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Asterias (Starfish or Sea star) (Phylum Echinodermata)

50.1 CLASSIFICATION

Phylum	—	**Echinodermata**
Subphylum	—	**Asterozoa**
Class	—	**Asteroidea**
Order	—	**Forcipulata**
Genus	—	***Asterias***

Asterias is commonly known as **starfish**. But this is not fish. Hence its name is misleading and now its more suitable common name is **sea star**. *Asterias* contains about 150 species, all of which have different geographical distribution. Some other common sea stars are *Pentaceros* (or *Oreaster*; it is an Indian species which is found in the Bay of Bengal and Arabian sea), *Astropecten*, *Heliaster*, *Solaster*, *Luidia*, etc.

50.2 HABIT, HABITAT AND EXTERNAL FEATURES

Habit and Habitat

Asterias is a free-living exclusively marine, bottom dwelling (or **benthonic**) animal. *Asterias* is found in shallow water in North Temperate seas and found abundantly on North-Atlantic Coast. It is found in abundance in India and U.S.A. *Asterias forbesi* occurs on the eastern sea shore from the Maine to the Gulf of Mexico and is found equally abundant on hard, rocky and sandy or soft bottom.

Most species of *Asterias* are **solitary** but under certain ecological constraints (*e.g.*, to avoid direct sunlight) many individuals may gather at some place for the purpose of protection. Most of them are **nocturnal**, remain quiet in day time but become active during night. They remain attached to rocks, shells, piles and piers, etc. Their oral surface faces the substratum. They slowly move by crawling with the help of arms on the rocky bottom. All sea stars are **carnivorous** and feed voraciously on almost any slow moving or sessile animals, chiefly on polychaetes, crustaceans, molluscs (snails, bivalves) and other echinoderms. They also feed on dead animals, so act as scavangers of sea. *Asterias* shows remarkable power of **autotomy** and **regeneration**.

External Features

1. Shape, size and colour. *Asterias* has a **radially symmetrical** star shaped body (Box 50.1). The diameter of body reaches upto 24 cm. Colour of *Asterias* varies from orange to purplish, the upper (aboral) surface being darker than the lower (oral) surface.

2. External structure. The body of *Asterias* consists of a central, pentagonal (5 sided) central disc from which radiate out five elongated, tapering, symmetrically spaced projections, the rays or arms. Each arm has the shape of an isosceles triangle (*i.e.*, triangle having two sides of equal length). The body lacks a well defined head and has two distinct surfaces. The lower surface, the one nor-mally kept towards the substra-tum, is flat and is known as the **oral** or **actinal surface** because it bears the mouth (Fig. 50.1). The upper surface is convex and is called the **aboral** or **abactinal surface** (Fig. 50.6). The oral and aboral surfaces are not the ventral and dorsal surfaces, but corres-pond to the left and right sides of the bilaterally symmetrical larva. The axes occupied by the arms are known as the **radii** and the regions of the central disc between the arms is the **inter-radii**.

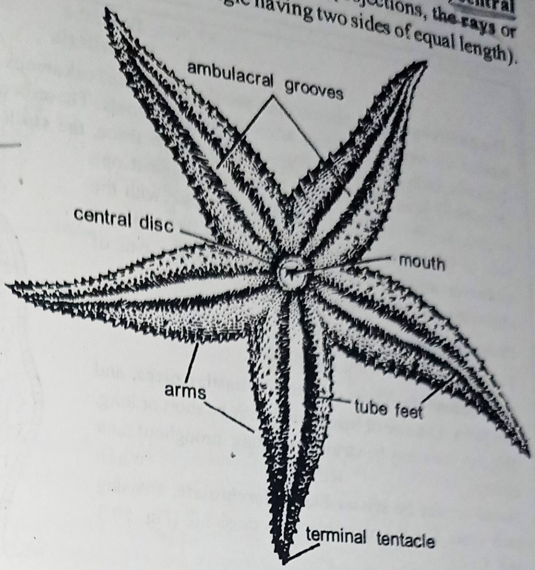

Fig. 50.1. *Asterias*. External features (oral view).

A. Oral Surface. The oral surface of *Asterias* contains following structures.

1. Mouth. Mouth is a circu-lar aperture at the top of 5-rayed (pentagonal) depression at the centre of the oral surface of the central disc. The depression is known as **actinostome**. The mouth is surrounded by a soft membrane, the **peristomial membrane** or **peristome.** Peristome is provided with a sphincter and is guarded by five groups of **oral spines** or **mouth papillae**.

Box 50.1

Symmetry of Echinodermata

Echinoderms are quite distinct in their morphology and differ from other coelomate animals in having a characteristic **pentamerous radial symmetry**. The radial symmetry is seen in majority of echinoderms except for some holothurians. The radial symmetry is not restricted to only the external form of an echinoderm, it is shown even by the arrangements, of internal organs.

In all echinoderms, the external surface is differentiated into five radial and five interradial areas. This gives pentamerous radial symmetry. The radial regions bear tube feet. These are called **ambulacral regions**. The areas between ambulacral regions are called **interambulacral regions** and they contain spines (Fig. 50.2). But in some holothurians, the tube feet are scattered all over the body surface. In Asteroidea and Ophiuroidea, the body is prolonged into arms in the direction of radii.

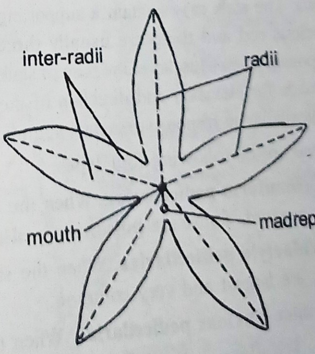

Fig. 50.2. Sea Star showing pentamerous radial symmetry.

The radical symmetry of echinoderms is exhibited only in the organisation of the adults and is acquired at the time of metamorphosis. The larval stages of different classes of Echinodermata exhibit a **bilateral symmetry**. In fact, the radial symmetry is not total or perfect, since, most radially symmetrical forms present indication, of bilateral symmetry, e.g., by the presence of a single madreporite, presence of single gonad and gonoduct in Holothruoids. Because of these reasons, it is generally believed that the radial symmetry of echinoderms has been secondarily acquired. It is also believed that the radial symmetry in ancestral echinoderms has evolved due to sedentary habit and that echinoderms have evolved from free-swimming bilaterally symmetrical, triploastic, coelomate ancestor.

Box 50.2
Pedicellaria

The **pedicellariae** are microscopic, peculiarly modified calcareous spines. They are found among the papulae around the simple spines in asteroids and echinoids. These occur on oral as well as on aboral surface. Typically each pedicellaria consists of a basilar piece, the **stalk** or **peduncle** and two or three movably articulated **jaws** (Fig. 50.3). Jaws work against one another like the blades of a forceps or scissor with the help of three paired muscles. There are two pairs of **adductor muscles** for closing the jaws and a pair of **abductor muscles** for opening them.

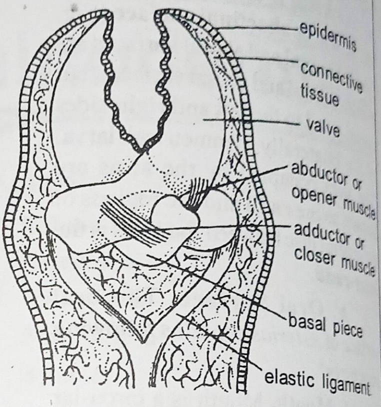

Fig. 50.3. Distal end of a scissor-type pedicellaria from *Asterias.*

Pedicellariae in Asteroidea

These are of following three types:

1. Pedunculate. These consist of a **basilar piece,** and two **jaws.** The size of basilar piece may be short or long. The two jaws may be **straight** meeting throughout their entire length when closed or may be **scissor-like** or **forcipulate,** crossing each other like the mandibles of a cross bill (Fig. 50.3 and 50.4).

2. Sessile. These pedicellariae lack the basilar piece or penduncle and two jaws are attached directly to the ossicles by the muscles. Sessile pedicellariae may be **spiniform,** when present in clusters on the adjacent ossicles or **fascicu-late,** when the cluster of spines is present on the same ossicles.

3. Alveolar. These are similar to sessile pedicellariae but differ from them in being partly embedded in the endoskeletal depression, called **alveolus.**

Pedicellariae in Echinoidea

Pedicellariae are characteristic of all echinoids. They are located over the general body surface as well as on the peristome. The echinoid pedicellaria is composed of a long stalk surmounted by jaws. The stalk may contain a supporting skeletal rod and there are usually three opposing jaws. Muscles at the base of stalk provide for elevation and direction of the pedicellariae in response to certain stimuli.

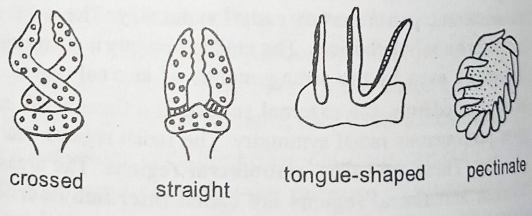

Fig. 50.4. Different type of pedicellariae of Asteroidea.

These are of following four types:

1. Gemmiform pedicellariae. When the stalk is very stiff and head is round. Each jaw is provided with poison gland. These are **poisonous pedicellariae.**

2. Tridactyle pedicellariae. When the stalk is very flexible and jaws are long tappering and serrated. They are largest and very common.

3. Ophiocephalous pedicellariae. When the stalk is very flexible and jaws are short, broad and toothed.

4. Trifoliate pedicellariae. They are smallest. Each consists of a very flexible stalk and short broad toothed jaws. Jaws do not meet at their tips.

