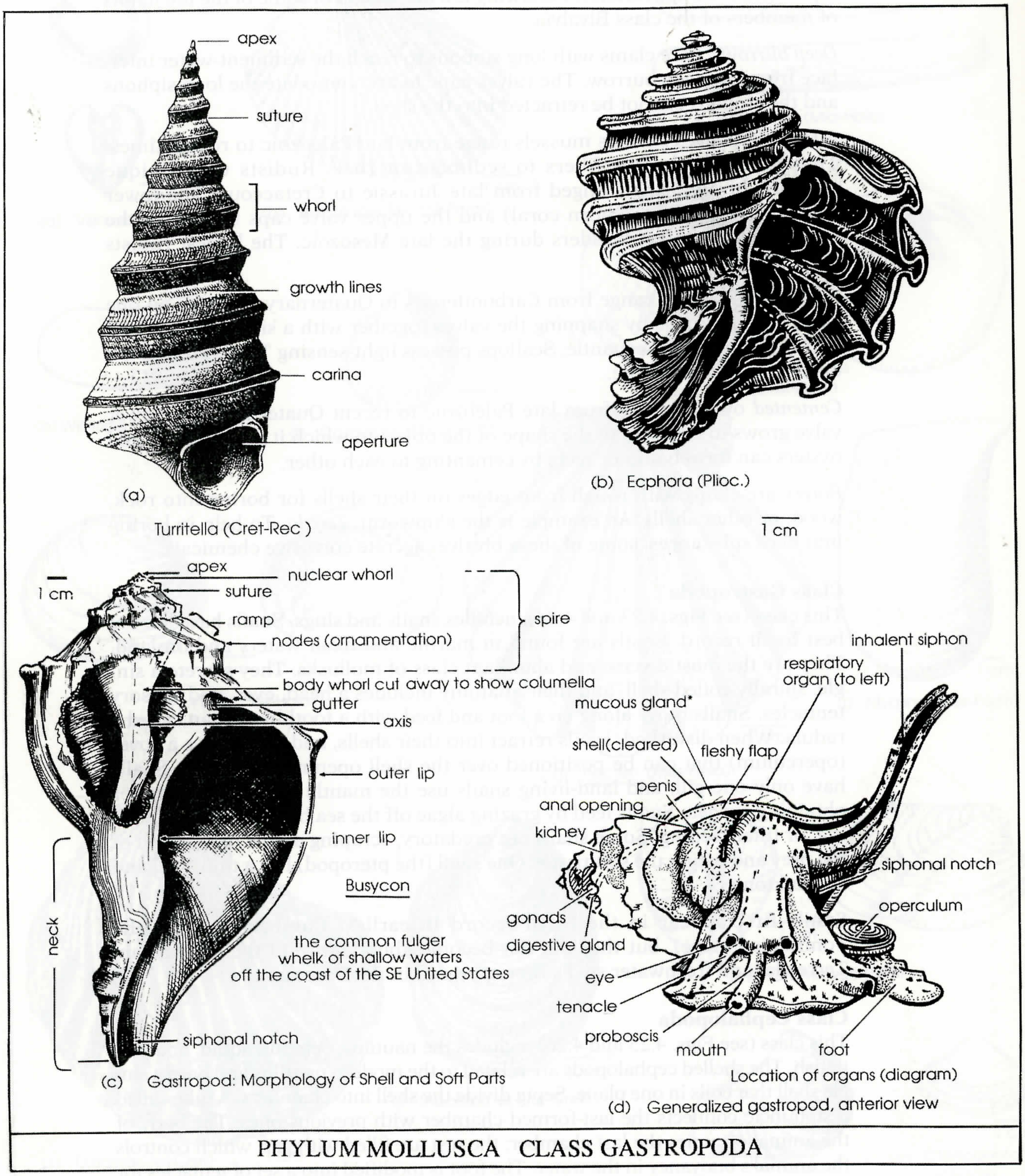


Figure 4.23 Phylum Mollusca, class Gastropoda

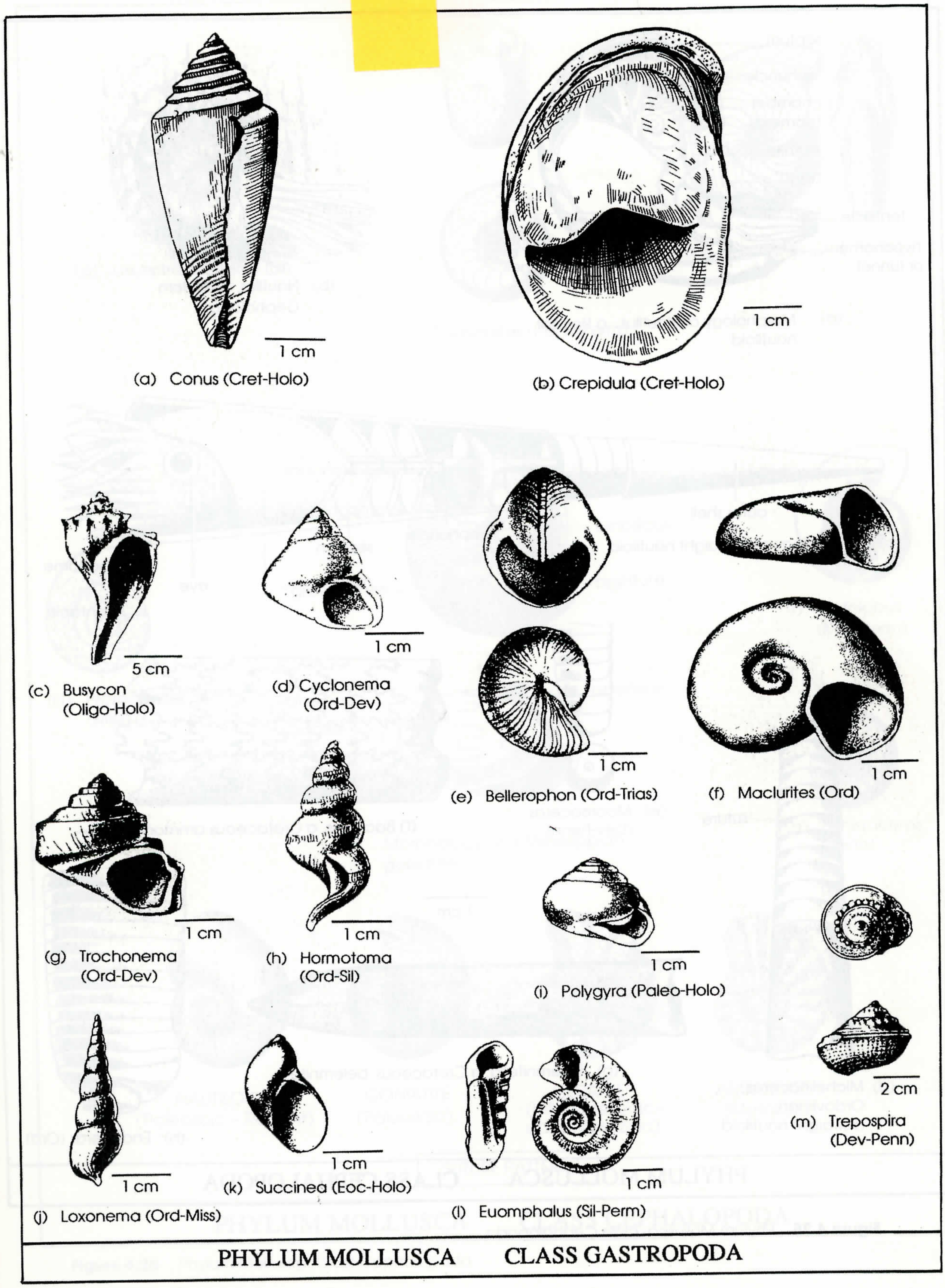


Figure 4.24 Phylum Mollusca, class Gastropoda

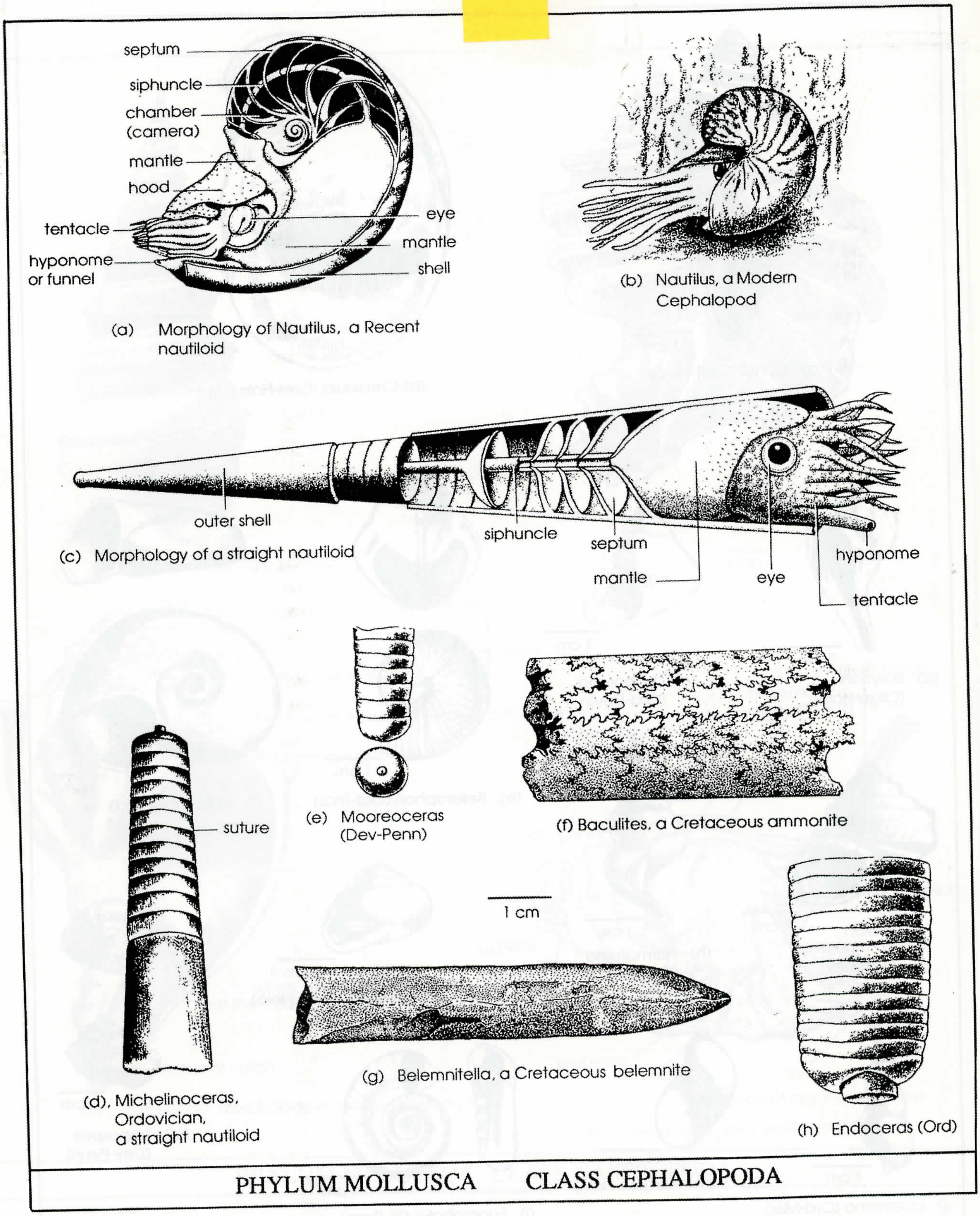


Figure 4.25 Phylum Mollusca, class Cephalopoda

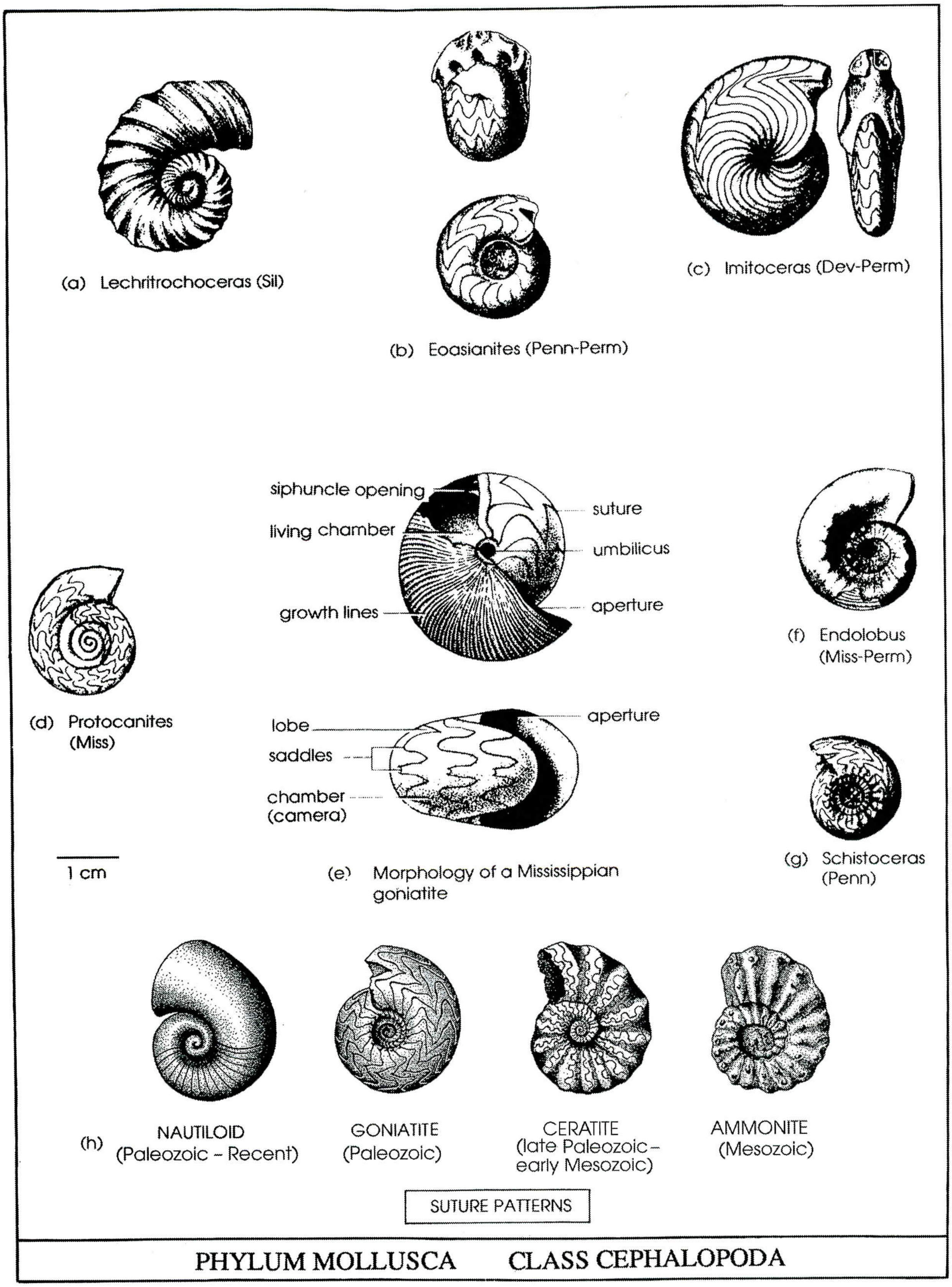


Figure 4.26 Phylum Mollusca, Class Cephalopoda

Early Paleozoic cephalopods were mostly straight-shelled and attained a length of up to 27 feet. Later cephalopods developed a coiled shell. Four major suture patterns developed in cephalopods, reflecting the nature of the interface between the septa and the chamber wall:

1. *Nautiloid*. This straight suture pattern is exhibited in cephalopods from Paleozoic to recent times.
2. *Goniatite*. This pattern consists of curved sutures and is found only on Paleozoic cephalopods.
3. *Ceratite*. This curved and crenulated pattern is found on cephalopods from the late Paleozoic to the early Mesozoic.
4. *Ammonite*. This highly crenulated pattern is found only on Mesozoic cephalopods. Ammonites became extinct with many other groups of organisms at the end of the Mesozoic.

