BAGHDAD UNIVERSITY
COLLEGE OF SCIENCE
GEOLOGY DEPARTMENT

MACROPALEONTOLOGY
(Course outline- 2o11/2012)

PREREQUISITE: The student attending the course of Macropaleontology should have passed the course of Historical Geology.

LECTURES: 1 lectures + 2 lab.

INSTRUCTORS:

Dr. Salam Ismaeal AL-Dulaimi

OBJECTIVES:

- To provide an overview on fundamental paleontologic principles such as the nature of fossils, modes of preservation, the fossil record, methods of classification, biostratigraphy and paleoecology.
- To learn the morphology, classification, life environment and ranges of important invertebrate fossil groups in order to gain the basic paleontologic skills required for more advanced paleontologic and stratigraphic investigations.

CONTENTS

I. PALEONTOLOGY, AN INTRODUCTION……….(Four Hours)

- Nature of fossil record.
- Chemical and mineralogical composition of the hard skeleton.
- Conditions of fossilization.
- Modes of preservation.
- Fossils and environment.
- Habit (mode of life) and uses of fossils.

II. TAXONOMY:

-Phylum protozoa

Order Foraminifera…………………….(Two Hours)

- Life cycle
- Feeding
- Life history and ecology
- Foraminiferal test
- Aperture
- Wall
- Fossil record of foraminifra
- Geologic significance

Order radiolalarians……………………..(Two Hours)

- **Introduction**
- **The living radiolarian**
- **The skeleton**
- **Wall structure**
- **Ecology**
- **Geologic distribution and imprtance**
- **Classification**

- Phylum Porifera ………………………… (Four Hours)

- Nature of soft part.
- Structure and chemical composition of the hard skeleton.
- Types of sponges.
- Classification.
- Ecology.
- Geologic history and significance.

- Phylum Cnidaria ……………………….. (Six Hours)

- Main characters of the phylum.
- Alternation of generations.
- Composition and structure of the hard skeleton.
- Class Hydrozoa.
- Class Scyphozoa.
- Class Anthozoa.
  * Subclass Alcyonaria.
  * Subclass Tabulata.
  * Subclass Zoantharia.
    Order Rugosa.
    Order Scleractinia
- Geological history and significance of corals.

- Phylum Bryozoa ………………….…….. (Four Hours)

- General features.
- Nature of soft part.
- Structure of the hard skeleton.
- Mode of life of bryozoa.
- Habitat.
- Factors controlling the distribution of bryozoa.
- Geologic history and evolution.

- Phylum Brachiopoda ……………………. (Four Hours)

- Introduction
- Habit
- Anatomy of soft part.
- Morphological features of the shell.
- Shell composition and structure.

- Homeomorphy.
- Classification.
- Geologic history.

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- Phylum Mollusca ………………………… .. (Eight Hours)

* Introduction:
    - Soft body
    - Habit and feeding
    - Classification

*** Class Amphineura**

*** Class Scaphopoda**

*** Class Pelecypoda**

- Behavior
- Musculature
- Shell
- Dentition
- Inequivalved pelecypods

*** Class Gastropoda**

- Shell morphology and composition.
- Aperture.
- Orientation.
- Habitat.
- Types of coiling.
- Extinct gastropods.

*** Class Cephalopoda**

- Morphology of the shell.
- Types of cephalopod shells.
- Septa and suture.
- Classification of cephalopods.
- Belemnites.

- Phylum Echinodermata(Four Hours)

- Introduction.
- Water vascular system and tube feet.
- Mode of life.
- **Classification:**

Subphylum Eleutherozoa:

- Class Echinoidea.
- Class Stelleroidea.
- Class Holothuroidea.

Subphylum Pelmatozoa:

- Class Cystoidea.
- Class Blastoidea.
- Class Edrioasteroidea.
- Class Crinoidea.

- Trilobites (Four Hours)

* Morphology of trilobite skeleton.
* Geologic history and significance.

- **Graptolites (Four Hour)**

* Morphology of graptolite skeleton.
* Geologic history and significance.

Refrences

*Moore R.C;2004;Invertebrate Fossils.
*Clarkson E.N.K;1988;Invertebrate Palaeontology and Evolution.
*Milson C. and Rigby S;2010;Fossils at a Glance.

Palaeontology

Palaeontology is the science which deals with studying life of past geologic ages (fossils).

Paleo = ancient onto = life logy = science

Fossils: are remains or traces of organisms (animals and plants), which inhabited the globe since the beginning of life.

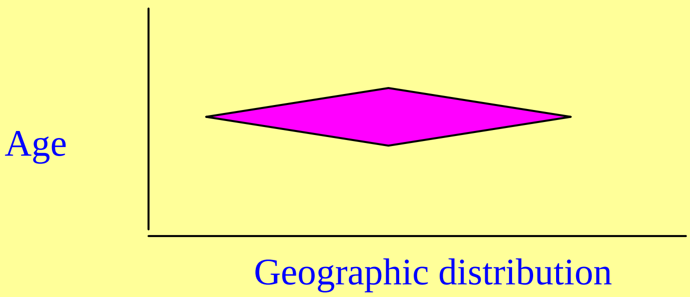
Kinds of fossils:

1- **Body fossils:** are fossils that represent remains of the actual organism or its skeleton. They occur in many ways, including: unaltered preservation, recrystallization, replacement, permineralization, carbonization, impressions, casts and molds.

2- **Trace fossils:** Unlike body fossils, where a portion of the actual organism or its skeleton is preserved, trace fossils are the remains of an organism's activity or behavior. Examples include tracks, trails, burrows, and borings.

3- **Pseudofossils:** unusual structures formed inorganically that, by chance, resemble body or trace fossils. examples dendrites. These are inorganic precipitates of manganese oxide that were described originally as fossil algae.

Fossils in general may have long range and these are called **Range fossils,** these fossils can’t be used as time indicators. Other fossils are characterized by wide geographic distribution and short range; these are called **Index (guide) fossils** and are useful in designating the age of strata.



Fossils which are washed out from the original beds and re-deposited in younger strata are called **Derived (drifted) fossil**.

Example: Cretaceous and Eocene fossils deposited in the Miocene basins of the Gulf of Suez.

Nature of fossil record:

All fossils should occur in sedimentary rocks being abundant in limestone and limy shale but rare in sandstone?. Fossils never occur in igneous rocks except when volcanic ash falls, or nearly cooled lava have overcome plants and animals. In Metamorphic rocks they are also absent except when these rocks were originally fossiliferous and subjected to very low grades of metamorphism.

In Nature fossils are found scattered in the rocks, in some cases they are accumulated in layers or patches. Those accumulated in layers or beds are called **Biostroms** whereas those accumulated without any distinctive layering are called **Bioherms**.

Conditions of preservation:

1-possession of hard skeleton:

In order to be preserved as fossil, the organism must have a hard skeleton. The soft parts decay after death and only the hard parts are preserved.

2-Rapid burial:

After death, the organism should be directly covered with sediments to prevent its destruction by waves or winds. On land, rapid burial is not common and hence land organisms have little chance of preservation than marine organisms.

Chemical and mineralogical composition:

The following minerals are the main constituents of fossil skeletons:

1. Aragonite: Aragonite ($CaCO_3$) is a form of calcium carbonate that is fairly unstable and commonly dissolves away. Skeletons made originally of aragonite are commonly recrystallized to calcite and preserved as molds. Aragonite is easy to recognize. It is usually (not always!) milky white and has no luster.
2. Calcite: Calcite ($CaCO_3$) is the more common form of calcium carbonate. It is more stable than aragonite and therefore does not dissolve as readily. Calcite usually has a grayish color and a slight vitreous (or glassy) luster when found as a skeletal mineral. It can be found as an original skeletal material, or as a recrystallization product.
3. Silica: Silica (SiO_2) is easy to distinguish from the carbonate minerals since it will not react with acid. Skeletons composed of this mineral will commonly have a brown, earthy color, with or without a vitreous luster, and can have a granular texture. Silica is rarely found as an original material and most commonly occurs as a replacement product.
4. Pyrite: Pyrite (FeS_2) or "fools' gold" is a golden colored mineral with a metallic luster and is therefore identified easily. It always appears as a replacement product.

The hard parts of **vertebrates** include bones (largely calcium phosphate and carbonate).
Invertebrate skeletons are mainly calcium carbonate (either calcite or aragonite), some skeletons are composed of silica (siliceous). The composition of major invertebrate groups is as follow:

Foraminifera: Calcareous ($Ca\ CO_3$) or agglutinated (sand grains, sponge spicules or mica flakes).
Sponge: calcareous ($CaCO_3$) and siliceous (silica).
Coelenterates: calcareous.
Bryozoa: calcareous.
Brachiopods: Calcareous and chitinophosphatic.
Mollusca: calcareous.
Echinoderms: calcareous.

Modes of preservation:

After death, the organisms are preserved in different forms as follow:

I. Unaltered remains: the hard skeleton of the organism or its soft part or both remains unchanged.

A) **Soft part (organic compounds):**

1- Mammoth: in the Pleistocene glaciers of Siberia.
2-Insect in Amber: the insects are preserved in the resin (Amber) such as those found in the Oligocene deposits of Baltic province.

B) **Hard skeleton (inorganic compounds):**
This is characteristic for Cenozoic shells which underwent little or no alteration of the original mineral substance.

II. Altered remains: The soft parts decay and the hard skeletons are completely altered. This takes the following forms:

1- **Carbonization:** This is the removal of volatile constituents such as oxygen, hydrogen and nitrogen from the organic compound leaving only carbon as a thin black film.

Ex. Graptolites, fishes and plants

2- **Recrystallization:** is the alteration of less stable inorganic compounds (e.g. aragonite) into more stable ones (e.g. calcite) without any chemical change.

Aragonite (less stable) ™ calcite

3-**Permineralization:** is the deposition of minerals in the interstices of skeleton.

Ex. Bone vertebra

4-**Replacement:** The original skeleton is removed and replaced by other mineral substances such as silica (silicification), pyrite, iron or carbonates.

Ex. Silicified wood (stone forests)

5 -Imprints, casts and Moulds:

Imprints (external molds): are impressions produced when something is pressed into soft sediment. They show only external detail, and they are negative in relief.

Cast: is the infilling of cavities of shells (external mold) by minerals or other sediments. It shows only external features, but will be positive in relief, not negative like an external mold.

Mould (internal)**:** moulds form when sediment infills a shell or skeleton, hardens, and the shell is worn away. What is left is a mould showing internal features and will most likely have positive relief.

6-**Evidence of the activity:** here we don't have anything of the body fossil itself but only traces of its movement. This branch of palaeontology is called Ichnology, which deals with traces of organisms.

Tracks: These are the traces of feet made by quadrepedal or bipedal vertebrates during moving on soft sediments.

Trails: These are the traces made by animals during crawling on sediments.

Burrows: are pathways made up by animals in soft sediments as a normal way of life (worm burrows).

Borings: are holes made by animals in hard rocks and shells either for protection or as parasites in search for food.

Excrements: these are called coprolites and they indicate the kind of food, which the organism had eaten.

Rules of species nomenclature

To write the name of a species we should follow the following:

1- **The species name must be binomial (two names); the first is the generic name to which the species belongs and the second is the specific name. This is followed by the name of the author who discovered the species and the year of discovery.**

Ex. *Ostrea khargensis* Abbass, 1962.

Generic name specific name author name year

2- **The generic and specific names must be written italic or underlined.**

3- **The first letter of the generic name must be capital letter but the specific name not.**

Geologic Time Scale

(mya = million years ago)

Phanerozoic Eon (544 mya to present)	Cenozoic Era (65 mya to today)	Quaternary (1.8 mya to today) Holocene (11,000 years t today Pleistocene (1.8 mya to 11,0 yrs) Tertiary (65 to 1.8 mya) Pliocene (5 to 1.8 mya) Miocene (23 to 5 mya) Oligocene (38 to 23 mya) Eocene (54 to 38 mya) Paleocene (65 to 54 mya)
	Mesozoic Era (245 to 65 mya)	Cretaceous (146 to 65 mya) Jurassic (208 to 146 mya) Triassic (245 to 208 mya)
	Paleozoic Era (544 to 245 mya)	Permian (286 to 245 mya) Carboniferous (360 to 286 mya) Pennsylvanian (325 to 286 mya (Mississippian (360 to 325 mya (Devonian (410 to 360 mya) Silurian (440 to 410 mya) Ordovician (505 to 440 mya) Cambrian (544 to 505 mya) Tommotian (530 to 527 mya)
Precambrian Time (4,500 to 544 mya)	Proterozoic Era (2500 to 544 mya)	Neoproterozoic (900 to 544 mya) Vendian (650 to 544 mya) Mesoproterozoic (1600 to 900 mya) Paleoproterozoic (2500 to 1600 mya)
	Archaean (3800 to 2500 mya)	
	Hadean (4500 to 3800 mya)	

Environment

As mentioned before, fossils are mostly found in marine rocks rather than continental ones since they had a better chance of preservation.
The marine environment (sea or ocean) is divided into zones, each has its own physical and chemical characteristics.(fig.1)

(1) Littoral (Tidal) zone:

This is the zone of water between highest and lowest tide. Living conditions are difficult because of alternate covering and exposure of the bottom materials and organisms due to tidal effect. In spite of that; some organisms adapt themselves to live in these conditions. These are mainly attached or burrowing organisms such as corals, worms, pelecypods, burrowing crustaceans together with lime-secreting algae.

(2) Neritic zone:

It is the zone of water between lowest tide and 200 m depth (edge of the continental shelf).

Organisms are abundant due to excellent light, oxygen and agitated water. This allows plants to grow and produce food by photosynthesis for animals living in this zone.

The majority of invertebrate fossil assemblages appear to have flourished upon the bottoms of the neritic zone. Also much of invertebrate evolution is thought to have take place upon the continental shelves of ancient seas.

(3) Bathyal zone:

It is the zone of water between 200 m and 4000 m.

Only the upper part of this zone has some light and so there is little or no plant life.

The inner part of this zone contains remains of neritic and even continental organisms transported by turbidity currents.

(4) Abyssal zone:

It is the zone of water between 4000 m and 5000 m.

Water is dark and cold, pressure is very great. There is no green plant life beside little animal life.

Remains of pelagic organisms called oozes are dominantly accumulated on the bottom of this zone. There are two types of these oozes:

1- **Foraminiferal (*Globigerina*) ooze:** **This consists of complete or broken tests of planktonic foraminifera.**

2- **Radiolarian Ooze:** **This consists of siliceous tests of Radiolaria beside other remains of siliceous composition such as diatoms.**

(5) Hadal zone:

It is the zone of water below 5000 m depth (deep sea trenches).

Habit (mode of life) of marine organisms:

Organisms are classified according to their mode of life into three categories:

1- **Planktonic: these are organisms which have no organs of locomotion and their movement is controlled by waves and currents. Upon death they sink to sea floor or may be washed ashore.**

Ex. Diatoms, foraminifera, radiolaria and some ostracods.

2- **Nektonic: are organisms which swim in water by their possession of organs locomotion, so they can control their movement.**

Ex. Fishes and some mollusca.

3- **Benthonic: are organisms which inhabit sea bottom. They are two types:**

a) **Epifaunal: living on sea bottom either sessile (fixed) or vagrant (free moving).**

b) **Infaunal: living buried within the sediments.**

TAXONOMIC HEIRACHY

Kingdom Animalia (all animals)
Subkingdom Metazoa (all animals consisting of more than one cell)
Phylum Chordata (possessing in axil dorsal nerve cord)
Subphylum Vertebrata (nerve cord surrounding by a bony spin)
Class Mammalia (true hair ,nursing of young ,brain of advanced type)
Order Primates (mostly tree dwelling placental mammals)
Suborder Anthropoida (monkeys, apes and man)
Family hominidae (man and his immediate ancestors)
Genus Homo man
Species sapiens (sensible ,judicious, wise)

Homo sapiens

Hippurites bioculata Lamarck,1801

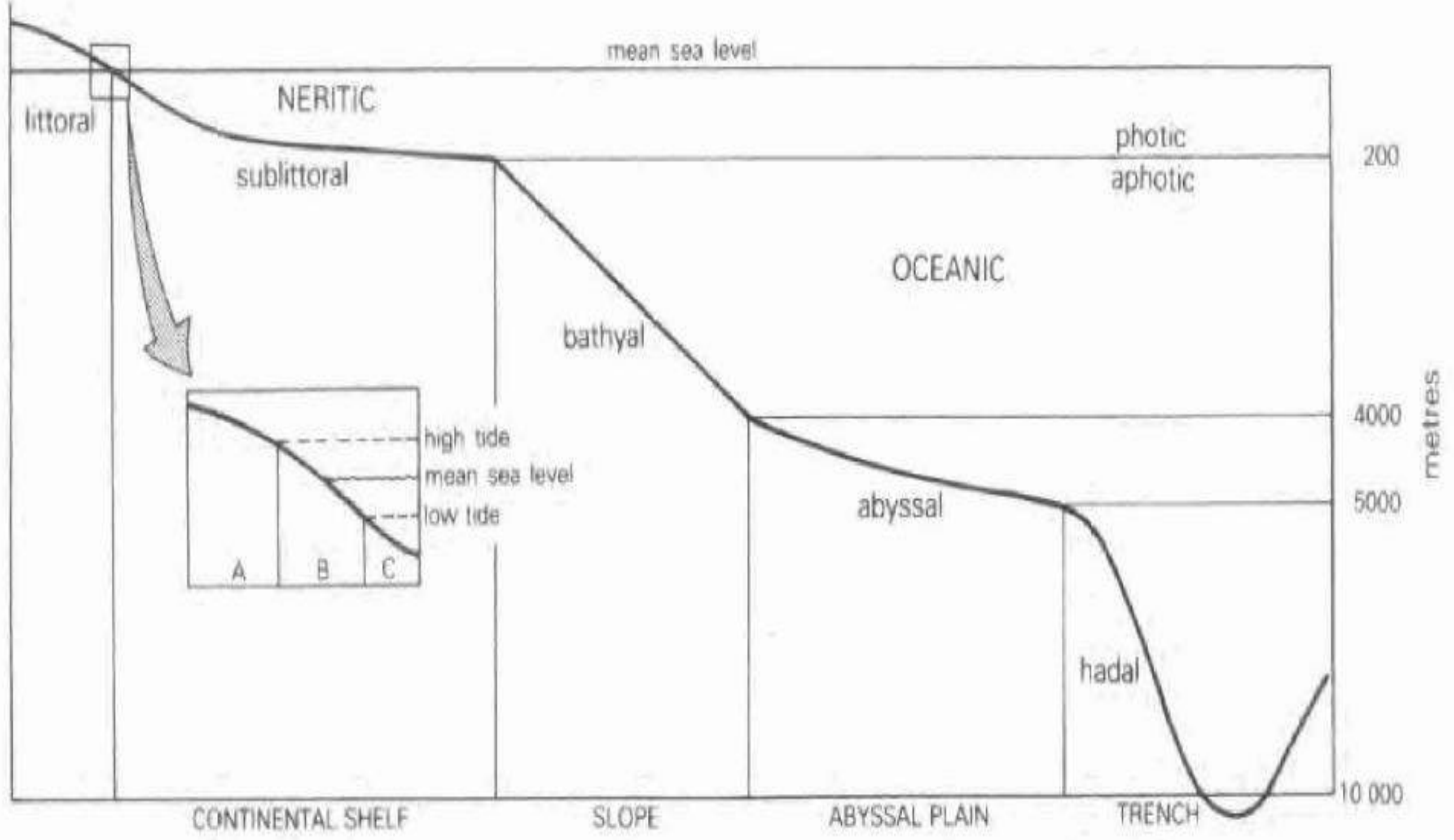


Figure 1.4 Modern marine environments. A, B and C in the inset refer to supralittoral, littoral and sublittoral environments. (Based on a drawing in Laporte, 1968.)

Phylum Porifera (Sponge)

The porifera or sponges represent the simplest group of multicellular(metazoan) animals. They have a few types of cells but are not organized into tissues and have no nervous system.

Ecology:

Sponges are exclusively aquatic and are found today in marine and fresh water. Sponges are benthic creatures, found at all latitudes beneath the world's oceans, and from the intertidal to the deep-sea. Since they are mostly sessile and benthic, and have a delicate water circulation system, sponges cannot tolerate environments with a high rate of sedimentation- their pores are easily clogged and the animals themselves have no defence against burial. Consequently, we find sponges most often in those areas where the water is "clean" and the sedimentation rate low.

Some sponges bore into the shells of bivalves, gastropods, and the colonial skeletons of corals by slowly etching away chips of calcareous material.

All sponges are filter- feeders where organic particles are extracted from water entering through sponge pores. Waste products are expelled outside through the mouth (osculum).

BODY:

The body of sponge is a cup-shaped with a central cavity (paragaster or spongocoel) that open at the top via an osculum. The body consists of three layers; an outer ectoderm, an inner endoderm and a middle layer called mesoderm. The mesoderm secrets the skeleton (spicules) as well as the reproductive organs. The outer surface of sponge is perforated by numerous pores (ostia) which lead to incurrent canals and then to chambers within sponge body. Water is filtered through the walls of this porous structure, using cells (collar cells or choanocytes) with a whip-like flagellum to generate currents and thus allow water to enter sponge body. Waste water is then exhaled through the main aperture of the cup (osculum) (fig.1).

SKELETON:

Sponge skeletons are secreted by specialized cells (spongocytes and sclerocytes) found in the middle layer, and can be composed of $CaCO_3$

(calcite or aragonite), SiO_2 (silica), spongin (a proteinaceous material; the spongy stuff) or a mixture of these materials.

Skeletal material is secreted as individual spicules which are sometimes fused together.

1- **Spongin:** a horny substance similar to silk in composition.

2- **Spicules:** small skeletal elements composed of silica (siliceous) or calcium carbonate (calcareous), secreted in the mesenchyme(fig.3&4) (middle layer by cells called scleroblasts).

TYPES of spicules:(megascleres &microscleres)

1) **Monaxon:** one- ray spine.**(Silica or calcite)(fig.5)**
2) **Triaxon:** three- rays spine.(Silica)(fig.5)
3) **Tetraxon:** four- rays spine.(Silica or Calcite)(fig.5)
4) **Hexaxon:** six- rays spine.(Silica)(fig.5)
5) **Desmas:** the spicules have no regular shape.(Silica)(fig.6)
6)**Polyaxon:**equal rays diverging from a point.(Silica)(fig.5)

The spicules tend to disaggregate after death and to be preserved separately. They are mostly seen in thin sections. This explains why fossil sponges are rare at least as complete fossils.

Since most sponges are soft and structurally weak though, the fossilization process usually destroys a considerable amount of morphological detail. Often the inner hollow of the animal (spongocoel) was filled with sediment which was later lithified (an internal mold), sometimes with impressions of the spicules on the outer surface. In many, if not most cases, fossil sponges are known only from small collections of loose spicules.

Types of living sponge:

Sponges fall into three main groups according to how their bodies are organized. The simplest sponges are the asconoid (fig.1a)sponges. These are shaped like a simple tube perforated by pores. The open internal part of the tube is called the spongocoel; it contains the collar cells. There is a single opening to the outside, the osculum. The next-most complicated group is the syconoids(fig.1b). These tend to be larger than asconoids. They also have a tubular body with a single osculum, but their body wall is thicker and the pores that penetrate it are longer, forming a system of simple canals. These canals are lined by collar cells, the flagella of which move water from the outside, into the spongocoel and out the osculum. The third category of body organization is leuconoid(fig.1c). These are the largest and most complex sponges. These sponges are made up of masses of tissue penetrated by numerous canals. Canals lead to numerous small chambers lined with flagellated cells. Water moves through the canals, into these chambers, and out via a central canal and osculu*m.*

Sponges are found in virtually all aquatic habitats, although they are most common and diverse in the marine environments. Many species contain toxic substances, probably to discourage predators. Certain other marine animals take advantage of this characteristic of sponges by placing adult sponges on their bodies, where the sponges attach and grow. The chemicals also probably play a role in competition among sponges and other organisms, as they are released by sponges to insure themselves space in the marine ecosystem. Some of these chemicals have been found to have beneficial pharmaceutical effects for humans, including compounds with respiratory, cardiovascular, gastrointestinal, anti-inflammatory, antitumor, and antibiotic activities. Sponges also provide a home for a number of small marine plants, which live in and around their pore systems. Symbiotic relationships with bacteria and algae have also been reported, in which the sponge provides its symbiont with support and protection and the symbiont provides the sponge with food. Some sponges (boring sponges) excavate the surface of corals and molluscs, sometimes causing significant degradation of reefs and death of the mollusc. The corals or molluscs are not eaten; rather, the sponge is probably seeking protection for itself by sinking into the hard structures it erodes. Even this process has some beneficial effects, however, in that it is an important part of the process by which calcium is recycled.

1-**Ascon:** the body is composed of a single chamber lined with choanocytes.(fig.1a)
2-**Sycon:** the body is composed of a number of grouped ascon-like chambers with a central opening.(fig.1b)
3-**Leucon**: the body is composed of a number of sycon-like chambers which open into the central cavity (paragaster).(fig.1c)

Classification:

At one time, a diagnostic feature of the Porifera was the presence of spicules. As a result, certain fossil groups whose organization was consistent with that of living sponges were not placed within the phylum Porifera. In particular, groups with a solid calcareous skeleton such as the Archaeocyatha, chaetetids, sphinctozoans, stromatoporoids, and receptaculids were problematic. A great deal of insight into the phylogenetic affinities of these groups was gained with the discovery of more than 15 extant species of sponges having a solid calcareous skeleton. These species are diverse in form, and would be classified with the chaetetids, sphinctozoans and stromatoporoids if found as fossils. However, with the living material in hand, histological, cytological, and larval characteristics can be observed. This information suggests that these 15 species can readily be placed within the Calcarea and the Demospongia. This radically changes our view of poriferan phylogeny.