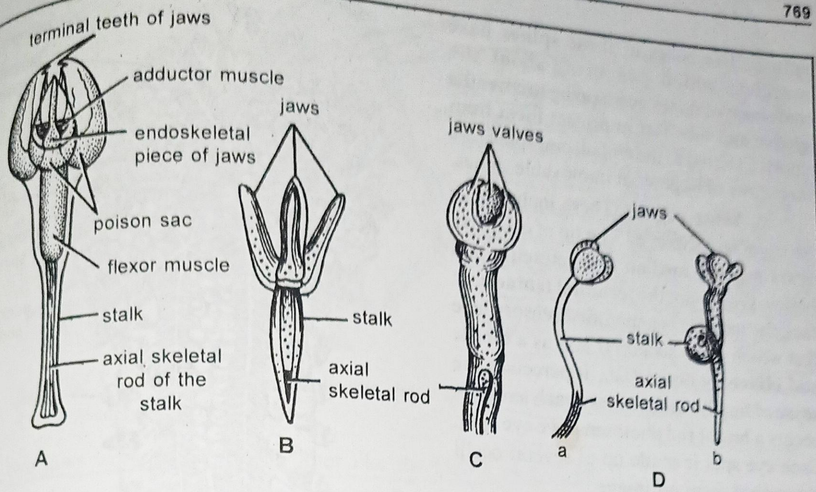

Fig. 50.5. Different types of pedicellariae in sea urchin A—Gemmiform; B—Tridactyl; C—Ophiocephalous; D—Trifoliate (*a*) of *Tripneustes* and (*b*) of *Echinus*.

Function. Pedicellariae are used for defence or for cleaning the body surface, biting and breaking up small particles of debris, which are then removed by the surface cilia. When the pedicellariae are touched on outside, they snap open; when touched on the inside, the snap shut. They also respond to chemical stimuli.

2. **Ambulacral groove.** There are five narrow grooves that radiate out from the angles of actinostome, one extending along the middle of the oral surface of each arm upto the tip.

3. **Tube feet or podia.** These are soft, thin-walled, tubular, retra-ctile structures which are arranged in four rows in each ambulacral groove. Each podium is provided with terminal sucker. Sucker func-tions as a suction pump to afford firm attachment on the surface to which it is applied. The tube feet are multipurpose organs. They mainly act as organs of locomotion and capturing food. They also help in respiration and adherence to substratum. Tube feet also act as sensory organs.

4. **Ambulacral spines.** The spines are short, stout outgrowths from the calcareous plates, the **ossicles,** embedded in the body wall and covered by epidermis. On the oral surface, there are two rows of spines along either border of each ambulacral groove. These are called the **ambulacral**

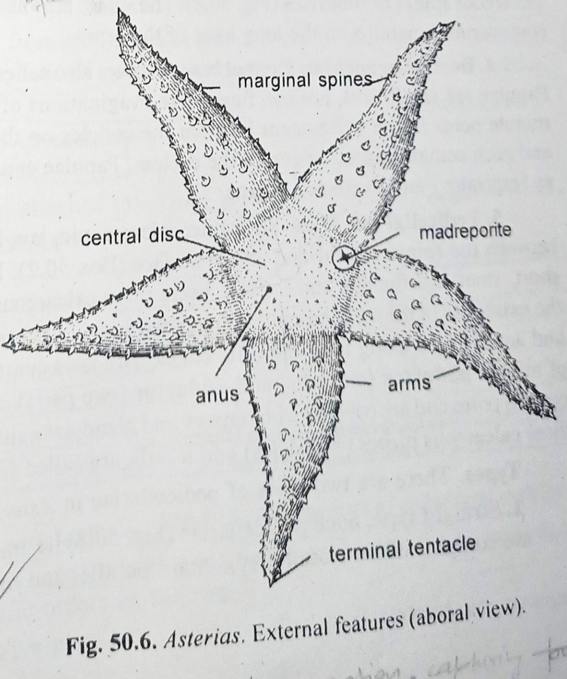

Fig. 50.6. *Asterias*. External features (aboral view).

spines. The bases of these spines have muscles, which can bring about the movement of spines overlapping to cover the groove and tube feet to protect them from injury. External to the ambulacral spines are three rows of large stout immovable spines.

5. Sense organs. These include five tentacles and five eyes. The tip of each arm bears a small median non-retractile and hollow projection, the **terminal tentacle**. In fact, the tentacle is a modified sensory tube feet which lacks sucker. It acts as a **tactile** and **olfactory** organ (*i.e.*, it perceives the sense of smell). At the base of each tentacles occurs a bright red photosensitive **eye spot**. Each eye spot is made up of several ocelli but cannot form an image.

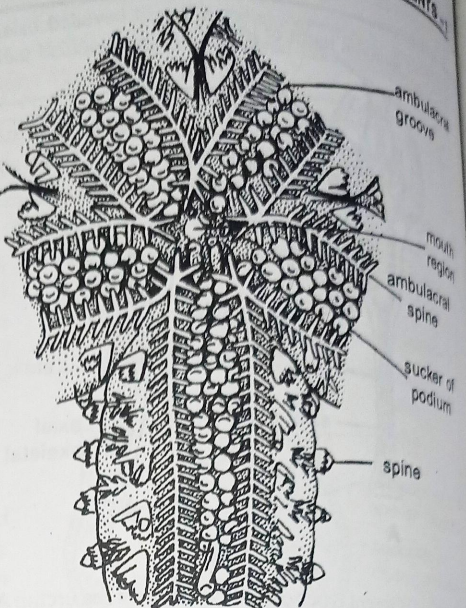

Fig. 50.7. *Asterias*. Oral surface of the disc and arm.

B. Aboral surface. The aboral surface of *Asterias* contains the following structures:

1. Anus. It is a small circular aperture. It is situated close to the centre of the central disc of aboral surface.

2. Madreporite. It is a large circular button-like porous plate. It is situated towards one side of the disc between two arms. These two arms are called **bivium** and remaining three arms—the **trivium**. Thus, madreporite introduces a bilateral symmetry in the radial symmetry of *Asterias*.

3. Spines. The entire aboral surface is covered with numerous short, strong, blunt, immovable, calcareous **spines** or **tubercles** (Fig. 50.8). The spines are variable in size and are arranged in irregular rows running parallel to the long axes of the arms.

4. Dermal branchiae. Dermal branchiae are also called **dermal gills** or **papulae** (Fig. 50.8 A). Papulae are small, soft, hollow, finger-like evaginations of the body wall. They protrude through minute pores in the integument between the ossicles on the aboral surface. They are thin-walled and each contains an extension of the coelom. Papulae can be extended and withdrawn and serve as respiratory and excretory organs.

5. Pedicellariae. These are white, microscopic, jaw-like or pincer-like structures occurring between the spines of oral and aboral surface (Box 50.2). Each pedicellaria consists of a long or short, stout and flexible **stalk**. Stalk bears three calcareous ossicles or plates: a **basilar plate** at the extremity of the stalk bearing at it top two jaws. Jaws are movably articulated with basilar plate and are serrated along their opposite edges. The jaws can be opened or closed by the contraction of minute **abductor** (one pair) and **adductor** (two pairs) muscles respectively. All three ossicles contain pores and are covered with sensory and glandular epithelium. The pedicellariae which contain three calcareous pieces (= ossicles) and a stalk are called **forcipulate pedunculate pedicellariae**.

Types. There are two types of pedicellariae in *Asterias*.

1. Straight type. Such pedicellariae (Fig. 50.8) lie among the dermal branchiae. In them two jaws are straight. When closed they remain parallel and meet throughout their length.

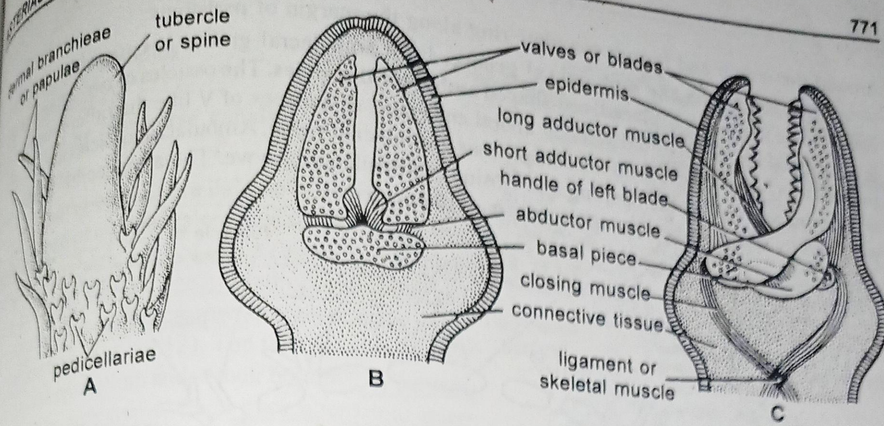

Fig. 50.8. *Asterias*. A—A cluster of pedicellariae, papulae and spine; B—Straight type pedicellaria; C—Crossed type pedicellaria.

The two jaws work against each other like the blades of forceps.

2. **Crossed type.** These pedicellariae are small and are arranged in rings round the white spines on the aboral surface. In them two jaws cross each other like a pair of scissors.

Function. Pedicellariae are sensitive to contact. They serve as defensive and offensive organs. They help in keeping the body surface free from debris and minute organisms (*e.g.*, larvae of sponges and coelenterates) which may settle on the body surface. In this way, they provide protection to gills. In some starfishes, they may also help in the capture of small prey.