Belemnites were relatives of the modern squid and possessed cigar-shaped internal calcite supports that are found as fossils in late Mesozoic and early Cenozoic strata.

Phylum Arthropoda

Arthropoda (see Figs. 4.27 and 4.28) possess an exoskeleton or carapace made of protein. In marine arthropods the carapace is reinforced with calcium carbonate or phosphate. The segmented body is divided into three major sections: head, thorax, and tail. Each segment usually has a pair of jointed appendages, specialized for feeding, sensory, or locomotive functions. In marine arthropods, respiration occurs by gills; in terrestrial arthropods air enters by pores leading to internal tubes. In order to grow, arthropods must shed their exoskeleton and secrete larger ones (molting). Arthropods have a well-developed nervous system and an open circulatory system with a heart, but they have no extensive blood-vessel system. The four main classes of arthropods are Uniramia, Chelicerata, Crustacea, and Trilobita:

Class Uniramia

This class consists of onychophorans, centipedes, and insects. Most of the Uniramia have a poor fossil record, but occasional insect specimens are found preserved in amber.

Class Chelicerata

Horseshoe crabs, eurypterids, scorpions, and spiders are chelicerates (see Fig. 4.27). Eurypterids (sea scorpions) lived in marine, brackish, and freshwater environments and can be found in rocks of lower Ordovician to Permian age. They are most common as fossils in the Silurian. The largest eurypterids attained a length of nearly nine feet. Other members of Chelicerata are poorly preserved as fossils.

Class Crustacea

This class includes ostracodes, barnacles, crabs, and lobsters (see Fig. 4.27). Only the ostracodes are common as fossils. Ostracodes are bivalved arthropods with shells of chitin and calcite. Their jointed legs can extend between the valves for feeding, swimming, and crawling. Individuals are very small, about 1 millimeter in size. They live in marine and freshwater environments, most commonly in shallow water. Ostracodes range in time from lower Cambrian to Recent. They are abundant in Paleozoic carbonate rocks and some species are useful as index fossils.