It is widely accepted among poriferan biologists that the Calcarea and the Demospongia are more closely related to each other than either is to the Hexactinellida. With the discovery of living chaetetids, stromatoporoids, and sphinctozoans, a fourth class was erected for these so-called sclerosponges. However, the Sclerospongia is not a natural monophyletic grouping and is thus being abandoned. The abundant fossil chaetetids, stromatoporoids, and sphinctozoans are probably part of the classes Demospongia and Calcarea, though some uncertainty still remains. The Archaeocyatha pose a special case. No living representative of this group has been discovered. Their organization is consistent with that of living sponges. The one phylogenetic analysis (carried out by Reitner) that included archaeocyaths with other sponges, grouped them as sisters to the demosponges. Therefore, although the taxonomic term Archaeocyatha is often accorded phylum status it is likely a sub-clade of the phylum Porifera, thereby violating the ranking system.

Class Calcarea :-

These are the sponge with calcareous skeleton normally consists entirely of calcite spicules; there is neither spongin nor silica. They are simple in structure or may have up to four rays. Most are tubular or vase-shape, and

they can have asconoid, syconoid or leuconoid organization. Calcareous sponges favour shallow water environments, especially high energy areas.

Class Hexactinellida: -

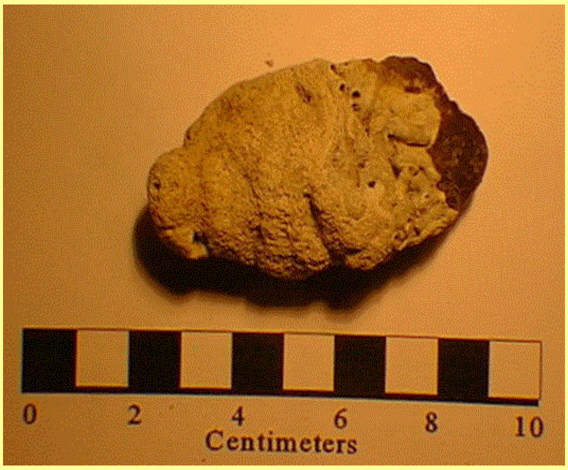
The Hexactinellida(Hyalospongia) are the glass sponge, so-called due to their siliceous skeletons. Hexactinellids construct a skeleton composed of simple to complex 6-rayed siliceous spicules, which in some groups are

fused into intricate basket-like structures. They are exclusively marine, and in the modern ocean are usually found in the deep ocean (generally 450 to 900 meters, but up to 5000 meters depth!), although earlier groups occupied shallower water. There is a very good fossil record of these organisms. Most Hexactinellida are syconoid or leuconoid in body organization. They inhabit deep water and are now found down to abyssal depths.(fig.4)

Class Demospongiae:

Demospongia include both fresh water and marine species. Demosponges are the most widespread and advanced class of sponges. They construct their skeletons from spongin fibers and/or monaxon or tetraxon siliceous spicules. Most living demosponges have skeletons of unfused spicules, although due to preservational effects, the fossil record of demosponges is skewed toward fused forms. While this class does contain freshwater groups, most are marine. Some demosponges are more than a cubic meter in size. Would you want to wash your car with any of these sponges? Most fossil demosponges are represented by siliceous spicules only where the skeleton have been collapsed.

Class Sclerospongia: -
These sponges are sometimes included in the Class Demospongia. They have a massive calcareous basal skeleton of laminar calcite or aragonite with some siliceous spicules. The living tissue lies mostly within the skeleton (extending outward very slightly). Their body plan is leuconoid.



They are found in marine environments, usually in association with coral reefs.

Archaeocyathids:

Archaeocyathids are a short-lived, Early Paleozoic group of enigmatic fossils. The organisms were constructed as a set of two concentric cylinders connected by transverse septa .The skelelton consists essentially of thin **outer wall** perforated by numerous **pores** and without skeletal elements inside porous wall.The **inner wall** parallel to the outer one with many pores .The space (**intervallum**) between the walls is divided into compartments by radial partitions(**parietes ,sig. Paries**) which are perforated by pores. Archaeocyathans wewe apparently benthic ,sessile ,suspention feeders (fig.7).

Recent work on the biomechanics of water flow through this structure has revealed that archaeocyathids operated much like sponges, and on that basis some workers have classified them with sponges, but it is unknown if the two phyla are closely related.

Archaeocyathids evolved in the early Cambrian and were completely extinct by the end of that period.

Stromatoporoids:

These are calcareous masses of layered and structured material found in carbonate rocks of Cambrian to Oligocene age. In cross-section, the stromatoporoids have a system of pillars connecting closely spaced laminae, while from a top view, a system of bumps and fine star-shaped grooves (Astrorhizae) similar to the exhalent canal system of sclerosponges can be seen.Th structure of stromatoporoids may be studied in vertical &tagential sections.It appears at first sight to be less defined than in corals, but the dominant structures are clear enough.

The morphology of stromatoporoids resembles that of the modern sclerosponges, which live in cryptic reef environments, although stromatoporoids lack spicules, and their affinities remain uncertain. The stromotoporoids formted massive calcareous skeletons and were important mid-Paleozoic (Silurian and Devonian) and mid-Mesozoic reef-forming organisms.

Sponges as reef-builders:

Sponges played an important role in building or colonizing reefs through the Phanerozoic. All reef-building sponges had a predominantly calcareous skeleton. Archaeocyathids evolved into some of the first reef-formers during a brief period in the Cambrian. They were small forms generally around 10 cm in height, with a cup-like shape. They were tropical and inhabited water less than 30 m deep.

Stromatoporoid reefs were common during the Silurian and Devonian and some occurred also in the Permian, Triassic and Jurassic. Their importance has declined in the Mesozoic and Cenozoic, possibly as a result of the rise of colonial corals with symbiotic algae.

Biogenic Silica:

Sliceous sponges were the main biological secretors of silica during the Cambrian, when they were mainly confined to shallow water. During the Cretaceous, siliceous sponges formed an important component of the chalk seas, and their silica often precipitated during burial to form flint. Flint nodules are most common in shallow water chalk, deposited in less than 100 m of water. Most modern hexactinellids or glass sponges are found in deep water between 200-600 m on the continental slope.

In modern oceans the combination of silioceous planktons and deep water siliceous sponges means that almost all biogenic silica is preserved in deep water sediments. In contrast to the Cambrian, the shelves are relatively starved of opaline silica, emphasizing the importance of evolution on major biogeochemical cycles.

GEOLOGIC HISTORY:

Sponges have been numerous in the seas since the Precambrian. Throughout most of the Phanerozoic, sponges have been major contributors to reef formation. Today, sponges are important ecological constituents of reef communities but they do not commonly contribute to the construction of reef frameworks as has been the case during most of their history. Sponges probably achieved their greatest diversity during the Cretaceous.

A diagnostic feature of the Porifera was the presence of spicules. As a result, certain fossil groups whose organization was consistent with that of living sponges were not placed within the phylum Porifera. In particular, groups with a solid calcareous skeleton such as the Archaeocyatha, chaetetids, sphinctozoans, stromatoporoids, and receptaculids were problematic. A great deal of insight into the phylogenetic affinities of these groups was gained with the discovery of more than 15 extant species of sponges having a solid calcareous skeleton. These species are diverse in form, and would be classified with the chaetetids, sphinctozoans and stromatoporoids if found as fossils. However, with the living material in hand, histological, cytological, and larval characteristics can be observed. This information suggests that these 15 species can readily be placed within the Calcarea and the Demospongia. This radically changes our view of poriferan phylogeny.

It is widely accepted among poriferan biologists that the Calcarea and the Demospongia are more closely related to each other than either is to the Hexactinellida. With the discovery of living chaetetids, stromatoporoids, and sphinctozoans, a fourth class was erected for these so-called sclerosponges. However, the Sclerospongia is not a natural monophyletic grouping and is thus being abandoned. The abundant fossil chaetetids, stromatoporoids, and sphinctozoans are probably part of the classes Demospongia and Calcarea, though some uncertainty still remains. The Archaeocyatha pose a special case. No living representative of this group has been discovered. Their organization is consistent with that of living sponges. The one phylogenetic analysis (carried out by Reitner) that included archaeocyaths with other sponges, grouped them as sisters to the demosponges. Therefore, although the taxonomic term Archaeocyatha is often accorded phylum status it is likely a sub-clade of the phylum Porifera, thereby violating the ranking system.

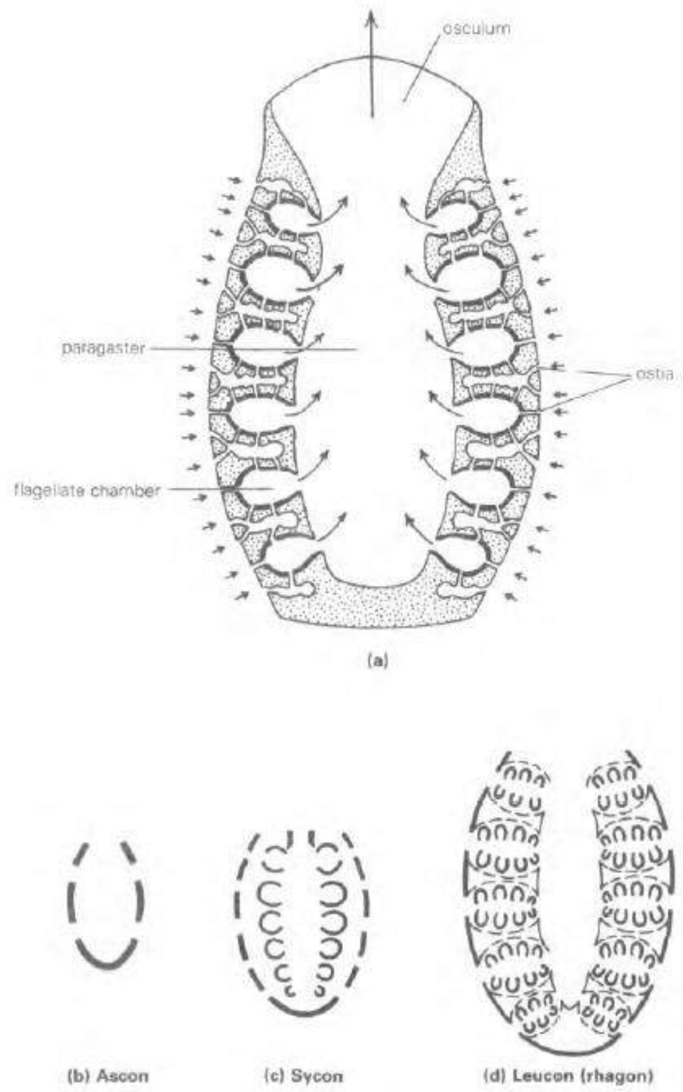


Figure 4.1 Elements of sponge morphology: (a) leucon (rhagon) type showing passage of water currents; (b)–(d) ascon, sycon and leucon grades of organization. [(a) based on drawing in Marshall, 1978.]

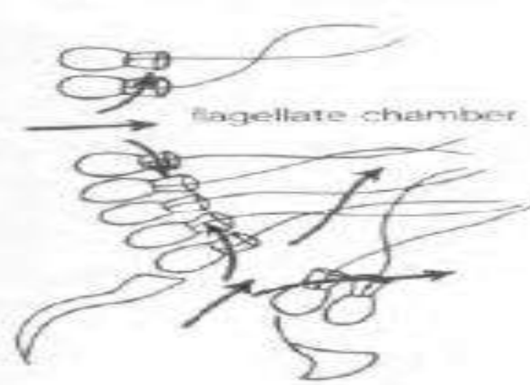


Figure 4.2 Wall of chamber, showing incurrent pores with arrows indicating current directions and collar cells (choanocytes).

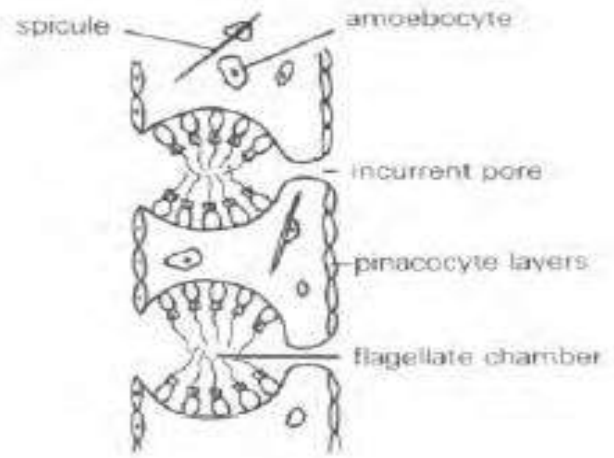


Figure 4.4 Wall structure of an advanced gelatinosan sponge. (Redrawn from Reid, 1958–1964.)

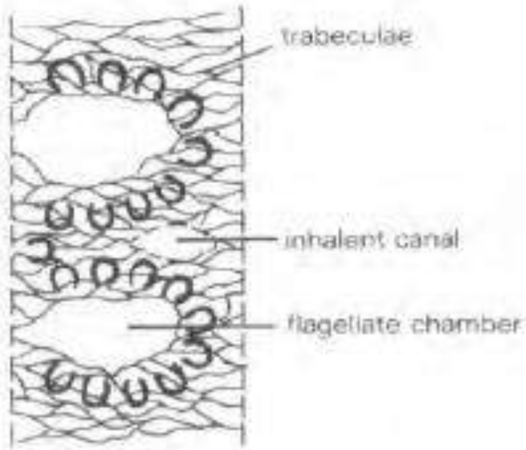


Figure 4.5 Wall structure of a hexactinellid (Nuda) of leucon grade. (Redrawn from Reid, 1958–1964.)

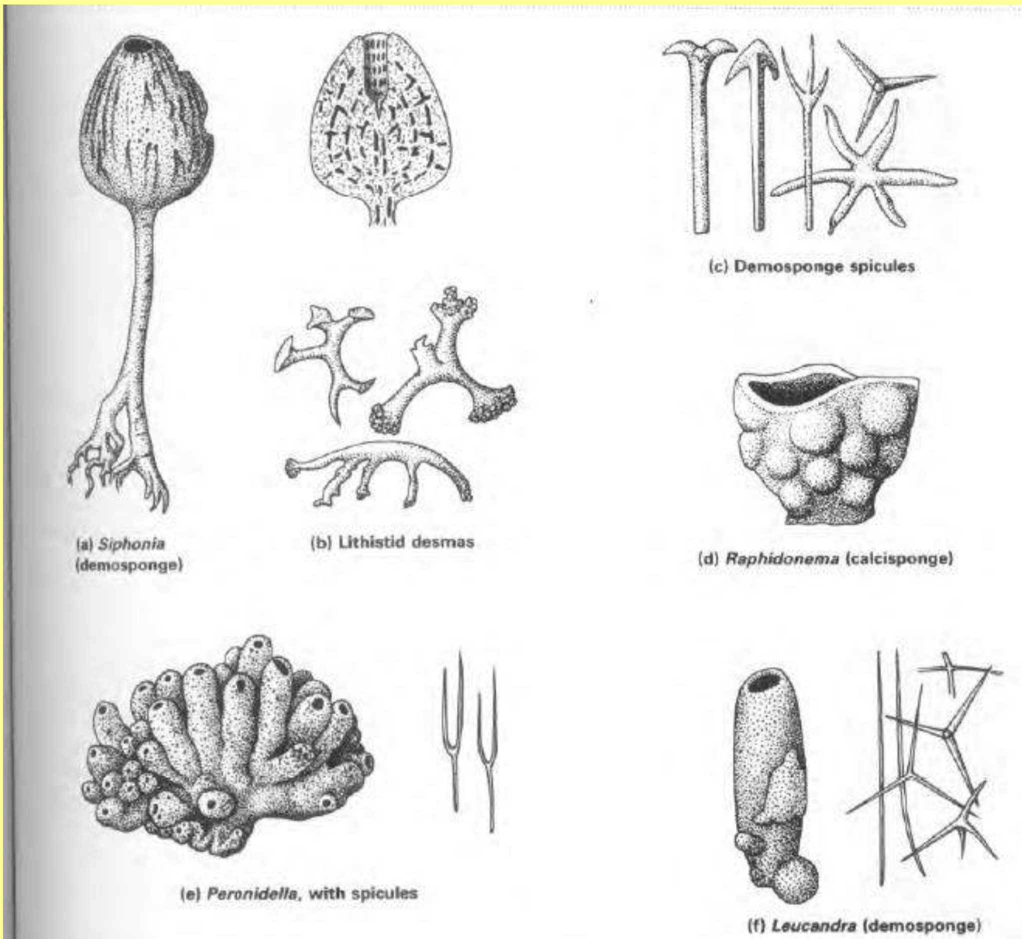


Figure 4.6 Demospongea and Calcarea: (a) *Siphonia* (Cret.), a stalked example (left) cut in section (right), showing the internal canals and paragaster (× 0.5); (b) lithistid desmas (× 25); (c) demosponge spicules (× 30); (d) *Raphidonema*, a Cretaceous calcareous sponge (× 0.25); (e) *Peronidella*, a Cretaceous calcareous sponge (× 0.5), with 'tuning fork' spicules (× 30); (f) *Leucandra*, a demosponge (× 0.5), with tetraxon spicules (× 30). (Mainly redrawn from Hinde, 1887–1893.)

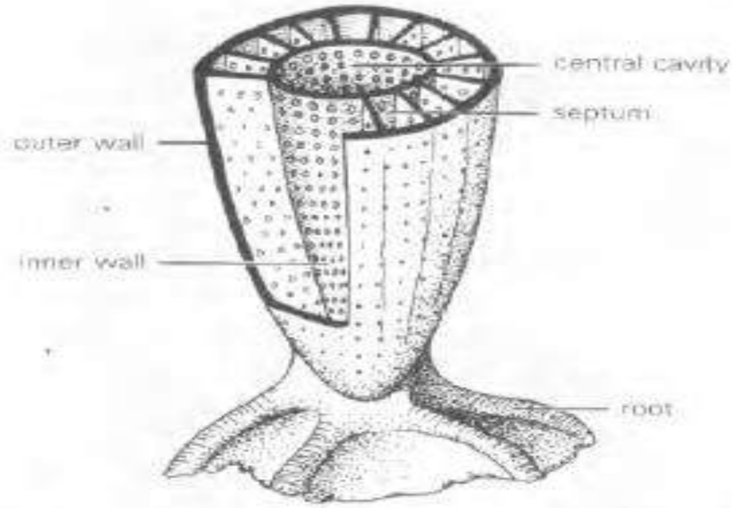


Figure 4.17 Archaeocyathid morphology modelled on *Ajacicyathus* (Cam.; × 1.5). (Modified from Hill in *Treatise on Invertebrate Paleontology*, Part E.)

Phylum Coelentrata (Cnidaria)

The Coelenterates are aquatic invertebrates having well developed body tissues. The majority are **marine** except very few forms adapted for existence in fresh water. They grow together as colonies, but solitary individuals also occur. Many are attached throughout life whereas others are free swimming.

The word Coelenterate (Coel, hollow, entron, gut) was originally applied to sponges and Coelenterates (hydrozoa and anthozoa). Because Coelenterates are characterized by the possession of **stinging cells**, the name Cnidaria (pronounced nidaria) which means knide or nettle is employed for them by some authors.

Body:

The individual coral animal or **polyp** is a simple jelly-like organism consisting of a bag-like body with a mouth at the top, surrounded by tentacles. The body wall consists of three layers; an inner, digestive endoderm and an outer ectoderm, which is sensory and bears stinging cells for protection and capture of prey. Between the ectoderm and endoderm lies a gelatinous layer; non-cellular in composition, called **mesogloea(**fig1a&c). The body cavity of coelenterates is divided by radially-emplaced curtains of tissue called **mesenteries.** These serve to increase digestive and absorptive area.

Reproduction:

Reproduction is either asexual (budding) or sexual (release of male and female gametes into the water). The budding process turns a solitary polyp into a compound individual; the continuation of the process results in a mass of polyps called a colony. Some corals reproduce by alternation of generations.(fig.1d)

Alternation of generations:

In coelenterates; two types of individuals exist, a fixed **polyp** and a free **medusa.**

These two forms (polyp and medusa) alternate successively where the polyp reproduce asexually to form a large number of medusa, each medusa reproduce sexually by the union of eggs and sperms to form zygote. The zygote grows into larva, which fix itself to a substrate and finally form a new polyp.(fig.1d)

This alternation of generations is characteristic for class Hydrozoa. In class Scyphozoa the medusoid stage is dominant and the polypoid stage is very reduced. In class Anthozoa the medusoid stage is absent and the polypoid stage has become the sexual generation.

Classification:

Coelenterates are divided into three classes, these are **Hydrozoa**, **Scyphozoa** and **Anthozoa.**

Class Hydrozoa

Hydrozoa are solitary (e.g. Hydra) or colonial (e.g. Obelia) organisms. Although most of them are of little importance in paleontology due to the absence of a hard skeleton, few kinds are rock builders having a calcareous hard part, which could be preserved as fossils. The skeletal structure of hydrozoa is not enough varied and distinctive to permit differentiation of species, which are useful in stratigraphic correlation or age determination. All recorded fossil hydrozoans are marine.

In hydrozoans both polyp and medusa body forms are present. The polyp is sessile and usually colonial in that sexual budding can take place but the individuals so formed remain attached to each other.

The medusa is a free-swimming member of the plankton and represents the sexually reproducing, dispersal phase. Hydra is an exceptional member of this class in that it only occurs as a polyp, which can reproduce sexually.

A great many hydrozoans are colonial. Some form delicate branched colonies, while others, known as "fire corals," form massive colonies that resemble true corals. Other hydrozoans have developed pelagic (floating) colonies that are often confused with jellyfish, but unlike jellyfish they are composed of many individuals, all specialized for various functions.

Hydroids:

This group includes the fresh water hydras and the marine water Obelia.

Some hydroids secrete calcium carbonate in the form of a thin encrusting layer on a shell or other foreign surface to which the colony is attached, or it may build moderately thick laminated masses of irregular form. A

thin layer of fleshy tissue covers the surface of the calcareous deposits and from this common colonial tissue the individual polyps rise.
Age: cretaceous.

Milleporids:
These are colonial Hydrozoa which secrete massive calcareous structures of varied form. They commonly grow in association with other corals and together with calcareous algae, contribute significantly to the building of coral reefs in warm shallow seas in many places.
The skeletal structure consists of finely porous deposits with innumerable interconnecting minute passageways, penetrated by relatively straight-sided tubes of larger size with axes normal to the surface of the colony. The tubes are circular or stellate in cross section and are intersected by transverse partitions called tabulae.
Two distinct sizes of tubes are observed, the larger are called dactylopores and the smaller are called gastropores. The individual polyps are joined laterally by a thin layer of colonial fleshy tissue, which covers the skeletal deposits between the pores.
Age: Cretaceous – Tertiary – Recent.

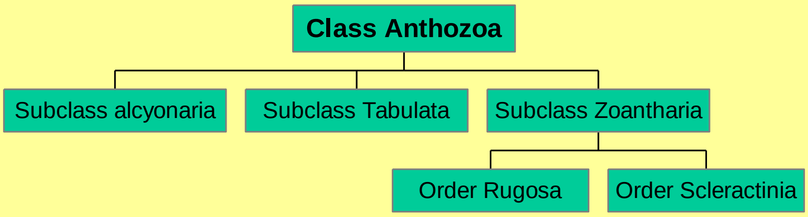
Class Scyphozoa

Scyphozoans emphasize the medusoid form, rarely if ever producing polyps. Most of these free swimming organisms have no hard skeleton, but the group still possesses a fossil record going back to the Precambrian. Scyphozoans include jelly- fishes which lack hard parts and consequently their preservation as fossils is uncommon except as impressions in the pre-Cambrian and Cambrian rocks, (Idiacara fauna in Australia).

Idiacara fauna: is a group of fossils found in Idiacara in Northwest Australia. They are collected from sandstones of Late Pre-Cambrian age. They are evidences that life started in Pre-Cambrian.

Class Anthozoa

This class includes the stoney corals, soft corals, and sea anemones. The anthozoan organism is always a polyp, sometimes solitary, although colonial forms are common. The fossil record of the Anthozoa is composed mainly of members of the three orders of stoney corals **Tabulata**, **Rugosa** and **Scleractinia**.



The Anthozoans are the most important coelenterates from the paleontologic viewpoint. They build a calcareous skeleton, which is significant in many rock formations.
The Anthozoa are distinguished by a radial compartmentation of the digestive cavity and the entire absence of a medusoid stage. They include **solitary** individuals but are mostly **colonial** and are exclusively marine. Although a majority secretes hard parts, several divisions are wholly soft-bodied and thus not suited for fossilization.

Skeleton of Anthozoa:

The coral polyp secretes a calcareous skeleton called **corallite**. This takes the form of a cup (**calice**) upon which the animal sits. There is a basal plate and radial walls (**septa**) extend from the periphery towards the center, these septa lie in-between the mesenteries and so reflect their number. Since the different coral orders have distinctive numbers of such mesenteries, the septa are of great taxonomic importance to the paleontologist.
As the polyp grows in size and the cup enlarges, more mesenteries are created and so more septa need to be inserted. The first formed septa (prosepta) are usually recognizable, being thicker and larger than the secondary (metasepta). All septa join the peripheral wall, which is called epitheca. As the polyp grows also, the coral secretes a horizontal floor called tabulae, this is secreted periodically as the polyp moves upward.
The skeleton is composed of **aragonite** in **modern corals** but in the **extinct orders**, it may have been either wholly or partially **calcite**.