Lastly, entire surface of the body, including that of its outgrowths such as tube feet, spines, pedicellariae and dermal branchiae is ciliated. The body of *Asterias* is enclosed in a hard but flexible integument. The hardness of the integument is due to the presence in it of calcareous ossicles.

50.3 ENDOSKELETON

Skeleton of echinoderms is derived from **mesoderm** or from **dermis** of body wall. Therefore it is called **endoskeleton**. It is formed of crystals of calcium carbonate ($CaCO_3$), *i.e.*, it is calcareous. Endoskeleton occurs in two forms:

1. In the form of **calcareous plates** or **ossicles** found in the soft dermis of bodywall.
2. In the form of **warts** or **tubercles**, attached to the calcareous plates of dermis. These projects out of the skin.

Skeleton of *Asterias* and other echinoderms differ from the skeleton of other invertebrates mainly in one character. The skeleton of invertebrates is developed from epidermis, but in echinoderms it develops from dermis or mesodermal layer. The body of starfish, thus, is enclosed in a tough, flexible integument containing numerous calcareous ossicles.

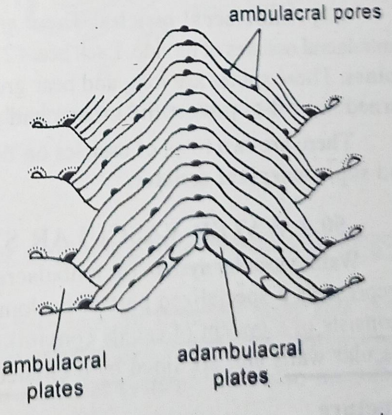

Fig. 50.9. Arrangement of ambulacral ossicles.

Arrangement of ossicles. Dermal ossicles have different but definite shapes and patterns. These are interconnected by connective tissue. In starfish, skeletal ossicles are arranged in a specific orders as follows:

(*i*) **Ossicles around the mouth.** Five plate-like ossicles, called **oral ossicles,** are arranged around the mouth and form a complete ring along the margin of peristome.

(ii) **Ossicles on the ambulacral groove.** Each ambulacral groove is covered by a double row of large transversely placed, rod-shaped **ambulacral ossicles.** The ossicles of two opposite rows are arranged like an inverted V. Their aboral ends meet at the apex of V like the rafters supporting the roof of a house. These form the conspicuous **ambulacral ridge.** Ambulacral ossicles are movably articulated and permit the opening and closing of ambulacral groove. The ambulacral ossicles are without any spines, tubercles or other external appendages.

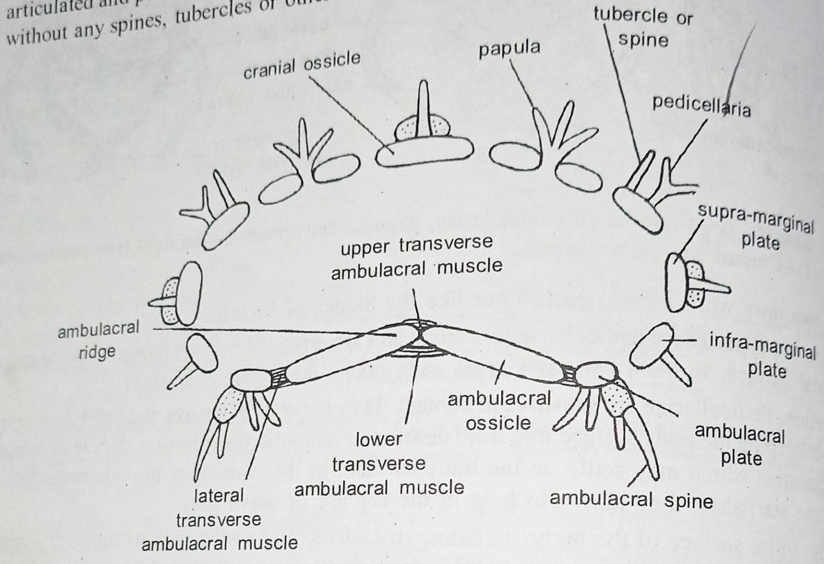

Fig. 50.10. Starfish. C.S. through the arm to show endoskeletal ossicles.

Each ambulacral ossicle has a notch on its outer as well as inner margin. The two notches of the adjacent ossicles together form an oval aperture, the **ambulacral pore** for the passage of tube-feet. The ambulacral pores are so arranged that they form two rows on each side of the ambulacral groove.

(iii) **Ambulacral ossicles.** These are present along the edges and are articulated with the ambulacral ossicles of its side. Each bears 2 to 3 movable spines on small tubercles, called **ambulacral spines.** These spines are long and bear groups of large straight **pedicellariae.** These spines can be turned inward to protect the groove and podia.

There are two rows of ossicles on the outside of ambulacral ossicles. These are called infra and **supramarginal ossicles.**

50.4 WATER VASCULAR SYSTEM (OR AMBULACRAL SYSTEM)

Water vascular system (or ambulacral system) is a typical and unique feature of echinoderms. It represents a specialized part of coelom, being developed from the left hydrocoel of the larva. It consists of a system of canals containing sea water and amoeboid corpuscles. The canals have muscular walls and are lined by a ciliated epithelium. It helps in locomotion.

Structure

Water vascular system of *Asterias* consists of the following parts (Fig. 50.11):

1. Madreporite
2. Stone canal

3. Ring canal
4. Tiedmann's bodies
5. Radial canals
6. Lateral or transverse canals
7. Tube feet

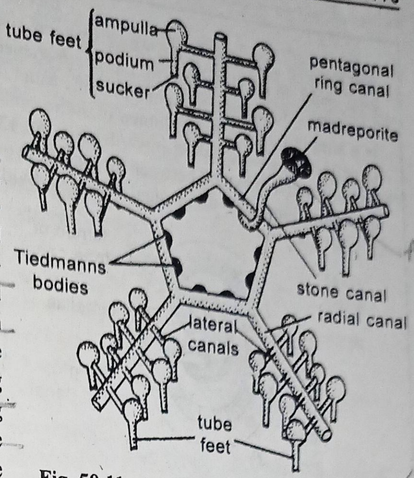

Fig. 50.11. *Asterias*. Water vascular system

1. Madreporite. It is a light-coloured, sieve-like, button-shaped or circular calcareous skeletal plate. It is located on the aboral surface of the central disc in inter-radial position. The surface of madreporite is marked by a number of radiating narrow, straight or wavy grooves or furrows (Fig. 50.12). The furrows are covered with ciliated epithelium and at their bottom they contain about 250 minute pores. Each pore opens into **pore canals**. The pore canals unite to form larger **collecting canals** within the substance of madreporite. Collecting canals lead into a sac-like **ampulla** below the madreporite. Ampulla is continued as a canal inside the stone canal.

2. Stone canal. It is S-shaped verti-cal canal which extends downwards (ora-lly) and opens into a ring canal. Its wall is supported by a series of calcified rings and is lined internally with tall ciliated cells. The beating of cilia draw water into the canal. The stone canal is a simple tube in a young starfish, but in adult, its wall produces a prominent **ridge** in the lumen of stone canal. The ridge is bifurcated to form two spirally rolled **lamellae** (Fig. 50.15). They ensure water circulation.

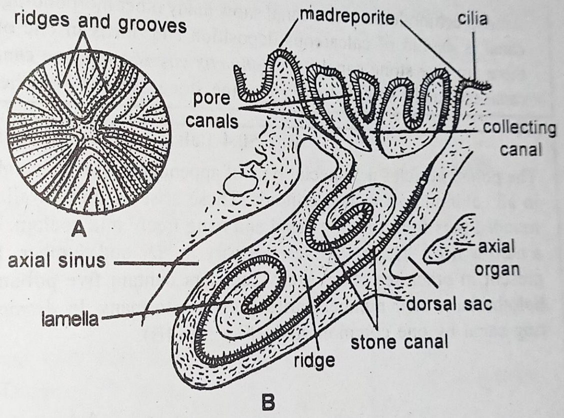

Fig. 50.12. *Asterias*. Madreporite. A—Surface view; B—Vertical section.

During its course, the stone canal along with an **axial gland** ensheathed by a wide, thin-walled tubular coelomic-sac, called **axial sinus**. This entire structure is called **axial complex.**

3. Ring canal. It is also called **ring vessel or water ring.** It is a wide five-sided (pentagonal) canal in the oral region around the oesophagus.

In most starfishes, but not in *Asterias*, the ring canal gives off from the inner side in each inter-radius a large, thin-walled, contractile, pear-shaped sac, the **polian vesicle.** The polian vesicles store water and help in regulating pressure in the water vascular system. They also manufacture amoeboid cells of water vascular system (Box 50.4).

4. Tiedmann's bodies. From its inner side, the ring canal produces five pairs of grεatly folded pouches, called **racemose vesicles** or **Tiedmann's bodies.** Each pair of these bodies has an inter-radial position. The cavity of each Tiedmann's bodies is divided into a number of chambers which communicate with the ring canal. In *Asterias*, there are only **nine** Tiedmann's bodies. The 10th body is absent and its place is occupied by the stone canal (Fig. 50.11).

Box 50.3 Stone canal

Stone canal is a part of the water vascular system of echinoderms. It connects madreporite with the ring canal. In starfish (*Asterias*), it is a S-shaped tube. It is called **stone canal** because its wall contains calcareous deposits. The lumen of stone canal is divided by a longitudinal ridge. In *Henricia*, the ridge is a simple bulging in the lumen of stone canal. In *Asterias*, this ridge is bifurcated into two vertical lamellae which are rolled inwards (Fig. 50.13A). In *Astropecten*, the coiled lamellae become very complicated and extend between the wall from one side to another of the lumen (Fig. 50.13B). In *Culcita* the whole lumen of stone canal becomes divided into a number of irregular chambers (Fig. 50.13C).