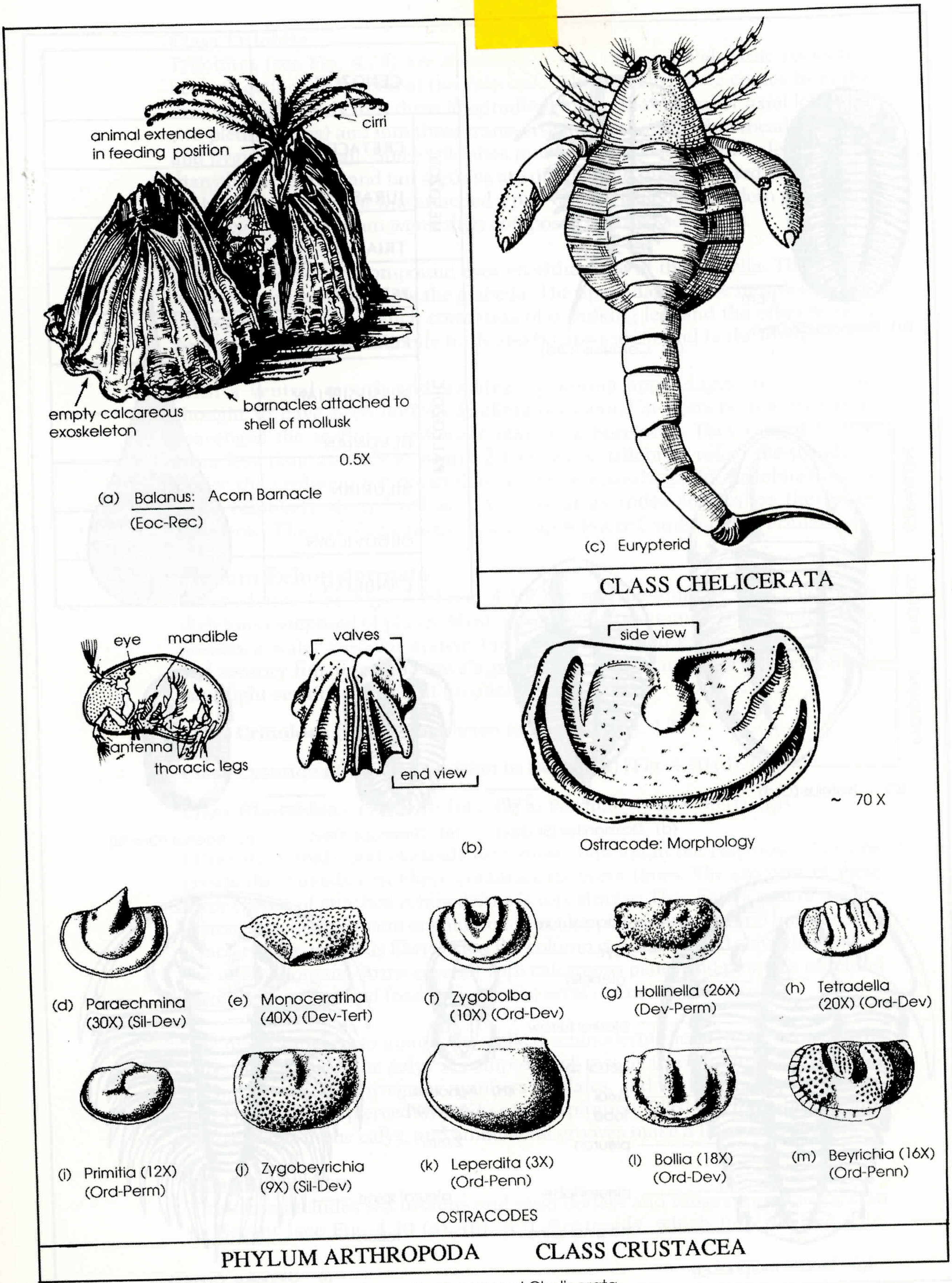


Figure 4.27 Phylum Arthropoda, classes Crustacea and Chelicerata

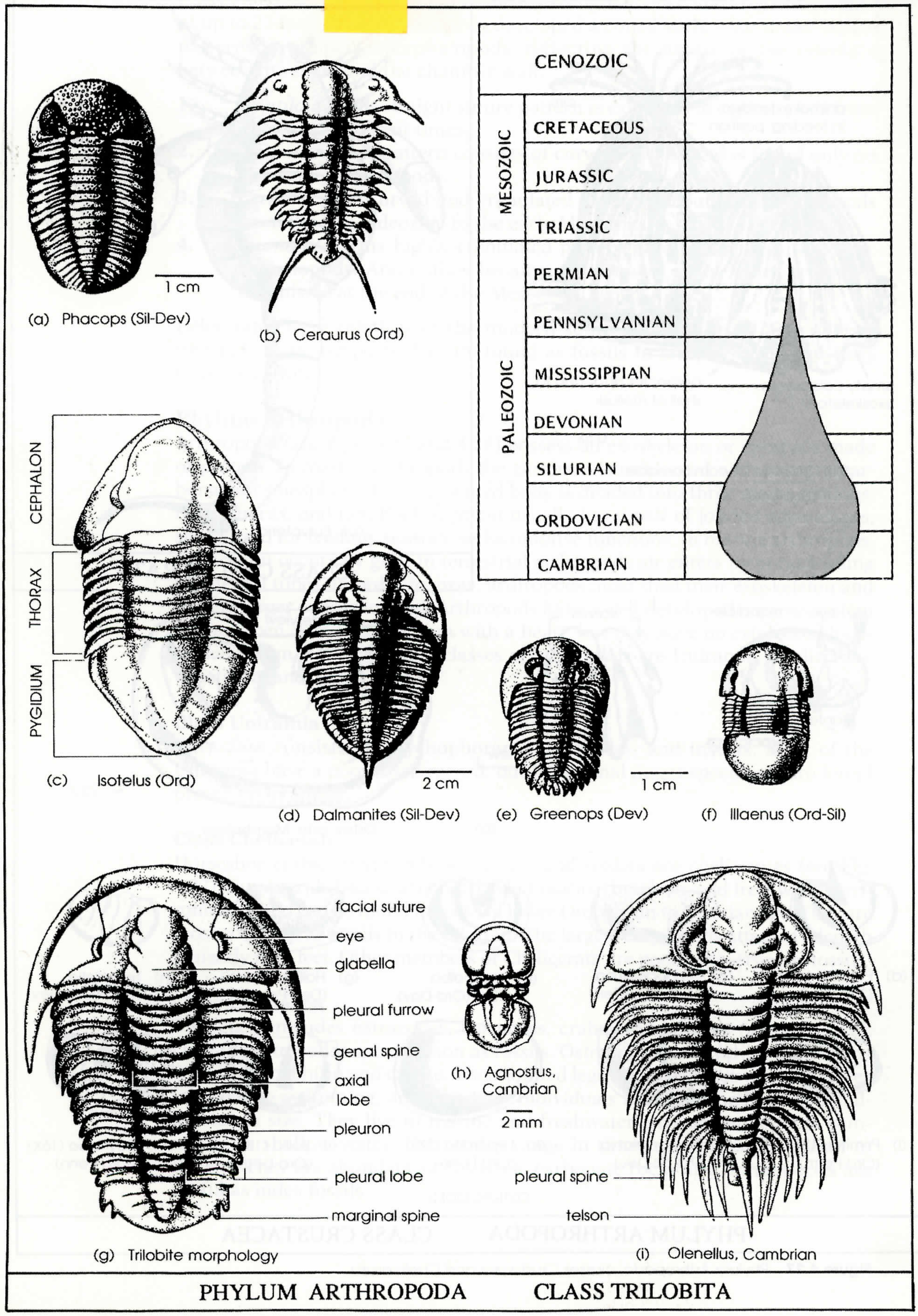


Figure 4.28 Phylum Arthropoda, class Trilobita

Class Trilobita

Trilobites (see Fig. 4.28) are abundant fossils in lower Paleozoic rocks but became extinct at the end of the Paleozoic. The name trilobite comes from the division of the body into three longitudinal lobes (the central or axial lobe and two pleural lobes) and into three transverse lobes, the cephalon (head), thorax, and pygidium, or tail. Since trilobites molted their skeletons in order to grow, many head, thorax, and tail sections are often found disarticulated in rocks. To each thoracic segment was attached a pair of legs, which are seldom preserved. The head and pygidium were often composed of fused segments.

Trilobites possessed compound eyes on either side of the glabella. The mouth is on the ventral side below the glabella. The appendages were biramous (two-branched) with one branch consisting of a walking leg, and the other branch having a gill. Definite trilobite trails and burrows are found in the fossil record.

With a ventral mouth and walking/swimming appendages, trilobites are thought to have been bottom-dwelling occasional swimmers that grazed or scavenged the seafloor, and some may have burrowed. They ranged in size from less than an inch to nearly 2 feet. Some trilobites rolled the pygidium under the cephalon for protection, as modern sowbugs do. Trilobite species were relatively short-lived and are useful as index fossils for the lower Paleozoic. Their geologic range as a group is lower Cambrian to Permian.

Phylum Echinodermata

Echinoderms (see Figs. 4.29 and 4.30) are marine animals with calcareous skeletons composed of plates. Most have fivefold (pentameral) symmetry. They possess a water vascular system for locomotion, food gathering, respiration, and sensory functions and have a poorly developed circulatory system. Some have light-sensitive cells that function as simple eyes.

Class Crinoidea (middle Cambrian to Recent) (Fig. 4.29)

Class Cystoidea (lower Ordovician to Devonian) [Fig. 4.30 (d), (e)]

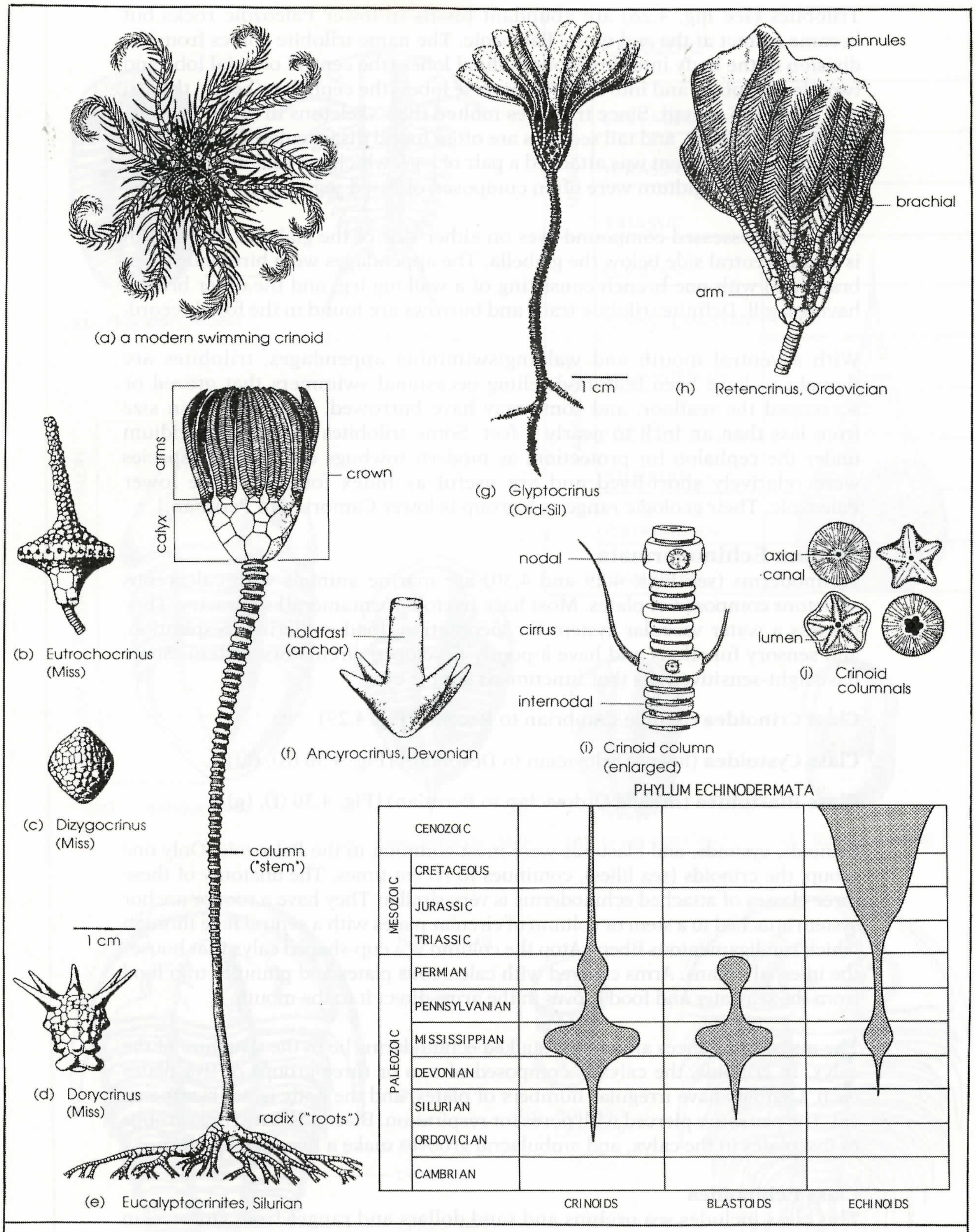
Class Blastoidea (middle Ordovician to Permian) [Fig. 4.30 (f), (g)]

Crinoids, cystoids, and blastoids were most common in the Paleozoic. Only one group, the crinoids (sea lilies), continues to recent times. The anatomy of these three classes of attached echinoderms is very similar. They have a root or anchor system attached to a stem or column of circular plates with a central hole through which run ligamentous fibers. Atop the column is a cup-shaped calyx that houses the internal organs. Arms covered with calcareous plates and pinnules trap food from the seawater and food groves in the arms direct it to the mouth.