Subclass: Alcyonaria:

Alcyonarians are anthozoans having eight branched tentacles and eight mesenteries. They are exclusively colonial but the polyps are not directly

joined with one another, as in many colonial corals, for they interconnect only by tubular passageways (stolons).
Newly formed polyps arise at various places along these stolons. The colonies are supported by a horny or calcareous skeleton. They include sea pens and sea fans.
Genus *Heliopora* is a representative of Alcyonarians. It contains wide tubular openings in which the polyps are lodged, these are separated by interspaces which consist of small tubules. Both sets of openings are intersected by transverse tabulae. The walls of the larger tubes are indented by 12-25 short inward projections, which are termed pseudosepta because their number and arrangement doesn't conform to the eight mesenteries.

The red organ-pipe coral *Tubipora* also belongs to Alcyonaria. In this genus, the polyps arise singly from a basal fleshy mat containing stolons.

Subclass: Tabulata

Tabulates are a Paleozoic group of exclusively colonial corals that produce calcite skeletons of varying shapes (e.g. mound-like, sheet-like, branching, and chain-like forms). The individual corallites (individual coral cups) are small, and lack septa (internal vertical walls). The group takes its name from the colony wide organization of the tabulae (little horizontal "floors" laid down by the coral polyps).
Tabulate corals first appear in the Lower Ordovician, they diversified rapidly in the Ordovician and quickly spread worldwide. A rapid radiation was followed by extreme decline in the end-Ordovician mass extinction. They recovered from this to reach diversity peak in the middle Devonian, but their recovery from the late Devonian extinctions was restricyed and they survived with limited diversity untile the end-Permian extinction. They form reefs together with rugose corals and stromatoporoids especially during the Silurian.

Ex. (1) ***Favosites***

- Prismatic, polygonal corallites.
- Abundant tabulae.
- Very short septa (spines).
- Mural pores connecting the corallites.

Ex. (2) ***Halysites***

- Corallites are joined end to end like a chain.
- They are elongated.

Ex. (3) ***Heliolites***

- No wall between corallites.
- There is a calcareous mass between them called Coenenchyme.

Tabulae: are flat horizontal plates forming a floor to cavity in which the polyp resided.

Subclass: Zoantharia (Corals)

Order Rugosa(tetracorallia)

Rugosans are an important group of Paleozoic corals. There are both solitary and colonial and produced a skeleton made up of calcite. Solitary rugosans typically have a horn shaped, while the colonial types commonly have hexagonal corallites. Both solitary and colonial rugosans have a distinctive **septal insertion** pattern, which gives most rugosans bilateral symmetry.

Septa are arranged in a bilateral symmetry as follow(fig.2):

1. The coral starts with two septa, one is called cardinal (C) and the other is called counter (K).

2. Two septa are then added on both sides of the cardinal septum called alar septa (A), also two septa are added on both sides of the counter septum called counter-lateral (KL). So we have a bilateral symmetry, all these septa are called **Prosepta** or **protosepta** or simply **primary** septa.

3. Septa are then added in **four** quadrants on the cardinal side of alar and counter lateral septa. These septa are called **metasepta** or secondary septa. Because metasepta are inserted in four, rugosa are also called **Tetracoralla**.

Calice: is the upper part of the corallite, which is occupied by the organism.

Dissepiments: are small plates found between septa.

Columella: is an axial structure arising in the central part of the corallite. The columella has different types: -

- **Solid:** a central rod.
- **Spongy:** formed by the inner ends of septa.
- **Papillose:** many small rods.
- **Lamellar:** plate-like.

Stratigraphic range of Rugose corals:

Rugose corals are totally Paleozoic corals, which appeared in Middle Ordovician where solitary forms were dominant.
In Middle Devonian colonial forms appeared, they formed reefs together with tabulates and stromatoporoids.
Generally, Rugose corals disappeared at the end of Paleozoic where they were replaced by Scleractinian corals.

Order: Scleractinia (Triassic - Recent):(fig.3)

Order Scleractinia contains both solitary and colonial forms. They secrete an aragonitic skeleton. Septal insertion occurs in multiples of six, and many scleractinian corals have 6-fold symmetry. Some scleractinians host symbiotic photosynthetic zooxanthellae. These so-called hermatypic corals can lay down massive amounts of limestone in the photic zone of shallow tropic seas.

Scleractinia includes all post-Paleozoic corals (from Middle Triassic to Recent). The septa are arranged in a radial symmetry where six primary septa are created, followed by metasepta inserted in cycles of 6, 12, 24, 48 …etc. The colonial forms are similar to those of rugose corals in addition to new forms termed plocoid, meandroid and hydnophoroid.

ORIGIN OF SCLERACTINIAN CORALS:

The origin of scleractinia is more controversial and two schools of thought are prominent. One notes the obvious similarities to the Rugosa and suggests direct descent, possibly polyphyletic, with different scleractinian suborders arising from different rugosan families. The second school notes the differences and the lack of 1 morphologic intermediates between Scleractinia and Rugosa, especially in the sequence and mode of septal insertion and in mineral composition, and the time gap between the two groups {there are no known Early Triassic corals). This school suggests that the Scleractinia evolved from a group of sea anemones, so that the rugosan similarities are due to a common ancestry rather than to direct descent. The second theory seems more likely at this time.

Incertae sedis Conularida

(Cambrian-Triassic)

Like the archaeocyatids and the stromatoporoids, this extinct group has defied easy classification. It is placed with the cnidarians based primarily on its four-fold symmetry. The soft parts of the organism are not known. The pyramidal test of this organisms is made of chitino-phosphate, a composite material containing apatite which is highly resistant to chemical weathering, and thus preserves well.

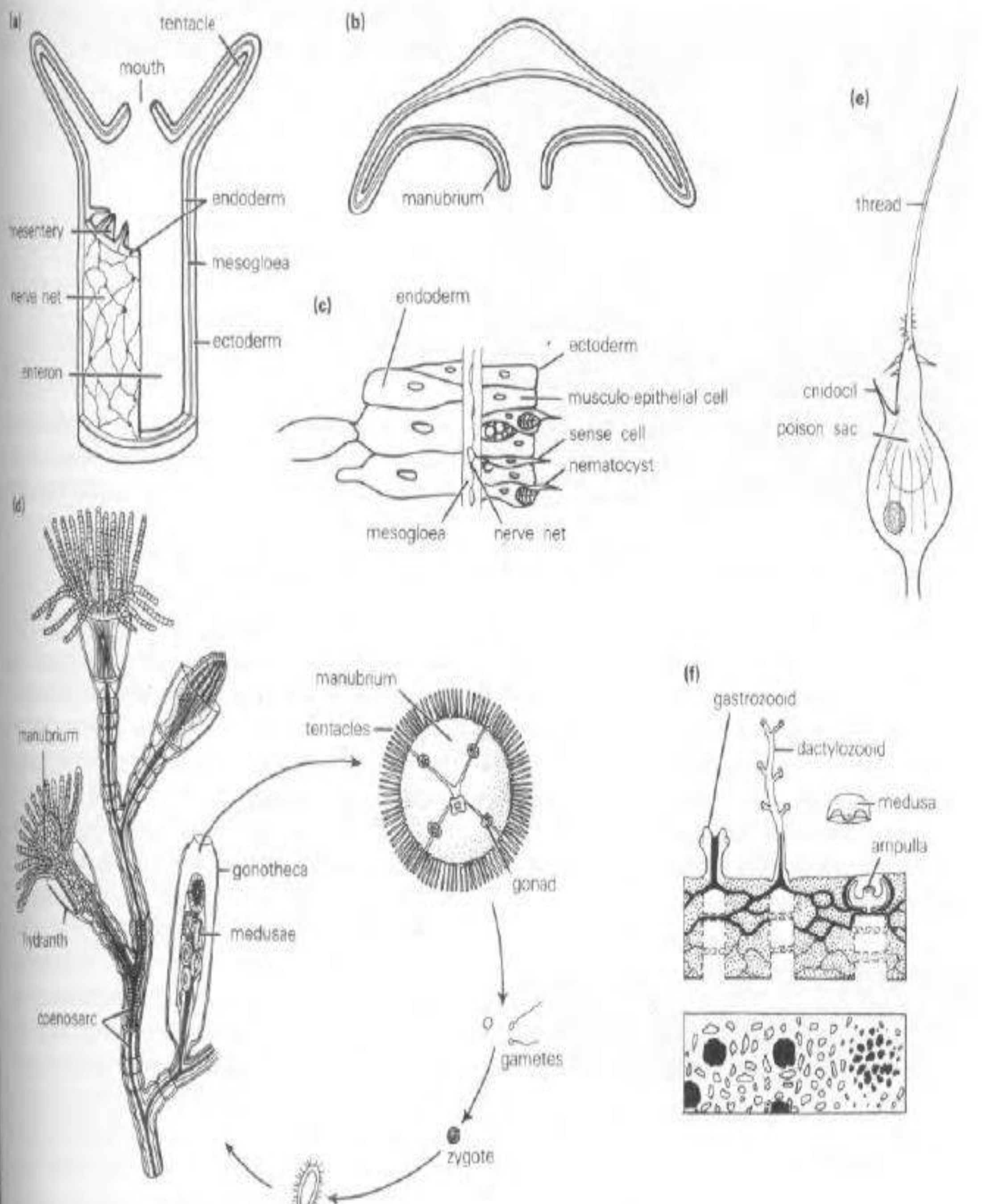


Figure 5.1 (a) Schematic diagram showing cnidarian hydroid cut longitudinally; (b) cnidarian medusoid with a thickened mesogloea above the manubrium; (c) body wall of a cnidarian, showing details of the diploblastic structure; (d) *Obelia* – morphology and life cycle (× 25): hydroid phase (left), medusoid (right) from below; (e) discharged nematocyst, showing spiral barbs near the base of the thread; (f) *Millepora* (Cret.–Rec.) – longitudinal section (above) and surface view (below) (× 10): the small medusa has recently been budded off from the ampulla. [(d) Modified from an illustration in Borradaile *et al.*, 1956; (f) based on a drawing by Boschma in *Treatise on Invertebrate Paleontology*, Part F.]

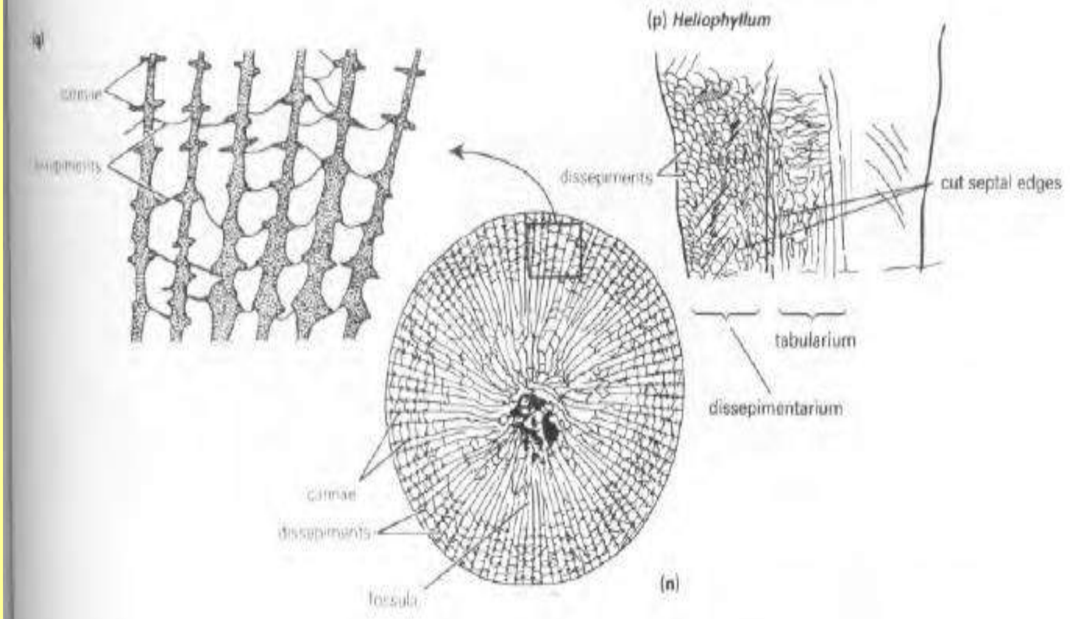


Figure 5.4 (a) Young *Caryophyllia*, a Recent scleractinian coral attached to the tube of the worm *Ditrupa*; (b) *Caryophyllia* vertical section; (c) transverse section through young (centre) and older (right) scleractinian coral (1, protoseptum; 2, 3, metasepta); (d) *Zaphrentites* (Carb.) with part of the epitheca removed, showing bilateral symmetry; (e) same, in transverse section; (f) septal emplacement shown by serial sections from tip (C, cardinal septum; KL, counter-lateral; K, counter-septum; A, alar); (g)–(m) examples of the *Zaphrentites delanouei* group (Carb.), including (g) *Z. delanouei*, (h) *Z. parallela*, (j) *Z. constricta*, (k) *Z. disjuncta* (early) and (m) *Z. disjuncta* (late) (not to scale); (n) *Heliophyllum* (Dev.), transverse section showing near-radial symmetry (× 1.5); (p) vertical section (× 1.5); (q) enlargement of peripheral zone, showing relationships of septa and yardarm carinae. [(a) Redrawn from Wilson, 1976; (d), (e) based on Milne-Edwards and Haime, 1850; (g)–(m) from Carruthers, 1910; (n)–(q) redrawn from Hill in *Treatise on Invertebrate Paleontology*, Part F.)

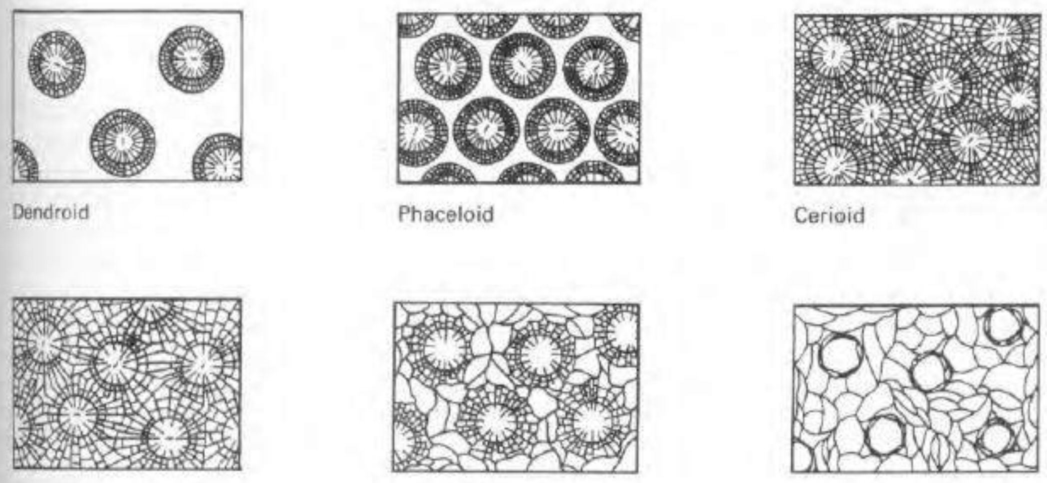


Figure 5.5 Transverse sections through compound rugose coral colonies, with terminology of different types.

Phylum Bryozoa

Bryozoans, or "**moss animals**," are filter-feeding, colonial animals that superficially resemble plants rather than animals. They have formed a significant part of the marine benthos since the Ordovician. It is the only phylum in which all known species are colonial. A colony consists of very small individuals called **zooids** that are physically connected. They grow by budding from a single individual called the **ancestrula**. Around 20,000 species are recognized, most of them from fossil record.
Some bryozoans encrust rocky surfaces, shells, or algae. Others form lacy or fan-like colonies that in some regions may form an abundant component of limestone. Bryozoan colonies range from millimeters to meters in size, but the individuals that make up the colonies are rarely larger than a millimeter.
Bryozoans are considered nuisances by some: over 125 species are known to grow on the bottoms of ships, causing drag and reducing the efficiency of the ships. Certain freshwater species occasionally form great jelly-like colonies so huge that they clog public or industrial water intakes. Yet bryozoans produce a remarkable variety of chemical compounds, some of which may find uses in medicine. One compound produced by a common marine bryozoan, the drug bryostatin 1, is currently under serious testing as an anti-cancer drug.

Organism: The bryozoan animal is called zooid. Zooids within a colony can differ distinctly in morphology and function. Some, if not all, are feeding colonies. However, many colonies possess polymorphic zooids that differ morphologically and perform specialized functions, including reproduction, colony support, cleaning and defence.

Feeding zooids have a fluid-filled body cavity (coelom), a protrusible tentacle-bearing feeding organ called the lophophore, a U-shaped digestive tract, muscles, a nervous system, and tissues attaching the digestive tract to the body-wall(fig.1). Eggs and sperms-producing organs are present in some feeding and non-feeding zooids in all colonies.

The lophophore consists of a ring of hollow tentacles and a supporting tentacle sheath. The sheath encloses the tentacles when they are retracted, and turns inside out for support when they protrude for feeding. The tentacles are covered with cilia that produce currents directed toward the mouth centered at the base of the tentacular ring. The mouth opens into the U-shaped digestive tract which ends at an anus on the side of the protruded tentacle sheath below the ring. Protrusion of the tentacles involves exerting hydrostatic pressure on the fluid of the body cavity. This pressure is produced in various ways, usually by muscles modifying the shape of the body cavity. Other muscles contract to bring about retraction of the tentacles.

Reproduction in Bryozoa occurs sexually by the union of sperms and eggs; the fertile eggs change into larvae which escape outwards and float in water. The larvae of marine bryozoa are ciliated and planktonic. After settling, a larva undergoes extensive reorganization of tissues to produce the first **zooid**, which is called the **ancestrula** of the colony. This first zooid then buds asexually to produce the succeeding individuals (colony).

Skeleton:
The skeleton of bryozoa is external and is made up of $CaCo_{3,}$ usually **calcite**, sometimes **aragonite** or **both**. The skeleton of one individual is called **Zooecium** and that of the colony is called **Zoarium**.

Ecology:
Bryozoans are common in most shallow marine environments. They can also colonize deeper water and a few live in fresh water. They are rock-formers, sometimes to a significant extent, for example during the Carboniferous period. They are able to colonize most substrates, but prefer hard substrates. In modern seas, bryozoans are the most important carbonate producers on the southern Australian and New Zealand shelves.

Classification and Taxonomy

Modern classifications of the Bryozoa recognize three classes within the phylum. The marine species are grouped into the classes **Stenolaemata** and **Gymnolaemata**. They are distinguished primarily by features of their soft-anatomy. The third class, **Phylactolaemata,** includes only freshwater species. No hard parts are mineralized by species in this class, but they have left a fossil record of imprints and tubes in deposits of Tertiary age.

Class Stenolaemata

The stenolaemates are highly calcified bryozoa with zooids living in tubes that grow throughout the life of the colony. This class includes four orders:

Order Trepostomata

These are the so-called "stony" bryozoans of the Early Paleozoic. Most formed massive to dendroid calcareous colonies. The feeding zooids were housed in long, circular to polygonal tubes in which transverse partitions, called **adiphragm**s, are present ,the thin-walled inner part of the colony ,which is made up the early-formed,relatively rapid-growing portions of the autopore tubes, is called the **immature region** (fig.2).Thethick walled outer part of colony, which represents a very slow growing or static condition of the tubes, is called **mature region**(fig. 2). Trepostomes appeared late in the Early Ordovician and diversified rapidly to a maximum in the Middle and Late Ordovician. They were the most abundant fossil group in some Ordovician beds. They declined markedly to two or three genera in the Triassic, when the trepostomes became extinct.

Order Cryptostomata(fig. 3)

These form delicate, less highly-calcified colonies than the trepostomes. They are characterized by short zooidal tubes in which the aperture is hidden or obscured. Diaphragms are commonly absent. A hemiseptum, a short plate that extends part way across the aperture at the top of the zooidal tube, may be present. These bryozoans range from the Ordovician into the Permian.

Order Fenestrata(fig4.)

The zooidal tubes in this order are similar to those in the Cryptostomata, although the chambers for feeding zooids are even smaller and are circular in cross-section. Colony form is sheet-like or fanlike in many species. Fenestrates appeared in the Early Ordovician; their maximum abundance was reached in the Lower Carboniferous and they became extinct during the Triassic.

Order Cyclostomata(fig.5)

Cyclostomes have plain rounded apertures, thin zooidal walls, and usually an absence of diaphragms. Colony form is variable. Most tube walls have very small communication pores. Cyclostomes first appeared in the Ordovician and formed small, insignificant colonies throughout the Paleozoic. During the Cretaceous, the Cyclostomata underwent an evolutionary explosion. The number of genera recognized quadrupled and the order reached maximum diversity. Cyclostomes declined at the end of the Cretaceous, with the number of genera dropping from about 175 to 50, a number that has remained more or less constant to the present. This is the only order of stenolaemates known from Jurassic and younger rocks.

Class Gymnolaemata
The gymnolaemates are generally less heavily mineralized and their zooids grow elegant boxes of fixed size. They occur as flat encrusting colonies dependent upon the substrate. The Class Gymnolaemata includes two orders.

Order Ctenostomata
Ctenostomes generally lack skeletons and are usually preserved as borings on calcareous substrates such as shells, or as encrustations. One genus is free-living. Colonies immersed in shells commonly consist of widely-spaced feeding zooids that are connected by tubular stems, termed stolons. The order ranges from the Upper Ordovician to the present. There is about 50 genera, most of which are known only from living specimens.

Order Cheilostomata(fig. 6)
Most cheilostomes have box-like colonies and an aperture closed by an operculum (lid). The growth habit includes encrusting to erect, shrub-like forms. Cheilostomes appear first in Late Jurassic rocks with only a few taxa, but the group radiated markedly in the mid-Cretaceous.

Bryozoan evolution:
Stenolaemates evolved to their greatest diversity during the Paleozoic. They were severely affected by the end-Permian mass extinction event and most orders were extinct by the end of the Triassic. Only Cyclostomata survived into the Mesozoic and radiated to a great abundance, especially during the Cretaceous. Many genera of cyclostomes became extinct at the end of the Cretaceous, but a few survive to the present day.
Gymnolaemates are known from the Ordovician, they are divided into two orders: the minor Ctenostomata which have been a small element of bryozoan fauna throughout the phanerozoic, and the hugely diverse order Cheilostomata. This group first appeared in the Jurassic and have come to dominate bryozoan assemblages.

Bryozoa as environmental indicators
Bryozoans are useful as environmental indicators since they are sensitive to environmental changes and their colony shape is largely controlled by environmental characteristics. In post-Paleozoic rocks and in the modern oceans, bryozoans are dominant members of shallow benthic communities in temperate latitudes, with normal

salinity and low to moderate rates of sedimentation. They are abundant in modern oceans at water depth of 40-90 m, and in sedimentation rates of less than 100 cm per thousand years.

Colony shape may also be used as environmental indicators for example encrusting forms (thin laminae on dead shells and hard objects) are common in shallow water. Erect forms (tree-like branches) are common in deep water. Free-living mobile forms (which can roll themselves on sea floor) are typical of sandy sea beds, where the bryozoan colony needs to be able to respond to a mobile substrate.

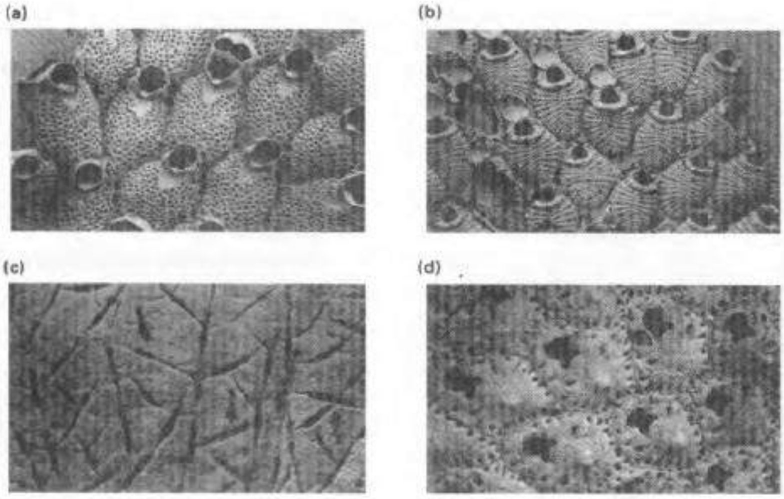


Figure 6.2 Bryozoan structure: (a) *Smittina* sp. (ascophoran cheilostome), Holocene, Antarctica (× 16); (b) *Castanopora magnifica* (Anascan cheilostome), Cretaceous, England (× 14); (c) *Orbignyopora* (cheilostome borings on brachiopod), Silurian, Pennsylvania (× 16); (d) *Crepidacantha* (ascophoran cheilostome), Recent, New Zealand. (All SEM photographs reproduced by courtesy of Dr P.D. Taylor.)