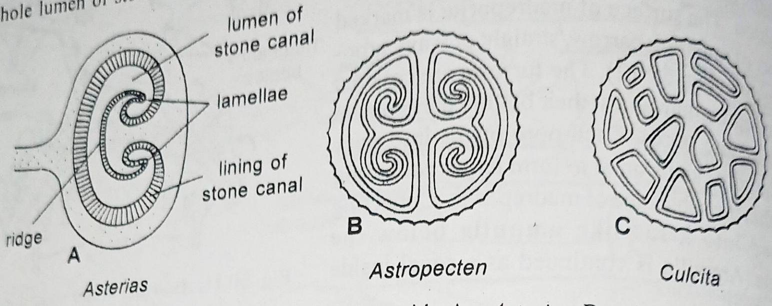

Fig. 50.13. Sectional view of stone canal in various Asteroids. A—*Asterias*; B—*Astropecten*; C—*Culcita*.

Among echinoderms stone canal show many other morpohological variations. In Ophiuroidea, the stone canal is devoid of calcareous deposition and opens in one of the oral plates. In *Trichaster elegans*, there are five stone canals. In *Ophiactis virens*, the stone canals are many. In holothurians, the stone canal is mostly single. In *Thyone*, the stone canal is branched.

Box 50.4 Polian vesicles in Echinodermata

The polian vesicles are special type of appendages of ring canals of water vascular system. They occur in all echinoderms except crinoids. These arise as thin - walled, bladder-like, pear shaped, ovoid or rounded sacs from the ring canal and hang freely into coelom. Polian vesicles open into ring canal by a narrow neck. The polian vesicles vary in size and number. They are absent in *Asterias rubens* but present in other sea stars. Many sea stars contain five polian vesicles inter-radially in the disc. In holothurians, their number varies from one to many. In *Astropecten*, a few polian vesicles open into ring canal by one common stalk (Fig. 50.14B).

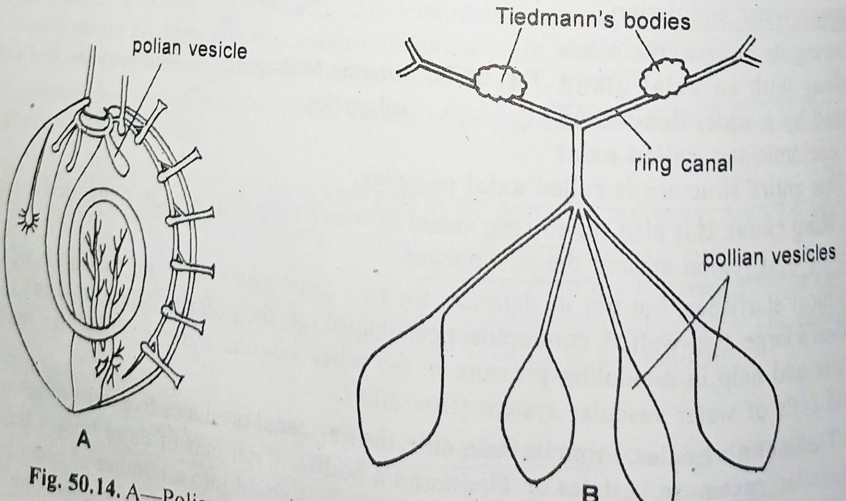

Fig. 50.14. A—Polian vesicle in *Holothuria*; B—Polian vesicles in *Astropecten*.

The actual function of Tiedmann's bodies is still unknown. They are supposed to be lymphatic glands to manufacture the **amoebocytes** of water vascular system. **Furguson** (1984) demonstrated that some sea water passes through these bodies into the perivisceral coelom. According to him these bodies participate in the production of coelomic fluid.

5. **Radial canals.** From the outer surface of the ring canal are given out five long, ciliated **radial canals.** One radial canal extends into each arm upto its extremity through the ambulacral groove of the arm. Radial canals run on the oral side of the ossicles and terminate as the lumen of terminal median tentacles.

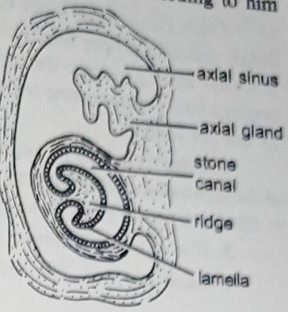

Fig. 50.15. *Asterias*. T.S. of axial complex.

6. **Lateral or transverse canals.** In each arm, the radial canal gives out two series of short, narrow, transverse branches called **lateral, transverse** or **podial canals.** Each lateral canal contains a **valve** to prevent backward flow of fluid into the radial canal and it opens into ampulla at the base of a tube foot.

7. **Tube feet.** A **tube foot** or **podium** is a hollow, elastic, thin-walled, closed sac-like structure. It contains an upper sac-like **ampulla,** a middle tubular **podium** and a lower disc-like flattened **sucker.** The ampulla lies within the arm, projecting into the coelom above the **ambulacral pore** which is a gap between the adjacent ambulacral ossicles for the passage of podium (Fig. 50.16). Tube feet, in fact, are external projections of the body wall; each of them has a lining of **ciliated epithelium** and a covering of **coelomic epithelium** or **peritoneum.** Between these two epithelia lie **connective tissue** and **longitudinal muscle fibres.** Contraction of the muscles of a side causes bending of a podium.

The podia are arranged in two double rows along the length of the ambulacral groove. They are chief locomotory and respiratory organs of *Asterias*.

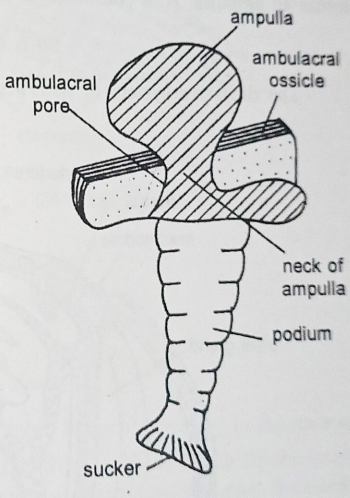

Fig. 50.16. *Asterias*. A tube foot.

Function

The water vascular system is lined with cilia and is filled with a fluid very similar to sea water. This fluid, however, contains **coelomocytes,** a little **protein** and a high concentration of **potassium ions.** The system operates as **hydraulic system** and brings about locomotion, adhesion to the substratum and the capture and handling of food. All these functions are performed by the help of tube feet.

(1) **Locomotion.** The beating of cilia causes water to enter through madreporite. It passes into the tube feet (= podia) and their ampullae. When the ampulla contracts, the valve in the lateral canal closes, and water (fluid) is pressed into tube feet which get distended (upto 5 cm) due to their muscular walls. The podium comes in contact with the substratum and the sucker adheres to it. Adhesion is also has a chemical base. The podium secretes a substance that makes bonds with the surface of substratum. Another secretion breaks the bonds and sucker becomes free (**Thomas and Hermans** 1985).

After their fixation with substratum, the tube feet contract in unison and push the body forward. Due to contraction of muscles, the fluid from each tube foot, returned to the ampulla and tube foot is shortened. This lessens the pressure at the tip so that the suckers detach. The same process is repeated again and again to bring about locomotion. In a section of arm most podia perform the same step and the animal moves forward. The action of podia is highly coordinated. During locomotion one or two arms act as leading arms and podia in all the arms move in same direction.

Other parts of the water vascular system—the madreporite, stone canal, ring canal and radial canals maintain proper fluid pressure necessary for the working of ampulae and podia. Some fluid is always lost by leakage through podial walls when fluid pressure increases in podia. To maintain constant fluid pressure some sea water is drawn through the madreporite. Star fish moves very slowly, 15 cm per minute.

2. Climbing. Due to turgidity and terminal suckers, the tube feet are able to take a firm grip of the substratum and this brings about adhesion. Combined action of podial suckers enables starfish to climb vertically over rocks.

3. If a star fish is turned over, it can right itself by folding.

4. Food capture. The suckers of the tube feet are also used to capture food.

50.5 LOCOMOTION

Starfish is a slow moving animal. Its locomotory organs are **tube feet** or **podia** which are arranged in four rows in the ambulacral groove of each arm. Each podium is hollow external projection form the body wall with a terminal sucker (Fig. 50.16). Each tube foot receives a lateral, transverse or podial canal from the radial canal of water vascular system. At the base of tube feet, podial canal forms an ampulla. It is continued as a canal inside the podium.

50.6 DIGESTIVE SYSTEM

The digestive system of *Asterias* comprises the **alimentary canal** and **digestive glands**.