The major differences among the stalked echinoderms lie in the structure of the calyx. In crinoids, the calyx is composed of two or three groups of five plates each. Cystoids have irregular numbers of plates, and the body is not symmetrical. The plates are pierced with pores for respiration. Blastoids have three groups of five plates in the calyx, and ambulacral grooves make a five-rayed pattern.

Class Echinoidea

This class includes sea urchins and sand dollars and ranges from Ordovician to Recent [see Fig. 4.30 (a), (b), (c)]. Echinoids, which fall into two cate-



PHYLUM ECHINODERMATA

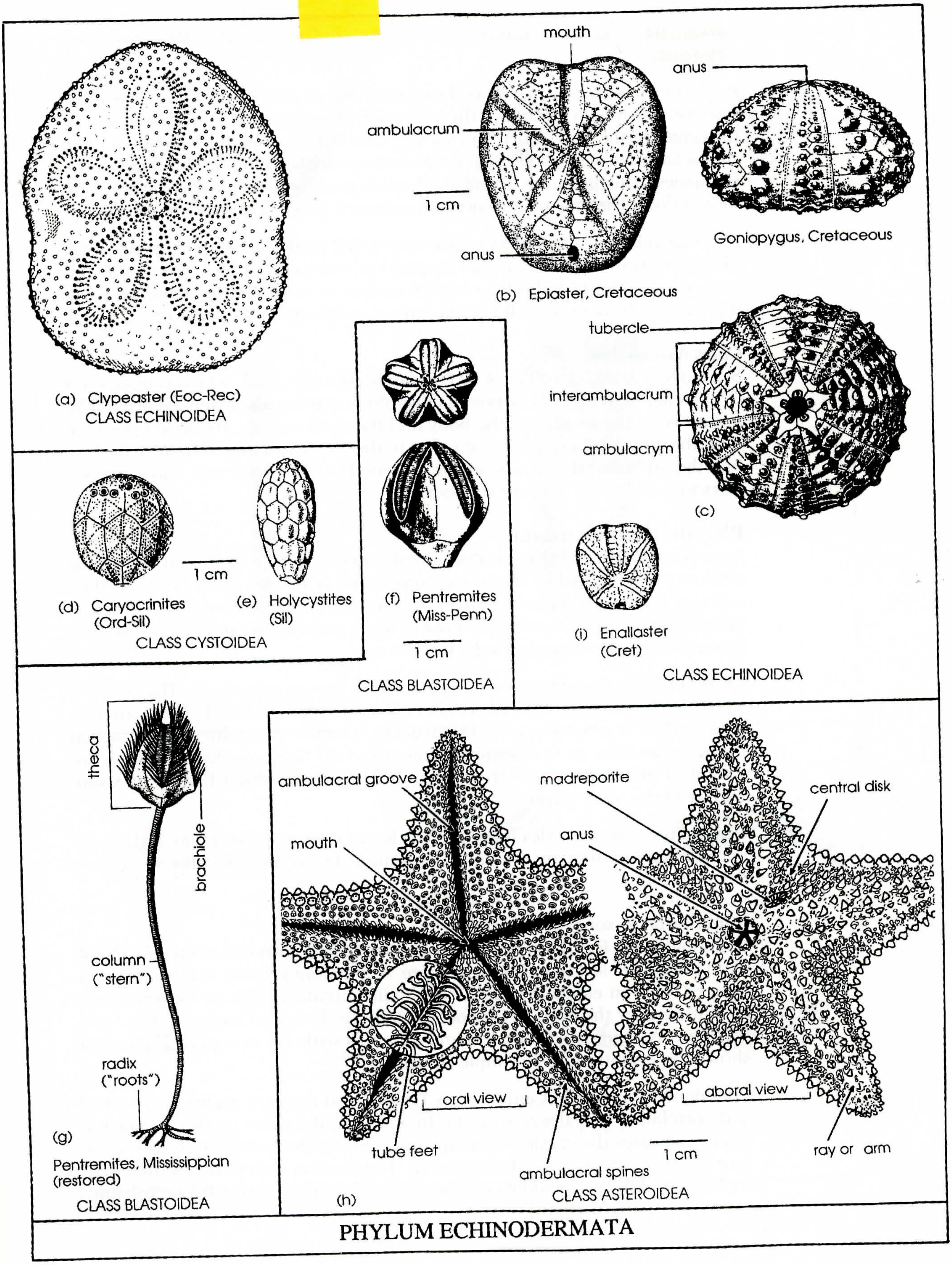


Figure 4.30 Phylum Echinodermata

gories, irregular and regular, are most common in the Mesozoic and Cenozoic.

Regular echinoids have pentameral symmetry and move in all directions across the seafloor. The mouth is found at the center of the bottom surface and the anus is at the center of the top surface. Spines and tube feet are used for locomotion. The spines are attached to body plates with ball-and-socket joints, and muscles move the spines in all directions. Regular echinoids graze on algae or scavenge flesh on the sea floor. Their spines are common sediment components in some strata.

Irregular echinoids have bilateral symmetry, and tend to be heart shaped or oval. They burrow in sediment and are suspension or deposit feeders. The mouth and anus are at opposite ends of the bottom surface. Sand dollars are flattened irregular echinoids that live under a thin layer of sediment on the sea floor.

Class Asteroidea

Sea stars (starfish) [see Fig. 4.30 (h)] fall within this class, which ranges from Ordovician to Recent. They possess fivefold symmetry and extended arms. The mouth is on the bottom of the body and the anus on top. The madreporite is both the entry and exit point for water to the water vascular system. Tube feet line the ambulacral grooves on the underside of the body and allow the sea stars to move freely over the seafloor.

Phylum Hemichordata

An extinct group called graptolites are the major fossil representatives of this phylum (see Fig. 4.31). They are considered hemichordates because they secreted tubes of protein similar to the modern hemichordate, *Rhabdopleura*. Graptolites are often found preserved in black shale as compressed carbonized impressions, sometimes replaced by pyrite.

Graptolites are thought to have been colonial marine organisms. The colonies were composed of short tubes connected by a common canal. There are two main orders of graptolites: (1) Dendroidea, bushlike graptolites that attached to the ocean floor or to floating seaweed, and (2) Graptoloidea, colonies consisting of branching stipes from an initial chamber, which floated or swam weakly in the open ocean.

Graptolites are good index fossils for the lower Paleozoic. Graptoloids declined and became extinct in the early Devonian. Dendroids became extinct in Permian times.

Conodonts (Taxonomy uncertain)

Conodonts (see Fig. 4.31) are toothlike structures composed primarily of calcium phosphate less than 1/4 inch in size. A conodont animal, only recently discovered, was an elongate eellike, soft bodied creature with an assemblage of conodonts near the head. It is about 1 1/2 inches long and had a bilobed head, transversely segmented muscles, and long fins with ray supports. The animal shows some similarities to simple chordates.

Conodonts range from Cambrian to Triassic and are very useful for zonation and correlation of Paleozoic strata. In addition, the color (amber to black to clear), indicates the maximum temperature to which the conodont, and therefore the rock, was subjected after burial. The thermal history of a sedimentary rock inferred from conodonts can be very useful in the search for petroleum.