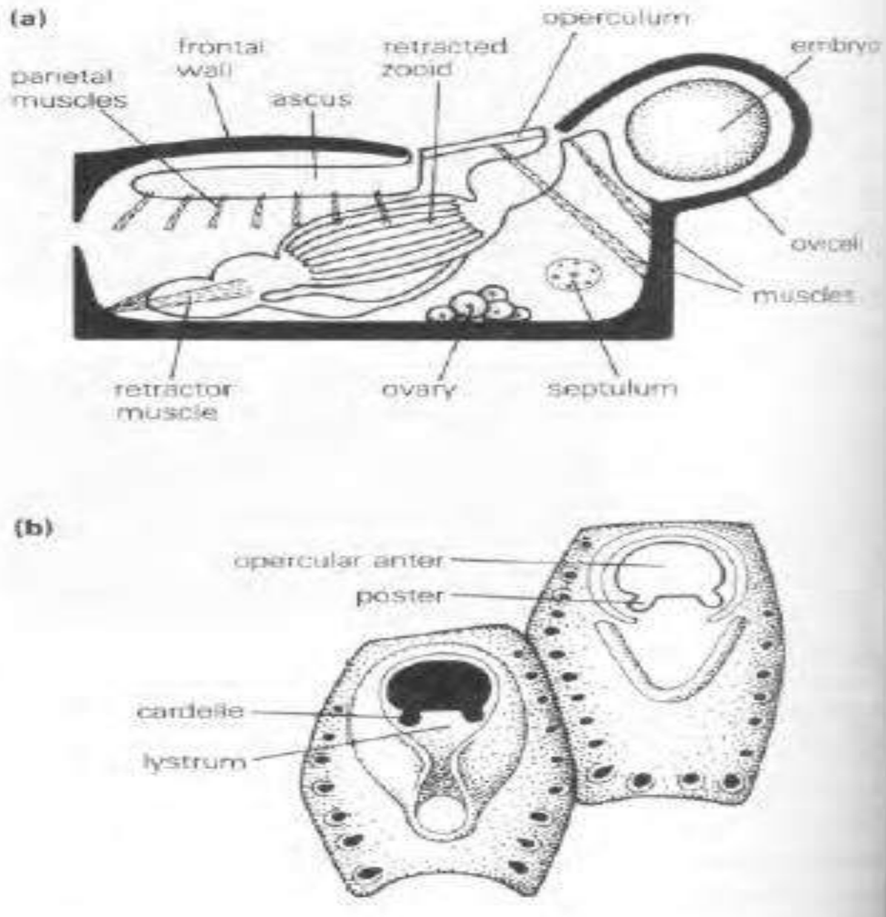


Figure 6.5 (a) Longitudinal section through a generalized ascophoran with zooids retracted; (b) *Smittoidea marmorea* showing progressive development of the peristomial region in young zooids. (Redrawn from Hayward and Ryland, 1979.)

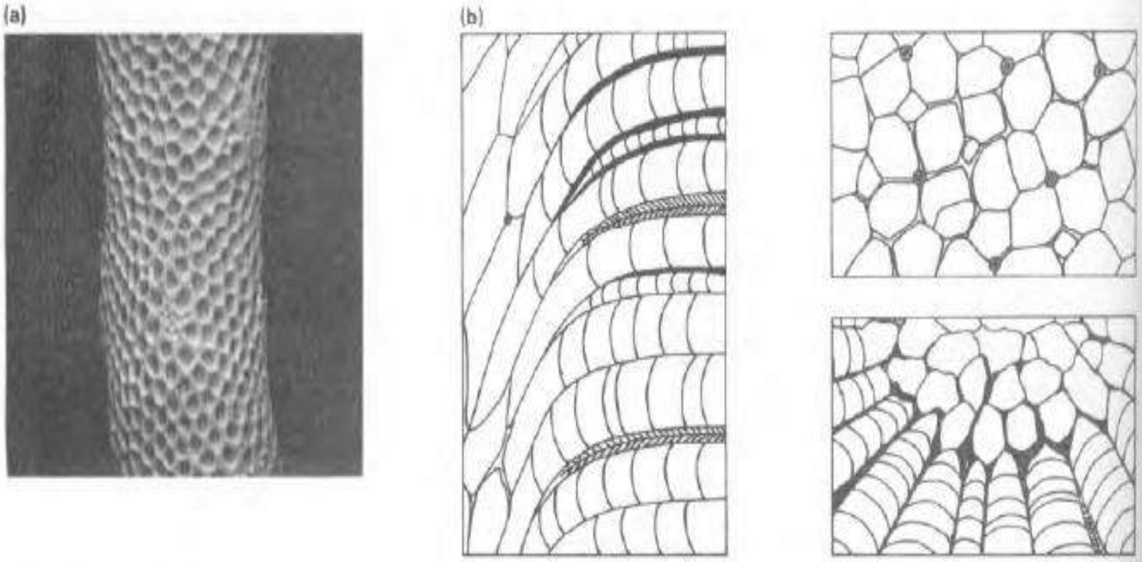


Figure 6.8 Trepostomes: (a) *Anisotrypa* (Carb.), Alabama (× 6); (b) *Dekayia* (Ord.) showing a longitudinal section (left), a tangential section with acanthostyles (above right) and a transverse section (below right). (Drawn from a photograph by J.P. Ross in *Journal of Paleontology*, 1962.)

Phylum Brachiopoda

Brachiopods are marine invertebrates in which the soft parts are enclosed by two deposits of shell termed **valves**(fig.1&2). Thus superficially they resemble the bivalves (pelecypods). However; they are distinguished from them by the inequality of the two valves in size and shape(fig.3), and by equilateral symmetry of each valve.

The name brachiopoda (brachio = arm, pod = foot), refers to internal paired appendages (brachia or lophophore) which at first were assumed to function for locomotion, like the foot of mollusks.

Members of the Phylum Brachiopoda were considered to be molluscs until well into the 19th century. Although there are only about 325 species in existence today, there are of the order of 12000 additional species known from fossils.

The phylum is quite important for biostratigraphy, paleoecology, and evolutionary studies because it shows a great variety of changes in form and function through time.

Habit and habitat:

All brachiopods are marine animals whose habitats range from the intertidal zone to deep ocean. After a pelagic (free-swimming) larval phase, brachiopods settle to the sea floor where they spend the rest of their lives in a **sessile** (immobile) existence. Most live permanently attached to a hard substrate, either by encrusting on the surface or cemented to it by a fleshy stalk called a **pedicle**. Brachiopods belonging to the Order Lingulida, however, are burrowers and use their pedicles to anchor themselves in soft sediment (sand or mud)(fig.4).

A few species of brachiopods live in deep water along the continental slops. **No** brachiopoda are known to have lived in **fresh water**. *Lingula* is an example of brackish water brachiopods.

Two main type of brachiopod shell are recognized: mostly diminutive forms having valves held together without hingement (**inarticulates**) and small to large forms having valves which bear teeth and sockets for articulation along edges hinged together (**articulates**).

Feeding:

The food of brachiopods consists of microscopic material, which is drawn to the interior of the slightly open valves by water currents induced by movement of cilia on arms or brachia. Food particles are filtered by means of a food- gathering organ called **lophophore**.

Lophophore: The lophophore (figs.1,5&6) is an appendage extending from the vicinity of the mouth into the mantle cavity.It consists of simply lobed disk or two elongate brachia arranged in folds or spirals.On its edge,
the lophophore bear long tentacle –like cirri,at the base of which is a groove leading to the mouth(fig. 1).The cirri bear numerous fine cilia, which vibrate so as to set up water currents that bathe the lophophore and carry food particles toward the mouth.In articulate brachiopoda the lophophore supported by calcareous structure is termed brachidia or brachial supports there are three types
1-Brachiophore:It consists of short relatively thick calcareous projection from the position of the dental sockets.
2-Crura:Are more advanced type of support from the basal part of the brachia.
3-Brachidium:Like loop or spiralium.

SOFT PARTS:

The brachiopod animal consists of soft parts which carry out essential body functions and hard parts which are mainly external and serve for protection.

The soft parts consist of the body covering (mantle), a digestive tract, visceral organs, various muscles and tentacle-bearing appendages, termed **brachia**. The mantle lines the inside of both valves and contains cells which deposit the mineral substance of the shell (calcium carbonate). In certain brachiopods the mantle projects outward into the shell which consequently produces a **perforate** or **punctuate** structure. Shells which don't have these perforation are called **impunctate**.

Pedicle: is a muscular stalk which serves as the attachment organ of brachiopods. It is attached to the floor of one of the valves called **pedicle valve(fig.1,6d).**

Articulation and valve movement:

The most common class of brachiopods, the Articulata, is characterized by the presence of two opposing calcareous valves hinged along the posterior edge. They usually have a series of sockets and teeth which allow valves to open anteriorly for feeding; they can also keep the valves firmly closed when necessary(fig.6e,f&fig.2c,d). In some brachiopods the articulating structures have been reduced or lost during evolution.

Two major muscle sets open and close the valves. **Diductor muscles** attach at one end to the floor of the ventral valve, and at the other end to a projection (cardinal process) in the dorsal valve. When these muscles contract, the hinge acts as a fulcrum, opening the valves anteriorly. **Adductor muscles**, which are attached between the floors of both valves, contract to close the valves and hold them shut.

HARD PARTS:

Brachiopods secrete a hard skeleton called shell, which consists of **two** valves enclosing the soft part. The valves are held together by **muscles** in case of **inarticulate** brachiopods and by **teeth and sockets** in case of **articulate** brachiopods. **Teeth** are found in one valve (**pedicle**) whereas **sockets** are found in the corresponding valve (**brachial**)(fig.2c&d).

MORPHOLOGICAL FEATURES:(fig.3)

Brachiopod shells are distinguished from bivalve shells by the inequality of the two valves.

Shells of articulate brachiopods are characterized by the possession of a **hinge line** which coincides with the posterior margin of each valve. The hinge line is absent in inarticulate brachiopoda. The pointed end of the pedicle valve is called **beak** and the arched part of the valve near the beak is called **umbo**. Each valve has a beak although that of brachial valve may project little or not at all above the hinge line. The beaks mark the beginning of shell growth as shown by concentric lines around them (growth lines) or by radially disposed ribs (costae) or shell corrugations (plication, folds, sulcus) which generally diverge from them. The line along which brachiopod valves come in contact at the anterior part is called **commissure line**, this may be plane or has many corrugations and is important in the identification of brachiopods.

The **posterior** part of the shell is that part near the hinge line whereas the **anterior** is that part away from it.

Length is the distance from the beak to the anterior extremity of the shell.

Width is the maximum distance between opposite points on the lateral margins of a valve or shell. **Thickness** is the maximum distance between opposite points on the surface of the two valves.

At the posterior part of the shell there is an area between the beak and the hinge line, this area is called **interarea(fig.2a)**. Beneath the beak the interarea of either valve may be interrupted by a triangular open space termed **delthyrium** in the pedicle valve and **notothyrium** in the brachial valve(fig.2a). The delthyrium provides space for passage of pedicle. It is sometimes covered by shell substance called **deltidium** if it consists of a single plate or **deltidial plates** if it consists of two plates. Those are termed **chilidium** and **chilidial plates** on the brachial valve(fig.2a&fig,7).

The rounded opening for passage of pedicle is **termed foramen or pedicle opening(fig.6a)**.
The hinge line of articulate brachiopods carries **teeth and sockets** where teeth are found on the pedicle valve and sockets on the brachial valve.

SHELL FORM:

Brachiopod shells have diverse shapes. Some shells tend to become transversely widened and so having the greatest width along the hinge line (e.g. *Spirifer*). Other shells become very narrow transversely and longitudinally extended (e.g. *Terebratula*).

The shape of one valve with respect to the other is important in the identification of brachiopods. The following shapes are recognized:
1- **Biconvex:** both valves are convex.(fig.7a)
2- **Plano - convex:** brachial valve plane, pedicle valve convex.(fig.7b)
3- **Concavo - Convex:** brachial valve concave , pedicle valve convex.(fig.7c)
4- **Convexi - concave:** brachial valve convex, pedicle valve concave.(fig.7d)
5- **Convexi - plane:** brachial valve conical, pedicle valve plane.(fif.7E)

SHELL COMPOSITION AND STRUCTURE:

Brachiopod shells are classified into two groups on the basis of their chemical composition. Most **inarticulate** brachiopoda have hard parts composed predominantly of **calcium phosphate and chitinous organic matter**, such shells are termed **chitinophosphatic**. In most **articulate** brachiopods the shell is composed of **calcium carbonate** (calcite), such shells and termed **calcareous**.

Shell Structure: The chitinophosphatic shells are of two types: one in which thin phosphatic laminae alternate with chitinous ones and the other in which calcium phosphate and chitinous material are uniformly admixed.

The calcareous shells are of three types called **impunctate**, **punctate** and **pseudo-punctate**. In each there are two shell layers: an outer thin finely laminated layer and an inner thick layer composed of inclined calcareous fibers. In **impunctate** shells, these layers are **solid**. In **punctate** shells, the inner fibrous layer is perforated by fine tubes or pores extending from the interior almost to the outer surface. **Pseudo-punctate** shells lack pores, but the fibrous layer contains rod-like bodies of calcite, the ends of which commonly form projections on the shell interior. Because the rod-like bodies tend to be dissolved more readily in weathering than the surrounding fibrous materials, rounded cavities resembling puncta may be produced. Thus the shell is **falsely** punctate.

HOMEOMORPHY:

Homeomorphy is an external resemblance among shells belonging to different genera. This means that shells belonging to different groups may have similar shapes, also their pattern of ornamentation may be nearly identical. In such cases, one should examine the internal structure of the shell which shows that these shells differ radically, or the shell substance of one is impunctate whereas the other is punctate (perforate). There are two types of homeomorphy: one refers to closely similar but unrelated shells having the same age (**isochronouse homeomorphy**), the other type includes two or more shells of different geologic age in which one simulates the other (**heterochronous homeomorphy**).

CLASSIFICATION

The brachiopods are divided into two classes, based primarily on shell morphology. The inarticulates have unhinged valves generally of a chitinophosphatic composition, while the articulates are brachiopods with hinged calcareous valves.

Class Inarticulata

Valves unhinged, lacking teeth and sockets, shell generally chitinophosphatic. Early Cambrian - Recent. Class Inarticulata contains five orders, only three of which are commonly encountered:

Order Lingulida

These are the most conservative of the brachiopods; one genus, *Lingula*, appeared in the Ordovician and is still alive today in essentially the same form. The shells of lingulids are made primarily of calcium phosphate, which appears dingy brown, and are always biconvex and oval to squarish in outline. The order first appeared in the Cambrian, and it has been found consistently throughout the record. They live burrowed in the soft sediment, anchored by their long pedicle.

Order Acrotretida

This group has also survived since the Cambrian with a fairly constant shell morphology. Acrotretid valves are generally subcircular to circular, unequally biconvex, and often have a pedicle opening. An important subgroup (the craniaceans) has no functioning pedicle; instead, they cement the ventral valve directly to the substrate.

Order Obolellida

These brachiopods resemble the acrotretids and some articulates, and so are rather difficult to identify. Their valves are circular to oval, the ventral one with a pseudo-interarea and a pedicle opening of some sort. Obolellids are known only from Cambrian rocks.

Class Articulata

Valves hinged, calcareous, generally bearing well-defined teeth and sockets. Early Cambrian - Recent. The articulates are a diverse and complex class, they have proven to be the most useful brachiopods for a variety of studies. Seven orders are recognized.

Order Orthida

Apparently the most ancestral of the articulates, these brachiopods are also the most difficult to work with. They are a generalized group lacking complex morphologic features, and they tend to resemble some of the other articulate orders. Orthids are almost always biconvex, with a fairly wide hinge line flanked by distinct interareas on each valve. The first known articulates to appear in the Cambrian are orthids. They change little in basic structure through the Paleozoic, and became extinct at the end of the Permian.

Order Pentamerida

This group usually has strongly biconvex valves that are smooth or finely costate. Their characteristic feature is a robust spondylium, which is a curved calcareous platform for muscle attachment in the beak region. The spondylium is seated in the ventral valve. Pentamerids probably arose from orthids in the later Cambrian; they went extinct in the Devonian. The pentamerids were most important in Silurian shelf seas.

Order Strophomenida

No other brachiopod order shows as much morphologic diversity as the strophomenids. Generally, they have plano-convex or concavo-convex shells with a costate surface and no pedicle opening. This simple plan though, has led to several distinct and sometimes exotic forms. They include:

Productids: These brachiopods have hollow spines and strongly concavo-convex shells. They include several large, very spiny brachiopods and specialized reef-forming groups. Productids are mostly upper Paleozoic.

"True Strophomenids": In this group the shell is usually wider than long and the body cavity is small. They are important in the lower Paleozoic, but range into the Jurassic.

Chonetids: These are small shells that resemble the "true strophomenids", but they have hollow spines along the posterior edge. Chonetids are especially prominent in upper Paleozoic rocks.

Oldhaminids: "A leaf in a gravy boat" is the best way to describe the most common oldhaminid genus, Leptodus. These are confined to the Upper Paleozoic and the Lower Mesozoic.

Order Rhynchonellida

The shells of this group are strongly biconvex, many to the point of being globose, heavily plicate, and have a very short hinge line. Rhynchonellids are simple internally and have no complicated supports for the brachidium. Most workers believe that they evolved from the pentamerids. The rhynchonellids appeared in the Middle Ordovician and are still extant. Most Mesozoic brachiopods are rhynchonellids.

Order Spiriferida

The shells of spiriferids have a hinge line so wide that they look winged. The group is defined by the possession of a spirally-coiled brachidium that "points" toward the cardinal extremities. Most spiriferids are strongly plicate or costate, and they usually bear a fold and sulcus. The group is important in the middle and upper Paleozoic and parts of the lower Mesozoic.

Order Terebratulida

These are the most abundant brachiopods today; they are the typical "lamp shells" known to beachcombers. Terebratulid shells are strongly biconvex and bear a short hinge line. The beak is prominent and usually has a rounded pedicle opening. The surface of a terebratulid is smooth or finely costate. This group first appears in Lower Devonian rocks, but it only becomes abundant in Mesozoic and Cenozoic strata.

RELATION TO SUBSTRATE(fig.4)

Most brachiopods have a fleshy stalk, termed the pedicle that protrudes posteriorly through one valve or between the valves and **attaches** permanently to the substrate. When the pedicle exits through a valve (by definition the ventral valve), it leaves an opening that varies greatly in form among brachiopod groups. In many the pedicle was lost during either ontogeny or the evolution of the lineage, leaving as evidence a hole partially or completely closed off by accessory plates or growth of the ventral valve.

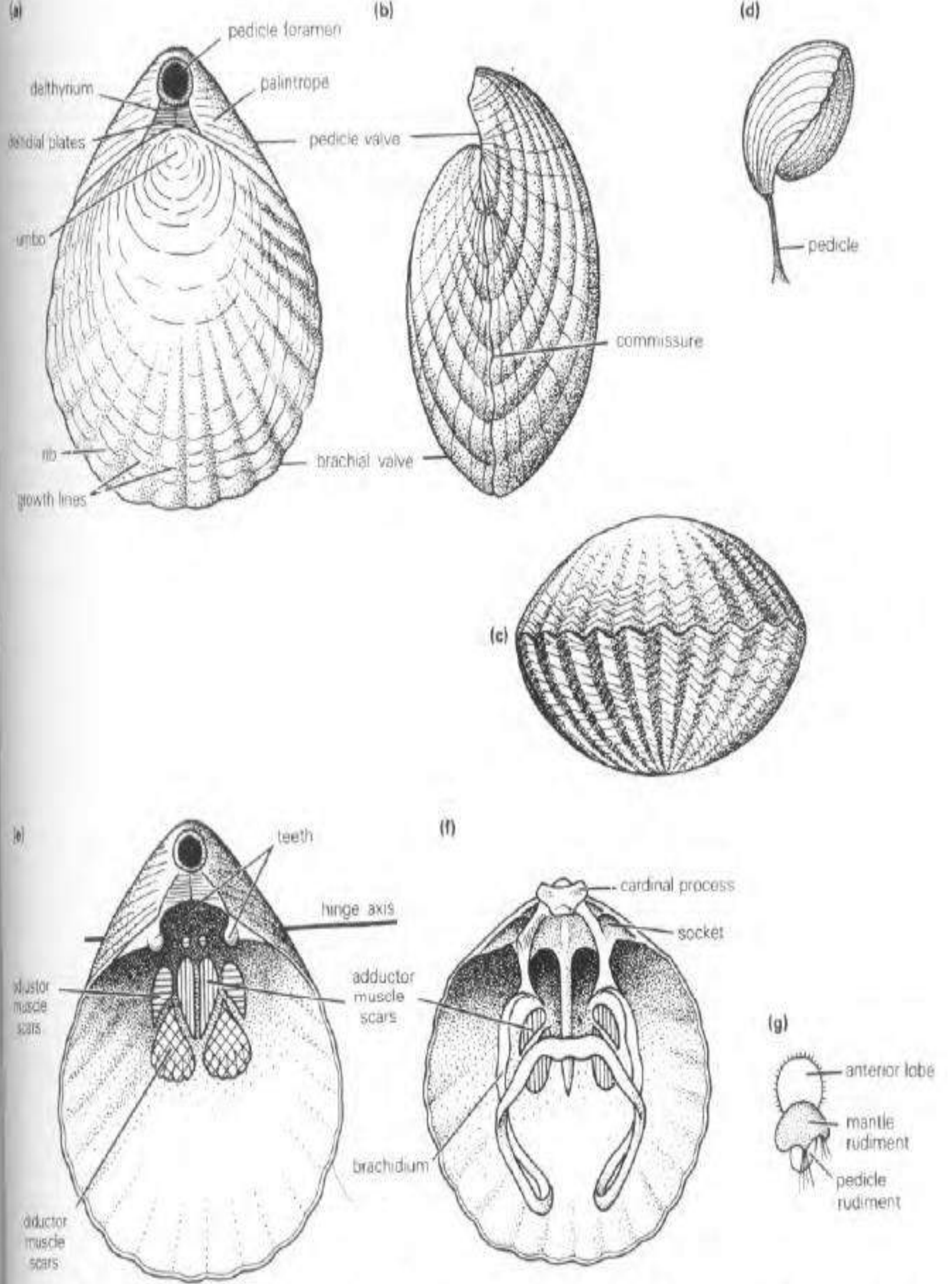
Some brachiopods had **no** pedicle and either lived **freely** on the substrate or **attached** their ventral valve directly to some firm object. The **free-living** types developed a wide variety of devices to protect themselves from burial in the sediment or disruption by currents (except for opening and closing the valves and some limited movement on the pedicle, brachiopods are strictly sessile) A few added heavy stabilizing calcite to the posterior and ventral portions of the shell; others had spines that could attach to the substrate or function as a "snowshoe" in muddy areas. Other brachiopods without pedicles were able to grow at a rate that kept the commissure above the sediment surface.

GEOLOGIC HISTORY

Brachiopods appear near the beginning of the Cambrian, but did not become abundant until the Early Ordovician. The remainder of the Paleozoic could be termed “the Age of Brachiopods” where several orders dominated the shallow shelf environments throughout the era.

Brachiopods were hard hit by the mass extinction which defines the Permian/Triassic boundary about 245 million years ago. It was shortly after this that bivalve molluscs came to dominate this ecological niche. Brachiopods still persist today, but are neither abundant nor diverse.

There are approximately 325 species of living brachiopods, which is a pale shadow of their former diversity of more than 12,000 described fossil species.



igure 7.1 *Magellania flavescens*: (a) upper surface with brachial valve (× 2 approx.); (b) lateral view (× 2 approx.; (c) anterior iew (× 2 approx.); (d) in life position, showing pedicle attachment; (e) internal view of pedicle valve (× 2 approx.); (f) internal view f brachial valve (× 2 approx.); (g) larva. [(a)–(f) Based on Davidson, 1851; (g) based on illustration in Percival, 1944.]

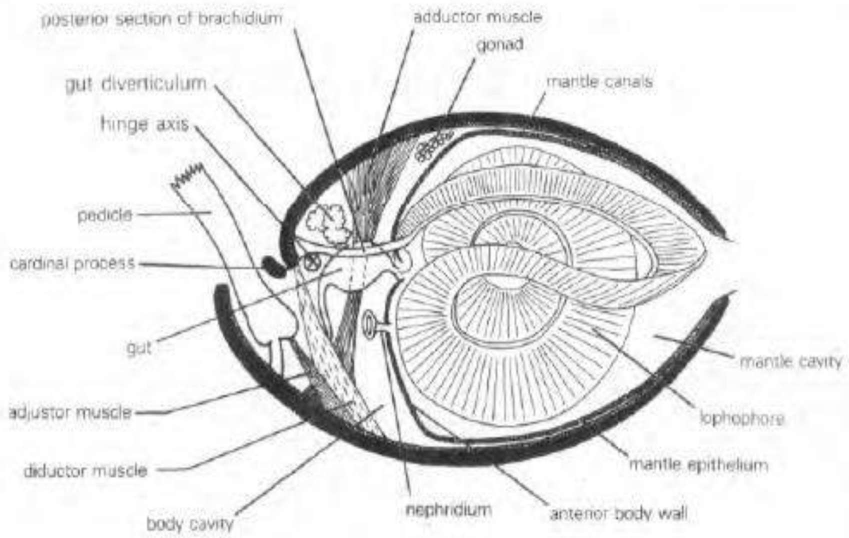


Figure 7.2 *Magellania flavescens*: median section, somewhat stylized.