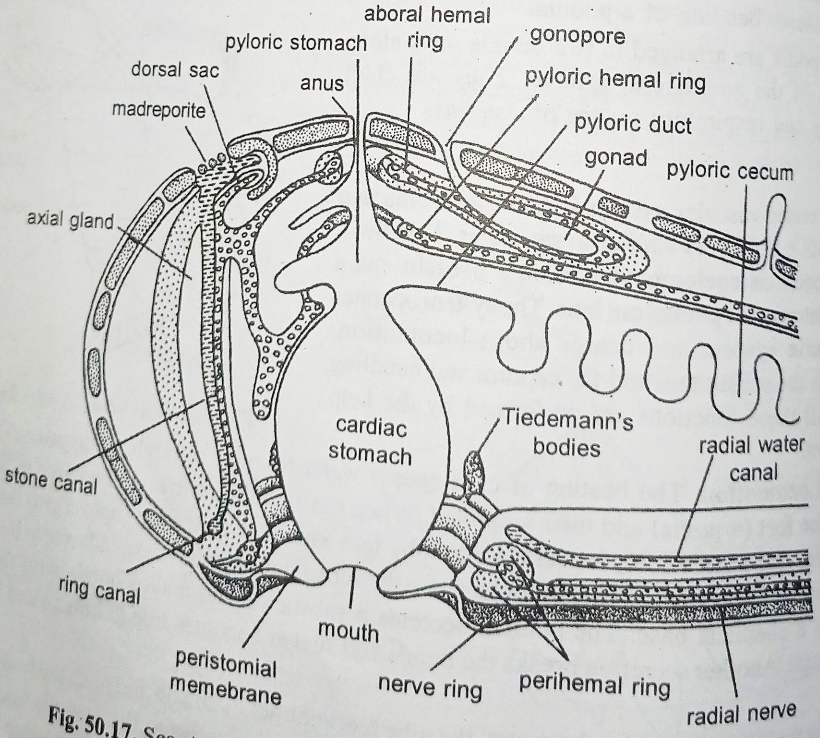

Fig. 50.17. Sea star. The central disc and base of one arm (vertical section).

Alimentary Canal

In *Asterias*, the alimentary canal is tubular, short but spacious canal which extends vertically along the oral-aboral axis in the central disc. It comprises of the following parts:

1. Mouth. The pentagonal actinostome leads into mouth which is situated on the oral surface in the centre of peristomial membrane. The mouth is surrounded by a sphincter muscle. The mouth leads upwards into the oesophagus.

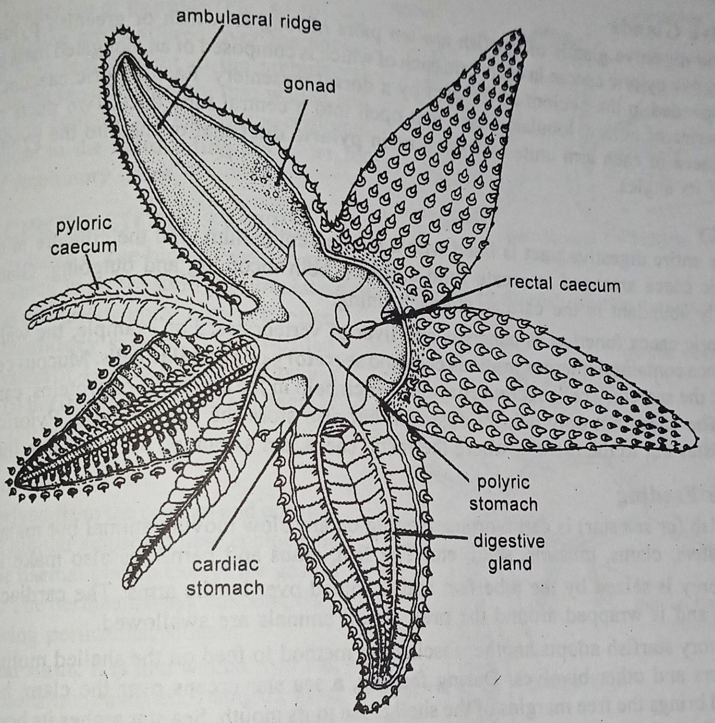

Fig. 50.18. *Asterias.* Digestive system.

2. Oesophagus. It is a very short, wide and vertical tube. It opens aborally in the stomach.

3. Stomach. The stomach is a large, thin-walled spacious five-iobed sac which fill the interior of the disc. It is typically divided by a horizontal constriction into a voluminous oral part, the **cardiac stomach** and a flattened aboral part, the **pyloric stomach.**

(*i*) **Cardiac stomach.** The cardiac stomach is connected with oesophagus. It has a muscular, highly folded wall which bulges out to form five lobes, one opposite, each arm. The cardiac stomach is held in position by five pairs of triangular **mesenteries** or **gastric ligaments** which are formed of connective tissue and muscles. A pair of gastric ligaments connect the cardiac stomach to the ambulacral ridge in each arm. During the feeding process, the cardiac stomach can be everted through the mouth by the contraction of muscles of body wall. The retraction of cardiac stomach is brought about by five pairs of **retractor muscles** which arise from the lateral sides of the ambulacral ridge.

(*ii*) **Pyloric stomach.** Cardiac stomach leads upwards into a small aboral pyloric stomach which is thin-walled flattened star-shaped sac. It is simply the reception chamber of the ducts from the pyloric caeca. It communicates with the intestine.

4. Intestine. It is a short, tubular, five-sided tube extending vertically from aboral side of pyloric stomach to open through a minute anus in the middle of aboral surface of disc. It gives out two or three small branched and brownish outpocketings called **rectal caecae** which are placed inter-radially. Rectal caecae are excretory glands; they secrete a brownish fluid.

5. Anus. The intestine open on the aboral surface of the central disc by a small rounded aperture, the **anus.**

Digestive Glands

The digestive glands of starfish are ten pairs of long brownish or greenish **pyloric caecae.** There are two pyloric caecae in each arm, each of which is composed of an elongated mass of glandular cells suspended in the coelom of the arm by a dorsal mesentery. Each pyloric caecum consists of double series of hollow lobulated sacs that open into a central tube duct. Two ducts of a pair of pyloric caeca of each arm unite to form a main **pyloric duct** that opens into the pyloric stomach at one of its angles.

Histology

The entire digestive tract is lined with a ciliated epithelium, and the cilia are in the ducts of the pyloric caeca arranged to create fluid currents, both incoming and outgoing. Gland cells are particularly abundant in the cardiac stomach lining.

Pyloric caeca function as pancreas and liver of vertebrates. For example, the wall of sacs of pyloric caeca contains numerous **mucous cells** and **secretory** or **granular cells.** Mucous cells produce mucus and the secretory cells secrete enzymes which help in the digestion of proteins, carbohydrates and fats. The caeca not only help in digestion but also store the reserve food. Pyloric ducts also convey wastes out to the rectum, where the rectal caeca, act as pumps for expulsion through anus.

Food and Feeding

Starfish (or sea star) is carnivorous, feeding on any slow moving animal but mainly molluscs such as oysters, clams, mussels, snail, etc. The fish, crabs and barnacles also make its food.

The prey is seized by the tube feet and is folded over by the arms. The cardiac stomach is everted out and is wrapped around the prey. Small animals are swallowed.

Predatory starfish adopts another fascinating method to feed on the shelled molluscs such as clams, oysters and other bivalves. During feeding, a sea star creeps over the clam, holds it with tube feet and brings the free margins of the shell close to its mouth. Sea star arches its body assuming a umbrella-like posture. It firmly attaches its tube feet to both shell valves and tries to pull apart them (these two shell valves are held tightly together by the powerful adductor muscles). The tube feet gripping the shell valves exert a steady pull till the adductor muscles of the clam are exhausted and give way. As the valves gape, the sea star inserts its everted cardiac stomach into the mantle cavity of clam to devour it. The everted cardiac stomach of some sea stars can squeeze through a space as slight as 0.1 mm. The gape increases as digestion ensues and the clams adductor muscles are attacked.

Digestion, Absorption and Egestion

Digestion in sea star is primarily extracellular. After everting the cardiac stomach over the captured prey, sea star pours out digestive enzymes secreted by the cardiac stomach and pyloric caeca over the prey. The enzymes digest the visceral organs of clam; they thus, converts **proteins** into **peptones** and **amino acids; polysaccharides** (carbohydrates) into **glucose** and **fats** (lipids) into **fatty acids** and **glycerol.** When the digestion is partially completed, the sea star withdraws its stomach along with the digested food by means of its retractor muscles and moves on leaving behind the empty shell of the prey. Remaining extracellular digestion of food occurs in cardiac stomach.

Products of stomach digestion are carried by ciliary tracts up the to stomach wall and through pyloric ducts into the pyloric caeca, where digestion is both **intracellular** and **extracellular** and absorption occurs. Products of digestion may be stored in the cells of pyloric caeca or passed through the caeca into the coelom for distribution. The undigested food is egested out through the anus.

50.7 RESPIRATION

Respiration in *Asterias* is brought about by the **dermal branchiae** or **papulae** (Fig. 50.19) and tube feet. Papulae are scattered over the aboral surface and tube feet project in the ambulacral grooves. Both these structures are thin-walled and enclose a part of coelom. They bring the coelomic fluid very close to the surrounding sea water for exchange of respiratory gases.

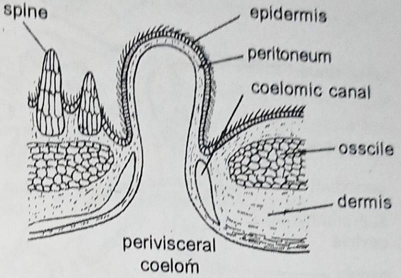

Fig. 50.19. Starfish. Section through papula.

50.8 CIRCULATORY SYSTEM

Asterias lacks a true-blood vascular system. The system which is responsible for circulation of digested food to various body organs is often known as **circulatory system.** The so-called circulatory system of *Asterias* includes following two systems (*i*) **perihaemal system;** (*ii*) **haemal** system (Fig. 50.20).