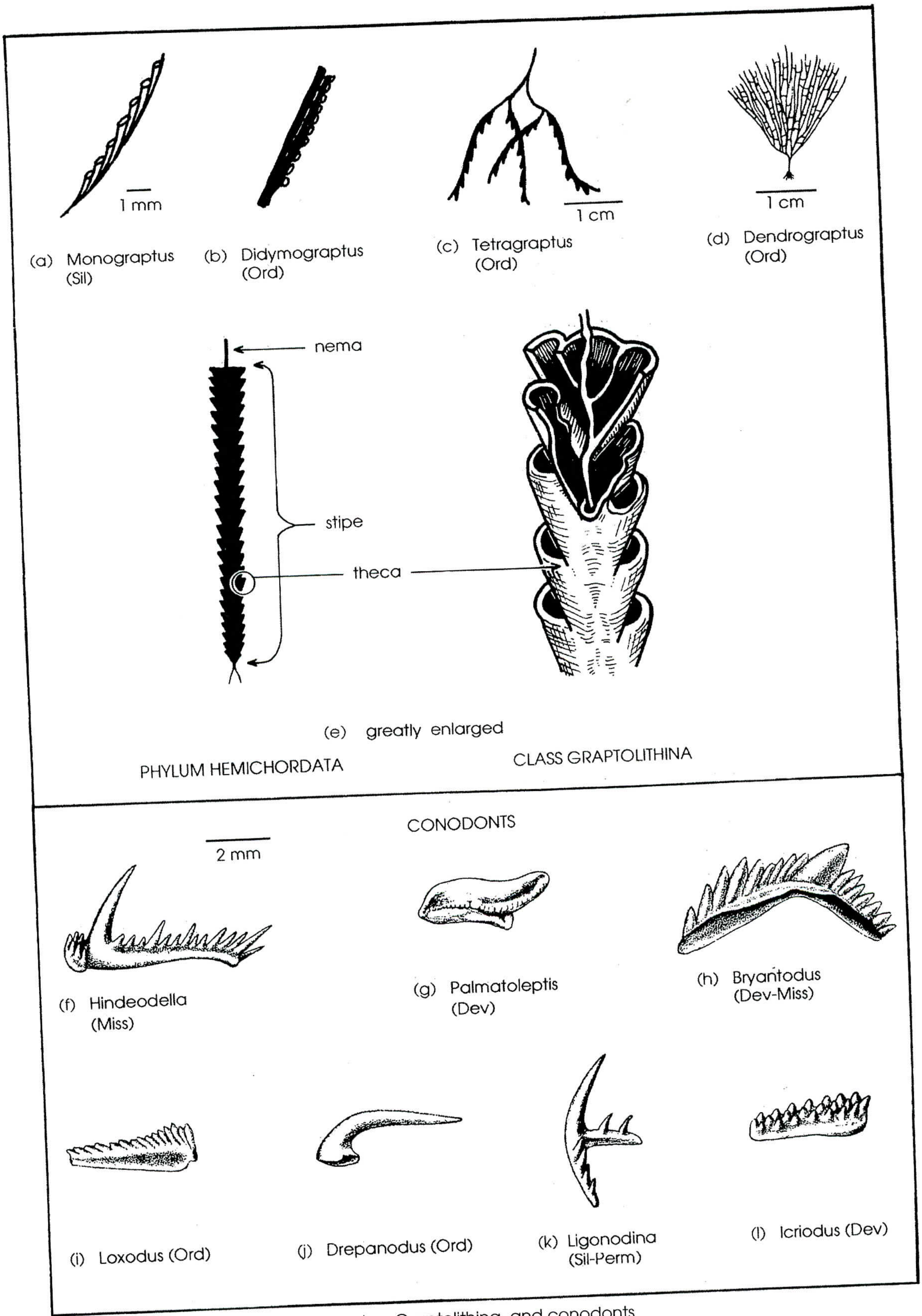


Figure 4.31 Phylum Hemichordata, class Graptolithina, and conodonts

Phylum Chordata (Figs. 4.32 and 4.33)
Chordates range in time from Cambrian to Quaternary and possess a spinal cord or notochord at some time during their lifetimes.

Subphylum Vertebrata
Vertebrates possess a spinal cord enclosed by vertebrae. Vertebrates possess an internal skeleton of bone or cartilage and well-developed nervous, circulatory, digestive, and muscular systems. The most commonly preserved portions of the internal skeleton are the bones and teeth of the animal. The teeth and bones are composed of apatite, which is a variety of calcium phosphate.

Class Agnatha
This class includes modern jawless vertebrates such as lamprey and hagfish. Fossil ostracoderms were jawless fish with platy armor. Class Agnatha ranges from Cambrian to Recent, but ostracoderms became extinct in the Devonian.

Class Placodermi
Placoderms were primitive jawed fish with platy armored skin. This class ranges from late Silurian to Carboniferous.

Class Chondrichthyes
Cartilaginous fishes include modern sharks, rays, and skates. Since the skeleton is composed of nonmineralized material, usually only the teeth and spines are fossilized. Chondrichthyes range from Silurian to Recent.

Class Osteichthyes
This class includes the bony fish. Major groups are (1) extinct forms called acanthodians; (2) ray-finned fish, including most modern gamefish and food fish; and (3) lobe-finned fish, which have bone structure in their fins that is similar to the limbs of other vertebrates. Lobe-finned fish called crossopterygians are considered ancestral to amphibians. The range of this class is Silurian to Recent.

Class Amphibia
The amphibians were the first vertebrates to live on land, although they need moisture in which to lay eggs. Juveniles are aquatic with gills; adults possess lungs. Labyrinthodont amphibians were common Paleozoic fossils. Modern representatives are frogs and salamanders. Amphibians range from Devonian to Recent.

Class Reptilia
Reptiles were the first vertebrates to conduct their lives fully on land, although many returned to aquatic environments. The key to this ability was the self-contained, amniotic egg. Modern representatives of Reptilia include turtles, crocodiles, snakes, and lizards. Fossil members include dinosaurs, flying reptiles, marine reptiles, phytosaurs, therapsids and many others. Reptiles range from upper Carboniferous to Recent.

Class Aves
Birds are warm-blooded, egg-laying vertebrates with an external covering of feathers. The earliest fossil bird, *Archaeopteryx*, is from the Jurassic. *Hesperornis* was a Cretaceous diving bird. Birds are very rare as fossils. Some