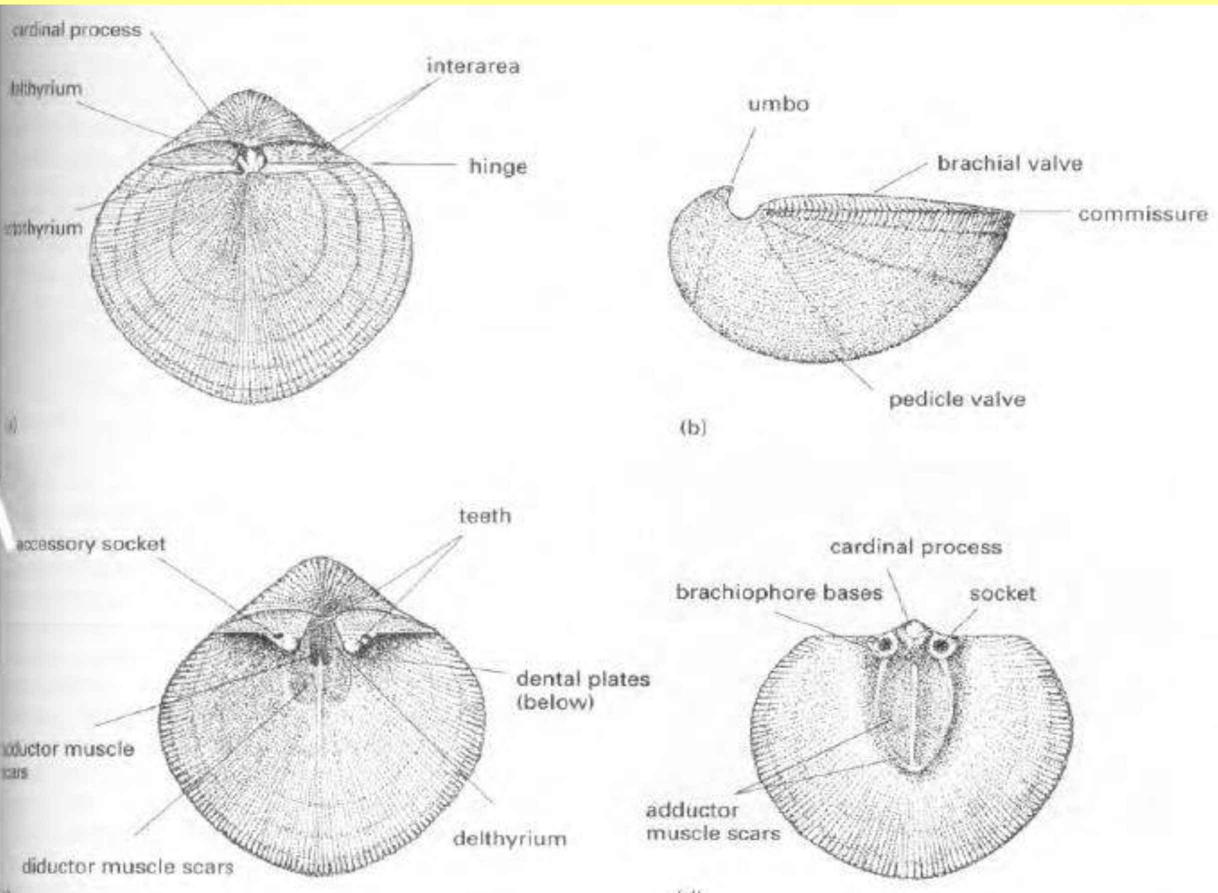


Figure 7.4 *Visbyella visbyensis* (Sil.): (a) complete shell, upper surface; (b) lateral view; (c) internal view of pedicle valve; (d) internal view of brachial valve (all × 5).

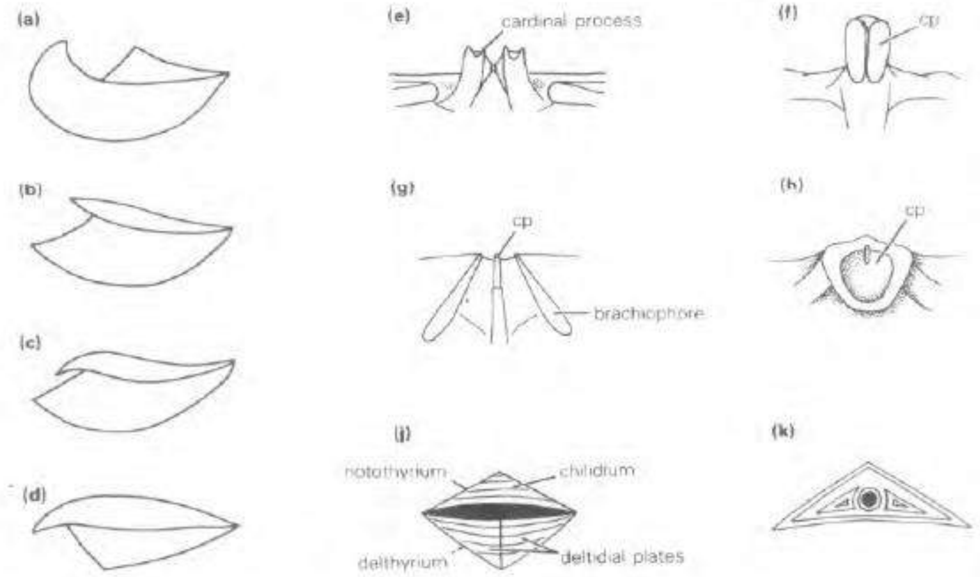


Figure 7.11 (a)–(d) Inclination of interareas: (a) brachial valve hypercline, pedicle valve anacline; (b) brachial valve anacline, pedicle valve apsacline; (c) brachial valve apsacline, pedicle valve apsacline; (d) brachial valve apsacline, pedicle valve procline; (e)–(h) cardinal processes: (e) *Strophomena*; (f) *Pustula*; (g) *Hesperorthis*; (h) *Leptellina*; (j) pedicle foramen with closing structures; (k) triangular stegidial plates closing delthyrium. (Redrawn from Williams and Rowell in *Treatise on Invertebrate Paleontology*, Part H.)

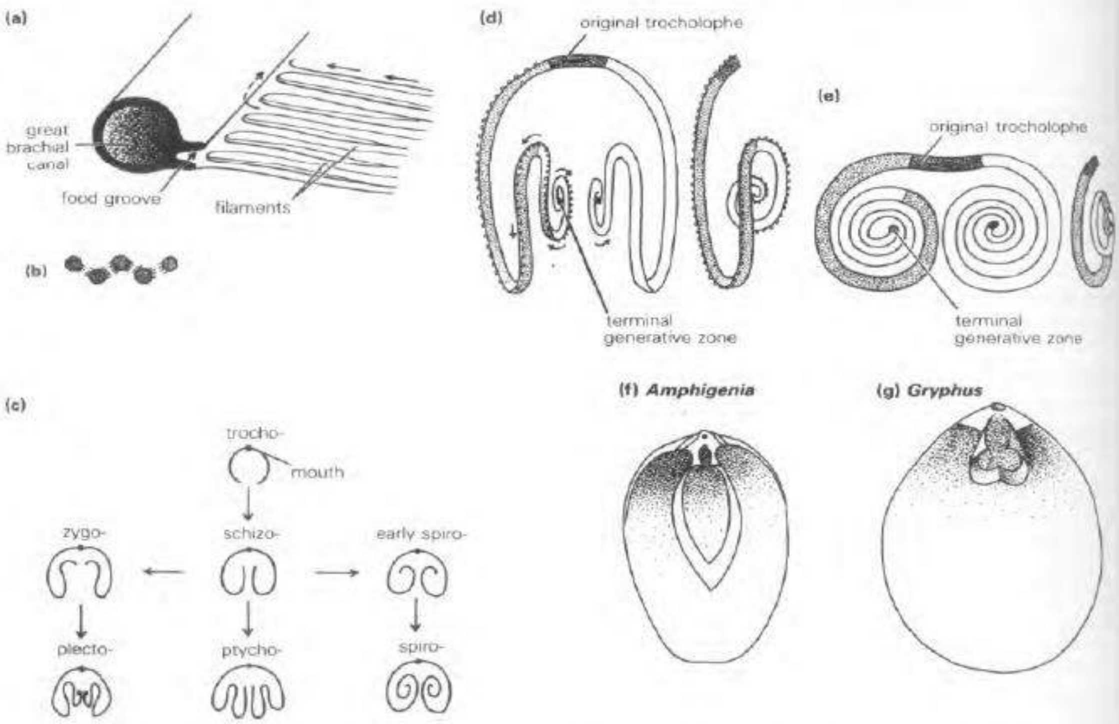


Figure 7.12 Brachiopod lophophores: (a) sectional view of lophophore with fluid-filled great brachial canal, food groove and filaments – arrows show the direction of movement of food particles; (b) arrangement of filaments in section; (c) the main types of lophophores showing various developmental pathways; (d) *Terebratula* plectolophe, showing mode of growth from a terminal generative zone; (e) *Rhynchonella* spirolophe, same; (f) *Amphigenia* (Dev.), primitive loop structure of early terebratulide (Centronellidina); (g) *Gryphus* (Rec.) short loop of Terebratulidina. [(a)–(c) Redrawn from Rudwick, 1970; (d), (e) redrawn from Williams and Wright 1961; (f), (g) redrawn from *Treatise on Invertebrate Paleontology*, Part H.)

Phylum Mollusca

The Mollusca are one of the largest groups of invertebrate animals, which are similar in biologic organization.
They are marine and only a few bivalves and gastropods can live in fresh water. One group of gastropods (the pulmonates) lives on the land.

Shell:

The Shell of mollusca may be chitinous or calcareous (calcite or aragonite) and is secreted by the mantle. Most molluscs have an external shell of calcium carbonate, some have an internal shell like Sepia and belemnites, and others don't have shell like Octopus and some gastropods (terrestrial gastropods).

Soft part:

The soft parts of mollusca (visceral mass) include the heart, alimentary tract divided into mouth, esophagus, stomach, an intestine and ends with the anus. There is also digestive glands, kidneys, nervous, circulatory and muscular systems. The anus discharges waste products into a posterior space termed the mantle cavity. This cavity has both an inlet and outlet to the sea, through which waste material discharges and respired water too. Gills are found in the mantle cavity, these gills are used for respiration as well as gathering food particles from the water. They are present in all mollusca except land gastropods (pulmonates) which have lungs.
All mollusca except pelecypods have a head with a mouth containing radula (a belt of teeth for mastication) and sense organs.

Feeding in Mollusca and their habit:

1. **Amphineura (*Chiton*) and gastropods:** are slow moving mollusca, which creep on a foot. They have radula and so are herbivores, carnivores or scavengers. Only the gastropods have a head with sense organs, which enable them actively to hunt.

2. **Bivalves:** are mostly suspension feeders and less commonly deposit feeders. They have limited capacity for movement.
3. **Cephalopods:** are nektonic animals and are fast-moving hunters. The radula is used for swallowing but cutting up of food is done by the powerful Jaws.
4. **Scaphopoda:** are benthonic, sessile animals which feed on small organisms using specially adapted tentacles.

CLASSIFICATION:

Mollusca are divided into five classes:(fig.1)

1. Class Amphineura.
2. Class Scaphopoda.
3. Class Pelecypoda
4. Class Gastropoda
5. Class Cephalopoda

Class Amphineura

The Amphineura are marine molluscs having a shell composed of eight calcareous plates. They are rare as fossils (see figure).

Ex. Chitons

Chitons are more or less flattened animals bearing eight transverse calcareous plates dorsally. They possess a broad creeping foot and a well-developed radula. Chitons are typically found on hard substrates, such as the larger rocks of exposed shores or on shells in more protected waters.

Class Scaphopoda:

The Scaphopods are marine molluscs with small tapering shell open at both ends (see figure). The anterior wider end is permanently embedded in sediment. The anus is at the upper end. They have a foot used for burrowing. The shell is aragonitic and sometimes longitudinally striated. They are rare as fossils.

Ex. G. ***Dentalium.***

Class Pelecypoda
(Bivalvia)

- Pelecypods are molluscan animals having a calcareous shell, consisting of **two valves**(fig.1,2&3). The soft parts are enclosed within these two valves.
- The two valves are articulated along a **hinge line**, which carries **teeth and sockets**. They are closed and opened by **muscles**.
- The soft parts are enclosed in the **mantle**, this mantle secrets the shell. The mantle is attached at the dorsal part but free at the ventral part leaving a depression known as **pallial line**.
- During life, all pelecypods must have a current of water entering the gills for respiration and for bringing food to the mouth. This current enters the body through a lower inhalent canal. The waste products are carried out through an upper exhalent canal. Some pelecypods have an exhalent tube called **siphon**; the siphon is drawn within the shell by muscles attached to the inner surface just below the posterior adductor muscles. The places of attachment of muscles form the embayment of the pallial line known as the **pallial sinus(fig.3)**.

Musculature

The valves of pelecypods are held together by **adductors muscles** which pass from one valve to the other. They close when the muscles contract and open when the muscles relax. There is also an elastic structure along the hinge line called **ligament(fig.3b-e)**which helps in opening the valves. The ligament is **external** but there is another similar structure helps in opening the shell, this structure is called **resilium.** The resilium is **internal** and lies in a depression called **resilifer.** Some species have both ligament and resilium.

Shells having one adductor muscle are called **monomyarian**, those having two muscles are called **dimyarian,** the two muscles may be equal (**isomyarian**) or unequal (**anisomyarian**)(fig.1iv).

Shell:

The shell of pelecypods as mentioned before, consists of two valves. The two valves articulate by means of teeth and sockets, which are found in each valve.

The earliest part of the valves is called **beak** and the rounded part adjacent to the beak is called **umbo**.

The shell is **bilaterally** symmetrical with the plane of symmetry passing **between** the valves(fig.1&2).

Structure of the shell:(fig.4)

When studying pelecypod shells in thin sections under microscope, three layers are recognized: -

1. **Periostracum:** this is the outer layer, usually of thin organic matter and so rarely preserved in fossil state.
2. **Prismatic layer:** this is the middle layer, composed of prisms of calcium carbonate arranged perpendicular to the surface of the shell.
3. **Lamellar layer:** this is the inner layer composed of thin laminae of calcium carbonate arranged parallel to the surface of the shell.

mineralogically , bivalve shells may be calcitic or aragonite or both together.

Brachiopods	Pelecypods
Inequivalved. Equilateral. Valves pedicle and Brachial. Plane of symmetry across valves and through beaks. Pedicle opening present. Teeth in one valve, sockets in the opposite (except in inarticulate). Valves open and close by muscles.	Equivalved. Inequilateral. Valves right and left. Plane of symmetry between valves. No pedicle opening. Teeth and sockets (if present) in each valve. Valves open by ligament or resilium.

Dentition

Dentition means the arrangement of teeth and sockets along the hinge line. Generally, there are two kinds of teeth:

1. **Cardinal teeth:** lie beneath the umbons.
2. **Lateral teeth:** lie on either side of the umbons.

Types of dentition:

1.Taxodont: Teeth are numerous and are arranged along a straight or curved hinge.
Ex. *Arca*, *Barbatia*, *Glycemeris*, *Nucula*.

2.Dysodont: Teeth are small and simple.
Ex. *Mytilus*

3.Isodont: Teeth are very large and lie on either side of a central ligament pit.
Ex. *Spondylus*

4. Schizodont: Teeth are very large and have many parallel grooves normal to the axis of the tooth.
Ex. *Trigonia*

5. Heterodont: with two or three cardinal teeth below the umbo as well as elongated lateral teeth anterior and posterior to these.
Ex. *Venus*

6. Pachydont: The teeth are very large, heavy and blunt.
Ex. Rudistids and G. *Chama*

7. Cryptodont (Desmodont): Neither teeth nor sockets.
Ex. *Praecardium*

Bivalve shell morphology and mode of life:(fig.6)

The shape and general morphology of bivalve shells directly reflects their mode of life. Modern bivalves are grouped into the following morphological categories:

1- Infaunal shallow burrowing. Ex. *Lucina, Venus.*
2- Infaunal deep burrowing. Ex. *Mya*
3- Epifaunal attached by byssus. Ex. *Mytilus, Tridacna*
4- Epifaunal cemented to the rock. Ex. Oysters
5- Free-lying. Ex. *Gryphaea*
6- Swimming. Ex. *Pecten*
7- Boring and cavity dwelling. Ex. *Lithophaga*

<u>Byssus</u>: is an organ composed of chitinous fibers, which attach the pelecypod shell to the substratum.

Classification of bivalves

Bivalves have always been found to classify. The problems are not acute at lower taxonomic levels, for species, genera ,and families seem on the whole to fall into clearly defined natural grouping. These are based upon **shell form** and **structure**, the presence or absence of a **pallial sinus**, **dentition** and **other characters**.

A recent classification given below and based on that in the (Treatise) uses **shell microstructure** , **dentition** and(to some extent) **hinge structure**, **gill type** , **stomach anat**omy and the **nature of the labial palpe**s as the stable characters, and in this classification six subclass are defined .

1-Subclass **PALAEOTAXODONTA**(Ord.-Rec.):Includes one order Nuculoida. Small protobranch, taxodont, infaunal , labial palp feeders with aragonitic shells.

2-Subclass**CRYPTODONTA**(Ord.-Rec.):A lagely toothless(dysodont), infaunal, aragonitic-shelled.

3-Subclass**PTERIOMORPHIA**(Ord.-Rec.):A rather heterogenous group of normally byssate bivalves with variable musculature and dentition. Shells may be calcite or aragonitic or both.

Order .1.ARCIDA:Isomyrian filibranchs with crossed lamellar shells, taxodont.

Order.2.MYTILOIDA:Anisomyrian filibranchs and eulamellibranchs, prismatic/nacreous shells byssate, dysodont.

Order.3.PTERIODA:Anisomyrian or monomyarian filibranchs or eulamellibranchs, shellstructure varied byssate or cemented. Includes all scallops , oysters, and pearl clams.

4-Subclass PALAEOHETERODONTA(Ord.-Rec.):Aragonitic shell ,including the following orders:

Order.1.MODIOMORPHOIDA:Heterodont teeth.

Order.2.UNIONOIDA:Hetrodont teeth non-marine genera with a long time range.

Order.3.TRIGONOIDA:bivalves with large trigonal shells and well developed schizodont teeth.

5-Subclass HETERODONTA(Trias-Rec.):Heterodont eulamellibranchs .Aragonitic crossed-lamellar shells ,adapted tovaried modes of life and especially to infaunal siphon feeding.

Order.1.VENEROIDA:Active hetrodonts with true hetrodont teeth.
Order.2.MYOIDA:Thin shelled burrowers and borers, and very inequivalves, siphons well developed.
Order.3.HIPPURITOIDA:Large, often coralloid, cemented extinct bivalves with pachydont dentition e.g. Rudists.

6-Subclass ANOMALODESMATA(Ord.-Rec.):Burroing or boring forms, very modified , with aragonitic shells and desmodont dentition. One order only ,PHOLADOMYOIDA.

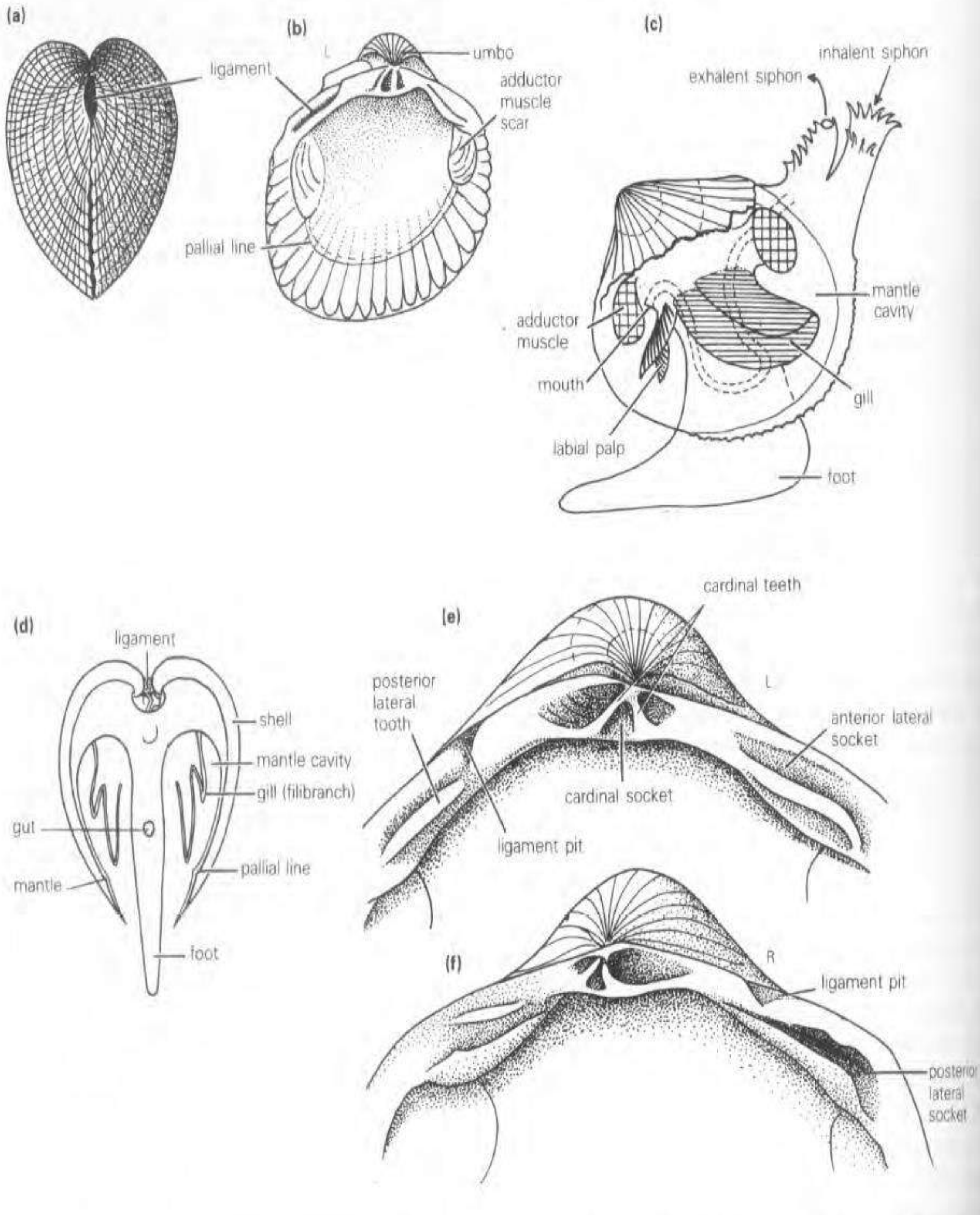


Figure 8.7 *Cerastoderma edule*, a Recent infaunal heterodont bivalve: (a) posterior view of intact shell; (b) interior of left valve; (c) right lateral view of living animal in life position with shell partially removed to show soft parts; (d) vertical section of living animal; (e), (f) cardinal region of left and right valves, respectively.

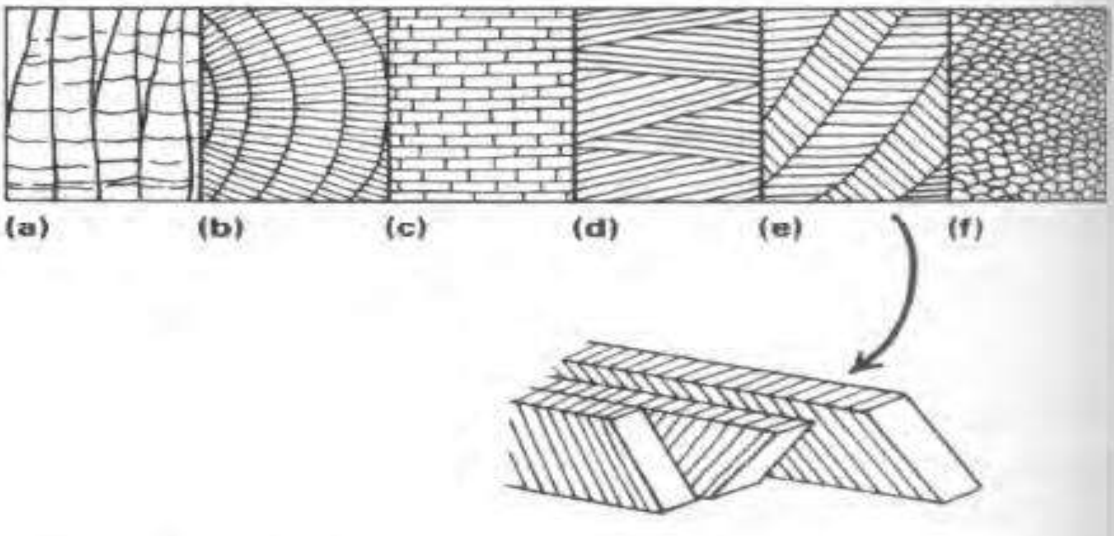


Figure 8.8 Bivalve shell layer morphology as seen in thin section: (a) simple prismatic; (b) compound prismatic; (c) sheet nacreous; (d) foliated; (e) crossed lamellar with inset showing disposition of stacked aragonite lamellae; (f) homogeneous. (Based on Taylor and Layman, 1972.)