1. Perihaemal System

It is derived from the coelom and consists of a series of tubular sinuses. These enclose the sinuses of the haemal system except the gastric haemal tufts. The perihaemal system comprises of the following perihaemal sinuses:

(*i*) **Axial sinus.** It is thin walled, vertical, wide tubular coelomic cavity enclosing the axial gland and stone canal. The axial sinus along with axial gland and stone canal form the **axial complex.**

(*ii*) **Aboral perihaemal ring sinus.** It is a tubular pentagonal sinus around the intestine, lying just inside the aboral wall of the central disc. It communicates with the axial sinus.

(*iii*) **Genital sinuses.** Aboral perihaemal ring sinus gives off five pairs of **genital branches,** one pair in each arm. These enclose the gonads and the genital haemal strands.

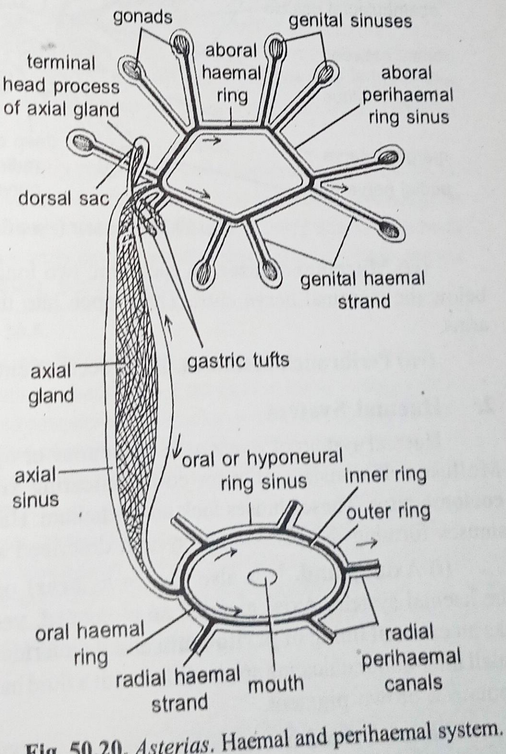

Fig. 50.20. *Asterias*. Haemal and perihaemal system.

(*iv*) **Oral hyponeural ring sinuses.** At its oral end, the axial sinus opens into the inner division of a circular channel, called the **oral hyponeural ring sinus** which runs around the mouth and above the nerve-ring. It is a large tubular sinus and is divisible into an inner narrow and an outer wide ring by an oblique circular septum called the **haemal strand.**

(v) Radial perihaemal sinuses. From the outer part of the oral ring sinus arise five radial **hyponeural** or **perihaemal sinuses**, each extending through an arm enclosing the radial haemal strands. These sinuses also give out fine channels into the tube feet.

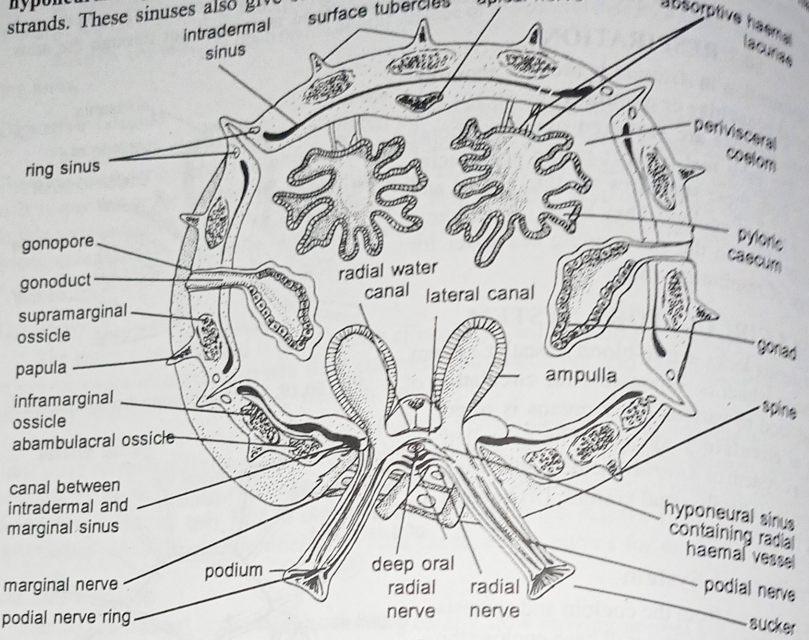

Fig. 50.21. Sea star (=starfish; *Asterias*). T.S. Arm.

(vi) Marginal sinuses. In each arm, two longitudinal marginal sinuses run one on each side below the marginal nerve cord. These open into the radial perihaemal sinuses of their respective arms.

(vii) Peribranchial sinuses. These occur as circular sinuses around the basal part of the papulae.

2. Haemal System

Haemal system of *Asterias* is of **lacunar** or **open type** like the haemocoel of Arthropoda and Mollusca. It consists of inter-communicating sinuses filled with **coelomic fluid** containing **coelomocytes.** These sinuses lack an epithelium. Haemal system is largely enclosed in the coelomic sinuses forming the perihaemal system described above. It comprises the following parts.

(i) Axial gland. It is also known as **heart** or brown **gland** and forms the principal part of the haemal system. Axial gland is an elongated, vertical, fusiform, brownish and spongy gland. It has an external lining of **peritoneum** and its interior is filled with connective tissue containing many small inter-communicating spaces filled with a fluid having amoeboid **coelomocytes.** The coelomocytes contain a brown pigment.

The axial gland is connected with the oral haemal sinus at its oral end and with the aboral haemal sinus at its aboral end. A small terminal **head process** arises from the aboral end of the axial gland. Head process lodged in a separate, closed contractile coelomic sac called **dorsal sac.** The dorsal sac is situated below the madreporite, close to the ampulla of the stone canal. A pair of **gastric tufts** arise from the haemal sinuses in the wall of cardiac stomach and open into the axial gland near its aboral end. Digested food from the stomach passes into the haemal circulation through the gastric tufts.

(ii) **Aboral haemal ring.** It is a pentagonal ring canal situated beneath the aboral surface of the central disc. It gives off five pairs of **genital haemal strands** to the gonads.

(iii) **Oral haemal ring.** It is the circular haemal sinus, located around the mouth just below the ring canal of the water vascular system.

(iv) **Radial haemal sinuses.** These arise radially from the oral haemal ring. In each arm extends one radial haemal sinus along the floor of the ambulacral groove. Each radial haemal sinus gives off branches to the tube feet or podia.

Function. The haemal system acts as a pathway for the distribution of food substances carried by the coelomocytes. The flow of fluid (*i.e.* colourless blood) within it is maintained by the contractile activity of the dorsal sac (or **heart;** see **Rupert** and **Barnes,** 1994). For example, in *Asterias forbesi* dorsal sac beats rhythmically—6 beats per minute. However, the pattern of circulation of fluid is unknown.

The axial gland acts as a genital stolon, producing sex cells which reaches the gonads through the aboral haemal ring and its branches.

50.9 EXCRETION AND OSMOREGULATION

In most echinoderms dissolved nitrogenous wastes (ammonia) diffuse across body surfaces to the outside. This type of excretion occurs across the podia and papulae in sea star and other asteroids. Precipitated material and other particulate wastes are phagocytosed by certain coelomocytes in the body fluids and then discharged by various methods. In sea star, waste-laden coelomocytes accumulate in the papulae, which then pinch off their distal ends, expelling the cells and waste material. Some studies indicate that the rectal glands or rectal caecae may also be involved in excretion (**Brusca** and **Brusca**, 2003).

Echinoderms are generally considered to be strictly marine, **stenohaline** creatures (Box 50.5). Consequently, they do not have problem of osmotic and ionic regulation. The evidence to date suggests that echinoderms are **osmo-conformers.** Both water and ions pass relatively freely across thin body surfaces and the tonicity of the body fluids varies with environmental fluctuations. There appear to be some ionic regulation through active transport, but it is minimal.

Box 50.5.

Animal response to osmotic conditions of the medium

There are two extreme patterns of response to osmotic conditions of the environment. Animals may be osmotically labile (dependent) and their body fluid concentration may change with the medium. These are **osmoconformers** or **poikilosmotic animals.** Other animals are osmotically stable (independent) and when the medium changes, the internal concentrations of the body fluid remains constant or unchanged. These are **osmoregulators** or **homoisomotic animals.**

Poikilosmotic animals which can tolerate wide ranges in salinity are known as **euryhaline,** *e.g.*, *Mytilus, Aplysia.* On the other hand poikilosmotic animals which cannot tolerate wide ranges in salinity are known as **stenohaline animals,** *e.g.*, most marine invertebrates (**Singh** and **Kumar** 2005).

5.10 REPRODUCTIVE SYSTEM

Autotomy and Regeneration

Echinoderms possess great power of **regeneration.** *Asterias* is capable to regenerate its any lost part of body at any time. Moreover, if an arm is injured or held up, *Asterias* usually cast it off near the base at the fourth or fifth ambulacral ossicle. This is called **autotomy.** The opening left in the central disc by broken off arm is immediately closed by the contraction of the adjacent body wall musculature for the protection of internal body organs and regeneration of new arm starts at that place. Autonomy is seen in most **ophiuroids,** some **asteroids** and some **holothuroids** but does not occur in **echinoids.** For example, many brittle stars, when are taken out of water, break off portions of their arms into pieces till the central disc completely devoid of arms is left.