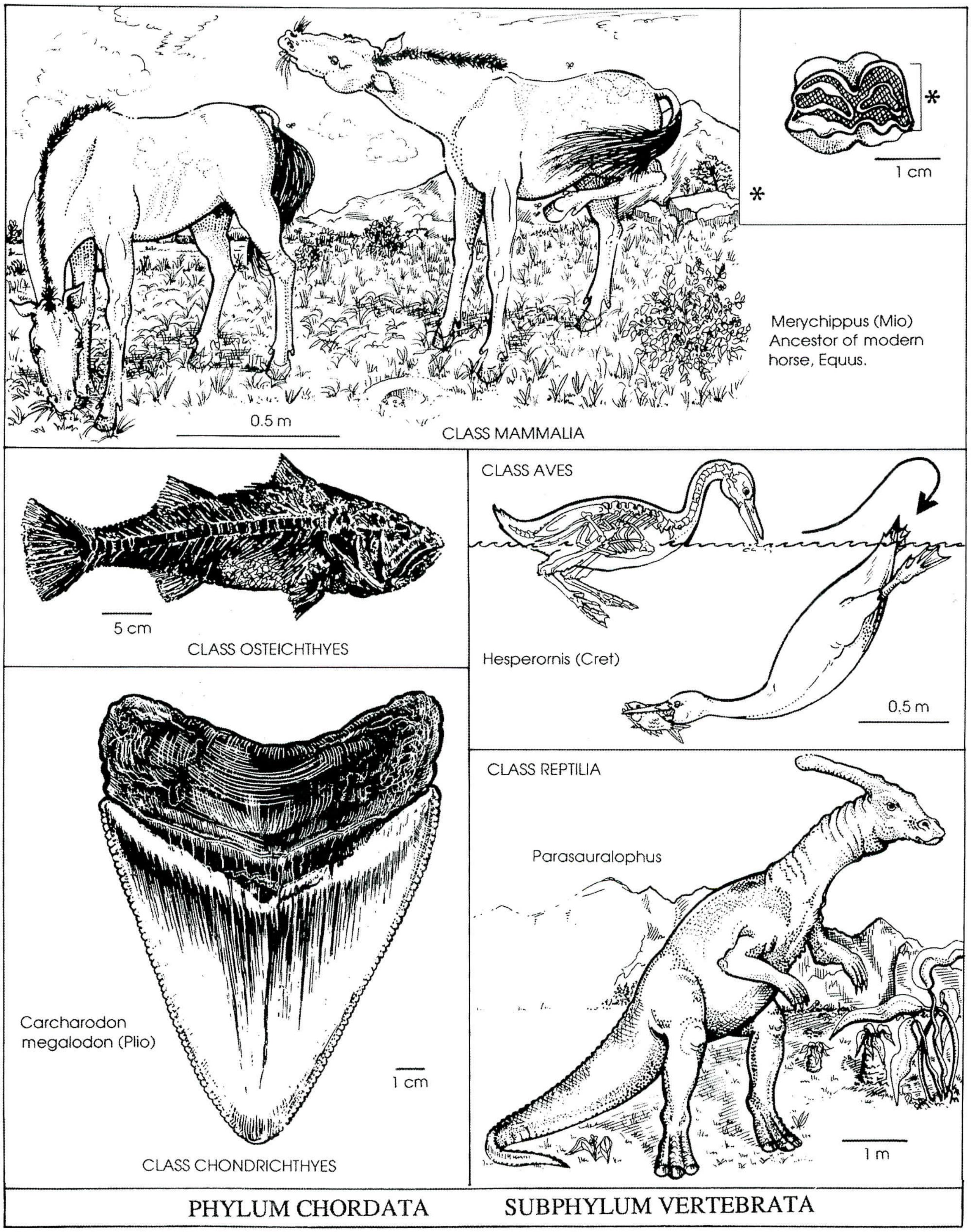


Figure 4.32 Phylum Chordata, subphylum Vertebrata

paleontologists consider birds to be descendants of small theropod dinosaurs. This class ranges from Jurassic to Recent.

Class Mammalia

Mammals have hair, are warm-blooded, and nurse their young. They range from late Triassic to Recent. There are three major modern groups:

Monotremes are egg-laying mammals and include the duckbill platypus and the echidna.

Marsupials are pouched mammals and include the kangaroo, koala, and opossum.

Placental mammals are born at a more advanced stage of development than marsupials, nourished within the female by the placenta. Examples are rodents, elephants, whales, horses, rabbits, bats, monkeys, and humans.

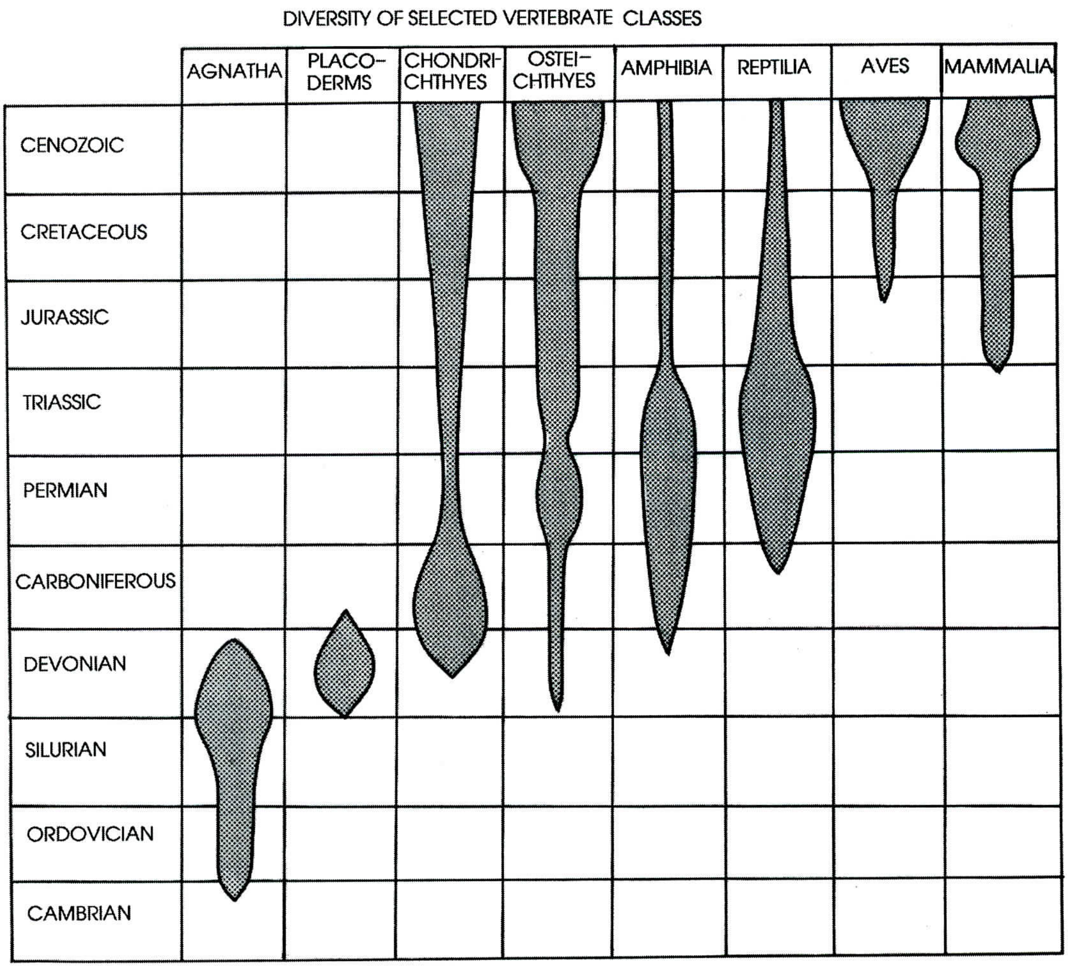


Figure 4.33 Diversity of selected vertebrate classes

IV. KINGDOM PLANTAE

The kingdom consists of multicellular organisms capable of photosynthesis, but lacking organs of sensation, digestion, respiration, or movement.

SUBKINGDOM ALGAE
DIVISION CHLOROPHYTA: green algae
DIVISION PHAEOPHYTA: brown algae
DIVISION RHODOPHYTA: red algae

SUBKINGDOM BRYOPHYTA
Mosses and liverworts are included in this group but are rare in the fossil record.

SUBKINGDOM TRACHEOPHYTA
Vascular plants [see Figs. 4.34 and 4.35 (a) and (b)] live on land and possess several requirements for such a life: (1) a pipe system for transferring water and nutrients from the soil to the cells of the plant, (2) a waxy leaf-covering for retaining moisture, (3) leaf pores for the exchange of gases, and (4) rigid stem cells to support the weight of the plant above the ground.

There are two general reproductive modes of vascular plants; spore-bearing plants have alternation of generations: a spore-bearing sexual phase and an asexual phase. The more advanced seed-bearing plants reproduce by seeds produced after pollination (sexual reproduction).

The study of plants and fossil pollens is essential to the interpretation of ancient terrestrial environments.

Paleozoic (Carboniferous) Tracheophytes

DIVISION LYCOPHYTA
Trees such as *Lepidodendron* and *Sigillaria* grew to heights of 125 feet and diameters of 6 feet. They were scale trees with distinctive leaf scar patterns.

DIVISION SPHENOPHYTA
Giant relatives of modern horsetail rushes, these trees grew to heights of 60 feet. *Calamites* is an example.

DIVISION PTERIDOPHYTA
Ferns are spore-bearing plants. Many varieties grew to treelike heights during the Carboniferous.

DIVISION PTERIDOSPERMOPHYTA
Seed ferns were trees with fernlike leaves; they reproduced by seeds.

DIVISION CONIFEROPHYTA
The Coniferophyta (conifers) are represented by modern evergreens and are the most successful gymnosperms today. The trees are characterized by a well-developed root system, well-defined woody stems, needles as leaves, and, commonly, seed-bearing cones. They reproduce by production of naked seeds through a slow reproductive cycle in the cone where eventually the seeds fall to the forest floor. About 550 species of conifers are known today; major species are pine, fir, spruce, juniper, redwood, and sequoias.

The conifers first appear in the late Carboniferous. It has been established that most of the trees replaced by silica in the Chinle Formation of Triassic age in the Petrified Forest of Arizona belong to the Coniferophyta. Evidence of conifers is also fairly abundant in the Newark beds of Triassic age in northeastern states. These rocks also contain numerous dinosaur tracks.