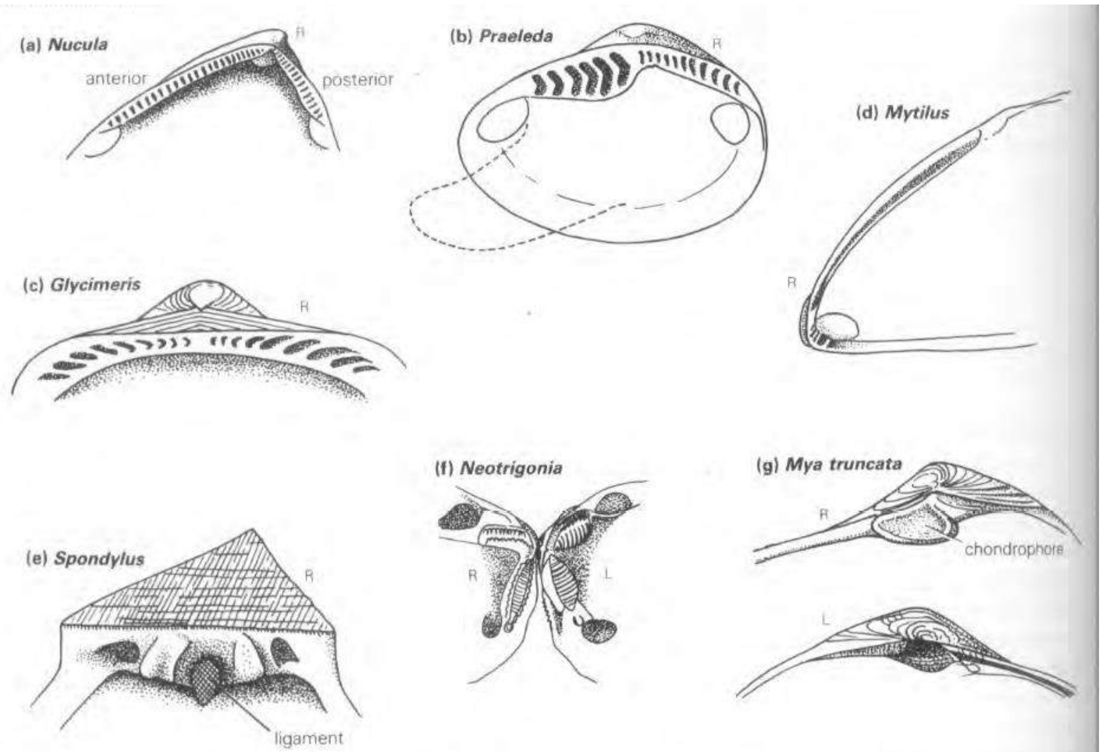


Figure 8.10 Bivalve hinge lines and dentition (not to scale): (a) *Nucula* (Tert.–Rec.), right valve (note that the umbones face posteriorly), taxodont hinge; (b) *Praeleda* (Ord.), right valve, modified taxodont hinge, foot position inferred; (c) *Glycymeris* (Tert.–Rec.), right valve, taxodont hinge; (d) *Mytilus* (Rec.), right valve, dysodont hinge; (e) *Spondylus* (Cret.), right valve, isodont hinge; (f) *Neotrigonia* (Rec.), schizodont hinge; (g) *Mya truncata* (Rec.), desmodont hinge with chondrophore. [(b) Redrawn from Bradshaw 1970; (c) redrawn from Woods, 1946.]

Oysters:

Oysters are pelecypods found in beds in shallow, warm waters of all oceans. The shell is made up of two unequal valves, the lower valve (larger) is convex and is cemented to the substrate. The upper one (smaller) is flat and acts as a lid or operculum. They are characterized by having one muscle scar (monomyarian), strongly curved beak and absence of teeth and sockets.

Oysters spend most of their life (except for the free-swimming larval stage) attached, having fused its valve with a sticky substance to a substratum of shells, rocks, or roots. After the oyster becomes sessile, it is victimized by oyster drills, starfish, and other enemies.

During Cretaceous oysters formed banks reaching more than 5 meters in height and extending for several kilometers. They are still living today and live in aggregates cemented together such as in the Gulf of Oman (Khor Fakkan). Ex. G. *Ostrea,* G. *Exogyra.*

Oysters are classified in the phylum Mollusca, class Pelecypoda or bivalvia, family Ostreidae.

Rudistids:

Rudistids are pelecypods, which have two **unequal** valves. The larger valve is the right valve, it has a conical shape and is fixed to the substrate. The smaller valve is the left one, which acts as a lid. They usually have a pachydont dentition.

Rudistids are **extinct** and died out at the end of the **Cretaceous**. They are good index fossils for time correlation and biostratigraphic Zonation. In Iraq, they are abundant at Aqra Formation and reach large sizes.
Ex. *Dictyoptychus* morgani

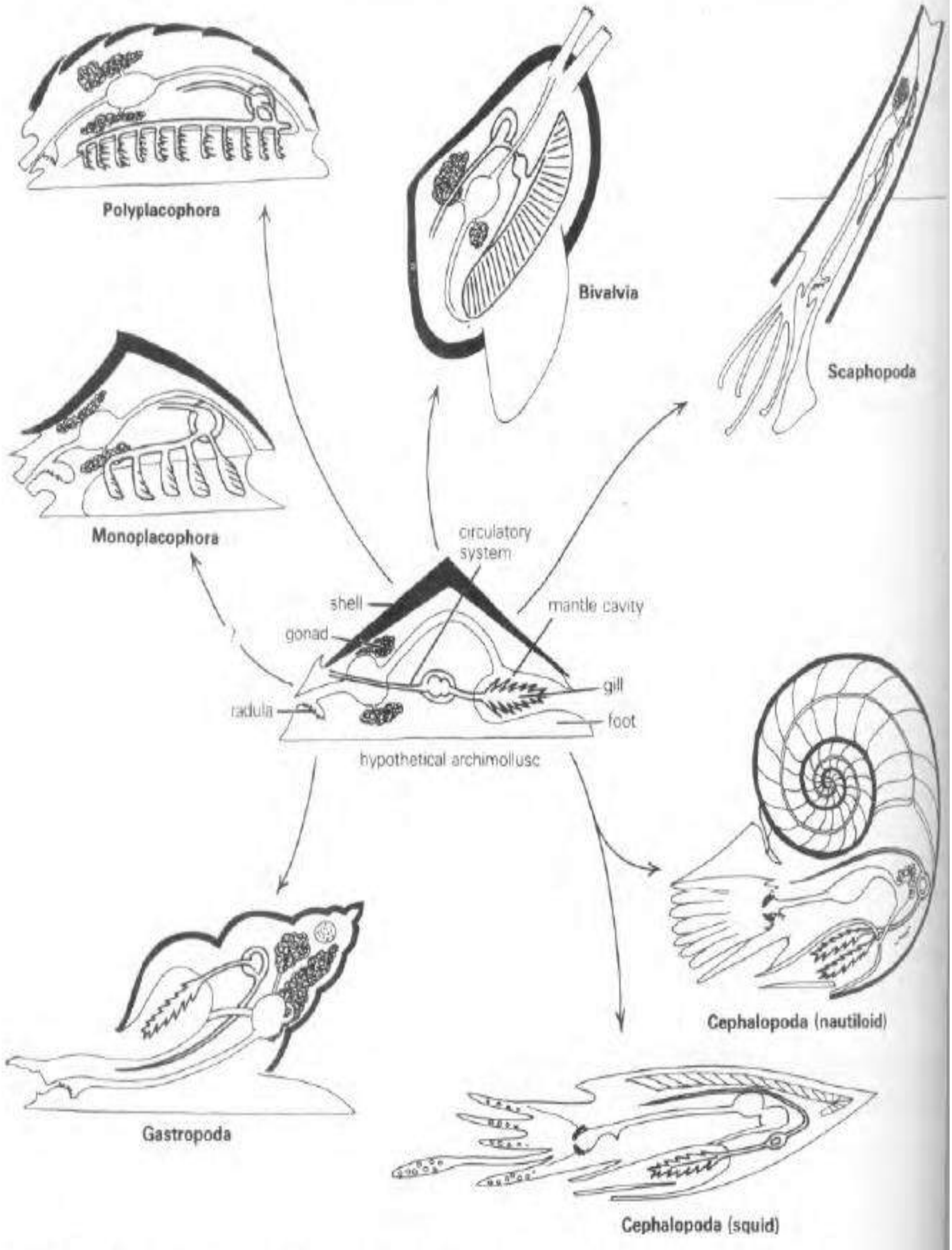


Figure 8.1 Morphology and relationships of molluscan classes with reference to a 'hypothetical archimollusc'.

Class Gastropoda

Gastropods are mollusca which have a shell made of a single piece, which is usually sealed apically and coiled helically and lacks serial muscle scars.
They have a well developed head region with tentacles, eyes and other sense organs(fig.1a). There is a ventral foot for creeping and specialized structures (gills or lungs) for breathing. Fertilization is internal and sexes are united or separate depending on the species.
The mouth contains the **radula**, which is the feeding organ in gastropods. The radula consists of rows of small teeth to shred food material. There is **no** radula in bivalves (Pelecypods).

Shell:

The gastropod shell begins with the protoconch, which consists of several minute whorls. The rest of the shell consists of a coiled cone, open at the larger end where the **aperture** lies. This cone is made up of several whorls; the line of contact between adjacent whorls is called **suture**. The suture is absent in shells which don't have the whorls in contact.
All whorls expect the last one constitutes the **spire**(fig.1i&iii), the last whorl constitutes the **body whorl**(fig.1ii&iii). Usually; the whorls are not divided into chambers except in rare cases where the whorl contains many chambers.
In some Gastropods there is only one chamber (uncoiled shells), in others, there are several whorls arranged along one plane (planispiral). In most gastropods, the whorls are coiled spirally in more than one plane, such coiling is called helicoid or **trochospiral** coiling.
If the whorls are in contact along the inner surface, an axial pillar will be formed in the place of the axis of coiling, this pillar is called **columella**.
If the whorls are not in the contact along the inner surface, there will be a space in the place of the axis of coiling, this space is called **umbilicus**.

Aperture:(fig.1)

It is an opening in gastropod shell found in the body whorl. In some gastropods the aperture is closed by a horny or calcareous plate called **operculum**.

The margin of the aperture adjacent to the columella or umbilicus is called **inner lip**; the opposite margin is called **outer lip**.

The aperture may be provided with a channel called **siphonal canal** to allow water from the gills to pass out to the exterior. Apertures with such siphons are called **siphonostomatus** whereas those without siphons are called **holostomatus**.

Orientation:

To orient a gastropod shell, hold it so that the apex is up and the aperture faces you

- If the aperture lies on the right, the shell is **dextral**.
- If it lies on the left, the shell is **sinistral**.

Shell composition:

Most gastropods have an aragonitic shell. In fossil shells the aragonite either recrystallizes to calcite or may be dissolved.

Habitat:

Most gastropods live in marine water, they also live in fresh water and on land. Land gastropods are called **pulmonates** because of having lungs instead of gills.

Extinct gastropods:

There is an important group of gastropods, which died out at the end of the **Cretaceous**, this is called **Nerinids**. The shells of Nerinids have a long spire and must be studied in thin sections.

Types of coiling in gastropods:

1- **Non-coiled:** cap-shaped gastropods without coiling.
Ex. *Patella*, *Fissurella*

1- **Planispiral:** coiling in which the whorls are arranged along one plan.

2- **Helicoid (Trochospiral):** coiling in which the whorls are arranged spirally in more than one plane.

There are different forms of helicoid shells(figs.1iv-ix&2;1-8):

A- **Conical (Trochiform):** conical shells with acute spire and flat base.
Ex. *Trochus, Tectus*.

B- **Biconical:** the shell appears as if it consists of two cones with a common base.
Ex. *Strombus, Conus*.

C- **Obconical:** similar to biconical but the upper cone (spire) is obtuse.
Ex. *Gisortia*

D- **Turbinate:** similar to conical but with convex base.
Ex. *Turbo*

D- **Turreted:** with long acute spire.
Ex. *Turritella*

F- **Fusiform:** spindle-shaped, thickest at the middle and tapering at each end.
Ex. *Fusus*

G- **Convolute:** The last whorl is very large and conceals all or nearly all earlier whorls.
Ex. *Cyprea*

H- **Vermiculate:** like worms.
Ex. *Vermetus*

I- **Auriculate:** the last whorl is very large with a large aperture.
Ex. *Haliotis*

Classification of gastropods

The classification of gastropods is based upon soft parts . **Gill** and **osphradial morphology** is most important, as the structure of the

nervous system, **heart**, **kidney** and **reproductive system**. A condensed version of that is given here:

1-Subclass **Prosobranchiata**(L. Cam.-Rec.):Shelled gastropods in which Torsion is complete.

Order **1. Archae ogastropoda** (L. Cam.-Rec.) :The gill **aspidobranch**. There may have two gills or one may be lost. The shell structure is variable ;symmetrical forms exist or are found as fossils , but the shells are normally helical spires. Nearly all marine.

Order **2. Mesogastropoda**(Ord.- Rec.) : Have **pectinibranch gills**. And are classified on **radular** structure.

Order **3. Neogastropoda**(Cret.-Rec.):Have **pectinibranch gills**.

2-Subclass **Opisthobranchiata**(? Carb.-Rec.):Marine gastropods which have largely or completely lost the shell. They have undergone detorsion and straightened themselves out. These include the planktonic pteropods and sea-slug , which carry secondary gill on the dorsal surface.

3-Subclass P**ulmonata**(Mesozoic-Rec.):Land dwelling (secondarily fresh water- dwelling)slugs and snails, the gills are lost and the whole surface of the mantle cavity is modified as a lung.Most of them have retained their shells though the land slugs have lost them altogether.

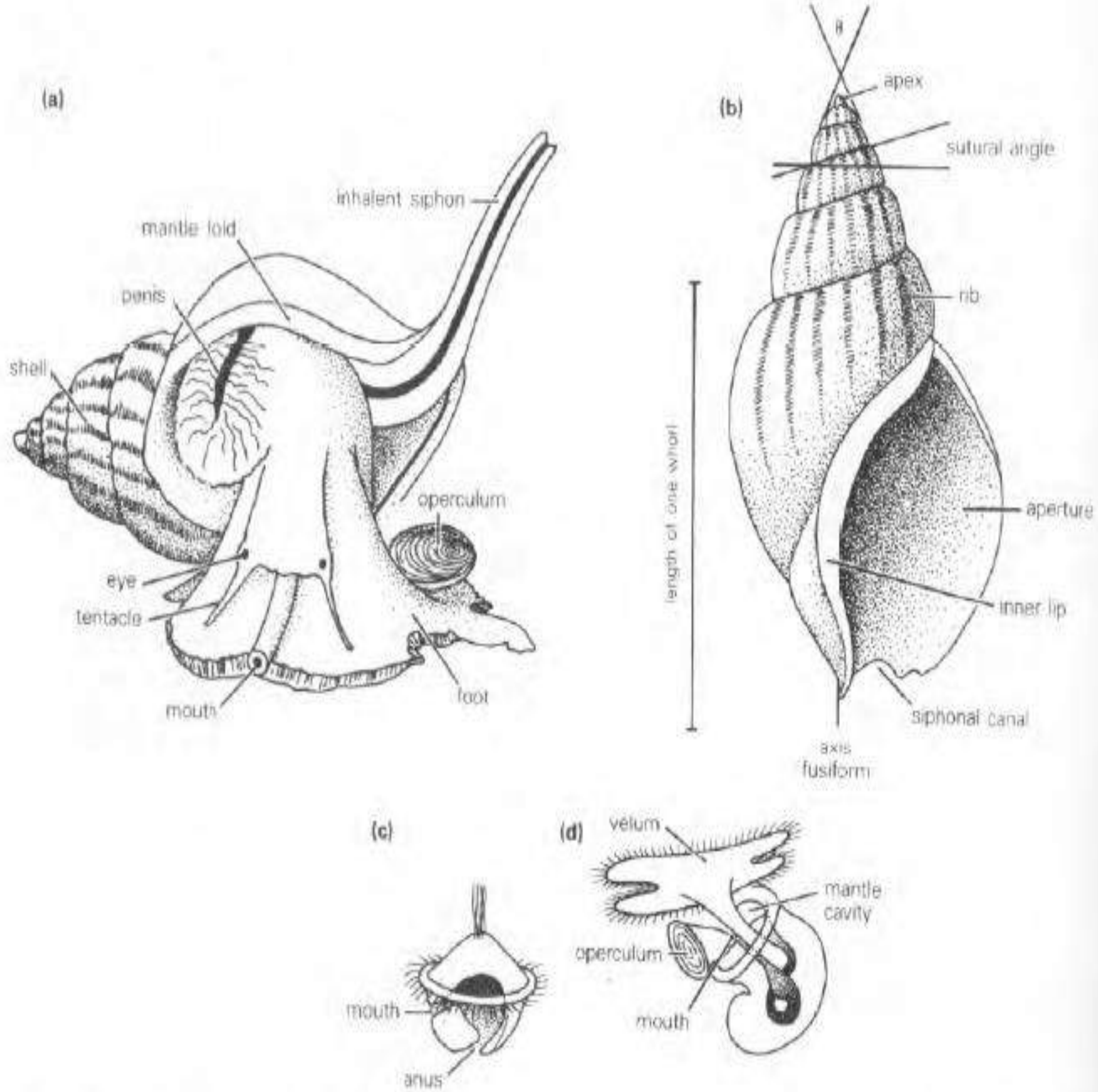


Figure 8.17 Gastropod morphology shown by *Buccinum* (Rec.): (a) living animal (× 1 approx.); (b) shell (fusiform); (c) trochophore larva; (d) veliger larva of gastropod. [(a) Redrawn from Cox in *Treatise on Invertebrate Paleontology*, Part I.)

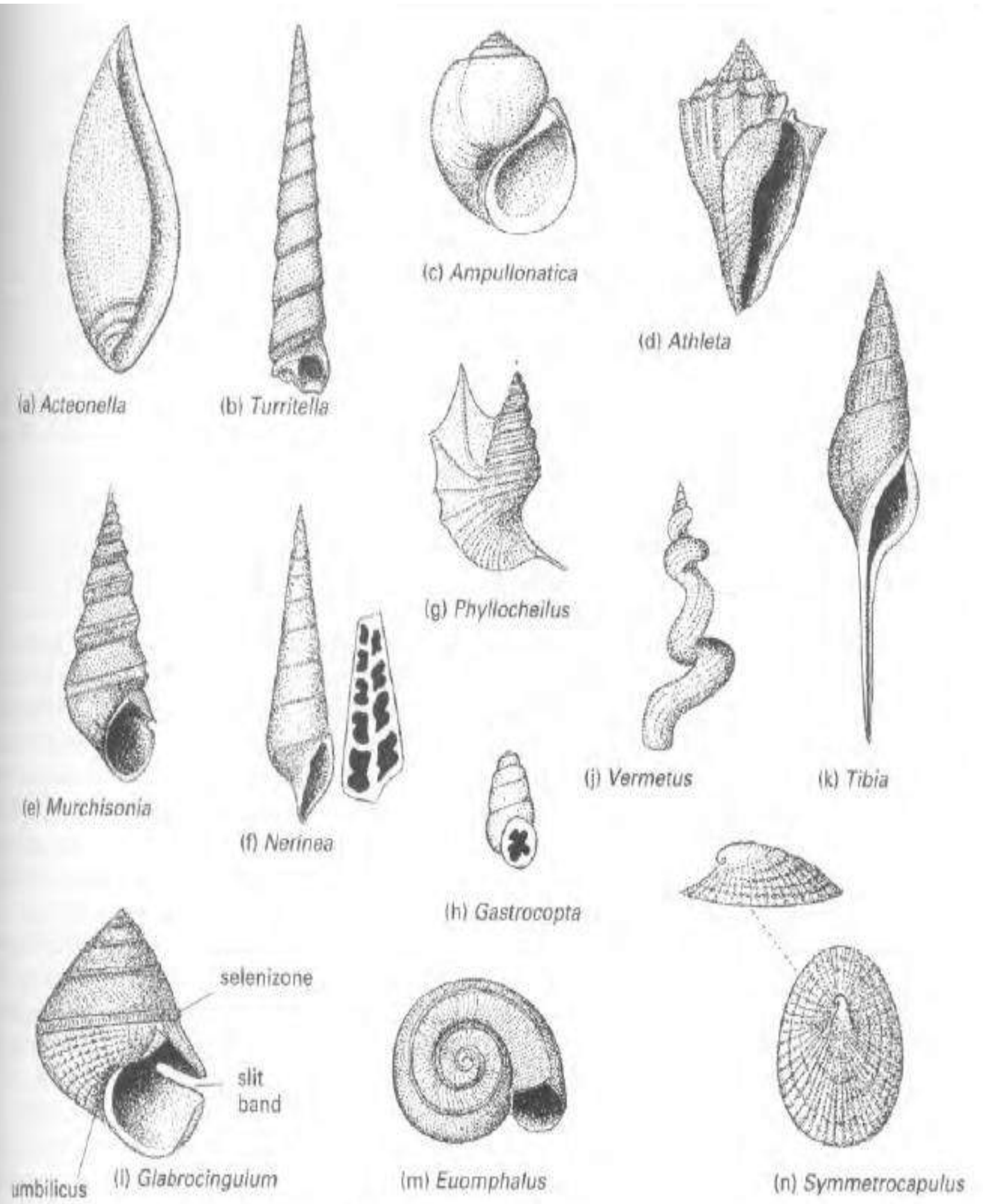


Figure 8.18 Gastropod shell shapes: (a) *Acteonella* (Rec.), convolute; (b) *Turritella* (Eoc.), turreted; (c) *Ampullonatica* (Eoc.), globular, low-spired; (d) *Athleta* (Eoc.), volutospine; (e) *Murchisonia* (Carb.), high-spired; (f) *Nerinea* (Jur.), with columella and internal folded thickenings within the whorls; (g) *Phyllocheilus* (Jur.), turbinate, with digitate aperture; (h) *Gastrocopta* (Rec.), pupiform, with constricted aperture; (j) *Vermetus* (Rec.) irregular, partially uncoiled; (k) *Tibia* (Eoc.), turbinate to high-spired, siphonate; (l) *Glabrocingulum* (Carb.), showing slit band for exhalant siphon; (m) *Euomphalus* (Carb.), discoidal, near planispiral; (n) *Symmetrocapulus* (Jur.), patellate. (Mainly redrawn from *Treatise on Invertebrate Paleontology*, Part I, and *British Cenozoic Fossils*, British Museum, 1979; not to scale.)

Class Cephalopoda

Cephalopods are mollusca having a bilaterally symmetrical body with a highly developed head surrounded by tentacles(fig.1)
Most cephalopods have a shell that is coiled **planispirally**_(planispiral coiling). Paleozoic cephalopods have a shell that is a straight, curved or coiled tapering cone. The shell may be **external**(fig.1a) (*Nautilus*) or **internal** (Sepia), other cephalopods have **no** shell (Octopus).
Some cephalopods died out at the end of Paleozoic (those having conical shells), others at the end of Mesozoic (ammonites and belemnites).

Cephalopods have been among the dominant large predators in the ocean at various times in geological history. Two groups of cephalopods exist today: The extant Nautiloidea, containing the pearly nautiluses which are phylogenetic relicts, are represented by only a few species, and the Coleoidea, containing the squids, cuttlefishes and octopods, are represented by about 700 species. Cephalopods are the most active of the molluscs and some squids rival fishes in their swimming speed. Although there are only about 700 species of living cephalopods, they occupy a great variety of habitats in all of the world's oceans.

Morphology of cephalopod shell (G. *Nautilus*):
The shell of *Nautilus* is planispirally coiled. The animal occupies the terminal living chamber.
As the animal grows it secretes a new chamber and shuts off the older one by a **septum**(fig.1a) (septum is a plate that closes the older chambers in Cephalopods).

Did you hear about septum before? Where?

The septa are perforated in the middle to allow the **siphon** to go through.
<u>**Siphon**</u>: is a fleshy tube that extends backward to the earlier chambers.
The siphonal tissues secrete a tube of calcium carbonate around it, this tube is called **Siphuncle(fig.1a&b)**

As mentioned before, the animal occupies the last chamber, which is called **body chamber**. The other chambers are called **gas chambers** because they are filled with gas similar to air but with more nitrogen and less oxygen. This **gas** increases the **buoyancy** of the shell, making it easier to swim.
All chambers except the last one are together forming the **phragmocone**. The last (body) chamber is **seldom** preserved in fossil state.

The animal protrudes outward through an opening called **aperture**. Some Cephalopods close their aperture by a single or double plate when the animal withdraws into the shell; this plate is calcareous and is called **aptychus** (double) or **anaptychus** (Single).

Types of Cephalopod shells:

1. **Orthocone:** straight, conical shell (fig,2.2)
   Ex. *Orthoceras*

2. **Cyrtocone**: curved shell(fig.2.1)
   Ex. *Cyrtoceras*

3. **Gyrocone**: shell coiled in an open spiral and the whorls don't touch each other(fig.2.7)

4. **Lituiticone:** coiled in the early stage and later uncoiled(fig.2.3)
   Ex. *Lituites*
5. **Planispiral**: shell coiled in one plane only.

   - **Evolute**: all whorls are visible (fig.2.8)
   - **Involute**: the last whorl covers all earlier ones(fig.2.9)

     Ex. *Dactylioceras:* **Evolute**
     Nautilus: **Involute**

6. **Trochospiral:** shell coiled in more than one plane (fig.2.10)
   Ex. *Turrilites*
7. **Brevicone:** Short , blunt shell.(fig.2.4&6)
8. **Ascocone;** slender curved early stage and short, mature stage(fig.2.5)

Septa and suture in Cephalopods:

Septa are transverse partitions in cephalopod shells that divide it into chambers or camerae. They are convex towards the **apex** and concave towards the **aperture**.
The line of contact of septa with the wall of the shell is called **suture**. The suture may be circular or undulated and is very important in the evolution of Cephalopods. The undulated suture consists of **saddles** and **lobes**(fig.3). Those convex towards the aperture are called **saddles** whereas those convex towards the apex are called **lobes**.

There are four types of suture(fig.1d,e,f&g)

Nautilitic: - Straight or curved suture line. - Ex. *Orthoceras* - Cambrian to Recent.	**Goniatitic:** - Rounded saddles and angular Lobes. - Ex. *Goniatites* - Devonian to Permian.
Ceratitic: - Rounded saddles and crinkled Lobes. - Ex. *Ceratites* - Permian to Triassic.	**Ammonitic** - Both saddles and lobes are Crinkled. - Ex. All Ammonite shells - Triassic to Cretaceous.