A disc deprived of all of its arms regenerates. In *Asternia vulgaris*, a single arm with a portion of disc regenerates an entire animal. But in *Linckia*, an arm totally devoid of disc can regenerate complete animal (Fig. 50.22). Specimens with regenerating arms at the base of the large original arm are called **comets.**

In **crinoids,** the arms as well as the visceral sac of the central disc are regenerated when these become accidentally removed. In **holothuroids,** the oesophagus or cloaca with Cuvierian organs is ejected on slightest danger (autotomy) and is regenerated again.

Reproduction in *Asterias* is mainly sexual. Most species of *Asterias* are **unisexual** or **dioecious,** *i.e.*, sexes are separate. Sexual dimorphism is absent. Reproductive organs of *Asterias* are of primitive type. They lack copulatory organs, accessory glands, receptacles for storing ova and reservoirs for storing mature spermatozoa.

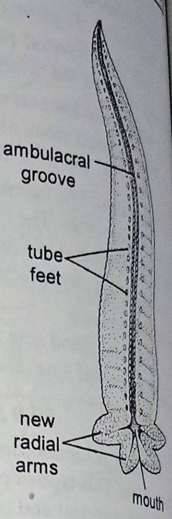

Fig. 50.22. Comet stage of *Linckia*.

Gonads

The **testes** (male gonads) and **ovaries** (female gonads) are morphologically similar but they show colour variation. The testes are pale grey and the ovaries vary from pink to orange. There are five pairs of gonads in either sex, a pair in each arm. The proximal end of gonads are attached to the aboral body wall and they lie laterally freely between pyloric caeca and ampullae of the tube feet.

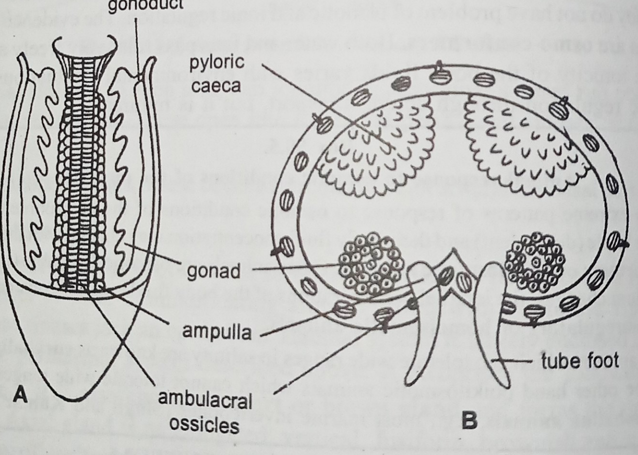

Fig. 50.23. *Asterias*. Gonads. A—An arm is cut open to show gonads. B—T.S. arm showing position of gonads.

The size of gonads varies with season of the year, being largest during the breeding period (late spring). At maturity gonads occupy a considerable portion of the perivisceral space. Each feathery tuft or bunch of grapes consisting of membranous and rounded follicles. It is enclosed in a genital sinus of the perihaemal system. Microscopic examination reveals that the gonad is lined by a germinal epithelium with a connective tissue matrix containing germ cells. From the proximal end of each gonad arises a short ciliated **gonoduct** which opens out laterally on the aboral surface by a minute **gonopore.**

Spermatozoa and ova are discharged by the male and female sea stars respectively into the sea water. Release of gametes is brought about by substances produced in the radial nerve.

In *Asterias*, there is a single breeding season in a year. It is the late spring and appears to be induced by the rising spring temperature. A single female lays about 200 million eggs in a season.

Fertilization

In *Asterias*, fertilization is external; it takes place in sea water.

Development

The embryological development of *Asterias* is **indirect** and includes various larval stages. The fertilized egg or zygote is spherical, 0.5 mm in diameter and contains little amount of yolk. The **cleavage** is rapid, **holoblastic,** equal, indeterminate and radial type (see Box 50.6). As a result, by the second day, a single layered, hollow, spherical, ciliated embryo, called **blastula** or **coeloblastula** is formed. Blastula contains a fluid-filled central cavity, the **blastocoel** and swims about in water freely. The blastula undergoes embolic **invagination** at its vegetal pole and becomes a two-layered, ciliated, cup-like **gastrula.** Its outer layer is formed of **ectoderm** and inner layer of **endoderm** (Fig. 50.24). The cavity of the gastrula which is lined by endoderm is known as **gastrocoel** or **archenteron.** It opens to the exterior by a wide aperture, called **blastopore.** On the ventral side of the embryo, a tubular ingrowth of ectoderm forms the **mouth.**

Box 50.6.

1. **Holoblastic cleavage.** When entire egg is divided by each cleavage furrow. When it produces equal-sized blastomeres, it is called **equal holoblastic cleavage.**
2. **Indeterminate cleavage.** When the fate of blastomere is not fixed.
3. **Radial cleavage.** When axes of the cleavage furrows are parallel or at right angles to the axis extending from animal to vegetal pole.

During gastrulation, the advancing tip of archenteron buds off **mesenchyme cells** into blastocoel, which form the **mesenchyme** or **mesoderm.** The advancing blind end of archenteron evaginates as two pouches, which finally get pinched off as the right and left sacs. These sacs enclose anterior part of archenteron, the **enterocoel,** and produce **coelom,** its mesodermal lining and water vascular system. Thus, in *Asterias*, mesoderm has a dual origin and coelom is **enterocoelous.** The embryo at this stage becomes a free-swimming larva.

Larval Development

The development of sea star includes the following larval stages:

1. Dipleurula larva. This is first larval stage and is commonly found in all echinoderms. It is egg-shaped having a bilaterally symmetrical body. The cilia which earlier cover the surface of embryo uniformly, become restricted to two ciliary wavy bands — a **peri-oral band** surrounding a concave area around the mouth and an **adoral band** lying inside the mouth. **Stomodaeum** develops as an ectodermal invagination on the ventral side of embryo and becomes continuous with the archenteron. The opening, thus, developed forms the **mouth** of larva. The archenteron gets differentiated into oesophagus, stomach and intestine. The blastopore becomes the **anus.** With these changes embryo develops into **dipleurula larva** which is capable of independent existence. This larva actively feeds on diatoms, etc. The adoral band of cilia helps in collecting the food particles. Dipleurula larva swims near the surface and rotates clock-wise with the help of cilia of peri-oral band.

2. Bipinnaria larva. In *Asterias*, the free swimming larva which is hatches out of the egg is called **bipinnaria larva.** It develops from zygote in about one week. It is a bilaterally symmetrical larva and possesses two ciliated bands: 1. **Preoral ciliated band** which surrounds the preoral lobe of larva; 2. **Postoral ciliated band** which appears to be longitudinally placed and form a complete

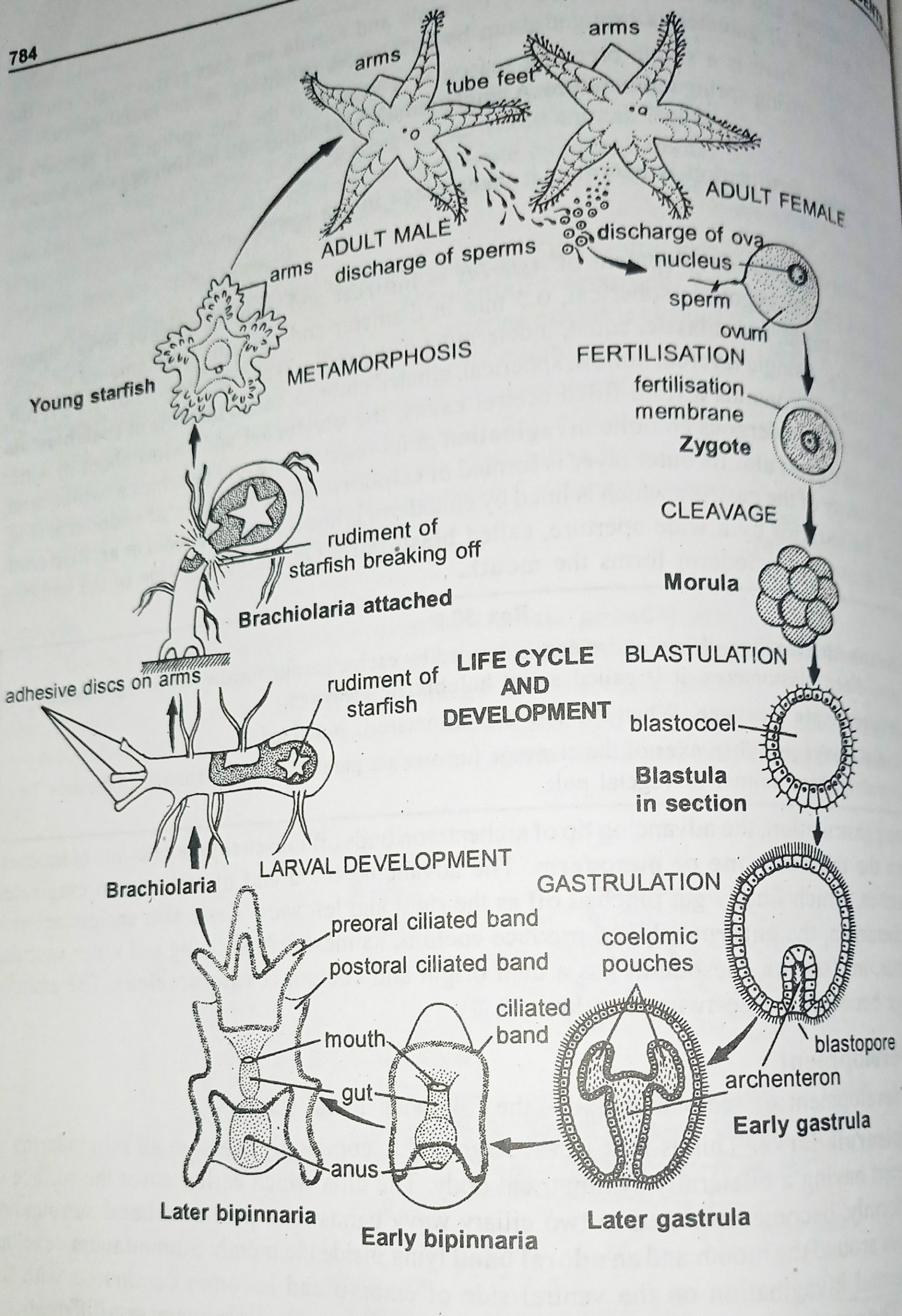

Fig. 50.24. *Asterias*. Development and life history.