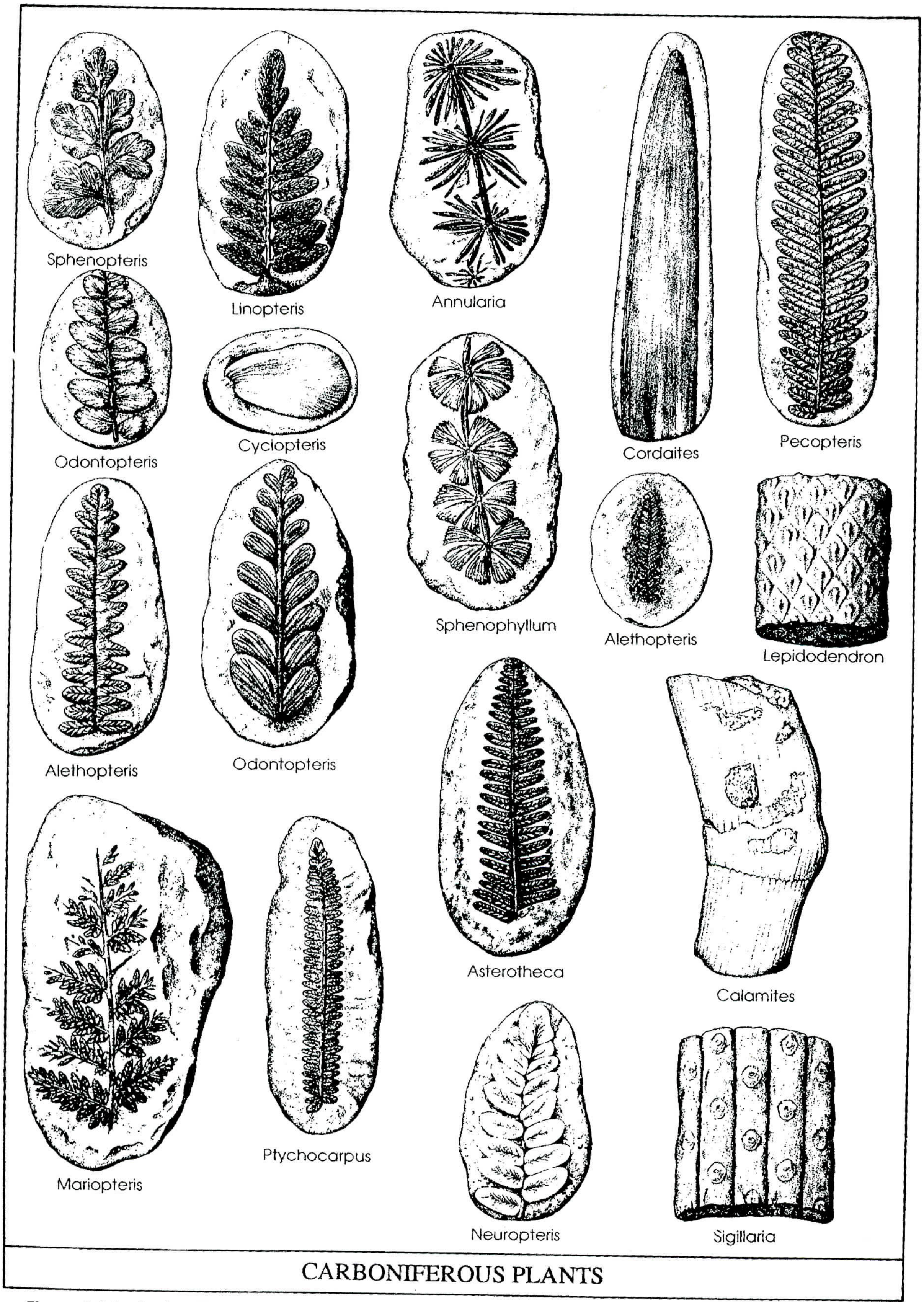


Figure 4.34 Carboniferous (Miss-Penn) plants

Mesozoic and Cenozoic Tracheophytes

DIVISION CYCADOPHYTA

Cycads are squat, palmlike trees that were very abundant in the Mesozoic but today are restricted to tropical and subtropical regions.

DIVISION ANTHOPHYTA

Angiosperms are represented by the flowering plants that first appeared in the Triassic and became the dominant plant group after the Cretaceous. In modern forms the angiosperms are characterized by an ovary within the flower and seeds surrounded by fruit. The pollination of the flowers is done by both wind and insects.

One important branch of scientific study associated with spores and pollen is called palynology. Palynology is used in petroleum geology to study microscopic spores and pollen grains and uses the resulting distribution patterns to correlate sedimentary rocks and determine directions of ancient wind and current systems. Palynology is also very important to climatologists, because the spores and pollens provide valuable information on the distribution and diversity of plant species in paleoenvironments and the paleoclimatic conditions existing in those environments.

Spores and pollens are durable and easily transported by wind or moving waters from ancient terrestrial environments to adjacent marine environments. Palynologists commonly recover them from marine shales or mudstones as insoluble residues.

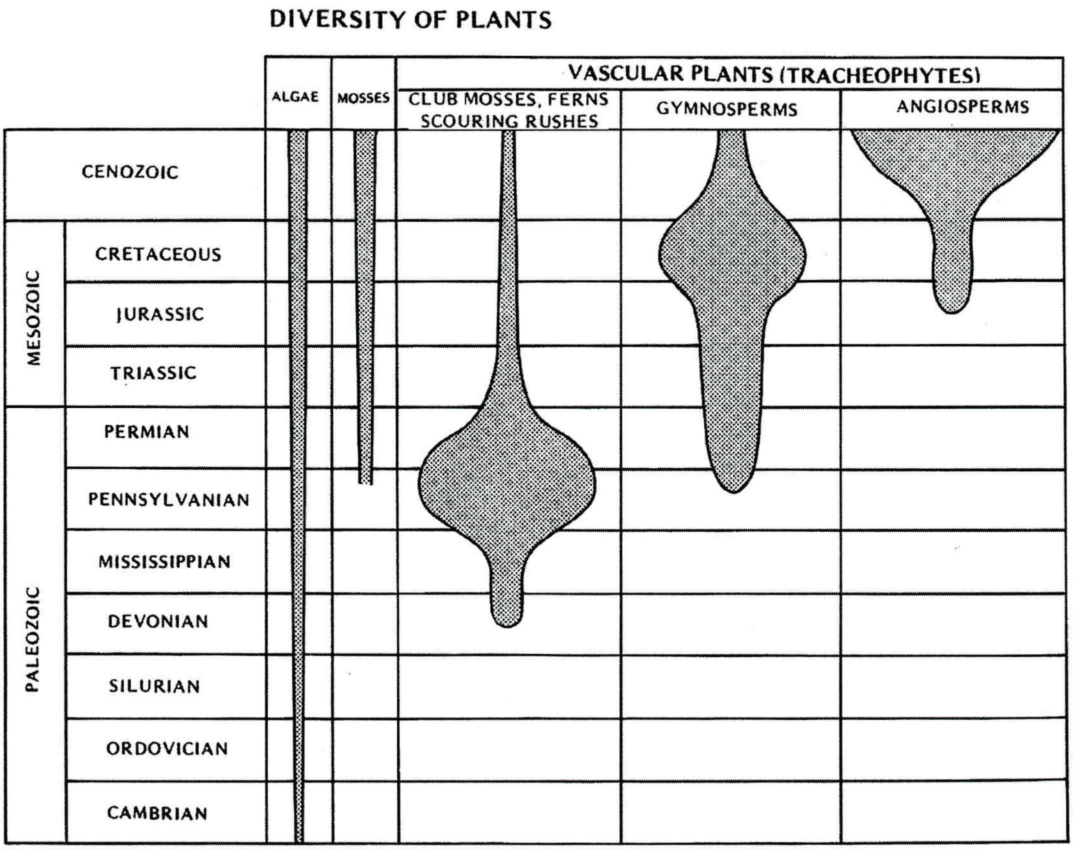


Figure 4.35(a) Plant diversity