Classification of Cephalopods:

Cephalopods are divided into three main subclasses

1- Subclass: Nautiloidea:

- Tetrabranchiate (four gills).
- **Shell:** External, calcareous.

Straight, curved or coiled.

- **Suture:** nautilitic.
- **Ex.** *Nautilus, Orthoceras, Cyrtoceras*.
- **Age:** Cambrian to Recent.

2- Subclass: *Ammonoidea*:

- This subclass includes extinct cephalopods which died out at the end of Cretaceous.
- **Shell:** External, calcareous (aragonitic)
  Straight, curved or coiled.
- **Suture:** goniatitic, ceratitic and ammonitic.
- **Ex.** *Goniatites, Ceratites, Turrilites, Scaphites*… etc.
- **Age:** Devonian to Cretaceous

3- Subclass: *Coleoidea*:

- This subclass includes a group of extinct organisms called Belemnites, which died out at the end of Cretaceous. Living Sepia and Octopus are also included in this subclass.
- Dibranchiate (two gills).
- **Shell:** internal, calcareous (Belemnites and Sepia)
  No shell (Octopus).
- This subclass is further subdivided into order Sepioidea and order Belemnoidea. The latter is very important index fossils especially in the Jurassic and Cretaceous.

Belemnites

Belemnites are extinct cephalopods, which lived during Jurassic and Cretaceous in the Boreal Realm (cold water areas). The tropical Tethyan Realm was not suitable for them and consequently they are not found in the Tethyan regions as Egypt, Emirates, North Africa, Syria, Lebanon and Palestine. These areas were dominated at that time by ammonites, corals and rudists. On the other hand, these cold water belemnites are common in Germany and England. They died out at the end of **Cretaceous** like **ammonites**.

The shell of Belemnites is internal and composed of three parts:

1. **Rostrum (guard):**
   This is a bullet-shaped cylinder of solid calcite. In cross section the rostrum consists of radially oriented calcite needles.
2. **Phragmocone :**
   This is a conical, thin-walled aragonitic structure; it is

divided into chambers (camerae) by septa. The septa are perforated by a siphuncle.

3. Pro-Ostracum:

This is a blade-like plate consists of calcified conchioline.
It extends from the dorsal part of the shell to protect the viscera.

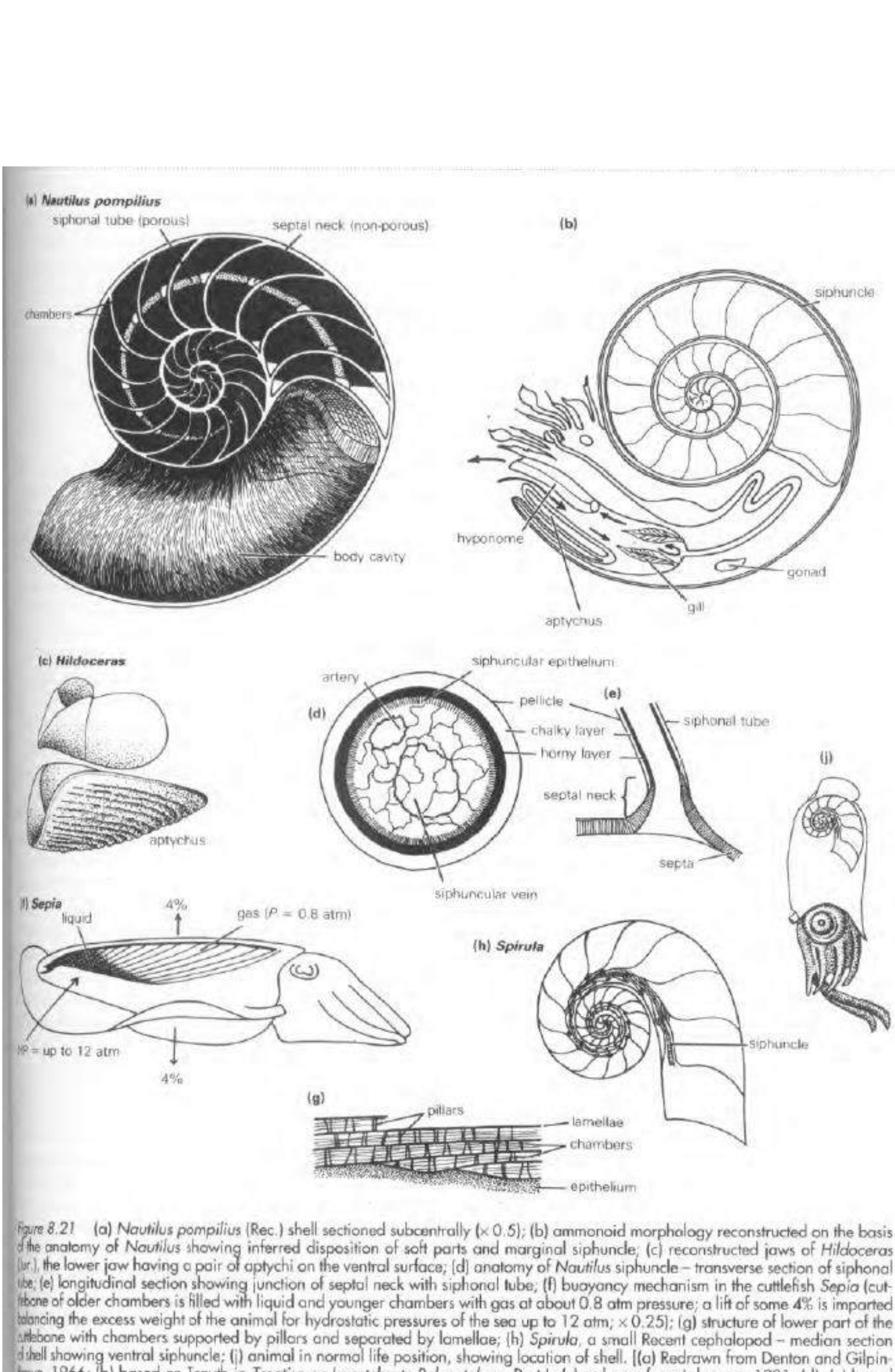


Figure 8.21 (a) *Nautilus pompilius* (Rec.) shell sectioned subcentrally (× 0.5); (b) ammonoid morphology reconstructed on the basis of the anatomy of *Nautilus* showing inferred disposition of soft parts and marginal siphuncle; (c) reconstructed jaws of *Hildoceras* (Jur.), the lower jaw having a pair of aptychi on the ventral surface; (d) anatomy of *Nautilus* siphuncle – transverse section of siphonal tube; (e) longitudinal section showing junction of septal neck with siphonal tube; (f) buoyancy mechanism in the cuttlefish *Sepia* (cuttlebone of older chambers is filled with liquid and younger chambers with gas at about 0.8 atm pressure; a lift of some 4% is imparted balancing the excess weight of the animal for hydrostatic pressures of the sea up to 12 atm; × 0.25); (g) structure of lower part of the cuttlebone with chambers supported by pillars and separated by lamellae; (h) *Spirula*, a small Recent cephalopod – median section of shell showing ventral siphuncle; (j) animal in normal life position, showing location of shell. [(a) Redrawn from Denton and Gilpin-Brown, 1966; (b) based on Trauth in *Treatise on Invertebrate Paleontology*, Part L; (c) redrawn from Lehmann, 1981; (d), (e) based on Denton and Gilpin-Brown, 1966; (f), (g) based on Denton, 1961.]

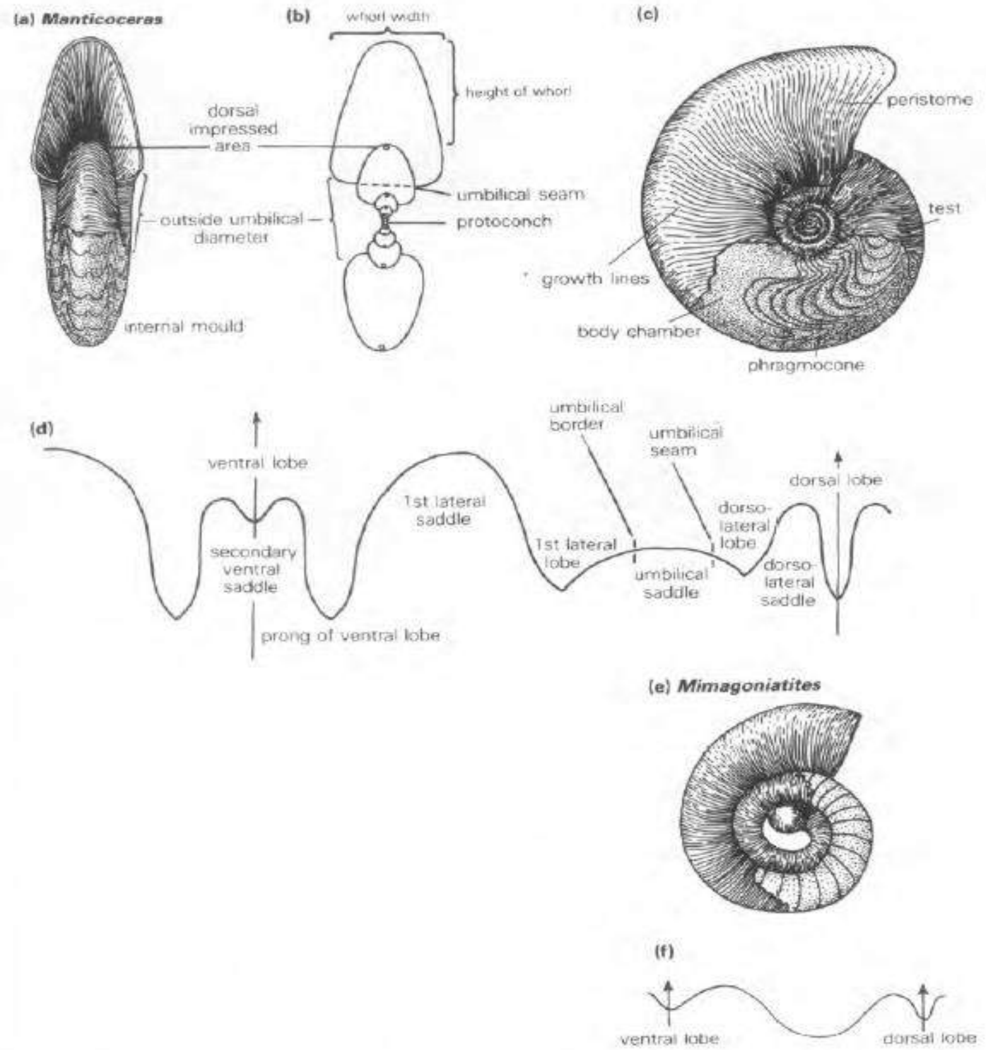


Figure 8.24 (a)–(d) *Manticoceras* (U. Dev.), a goniatite exemplifying ammonoid structure: (a) ventral view; (b) cross-section; (c) lateral view with shell partially removed, showing internal mould with sutures (all × 0.7); (d) suture line; (e), (f) *Mimagoniatites* (L. Dev.), a very early goniatite with perforated umbilicus and exposed phragmocone – the shell is partially removed to show chambers; (e) lateral view (× 5); (f) suture line. [(a)–(d) Redrawn from Miller and Furnish and (e), (f) after Schindewolf, all in *Treatise on Invertebrate Paleontology*, Part L.]

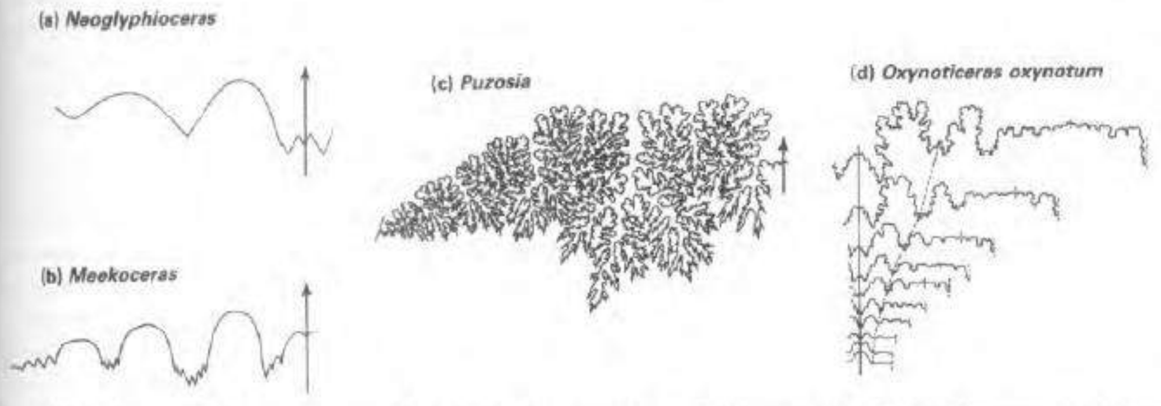


Figure 8.26 Suture morphology in ammonoids: (a) goniatitic suture (*Neoglyphioceras*; L. Carb.); (b) ceratitic suture (*Meekoceras*; Trias.); (c) ammonitic suture (*Puzosia*; L. Cret.); (d) sutural ontogeny in *Oxynoticeras oxynotum* (Jur.). (Modified from various authors in *Treatise on Invertebrate Paleontology*, Part L.)

Echinodermata

Echinoderms are organisms characterized by having an internal skeleton of porous calcite plates, which are normally spiny and covered outside and inside by a thin protoplasmic skin.

Echinos = spiny derma = skin

Normally the skeletons have a five - rayed or pentameral symmetry, though in some fossil groups and some modern sea - urchins there is a bilateral symmetry.

Echinoderms are exclusively marine animals, they appeared in Cambrian and are still living. Representatives today include starfish and sea - urchins which are so common in shallow waters.

Because of the calcitic nature of echinoderm skeleton; they are very abundant in the fossil record and often their remains have greatly contributed to carbonate sediments.

EX. Crinoidal limestone

water vascular system:(fig.1)

This is an internal apparatus in Echinodermata. It consists of five radial canals which are connected with tube feet.

The water vascular system is used to operate the tube feet by creating water pressure in the tube feet, by this way they can extend outside the skeleton (test). The system gets its water from the canals which are joined with the ocular pores at the upper part and from the madreporite.

Tube feet:

Tube feet are tubes connected with the water vascular system. They extend outside the test through pores found in the skeleton. They are used for locomotion, respiration and feeding.

Reproduction:

Reproduction in Echinoderms is usually sexual and both sexes are separate. They live in clumps or congregates and this gives a chance for eggs and sperms to fertilize.

Classification

Echinoderms are subdivided on the basis of their **mode of life** into two subphyla:

1- Subphylum: Pelmatozoa ------------> Sessile

2- Subphylum: Eleutherozoa -----------> Free - moving

Subphylum Eleutherozoa

This subphylum includes all **free - moving** echinoderms. It is divided into three classes:

1- Class: Echinoidea ----------> Ex. sea urchin

2- Class: Stelleroidea ----------> Ex. star fish.

3- Class: Holothuroidea ------> Ex. sea cucumber

Class Echinoidea is the most important as fossils and it will be studied here in detail.

Class Echinoidea(Echinoids):(fig. 3)

Echinoids have a test consists of four parts:

* Corona.
* Oculo- genital system (apical system).
* Peristome (around mouth).
* Periproct (around anus).

Corona:

The corona consists of ten segments extending from the apical disc on the upper surface to the peristome on the lower surface.

Five segments of these ten are narrow, and are connected with the ocular plates, these are called **Ambulacra**. The other five are wide and are connected with the genital plates, they are called **interambulacra**.

The ambulacra and interambulacra consist of calcite plates which meet along a zigzag suture.

The ambulacral plates have pores arranged **in pairs** near the outer edge of the plate. There are no pores in the interambulacral plates but are tubercular.

Function of pores:

They are the sites where the tube feet emerge through the test from the internal part of the water vascular system.

Apical system (Oculo-genital system):

The apical system is a disc of 10 plates surrounding a central hole (Periproct) which contains the anus. Five plates of these are larger called **genital plates** and are perforated by pores called **genital pores** through which eggs and sperms go outside. The other five plates are smaller and called **ocular plates**. They are also perforated by **ocular pores,** which are connected by tubes of the water vascular system.

One genital plate is larger than the others, this is called **madreporite**. It has numerous tiny perforations, which lead into the water vascular system below.

Periproct (around the anus):

This is a central hole containing the anus on the upper surface (aboral surface).

aboral ----------> away from the mouth

peristome (around the mouth):

This is a sheath surrounding the mouth and **Aristotle's lantern** . It lies on the lower surface (adoral surface).

adoral ---------> towards the mouth

Aristotle's Lantern:

This is a lantern-shaped structure located on the lower surface of echinoid test.

It has five strong jaws, each with a single calcitic tooth. The jaws are used to catch organic material on the sea floor and pass it inwards to the mouth.

Regular and irregular echinoids:

There are two kinds of echinoid tests; regular and irregular:

Regular echinoids: are those which have the periproct in the center of the apical disc (endocyclic). In this case the mouth and anus lie on both ends of a vertical axis.

These forms have a **pentameral** symmetry. They live either on the sea floor or in cavities and can move easily in any direction.

Irregular echinoids: are those which have the periproct outside the apical disc (exocyclic). In this case the mouth and anus don't lie on a vertical axis, the mouth migrates anterior whereas the anus migrates posterior.

These forms are usually heart - shaped and have a **bilateral** symmetry.

They are usually infaunal and can move in one direction.

Subphylum Pelmatozoa

This subphylum includes all attached (**sessile**) echinoderms. It is divided into four classes:

1- Class: Cystoidea (Cambrian - Permian)
2- Class: Blastoidea (Silurian - Permian)
3- Class: Edrioasteroidea (L. Cambrian - Carboniferous)
4- Class: Crinoidea (M. Cambrian - recent)

Note that: sessile echinoderms dominated during Paleozoic, most of them are extinct except Crinoids.

Class: Crinoidea(fig. 2)

Crinoids are echinoderms, which live in congregates called lillie gardens and include sea lillies or stone lillies (fossils).
The skeleton consists of three parts:

Stalk:

The stalk consists of a number of segments called **columnals**, these columnals are articulating together to give the stalk a sort of flexibility for resisting waves.
The columnals are pierced centrally for the passage of blood vessels and nerves.

Calyx:

This is the part of skeleton in which the organism lives. It is cup - shaped and may be covered with a leathery covering termed **tegmen.**
The calyx consists of a number of plates arranged in cycles about a central plate called **Centrodorsal** plate, located at the top of the stem and forming the base of the calyx. The plates from base to top of calyx are called **infrabasals, basals, radials, and interradials.**
Crinoids with infrabasals are called **Dicyclic,** some crinoids don't have infrabasal plates (**monocyclic**).

Arms:

These are usually five in number, each arm consists of a single row of plates tapering to the free end.

Some crinoids are attached to the substrate by their **stem** (stalk), others have **roots**.
Crinoids are **still living** today and were also abundant in the Paleozoic

Ex. Crinoidal limestone

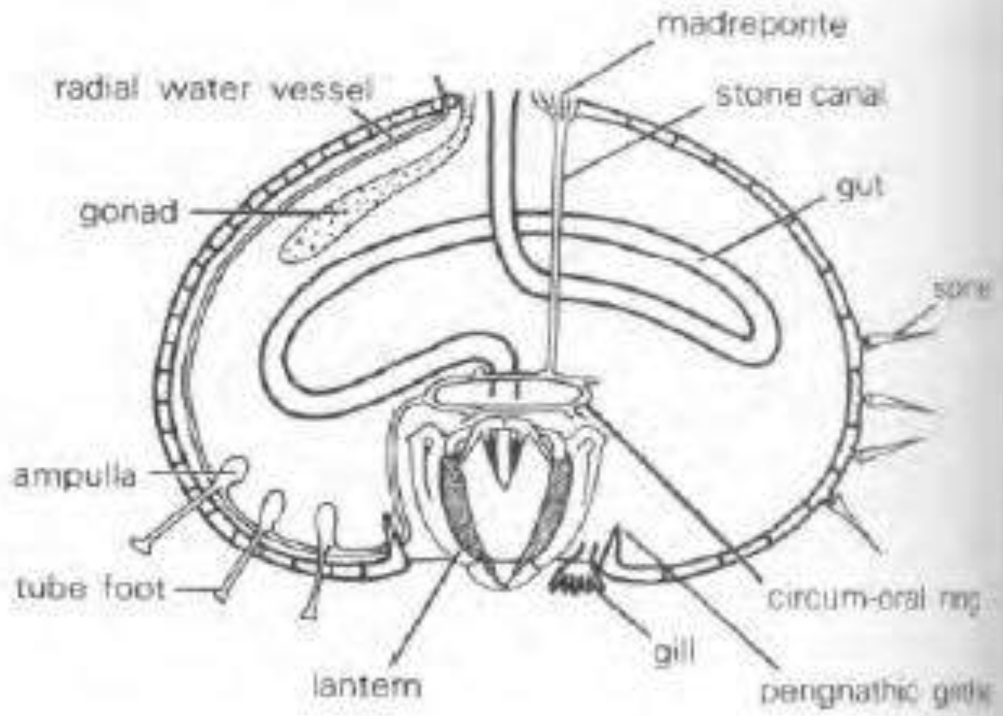


Figure 9.2 Internal morphology of *Echinus* (simplified) passing through an ambulacrum (left side) and interambulacrum (right side).

OSTRACODA

Class of **ostracoda** it is important class belong to phylum **Crustacea**, Superphylum **Arthropoda**.

The ostracod carapace (shell) is usually ovate, kidney or bean-shaped(fig.1) and from 0.3mm to 300mm long ,although most adult carapaces measure only 0.5 to 3.0mm long .The carapace consists of a **right** and **left** valve, one of which is slightly larger and partially overlaps the other ,with **a hinge along the dorsal margin** .

As mentioned, the valves are united and opened by an elastic, chitinous portion of the outer lamella called **the ligament**, but they are closed by a series of transverse **adductor muscles** .These are generally attached to the inside of the valves in a region just anterior of the valve centre,leaving a cluster of adductor muscle **scars on the inside** of the valve .The external surface of the valve it is convex with many types of ornamentation(fig.2) ,but the internal side concave and distinguish by muscle scars .

Fig.1 fig.2

Orientation of shell

A-To distinguish between the **dorsal** and **ventral** side ,should be helped by the guidelines below:

1-The dorsal side usually **convex**, but the **ventra**l side is sometimes straight or gently concave or convex fig.3.

Fig.3

2-The **hinge line** in the open carapace due to dorsal side fig.4.

Fig.4

3-**Lobes&sulcus**:In many species with long straight dorsal margins, the general vaulting of the valve surface is modified by elevation and depressions which are also reflected on the external surface of the valve .The elevations are called lobes , and the intervening depressions sulcus. The sulcus are designated from anterior to posterior as **S_1,S_2,S_3**,the lobes in same way as **L_1-L_4** .The most persistant sulcus is the **S_2,**called also mediam sulcus ,this sulcus near to the dorsal side fig.5.

Fig.5

4-**Ala**:It is prolongation in the posterior-ventral side of the valve fig.6.

Fig.6

5-**Frill or carinae** :It is a thick or sharp edge in the ventral side or parallel to the ventral margin fig.7.

Fig.7

6-**Eye tubercle or eye spot:** It is indicator for the anterior - dorsal side of the carapace fig.8.

Fig.8

7-**beak(rostrum)**:The long and active antennules and antennae have in some cases led to formation of rostal incisures(beak) and projection rosta at the anterior-ventral side fig.9.

Fig.9

8-**Marginal denticulation** :This denticulation like teeth ,it is indicator to the ventral side of the carapace fig.10.

Fig.10

9-**Hing ear:** It is a node of calcium carbonate , indicator to the anterior ventral side of the carapace fig.11.

Fig.11

B-To distinguish between the posterior and anterior ends of the carapace should be helped by the guidelines below:

1-In general the pointed end is posterior ,the **anterior** end highest in side view fig.3.

2-**Eye tubercle or eye spo**t :refer to the anterior end.

3-**S2** :refer to the anterior end.

4**-Ala**:refer to the posterior end.

5-**beak**(rostrum):refer to the anterior end.

6-**Caudal process:** at the posterior end fig.12.

Fig.12

NOTE: The posterior end is commonly widest than anterior end at the dorsal view in closed carapace fig.13.

Fig.13

Q:How can distinguish between the left and the right valve?

To distinguish between the left and right valve, if the **external s**urface (consists ornamentation)appear and the **anterior point** refer to the right this valve is **right valve** ,but if the **anterior** of the **internal** surface refer to the **right** ,this valve is **left** valve fig.14.

Fig.14

Ornamentation :It is defined as only those features of the **outer** valves surface which are not reflected by the general vaulting of the inner valve surface .There are many types of ornamentations illustrated below and in fig.15.

1-Frill or carina.

2-Spines.

3-Nodes.

4-Punctate(smaller pores).

5-Cocellate(larger pores).

6-Reticulate.

7-Ribes&costa.

8-Lobes&sulcus.

9Smooth.

FIG.15

Arthropods

Arthropods are organisms possessing a hard outer coat or **exoskeleton** and jointed appendages, which they use for movement, and feeding. They include insects, crustaceans and spiders as well as extinct trilobites and eurypterids (the giant Paleozoic water scorpions).

Arthron =joint Podus =foot

Fossil arthropods are common, most important of these are **trilobites** which are good index fossils.

Trilobites

Tri =three

The name trilobites refers to the fact that the body is divided longitudinally as well as transversely into three portions(fig.1)

Longitudinally:

The body is divided into three lobes: **axial** lobe in the middle and two **lateral** (pleural) lobes on both sides(fig.1a).