ring between the mouth and anus. Both of these ciliated bands are continued over a series of prolongations or projections of the body, called **lobes** or **larval arms** (Fig. 50.25). The name and number of arms developing from preoral and postoral ciliated bands are as follows:

Name of lobe or arm	Number
1. Dorso-median	One
2. Ventro-median	One
3. Pre-oral	Two

4. Antero-dorsal	
5. Postero-dorsal	Two
6. Post-oral	Two
7. Postero-lateral	Two
	Two

The pre-oral and ventro-median arms develop from the pre-oral ciliated band and rest of the arms develop from the post-oral ciliated band. The arms are provided with muscles and are contractile in a nature. Inside the body occur the coelomic apparatus and the alimentary canal. The bipinnaria larva feeds, on diatoms, etc., by creating food-bearing currents by ciliary tracts in the stomodeal wall. It swims freely by forwarding its anterior end, with a clockwise rotation. After sometime bipinnaria larva develops into the next larval stage called **brachiolaria larva.**

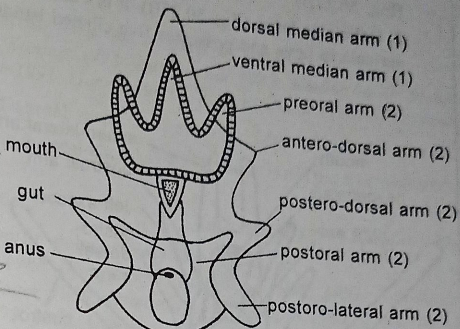

Fig. 50.25. *Asterias*. Bipinnaria larva.

3. **Brachiolaria larva.** The lobes of bipinnaria larva become modified into long, slender and ciliated **larval arms.** From the preoral lobes arise three short and non-ciliated processes ending into adhesive **fixation discs** or **suckers.** These are called **brachiolar arms.** These arms are devoid of calcareous rods and have prolongations from the coelomic cavity. Its alimentary canal consists of mouth, stomach, intestine and anus. Brachiolaria larva swims and feeds like bipinnaria larva. The appearance of sucker marks the beginning of metamorphosis.

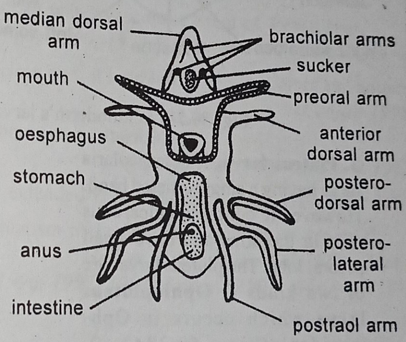

Fig. 50.26. Brachiolaria larva.

Other echinoderms produce a variety of larval forms such as **auricularia, doliolaria, ophiopluteus, echino-pluteus,** etc. (see Box. 50.7).

Box 50.7.

Other larval forms of echinoderms

1. **Auricularia larva.** In most holothuroids, the eggs are rich in yolk and deve-lopment is direct, but in some cases the egg hatches into a free - swimming bila-terally symmetrical larva. It is known as **auricularia larva** (Fig. 50.27A). It is transparent pelagic orga-nism of about 1 mm size. The body is provided with single longitudinal ciliated band which forms a **pre-oral loop** around the mouth and **anal loop** encircling anus. These help in swimming. The **pre-oral lobe** is very well - formed. There are no calcareous rods, being replaced by spheroids, star - shaped or wheel - like bodies.

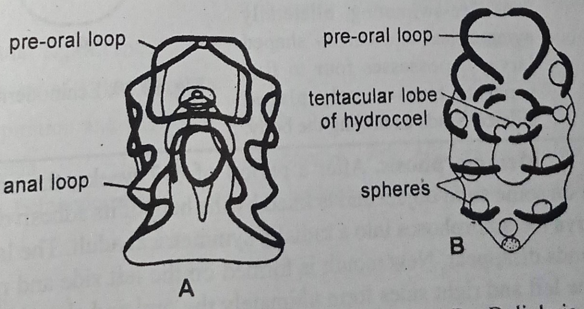

Fig. 50.27. Enhinoderm's larva A—Auricularia; B—Doliolaria.

The interior of larva is occupied by the curved gut with saccular stomach, hydrocoel and right and left stomocoels. The hydrocoel is produced into primary tentacles and communicates with the hydropore by canal.

The auricularia larva metamorphoses into second larval stage known as doliolaria larva (Fig. 50.27B).

2. Doliolaria larva (Fig. 50.27B). It is a barrel-like larva of Holothuroidea which develops from auricularia larva and possesses five ciliated bands. It is also called **pupa stage.**

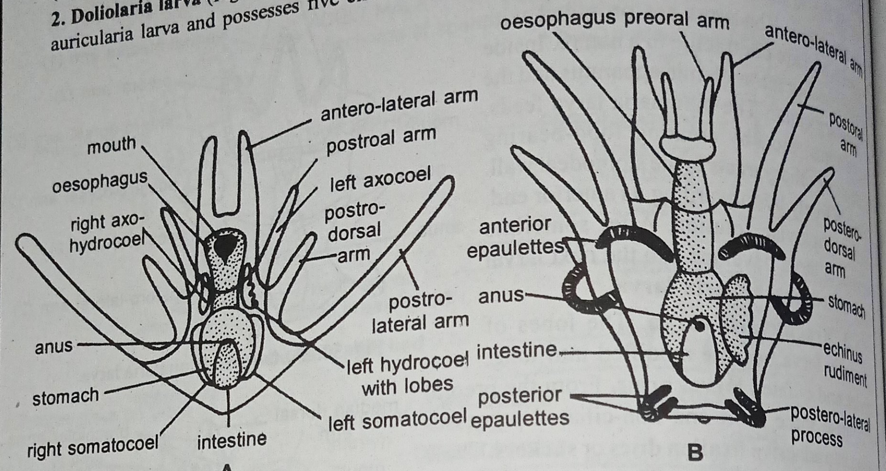

Fig. 50.28. Echinoderm's larva A—Ophiopluteus; B—Echinopluteus.

3. Pluteus larva. It is auricularia larva having a single ciliated band. However it contains calcareous rods in the arms and have small preoral lobe. The pluteus larvae are of two kinds 1. **Ophiopluteus larva** which occurs in Ophiuroidea (Fig. 50.28A) 2. **Echinopluteus larva** which occurs in Echinoidea (Fig. 50.28B).

4. Vitellaria or Yolk Larva. This larval stage is present in *Antedon*. It is free-swimming, bilaterally symmetrical and barrel- shaped larva. It possesses four to five separate trans-versely placed ciliated bands encircling the body.

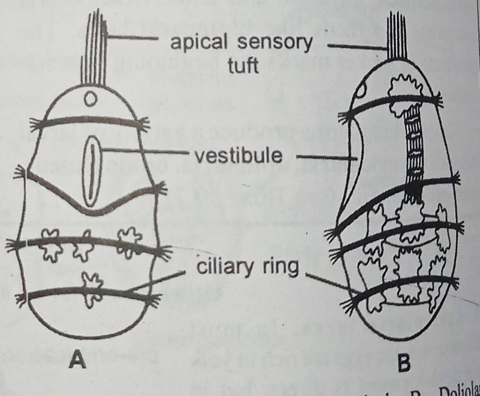

Fig. 50.29. Echinoderm's larva A—Auricularia; B—Doliolaria.

Metamorphosis. After a period of 6–7 weeks, the brachiolaria larva settles on the bottom or on some solid object and is fixed by the help of its adhesive arms. Now the bilaterally symmetrical larva metamorphoses into a radially symmetrical adult. The larval mouth and anus close. The ciliary bands disappear. New mouth is formed on the left side and new anus on the right side of the larva. The left and right sides form ultimately the oral and aboral surfaces respectively. Five lobes, called **arm rudiments,** develop around oral-aboral axis. Skeletal elements develop on the arm rudiments and the radial canals grow into the arms. The coelom of the adult develops from the right and left coelomic pouches of the larva. In each arm two pairs of outgrowths from the coelom form the first tube feet and serve for attachment. Further complex reorganisational changes result in the formation of adult *Asterias*. The newly detached rudiment of the body of sea star is about 1 mm in diameter and contains short stubby arms.

QUESTIONS

Long Answer Questions

1. Give an account of habit and habitat of starfish. Describe its external features.
   (*Bundelkhand 1988; Kumaun 1992; Kanpur 1993; Purvanchal 1989; Raipur 1990; Meerut or CCS 1990, 1996; Bhopal 1993; Jabalpur 1991; Gorakhpur 1992; Rohilkhand 1993, 1994, 1996*)
2. Describe structures present on the oral and aboral surfaces of starfish. (*Agra 1988; Jiwaji 1992*)
3. Describe th