Transversely:

The body is divided into three parts; **head** (cephalon), **thorax** and **pygidium**(fig.1a).

Ecdysis:This is the scientific for the moulting of the exoskeleton .Because this armour does not expand, it must sloughed off , and a new,larger one developed. Increase in size is therefore restricted to the soft stage , when the animal is extremely vulnerable to predators. Arthropods may go through this process many times in their lives , and each completed cycle from soft shell to eventual ecdysis is called instar.

Different groups of arthropods have different systems of ecdysis. Some moult only the adult form is reached while others go on growing and ecdyse more or less continuously. Trilobites apparently fell into this second group . This means that for every one trilobite which lived, there were many potentially fossilizable moults produced in addition to the one , eventual , entire body fossil.

MORPHOLOGY

Head

The head consists of a **glabellum** in the center and two **cheeks** on both sides called **pleural (lateral) cheeks**. Each cheek carries a compound eye. Some trilobites are however **blind**. Each cheek is divided by a facial suture into a free cheek and a fixed one(fig.1a &3).

Facial suture: **Isimpotant in classification , but it was also important to the living trilobite ,since It was the line along which the cephalon split open during ecdysis .Typically this Suture runs along the front of the glabella ,around the eyes and then either towards the anterior margin ,the posterior margin or the genal angel . During moulting the fixed cheek remained attached to the glabella , while free cheek fell away . The compound were left attached to the soft shell. Four types of facial suture as follow:**

1-Marginal facial suture(fig.2iii)

2-Proparian facial suture (fig. 2 iv)cuts margin in the front of genal angel.

3-Gonatoparian facial suture(fig. 2 v)cuts margin at genal angel .

4-Opisthoparian facial suture(fig. 2 vi)cuts margin behind genal angel.

Eyes(figs.1a&3ii) The compound eyes of the trilobite are the earliest example of efficient vision in animal kingdom. Their similarity to the eyes of insects .Each eye is divided into many lenses ,each of which covers a small portion of the visual field. Many trilobites had no eyes, while others had eyes so large they

even dwarfed The glabella. These differences obviously tell us about mode of life ,and further discussed below .Rare trilobites Bore their eyes upon stalks ,and some ,though apparently possessed of eyes,were probably blind nevertheless.
We believe this because the eyes structure,when examined in detail ,show variable of lenses from one specimen to another Or less disordered pattern. This is thought to indicate functional degeneracy.

Thorax

The thorax consists of a variable number of segments,
each segment is provided with a pair of appendages.
The thoracic segments are **never** fused(fig1a&4).

Pygidium

The pygidium consists of a number of segments **either** distinct or fused.
In primitive (Early Cambrian) trilobites, there is no pygidium, these are called **apygous**.
Forms with small pygidium are called **micropygous** and those having a pygidium equal in size to the head are called **isopygous** and pygidium of greater area than cephalon are called **macropygous** (fig.4).

MODE OF LIFE

The many forms seen in trilobites probably reflect different modes of life.The trilobite eyes can show various degrees of Development or suppression. Trilobites which were blind may have been nocturnal in habit, or may have lived in cavities Such occur in reefs. Alternatively, they might have been burrowers. The absence of eyes is difficult feature to which ascribe
Any definite single cause .It is best weighed with other features before deciding. For example those forms with small eyes

Combined with a wide axil region and smooth carapace, whose thoracic segments appear to have fitted very closely, may have been
Burrowers. Some trilobite is often found in life position ,its cephalon peeping up above the bedding plane and the rest of its Body buried vertically in sediment. This was probably a posture adapted while waiting for its prey. Forms with very large eyes Could not have been benthic, such a degree of all-round vision could only have been of use to a free swimming .They may have Swum upside down the surface so keeping a sharp looke –out for prey or predators. They are in fact often found in deep water Deposits.

Habit and habitat

Trilobites are either **free-swimming** (**nektonic**) or **crawling on the bottom of the ocean**. The crawling forms may have been blind.
They are exclusively **marine** and are found with rugose corals, crinoids, brachiopods and cephalopods.

Classification

One early system used certain heavily weighed characters (notably the type of facial suture) to create three Orders.
It was assumed that the suture types(proparian, opisthoparian ,gonatoparian) were natural lables which reflected
Three distinct phlylogenetic lines.The discovery of larval stages whose ontogeny involved the migration of suture from one condition to anther .The new classification of the trilobite recognizes nine orders based on:
The facial suture;features of glabella ;the number of the thorax somites ;nature of bygidium ;eyes types and

natural phylogenetic. These orders set in (fig.5) and describe as follow:

* Ordre Redlichidae(L.-M.Cam.) large semicircular cephalon ; strong genal spins ;spiny thorax segments; Tiny pygidium ;eyes large;opisthoparian.

*Ordere Agnostida(L.Cam-U.Ord.) small trilobites; with subequal cephalon and pygidium; thorax segments number Only two ;Eyes and sutures absent except in eodiscid family.

*Ordere Naroida(M.Cam.) uncalcified trilobite with no thorax segments.

*Ordere Corynexochida(L.-U.Cam.)glabella varied shape;suture opisthoparin;thorax with 7-8 segments.

*Ordere Lichida(L.Ord.-U.Dev.) large trilobite ;opisthoparian ;pygidium larger than cephlon .

*Ordere Phacopida(L.Ord.-U.Dev.)suture gonatoparian or prpparian;11-19thorax segments.

*Ordere Ptychopariida(L.Cam.-U.Perm.)simple glabella ;thorax larger than pygidium.

*Ordere Asaphida(U.M.Cam.-L.Ord.)large ;subequal cephalon and pygidium; suture opisthoparian; Large eyes.

*Order Proetida(Ord.-Perm.)glabella large with genal spines ;opisthoparian;large eyes; thorax with 8-10 Segmentes.

Geologic History:

Trilobites are very ancient organisms; **they appeared in Early Cambrian** and died out at the end of Paleozoic (Late Permian). **They are good index fossils for Paleozoic.**

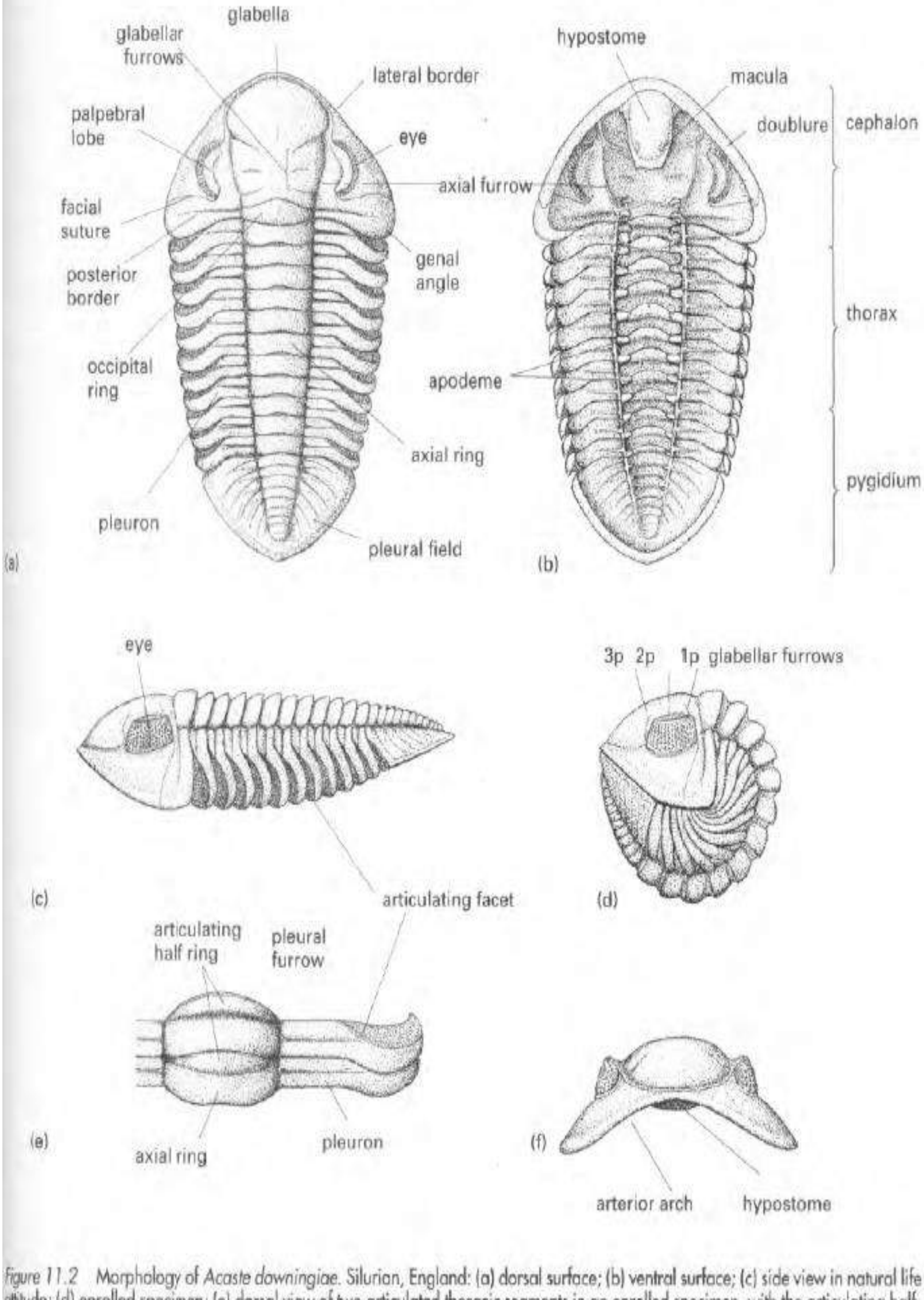


Figure 11.2 Morphology of *Acaste downingiae*. Silurian, England: (a) dorsal surface; (b) ventral surface; (c) side view in natural life attitude; (d) enrolled specimen; (e) dorsal view of two articulated thoracic segments in an enrolled specimen, with the articulating half-ring exposed; (f) frontal view showing anterior arch. [All × 2 except (e)]. For additional terminology see text.

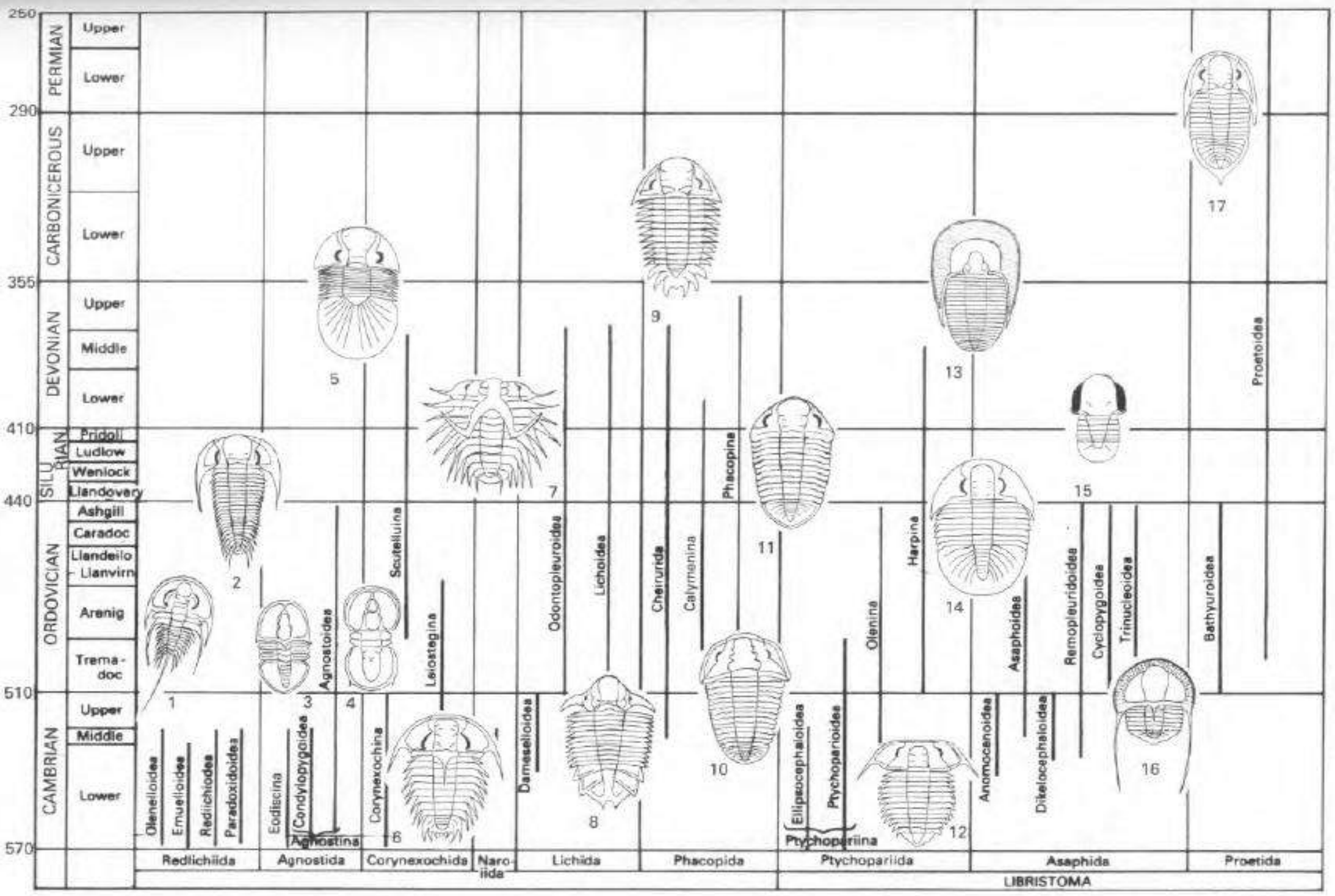


Figure 11.20 Time ranges of orders (e.g. Phacopida) and suborders (e.g. Calymenina) of trilobites. Genera illustrated are as follows: 1, *Paedumias* (L. Cam.); 2, *Paradoxides* (M. Cam.); 3, *Eodiscus* (L. Cam.); 4, *Agnostus* (U. Cam.); 5, *Scutellum* (L. Dev.); 6, *Kootenia* (M. Cam.); 7, *Dicranurus* (Dev.); 8, *Trochurus* (U. Ord.–M. Sil.); 9, *Cheirurus* (U. Ord.–M. Sil.); 10, *Calymene* (Sil.–Dev.); 11, *Acaste* (Sil.); 12, *Olenus* (U. Cam.); 13, *Harpes* (M. Dev.); 14, *Ogygiocaris* (M. Ord.); 15, *Cyclopyge* (Ord.); 16, *Trinucleus* (Ord.); 17, *Paladin* (L. Carb.).

Graptolites

(Phylum Chordata)

Graptolites are **extinct marine Paleozoic** organisms (like trilobites) that built small dendritic or saw-blade like colonial exoskeleton of chitinous material.

Graptos = writing

They are preserved as carbonized remains of the original chitinous exoskeleton resembling writing.
Graptolites live in colonies called rhabdosome;
each rhabdosome consists of a number of branches
Called **stipe**.
Graptolites with one branch are called **monograptus**,
Two are called **didymograptus**, four are called
Tetragraptus, and eight are called **dichograptus(fig. 1)**.

Each branch (stipe) consists of a number of tubes called **theca**(fig. 2); the primitive tube is the **sicula**. The sicula is prolonged as a chitinous thread called **nema** which is used for attachment. The colony increases by budding.

Habit and Habitat:

Graptolites are either **planktonic or benthonic and are marine**.

CLASSIFICATION

Graptolites are divided into two important orders :the Dendroidea and Graptoloidea(fig.3).But there are also some short-lived orders (Tuboidea, Stolonoidea, Camaroidea and Crustoidea).

1-Order DENDROIDEA(M.Cam.-Carb.):Have four families(fig.3).

2-Order GRAPTOLOIDDEA(L.Ord.-L.Dev.):Rhabdosomes have few stipes up to eight in the early forms, but reducing in later genera to two and finely to one (fig.4).Clssifiedin four suborders:

- Suborder Didymograptina(Ord.)
- Suborder Glossograptina(Ord.)
- Suborder Diplograptina(Ord.-Sil.)
- Suborder Monograptina(Sil.)

Evolutionary trends in position of stipes

The branches of graptoloides show evolutionary trend from a position in which they hang downword from nema and sicula,through intermediate position, to the scandent type of growth, in which stipes grow upword along the nema(fig.4).

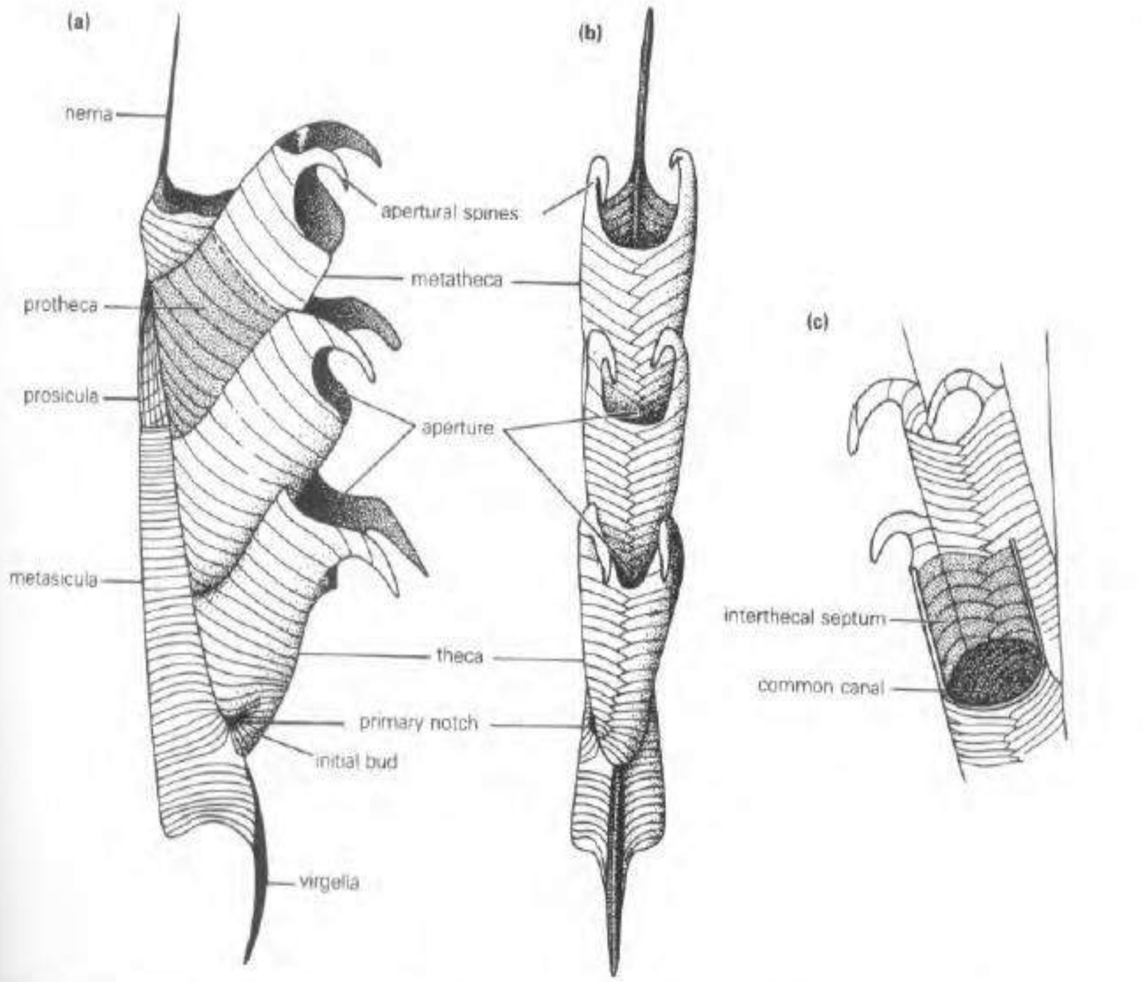
- **Scandent**:Stipes growing upward along nema;most advanced position.
- **Reclined**:Stipes straight, growing upword and outword.
- **Recurved**:Stipes curved, rising upword and outword.
- **Horizontal**:Stipes growing out horizontally.
- **Decurved**:stipes curved , sloping downword.
- **Declined**:Stipes straight ,sloping downword.
- **Pendent**:Stipes hanging downword; most primitive position.

3-Order TUBOIDEA(L.Ord.-Sil)(fig.5a)
4-Order CAMAROIDEA(Ord.)(fig.5b)
5-OrderCRUSTOIDEA(L.Ord.-U.Ord.)(fig.5c)
6-Order STOLONOIDEA(Ord.)(fig.5d)

Geologic History:

Graptolites appeared in the Middle Cambrian and reached their acme in the Ordovician and Silurian. They started to decline in the Mississippian (Early Carboniferous).

They are common in black shale but they are also present in shale of other colors as well as sandstone and limestone and in chert nodules.



igure 10.1 Morphology of *Saetograptus chimaera*: (a) lateral view; (b) frontal view; (c) structure of theca and common canal with ...t removed (× 40 approx.). (Modified from Urbanek, 1958.)

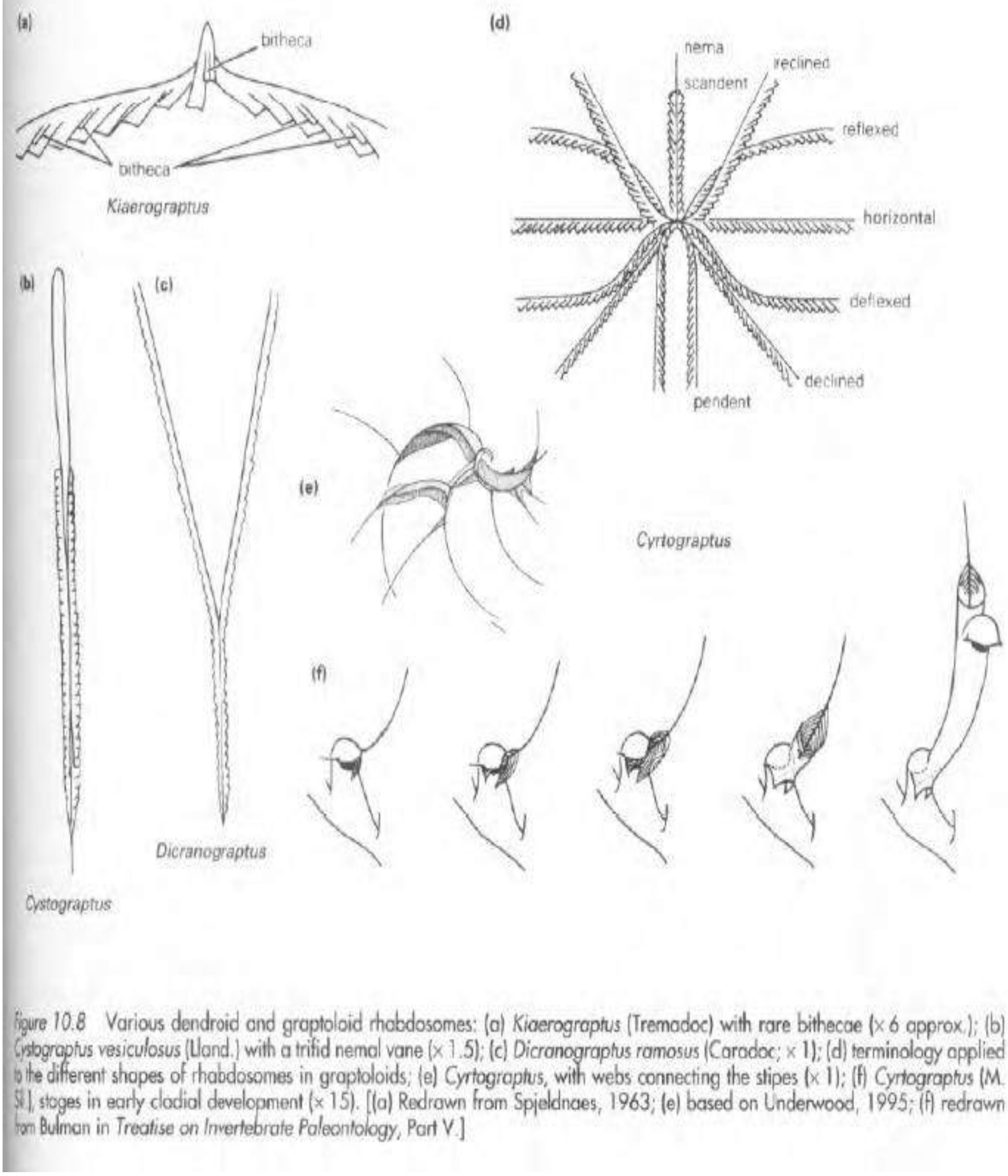


Figure 10.8 Various dendroid and graptoloid rhabdosomes: (a) *Kiaerograptus* (Tremadoc) with rare bithecae (× 6 approx.); (b) *Cystograptus vesiculosus* (Lland.) with a trifid nemal vane (× 1.5); (c) *Dicranograptus ramosus* (Caradoc; × 1); (d) terminology applied to the different shapes of rhabdosomes in graptoloids; (e) *Cyrtograptus*, with webs connecting the stipes (× 1); (f) *Cyrtograptus* (M. Sil.), stages in early cladial development (× 15). [(a) Redrawn from Spjeldnaes, 1963; (e) based on Underwood, 1995; (f) redrawn from Bulman in *Treatise on Invertebrate Paleontology*, Part V.]